Propagation of Sound in Air

A BIBLIOGRAPHY WITH ABSTRACTS

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PREFACE

This bibliography was compiled at the Institute of Science and Technology for the U. S. Army Electronics Command, as a task of Project MICHIGAN, under Contracts DA-36-039 SC-52654 and DA-36-039 SC-78801. A volume of this sort is especially valuable to students and researchers, and to make possible its general availability, Project MICHIGAN's sponsor has permitted the Industry Program of the University's College of Engineering to underwrite the publication of this edition.

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ABSTRACT

This bibliography contains several thousand abstracts from the unclassified literature on the propagation of sound in air. The subject is treated in depth for the years 1929 to 1963. Some abstracts on earlier works of lasting interest and many abstracts from English translations of foreign journals are included. The abstracts are grouped according to subject matter. Subject and author indexes are furnished. Accessions Document (AD and earlier ATI) numbers used by both the Defense Documentation Center (formerly ASTIA) and the Office of Technical Services (OTS) are furnished wherever possible.

CONTENTS

A GUIDE TO THE USE OF THIS BIBLIOGRAPHY

This bibliography is arranged alphabetically by subject, and alphabetically by author under each subject; it includes a total of 4461 abstracts, numbered consecutively to permit quick access to particular subjects or authors. The consecutive numbering system is the basis for an index of subjects, an index of authors, and cross-indexing number lists labeled "see also." The indexes become self-explanatory with use. The "see also" entries touch significantly upon the subjects under which they are listed, but deal primarily with other topics; such a list follows the last abstract of each subject.

An appropriate subject heading is printed in large type at the top of each page throughout the bibliography. There are 104 of these basic subjects. They are listed in alphabetical order in the table of contents. The table of contents may be used as a rudimentary subject index and may, in fact, be preferred to the full subject index when a reader wishes to make only a quick search of the literature on a specific and limited topic. On the other hand, the reader who is seeking both basic information and additional literature closely related to a chosen topic will find the subject index at the back of the bibliography much more useful than the table of contents. The subject index contains all the topics listed in the table of contents, plus a large number of synonyms for these topics, and many terms that encompass two or more basic topics.

The index of authors gives the abstract numbers of all abstracts credited to a contributor, without regard to whether he is an author or coauthor. The index of sources gives the full names of journals, publishers, etc., that are abbreviated in the bibliographical entries.

In summary, use the table of contents as a "quick-look" index. Use the "see also" number lists to find additional abstracts which touch significantly on the chosen topic. Use the subject index to conduct a thorough search of the literature on the topic of interest and closely related topics. Use the source and author indexes for their obvious purposes.

ABSORPTION, BOUNDARY LAYER AND SURFACE

1

Ackerman, E., and F. Oda, "Acoustic Absorption Coefficients of Human Body Surfaces," Final Rept. No. MRL TDR 62-36, Penn. State Univ., University Park, 1962. AD-283 387

Reverberation chamber decay times were measured with and without human body surfaces exposed to the sound field. From these measurements, acoustic absorption coefficients were computed for human body surfaces. These were small compared to similar coefficients for laboratory animals. Typical values for the absorption coefficients for human body surfaces ranged from 1 to 2%. Little variation was found from 1 to 20 kc, and measurements were not made outside of these limits. The results are discussed and compared with other values obtained by different methods.

2

Ancel, J. E., "A Practical Noise Reduction Treatment for Diesel Engines," J. Acoust. Soc. Am., 25, 1163-1166, 1953.

A noise reduction treatment for Diesel engines is described, which, though not the ideal approach to the problem, is practical, economical, and applicable to both new engines and those already in the field. This treatment was designed by making use of the results of a survey of the relative importance of the various noise sources on the Diesel engine. The treatment consisted of a set of sheet metal covers, lined internally with acoustical absorbing material and mounted directly over the noisy areas of the engine by means of built-in vibration isolation. Noise reductions for the direct sound of at least 8 to 12 db were observed at a distance of one foot from the engine. The total loudness of the engine noise at six feet was reduced from 320 to 220 sones. This is a substantial improvement with regard to voice communication in the immediate vicinity. The speech interference level of the engine noise at six feet was reduced from 87 to 82 db.

3

Beranek, L. L., S. Labate, and U. Ingard, "Noise Control for NACA Supersonic Wind Tunnel," J. Acoust. Soc. Am., 27, 85-98, 1955.

To reduce an intense noise with frequency components extending from 5 to 10,000 cps due to the burning of a jet engine in the test section of a supersonic wind tunnel, a special muffler was built having an open cross-sectional area of 600 square feet. For frequencies below 11 cps, large Helmholtz type resonators were employed. Between 20 and 800 cps a tuned set of six fiberglas lined square ducts, were constructed. At higher frequencies two lined bends were employed to reduce the noise. Performance data measured in models and in the full scale wind-tunnel are presented. The result is a wind tunnel that is so quiet that nearby listeners are unaware of its operation.

4

Bies, D. A., J. H. Caffrey, and O. B. Wilson, Jr., "A Study of Internal Acoustic Absorbers as a Technique for Turbojet Engine Noise Reduction," Final Rept. No. 94, Vol. 1, Soundrive Engine Co., Los Angeles, Calif., 192 pp., 1957. AD-150 553.

A comprehensive investigation was begun of several configurations of a modified J34 WE-42 turbojet engine designed for sound suppression. Twenty-two configurations of mild engine changes involving acoustic suppression means were tested, and some of these showed a reduction in particular frequency bands. The sound radiated from a particular configuration was not reduced by more than 1 db. Three tests were made with an untreated engine to establish a standard for comparing the efficacy of the

various acoustic absorbers under investigation. Two configurations involving acoustic treatment to the diffuser cone which were not effective in reducing the radiated sound did improve the engine thrust by about 5%. The validity of internal noise measurements was questionable. Possibly less than half of the noise radiated from the turbojet had its origin with the engine.

5

Bies, D. A., J. H. Caffrey, and O. B. Wilson, Jr., "A Study of Internal Acoustic Absorbers as a Technique for Turbojet Engine Noise Reduction," Final Rept. No. 94, Vol. 2, Soundrive Engine Co., Los Angeles, Calif., 166 pp., 1957 AD-150 554.

Data sheets are presented for the 22 configurations of the modified J34 WE-42 turbojet engine and 3 untreated engines.

6

Brekhovskikh, L. M., "Field of a Point Source of Radiation in a Stratified-Inhomogeneous Medium, III. Average Laws of Attenuation" (in Russian), Izv. Akad. Nauk SSSR, Ser. Fiz., 13, 534-545, 1949.

The two kinds of waves emitted by the source (i.e., those of the "discrete" spectrum and the two lateral waves) are damped according to two different laws: the first of the form $\exp(-\beta_\ell r)/\gamma r$, and the second of the form $\exp(-\gamma_i r)/r^2$, where the two coefficients β_ℓ, γ_i are imaginary. The physical character of the damping process is also different in the two cases: in the first case, energy leaks through the boundary layers; in the second, the waves are absorbed in the boundary layers. At a great distance from the source the field is determined by the least damped wave of the discrete spectrum, or by the lateral waves; at short distances, however, other waves of the discrete spectrum become important, too, whereas the lateral waves have only a negligible influence. The field in the layer has a complicated interference structure owing to the superposition of the waves of the discrete spectrum. The formulas of Parts I and II permit averaging processes, which simplify the picture and make physical sense.

7

Brekhovskikh, L. M., and I. D. Ivanov, "Concerning One Type of Attenuation of Waves Propagating in Inhomogeneously-Stratified Media," Soviet Phys. Acoust., English transl., 1, 23-31, 1957.

The propagation is considered of waves in a layer bounded on one side by a nonuniform medium in which the velocity of propagation falls off with distance from the layer boundary. It is shown that in these conditions propagation is associated with an additional weakening caused by energy being "siphoned off" from the waves into the nonuniform medium. The full theory of the effect is given and its magnitude determined.

8

Brosio, E., "Measurements on Acoustic Absorbing Structures by Resonance," Tech. Notes No. FRL TN 10, trans. of Alta Frequenza 25:32-37, Feltman Res. Labs., Picatinny Arsenal, Dover, N. J., 7 pp., 1960. AD-245 380

To obtain high acoustic coefficients at low frequencies, it is possible to use membranes of plastic material stretched over frames. Results are reported of laboratory measurements on structures of this kind.

9

Cramer, W. S., "Acoustic Absorption Coefficients at High Frequencies," J. Acoust. Soc. Am., 22, 260-262, 1950.

The measurement of the acoustic absorption coefficient by a steady state method was carried out at frequencies of 9, 20, and 30 kc for seven different materials. This involved constructing a sound chamber with facilities for creating a diffuse sound field and a sample area where materials could be mounted. The average intensity in the chamber was measured with the sample area covered by the material under test, and the results were compared with similar measurements when the area was covered with a material of negligible absorption and when it was open to the air outside. The expression giving the absorption coefficient in terms of these three relative intensity readings is derived.

10

Doak, P. E., "The Reflection of a Spherical Acoustic Pulse by an Absorbent Infinite Plane and Related Problems, "Proc. Roy. Soc. (London) A, 215, 233-254, 1952.

Experimental results of the reflection of a short train of sine waves of about 10 m duration by an infinite plane absorption wall are analyzed and discussed theoretically in relation to blast waves and electromagnetic waves. Some possible direct applications are indicated as to reflection of blast waves and waves of transient radiation by an electric dipole.

11

Fay, R. D., "Attenuation of Sound in Tubes," J. Acoust. Soc. Am., 12, 62-67, 1940.

Refinements in method and apparatus have made possible the precise measurement of attenuation of sound in tubes. Preliminary results strongly substantiate the tube wall effect predicted by Kirchhoff. Also, an unexpectedly large effect has been found, which depends on the first power of the frequency. Further measurements are required to find whether this loss exists in free air or is due in port to the tube walls.

12

Franken, P. A., "The Field of a Random Noise Source Above an Infinite Plane," Acoust. Lab., Mass. Inst. Tech., Cambridge, 1955.

This report on the field of a random noise source above an infinite plane represents one phase of a general program of research in atmospheric acoustics initiated in May 1953 under NACA sponsorship at the Acoustics Laboratory of MIT.

The sound field from a random noise source above ground as measured by a receiver with a finite band width is studied theoretically. For simplicity, only the far field has been considered. The special case of the perfectly reflecting plane is discussed, and nondimensional curves are given of sound pressure level versus distance for two different receiver band widths. The analysis is then extended to a plane of arbitrary impedance, and pressure level-versus-distance curves are given for typical field operating conditions. The sound field consists of two major regions. In the first, the sound pressure level fluctuates about an average curve sloping approximately 6 db per doubling of distance. Later, beyond a certain distance from the source, the level decreases monotonically 12 db per doubling of distance. The fluctuations depend on the band width of the receiver and on the ground impedance. With, for example, an octave band of 1000 to 2000 cycles and the receiver 10 feet above a ground of normal impedance ρc, the maximum pressure level fluctuation is about 2 db and occurs around 300 feet from the source, and the transition between the 6-db slope region and the 12-db slope region occurs around 700 feet from the source.

13

Gemant, A., "Frictional Phenomena," III-IV, J. Appl. Phys., 12, 718-734, 1941.

III. The part played by viscous forces in the absorption of acoustic waves traveling freely in the gas along with absorption due to heat conduction by the gas gives sound-absorption coefficients which, in nearly every case, are too small. Kneser's theory of a relaxation time explains the divergence as due to intramolecular vibrations, and the absorption in air is reduced by humidity because the water molecules reduce the relaxation time of the air molecules and shift the maximum absorption to higher frequencies. IV. The principles of room acoustics are discussed, and the sound-absorbing property of materials is explained on the basis of viscous processes in the pores of the material. Two methods are described for determining experimentally the acoustical resistance of a material: (1) The flow resistance is compared with that of a glass capillary; the units are placed in series and the same current of air is sucked through both; the pressure differences between the ends of the units are $\propto$ the respective resistances; experiment gave 14×10^3 for insulite and 18×10^3 for celotex, in absolute units. (2) The velocity of the gas is measured by means of a chemical indicator; the method is not suitable for low-resistance material. The properties of absorbents are discussed in relation to room acoustics.

14

Hardy, H. C., "Noise Control Measures for Jet Engine Test Installations," J. Acoust. Soc. Am., 25, 423-428, 1953.

The various schemes currently used for controlling the noise of aircraft engine test-stands and warm-up operations on the ground are briefly surveyed. The first step is to evaluate a design goal for acceptable levels in the neighborhood for the installation. The size of cross section required to handle the intake and exhaust gases is determined from the amount of air consumed, the temperature, acceptable gas velocities, and the aerodynamic pressure drops. The modern trend in engine size requires cross sections of 200 square feet or more. Several different styles of structures have been successful. The various types used—steel mufflers, duct splitters, and plenums and 180-degree bends—are discussed, and typical data are given for each type. Economic considerations are emphasized. The use of scale model acoustic tests for untried acoustic designs is strongly recommeded.

15

Hartig, H. E., and R. F. Lambert, "Attenuation in a Rectangular Slotted Tube of (1, 0) Transverse Acoustic Waves," J. Acoust. Soc. Am., 22, 42-47, 1950.

A pickup device for measuring the standing wave ratio of transverse acoustic waves is described. One of the important features of this device is the elimination of interference from the residual plane wave. This paper presents an experimental study of the attenuation characteristics of (1, 0) transverse acoustic waves propagated in air in a rectangular metal tube employing such a pickup device. This study reveals that three losses are important contributors to the attenuation. The results agree well with a tube wall effect predicted by Kirchhoff. In evidence in the medium is a gaseous absorption due to thermal equilibrium adjustments. The remaining attenuation is appreciable and appears to vary with frequency as $f^2[1 - f_c^2/f^2]^{-1/2}$. This factor is here attributed to a vibration of the tube walls.

16

Herzfeld, K. F., "Reflection of Sound," Phys. Rev., 53, 899-906, 1938.

The losses in the reflection of sound on solids are investigated. The heat conduction of the solid disturbs the temperature distribution in the gas and sets up a temperature wave. That the pressure in the gas near the wall is no longer in phase with the density results in a heating of the gas on the wall. The effect amounts to a few percent for a million cycles. The scattering of the molecules on the wall, the scattering of the sound waves by uneven places, and the effect of absorption are also investigated. They become important only at higher frequencies.

17

Hollyer, R. N., "Attenuation in the Shock Tube, I., Laminar Flow." J. Appl. Phys., 27, 253-261, 1956.

The ideal flow predicted for an inviscid adiabatic shock tube is not realized in experiments. The ideal theory for the viscous stresses and heat losses arising from the interaction of the gas flow with the tube walls is corrected by calculation. The boundary layer is regarded as a distribution of sinks of energy and momentum. The actual distribution is approximated by that behind a constant strength shock front and is calculated for laminar flows. The change in shock strength caused by a single sink located at a fixed distance behind the shock front is determined and this result is integrated over the distribution previously calculated. Interactions between the expanding compression chamber gas and the wall are neglected. Comparison with experiment shows that the interactions treated account for the major part of the attenuation of the shock front. It is pointed out that more data are required to evaluate precisely the assumptions used in the calculation.

18

Ingard, U., "Attenuation and Regeneration of Sound in Ducts and Jet Diffusers," J. Acoust. Soc. Am., 31, 1202-1212, 1959.

The effect of noise regeneration by fluid flow on the performance of noise-attenuating structures is examined with special attention to muffler design. The insertion loss of a single element, as well as a continuous distribution of attenuating and noise-regenerating elements, is studied. For example, in a duct with an attenuation constant β per unit length and a regeneration r per unit length, the upper limit of the insertion loss is 10 log (2 $E\beta/r$), where E is the source strength. It should be noted that the insertion loss of a noise-regenerating attenuator depends on the sound level to be reduced.

An analysis of experimental data on jet noise indicated that the power spectrum of a circular jet depends on frequency f and Mach number M, approximately, as f^2M^5 at low frequencies, as $f^{-2.5}M^{9.5}$ at high frequencies, and as M^7 at the peak frequency. In terms of the corresponding jet spectrum, for which an empirical analytical expression is given, the maximum attainable insertion loss of a jet muffler diffuser is presented as a function of frequency. The deviation of the characteristics of a lossy diffuser from this upper limit depends on the attenuation and regeneration characteristics of the acoustical elements in the muffler. These characteristics are investigated for the special element consisting of a perforated sheet, and the results are applied to an analysis of the insertion loss of a muffler diffuser of the perforated basket type.

19

Ingard, U., "Influence of Fluid Motion Past a Plane Boundary on Sound Reflection, Absorption, and Transmission," J. Acoust. Soc. Am., 31, 1035-1036, 1959. AD-226 926.

The effect of fluid motion past a plane boundary on the reflection and absorption of sound is equivalent to an increase of the normal acoustic impedance of the boundary by a factor $(1 + M \sin \theta)$, where θ is the angle of incidence of the sound wave, and M is the Mach number of the flow velocity component in the incidence-reflection plane of the wave. Similarly, the acoustic energy flux perpendicular to the boundary and the flow is shown to be increased by the same factor. Reflection and transmission coefficients of a thin solid interface between a fluid in motion and one at rest are given. Furthermore, some comments on the problem of transmission in ducts are given. For propagation between two plane parallel boundaries with the same acoustic admittance, for sufficiently small values of the admittance, the sound pressure attenuation constant of the fundamental mode is modified approximately by the factors $(1 + M)^{-2}$ and $(1 - M)^{-2}$ for downstream and upstream propagation, where M is the flow Mach number.

20

Ingard, U., and D. Pridmore-Brown, "Propagation of Sound in a Duct with Constrictions," J. Acoust. Soc. Am., 23, 689-694, 1951.

The transmission of sound through a duct periodically loaded with constrictions (iris partitions) is studied. The attenuation is given as a function of frequency in such ducts with both hard and absorptive side walls. For a hard-walled duct, the results of the analysis are presented in chart form. It is shown that by proper choice of side wall absorption and iris partitions a broad attenuation band can be obtained. Measured values of the attenuation are found to agree well with the theory.

21

Jackson, R. S., "The Performance of Acoustic Hoods at Low Frequencies," Acustica, 12, 139-152, 1962.

An investigation has been made into the performance of acoustic hoods at low frequencies, in the range where difficulties are often encountered in obtaining adequate attenuation. The problem was analysed for the case of one dimension, and with the aid of small boxes and panels the solution is shown to be of practical value. The importance of having a sealed enclosure with stiff walls is illustrated; several methods of introducing wall rigidity were investigated. When consideration need only be given to higher frequencies, limp wall techniques may be used to advantage, if adequate mechanical damping resides in the system. Methods of introducing wall damping were investigated and discussed, and some further factors influencing the low-frequency performance are included. It is concluded that further research into devising highly-damped stiff structures would be advantageous.

22

Kaye, G. W. C., and E. J. Evans, "Sound-Absorbing Properties of Common Outdoor Materials," Proc. Phys. Soc. (London), 52, 371-379, 1940.

The sound absorption coefficients of pure sounds of frequencies from 125 to 4000 cps have been measured at random incidence for specimens of some commonly occurring outdoor materials, such as gravel, turf, sand, ashes, railway-track ballast, and snow. They mostly share the common characteristic of increased absorption with rising pitch. Some of the materials (e.g., loose gravel, soil and ashes) are highly absorbent; snow is remarkably so, while others (e.g., compressed gravel and wet sand) are indifferent absorbents. Some practical aspects are discussed, as is the influence of nearly grazing incidence, such as often obtains with outdoor sounds, in raising the degree of absorption.

23

Klimov, B. M., and A. N. Rivin, "Sound Absorbing Phenopolyurethane Wedge Coatings," Soviet Phys. Acoust., English transl., 8, 286-287, 1963.

This brief communication presents test results on the absorptive properties of phenopolyurethane coatings applied to wedges for use in anechoic chambers. This material is of interest because of its great mechanical strength in comparison to the fiberglass materials normally used. Although the polyurethane coatings have almost twice the reflectivity of fiberglass, it nonetheless appears that they can assure absorption of over 99% of incident acoustic energy in a chamber for all frequencies above 200 cps. The coefficient of reflection fluctuates between 10% and 20% for frequencies between 100 and 200 cps.

24

Kuckes, A. F., and U. Ingard, "A Note on the Acoustic Boundary Dissipation Due to Viscosity," J. Acoust. Soc. Am., 25, 798, 1953.

This mathematical note deals with the energy losses due to viscous dissipation in the regions close to boundaries of the sound field where large velocity gradients occur in the boundary layer. In the case of an aperture in a thin plate, almost the entire dissipation is associated with a region very close to the hole and the curved part of the boundary. The result is therefore strongly dependent on the value of surface resistance of the curved part.

25

Lawhead, R. B., and I. Rudnick, "Acoustic Wave Propagation Along a Constant Normal Impedance Boundary," J. Acoust. Soc. Am., 23, 546-549, 1951.

An expression is obtained for the amplitude and phase of an acoustic wave above a boundary due to a point source on or near a boundary which exhibits a constant, normal, specific, acoustic impedance. This is shown to be a special case of the solution for an isotropic medium with constant, characteristic, acoustic impedance; specifically, one in which the ratio of the propagation constant in the upper medium to that in the lower approaches 0. A material which obeyed a constant, normal, impedance, boundary condition was constructed from ordinary drinking straws. Measurements of amplitude and phase as a function of receiver position along and above the boundary showed good agreement with theory. The nature of the approximations involved in the solution is discussed and shown to be an adequate representation of the sound field for distances greater than one wavelength from the source.

26

Lawhead, R. B., and I. Rudnick, "Measurements on an Acoustic Wave Propagated Along a Boundary," J. Acoust. Soc. Am., 23, 541-545, 1951.

The sound field of a point source located at a plane boundary was measured both with respect to its amplitude and phase characteristics. This was done for a very high impedance boundary and one composed of material which is relatively absorbing. The fields were calculated; for the latter material, calculations were based on measured values of impedance and propagation constant, and found to agree well with those measured.

27

Lawley, L. E., "The Absorption of Sound in Carbon Dioxide Contained in Narrow Tubes," Proc. Phys. Soc. (London) B, 67, 65-69, 1954.

Measurements were made with carbon dioxide contained in tubes ~1-mm diameter. Frequencies used were between 40 and 120 kcs. Results showed that over a considerable range of frequency/pressure on either side of the relaxation peak of CO_2, the total absorption was given by the sum of the Helmholtz-Kirchhoff tube absorption and the thermal relaxation absorption of the gas. The tube absorption, however, was found to be a few percent higher than that calculated theoretically.

28

Lisman, H., "Dependence of Transmission of Shock Waves on Sharpness of Boundary of Two Media," Eng. Rept. E-1114, Evans Signal Lab., Signal Corps Eng. Labs., Delmar, N. J., 7 pp., 1953.
AD-12, 162.

The pressure amplitudes of an acoustic wave and of two shock waves are traced from one layer of air through a boundary into another layer under the condition that the ratio of the acoustic velocity in the first medium to that in the second is $(0.875)^{1/2}$. Another calculation is made for the case of an intermediate layer such that the ratio of velocities in adjacent layers is $(0.875)^{1/4}$. Transmission across the boundary of two media, in the case of shock waves, is improved if a stepwise transition is made. The energy loss across a boundary becomes greater as the shock strength increases, and the percent of improvement of energy transmitted for stepwise transmission is greater for strong shocks than for relatively weaker one.

29

London, A., "The Determination of Reverberant Sound Absorption Coefficients from Acoustic Impedance Measurements," J. Acoust. Soc. Am., 22, 263-269, 1950.

A method is described for utilizing normal absorption coefficient or acoustic impedance measurements to predict reverberant sound absorption coefficients. The average of coefficients for the six standard frequencies determined from acoustic impedance measurements agrees closely with the average reverberant coefficient for cases where the material may be said to obey the normal impedance assumption. The normal absorption coefficients of some 26 different acoustic materials were measured at 512 cps. By using the method given in the paper, the predicted reverberant coefficient deviated from the measured reverberant coefficient by 0.05 or less for 18 materials; in only 3 cases were the deviations greater than 0.10. The method should be particularly applicable to the problem of acceptance testing of installed acoustic materials.

In the theoretical development, best agreement with experiment was obtained by introducing a new kind of reverberant statistics, which associates with each wave packet in a random field a scalar quantity equal to the square of the absolute value of the sound pressure in each packet, instead of the customary energy flow treatment. Also, it was found necessary to carry out the analysis by using a concept of equivalent real impedance to replace the usual complex impedance.

30

Mawardi, O. K., "On Acoustic Boundary Layer Heating," J. Acoust. Soc. Am., 26, 726-731, 1954.

The conventional investigations of the propagation of sound waves in conduits, when the effect of dissipation through friction and conduction of heat through the walls is taken into account, assume that the fluctuating part of the temperature of the gas vanishes at the boundaries. This is in essence a first-order approximation. Very different effects, however, are expected when sound-order terms are considered. The purpose of the present paper is to discuss in detail the nature of the solution obtained from a second-order approximation.

31

Mirels, H., "Attenuation in a Shock Tube Due to Unsteady-Boundary-Layer Action," Rept. No. 1333, Nat. Advis. Com. Aeron., Washington, D. C., 19 pp., 1956.
AD-158 942.

A method is presented for obtaining the attenuation of a shock wave in a shock tube due to the unsteady boundary layer along the shock-tube walls. It is assumed that the boundary layer is thin relative to the tube diameter and that it induces one-dimensional longitudinal pressure waves whose strength is proportional to the vertical velocity at the edge of the boundary layer. The method is shown to be in reasonably good agreement with existing experimental data.

32

Morse, P. M., and R. H. Bolt, "Sound Waves in Rooms," Revs. Mod. Phys., 16, 69-150, 1944.

This is a critical discourse and survey on the present position of room acoustics. It begins with Sabine's pioneer work, gives an account of progress, and points out where further research is required. It discusses the general principles of wave acoustics and shows how they clarify and supplement the geometrical results of earlier workers. It examines the importance of the reverberation time T, background noise, loudness of source, and shape of room, as they affect the recognizability of speech. The value of T given by Knudsen includes the absorptive effect of the air, for above 4000 cps this absorption may be several times the total absorption at the boundaries of the room. Methods of measuring room acoustics reveal the inadequacies of the geometrical theory. The general aspects of wave acoustics studied are the nature of the reaction between the sound wave and the walls of the room and the natures of the steady-state and transient response to a source of sound. The first of these involves a knowledge of the acoustic impedance of the surface; in the second and third the reverberant sound has the characteristic frequencies of the normal modes of vibration of the room and not necessarily the frequency of the source. In a simple rectangular room, a number of different decay rates exist; thus the decay curve cannot be a straight line, and rooms having smooth, regularly-shaped walls show the greatest divergence of decay rates for different standing waves. In general, wave acoustics will have to be used for small regularly shaped rooms, and geometrical acoustics will be sufficient for the analysis of most large auditoriums. The report ends with a very full bibliography.

33

Rogers, C., and R. Watson, "Determination of Sound Absorption Coefficients Using a Pulse Technique," J. Acoust. Soc. Am., 32, 1555-1558, 1960.

Determining sound absorption coefficients by a pulse method using a sound mirror to produce directed sound pulses allows determination of the coefficients by a free field method but within the confines of an ordinary laboratory. Average pulse pressures for brief pulses are obtained over both space and time to allow evaluation of the absorption coefficient as a function of angle of incidence. When averaged over angle of incidence, this function leads to average absorption coefficients, which were obtained for samples of two different materials. These coefficients, for a pulse two cycles long at 2000 cps, are 0.56 and 0.182. Comparable values computed from impedance tube data are 0.57 and 0.186; and values obtained from reverberation chamber measurements are 0.57 and 0.130. In each case the three values for each material lie within the estimates of error assigned. It is concluded that while the pulse method is confined to short pulses having relatively wide frequency spectra, the method is useful both in producing values of sound absorption coefficients as a function of angle of incidence and of average values of these coefficients.

34

Rudnick, I., "Measurements of the Attenuation of a Repeated Shock Wave," Tech. Rept. No. 3, Soundrive Engine Co., Los Angeles, Calif., 19 pp., 1953.
AD-10, 268.

The rate of attenuation of large-amplitude sound waves in the 30- to 200-cps range was measured as a function of distance along a tube 10 inches in diameter and 60 feet long connected to a siren. The waves approximated a saw-toothed wave form. Expressions are developed for the attenuation caused by the tube walls and by the shock character of the wave. The effect of dc flow of air through the tube is evaluated.

35

Schilz, W., "Application of Plate Absorbers to the Acoustic Suppression of Wind Tunnels," Acustica, 12, 202-205, 1962.

Plate absorbers are suitable for acoustic silencing of wind tunnels because of their aerodynamically smooth and tight surfaces. In a wind tunnel of small cross section, several types of plate absorbers were tested. For flow velocities below 20 m/sec absorbers with thin foils and with damped resilient volumes can be used. For greater flow velocities the onset of turbulence necessitates resilient plates. Promising values of attenuation were found for resilient plates with great internal losses (verneer sheet). Special care in the design of plate absorbers must be given to the reduction of the propagation of structure-borne sound.

36

Schilz, W., "Investigation of the Interaction Between the Sound Field and Flow in a Duct Coated with Porous Absorbers and Helmholtz Resonators," Acustica, 11, 137-151, 1961.

Sound attenuation in ducts with absorbent coating of the walls is strongly dependent on the direction and velocity of the air flow. The change of attenuation is brought about by a change of the characteristic properties of the absorbing material and by the deformation of the phase surface of the sound field caused by the air flow. Calculated values of the attenuation, with both effects taken into account are in good agreement with experimental values. The sound amplification mechanism in a duct coated with undamped Helmholtz resonators is explained in the interaction between the soundfield and the turbulence of flow. Conversion of flow energy into sound energy is effected by synchronization of the turbulence. Under favorable circumstances this synchronization leads to the formation of a stable pseudosound wave. Pseudosound and sound interact at the resonator necks.

37

Shaw, E. A. G., "The Acoustic Wave Guide, I., An Apparatus for the Measurement of Acoustic Impedance Using Plane Waves and Higher Order Mode Waves in Tubes," J. Acoust. Soc. Am., 25, 224-230, 1953.

The (1 0) and (2 0) modes of acoustic waves in rectangular wave guides have been excited to the virtual exclusion of plane waves. The experimental techniques depend on the use of acoustic sources equivalent to two or more pistons with appropriate relative phases and amplitudes, precise adjustment of which is accomplished with the aid of an accurately located probe microphone. The standing wave pattern which arises when the wave guide is terminated by a partially absorbing surface may be used to determine the specific normal impedance of the surface, the value of which is characteristic of waves having a particular oblique angle of incidence and may be compared with normal incidence values obtained from plane-wave measurements in the same wave guide and at the same frequency; the angle of oblique incidence may be varied by changing the frequency. The apparatus operates in the 1- 3-kc/sec frequency region, and the accuracy of impedance measurement with (1 0) and (2 0) waves is comparable to that attainable with the usual plane-wave tube techniques. Equivalent angles of incidence at the absorbing surface of up to 84^{o} have been used. The principles underlying the design of the apparatus and some of the distinctive problems which arise with higher order mode waves are discussed.

38

Shaw, E. A. G., "The Acoustic Wave Guide, II., Some Specific Normal Acoustic Impedance Measurements of Typical Porous Surfaces with Respect to Normally and Obliquely Incident Waves," J. Acoust. Soc. Am., 25, 231-235, 1953.

ABSORPTION, BOUNDARY LAYER AND SURFACE

The experimental techniques described in Part I have been applied to the measurement of some acoustic properties of rock-wood, hairfelt, and acoustic tile, backed by a rigid wall. The more porous surfaces show substantial increases in resistance at oblique angles of incidence (in one case an increase of nearly 100% at 80° incidence was observed); also, smaller changes in reactance occur. The absorption coefficients corresponding to impedance measurements at oblique incidence are compared with those "predicted" from normal incidence impedance measurements, and significant differences are found. The measurement of surfaces having structures of finite dimensions is discussed with particular reference to an acoustic tile, the impedance of which varies only slightly with angle of incidence. In some cases, slight scattering of acoustic energy from one mode to another provides evidence of the lack of uniformity of impedance over the surface of the specimen.

39

Shields, F. D., and R. T. Lagemann, "Tube Corrections in the Study of Sound Absorption," J. Acoust. Soc. Am., 29, 470-475, 1957.

The absorption and velocity of sound in argon, nitrogen, and carbon dioxide have been investigated over a range of frequency, pressure, and temperature conditions. A movable sound source and a stationary microphone were used, both employing the principle of the ribbon microphone, located inside glass tubing 1.73 cm in diameter. It was found that Kirchhoff's equations correctly predicted the absorption and velocity as the temperature was varied from 0 to 200° C for argon and from 0 to 150° C for N_2. Not only did the tube absorption vary as a function of $(f/p)^{1/2}$, but the factor incorporating the physical properties also appears to be valid. Certain earlier experiments have not agreed with the Kirchhoff predictions of the magnitude of the factor which depends on the physical properties, and the success in checking the theory is attributed to the use of improved data for the properties and to the use of precision bore tubing in the apparatus.

40

Syono, S., "Anomalous Propagation of Sound at a Short Distance," Geophys. Mag. (Tokyo), 9, 175-194, 1935.

In a former paper the author explained by an approximate method some anomalous sound wave propagation phenomena described by J. Kolzer. The present paper, which is almost entirely mathematical, is concerned with making the treatment more rigorous by taking into account the effects of wind and absorption of the earth's surface.

41

Trimpi, R. L., and N. B. Cohen, "A Nonlinear Theory for Predicting the Effects of Unsteady Laminar, Turbulent, or Transitional Boundary Layers on the Attenuation of Shock Waves in a Shock Tube with Experimental Comparison," Tech. Note TN-4347, Nat. Advis. Com. Aeron., Washington, D. C., 105 pp., 1958.
AD-203 726L.

The linearized attenuation theory of NACA Technical Note 3375 is modified in the following manner: (a) an unsteady compressible local skin-friction coefficient is employed rather than the equivalent steady-flow incompressible coefficient; (b) a nonlinear approach is used to permit application of the theory to large attenuations; and (c) transition effects are considered. Curves are presented for predicting attenuation for a shock pressure ratio up to 20 and a range of shock-tube Reynolds numbers. Comparison of theory and experimental data for shock-wave strengths between 1.5 and 10 over a wide range of Reynolds numbers shows good agreement with the nonlinear theory evaluated for a transition Reynolds number of 2.5×10^6.

42

Waetzmann, E., and W. Wenke, "Sound Damping in Rigid and Elastic Walled Tubes" (in German), Akust. Z., 4, 1; translated by L. L. Beranek, J. Acoust. Soc. Am., 11, 154-155, 1939.

The attenuation due to tube walls was measured, and the results are presented in this paper. Rigid, smooth, rough, and porous tubes, and also elastic hoses were investigated. Attenuation was measured as a function of frequency and tube diameter.

43

Watson, R. B., "On the Propagation of Sound over Snow," J. Acoust. Soc. Am., 20, 846-848, 1948.

Many qualitative observations have been made on the quieting effect of newly fallen snow, which must depend on its acoustical properties. The physical constants for snow vary over a considerable range, and data for calculating its acoustic constants are meagre. The calculated absorption coefficient ranges uniformly from 0.25 at 100 cps to 0.75 at 2000 cps. Calculations are made of the sound level at an observer's position due to sound transmitted over a layer of snow. Because of the appreciable absorption, the sound level is found to be considerably reduced at distances as small as 500 feet from the source.

Absorption, Boundary Layer and Surface — See also Terrain Effects
See also — 76, 78, 90, 105, 123, 133, 140, 141, 255, 350, 378, 429, 431, 434, 435, 442, 449, 453, 452, 457, 458, 459, 461, 465, 471, 478, 486, 488, 516, 528, 529, 554, 568, 789, 795, 910, 925, 1018, 1057, 1071, 1077, 1086, 1191, 1573, 1581, 1607, 1890, 1910, 1970, 1991, 2000, 2032, 2080, 2100, 2106, 2244, 2265, 2649, 2721, 2819, 3200, 3463, 3544, 3549, 3550, 3551, 3553, 3556, 3563, 3570, 3582, 3590, 3639, 3663, 3688, 4036, 4115, 4210

ABSORPTION, CLASSICAL

44

Bhatia, A. B., "Sound and Ultrasound Absorption Resulting from Heat Radiation," J. Acoust. Soc. Am., 29, 823-824, 1957.

Following a suggestion by Markham, Beyer and Lindsay (Rev. Mod. Phys., 23, 353-411, 1951), the Stefan-Boltzmann radiation law is applied to estimate the attenuation of approximately plane compression waves resulting from heat radiation. The attenuation is found to be independent of the frequency of the compression waves in the entire relevant frequency range and inversely proportional to a linear dimension of the wave fronts. At ordinary temperatures, this attenuation is negligible compared to that due to thermal conduction and viscosity, verifying the results of Rocard and Rayleigh. In gases at temperatures of 1000°K or more, however, the attenuation due to heat radiation is not entirely negligible under certain conditions.

45

Dean, E. A., "Absorption of Low Frequency Sound in a Homogeneous Atmosphere," Schellenger Res. Lab., Texas Western College, El Paso, 1959.

This is a review of the classical and molecular theory of the absorption of sound, with particular attention to the absorption of frequencies less than 1000 cps in the atmosphere from sea level to 50 km. The variation of the theoretically predicted absorption with the meteorological parameters—pressure, temperature, and humidity—is investigated. Recent work involving absorption due to radiation is included. It is found that the absorption can be expressed as:

$$\frac{2.5 \times 10^{-7}(T^*)^{0.3}f^2}{P^*} + \frac{5.3 \times 10^{-5}(T^*) f}{P^*} + \frac{1.0 \times 10^2 f}{(T^*)^{2.5}e^{8.3/T^*}} \frac{2f_0 f}{f_0^2 + f^2}$$

db/mile, where

$$f_0 = \frac{P^*}{(T^*)^{0.8}} \left[900 \left(\frac{wT^*}{P^*}\right)^2 + 500 \frac{wT^*}{P^*} + 50\right]$$

$T^* = T/273$, $T = {}^0K$, P^* = pressure in atmospheres, and w is the absolute humidity in gm/m^3.

The absorption has been calculated for various altitudes, humidities, and frequencies. These data are presented in tabular form in the appendix. Although the absorption varies in a rather complicated manner with the meteorological parameters, it is found to be quite small for the very low frequencies, resulting in a predicted long distance propagation with small attenuation if the geometry of propagation is advantageous.

46

Dean, E. A., "Absorption of Sound in the Atmosphere," Proc. Symp. Atmos. Acoust. Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. M., 1, 50-56, 1961.
AD-408 716.

The classical and molecular theories of the absorption of sound for low f/p ratios are reviewed. The absorption is discussed as a function of frequency and atmospheric pressure, temperature, and composition, including recent work on the determination of the vibrational relaxation time due to small amounts of water vapor. The possible importance of absorption due to radiation is mentioned.

47

Dubois, M., "The Absorption of Sound and Ultrasonics in Gases" (in French), J. Phys. Radium, 12, 876-884, 1951.

This article reviews the general problem of the attenuation, of a plane wave during propagation, due to the properties of the medium and the local modifications produced by the passage of the wave. Viscosity, conductivity rise and fall of temperature, and the variations in the translational and vibrational energy of the molecules are considered. Theoretical and experimental results are compared, and an extensive bibliography is given.

48

Gemant, A., "Frictional Phenomena," III-IV, J. Appl. Phys., 12, 718-734, 1941.

III. The part played by viscous forces in the absorption of acoustic waves traveling freely in the gas along with absorption due to heat conduction by the gas gives sound-absorption coefficients which, in nearly every case, are too small. Kneser's theory of a relaxation time explains the divergence as due to intramolecular vibrations, and the absorption in air is reduced by humidity because the water molecules reduce the relaxation time of the air molecules and shift the maximum absorption to higher frequencies. IV. The principles of room acoustics are discussed, and the sound-absorbing property of materials is explained on the basis of viscous processes in the pores of the material. Two methods are described for determining experimentally the acoustical resistance of a material: (1) The flow resistance is compared with that of a glass capillary; the units are placed in series and the same current of air is sucked through both; the pressure differences between the ends of the units are $\propto$ the respective resistances; experiment gave 14×10^3 for insulite and 18×10^3 for celotex, in absolute units. (2) The velocity of the gas is measured by means of a chemical indicator; the method is not suitable for low-resistance material. The properties of absorbents are discussed in relation to room acoustics.

49

Greenspan, M., "Propagation of Sound in Five Monatomic Gases," J. Acoust. Soc. Am., 28, 644-648, 1956.

The speed and attenuation of sound at 11 mcs were measured in He, Ne, A, Kr, and Xe at various pressures between atmospheric and a few mm Hg; the results are compared with existing theories.

50

Hoff, L., "Volume Viscosity and Compressibilities from Acoustic Phenomena," J. Acoust. Soc. Am., 23, 12-15, 1951.

A phenomenological theory of volume viscoelasticity is formulated, resulting in an equation recently used by Hall. Application of this equation to the dispersion and absorption of sound in fluids is extended to the whole range of frequencies. Results of calculations of the volume viscosity and the instantaneous and relaxational compressibilities for gases and liquids from certain available absorption data are given. The bearing of this theory on the classical theory of hydrodynamics is pointed out.

51

Horiuchi, I., "Absorption of Sound in Air at Very Low Densities," Tech. Rept. No. 11, Columbia Univ., New York, 1958.
AD-201 133

The "super-Burnett" approximation to the Boltzmann collisional equation has been applied to the evaluation of the absorption of sound in air at low densities. The solutions which were obtained on the REAC analogue computer yield magnitudes somewhat smaller than were obtained by successive approximation methods. A maximum absorption per wavelength of $\bar{\mu} = 1.45$ was obtained for diatomic molecules. Comparison of the translational absorption with that due to rotational and vibrational degrees of freedom shows that it becomes predominant at ratios of frequency to pressure exceeding 100 Mc/atm.

52

Huetz-Aubert, M., and J. Huetz, "Ultrasonic Absorption and Dispersion in Monatomic Gases: The Three Sources of Classical Irreversibility" (in French), J. Phys. Radium, 20, 7-15, 1959.

The study of dispersion and absorption effects, so called "classical effects" or effects of translation, since they affect the molecular degrees of freedom, is most useful for separating the global effects which are the only ones accessible to experiment, from those which are due to intramolecular relaxation. As this latter cannot affect the behavior of monatomic gases, the experimental control is easier if it is confined to these gases. Viscosity and conduction are the most important classical effects, but radiation leads to dispersion and absorption equations identical to those which are found by relaxation. Thus, irreversibiltiy does not essentially differ according to its inter- or intramolecular origin. It can be concluded that the theory of effects of translational absorption and dispersion is verified.

53

Kanwal, R. P., "Absorption and Dispersion of Forced Spherical and Cylindrical Sound Waves According to the Navier-Stokes Equations," J. Acoust. Soc. Am., 29, 593-595, 1957.
AD-147 806.

In his classical paper on infinitesimal sound waves in perfect gases endowed with shear viscosity, bulk viscosity, and heat conduction, Kirchhoff considered not only plane waves but also a certain class of curves waves. He showed that the absorption and dispersion of these waves is determined by the solution of a biquadratic equation for the complex frequencies; but, in discussing the behavior of particular waves, he employed only one of the two pairs of roots, and this he linearized with respect to the driving frequency. The biquadratic itself, as extended by Langevin to hold for fluids obeying an arbitrary equation of state, has been solved exactly and generally by C. A. Truesdell (1953). In his comprehensive analysis and interpretation of the solutions, however, Truesdell considered only forced plane waves. The present article gives a new version of Kirchhoff's approach to curved waves of expansion (an arbitrary motion may be regarded as the vector sum of an isochoric irrotational motion, a set of vorticity waves, and a set of expansion waves. Vorticity waves are not considered. As has been remarked in varying degrees of generality by M. Lessen (1954); Lagerstrom, Cole and Trilling (1949); S. Jarvis, Jr. (1954); and U. Yao-Tsu Wu (1956), the propagation of linearized vorticity is independent of bulk viscosity and heat conduction, and it is shown how Truesdell's results on plane waves may be adjusted to apply to the class of curved waves considered. Spherical and cylindrical waves are analyzed in some detail. Proper treatment of this problem requires dimensionless variables and hence some reference standard of length. Two alternatives are considered: (1) the unit of length is a linear dimension of a given oscillator; (2) the unit of length is the wavelength corresponding to the driving frequency according to the theory of nondissipative fluids. In the brief remarks of Kirchhoff, apparently only the first possibility was noticed. For the second class of spherical waves, the absorption coefficient per cm is shown always to be much less than that for the first class. There is a frequency-dependent factor which tends to increase the amplitude with the frequency. Similar analysis is carried out for cylindrical waves, which are shown to behave in a fashion intermediate between plane and spherical waves.

54

Keller, H. H., "Absorption of hf Sound Waves in Gases" (in German), Physiks Z., 41, 16, 1940.

The method used by Petersen to measure the absorption of supersonic waves in gases has been further developed. In these measurements a monochromatic, parallel light beam is diffracted by inhomogeneities in density of the gas, which are produced by sound waves traveling through it. The decrease in sound intensity with distance from the source produces a change in the distribution of the light on the photographic plate in the first order. Photometric measurements can therefore be used to determine the absorption coefficient. A classical theory of absorption assumes that the energy absorbed from the sound wave is distributed among the translational degrees of freedom. Measurements of the absorption coefficient as a function of the pressure of the gas were made in A, N, NH_3, CO_2, and CO_2 plus 8% H, at a frequency of 4 mcs. A theoretical relation was derived which enabled the author to determine the absorption coefficient for these substances as a function of the frequency for atmospheric pressure. This was checked against the results predicted by the classical theory. For A, the experimental results agree with those predicted by the theory. This is taken to be a check on the experimental method and on the way in which the results are interpreted. The absorption coefficients of the other substances are larger than those predicted by the theory. This is taken to mean that in these molecules some of the energy absorbed from the sound wave is distributed among the rotational degrees of freedom. Thus, NH_3 has a higher absorption coefficient than N because it requires higher energies to excite its rotational states than does N. Hence NH_3 should have a longer relaxation time.

55

Kneser, H. O., "Compression- and Shear-Viscosity in Gases" (in German), Ann. Physik, 6, 253-256, 1949.

Not all the energy used in compressing a fluid is available on reexpansion. The energy absorbed may be expressed in terms of the compression viscosity ζ, the relation being similar to that between the shear-viscosity η and the energy used in shear deformation. In Stokes's theory of sound absorption the compression viscosity is neglected; its value can therefore be estimated from discrepancies between experimental observations and Stokes's theory. Available data on sound-absorption in He, Ar, H_2 and N_2 is examined from this point of view. It is found that for the monatomic gases $\zeta = 0$; for N_2 ζ is of the same order as η, while for H_2 ζ approx. = 60 η at low frequencies, decreasing rapidly with increasing frequency. These results are in general agreement with predictions from kinetic theory.

56

Knudsen, J. R., "The Effects of Viscosity and Heat Conductivity on the Transmission of Plane Sound Pulses," J. Acoust. Soc. Am., 26, 51-57, 1954.

The dissipative effects of viscosity and heat conductivity are studied here in connection with the flow of a compressible fluid in a parallel channel or tube. Two kinds of waves or pulses are considered, and the distortion from the customary square wave is calculated. One observer at a fixed point on the channel, and two travelling with the wave, are seen to give information on the order of decay or dissipation of the wave with increasing time.

57

Kohler, M., "Sound Absorption in Binary Gas Mixtures" (in German), Z. Physik, 127, 41-48, 1950.

Extension of the author's theory of sound absorption in binary mixtures of monatomic gases by Meixner (Ann. Physik, 43, 470, 1943) is discussed with special reference to large ratios of molecular mass and diameter. Numerical calculations based on experimentally-found constants are given for 50% A-He and 50% A-H_2 mixtures, and it is shown that the absorption of the mixture > absorption of pure gas.

58

Kohler, M., "Sound Absorption in Mixtures of Monatomic Gases" (in German), Ann. Physik, 39, 209-225, 1941.

The influence of ordinary diffusion and thermal diffusion on sound absorption in monatomic gases is examined by the use of the Enskog equations. On the basis of the kinetic gas theory, the equations of motion are derived for the monatomic gas mixture. Nine independent equations are obtained for the 9 unknowns u_1, v_1, w_1, u_2, v_2, w_2; ρ_1 and ρ_2; and T. The propagation of density waves of infinitely small amplitude is considered. The three new terms due to diffusion depend on frequency and pressure, as do the Kirchhoff terms arising from friction and heat conduction, and they are fully discussed. The first term is due to the effect of ordinary diffusion and is proportional to the diffusion coefficient D_{12}, to $(M_2 - M_1)^2/M_0^2$ (M = mol. wt.), to the ratio c_p/c_v of the sp. hts. and to the product c_1c_2 of the mol. concentrations. The second is due to thermal diffusion and is proportional to (c_p/c_v) -1, to c_1c_2, to $(M_2 - M_1)/M_0$ and to a coefficient v_{12} which determines the thermal diffusion. The third is occasioned by the increased heat conduction due to thermal diffusion. The possibility of determining thermal-diffusion coefficients from measurements of sound absorption in gas mixtures is mentioned.

59

Kohler, M., "The Volume Viscosity of Gases as a Gas-Kinetical Transport Phenomenon" (in German), Naturwissenschaften, 33, 251-252, 1946.

The volume viscosity μ is defined by $T_{ii} = p - \mu \text{div} \rightarrow v - 2\eta (d_{ii} - \frac{1}{3} \text{div } v)$, where the T_{ii} (i = 1, 2, 3) are the diagonal elements of the stress tensor, p = the pressure, $\vec{v} = (v_1, v_2, v_3)$ the velocity, η = the ordinary viscosity and $d_{ii} = \partial v_i/\partial x_i$. The Maxwell relation $\mu = 0$ is true only for a monatomic gas. A polyatomic gas, in which the oscillations are not excited and the rotations are fully excited, can be treated by representing the molecules as rough spheres. If $K = 4\pi I/MD^2$ is used as an expression for the density distribution in the sphere (I = moment of inertia, m = mass, D = diameter), this model gives:

$$\mu/\eta = (1 + \frac{13}{6} K)/10K > 0.336$$

The volume viscosity causes an increase in the absorption of sound. For $C_p/C_v = 4/3$ this amounts to more than 20% of the contribution due to viscosity and thermal conductivity. This result agrees with experiment.

60

Lukasik, S. J., "Acoustic Relaxation by Radiation," J. Acoust. Soc. Am., 28, 455-458, 1956.

The effect on the vibrational and rotational relaxation time of deexcitation by photon emission in four gases possessing a permanent electric dipole moment is investigated. Such radiative energy losses are independent of pressure, and may be expected to control the relaxation process at low pressure when collisions become relatively infrequent. Calculations are shown for N_2O, OCS and SO_2. Estimates of the efficiency of collisions to deactivate a vibrational level in HCl, indicate that the radiation effect on the vibrational relaxation time of this gas should be the easiest to measure; at a pressure of 10^{-2}-10^{-3} atm., deexcitation by radiation should be as important as collisional deexcitation. Radiative deexcitation will become increasingly important at low temperatures because of the consequent increase of the collisional relaxation time.

61

Oberst, H., "Absorption of Sound in Gases," Z. Tech. Phys., 17, 580-582, 1936.

Measurements are described of the absorption of sound in a gas contained in a tube. The sound is excited by a loudspeaker placed at one end of the tube with a diaphragm so heavy that reaction upon it can be neglected. A condenser microphone at the other end of the tube serves to determine the response. The absorption at various frequencies in the range 700-4000 ~ is deduced from the breadth of selected resonances of the gas contained in the tube. To minimize absorption by the tube walls, tubes of thick brass or glass are used. In one series of measurements, N_2 is used at a range of pressures. Since molecular absorption can be neglected in this gas, the absorption deduced should agree with that predicted from Kirchhoff's formula. Actually, the measured absorption is about 15% higher. Measurements are also made in dry and moist O_2, and results are obtained which agree well with those of Kneser and Knudsen. It is suggested that this experimental method would be suitable for determining molecular absorption in gases.

62

Offerhaus, M. J., "On Sound Propagation in a Monatomic Gas," Univ. of Wisconsin, Madison, 37 pp., 1962. AD-285 204.

Two methods for a theoretical discussion of sound propagation in a monatomic gas are discussed; they both aim at finding periodic solutions, one of the hydrodynamical equations, the other of the Boltzmann equation; and we refer to them as the hydrodynamical and the kinetic method. Both lead to solutions on successive levels of approximation, the first by gradually including, in the hydrodynamical equations, terms with gradients of higher order; the second by gradually increasing the number of functions from which to build a velocity distribution. The main result reached by either method is a law of attenuation (dispersion and absorption) of the sound; the forms which this law takes, in both treatments, in consecutive approximations are discussed and compared. The treatment holds for a gas with a Maxwellian intermolecular potential, but the results can, in good approximation, be taken over to a real monatomic gas. A comparison is finally made with experiments in monatomic gases done by Greenspan, who has extended his measurements into the region where the sound frequency becomes comparable to the collision frequency by decreasing the latter. It is shown that in this region the available approximation schemes prove necessarily inadequate.

63

Petralia, S., "Effects of Diffusion on the Absorption of Ultrasonics in Gas Mixtures" (in Italian), Nuovo Cimento (Ser. 10), 1, 351-354, 1955.

Continuation of the work described in Nuovo Cimento, 11, 570-571, 1954. Values of α/f^2 as a function of concentration for the mixtures He-Kr, He-Ne, Ne-A, A-Kr and Ne-Kr are shown graphically and tabulated. The values are compared with those calculated from Kohler's relation (Ann. Physik, 39, 209, 1941).

64

Pielemeier, W. H., "Observed Classical Sound Absorption in Air," J. Acoust. Soc. Am., 17, 24-28, 1945-1946.

A brief treatment of the theory and methods of measuring absorption of sound in gases precedes graphical data. The measurements were made with a Pierce acoustic interferometer at a frequency of 1927 kcs in air. This frequency is high enough to satisfy Hardy's and Krasnooshkin's required conditions to obtain reliable results. The experimental result agrees with Krasnooshkin's value of $\alpha_0\lambda_0^2 = (225 \pm 5) \times 10^{-6}$ cm.

65

Rocard, Y., "Absorption of Sound in Gases," Rev. Acoust., 3, 47-62, 1934.

This is a mathematical paper in which the magnitudes and frequency variations of the effects of thermal conduction, viscosity, diffusion in gas mixtures, and the transfer of molecular vibrational energy on the absorption of sound in a gas are considered and compared.

66

Rocard, Y., "Damping of Sound Waves," J. Phys. Radium, 1, 426-437, 1930.

This article discusses the damping of sonorous or ultrasonorous waves in a homogeneous gaseous medium. It reviews the work of Stokes, Rayleigh, and Chapman on the modifications to be introduced into the fundamental hydrodynamical equations in order to allow for viscosity, the influence of the radiation of heat, and the thermal conductivity of air. It considers the damping due to the reciprocal diffusion in air of its constituent elements. By this the condition of adiabatism is altered, and a new adiabatic equation is deduced. This new equation has a form $PV^{\gamma+i\beta\gamma}$ = const., where the imaginary, i, indicates a displacement of phase between the variations of pressure and volume for the particular frequency used in determining the value of $\Delta\omega$. The value of $\Delta\gamma$ once obtained, it is easy to calculate the amount of damping due to this cause. The same method is used in a revision of the previous work of Stokes, Rayleigh, and Chapman. The relative importance of the different causes of damping is discussed.

67

Shields, F. D., and R. T. Lagemann, "Tube Corrections in the Study of Sound Absorption," J. Acoust. Soc. Am., 29, 470-475, 1957.

The absorption and velocity of sound in argon, nitrogen, and carbon dioxide have been investigated over a range of frequency, pressure, and temperature conditions. A movable sound source and a stationary microphone were used, both employing the principle of the ribbon microphone, located inside glass tubing 1.73 cm in diameter. It was found that Kirchhoff's equations correctly predicted the absorption and velocity as the temperature was varied from 0 to 200^o C for argon and from 0 to 150^o C for N_2. Not only did the tube absorption vary as a function of $(f/p)^{1/2}$, but the factor incorporating the physical properties also appears to be valid. Certain earlier experiments have not agreed with the Kirchhoff predictions of the magnitude of the factor which depends on the physical properties, and the success in checking the theory is attributed to the use of improved data for the properties and to the use of precision bore tubing in the apparatus.

68

Skudrzyk, E., "The Theory of Internal Friction in Gases and Liquids, and Sound Absorption" (in German), Acta Phys. Austriaca, 2, 148-181, 1948.

The theories of sound attenuation due to viscosity and heat conduction, developed by Stokes and Kirchhoff, are inadequate to explain the experimental observations. Introducing the Boltzmann fundamental equation for gas theory, equations are derived for wave propagation in a viscous medium, the phase velocity and damping being derived from the complex sound velocity at a wide range of frequencies. Tables compare the "classical" values of sound absorption in various gases and in liquids with the "corrected" values.

69

Smith, P. W., Jr., "Effect of Heat Radiation on Sound Propagation in Gases," J. Acoust. Soc. Am., 29, 693-698, 1957.

The effect is reexamined after considerable modification of the classical analysis. Account is taken of the fact that a gas radiates energy of a given electromagnetic wavelength in proportion to its corresponding coefficient of absorption, which is a strongly varying function of wavelength with a number of isolated peaks. No restriction is placed upon the value of the electromagnetic absorption per acoustic wavelength. The results indicate that the acoustic attenuation, which generally increases with decreasing frequency, will show a plateau of very flat peak near those frequencies at which one of the peaks of electromagnetic absorption reaches a value of 4π nepers per acoustic wavelength. An upper bound for the effect shows that dispersion attenuation will be negligible at all frequencies for gases at atmospheric pressure and room temperature, but may become significant in rarified gases or at elevated temperatures.

70

van Itterbeek, A., and L. Thys, "Velocity and Absorption of Sound in Nitric Oxide in a Magnetic Field," Physica, 5, 640-642, 1938.

From previous measurements on the absorption of sound in O_2, it was established that the absorption decreases strongly (about 20%) under the influence of a magnetic field (strength 5 k Gauss). The authors have now investigated NO in a magnetic field of the same strength. No influence of the magnetic field on the absorption is found. The absorption was determined as a function of pressure. The results obtained are in complete agreement with the theory of classical absorption. The velocity of sound in NO at 16.3^{o}C was found to be 333.9 m/sec.

71

Weston, D. E., and I. D. Campbell, "Experiments on the Propagation of Plane Sound Waves in Tubes, I., The Adiabatic Region," D. E. Weston; "II., The Transition Region," D. E. Weston and I. D. Campbell, Proc. Phys. Soc. (London) B, 66, 769-774, 1953.

I. An experimental investigation using an acoustic interferometer with a magnetostriction source is described. Results on attenuation and velocity in tubes of radius 0.013 cm and upwards, from 10 to 20 kcs, and for a variety of tube materials and gases are given. These confirm a modified Kirchhoff's formulae. II. The velocity and attenuation of plane sound waves in tubes of radius 0.02 cm have been measured in the transition region between adiabatic and isothermal flow.

72

Wilkes, M. V., "Atmosphere Oscillations," Nature, 164, 281, 1949.

In order to remove certain difficulties in the treatment by Pekeris (Proc. Roy. Soc. A, 158, 650, 1937) of long-period oscillations, the author first discusses the effect of heat conductivity on the damping of atmospheric waves. He shows that the two recognized ways in which damping may arise through heat conductivity do not apply to the same physical system. Accordingly he finds that in the analysis followed by Pekeris there are no general grounds for supposing that the wave will be attenuated in the direction of energy flow. If, however, radiation is taken as the damping agency, the difficulty is removed, and an analysis similar to that of Pekeris gives a wave always attenuated in the direction of propagation.

73

Zhumartbaev, M., "Absorption of Sound and the Width of Shock Waves in Relativistic Hydrodynamics," Soviet Phys. JETP, English transl., 37(10), 711-713, 1960.

The absorption coefficient of sound due to viscosity and heat conduction of the medium is derived in relativistic hydrodynamics. The structure of relativistic low-intensity shock waves is considered.

Absorption, Classical
See also—24, 27, 86, 87, 89, 92, 101, 124, 126, 140, 141, 142, 145, 147, 148, 152, 153, 159, 180, 181, 194, 202, 205, 215, 216, 233, 234, 235, 244, 245, 246, 248, 257, 263, 267, 271, 281, 282, 322, 440, 554, 590, 747, 782, 813, 833, 904, 930, 941, 942, 943, 944, 955, 1182, 1322, 1908, 2625, 3075, 3178, 3185, 3196, 3212, 3553, 3633, 3634, 4321, 4337

ABSORPTION, MEASUREMENT

74

Ackerman, E., and F. Oda, "Acoustic Absorption Coefficients of Human Body Surfaces," Final Rept. No. MRL TDR 62-36, Penn. State Univ., University Park, 1962.
AD-283 387

Reverberation chamber decay times were measured with and without human body surfaces exposed to the sound field. From these measurements, acoustic absorption coefficients were computed for human body surfaces. These were small compared to similar coefficients for laboratory animals. Typical values for the absorption coefficients for human body surfaces ranged from 1 to 2%. Little variation was found from 1 to 20 kc, and measurements were not made outside of these limits. The results are discussed and compared with other values obtained by different methods.

75

Adolph, R., and H. O. Kneser, "Applications of the Impulse Method to Physical Problems" (in German), Z. Angew. Phys., 1, 382-387, 1949.

The applications of pulse techniques to the measurement of the velocity and absorption of sound waves in solids, liquids and gases are surveyed. In solids, an echo-sounding technique is used for flaw detection, employing ultrasonic waves of frequency 5 mcs. Absorption measurements are made on solids by means of ultrasonic frequencies to develop materials suitable for delay lines and to study the heating effect of ultrasonic vibrations. Very accurate measurements can be made by the echo technique to determine the velocity of ultrasonic waves in liquids. It has been found with liquids that the absorption increases with the square of the frequency, so that some materials become almost impermeable to sound at very high frequencies. The troposphere is studied by echo-sounding with the impulse technique using frequencies of 1-4 kcs.

76

Angona, F. A., "The Absorption of Sound in Gas Mixtures," J. Acoust. Soc. Am., 25, 1116-1122, 1953.

The absorption of sound has been measured in CO_2, CS_2, C_2H_4O, and in mixtures of the latter two gases with CO_2 over the frequency and pressure ranges, and by the method reported in the preceding abstract. The measured absorption coefficient was corrected for the effect of the tube and also for the absorption due to viscosity and heat conduction of the gas. The corrected absorption coefficient was then plotted as the attenuation coefficient per wavelength against the logarithm of the ratio of frequency over pressure. These curves were then compared to those determined from Bourgin's theory for mixtures of absorbing gases. The agreement between the observed attenuation and that predicted by the theory was within 5%.

77

Angona, F. A., "The Absorption of Sound in Gas Mixtures," Tech. Rept. No. 5, Univ. of Calif., Los Angeles, 87 pp., 1953.
AD-3 861.

The molecular absorption of sound in CO_2, CS_2, C_2H_4O, and their mixtures were measured. The sound tube method used in this investigation was readily adaptable to both frequency and pressure control. The attenuations for pure CO_2, CS_2, and C_2H_4O agreed closely with the attenuations predicted by Bourgin's theory for a single gas. The attenuation for mixtures of CO_2 and CS_2 agreed within 2 to 5% of the theoretically predicted values, and within less than 2% for the CO_2 - C_2H_4O mixture. Information was also obtained concerning the collision parameters of a gas or gas mixture. For example, the number of collisions required to remove a quantum of vibrational energy from a molecule and the probability of a transition occurring because of a single collision can be calculated from experimentally determined transition rates.

78

Angona, F. A., "Attenuation of Sound in a Tube," J. Acoust. Soc. Am., 25, 336, 1953.

An experimental method of measuring the attenuation of sound in a circular tube for gases at reduced pressures has been developed. Since the tube effect is inversely proportional to the square root of the pressure, a reduction in pressure increases the attenuation and thus increases the experimental accuracy. The tube attenuation was measured for the frequency over pressure ratio of 8 to 2000 kc/atm. The measured attenuation was found to be 4.5% greater than that predicted by the Kirchhoff formula.

79

Beyer, R. T., "A Review of Sound Absorption in Fluids—and Appendix," Brown Univ., Dept. Of Phys., Providence, R. I., 89 pp., 1951.
ATI-121 079.

Sound Absorption in fluids is reviewed. The principal methods of sound absorption measurements are described, with some discussion of errors and limitations involved in each method. The most significant results are reported, differentiated as far as possible between reliable and unreliable values in the literature. Sound absorption measurements are classified roughly into three groups—mechanical, optical, and electrical. Experimental results with gases and with liquids are included with tables. Experimental results with solutions are also presented.

80

Brosio, E., "Measurements on Acoustic Absorbing Structures by Resonance," Tech. Notes No. FRL TN 10, trans. of Alta Frequenza 25:32-37, Feltman Res. Labs., Picatinny Arsenal, Dover, N. J., 7 pp., 1960.
AD-245 380

To obtain high acoustic coefficients at low frequencies, it is possible to use membranes of plastic material stretched over frames. Results are reported of laboratory measurements on structures of this kind.

81

Chandler, D. E., "Molecular Absorption of Sound in Carbon Dioxide," Tech. Rept. No. 11, California Univ., Los Angeles, 71 pp., 1958.
AD-218 756.

Study was made of the propagation of sound through a gaseous medium, pure CO_2, and in CO_2 with the addition of a controlled amount of impurity. The sound propagation was studied as a function of frequency in the range where nonclassical absorption occurs. The apparatus consisted of a tube to contain the gas and the sound, with devices to generate and detect the acoustic waves. The equipment was constructed to permit temperature to be set and maintained at any value between room temperature and 100°C. Results of tests on the pure CO_2 indicated that no marked divergences from the smooth symmetrical bell-shaped curve of the simple theories occurred in the temperature range studied. The maximum absorption per wavelength, frequency of maximum absorption, the relaxation times based on the assumption of two independent internal vibrational degrees of freedom, and the number of CO_2-CO_2 collisions required to deexcite a vibrationally excited CO_2 molecule were determined. Results with the impure CO_2 molecule showed that the shape of the curves of absorption per wavelength is unaltered within the resolution of the apparatus by the addition of small amounts of H to dry CO_2. On the basis of the experimental evidence, it cannot be stated unequivocally that the assumption of two independent relaxation times is correct. However, the expressions derived based on this assumption will yield values which fit the experimental data.

82

Chrisler, V. L., and C. E. Miller, "Factors Which Affect the Measurement of Sound Absorption," Bur. Standards J. Research, 9, 175-185, 1932.

It has been found that air has an appreciable absorption for sound at frequencies as low as 512 ~. This absorption varies with the temperature, the moisture content and the barometric pressure. Curves are given showing such changes in absorption in the reverberation room at the Bureau of Standards. Attention is called to the fact that when a highly absorbent sample is placed in a very reverberant room the decay curve may not be logarithmic.

83

Coast Guard, "General Report on the Attenuation of Sound Transmitted over Water," Rept. No. General-4, Washington, D. C., 23 pp., 1960.
AD-242 003.

Data on fog signal attenuation versus range for various frequencies were processed to permit direct comparison of the shape of the attenuation function. A comparison procedure was devised and applied to a comparison of the signal levels based upon the various attenuation functions for downwind transmission. Attenuation curves for upwind transmission of fog signals is extremely diverse. The Coast Guard data agrees with the attenuation versus range expected from theory.

84

Cramer, W. S., "Acoustic Absorption Coefficients at High Frequencies," J. Acoust. Soc. Am., 22, 260-262, 1950.

The measurement of the acoustic absorption coefficient by a steady state method was carried out at frequencies of 9, 20, and 30 kc for seven different materials. This involved constructing a sound chamber with facilities for creating a diffuse sound field and a sample area where materials could be mounted. The average intensity in the chamber was measured with the sample area covered by the material under test, and the results were compared with similar measurements when the area was covered with a material of negligible absorption and when it was open to the air outside. The expression giving the absorption coefficient in terms of these three relative intensity readings is derived.

85

Danner, P. A., E. Ackerman, and H. W. Frjngs, "Heating of Haired and Hairless Mice in High Intensity Sound Fields from 6 to 22 KC," J. Acoust. Soc. Am., 26, 731-739, 1954.

Experiments have been conducted to provide a comparison of sound absorption by haired and hairless mice in high intensity airborne sound fields. At 18-20 kc, threshold intensities for heating of the mice are 144 ± 2 db for haired animals and 155 ± 2 db for hairless animals. From 6-22 kc, effectiveness of the sound in heating the mice increased with frequency. Absorption coefficients computed from the data are higher at higher frequencies for both types of animals. Death time depends upon the intensity and frequency of the sound, the external covering of animals, and the portion of the animal exposed to the most intense part of the sound field. The configuration of the sound field and its relation to the results are discussed. Measurements of the field made with and without a hairless mouse showed increased distortion at higher frequencies of the sound field by the body of the mouse.

86

Delsasso, L. P., "Attenuation and Dispersion of Sound by Solid Particles Suspended in a Gas," Univ. of Calif., Los Angeles, 36 pp., 1957.
AD-144 065.

Measurements were made on audio frequency sounds propogating through a gaseous medium containing small solid particles in suspension. Two effects measured were attenuation and dispersion of sound in the dust-filled gas. The measurements were made by sending a short train of sine waves through the dust-filled gas and observing the changes produced in the transmitted sine burst. The velocity shift caused by the suspended dust was determined by the changes in arrival time of the short train of waves. Changes in height of the received sine burst provided a measure of the attenuation. The particles were suspended in air, argon, oxygen, and helium gases. The measured attenuation has been compared with existing theory and found to agree within experimental error. The theory takes into account viscous and thermal losses brought about when particles are present. A theory for the corresponding dispersion is presented. This predicts the change in velocity produced by an alteration of the heat capacity and density of the gas when filled with dust particles. The attenuation dispersion results are shown.

87

Delsasso, L. P., "The Attenuation of Sound in the Atmosphere," Dept. of Phys., Univ. of Calif., Los Angeles, 37 pp., 1953.
AD-89 256.

The attenuation of sound at sea level pressures and normal temperatures is extended to pressures and temperatures which may be encountered in acoustical signalling and tracking problems. Measurements were made both in the laboratory and in the field. In the laboratory results are reported for the frequency range 1000 to 6000 cps for a temperature range of from 2^{o} to $35^{o}C$ and for pressures from 76 to 26 cm of Hg. In the field, measurements have been obtained at an altitude of 10,000 feet for representative variations of meteorological conditions. Limits for the possible absorption coefficients to be met with in practice have been extablished. Progress is reported on the development of instruments to measure more accurately the details of the meteorological conditions excountered, particularly with reference to the accurate description of natural fogs. Instrumentation for measuring the attenuation of sound under laboratory conditions and the attenuation of sound propagating outdoors is described and illustrated.

88

Delsasso, L. P., "The Propagation of Sounds Through Moisture-Laden Atmospheres," Dept. of Phys., Univ. of Calif., Los Angeles, 1956.
AD-82 153.

This report covers the experimental information obtained on the transmission of audio-frequency sounds in moisture-laden atmospheres. It constitutes a progress report on a long-term program aimed at obtaining experimental information of the attenuation and velocity fluctuations of sound in the free atmosphere under normal and extreme meteorological conditions.

The absorption of sound in the free atmosphere in these experiments in determined by observing the reduction in sound intensity with distance from a small explosive source. Absorption coefficients under various meteorological conditions are determined from the expression

$$\alpha = \frac{2\left(\ell n \frac{P_1}{P_2} - \ell n \frac{r_2}{r_1}\right)}{r_2 - r_1}$$

where α = coefficient of absorption
P_1 and P_2 = sound pressures at points 1 and 2
r_1 and r_2 = distances from source to points 1 and 2

Transit times are measured as a basis for determining velocity fluctuations. All transit times and attenuation data are correlated with simultaneously recorded meteorological data. The results are presented as a series of charts or records.

89

Delsasso, L. P., and R. W. Leonard, "The Attenuation of Sound in the Atmosphere—and Appendix A.," Dept. of Phys., Univ. of Calif., Los Angeles, 45 pp., 1949.
ATI-96 177.

Progress is reported on the investigation of the transmission of sound under various atmospheric conditions. Primarily the work deals with laboratory measurements, where conditions can be well controlled, and, secondly, with field measurements under varying atmospheric conditions. The ultimate goal is to correlate the two experiments and make it possible to predict the value of attenuation and velocity for any given set of atmospheric conditions. In general, the laboratory measurements confirm previous findings on the variation of the absorption with the moisture content of the air. These results are plotted. Typical values for open air transmission are shown in a graph. Instrumentation for making acoustic attenuation measurements in the laboratory and in the field is described and illustrated. Circuit diagrams are included.

90

Edmonds, P. D., and J. Lamb, "A Method for Deriving the Acoustic Absorption Coefficient of Gases from Measurement of the Decay-Time of a Resonator," Proc. Phys. Soc. (London), 71, 17-32, 1958.

A unique result for the absorption coefficient is obtained from calculations based on measurement of the decay-time using longitudinal and radial modes of propagation. Expressions are given for the losses in the viscous and thermal boundary layers at the walls of the resonator. The method is applicable in the range of frequency divided by pressure of 1 to 45 kcs/atm. Calibration measurements have been made using argon and nitrogen: the relaxational contribution to the absorption has been evaluated in the case of cyclopropane.

91

Eucken, A., and E. Numann, "Excitation of Intramolecular Vibrations in Gases and Gas Mixtures by Collisions, Part IV," Z. Physik. Chem., 36, 163-183, 1937.

Measurements of the dispersion and absorption of sound were made in pure CO_2 and N_2O at temperatures up to 400°C. In these substances, and also when He and H_2O are added to them, the valency vibrations are excited as easily as the deformation vibrations. This effect is supposedly due not to a simple equality of sensitiveness to impact, but to a very rapid adjustment of equilibrium of the energy in the two forms of vibration. In CO_2 the mean number of collisions passes through a minimum value as the temperature rises, whereas in N_2O there is a continuous increase in this number. An explanation of this is suggested.

92

Evans, E. J., and E. N. Bazley, "The Absorption of Sound in Air at Audio Frequencies," Acustica, 6, 238-245, 1956.

The sound-absorbing properties of air at frequencies from 1 to 12.5 kcs are determined for values of the relative humidity from about 5% to 85% at 20°C. The measurements were made in a large reverberation chamber, in which the surface absorption was very small. The absorption due to the air was evaluated by an analysis of the results and closely agrees with the relaxation theory. A general expression is derived for the attenuation of sound in air as a function of the frequency, humidity, and temperature.

93

Fay, R. D., "Attenuation of Sound in Tubes," J. Acoust. Soc. Am., 12, 62-67, 1940.

Refinements in method and apparatus have made possible the precise measurement of attenuation of sound in tubes. Preliminary results strongly substantiate the tube wall effect predicted by Kirchhoff. Also, an unexpectedly large effect has been found, which depends on the first power of the frequency. Further measurements are required to find whether this loss exists in free air or is due in part to the tube walls.

94

Fricke, E. F., "The Absorption of Sound in Five Triatomic Gases," J. Acoust. Soc. Am., 12, 245-254, 1940.

The sound absorption coefficients have been measured between 8 and 130 kc for the five triatomic gases—CO_2, N_2O, COS, CS_2, and SO_2. The frequencies of maximal absorption for these molecules were found to be 20, 153, 287, 379, and 1040 kc, respectively. For the linear molecules CO_2, N_2O, COS, and CS_2, a linear relationship was found between the maximal absorption coefficients and the frequencies at which these maxima occur. It was also found that the lower the fundamental frequencies of vibration of the 4 linear molecules, the higher are the acoustic frequencies of maximal absorption (i.e., the shorter are the lifetimes of the energy quanta); and that the sonically activated fundamentals and harmonics of each of the above linear molecules commute and have the same lifetime, with the possible exception of CO_2. From the experimental data it was possible to calculate the reaction rates, probabilities of removal of vibrational quanta, the numbers of collisions necessary to remove the quanta of energy, and the numbers of quantum transitions per second. In addition to the above data, a technique is presented which enables one to find the frequencies of maximal absorption for gases when these frequencies occur in a range beyond the scope of the apparatus.

95

Gorshkov, N. F., "The Propagation of Pulses in an Elastic Absorptive Medium," Soviet Phys. Acoust., English transl., 3, 163-172, 1958.

The propagation is considered of two types of wave—unit function and square wave—through an elastic medium, the absorption of which is proportional to the frequency or to its square. Estimates are made of the distortion the pulses undergo on account of the absorption. A proposal is made for determining the absorption coefficient from the change in slope of the forward edge of a pulse, and experiments in air are quoted in support.

96

Hardy, H. C., "Use of the Pierce Interferometer for Measuring the Absorption of Sound in Gases," J. Acoust. Soc. Am., 15, 91-95, 1943.

A rigorous derivation of Pielemeier's empirical equation for the absorption of sound in gases is obtained by making use of the principles of the Pierce ultrasonic interferometer and the quartz oscillator. The Pielemeier method gives a fair approximation when the reaction of the sound wave on the crystal is small; it enables both velocity and absorption to be measured. The limits of precision in its use were tested experimentally and agree with theory.

97

Harris, C. M., "Absorption of Sound in Air in the Audio-Frequency Range," J. Acoust. Soc. Am., 35, 11-17, 1963.

This paper, concerning the absorption of sound in air as a function of humidity, presents new data in the frequency range between 2000 and 12,500 cps. These data are for air at normal atmospheric pressure and at a temperature of 20°C. First the measurement system is described. Then the data are compared with theory and with other published results in the same frequency range. The data also are presented in a graphical form that is particularly convenient for use in computing the contribution of air absorption to the total absorption of sound in a room. In this form the data are plotted directly in terms of the quantity 4mV as a function of frequency and humidity, where m is the attenuation coefficient and V is the volume of the room.

98

Hartig, H. E., and R. F. Lambert, "Attenuation in a Rectangular Slotted Tube of (1, 0) Transverse Acoustic Waves," J. Acoust. Soc. Am., 22, 42-47, 1950.

A pickup device for measuring the standing wave ratio of transverse acoustic waves is described. One of the important features of this device is the elimination of interference from the residual plane wave. This paper presents an experimental study of the attenuation characteristics of (1, 0) transverse acoustic waves propagated in air in a rectangular metal tube employing such a pickup device. This study reveals that three losses are important contributors to the attenuation. The results agree well with a tube wall effect predicted by Kirchhoff. In evidence in the medium is a gaseous absorption due to thermal equilibrium adjustments. The remaining attenuation is appreciable and appears to vary with frequency as $f^2[1 - f_c^2/f^2]^{-1/2}$. This factor is here attributed to a vibration of the tube walls.

99

Hayhurst, J. D., "The Attenuation of Sound Propagated Over the Ground," Acustica, 3, 227-232, 1953.

Theoretical calculations by Knudsen, supported by the results of laboratory experiments, have established the attenuation of sound in still air. Little work has hitherto been done out-of-doors because of the difficulty in allowing for the effect of wind on the attenuation. In the course of an aircraft-noise-abatement investigation made recently by the Ministry of Civil Aviation, the effect of wind on the propagation of sound over a dry concerte runway has been explored up to a distance of about half a mile from a source of sound. It was found that the only significant parameter was the component of wind in the direction of propagation, and the values that emerged showed that wind effects cannot be neglected in any acoustic work made out-of-doors. By interpolation the attenuations corresponding to a zero wind component in the direction of propagation were derived and were found to be substantially greater than those previously determined for still air. The attenuations were, however, statistically independent of the absolute wind speed. Repetition of the investigation over grassed areas produced no reliable results.

100

Horiuchi, I., "The Absorption of Sound in Humid Air at Low Audio Frequencies," Tech. Rept. No. 6, Columbia Univ., New York, 48 pp., 1957.
AD-140 786.

The reverberation technique of Kudsen has been applied to the measurement of the absorption of sound in air over the frequencies 300 to 1100 cps with mole ratio concentrations of water vapor ranging from zero to 0.1. Pressures from 20 cm Hg to atmospheric, and temperatures from 0°C to 55°C were employed in the study. With the use of a 66-inch spherical resonator and dry nitrogen gas as reference, following the method of Delsasso and Leonard, it has been possible to observe the anomalous absorption of humid air down to 300 cps. Pertinent graphs, theory, and a detailed description of the experimental apparatus are presented.

101

Horiuchi, I., "A Review of Laboratory Measurements of the Absorption of Sound in Air," Tech. Rept. No. 1, Columbia Univ., N. Y., 1955
AD-77 462.

This report reviews the subject of absorption of sound in air. The frequencies of sound considered lie in the audible range from 20 cps to 5 kcs. The factors which cause absorption are limited to those readily controlled or obtainable in the laboratory. Hence, such atmospheric phenomena as turbulence, wind and temperature gradients are excluded. Only the chemical agents—viscosity, thermal conduction, diffusion—and radiation and relaxation effects are discussed.

102

Horiuchi, I., "The Temperature and Humidity Dependence of Sound Absorption," Tech. Rept. No. TR-7, Electron. Res. Labs., Columbia Univ., New York, 20 pp., 1957.
AD-155 171.

Results have been obtained for the absorption of low-frequency sound in humid air at temperatures of 0°C and 55°C. The pressure ranged from 20 cm Hg to atmospheric, while the relative humidity was varied from 2% to 80%. The frequencies employed were the first five radial modes of a 66-inch spherical resonator: 300, 500, 700, 900, and 1100 cps, approximately. The experimental results show the absorption to follow the Knudsen-Kneser theory closely, except that under extreme relative humidity, large departures occur.

103

Ivanov-Shits, K. M., and F. V. Rozhin, "Investigation of Surface Waves in Air," Soviet Phys. Acoust. English transl., 5, 510-512, 1960.

An apparatus was designed to observe traveling surface waves in air. A battery of loudspeakers transmitted sound over an aluminium grill onto a rigid reflector. Theory suggests that surface waves originating beneath the grill should show a pressure variation obeying P_oe-az-ihx, where a is the attenuation factor and h the wave number of the surface. Measurements were made between 200 and 500 cps because at lower frequencies the waves have small attenuation and velocity dispersion and at higher frequencies they become concentrated into a thin layer.

A rapid-response level recorder connected mechanically with a microphone enables the acoustic pressure to be measured along the three perpendicular directions. From such records the velocity and attenuation of the waves were determined and compared with calculated quantities.

104

Kaye, G. W. C., and E. J. Evans, "Sound-Absorbing Properties of Common Outdoor Materials," Proc. Phys. Soc. (London), 52, 371-379, 1940.

The sound absorption coefficients of pure sounds of frequencies from 125 to 4000 cps have been measured at random incidence for specimens of some commonly occurring outdoor materials, such as gravel, turf, sand, ashes, railway-track ballast, and snow. They mostly share the common characteristic of increased absorption with rising pitch. Some of the materials (e.g., loose gravel, soil and ashes) are highly absorbent; snow is remarkably so, while other (e.g., compressed gravel and wet sand) are indifferent absorbents. Some practical aspects are discussed, as is the influence of nearly grazing incidence, such as often obtains with outdoor sounds, in raising the degree of absorption.

105

Kemp, G. T., and A. W. Nolle, "The Attenuation of Sound in Small Tubes," J. Acoust. Soc. Am., 25, 1083-1086, 1953.

An experimental investigation of the attenuation of sound in two air-filled tubes of 0.238- and 0.092-cm inside radius in the frequency range from 3.8 to 20 kc was conducted, and the results were compared with values of attenuation calculated from the Kirchhoff theory for rigid walled tubes. Agreement of experimental with theoretical values was found within the accuracy of the experiment, provided that the comparison is made only with the portion of attenuation proportional to square root of frequency, as suggested by Fay. The attenuation was determined by a method which was different, in some respects, from those previously employed. The variable-length, closed tube was driven with a high-impedance source, and the input pressure was sampled with a high-impedance microphone probe. The input pressure was recorded as a function of closed tube length. Since the input pressure can be assumed to be proportional to input impedance for these conditions, the attenuation can readily be determined from the ratio of the pressure maxima or minima.

106

Kneser, H. O., "Sound Absorption, Specific Heat and Period of Adjustment of the Electron Spin in NO" (in German), Ann. Physik, 39, 261-272, 1941.

The half-value widths and the frequencies of the resonance points of a cylindrical resonator are measured in NO with the aid of the condenser microphone; from these results the absorption and the velocity of sound are determined, the latter relative to air. Between 300 and 3000 cps the sound absorption is too small to be measured. From the velcoity a value is obtained for the sp ht, which is very close to that calculated from spectroscopic data. From both it follows that at these sound frequencies a delay in establishing thermic equilibrium is not observable, and that especially the distribution of the molecules on the two levels of the split ground state occurs in less than 10^{-6} sec. The probability of reversal of the electron spin in a gas-kinetic collision is thus > 1:6500.

107

Knudsen, V. O., "Absorption of Sound in Air, Oxygen and Nitrogen, Effects of Humidity and Temperature," J. Acoust. Soc. Am., 5, 112-121, 1933.

The rates of decay of sound in two gas-filled chambers of unequal volume are determined by an electro-acoustical apparatus similar to that described by Norris and Andree; the absorption of sound is calculated from the results. Alternatively, by means of a preliminary calibration, the required absorption coefficient is determined by measurements in only one chamber. The effects of temperature, frequency of note, and size of chamber on the absorption of sound in air-water vapor mixtures are shown by a series of curves. These indicate that a maximum of absorption occurs when the percentage of water molecules is between 0.2 and 0.4, and that the maximum absorption coefficients are approximately proportional to the first power of the frequency. On account of their theoretical importance absorption curves were also determined for O_2-water vapor and N_2-water vapor mixtures. For O_2 the maximum values of the absorption coefficients are some five times greater than the corresponding ones for air and occur when the percentage of water molecules is greater. With N_2 the absorption coefficient is almost independent of the presence of water molecules. The paper concludes with some remarks on the bearing of these experiments on architectural acoustics and sound signalling.

108

Knudsen, V. O., "Effect of Humidity upon Absorption of Sound in a Room, Determination of Coefficients of Absorption," J. Acoust. Soc. Am., 3, 126-138, 1931.

The results of the author's experiments confirm the general findings of Sabine and Meyer and throw further light on points of theoretical and practical interest. The author has taken advantage of the special atmospheric conditions at Los Angeles, where the investigations were carried out in the two test chambers of the acoustical laboratory of the University of California. Each of these rooms is enclosed by two separate walls, 12 inches thick, of reinforced concrete, and the floors rest upon a 6-inch fill of sand and a 2-inch slab of cork, thus being insulated from the effects of external vibration, sound, and heat. Owing to the small temperature changes throughout the seasons of the year, the temperature in the room was never lower than 20°C and never higher than 22°C, and it usually differed by only 0.2 or 0.3 of a degree from 21°C. The relative humidity, on the other hand, followed closely the changes of the outside humidity, and changes from 14% to 70% within a period of 48 hours were not infrequently noted. Thus the effects of relative humidity on sound absorption could easily be investigated within a wide range without resorting to artificial aids. Humidities above 70% were readily obtained by evaporation of water in the room. Reverberation times were measured (1) by obtaining oscillographs of the decay of sound; (2) by measuring the times for specified amounts of decay by means of a microphone pick-up, a five stage amplifier, and a relay-controlled chronograph; and (3) by making reverberation measurements with the ear and a recording chronograph. In the oscillograph and relay methods "warble" tones were used, having a bandwidth of 200 ~ and a frequency of warble of 5 to 7 ~ per sec. The results are given in photographs of oscillograms, curves, and tables; they cannot be stated in a short abstract, but in general the experiments indicate that the absorption of sound in the air is an important factor which must be considered in problems in sound signalling and in architectural acoustics.

109

Knudsen, V. O., and E. F. Fricke, "The Absorption of Sound in CO_2, N_2O, COS, and CS_2, Containing Added Impurities," J. Acoust. Soc. Am., 12, 255-259, 1940.

We have investigated the absorptive characteristics of CO_2, N_2O, COS, and CS_2, as influenced by the addition of certain gases, such as H_2, H_2O, H_2S, CH_3OH, etc., acting as "catalysts." These catalysts shift the absorption bands to higher frequencies; the magnitudes of these shifts yield information respecting (1) the frequency to which each pure gas has its maximal absorption, and

(2) the nature of the molecular collisions involved, especially the effectiveness of these collisions in distributing the vibrational states of the absorptive molecules. The results indicate that at atmospheric pressure and 23°C, the absorption maxima for pure CO_2, N_2O, COS, and CS_2 are shifted in each case by amounts proportional to the concentration of the added catalyst. The addition of 1% of H_2O to CO_2 shifts the absorption band for CO_2 2250 kc; similarly, 1% of H_2O shifts the CS_2 band 2460 kc, the COS band 4200 kc, and the N_2O band 427 kc. One percent of the other impurities produced shifts which varied from 20 to 1830 kc. Transition probabilities for the above gases have been calculated. These probabilities are characteristic of the colliding pair of molecules.

110

Knudsen, V. O., and E. F. Fricke, "Absorption of Sound in CO_2 and Other Gases," J. Acoust. Soc. Am., 10, 89-97, 1938.

Sound absorption measurements in pure CO_2 at 1 atm and 22°C have been conducted; together with measurements by others, these confirm the collision theory of anomalous absorption as developed by Einstein, Kneser, and others. The absorption coefficient is appreciable at frequencies as low as 2000~, and increases to a maximum of 0.317 per wavelength at 77,000 ~. This maximum is higher than values obtained by previous workers, and indicates that both the deformation and symmetrical valence vibrations participate in the exchanges between translational and vibrational energy. Small impurities, such as water or alcohol vapors, affect the absorption greatly; the entire absorption band is shifted to higher frequencies. Measurements in mixtures of CO_2 in O_2 and CO_2 in N_2 indicate that neither the O_2 nor N_2 is appreciably excited by collisions with CO_2. Measurements in CS_2 reveal an absorption similar to that for CO_2 except that the absorption begins at about 10,000 ~. In mixtures of CS_2 and O_2, the observed absorption at frequencies below 10,000 ~ is accounted for by assuming that only the vibration of O_2 molecules is excited by collisions with CS_2 molecules; at higher frequencies the CS_2 molecules also are excited, principally by collisions with other CS_2 molecules.

111

Knudsen, V. O., J. V. Wilson, and N. S. Anderson, "The Attenuation of Audible Sound in Fog and Smoke," J. Acoust. Soc. Am., 20, 849-857, 1948.

Measurements of the rate of decay of sound in a reverberation room, first with no fog or smoke in the room and then with fog or smoke of known concentration and particle size added to the room, show that the attenuation of sound in a number of aerosols is in approximate agreement with values predicted by the theories of Sewell, Epstein and Oswatitsch. In a water fog having a concentration of 2.0×10^{-6} g/cm^3 and an average droplet radius of 6.25×10^{-4} cm, the attenuation due to the fog increased from about 5 db/sec at 500 cps to 13 db/sec at 8000 cps. In a very similar fog of mineral oil, the corresponding attenuation increased from 1.6 db/sec at 500 cps to 21 db/sec at 8000 cps. At very low frequencies, a fog of water is much more absorptive than is a fog of oil; the difference is ascribed to a "relaxation" effect of evaporation from and recondensation on the droplets, which is >> for water than for oil. The attenuation of sound in smoke may become rather high, amounting to 58 db/sec at a frequency of 6000 cps for a moderately dense smoke of NH_4Cl (180 g in a volume of 6080 ft^3).

112

Knudsen, V. O., and L. Obert, "Absorption of H. F. Sound in Oxygen Containing Small Amount of Water Vapor or Ammonia," J. Acoust. Soc. Am., 7, 249-253, 1935.

Using a new technique, the author has extended his measurements upon the absorption of hf sound in gases to higher frequencies (up to 34,000 ~). The gas is contained in a small steel box and the sound is generated in the box by a magnetostriction oscillator. The intensity of the sound generated in the box is measured, and thus the sound absorption in the gas is determined. The results confirm the earlier results, (i.e., the absorption is a maximum at a certain frequency which depends upon the amount and kind of the gaseous impurity, and this frequency increases almost linearly with the concentration of most impurities, but in the case of water impurity is a quadratic function of the concentration). This latter fact suggests that a collision of an O_2 molecule with two molecules of H_2O is more efficient in producing a transition within the molecule than is a collision with a single H_2O molecule. The theoretical value of the maximum absorption per unit wavelength agrees within experimental error with the measurements. Other measurements have shown that CO_2 and H_2 are also absorptive in the frequency range 7000 ~ to 34,000 ~.

113

Kosten, C. W., "A New Method for Measuring Sound Absorption," Appl. Sci. Res., B1, 35-49, 1947.

The electrical impedance of a loudspeaker depends upon the acoustical load and may be used for measuring this load. The relation between the electrical impedance of an electrodynamic loudspeaker and the acoustic impedance in front of the loudspeaker is given and discussed in detail. The consequences of the flexibility of the cone are studied. Simple formulas and graphs are given, connecting the electrical behavior and the absorption coefficient corresponding to the load on the loudspeaker. The method seems to permit absorption measurements at low frequencies (50-500 cps).

114

Krudryavtsev, B. B., "Sound Absorption in Air Under Ultra-Violet Irradiation" (in Russian), J. Exptl. Theoret. Phys. (USSR), 19, 155-157, 1949.

Comparative measurements by acoustic interferometer of sound absorption in ordinary air and in air under uv irradiation are described. In all, 104 ratios of absorption coefficients for the two cases were established. The statistical evaluation of the results leads to the conclusion that the coefficient for irradiated air is somewhat < for radiation-free air.

115

Kushner, S. S., and J. C. Johnson, "Determination of the Sound Transmission Characteristics of Various Aircraft Sound-Proofing Materials," Final Rept. No. 2490-1-F, Willow Run Labs., Univ. of Mich., 1958.

Determination of the sound transmission characteristics for various aircraft fuselage acoustic treatments was accomplished utilizing a small sample transmission-loss apparatus. The materials tested were ranked in relation to the theoretical weight-law attenuation of a 0.020-inch-thick dural panel.

116

Lawley, L. E., "The Absorption of Sound in Carbon Dioxide Contained in Narrow Tubes," Proc. Phys. Soc. (London) B, 67, 65-69, 1954.

Measurements were made with carbon dioxide contained in tubes ~1-mm diameter. Frequencies used were between 40 and 120 kcs. Results showed that over a considerable range of frequency/pressure on either side of the relaxation peak of CO_2, the total absorption was given by the sum of the Helmholtz-Kirchhoff tube absorption and the thermal relaxation absorption of the gas. The tube absorption, however, was found to be a few percent higher than that calculated theoretically.

117

Leonard, R. W., "The Absorption of Sound in Carbon Dioxide," J. Acoust. Soc. Am., 12, 241-244, 1940.

The absorption was measured by a direct method over frequencies between 22 and 112 kc. A microphone responding to the sound pressure is moved away from a piston source located in a flat surface. The output of the microphone is amplified and recorded photographically. The resulting pressure-distance curve yields the pressure attenuation coefficient. The measurements were made in carbon dioxide which was carefully dried by being passed through phosphorous pentoxide. The results obtained for the frequency at which the absorption per wavelength μ is a maximum was 30 kc. In order to account for the maximal value μ obtained experimentally, it is necessary to assume that both the symmetrical valence vibration and the deformation vibration are effective in producing the absorption; and, in addition, that the second harmonic of the deformation mode also participates in the absorptive process. Velocity measurements made with the same apparatus have shown a reasonable agreement between the dispersion and absorption in carbon dioxide.

118

Leonard, R. W., "Improved Apparatus for Direct Measurement of Absorption of Sound in Gases," Rev. Sci. Instr., 11, 389-393, 1940.

An improved apparatus has been tested with the highly absorptive gases CO_2 and N_2O. Measurements are made of the sound pressure by a microphone as it is moved away from a piston source vibrating in a large baffle. The resulting pressure/distance curves are recorded photographically and yield the absorption coefficient. Reflections from the walls of the cylindrical measuring chamber are reduced materially by specially designed glass baffles. The source is the end of a magnetostrictive rod driven by an improved Pierce-type oscillator with a frequency range of 11.3 to 112 kc.

119

London, A., "The Determination of Reverberant Sound Absorption Coefficients from Acoustic Impedance Measurements," J. Acoust. Soc. Am., 22, 263-269, 1950.

A method is described for utilizing normal absorption coefficient or acoustic impedance measurements to predict reverberant sound absorption coefficients. The average of coefficients for the six standard frequencies determined from acoustic impedance measurements agrees closely with the average reverberant coefficient for cases where the material may be said to obey the normal impedance assumption. The normal absorption coefficients of some 26 different acoustic materials were measured at 512 cps. By using the method given in the paper, the predicted reverberant coefficient deviated from the measured reverberant coefficient by 0.05 or less for 18 materials; in only 3 cases were the deviations greater than 0.10. The method should be particularly applicable to the problem of acceptance testing of installed acoustic materials.

In the theoretical development, best agreement with experiment was obtained by introducing a new kind of reverberant statistics, which associates with each wave packet in a random field a scalar quantity equal to the square of the absolute value of the sound pressure in each packet, instead of the customary energy flow treatment. Also, it was found necessary to carry out the analysis by using a concept of equivalent real impedance to replace the usual complex impedance.

120

Mariner, T., "Critique of the Reverberant Room Method of Measuring Air-Borne Sound Transmission Loss," J. Acoust. Soc. Am., 33, 1131-1139, 1961.

Some obscure but important philosophical difficulties with the standard method of measuring transmission loss by the reverberant room method have led to reexamination of the basic concepts. An equation is derived relating transmission loss to the "total loss area" H_2 of the receiving room. H_2 is found to be measurable within a negligibly small uncertainty by using familiar sound-decay techniques, providing that T_2/T_1, the ratio of "natural" reverberation times of the receiving and source rooms, is properly adjusted. It is shown that the equations commonly used in the existing standard method require knowledge of A_2, the total absorption of the receiving room, implicitly excluding transmission through the panel. A_2 is generally not measurable without prior knowledge of the transmission loss of the test panel. These and other considerations result in the proposal of a new procedure.

121

Northwood, T. D., and H. C. Pettigrew, "The Horn as a Coupling Element for Acoustic Impedance Measurements," J. Acoust. Soc. Am., 26, 503-506, 1954.

Impedance tube methods of testing acoustical materials are restricted to frequencies below the value for which the wavelength is approximately equal to the largest lateral dimension of the tube. Above this frequency, extraneous modes of propagation interfere with measurements. The restriction is a serious one for typical acoustical materials that cannot adequately be sampled in less than 1 square foot. It has been found that the difficulty may be circumvented by using a horn to couple a large sample to a small impedance tube. Comparisons between horn and tube measurements have been made for a range of absorptive materials.

122

Oberst, H., "Absorption of Sound in Gases," Z. Tech. Phys., 17, 580-582, 1936.

Measurements are described of the absorption of sound in a gas contained in a tube. The sound is excited by a loudspeaker placed at one end of the tube with a diaphragm so heavy that reaction upon it can be neglected. A condenser microphone at the other end of the tube serves to determine the response. The absorption at various frequencies in the range 700-4000 ~ is deduced from the breadth of selected resonances of the gas contained in the tube. To minimize absorption by the tube walls, tubes of thick brass or glass are used. In one series of measurements, N_2 is used at a range of pressures. Since molecular absorption can be neglected in this gas, the absorption deduced should agree with that predicted from Kirchhoff's formula. Actually, the measured absorption is about 15% higher. Measurements are also made in dry and moist O_2, and results are obtained which agree well with those of Kneser and Knudsen. It is suggested that this experimental method would be suitable for determining molecular absorption in gases.

123

Oura, H., "Reflection of Sound at Snow Surface" (in Japanese), Tokyo, 12, 273-275, 1950.

The reflections of sound at the snow surface were observed with the method of standing wave. If the amplitude of the incident wave is a, and that of the reflected wave is b, then the maximum amplitude of standing wave is a + b, and the minimum is a - b. These values were measured with the carbon microphone and the Brown tube. From these values the rate of absorption, $A = (a^2 - b^2)/a^2$, was calculated. The results, in tables, show that: (1) the rate of absorption A is very large; (2) the smaller the density, the larger the absorption; (3) for settled snow, the higher the frequency of sound, the larger the absorption; and (4) for settled snow, when the snow was warmed and wetted, the absorption increased.

124

Parker, J. G., C. E. Adams, and R. M. Stavseth, "Absorption of Sound in Argon, Nitrogen, and Oxygen at Low Pressures," J. Acoust. Soc. Am., 25, 263-269, 1953.

The amplitude absorption coefficient for pulsed sound waves in argon, nitrogen, and oxygen has been measured over a range of pressure p from 1 to 10 mm Hg for frequencies of between 60 and 70 kc, the temperature in all cases being held nearly constant at 20^oC. For the three gases used, the following experimental values of $(p\alpha/f^2)\ 10^7$ (cgs units) were obtained: (1) for argon, 1.86 with an rms deviation of 0.03; (2) for nitrogen, 1.64 with an rms deviation of 0.04, and (3) for oxygen; 1.92 with an rms deviation of 0.03. The corresponding values computed from the classical absorption equation are (1) for argon, 1.87; (2) for nitrogen, 1.31; and (3) for oxygen, 1.61. Thus the absorption in argon is classical, while in nitrogen and oxygen it exceeds the classical value. These excesses are attributed to rotational relaxation, and the associated relaxation times are calculated in accordance with the thermal relaxation theory of Herzfeld and Rice, and Kneser. For nitrogen, the relaxation time (reduced to STP conditions) is 4.85×10^{-10} sec; for oxygen, 4.95×10^{-10} sec. Both these values are significantly smaller than the values obtained by other workers at higher frequencies.

125

Parkin, P. H., and W. E. Scholes, "Air-to-Ground Sound Propagation," J. Acoust. Soc. Am., 26, 1021-1023, 1954.

The attenuation of sound in air, in the vertical direction, has been measured on six occasions by using an aircraft flying at various heights over a microphone at ground level. Negligible attenuation was always found at frequencies below 1000 cps even though the air was turbulent; at higher frequencies the attenuation was found to be of the same order as the Knudsen-Kneser results for attenuation due to molecular absorption.

126

Petralia, S., "Absorption of Ultrasonics in Mixtures of Gas Containing Hydrogen" (in Italian), Nuovo Cimento (Ser. 10), 2, 241-254, 1955.

Absorption measurements were made in pure hydrogen and in mixtures of hydrogen and argon, and hydrogen and oxygen, in order to study the influence of extraneous gases on the rotational relaxation time of hydrogen and to verify that Kohler's theory of the classical type of absorption, holding for mixtures of monatomic gases, could be extended to the case of biatomic gases. The effect of the presence of biatomic impurities in strong concentration is to shorten the relaxation time of hydrogen. This shortening does not exceed 10% for argon and is much greater for oxygen. Here the relaxation time decreases continually from the value applying to hydrogen to that applying to oxygen. The author found a relaxation time for oxygen which is shorter than that given by Thaler, but which agrees with the result of a theoretical calculation by Brout. The conclusion may be drawn that Kohler's theory does not apply to the mixtures studied.

127

Pielemeier, W. H., "Observed Classical Sound Absorption in Air," J. Acoust. Soc. Am., 17, 24-28, 1945-1946.

A brief treatment of the theory and methods of measuring absorption of sound in gases precedes graphical data. The measurements were made with a Pierce acoustic interferometer at a frequency of 1927 kcs in air. This frequency is high enough to satisfy Hardy's and Krasnooshkin's required conditions to obtain reliable results. The experimental result agrees with Krasnooshkin's value of $\alpha_0\lambda_0^2 = (225 \pm 5) \times 10^{-6}$ cm.

128

Pielemeier, W. H., "Supersonic Dispersion and Absorption in CO_2," Phys. Rev., 41, 833-837, 1932.

Since supersonic velocity determinations in air near a crystal oscillator usually yield values in excess of the accepted value, $V_0 = 331.6$ m/sec, a similar effect with CO_2 was suspected. The velocity and the absorption coefficient were measured at frequencies beginning in the dispersion region, theoretically and experimentally investigated by Kneser, and extending beyond it to 2.09 megacycles. The author's velocity values are slightly less than Kneser's experimental values, but they fit his theoretically determined dispersion curve equally well. At the lowest frequency tested (303 kc) the absorption coefficient was found to exceed, by the greatest amount, its value computed from Lebedew's formula. This frequency is near the middle of the dispersion region where maximum absorption is expected. According to Pierce, the absorption becomes excessive also when this frequency is approached from lower values. The results are presented in tabular and in graphical form. A sharp absorption maximum appears at 217 kc.

129

Pielemeier, W. H., "Ultrasonic Velocity and Absorption in Oxygen," Phys. Rev., 36, 1005-1006, 1930.

The velocity and absorption in oxygen at room-temperature were measured at five ultrasonic frequencies located in the two octaves, 316 to 1264 kcs. The observed velocities reduced to 0^oC do not differ more than 0.2% from Dulong's observed value of V_0 for audible sound (317.2 Mcs). The theoretical value ($V_0 = (\gamma p/d)^{1/2}$) is 314.76 Mcs. The observed absorption values vary with frequency as expected, but the deviations from the theoretical values are greater than the velocity deviations.

130

Pielemeier, W. H., and W. H. Byers, "Supersonic Measurements in CO_2 and H_2O at 98^oC," J. Acoust. Soc. Am., 15, 17-21, 1943.

Following a previous method, the velocity and absorption were measured in CO_2 containing water vapor at 98^oC. The apparent change in relaxation times from 28^o to 98^o was not entirely expected, and the minor absorption peaks were not rendered more prominent. The sp ht of CO_2 calculated from the results agrees with the values obtained from spectroscopic data and with reliable calorimetric results.

131

Podoshevnikov, B. F., and B. D. Tartakovskii, "On the Attenuation of Finite-Amplitude Plane Sound Waves in Gases," Soviet Phys. Acoust. English transl., 4, 382-384, 1959.

Attenuation of 13-kcs acoustic waves in air was studied as a function of the acoustic intensity. An electrodynamic resonance generator was used to excite air in a tube 125 cm long and 12.4 cm in diameter. The radiated wave was not quite planar. The attenuation coefficient was found to increase linearly with rise of the mean acoustic pressure.

132

Prout, J. H., "Some Measurements of the Absorption Coefficients of Soil Using the Impedance Tube Technique," Rept. No. 2900-257-S, Inst. Sci. Tech., The Univ. of Michigan, Ann Arbor, 1961. AD-261 359.

In any field tests which involve horizontal propagation of sound, it is desirable to know how much is absorbed by the ground. Since the sound-absorption properties of the ground are affected by many factors, it is usually necessary to estimate this effect. This paper describes an experiment for measuring the absorption coefficient of the soil by means of an impedance tube. Controlled laboratory tests are described which measured the effect of moisture content and particle size on the absorption coefficient. Effects of grass on the absorption coefficient are also noted.

133

Rettinger, M., "Selected Problems in Architectural Acoustics," Proc. I.R.E., 31, 18-22, 1943.

This paper deals with the absorption of hf sound in air, the change of hf reverberation with the relative humidity of the air and the average surface absorptivity required to provide constant reverberation time for frequencies > 1 kcs. Also noted is that the energy reduction of hf sound with change in reverberation and the air attenuation of hf sound interference are pictured as a function of the distance between source of sound and the point of observation.

134

Richardson, E. G., "Relaxation Spectrometry," North Holland Publishing Co., Amsterdam (Interscience Publishers, Inc., New York), 140 pp., 1957.

For the most part the author discusses experimental devices for studying the behavior of viscoelastic media in both the sonic and ultrasonic frequency ranges. Much of the work referred to has come out of his own laboratory. For gases, standard elastic liquids, and solids, he confines himself to presenting typical examples of relaxation absorption and dispersion of high-frequency sound. There is a very brief treatment of dielectric relaxation in solids and liquids, with a comparison between it and acoustic relaxation.

135

Rogers, C., and R. Watson, "Determination of Sound Absorption Coefficients Using a Pulse Technique," J. Acoust. Soc. Am., 32, 1555-1558, 1960.

Determining sound absorption coefficients by a pulse method using a sound mirror to produce directed sound pulses allows determination of the coefficients by a free field method but within the confines of an ordinary laboratory. Average pulse pressures for brief pulses are obtained over both space and time to allow evaluation of the absorption coefficient as a function of angle of incidence. When averaged over angle of incidence, this function leads to average absorption coefficients, which were obtained for samples of two different materials. These coefficients, for a pulse two cycles long at 2000 cps, are 0.56 and 0.182. Comparable values computed from impedance tube data are 0.57 and 0.186; and values obtained from reverberation chamber measurements are 0.57 and 0.130. In each case the three values for each material lie within the estimates of error assigned. It is concluded that while the pulse method is confined to short pulses having relatively wide frequency spectra, the method is useful both in producing values of sound absorption coefficients as a function of angle of incidence and of average values of these coefficients.

136

Rogers, H. H., "Absorption of Supersonic Waves in Mixtures of Air and Carbon Dioxide at Different Relative Humidities," Phys. Rev., 45, 208-211, 1934.

The absorption of supersonic waves of frequency 409.6 kcs was measured in mixtures of air and CO_2 at eight relative humidities ranging from 10 to 75%. The source of the radiation was a quartz crystal oscillator. The receiver was an acoustic radiometer of the torsion vane type. Curves of the logarithm of the radiometer readings as a function of distance between radiometer and crystal face were straight lines, the slopes of which gave the absorption constant k. The absorption constant k is a linear function of the percent of CO_2. For a given mixture of air and CO_2 it is a nonlinear function of the relative humidity increasing to a maximum of 45% and then dropping off rapidly. The values of k are given in a table in the original.

137

Sessler, G., "Sound Absorption and Sound Dispersion in Gaseous Nitrogen and Oxygen at High Frequency Pressure Values," Acoustica, 8, 395-397, 1960.

Sound absorption and dispersion in nitrogen and oxygen at 20°C and at frequency/pressure (f/p) values of 10^6 to 10^9 cycles/atm have been measured. The method used is the interferometric arrangement described in an earlier paper (Meyer, E., and G. Sessler, Z. Physik, 149, 15-39, 1957). Reference is also made to a paper by Greenspan (J. Acoust. Soc. Am., 30, 672, 1958). Experimental values of the ratios of absorption α to dispersion β (α/β) are plotted as a function of the ratio f/p. For nitrogen the ratio α/β falls from 0.3 to 0.01 as the ratio f/p decreases from 10^9 to 10^7. For oxygen the experimental curve is much the same. The experimental results agree well with theory.

138

Shaw, E. A. G., "The Acoustic Wave Guide, II., Some Specific Normal Acoustic Impedance Measurements of Typical Porous Surfaces with Respect to Normally and Obliquely Incident Waves," J. Acoust. Soc. Am., 25, 231-235, 1953.

The experimental techniques described in Part I have been applied to the measurement of some acoustic properties of rockwood, hairfelt, and acoustic tile, backed by a rigid wall. The more porous surfaces show substantial increases in resistance at oblique angles of incidence (in one case an increase of nearly 100% at 80° incidence was observed); also, smaller changes in reactance occur. The absorption coefficients corresponding to impedance measurements at oblique incidence are compared with those "predicted" from normal incidence impedance measurements, and significant differences are found. The measurement of surfaces having structures of finite dimensions is discussed with particular reference to an acoustic tile, the impedance of which varies only slightly with angle of incidence. In some cases, slight scattering of acoustic energy from one mode to another provides evidence of the lack of uniformity of impedance over the surface of the specimen.

139

Shields, F. D., "Measurements of Thermal Relaxation in CO_2 Extended to 300°C," J. Acoust. Soc. Am., 31, 248-249, 1959. AD-219 466.

The tube method has been used to extend measurements of sound absorption in CO_2 to 300°C. Results indicate that all of the vibrational specific heat in CO_2 relaxes with a single relaxation time, which, at 305°C was found to be 3.05×10^{-6} sec.

140

Shields, F. D., "Thermal Relaxation in Carbon Dioxide as a Function of Temperature," J. Acoust. Soc. Am., 29, 450-454, 1957.

Sound absorption and velocity have been measured in carbon dioxide between 0 and 200°C. The relaxation absorption was isolated by subtracting the tube and classical absorptions from the measured absorption. The Kirchhoff equations, which had been justified previously by measurements in A and N_2, were used to make these corrections. From the relaxation absorption were determined the temperature variation of the thermal relaxation time, the transition probability, and the collision efficiency. The results indicate that, for the frequencies and pressures here employed, the relaxation absorption and velocity effects are a function of f/p. This means that only binary collisions are effective in transferring energy between the vibrational and translational modes. The relaxation theory with a single relaxation time for all the vibrational modes adequately predicts the observed absorption and velocity. It is estimated that a separation in the relaxation times of the two lowest modes by a factor of more than two could not have gone undetected at 100°C. The temperature variation of the collision efficiency was adequately predicted by the Landau-Teller equation.

141

Shields, F. D., and Kun Pal, Lee, "Sound Absorption and Velocity Measurements in Oxygen," Univ. of Mississippi, University, J. Acoust. Soc. Am., Letter to the Editor, 35, 251-252, 1963.

The tube method has been used to measure sound absorption and velocity in pure oxygen at 23.5°, 208.7°, and 301.3°C. At the elevated temperatures, the absorption was in excess of the classical value. This was attributed to thermal relaxation of the vibrational energy. At 208.7° and 301.3°C, the peak value of the relaxation-absorption curve is estimated to fall at 100 ± 4 and 175 ± 13 cps/atm, respectively. These values correspond to relaxation times of 1.71×10^{-3} and 1.01×10^{-3} sec and are considerably longer than would be expected by interpolation from previous data at higher and lower temperatures.

142

Sivian, L. J., "High Frequency Absorption in Air and Other Gases," J. Acoust. Soc. Am., 19, 914-916, 1947.

The absorption coefficients were measured for gases: (a) O_2, (b) N_2, (c) $O_2 + N_2$ in normal air proportions; (d) $O_2 + N_2 + CO_2$ in normal air proportions; (e) $O_2 + N_2 + CO_2$ in normal air proportions, plus H_2O vapor at 37% rh at 26.5°C; (f) $O_2 + N_2$ in normal air proportions, plus a CO_2 content varied from zero to 1.15% by volume. Let R denote the ratio of the measured absorption coefficient to that computed from the Stokes-Kirchhoff equation. For gases (a), (b), (c), and (d), $R \approx 1.5$. For gas (e), $R \approx 10$ at 15 kcs, and approaches 1.5 with increasing frequency. For gas (f) at 89 kcs, R increases with rising CO_2 content, attaining $\sim R = 20$ at 1.15% CO_2 content.

143

Slavik, J. B., and J. Tichy, "An Evluation of the Sound Absorption Coefficients Measured by the Standing-Wave Method and by the Reverberation Method" (in Czech), Slaboproudy Obzor, 18, 545-548, 1957.

Previously reported experimental results (Tichy, Slaboproudy Obzor, 17, 197-202, 1956; Faiman, 322-324; and Kolmer, ibid., 500-507) are quoted and compared, together with some supplementary data. Great discrepancies are found between the values obtained by the two methods. It is therefore thought necessary to employ both types of measurement until the value of the reverberation method is definitely established.

144

Smith, F. A., and W. Tempest, "Low-Frequency Sound Propagation in Gases," J. Acoust. Soc. Am., 33, 1626-1627, 1961.

A resonance-tube method has been developed for the measurement of sound absorption and velocity in gases at frequency to pressure ratios from 36 to 3800 cps/atm. Measurements in oxygen at 30°C show velocity dispersion and excess absorption due to relaxation of the vibrational mode of the oxygen molecule with a relaxation time of $3.2 \pm 0.3 \times 10^{-3}$ sec. The results agree with those obtained by Knotzel and Knotzel.

145

Tempest, W., and H. D. Parbrook, "Absorption of Ultrasound in Light Gases," Nature, 177, 181, 1956.

A pulse method is described for measurements at 1 Mcs. Absorption coefficients of 1.240 and 1.235 times the classical value are quoted for oxygen and nitrogen, respectively. The technique is being developed for measurements up to 20 Mcs.

146

Thaler, W. J., "The Absorption and Dispersion of Sound in Oxygen as a Function of the Frequency-Pressure Ratio," J. Acoust. Soc. Am., 24, 15-18, 1952.

The velocity and absorption of ultrasonic waves in oxygen were measured by means of an improved ultrasonic interferometer in the range from 1 to 100 Mcs atm. Dispersion of the velocity ranged from 333.14 m/sec to 357.22 m/sec at 30°C. The ratio ($\alpha_{exper}/\alpha_{class}$) dropped from 3.68 to 2.05, and the corresponding value of C_v/R dropped from 2.50 to 1.61. The increase in velocity and the decrease in ($\alpha_{exper}/\alpha_{class}$) is interpreted as caused by the slow exchange of energy between the translational and rotational degrees of freedom. The relaxation time for the rotation was 5.24×10^{-9} sec.

147

van Itterbeek, A., and L. Thys, "Absorption and Velocity of Sound in H_2, D_2, He and Ne," Physica, 5, 889-897, 1938.

Measurements on the velocity and the absorption of sound by using supersonics have been made in H_2, D_2, He, and Ne between room-temperature and the boiling point of liquid O_2. As was observed by other investigators (Abello, Curtis), the values found for the absorption in H_2 and He do not agree with theory. For H_2 the authors found for the absorption coefficient (α in cm^{-1}) a value which is 20 times the classical theoretical value. For D_2 the experimental value is too great by a factor of 10; for He and Ne, by a factor 4 and 3, respectively. From measurements made at the boiling point of liquid O_2 and H_2 containing about 1.5% O_2, an influence is found on the absorption of transitions occurring between even and odd rotational energy levels. At liquid-H_2 temperatures, the absorption in H_2 becomes very small and seems to agree with the classical theoretical value. For the four gases in question, a decrease is found in the absorption coefficient as a function of temperature. For H_2 and D_2 this decrease seems to be greater than for the other two gases.

148

van Itterbeek, A., and L. Thys, "Influence of a Magnetic Field on the Absorption of Sound in Oxygen," Physica, 5, 298-304, 1938.

The absorption of sound as a function of pressure is measured at 20°C and 50°C in O_2 placed in a magnetic field (maximum field-strength of 6 kG) of which the lines of force are perpendicular to the direction of motion of the sound waves. A great decrease is found—about 20% at 1 atm. The influence decreases with decreasing pressure and disappears completely at room-temperature at a pressure of about 0.3 atm. At 50^0 and a lower pressure the effect disappears. A possible explanation of the effect is given by an influence of the magnetic field on the vibrational state of the O_2 molecule. The velocity of sound in O_2 is not influenced by the magnetic field. Measurements are also carried out on N_2 at room-temperature. The absorption of sound of this gas is not influenced by a magnetic field. The absorption of sound in N_2 as a function of pressure is in complete agreement with the formula of Kirchhoff-Helmholtz.

149

van Itterbeek, A., and L. Thys, "Velocity and Absorption of Sound in Nitric Oxide in a Magnetic Field," Physica, 5, 640-642, 1938.

From previous measurements on the absorption of sound in O_2, it was established that the absorption decreases strongly (about 20%) under the influence of a magnetic field (strength 5 k Gauss). The authors have now investigated NO in a magnetic field of the same strength. No influence of the magnetic field on the absorption is found. The absorption was determined as a function of pressure. The results obtained are in complete agreement with the theory of classical absorption. The velocity of sound in NO at 16.3^oC was found to be 333.9 m/sec.

150

van Itterbeek, A., and P. Mariens, "Absorption of Sound in Carbon Dioxide," Physica, 5, 153-160, 1938.

An earlier paper describes measurements of the absorption of supersonic sound in O_2, H_2, and CO. The experiments are now extended to CO_2. The absorption in this gas is markedly influenced by impurities, especially water vapor. By using the method of preparation described by Eucken, CO_2 is obtained sufficiently pure to avoid marked effects of this kind. The absorption is measured as a function of pressure at four different temperatures between -31.0 and 51.3^oC and at frequencies of 304 and 599 kcs. The relaxation time is inversely proportional to the pressure, and the absolute values agree with those of Eucken. It is concluded that the results agree with Kneser's theory. From the values of the relaxation times the number of efficient collisions is calculated.

151

van Itterbeek, A., and P. Mariens, "Absorption of Sound in O_2 and in CO_2 Containing Small Quantities of H_2O, D_2O, and Ne, Relaxation Times for the Vibrational Energy," Physica, 7, 125-130, 1940.

Measurements were made on the absorption of sound between room temperature and about 90^oC, first on pure CO_2 and then on CO_2 to which small quantities of H_2O or D_2O-vapor were added. From these measurements the relaxation times were computed. It was found the $\beta_{CO_2D_2O}/\beta_{CO_2H_2O}$ is equal to about 1.5 and that this ratio is nearly independent of the temperature. Measurements were also made on CO_2 gas to which a small quantity of Ne gas was added. A small excitation of CO_2 by Ne was observed. Finally, measurements were made on the absorption of sound in oxygen gas between 50^oC and 150^oC. From these data the relaxation times were computed.

152

van Itterbeek, A., and P. Mariens, "Velocity and Absorption of Sound at Ordinary and Low Temperatures," Physica, 4, 207-215, 1937.

Experiments with ultrasonics are made on the velocity and absorption of sound in O_2, N_2, and H_2 at ordinary and low temperatures. The influence of a magnetic field perpendicular to the direction of propagation of the velocity and the absorption of sound in O_2 is studied. No influence is found on the velocity; the absorption, however, seems to decrease. At low temperatures, measurements are made at the boiling point of O_2. The dependence of the velocity and absorption of sound on pressure in O_2, N_2, and H_2 is studied. Concerning the velocity in O_2 and N_2, a good agreement with the Leiden measurements if found. The dependence on pressure, found for the absorption coefficient of O_2 and N_2, corresponds fairly well with the classical theoretical absorption. The values found for the absorption coefficient of H_2 show that at the boiling point of O_2 there is still a dispersion effect.

153

van Itterbeek, A., and P. Mariens, "Velocity and Absorption of Sound at Ordinary and Low Temperatures," Physica, 4, 609-616, 1937.

The absorption and velocity of sound in O_2, H_2, and CO have been measured as a function of pressure and temperature. The relaxation time for O_2 is calculated and found to vary inversely as the pressure at a temperature of about 13^oC. A departure from this law occurs at higher temperatures; at low temperatures, the absorption coefficients are higher than those predicted by the classical formula. As in earlier measurements, absorption in H_2 is found to be very high. The absorption in this gas is unaffected by increasing the concentration of parahydrogen. Measurements made in CO, for which the vibrational energy is small at ordinary temperatures, also show deviations from the classical formula.

154

Verma, G. S., "Effects of Humidity on Ultrasonic Absorption in Air at 1.46 Megacycles," J. Acoust. Soc. Am., 22, 861-862, 1950.

The absorption coefficient for moist air has been measured at 1.46 Mcs for relative humidities varying from zero to 84%. Maximum absorption at this frequency (α = 0.52 cm^{-1}) is found to occur at 46% relative humidity.

155

Waetzmann, E., and W. Wenke, "Sound Damping in Rigid and Elastic Walled Tubes" (in German), Akust. Z., 4, 1; translated by L. L. Beranek, J. Acoust. Soc. Am., 11, 154-155, 1939.

The attenuation due to tube walls was measured, and the results are presented in this paper. Rigid, smooth, rough, and porous tubes, and also elastic hoses were investigated. Attenuation was measured as a function of frequency and tube diameter.

156

Walther, K., "Electrical Analogues of Acoustic Relaxation Phenomena" (in German), Acustica, 6, 245-251, 1956.

The possibilities of directly measuring relaxation time and characteristics from the distortion of an acoustic rectangular pulse are considered. Because of the necessary wide bandwidth it is not possible to realize these considerations experimentally with the electroacoustic transducers available. The acoustic phenomena are translated into electrical analogues. The problem of the separation of two relaxation times is investigated with a two-terminal network.

157

White, J. E., "A Method for Measuring Source Impedance and Tube Attenuation," J. Acoust. Soc. Am., 22, 565-567, 1950.

If the active face, or acoustic output terminal, of a sinusoidal sound source moves as a plane piston, then the source can be characterized by a blocked pressure and an acoustic output impedance. If this piston is coupled to a microphone by means of a closed air column, the pressure at the microphone depends on the acoustic impedance of the microphone, on the impedance of the source, and on the air column. An expression for this pressure as a function of the length of the air column is developed, and data are presented which show how source impedance, tube attenuation, and other quantities may be obtained.

158

Young, J. E., and O. K. Mawardi, "Molecular Absorption of Sound in Gases at High Temperatures," J. Chem. Phys., 24, 1109, 1956.

This paper presents results of measurements of molecular absorption due to the so-called molecular thermal relaxation processes; the measurements were carried out with dry air at 2000 cps and 600^o-1200^oK. The results fit a curve $\mu = CT^{\beta}$, where μ is the absorption reduced to an attenuation per (waveguide) wavelength.

159

Zink, J. W., and L. P. Delsasso, "Attenuation and Dispersion of Sound by Solid Particles Suspended in a Gas," J. Acoust. Soc. Am., 30, 765-771, 1958.

Observations were made on audio-frequency sounds propagating through a gaseous medium containing small solid particles in suspension. Two effects were observed—the attenuation and the dispersion. The measurements were carried out by sending short trains of sine waves through the particle-filled gas and observing the changes in the transmitted train of waves after the particles settled out of the gas. The variation in arrival time of the pulse was used to determine the velocity change caused by the suspended particles. The variations of the attenuation and velocity with frequency due to the particle-filled gas were obtained and the results compared with theory. The measured attenuation agreed with existing theory. The observed dispersion is satisfactorily accounted for by a theory that is introduced in this paper. The attenuation theory takes into account enhanced viscous and thermal losses caused by the suspended particles. The dispersion theory predicts the velocity shift resulting from changes of the heat capacity and the density of the gas containing the suspended particles.

160

Zmuda, A. J., "Dispersion of Velocity and Anomalous Absorption of Ultrasonics in Nitrogen," J. Acoust. Soc. Am., 23, 472-477, 1951.

By means of the interferometer, the velocity and absorption of ultrasonic waves in N were measured at the frequency of 2.992 Mcs in the pressure range of 2.09 to 76 cm of Hg at a temperature of 29^oC. A dispersion of velocity was found ranging from 354.3 m/sec to 364.4 m/sec. The ratio $\alpha_{exp}/\alpha_{class}$ dropped from 1.40 to 1.32, and the corresponding value of C_v/R dropped from 2.50 to 2.08. Theoretical values for the change in velocity and in the absorption ratio, calculated by applying the equations for the exchange of energy between translational and vibrational degrees of freedom, show good agreement with the observed values. The increase in velocity and the decrease in $\alpha_{exp}/\alpha_{class}$ is interpreted as due to the slow exchange of energy between the translational and rotational degrees of freedom. The relaxation time for rotation was found to be 1.2×10^{-9} sec.

Absorption, Measurement
See also—20, 32, 39, 49, 54, 71, 169, 171, 181, 182, 186, 194, 197, 202, 205, 207, 209, 217, 245, 266, 267, 269, 271, 274, 278, 279, 294, 299, 300, 303, 305, 310, 316, 318, 327, 429, 431, 432, 435, 449, 450, 452, 453, 467, 480, 529, 590, 780, 789, 821, 928, 980, 993, 996, 1057, 1061, 1134, 1141, 1143, 1182, 1322, 1427, 1443, 1581, 1646, 1690, 1866, 2081, 2184, 2980, 3178, 3212, 4113, 4133

ABSORPTION, MOLECULAR

161

Amme, R. C., "The Influence of Atmospheric Parameters on Sound Absorption," Proc. of the Sumposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 57-68, 1961.
AD-408 716.

Absorption of an acoustic wave in air occurs because of the effects of viscosity, heat conduction, radiation, unmixing (diffusion) and internal degrees of freedom. Under certain conditions the latter contribution is the most important.

Absorption due to molecular rotation and vibration is described relative to atmospheric pressure, temperature, and composition. Specifically, absorption due to the vibrational relaxation of molecular oxygen is examined; deactivation of O_2 vibrations by collisions with other constituents of the air as a function of temperature is described.

162

Angona, F. A., "The Absorption of Sound in Gas Mixtures," J. Acoust. Soc. Am., 25, 1116-1122, 1953.

The absorption of sound has been measured in CO_2, CS_2, C_2H_4O, and in mixtures of the latter two gases with CO_2 over the frequency and pressure ranges, and by the method reported in the preceding abstract. The measured absorption coefficient was corrected for the effect of the tube and also for the absorption due to viscosity and heat conduction of the gas. The corrected absorption coefficient was then plotted as the attenuation coefficient per wavelength against the logarithm of the ratio of frequency over pressure. These curves were then compared to those determined from Bourgin's theory for mixtures of absorbing gases. The agreement between the observed attenuation and that predicted by the theory was within 5%.

163

Angona, F. A., "The Absorption of Sound in Gas Mixtures," Tech. Rept. No. 5, Univ. of Calif., Los Angeles, 87 pp., 1953.
AD-3 861.

The molecular absorption of sound in CO_2, CS_2, C_2H_4O, and their mixtures were measured. The sound tube method used in this investigation was readily adaptable to both frequency and pressure control. The attenuations for pure CO_2, CS_2, and C_2H_4O agreed closely with the attenuations predicted by Bourgin's theory for a single gas. The attenuation for mixtures of CO_2 and CS_2 agreed within 2 to 5% of the theoretically predicted values, and within less than 2% for the CO_2 - C_2H_4O mixture. Information was also obtained concerning the collision parameters of a gas or gas mixture. For example, the number of collisions required to remove a quantum of vibrational energy from a molecule and the probability of a transition occurring because of a single collision can be calculated from experimentally determined transition rates.

164

Chandler, D. E., "Molecular Absorption of Sound in Carbon Dioxide," Tech. Rept. No. 11, California Univ., Los Angeles, 71 pp., 1958.
AD-218 756.

Study was made of the propagation of sound through a gaseous medium, pure CO_2, and in CO_2 with the addition of a controlled amount of impurity. The sound propagation was studied as a function of frequency in the range where nonclassical absorption occurs. The apparatus consisted of a tube to contain the gas and the sound, with devices to generate and detect the acoustic waves. The equipment was constructed to permit temperature to be set and maintained at any value between room temperature and 100°C. Results of tests on the pure CO_2 indicated that no marked divergences from the smooth symmetrical bell-shaped curve of the simple theories occurred in the temperature range studied. The maximum absorption per wavelength, frequency of maximum absorption, the relaxation times based on the assumption of two independent internal vibrational degrees of freedom, and the number of CO_2-CO_2 collisions required to deexcite a vibrationally excited CO_2 molecule were determined. Results with the impure CO_2 molecule showed that the shape of the curves of absorption per wavelength is unaltered within the resolution of the apparatus by the addition of small amounts of H to dry CO_2. On the basis of the experimental evidence, it cannot be stated unequivocally that the assumption of two independent relaxation times is correct. However, the expressions derived based on this assumption will yield values which fit the experimental data.

165

Dean, E. A., "Absorption of Low Frequency Sound in a Homogeneous Atmosphere," Schellenger Res. Lab., Texas Western College, El Paso, 1959.

This is a review of the classical and molecular theory of the absorption of sound, with particular attention to the absorption of frequencies less than 1000 cps in the atmosphere from sea level to 50 km. The variation of the theoretically predicted absorption with the meteorological parameters—pressure, temperature, and humidity—is investigated. Recent work involving absorption due to radiation is included. It is found that the absorption can be expressed as:

$$\frac{2.5 \times 10^{-7}(T^*)^{0.3}f^2}{P^*} + \frac{5.3 \times 10^{-5}(T^*)\,f}{P^*} + \frac{1.0 \times 10^2 f}{(T^*)^{2.5}e^{8.3/T^*}}\;\frac{2f_0 f}{f_0^{\,2} + f^2}$$

db/mile, where

$$f_0 = \frac{P^*}{(T^*)^{0.8}}\left[900\left(\frac{wT^*}{P^*}\right)^2 + 500\,\frac{wT^*}{P^*} + 50\right]$$

$T^* = T/273$, $T = {}^{\circ}K$, P^* = pressure in atmospheres, and w is the absolute humidity in gm/m^3.

The absorption has been calculated for various altitudes, humidities, and frequencies. These data are presented in tabular form in the appendix. Although the absorption varies in a rather complicated manner with the meteorological parameters, it is found to be quite small for the very low frequencies, resulting in a predicted long distance propagation with small attenuation if the geometry of propagation is advantageous.

166

Dean, E. A., "Absorption of Sound in the Atmosphere," Proc. Symp. Atmos. Acoust. Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. M., 1, 50-56, 1961.
AD-408 716.

The classical and molecular theories of the absorption of sound for low f/p ratios are reviewed. The absorption is discussed as a function of frequency and atmospheric pressure, temperature, and composition, including recent work on the determination of the vibrational relaxation time due to small amounts of water vapor. The possible importance of absorption due to radiation is mentioned.

167

deGroot, S. R., "Acoustic Relaxation in Gases" (in Dutch), Ned, Tijdschr. Natuurk., 1, 1-13, 1950.

Mathematical theory shows that changes in intramolecular vibrational energy are the main cause of the variation with frequency of the velocity and absorption of hf sound waves in gases. The exact definition of "relaxation time" is still uncertain and the explanation of the influence on it of impurities in the gas, etc., is obscure.

168

Dubois, M., "The Absorption of Sound and Ultrasonics in Gases" (in French), J. Phys. Radium, 12, 876-884, 1951.

This article reviews the general problem of the attenuation, of a plane wave during propagation, due to the properties of the medium and the local modifications produced by the passage of the wave. Viscosity, conductivity rise and fall of temperature, and the variations in the translational and vibrational energy of the molecules are considered. Theoretical and experimental results are compared, and an extensive bibliography is given.

169

Dwyer, R. J., "Persistence of Molecular Vibration in Collisions," J. Chem. Phys., 7, 40-44, 1939.

The dispersion of sound is theoretically interpreted by the idea that the exchange of energy in collisions between molecular translation and rotation on one side and vibration on the other side is much slower than, for example, between the various translational degrees of freedom. It seemed desirable to find a direct optical method of observing this hypothetical effect. Apparatus has been developed for the purpose of investigating molecules present in very small concentration, like radicals, by their absorption spectra; with this method, relative concentrations of molecules are determined by comparing intensities of certain rotational lines. This test was applied to the higher vibrational levels of the I_2 molecule. Their concentration was artificially increased beyond the small amount present in thermal equilibrium by an electric discharge of brief duration. By varying the phase between an electric switch and optical shutter, snapshots of the absorption spectrum could be taken at different intervals after the discharge was interrupted. The result was that I_2 molecules raised from the ground level to the first excited vibrational level are able to persist in this level through several thousand collisions with other I_2 molecules before losing their vibration.

170

Eucken, A., and E. Numann, "Excitation of Intramolecular Vibrations in Gases and Gas Mixtures by Collisions, Part IV," Z. Physik. Chem., 36, 163-183, 1937.

Measurements of the dispersion and absorption of sound were made in pure CO_2 and N_2O at temperatures up to 400°C. In these substances, and also when He and H_2O are added to them, the valency vibrations are excited as easily as the deformation vibrations. This effect is supposedly due not to a simple equality of sensitiveness to impact, but to a very rapid adjustment of equilibrium of the energy in the two forms of vibration. In CO_2 the mean number of collisions passes through a minimum value as the temperature rises, whereas in N_2O there is a continuous increase in this number. An explanation of this is suggested.

171

Eucken, A., S. Aybar, and K. Schafer, "Excitation of Intra-Molecular Vibrations in Gases and Gas Mixtures, VI., Sound-Absorption and Dispersion Measurements on CH_4, COS and Their Mixtures with Other Gases (Eucken and Aybar), VII., Theory of Sound Dispersion in the Presence of Several Normal Vibration (Schafer)" (in German), Z. Physik. Chem. B, 46, 195-228, 1940.

The average time required for the exchange of translational and vibrational energy is investigated between 20° and $400^{\circ}C$ by the method of sound absorption and dispersion. The results of previous investigations with other gases (Kuchler, Z. Physik. Chem. B, 41, 199-214, 1938) are confirmed: there is no indication of different relaxation times for the single vibrations, a uniform period of adjustment holds for the total heat of vibration, and the additional gases are the more effective the easier they react with the main gas. A higher percentage of additional gas was investigated. A corrected formula for determining the average relaxation time is given. The inert gases are generally more effective than the main gas although less so than chemically active gases. Previous theories of sound dispersion (Rutgers and Kneser, Ann. Physik, 16, 350-361, 1933) were based on the presence of only one normal vibration. The author investigates the case of several vibrations excited simultaneously. Similar dispersion curves are obtained, as in the case of only one normal vibration. From the slight deviation of the experimental dispersion curves from standard type, the ratio of the relaxation times for single normal vibrations may be determined. The necessary equations are derived and an example of the application of the theory is given. The theory provides an explanation of the anomalous temperature coefficients of the relaxation times different from that of other investigators (Eucken and Kuchler, Z. Tech. Phys., 19, 517-521, 1938).

172

Evans, E. J., and E. N. Bazley, "The Absorption of Sound in Air at Audio Frequencies," Acustica, 6, 238-245, 1956.

The sound-absorbing properties of air at frequencies from 1 to 12.5 kcs are determined for values of the relative humidity from about 5% to 85% at $20^{\circ}C$. The measurements were made in a large reverberation chamber, in which the surface absorption was very small. The absorption due to the air was evaluated by an analysis of the results and closely agrees with the relaxation theory. A general expression is derived for the attenuation of sound in air as a function of the frequency, humidity, and temperature.

173

Faure, J., "Rotational and Vibrational Relaxation in Gases, I." (in French), Ann. Phys., 7, 13-25, 1962.

This is the first of two articles related to deriving the elements of rotational and vibrational energy transfer in gases. Briefly discussed are (1) derivation of the linear relaxation equation and the parameters relevant to a microscopic as well as macroscopic description, (2) the Landau-Teller theory of the excitation probability of an internal energy mode, (3) the ultrasonic impact tube and shock tube methods for studying relaxation phenomena.

174

Faure, J., "Rotational and Vibrational Relaxation Phenomena in Gases, II." (in French), Ann Phys., 7, 115-122, 1962.

In this second part the author first lists experimental results about relaxation times referring to translational, rotational, and vibrational motion. He then discusses the equilibrium in the exhaust gases of a rocket, and the consequences on the ejection velocity of the fact that the vibrational degrees of freedom will not be in equilibrium.

175

Gemant, A., "Frictional Phenomena," III-IV, J. Appl. Phys., 12, 718-734, 1941.

III. The part played by viscous forces in the absorption of acoustic waves traveling freely in the gas along with absorption due to heat conduction by the gas gives sound-absorption coefficients which, in nearly every case, are too small. Kneser's theory of a relaxation time explains the divergence as due to intramolecular vibrations, and the absorption in air is reduced by humidity because the water molecules reduce the relaxation time of the air molecules and shift the maximum absorption to higher frequencies. IV. The principles of room acoustics are discussed, and the sound-absorbing property of materials is explained on the basis of viscous processes in the pores of the material. Two methods are described for determining experimentally the acoustical resistance of a material: (1) The flow resistance is compared with that of a glass capillary; the units are placed in series and the same current of air is sucked through both; the pressure differences between the ends of the units are $\propto$ the respective resistances; experiment gave 14×10^3 for insulite and 18×10^3 for celotex, in absolute units. (2) The velocity of the gas is measured by means of a chemical indicator; the method is not suitable for low-resistance material. The properties of absorbents are discussed in relation to room acoustics.

176

Harris, C. M., "Absorption of Sound in Air in the Audio-Frequency Range," J. Acoust. Soc. Am., 35, 11-17, 1963.

This paper, concerning the absorption of sound in air as a function of humidity, presents new data in the frequency range between 2000 and 12,500 cps. These data are for air at normal atmospheric pressure and at a temperature of $20^{\circ}C$. First the measurement system is described. Then the data are compared with theory and with other published results in the same frequency range. The data also are presented in a graphical form that is particularly convenient for use in computing the contribution of air absorption to the total absorption of sound in a room. In this form the data are plotted directly in terms of the quantity 4mV as a function of frequency and humidity, where m is the attenuation coefficient and V is the volume of the room.

177

Harris, C. M., "Quarterly Progress Reports, Jan.-Mar. 56, Apr.-June 56," Columbia Univ., Acoustics Lab., Electronics Res. Labs., 1956.

These reports present the results obtained from measurements of the absorption of sound in humid air at low audio frequencies. They contain (1) a brief summary of the experimental apparatus and procedure, (2) some theory, (3) results obtained, and (4) a comparison of these results with similar work by other investigators in the past.

Work was confined to the frequencies from about 300 cycles to 1100 cycles. Pressures from 20 cm Hg to atmospheric and temperatures from $0^{\circ}C$ to $65^{\circ}C$ were employed. The moisture content of the air was varied in mol ratio concentration from zero to 0.02.

The development, construction and field testing of a 45-cps, 10-element phased array of microphones is described. Phasing requirements, directional characteristics, and sensitivity of system are explained in detail.

178

Horiuchi, I., "The Absorption of Sound in Humid Air at Low Audio Frequencies," Tech. Rept. No. 6, Columbia Univ., New York, 48 pp., 1957.
AD-140 786.

The reverberation technique of Kudsen has been applied to the measurement of the absorption of sound in air over the frequencies 300 to 1100 cps with mole ratio concentrations of water vapor ranging from zero to 0.1. Pressures from 20 cm Hg to atmospheric, and temperatures from 0°C to 55°C were employed in the study. With the use of a 66-inch spherical resonator and dry nitrogen gas as reference, following the method of Delsasso and Leonard, it has been possible to observe the anomalous absorption of humid air down to 300 cps. Pertinent graphs, theory, and a detailed description of the experimental apparatus are presented.

179

Horiuchi, I., "The Temperature and Humidity Dependence of Sound Absorption," Tech. Rept. No. TR-7, Electron. Res. Labs., Columbia Univ., New York, 20 pp., 1957.
AD-155 171.

Results have been obtained for the absorption of low-frequency sound in humid air at temperatures of 0°C and 55°C. The pressure ranged from 20 cm Hg to atmospheric, while the relative humidity was varied from 2% to 80%. The frequencies employed were the first five radial modes of a 66-inch spherical resonator: 300, 500, 700, 900, and 1100 cps, approximately. The experimental results show the absorption to follow the Knudsen-Kneser theory closely, except that under extreme relative humidity, large departures occur.

180

Hunt, F. V., "Notes on the Exact Equations Governing the Propagation of Sound in Fluids," J. Acoust. Soc. Am., 27, 1019-1039, 1955.

The assumption underlying the exact equations of motion for thermoviscous fluid are reviewed, and the complete equations are given, for reference convenience, in both tensor and vector form. The first- and second-order acoustic equations are then exhibited and used to obtain the source terms that account for the generation of vorticity and streaming. In order to preserve a broad base from which to make the approximations appropriate under various circumstances, all terms are retained explicitly, including those arising from any functional dependence of the viscosity and thermal coefficients on the state variables. The distinction between spatial and material coordinate systems is carefully drawn and conversion transforms are derived rigorously and their use illustrated. The general properties of finite-amplitude waves are demonstrated by including the second-order terms in a plane-wave solution of the exact wave equation in material coordinates, with special concern for the effects of large amplitude on speed of propagation and on wave-form distortion. Sound absorption and dispersion measures for a viscous conducting fluid are analyzed in terms of Truesdell's recent exact solution of the first-order secular equation. These differ characteristically from the corresponding measures predicted for pure relaxation in a two-fluid mixture. It is concluded that a complete and adequate theory of sound absorption and dispersion will need to take into account both relaxation and viscothermal phenomena as well as their interaction, and that until such a general theory is available, the exact theory of viscothermal effects — rather than the crude linear approximation commonly, but inappropriately, called "classical" — should be used in computing the "excess" absorption and dispersion to be accounted for by relaxation processes. The exact solutions of the secular equation permit a new evaluation, in series form, of the characteristic acoustic impedance for a thermoviscous medium. The notes conclude with a revised account of the spectral character of thermal noise in the acoustic medium based on the quantum hypothesis and a merger of the concepts of architectural acoustics and specific-heat theory.

181

Kneser, H. O., "Absorption of Sound in Gases," Z. Tech. Phys., 16, 213-219, 1935.

This article reviews work on the absorption of sound in gases from the time of Kirchhoff up to the present. The failure of Kirchhoff's formula is due to the fact that the time required to establish thermal equilibrium is not small compared with frequency of the sound wave. Recent measurements in air, O_2, and CO_2 agree with the theory of molecular absorption. The effect of foreign gases is discussed. A table of calculated values of the absorption coefficient in air is given for different temperatures and concentrations of impurity.

182

Kneser, H. O., "Absorption of Sound in Oxygen," Z. Tech. Phys., 15, 559-560; Physik. Z., 35, 983-984, 1934.

The excitation of nuclear vibrations by molecular collision in O_2 in thermal equilibrium is briefly discussed. The duration of the vibratory state of the molecule is shown to be obtainable from measurements of the sound absorption in the gas, maximum absorption occurring when the reciprocal of the angular frequency is equal to the average life of the excited state. Measurements in O_2 indicate that the absorption at any one frequency is markedly increased by the presence of small quantities of impurity and by further additions of the impurity that may pass through a maximum and decrease again. This is ascribed to the fact that the mean life of the excited molecule decreases as the amount of impurity increases. The resulting dependence of the frequency of maximum absorption upon the concentration of various impurities is investigated. By extrapolating from these results, the life of the excited state in pure oxygen appears to be $> 10^{-3}$ sec; the corresponding frequency of maximum absorption would thus be below 160 ~.

183

Kneser, H. O., "Acoustic Relaxation Phenomena," Z. Tech. Phys., 19, 486-492, 1938.

Acoustic relaxation occurs when, with rapid compression, the compressional energy communicated to a body is not distributed over all the degrees of freedom of the molecules as in thermal equilibrium. In consequence there is an apparent increase in compressibility and an increased velocity of sound; in addition, the cycle is irreversible for frequencies of the order of the reciprocal of the relaxation time, and sound energy is absorbed. In gases the absorption of sound and dispersion phenomena have been observed and can be ascribed to the transformation of translational and rotational energy into energy of vibration. The appropriate period of relaxation is of the order of 10^{-3} to 10^{-5} sec. The life of vibration quanta has a molecular-kinetic significance. In liquids there is also strong absorption of sound which is put down to relaxation, but a maximum of absorption has not been attained. Consequently, only an upper limit can be given for the period of relaxation, namely 10^{-8} sec and the significance of this still remains uncertain.

184

Kneser, H. O., "General Theory of Absorption of Sound in Gases and Liquids" (in German), Nuovo Cimento, 7, 231-235, 1950.

The absorption of sound in liquids and gases as measured experimentally is in most cases much larger than expected from the classical theory, based on the thermal conductivity and viscosity of the material. Here a theory of sound absorption is based on plausible, generally accepted assumptions regarding the process of relaxation, and it leads to a general absorption formula.

185

Kneser, H. O., "The Interpretation of the Anomalous Sound-Absorption in Air and Oxygen in Terms of Molecular Collisions," J. Acoust. Soc. Am., 5, 122-126, 1933.

The anomalous sound absorption in moist air discovered by V. O. Knudsen cannot be explained on the basis of the classical theory of Rayleigh, Kirchhoff and Stokes. Further facts and theories are presented.

186

Kneser, H. O., "A Nomogram for Determination of the Sound Absorption Coefficient in Air" (in German), Akust. Z., 5, 256-257, 1940.

The non-classical or molecular absorption of sound in the earth's atmosphere is usually many orders of magnitude greater than the so-called classical absorption. Molecular absorption is principally due to the exchange of translational and vibrational energy between colliding molecules. In air, it is a function of temperature, humidity, and frequency. Kneser's nomogram combines the several sets of curves for molecular absorption as a function of each variable. By using this nomogram one can quickly and easily determine a value for the attenuation constant in air caused by molecular absorption at any desired frequency from 100 cps to 80 kc, for any temperature from -20° to +40°C, and for relative humidities from 10% to 100%.

187

Kneser, H. O., "Relation Between Sound Velocity and Absorption with Acoustic Relaxation" (in German), Ann Physik., 43, 465-469, 1943.

Formulas for the variation of sound velocity and absorption with frequency are derived by two independent methods. For a given temperature, experimental values may be plotted on a simple geometric semi-circular diagram. The relaxation time and the phase angle between pressure and contraction can be read off directly from this diagram. Results of absorption and velocity measurements with oxygen of varying purity and carried out by different observers closely agree with the predicted semi-circular diagram and corroborate the theory.

188

Kneser, H. O., "Sound Absorption in Multiatomic Gases," Ann. Physik, 16, 337-349, 1933.

The factors in classical mechanics responsible for sound absorption, namely friction and heat conduction, are insufficient to explain absorption; a theory is stated, based on the finite period of adjustment of thermal equilibrium. The experimental facts of absorption can, to some extent, be explained quantitatively. The agreement of the theoretical absorption with that measured by different investigators is tested in the cases of CO_2, N_2O, SO_2, O_2, and air.

189

Kneser, H. O., and V. O. Knudsen, "Period of Readjustment of Oscillation Energy in O_2 and its Modification by Foreign Gases," Ann. Physik, 21, 682-696, 1935.

This paper describes a resonance method which leads to the determination of the absorption of sound in gases; results are obtained for the absorption due to O_2 at room temperatures. From the absorption curves the period of readjustment of the heat oscillation and also the mean life period of the oscillation quantum are determined. This period is considerably shortened by the presence of foreign gases. The transference of energy from one gas molecule to another due to collision between molecules having translational or rotational energy can be calculated. The different results for various foreign gases are discussed.

190

Knudsen, V. O., "Absorption of Sound in Gases," J. Acoust. Soc. Am., 6, 199-204, 1934.

The author's experiments upon the absorption of sound in O_2 and air are discussed in relation to Kneser's theoretical work. Kneser's prediction that the sound absorption in a gas at a given frequency should pass through a maximum as the concentration of a given impurity is varied is confirmed. The value of the maximum absorption is apparently proportional to the frequency: this is also predicted by Kneser's equations. A result which does not appear to have any rigorous theoretical explanation is also obtained; that is, that the concentration at which maximum absorption occurs is proportional to the frequency for all impurities except H_2O. From this result it is possible to deduce absorption coefficients which fit the observed values very well. Kneser's calculations indicate that the number of transitions between the excited and unexcited molecular states should equal 2π times the frequency at which the maximum absorption occurs. The experiments thus provide a simple method of measuring the rate of interchange of energy in molecular collisions.

191

Knudsen, V. O., and E. F. Fricke, "The Absorption of Sound in CO_2, N_2O, COS, and CS_2, Containing Added Impurities," J. Acoust. Soc. Am., 12, 255-259, 1940.

We have investigated the absorptive characteristics of CO_2, N_2O, COS, and CS_2, as influenced by the addition of certain gases, such as H_2, H_2O, H_2S, CH_3OH, etc., acting as "catalysts." These catalysts shift the absorption bands to higher frequencies; the magnitudes of these shifts yield information respecting (1) the frequency to which each pure gas has its maximal absorption, and (2) the nature of the molecular collisions involved, especially the effectiveness of these collisions in distributing the vibrational states of the absorptive molecules. The results indicate that at atmospheric pressure and 23°C, the absorption maxima for pure CO_2, N_2O, COS, and CS_2 are shifted in each case by amounts proportional to the concentration of the added catalyst. The addition of 1% of H_2O to CO_2 shifts the absorption band for CO_2 2250 kc; similarly, 1% of H_2O shifts the CS_2 band 2460 kc, the COS band 4200 kc, and the N_2O band 427 kc. One percent of the other impurities produced shifts which varied from 20 to 1830 kc. Transition probabilities for the above gases have been calculated. These probabilities are characteristic of the colliding pair of molecules.

192

Knudsen, V. O., and E. F. Fricke, "Absorption of Sound in CO_2 and Other Gases," J. Acoust. Soc. Am., 10, 89-97, 1938.

Sound absorption measurements in pure CO_2 at 1 atm and 22°C have been conducted; together with measurements by others, these confirm the collision theory of anomalous absorption as developed by Einstein, Kneser, and others. The absorption coefficeient is appreciable at frequencies as low as 2000 ~, and increases to a maximum of 0.317 per wavelength at 77,000 ~. This maximum is higher than values obtained by previous workers, and indicates that both the deformation and symmetrical valence vibrations participate in the exchanges between translational and vibrational energy. Small impurities, such as water or alcohol vapors, affect the absorption greatly; the entire absorption band is shifted to higher frequencies. Measurements in mixtures of CO_2 in O_2 and CO_2 in N_2 indicate that neither the O_2 nor N_2 is appreciably excited by collisions with CO_2. Measurements in CS_2 reveal an absorption similar to that for CO_2 except that the absorption begins at about 10,000 ~. In mixtures of CS_2 and O_2, the observed absorption at frequencies below 10,000 ~ is accounted for by assuming that only the vibration of O_2 molecules is excited by collisions with CS_2 molecules; at higher frequencies the CS_2 molecules also are excited, principally by collisions with other CS_2 molecules.

193

Knudsen, V. O., and L. Obert, "Absorption of H. F. Sound in Oxygen Containing Small Amount of Water Vapor or Ammonia," J. Acoust. Soc. Am., 7, 249-253, 1935.

Using a new technique, the author has extended his measurements upon the absorption of hf sound in gases to higher frequencies (up to 34,000 ~). The gas is contained in a small steel box and the sound is generated in the box by a magnetostriction oscillator. The intensity of the sound generated in the box is measured, and thus the sound absorption in the gas is determined. The results confirm the earlier results, (i.e., the absorption is a maximum at a certain frequency which depends upon the amount and kind of the gaseous impurity, and this frequency increases almost linearly with the concentration of most impurities, but in the case of water impurity is a quadratic function of the concentration). This latter fact suggests that a collision of an O_2 molecule with two molecules of H_2O is more efficient in producing a transition within the molecule than is a collision with a single H_2O molecule. The theoretical value of the maximum absorption per unit wavelength agrees within experimental error with the measurements. Other measurements have shown that CO_2 and H_2 are also absorptive in the frequency range 7000 ~ to 34,000 ~.

194

Mokhtar, M., and E. G. Richardson, "Supersonic Dispersion in Gases, II. Air Containing Water Vapor," Proc. Roy. Soc. (London) A, 184, 117-128, 1945.

The apparatus and method of measurement are described. Curves are given showing the variation, at various frequencies, of the supersonic absorption coefficient μ and the supersonic velocity with the water vapor pressure. The results deduced are: (1) the velocity in dry air is independent of frequency; (2) the measured values for μ in dry air are several times larger than those calculated from the Stokes-Kirchhoff formula and indicate an approximately linear dependence on the frequency; (3) in humid air μ reaches a maximum, two or three times its value in dry air, at a vapor pressure which decreases as the frequency increases; (4) the maximum of dispersion in velocity decreases as the frequency increases.

195

Nomoto, O., "Origin of Phase Difference Between Pressure- and Density-Waves During Molecular Absorption of Sound in Gases (in German), Simple Derivation of Dispersion and Absorption Formulae," Proc. Phys.-Math. Soc. Japan, 22, 77-90, 1940.

The origin of the phase difference between pressure and density waves during molecular absorption of sound in gases is shown to have a direct connection with the period of adjustment of the vibrational energy. In addition, the formulae of absorption and dispersion are derived by a simple method and agree with those of Kneser and Landau. It is also shown that the period of adjustment β' of these authors is related to the ordinary value β by the equation: $\beta' = \beta C_\infty/C_0$, where C and C_0 are the specific heats for infinitely rapid and infinitely slow changes of volume.

196

Nomoto, O., "Phenomenological Theory of the Molecular Absorption and Dispersion of Sound in Fluids and the Relation Between the Relaxation Time of the Internal Energy and the Relaxation Time of the Internal Specific Heat," J. Phys. Soc. Japan, 12, 85-99, 1957.

Molecular absorption and dispersion formulae applicable to both liquids and gases have been derived in a phenomenological manner. It is pointed out that the relaxation time of the molecular internal energy γ must be distinguished from the relaxation time of the internal specific heat β, and the relation between these two quantities is discussed in detail. The relaxation time γ has the advantage of making the dispersion formula simpler and directly comparable with the dispersion formulae in other cases, such as the relaxation of shear viscosity. The relaxation time β on the other hand, is more closely related to the collision excitation probability of the molecules than γ.

197

Pielemeier, W. H., "Kneser's Sound Absorption Nomogram and Other Charts," J. Acoust. Soc. Am., 16, 273-274, 1944.

The author plots the maximum value of the molecular absorption per wavelength as a function of the temperature, and obtains agreement with the theoretical values found by Kneser, the measured values of Knotzel and Kneser, and those of Knudsen. Kneser's nomogram is modified so that the molecular absorption can be found for ordinary conditions of temperature, humidity, and sound frequency; an example is given.

198

Pielemeier, W. H., "Supersonic Measurements in CO_2 at 0^o to 100^oC," J. Acoust. Soc. Am., 15, 22-26, 1943.

An attempt to harmonize the best data on the velocity and absorption of lf and hf sound waves CO_2. Velocity/temperature graphs are drawn, as are curves to show how the frequency for maximum absorption per wavelength depends on the water vapor concentration in the CO_2 at 1 atm pressure. Two distinct relaxation times are indicated for each concentration, and acetaldehyde is cited as a gas in which three relaxation times have been found.

199

Polyakova, A. L., "On Absorption of Finite-Amplitude Sound (Waves) in a Relaxing Medium" (in Russian), Dokl. Akad. Nauk SSSR, 122, 51-53, 1958.

An acoustic wave of finite amplitude, originally sinusoidal, becomes saw-tooth in form as it propagates through a real medium. Such a saw-tooth wave is absorbed more strongly than a wave of infinitely small amplitude. The present paper deals theoretically with absorption of acoustic waves of finite amplitude in a medium in which the energy of the progressive motion of molecules is transferred to their internal degrees of freedom. Such a process produces relaxation and consequently absorption of those acoustic frequencies which are close to the relaxation frequency.

200

Polyakova, A. L., "Thermodynamic Theory of the Absorption of Finite-Amplitude Sound in Relaxing Media," Soviet Phys. Acoust., English Transl., 5, 85-90, 1959.

Propagation of sound of finite amplitude is considered by using thermodynamics of irreversible processes. It is assumed that two states are possible in the medium in which sound is propagated; transition between these two states occurs under the action of sound (relaxation). Such transitions are due to transfer of translational energy of molecules to internal processes (for example, vibrational or rotational decrease of freedom, chemical reactions, etc.). An expression is obtained for energy dissipated in such processes. It is shown that finite-amplitude sound is absorbed more strongly than sound of infinitely small amplitude. The absorption maximum is found to be displaced towards frequencies lower than the relaxation frequency.

201

Rocard, Y., "Absorption of Sound in Gases," Rev. Acoust., 3, 47-62, 1934.

This is a mathematical paper in which the magnitudes and frequency variations of the effects of thermal conduction, viscosity, diffusion in gas mixtures, and the transfer of molecular vibrational energy on the absorption of sound in a gas are considered and compared.

202

Rocard, Y., "Molecular Absorption of Sound in Gases," Compt. Rend., 198, 802-803, 1934.

If sound passes through a gas, most of whose molecules are without vibrational energy, the alternating temperature effects will vary the number of such molecules. The resulting absorption of energy is discussed and the following facts are pointed out: (a) from measurements of the absorption of sound in air it may be deduced that under normal conditions only 1/100 of the molecular energy is vibrational; (b) the critical frequency for air is about 8×10^5 ~; (c) at this frequency the absorption is mainly due to the above-mentioned effect; (d) above the critical frequency the absorption is principally due to viscosity, conductivity, etc.; and (e) at audible frequencies the molecular absorption is of greater importance than the absorption due to viscosity and conductivity.

203

Shields, F. D., "Measurements of Thermal Relaxation in CO_2 Extended to 300°C," J. Acoust. Soc. Am., 31, 248-249, 1959. AD-219 466.

The tube method has been used to extend measurements of sound absorption in CO_2 to 300°C. Results indicate that all of the vibrational specific heat in CO_2 relaxes with a single relaxation time, which, at 305°C was found to be 3.05×10^{-6} sec.

204

Shields, F. D., "Thermal Relaxation in Carbon Dioxide as a Function of Temperature," J. Acoust. Soc. Am., 29, 450-454, 1957.

Sound absorption and velocity have been measured in carbon dioxide between 0 and 200°C. The relaxation absorption was isolated by subtracting the tube and classical absorptions from the measured absorption. The Kirchhoff equations, which had been justified previously by measurements in A and N_2, were used to make these corrections. From the relaxation absorption were determined the temperature variation of the thermal relaxation time, the transition probability, and the collision efficiency. The results indicate that, for the frequencies and pressures here employed, the relaxation absorption and velocity effects are a function of f/p. This means that only binary collisions are effective in transferring energy between the vibrational and translational modes. The relaxation theory with a single relaxation time for all the vibrational modes adequately predicts the observed absorption and velocity. It is estimated that a separation in the relaxation times of the two lowest modes by a factor of more than two could not have gone undetected at 100°C. The temperature variation of the collision efficiency was adequately predicted by the Landau-Teller equation.

205

Smith, D. H., and H. J. Wintle, "The Propagation of Sound in Relaxing Gases in Tubes at Low Frequencies," J. Fluid Mech., 9, 29-38, 1960.

The frequency dependence of the velocity and the attenuation of sound waves in a gas which undergoes vibrational relaxation have been investigated theoretically. At low audible frequencies the attenuations due to viscosity, thermal conduction, and relaxation in the gas add linearly, while the velocity is the relaxation velocity diminished by the Helmholtz-Kirchhoff factor. The relations have been confirmed experimentally, and the free gas velocities of sound at zero frequency, one atm. pressure and 30°C, found for carbon dioxide, air and oxygen, are 270.57 ± 0.04 m/sec^{-1}, 349.18 ± 0.02 m/sec^{-1}, and 331.33 ± 0.03 m/sec^{-1}, respectively. The corresponding specific heats are $C_p/R = 4.537 \pm 0.008$ for carbon dioxide and $C_p/R = 3.547 \pm 0.003$ for oxygen.

206

Solov'ev, V. A., "Relaxation of Molecular Vibrational Levels," Soviet Phys. Acoust., English Transl., 7, 269-274, 1962.

The process of arriving at equilibrium in the energy distribution between the translational degrees of freedom and the intramolecular oscillations, with allowance for the excitation of higher levels, must be described by a large number of relaxation times. To compute them, it is necessary to introduce "normal coordinates," in which the system of equations for the excitation reaction breaks down into independent equations. If the probability of transitions between levels is of the same form as for dipole transitions accompanied by radiation, this problem can be solved. An exact equation is obtained for isothermal relaxation, along with a solution in the acoustical approximation for relaxation at variable temperature. The case in which there is also direct exchange of vibrational quanta between molecules is considered in the acoustical approximation. It is shown that in a sound wave of small amplitude only one normal coordinate is significant and has the sense of vibrational energy. The nature of the solution for other values of the transition probability is discussed.

207

Stewart, E. S., "Dispersion of the Velocity and Anomalous Absorption of Sound in Hydrogen," Phys. Rev., 69, 632-640, 1946.

The velocity and absorption of sound in hydrogen were measured at 25°C at 3.855 and 6.254 mcs and at pressures of 1.00, 0.83, 0.67 and 0.50 atm. Dispersion of the velocity from 1321.9 m/sec to 1382.0 m/sec and anomalous absorption observed are interpreted as caused by molecular absorption induced by loss of the rotational degrees of freedom. Calculations place the inflection point of the dispersion curve at 10.95 Mcs the peak of the absorption curve at 10.0 Mcs from velocity data, and at 16.1 and 14.8 Mcs, respectively, from absorption data. The relaxation times for pressures of 1 atm. from the two sets of data are 1.9 and 1.7×10^{-8} sec. The f/p law is not strictly obeyed.

208

Verma, G. S., "Effects of Humidity on Ultrasonic Absorption in Air at 1.46 Megacycles," J. Acoust. Soc. Am., 22, 861-862, 1950.

The absorption coefficient for moist air has been measured at 1.46 Mcs for relative humidities varying from zero to 84%. Maximum absorption at this frequency (α = 0.52 cm^{-1}) is found to occur at 46% relative humidity.

209

Wight, H. M., "Vibrational Relaxation in N_2O-H_2O and N_2O-D_2O Mixtures," J. Acoust. Soc. Am., 28, 459-461, 1956.

Ultrasonic absorption measurements were made to compare the relative effectiveness of H_2O and D_2O molecules in influencing thermal vibrational relaxation in N_2O molecules. The displacement rates of the absorption per wavelength maxima induced by H_2O and D_2O were compared in N_2O-H_2O and N_2O-D_2O mixtures. Experimental apparatus constructed for these measurements utilized the "direct" absorption technique in conjunction with pulsed sound waves having a frequency of approximately 113 kcs. The parameter of frequency/pressure was varied by changing the gas pressure. The data were taken at a temperature of 21°C in the f/p range of of 100-700 kcs per atm. The maximum amplitude of the molecular absorption coefficient per wavelength in dry N_2O was 0.153 and this occurred at 210 kcs per atmos. Measurements were taken in N_2O-H_2O and N_2O-D_2O mixtures at H_2O vapor and D_2O vapor concentrations of 0.39%, 0.77% and 1.14%. The usual single relaxation time theoretical absorption curve could be fitted to the data for dried N_2O. However, in the mixtures there was some evidence of two separate relaxation times, one possibly associated with N_2O-N_2O collisions and the other with N_2O-H_2O or N_2O-D_2O collisions. The maximum absorption coefficient in the mixtures was somewhat less than that observed in the dried N_2O. The H_2O molecules were 1.72 times more effective than the D_2O molecules in shifting the frequency associated with the absorption maximum.

210

Young, J. E., and O. K. Mawardi, "Molecular Absorption of Sound in Gases at High Temperatures," J. Chem. Phys., 24, 1109, 1956.

This paper presents results of measurements of molecular absorption due to the so-called molecular thermal relaxation processes; the measurements were carried out with dry air at 2000 cps and 600°-1200°K. The results fit a curve $\mu = CT^{\beta}$, where μ is the absorption reduced to an attenuation per (waveguide) wavelength.

211

Zmuda, A. J., "Dispersion of Velocity and Anomalous Absorption of Ultrasonics in Nitrogen," J. Acoust. Soc. Am., 23, 472-477, 1951.

By means of the interferometer, the velocity and absorption of ultrasonic waves in N were measured at the frequency of 2.992 Mcs in the pressure range of 2.09 to 76 cm of Hg at a temperature of 29°C. A dispersion of velocity was found ranging from 354.3 m/sec to 364.4 m/sec. The ratio $\alpha_{exp}/\alpha_{class}$ dropped from 1.40 to 1.32, and the corresponding value of C_v/R dropped from 2.50 to 2.08. Theoretical values for the change in velocity and in the absorption ratio, calculated by applying the equations for the exchange of energy between translational and vibrational degrees of freedom, show good agreement with the observed values. The increase in velocity and the decrease in $\alpha_{exp}/\alpha_{class}$ is interpreted as due to the slow exchange of energy between the translational and rotational degrees of freedom. The relaxation time for rotation was found to be 1.2×10^{-9} sec.

Absorption, Molecular — see also Attenuation, Atmospheric

See also — 16, 27, 32, 51, 54, 61, 82, 84, 86, 90, 94, 101, 107, 108, 111, 117, 124, 125, 126, 130, 131, 136, 141, 142, 144, 146, 147, 150, 151, 153, 212, 216, 224, 245, 246, 247, 248, 250, 255, 257, 270, 274, 276, 278, 281, 282, 303, 305, 327, 429, 430, 433, 437, 440, 445, 451, 452, 453, 455, 460, 461, 467, 471, 476, 479, 480, 481, 485, 486, 487, 542, 554, 590, 808, 809, 810, 821, 824, 839, 846, 847, 944, 1057, 1266, 2100, 2213, 3071, 3075, 3078, 3178, 3185, 3212, 3286, 3352, 3652, 4337, 4381

ABSORPTION, THEORY

212

Beyer, R. T., "Double Relaxation Effects," J. Acoust. Soc. Am., 29, 243-248, 1957.

Detailed consideration is given to several situations in which two relaxation processes contribute to the absorption of ultrasound. A general but rather involved expression is given for $\alpha\lambda$. From the particular cases examined, it appears that when the relaxation frequencies of the two processes are close together, a single experimental relaxational frequency will be observed, with ($\alpha\lambda$) maximum somewhat higher than the value obtained by combining the two separate peaks. The observed relaxation frequency will be approximately equal to the lower of the two individual relaxation frequencies.

213

Bhatia, A. B., "Sound and Ultrasound Absorption Resulting from Heat Radiation," J. Acoust. Soc. Am., 29, 823-824, 1957.

Following a suggestion by Markham, Beyer and Lindsay (Rev. Mod. Phys., 23, 353-411, 1951), the Stefan-Boltzmann radiation law is applied to estimate the attenuation of approximately plane compression waves resulting from heat radiation. The attenuation is found to be independent of the frequency of the compression waves in the entire relevant frequency range and inversely proportional to a linear dimension of the wave fronts. At ordinary temperatures, this attenuation is negligible compared to that due to thermal conduction and viscosity, verifying the results of Rocard and Rayleigh. In gases at temperatures of 1000°K or more, however, the attenuation due to heat radiation is not entirely negligible under certain conditions.

214

Bhatnagar, P. L., E. P. Gross, and M. Krook, "A Model for Collision Processes in Gases, I. Small Amplitude Processes in Charged and Neutral One-Component Systems," Phys. Rev., 94, 511-525, 1954.

A kinetic-theory approach to collision processes in ionized and neutral gases is presented. This approach is adequate for the unified treatment of the dynamic properties of gases over a continuous range of pressures from the Knudsen limit to the high-pressure limit where the aerodynamic equations are valid. It is also possible to satisfy the correct microscopic boundary conditions. The method consists in altering the collision terms in the Boltzmann equation. The modified collision terms are constructed so that each collision conserves particle number, momentum, and energy; other characteristics, such as persistence of velocities and angular dependence, may be included. The technique for a simple model involving the assumption of a collision time independent of velocity is illustrated; this model is applied to the study of small-amplitude oscillations of one-component ionized and neutral gases. The initial value problem for unbounded space is solved by performing a Fourier transformation on the space variables and a Laplace transformation on the time variable. The result for uncharged gases is the correct adiabatic limiting law for sound-wave propagation at high pressures; in addition, one obtains a theory of absorption and dispersion of sound for arbitrary pressures. For ionized gases the difference in the nature of the organization in the low-pressure plasma oscillations and in high-pressure sound-type oscillations is studied. Two important cases are distinguished. If the wavelengths of the oscillations are long, compared to either the Debye length or the mean free path, a small change in frequency is obtained as the collision frequency varies from zero to infinity. The accompanying absorption is small; it reaches its maximum value when the collision frequency equals the plasma frequency. The second case refers to waves shorter than both the Debye length and the mean free path; these waves are characterized by a very heavy absorption.

215

Bourgin, D. G., "Sound Absorption in Non-Reactive Gases," J. Acoust. Soc. Am., 5, 59, 1933.

The author discusses the conclusions reached by R. Lawlor—that the gas absorption in a mixture of nonreactive gases depends linearly upon the concentration—and decides that this result is untrue.

216

Bourgin, D. G., "Sound Absorption and Velocity in Mixtures of Gases," Phys. Rev., 50, 355-369, 1936.

The author has developed a theory of sound absorption in mixtures of gases in which are considered the effects on sound propagation of (a) collision excitation probabilities dependent on the internal energy specification of the impinging molecules, (b) transitions in both colliding members, (c) triple and higher order collisions, and (d) viscosity and conduction. A comparative study of the generalized Kneser-Ruttgers method and the writer's method of investigation reveals that the two are developments of the same physical theory and may be regarded as a thermodynamic and a kinetic theory transcript, respectively. Formulae are derived for the velocity and the absorption coefficient in convenient form for application.

217

Brandt, O., H. Freund, and E. Hiedemann, "Motion of Particles in a Sound Field," Z. Physik, 104, 511-533, 1937.

A theoretical and experimental study is made of the motion of particles in a sound field. The relation between the amplitudes of the particles and of a gas in which they are suspended is deduced; it appears that there is a limiting frequency, below which the particle or gas amplitudes are the same but above which the particle amplitude decreases and finally, for high frequencies, becomes zero. The radius of the particle and the frequency are so related that for similar values of the expression $a^2 v$ (a = amplitude, v = frequency), particles behave similarly. Photographs of the particle motion show good agreement with the above theoretical work. The fact that the gas and particle amplitude are different above the limiting frequency leads to calculable losses due to friction, and the absorption of sound passing through a dispersed system is calculated on this basis. The fact that above the limiting frequency particles having different radii also have different amplitudes leads to attractive forces between the particles. On this basis the coagulating effect of ultrasonic radiation is calculated. By observation of the light scattered from the particles, it is shown that the sound causes them to orient themselves in a manner depending upon their shape.

218

Clark, R. O., "A Study of Shock Wave Attenuation in Tunnels," Memo Rept. No. 1401, Ballistic Res. Labs., Aberdeen Proving Grounds, Md., 47 pp., 1962.
AD-278 595.

A theoretical investigation of shock wave expansion and viscous attenuation in a tunnel is described. In particular, relationships between the applied and transmitted shock pressure are presented for various entrance configurations and orientations. Shock tube data are given to verify the theory. Working equations and graphs are given to aid in the solution of other shock wave-tunnel problems, assuming a classical wave form for the shock wave and a constant tunnel cross-section.

219

Dean, E. A., "Absorption of Low Frequency Sound in a Homogeneous Atmosphere," Schellenger Res. Lab., Texas Western College, El Paso, 1959.

This is a review of the classical and molecular theory of the absorption of sound, with particular attention to the absorption of frequencies less than 1000 cps in the atmosphere from sea level to 50 km. The variation of the theoretically predicted absorption with the meteorological parameters—pressure, temperature, and humidity—is investigated. Recent work involving absorption due to radiation is included. It is found that the absorption can be expressed as:

$$\frac{2.5 \times 10^{-7}(T^*)^{0.3} f^2}{P^*} + \frac{5.3 \times 10^{-5}(T^*)\, f}{P^*} + \frac{1.0 \times 10^2 f}{(T^*)^{2.5} e^{8.3/T^*}} \; \frac{2 f_0 f}{f_0^2 + f^2}$$

db/mile, where

$$f_0 = \frac{P^*}{(T^*)^{0.8}} \left[900 \left(\frac{wT^*}{P^*}\right)^2 + 500\,\frac{wT^*}{P^*} + 50\right]$$

$T^* = T/273$, $T = {}^{\circ}K$, P^* = pressure in atmospheres, and w is the absolute humidity in gm/m^3.

The absorption has been calculated for various altitudes, humidities, and frequencies. These data are presented in tabular form in the appendix. Although the absorption varies in a rather complicated manner with the meteorological parameters, it is found to be quite small for the very low frequencies, resulting in a predicted long distance propagation with small attenuation if the geometry of propagation is advantageous.

220

Dean, E. A., "Absorption of Sound in the Atmosphere," Proc. Symp. Atmos. Acoust. Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. M., 1, 50-56, 1961.
AD-408 716.

The classical and molecular theories of the absorption of sound for low f/p ratios are reviewed. The absorption is discussed as a function of frequency and atmospheric pressure, temperature, and composition, including recent work on the determination of the vibrational relaxation time due to small amounts of water vapor. The possible importance of absorption due to radiation is mentioned.

221

deGroot, S. R., "Acoustic Relaxation in Gases" (in Dutch), Ned, Tijdschr. Natuurk., 1, 1-13, 1950.

Mathematical theory shows that changes in intramolecular vibrational energy are the main cause of the variation with frequency of the velocity and absorption of hf sound waves in gases. The exact definition of "relaxation time" is still uncertain and the explanation of the influence on it of impurities in the gas, etc., is obscure.

222

Dutta, A. K., "Molecular Motion in Fluids and Internal Dispersion and Absorption of Elastic and Optical Waves," Sci. Cult. (Calcutta), 16, 576-579, 1951.

Elastic waves have been treated on the same lines as optical waves, on the basis of molecular motion. By starting with the relation, $d\rho/\rho = Kdp/p$, where $K = p/\rho V^2$ is the dielastic constant, corresponding to the dielectric constant in the optical case, and by taking the equation of motion for an ideal fluid, with due considerations for the forces of friction and restitution, relations have been obtained for the polarization pressure P and the dielastic constant K. They come out in the form $P = NmR(\gamma - 1)(1 + \alpha)\omega^2\xi$ and $K = 1 - R(1 + \alpha)(\gamma - 1)[(1 + \alpha)\{1 + R(\gamma - 1)\} - f - ig\omega]^{-1}$ where N = number of molecules per cm^2, m = mass of molecule, γ = ratio of sp ht in any gaseous state, R = ratio of densities of the state under consideration to the gaseous state with the particular value of γ, α = excitation constant, ω = wave frequency $\times 2\pi$, ξ = displacement due to pressure variation, f and g = coefficients of restitution and friction, acting on a molecule. The relations explain all the characteristics of supersonic absorption and also an internal dispersion indicated by the author. The effect of molecular motion on optical waves has also been stressed.

223

Epstein, P. S., and R. R. Carhart, "The Absorption of Sound in Suspensions and Emulsions, I. Water Fog in Air," J. Acoust. Soc. Am., 25, 553-565, 1953.

The suspended particles are approximated by spheres, and the diffraction problem for a fluid sphere in a fluid medium is solved, taking into consideration viscosity and thermal conduction. The results are discussed numerically for water droplets in air, and a satisfactory agreement with Knudsen's attenuation measurements in water fog is found.

224

Ginsburg, V. L., "Concerning the General Relationship Between Absorption and Dispersion of Sound Waves," Soviet Phys. Acoust., English transl., 1957, 1, 32-41.

This same topic is discussed first in application to the propagation of electromagnetic waves and results known previously are obtained. Next analogous formulas connecting velocity and sound absorption coefficient are derived. Lastly the peculiarities distinguishing the acoustic case from the electromagnetic are discussed.

225

Givens, M. P., W. L. Nyborg, and H. K. Schilling, "Theory of the Propagation of Sound in Scattering and Absorbing Media," J. Acoust. Soc. Am., 18, 284-295, 1946.

The theory predicts that curves of physical transmission loss against distance should be convex upward if the sound is detected by means of a directional microphone directed toward the source, and concave upward if perpendicular to a line from the source. The theory also predicts the directionality of sound in the medium and is applied to transmission through forests and through open air containing inhomogeneities.

226

Herman, R., and R. J. Rubin, "Model for Vibrational Relaxation of Diatomic Gases Behind Shock Waves," Phys. Fluids, 2, 547-550, 1959.

The problem of the vibrational relaxation of a system of harmonic oscillators is examined for the case in which the oscillators are in contact with a heat bath whose total heat capacity is finite and whose temperature therefore varies during the relaxation process. An analysis is carried out for processes in which the initial distribution of vibrational energy is a Boltzmann distribution. Application is made to the vibrational relaxation of a diatomic gas behind a shock wave.

227

Hoff, L., "Volume Viscosity and Compressibilities from Acoustic Phenomena," J. Acoust. Soc. Am., 23, 12-15, 1951.

A phenomenological theory of volume viscoelasticity is formulated, resulting in an equation recently used by Hall. Application of this equation to the dispersion and absorption of sound in fluids is extended to the whole range of frequencies. Results of calculations of the volume viscosity and the instantaneous and relaxational compressibilities for gases and liquids from certain available absorption data are given. The bearing of this theory on the classical theory of hydrodynamics is pointed out.

228

Horiuchi, I., "Absorption of Sound in Air at Very Low Densities," Tech. Rept. No. 11, Columbia Univ., New York, 1958. AD-201 133

The "super-Burnett" approximation to the Boltzmann collisional equation has been applied to the evaluation of the absorption of sound in air at low densities. The solutions which were obtained on the REAC analogue computer yield magnitudes somewhat smaller than were obtained by successive approximation methods. A maximum absorption per wavelength of $\mu = 1.45$ was obtained for diatomic molecules. Comparison of the translational absorption with that due to rotational and vibrational degrees of freedom shows that it becomes predominant at ratios of frequency to pressure exceeding 100 Mc/atm.

229

Hunt, F. V., "Notes on the Exact Equations Governing the Propagation of Sound in Fluids," J. Acoust. Soc. Am., 27, 1019-1039, 1955.

The assumption underlying the exact equations of motion for thermoviscous fluid are reviewed, and the complete equations are given, for reference convenience, in both tensor and vector form. The first- and second-order acoustic equations are then exhibited and used to obtain the source terms that account for the generation of vorticity and streaming. In order to preserve a broad base from which to make the approximations appropriate under various circumstances, all terms are retained explicitly, including those arising from any functional dependence of the viscosity and thermal coefficients on the state variables. The distinction between spatial and material coordinate systems is carefully drawn and conversion transforms are derived rigorously and their use illustrated. The general properties of finite-amplitude waves are demonstrated by including the second-order terms in a plane-wave solution of the exact wave equation in material coordinates, with special concern for the effects of large amplitude on speed of propagation and on wave-form distortion. Sound absorption and dispersion measures for a viscous conducting fluid are analyzed in terms of Truesdell's recent exact solution of the first-order secular equation. These differ characteristically from the corresponding measures predicted for pure relaxation in a two-fluid mixture. It is concluded that a complete and adequate theory of sound absorption and dispersion will need to take into account both relaxation and viscothermal phenomena as well as their interaction, and that until such a general theory is available, the exact theory of viscothermal effects — rather than the crude linear approximation commonly, but inappropriately, called "classical" — should be used in computing the "excess" absorption and dispersion to be accounted for by relaxation processes. The exact solutions of the secular equation permit a new evaluation, in series form, of the characteristic acoustic impedance for a thermoviscous medium. The notes conclude with a revised account of the spectral character of thermal noise in the acoustic medium based on the quantum hypothesis and a merger of the concepts of architectural acoustics and specific-heat theory.

230

Ingard, U., and D. Pridmore-Brown, "Propagation of Sound in a Duct with Constrictions," J. Acoust. Soc. Am., 23, 689-694, 1951.

The transmission of sound through a duct periodically loaded with constrictions (iris partitions) is studied. The attenuation is given as a function of frequency in such ducts with both hard and absorptive side walls. For a hard-walled duct, the results of the analysis are presented in chart form. It is shown that by proper choice of side wall absorption and iris partitions a broad attenuation band can be obtained. Measured values of the attenuation are found to agree well with the theory.

231

Ivanoskii, A. I., "The Connection of Acoustic Streaming with Absorption," Soviet Phys. Acoust., English Transl., 142-152, 1958.

A theoretical paper examining the hydrodynamics of the problem and putting forward a method of deriving the equations for a "Stokes-Navier" medium. The equations obtained show that the occurrence of streaming is associated with the total absorption coefficient and that the frequency dependence of streaming velocity is completely determined by the frequency variation of this coefficient.

232

Kanwal, R. P., "Absorption and Dispersion of Forced Spherical and Cylindrical Sound Waves According to the Navier-Stokes Equations," J. Acoust. Soc. Am., 29, 593-595, 1957.
AD-147 806.

In his classical paper on infinitesimal sound waves in perfect gases endowed with shear viscosity, bulk viscosity, and heat conduction, Kirchhoff considered not only plane waves but also a certain class of curves waves. He showed that the absorption and dispersion of these waves is determined by the solution of a biquadratic equation for the complex frequencies; but, in discussing the behavior of particular waves, he employed only one of the two pairs of roots, and this he linearized with respect to the driving frequency. The biquadratic itself, as extended by Langevin to hold for fluids obeying an arbitrary equation of state, has been solved exactly and generally by C. A. Truesdell (1953). In his comprehensive analysis and interpretation of the solutions, however, Truesdell considered only forced plane waves. The present article gives a new version of Kirchhoff's approach to curved waves of expansion (an arbitrary motion may be regarded as the vector sum of an isochoric irrotational motion, a set of vorticity waves, and a set of expansion waves. Vorticity waves are not considered. As has been remarked in varying degrees of generality by M. Lessen (1954); Lagerstrom, Cole and Trilling (1949); S. Jarvis, Jr. (1954); and U. Yao-Tsu Wu (1956), the propagation of linearized vorticity is independent of bulk viscosity and heat conduction, and it is shown how Truesdell's results on plane waves may be adjusted to apply to the class of curved waves considered. Spherical and cylindrical waves are analyzed in some detail. Proper treatment of this problem requires dimensionless variables and hence some reference standard of length. Two alternatives are considered: (1) the unit of length is a linear dimension of a given oscillator; (2) the unit of length is the wavelength corresponding to the driving frequency according to the theory of nondissipative fluids. In the brief remarks of Kirchhoff, apparently only the first possibility was noticed. For the second class of spherical waves, the absorption coefficient per cm is shown always to be much less than that for the first class. There is a frequency-dependent factor which tends to increase the amplitude with the frequency. Similar analysis is carried out for cylindrical waves, which are shown to behave in a fashion intermediate between plane and spherical waves.

233

Kanwal, R. P., "Absorption of Sound Waves in a Uniform Stream," MRC Tech. Summary Rept. No. 25, Math. Res. Ctr., Univ. of Wisconsin, Madison., 7 pp., 1958.
AD-161818.

The absorption of sound waves in a stream moving with a uniform velocity is discussed. Both the vorticity waves and expansion waves are considered. The propagation of linearized vorticity waves is independent of bulk viscosity and heat conduction; therefore, Lin's analysis (On Periodically Oscillating Wakes in the Oseen Approximation, Studies in Mathematical Mechanics, presented to Richard von Mises, 1954, Academic Press, Inc., N. Y.) for the vorticity waves in an incompressible perfect fluid for cylindrical waves is shown to describe the absorption of these waves in the general class of fluids considered. These results are then extended to three-dimensional flows. With respect to the expansion waves it is shown that the absorption and dispersion of these waves is governed by Langevin's generalization of Kirchhoff's biquadratic equation.

234

Kaspar'iants, A. A., "The Problem of Sound Wave Propagation in 'Van Der Waals' Gases and Liquids," Soviet Phys. Acoust., English Transl., 4, 336-343, 1959.

It is assumed that the medium in which sound waves are propagated obeys van der Waals' equation of state. Navier-Stokes' linear equations are applied to such a medium. The velocity of sound and the absorption coefficient are derived in a form convenient for further calculations. The differential equations of acoustic wave propagation may be used to find the spatial distribution of the acoustic field, allowing for the viscosity and thermal conductivity of the medium.

235

Kleiman, Ia. Z., "Damping of Harmonic Waves in Mixtures," Soviet Phys. Acoust., English Transl., 4, 377-380, 1959.

The author discusses attenuation of plane harmonic waves in a two-component medium (gas or liquid). The attenuation is taken to be due only to friction caused by the difference in velocities of particles of the two components; viscosities of both components taken singly are neglected.

236

Kneser, H. O., "Absorption of Sound in Gases," Z. Tech. Phys., 16, 213-219, 1935.

This article reviews work on the absorption of sound in gases from the time of Kirchhoff up to the present. The failure of Kirchhoff's formula is due to the fact that the time required to establish thermal equilibrium is not small compared with frequency of the sound wave. Recent measurements in air, O_2, and CO_2 agree with the theory of molecular absorption. The effect of foreign gases is discussed. A table of calculated values of the absorption coefficient in air is given for different temperatures and concentrations of impurity.

237

Kneser, H. O., "Compression- and Shear-Viscosity in Gases" (in German), Ann. Physik, 6, 253-256, 1949.

Not all the energy used in compressing a fluid is available on reexpansion. The energy absorbed may be expressed in terms of the compression viscosity ζ, the relation being similar to that between the shear-viscosity η and the energy used in shear deformation. In Stokes's theory of sound absorption the compression viscosity is neglected; its value can therefore be estimated from discrepancies between experimental observations and Stokes's theory. Available data on sound-absorption in He, Ar, H_2 and N_2 is examined from this point of view. It is found that for the monatomic gases $\zeta = 0$; for N_2 ζ is of the same order as η, while for H_2 ζ approx. = 60 η at low frequencies, decreasing rapidly with increasing frequency. These results are in general agreement with predictions from kinetic theory.

238

Kneser, H. O., "General Theory of Absorption of Sound in Gases and Liquids" (in German), Nuovo Cimento, 7, 231-235, 1950.

The absorption of sound in liquids and gases as measured experimentally is in most cases much larger than expected from the classical theory, based on the thermal conductivity and viscosity of the material. Here a theory of sound absorption is based on plausible, generally accepted assumptions regarding the process of relaxation, and it leads to a general absorption formula.

239

Kneser, H. O., "The Interpretation of the Anomalous Sound-Absorption in Air and Oxygen in Terms of Molecular Collisions," J. Acoust. Soc. Am., 5, 122-126, 1933.

The anomalous sound absorption in moist air discovered by V. O. Knudsen cannot be explained on the basis of the classical theory of Rayleigh, Kirchhoff and Stokes. Further facts and theories are presented.

240

Kneser, H. O., "Sound Absorption in Multiatomic Gases," Ann. Physik, 16, 337-349, 1933.

The factors in classical mechanics responsible for sound absorption, namely friction and heat conduction, are insufficient to explain absorption; a theory is stated, based on the finite period of adjustment of thermal equilibrium. The experimental facts of absorption can, to some extent, be explained quantitatively. The agreement of the theoretical absorption with that measured by different investigators is tested in the cases of CO_2, N_2O, SO_2, O_2, and air.

241

Knudsen, J. R., "The Effects of Viscosity and Heat Conductivity on the Transmission of Plane Sound Pulses," J. Acoust. Soc. Am., 26, 51-57, 1954.

The dissipative effects of viscosity and heat conductivity are studied here in connection with the flow of a compressible fluid in a parallel channel or tube. Two kinds of waves or pulses are considered, and the distortion from the customary square wave is calculated. One observer at a fixed point on the channel, and two travelling with the wave, are seen to give information on the order of decay or dissipation of the wave with increasing time.

242

Kohler, M., "Sound Absorption in Binary Gas Mixtures" (in German), Z. Physik, 127, 41-48, 1950.

Extension of the author's theory of sound absorption in binary mixtures of monatomic gases by Meixner (Ann. Physik, 43, 470, 1943) is discussed with special reference to large ratios of molecular mass and diameter. Numerical calculations based on experimentally-found constants are given for 50% A-He and 50% A-H_2 mixtures, and it is shown that the absorption of the mixture > absorption of pure gas.

243

Kohler, M., "Sound Absorption in Mixtures of Monatomic Gases" (in German), Ann. Physik, 39, 209-225, 1941.

The influence of ordinary diffusion and thermal diffusion on sound absorption in monatomic gases is examined by the use of the Enskog equations. On the basis of the kinetic gas theory, the equations of motion are derived for the monatomic gas mixture. Nine independent equations are obtained for the 9 unknowns u_1, v_1, w_1, u_2, v_2, w_2; ρ_1 and ρ_2; and T. The propagation of density waves of infinitely small amplitude is considered. The three new terms due to diffusion depend on frequency and pressure, as do the Kirchhoff terms arising from friction and heat conduction, and they are fully discussed. The first term is due to the effect of ordinary diffusion and is proportional to the diffusion coefficient D_{12}, to $(M_2 - M_1)^2/M_0^2$ (M = mol. wt.), to the ratio c_p/c_v of the sp. hts. and to the product c_1c_2 of the mol. concentrations. The second is due to thermal diffusion and is proportional to $(c_p/c_v) -1$, to c_1c_2, to $(M_2 - M_1)/M_0$ and to a coefficient v_{12} which determines the thermal diffusion. The third is occasioned by the increased heat conduction due to thermal diffusion. The possibility of determining thermal-diffusion coefficients from measurements of sound absorption in gas mixtures is mentioned.

244

Lawlor, R., "Sound Absorption in Non-Reactive Gas Mixtures," J. Acoust. Soc. Am., 4, 284-287, 1932.

Abello's results for binary gas mixtures may be derived simply if it is assumed that the gases mixed are nonreactive. It is found that if any number of nonreactive gases are mixed, the attenuation constant of the mixture is a linear homogeneous function of the volume percentages of the components. Values of the absorption coefficients of CO_2, N_2O, H_2, He, A, and N_2 at 612 kc are calculated.

245

Linsay, R. B., "Transmission of Sound Through Air at Low Pressure," Am. J. Phys., 16, 371-377, 1948.

The problem is treated in terms of relaxation dissipation. Consideration is given to (1) wave propagation with relaxation dissipation; (2) viscosity and heat-conduction dissipation; (3) classical approximation for very high frequency. Experiments are described in which transmission loss is measured in a low-pressure tank, at 384-6950 cps. Over the pressure (atmospheric to 5 mm of Hg) and frequency ranges employed, the absorption due to viscosity and heat conduction is negligible (in agreement with the theory). The pressure tank measurements indicate increasing impedance mismatch (transmitter-medium-receiver) with decreasing pressure.

246

Markham, J. J., R. T. Beyer, and R. B. Lindsay, "Absorption of Sound in Fluids," Rev. Mod. Phys., 23, 353-411, 1951.

A complete review of the basic concepts including the old and more modern theories. The paper forms an excellent introduction to the subject and gives an exhaustive list of references.

247

Meixner, J., "Absorption and Dispersion of Sound in Gases with Chemically Reacting and Excitable Components, I." (in German), Ann. Physik, 5, 43, 470-478, 1943.

The absorption and dispersion of sound in ideal gases of any composition is mathematically investigated; the component gases may consist of chemically reacting or excited molecules. The irreversible processes of internal friction, heat conduction, diffusion, chemical reaction, and excitation each contribute to the absorption and dispersion. The contributions are not simply additive, however, but are inter-related. The relation between sound absorption and local entropy and energy dissipation is investigated for the case of high frequency and low transformation velocity.

248

Meixner, J., "General Theory of Sound Absorption in Gases and Liquids, Taking into Account Transport Phenomena" (in German), Acustica, 2, 101-109, 1952.

The author computes the complex velocity of sound—and hence the absorption and the dispersion of sound—for an arbitrary fluid medium in which internal transformations take place, including the contribution of transport phenomena (conduction of heat, diffusion, thermodiffusion, and fluid friction). Applying the thermodynamical theory of irreversible processes permits the derivation of general results without undertaking to exemplify the special nature of the internal transformations. Apart from the relaxation time, all of the quantities determining the complex velocity of sound are thermodynamical ones. One can find them for a special problem from an appropriate model by using the methods of statistical mechanics. With good approximation sound absorption due to transport phenomena may be added to that due to internal transformation in the whole frequency range. With respect to sound absorption by internal transformation only, there are eight diverse, but equivalent, equations from which all known results can be derived in a simple way.

249

Nomoto, O., "Phenomenological Theory of the Molecular Absorption and Dispersion of Sound in Fluids and the Relation Between the Relaxation Time of the Internal Energy and the Relaxation Time of the Internal Specific Heat," J. Phys. Soc. Japan, 12, 85-99, 1957.

Molecular absorption and dispersion formulae applicable to both liquids and gases have been derived in a phenomenological manner. It is pointed out that the relaxation time of the molecular internal energy γ must be distinguished from the relaxation time of the internal specific heat β, and the relation between these two quantities is discussed in detail. The relaxation time γ has the advantage of making the dispersion formula simpler and directly comparable with the dispersion formulae in other cases, such as the relaxation of shear viscosity. The relaxation time β on the other hand, is more closely related to the collision excitation probability of the molecules than γ.

250

Oswatitsch, K., "The Dispersion and Absorption of Sound in Clouds," Physik Z., 42, 365-378, 1941.

A theoretical investigation of the effect on the propagation of sound of the condensation or evaporation of water drops suspended in the atmosphere. At sufficiently low sound frequencies, condensation or evaporation of water vapour in clouds or fog can occur in appreciable quantity, leading to absorption and dispersion phenomena. Whereas in clouds the dispersion region is always below the range of human audibility, in clouds laden with small drops of water the absorption region extends into the range of the deep audible tones in agreement with the known strong absorption of thunder.

251

Polyakova, A. L., "On Absorption of Finite-Amplitude Sound (Waves) in a Relaxing Medium" (in Russian), Dokl. Akad. Nauk SSSR, 122, 51-53, 1958.

An acoustic wave of finite amplitude, originally sinusoidal, becomes saw-tooth in form as it propagates through a real medium. Such a saw-tooth wave is absorbed more strongly than a wave of infinitely small amplitude. The present paper deals theoretically with absorption of acoustic waves of finite amplitude in a medium in which the energy of the progressive motion of molecules is transferred to their internal degrees of freedom. Such a process produces relaxation and consequently absorption of those acoustic frequencies which are close to the relaxation frequency.

252

Polyakova, A. L., "Thermodynamic Theory of the Absorption of Finite-Amplitude Sound in Relaxing Media," Soviet Phys. Acoust., English Transl., 5, 85-90, 1959.

Propagation of sound of finite amplitude is considered by using thermodynamics of irreversible processes. It is assumed that two states are possible in the medium in which sound is propagated; transition between these two states occurs under the action of sound (relaxation). Such transitions are due to transfer of translational energy of molecules to internal processes (for example, vibrational or rotational decrease of freedom, chemical reactions, etc.). An expression is obtained for energy dissipated in such processes. It is shown that finite-amplitude sound is absorbed more strongly than sound of infinitely small amplitude. The absorption maximum is found to be displaced towards frequencies lower than the relaxation frequency.

253

Rocard, Y., "Absorption of Sound in Gases," Rev. Acoust., 3, 47-62, 1934.

This is a mathematical paper in which the magnitudes and frequency variations of the effects of thermal conduction, viscosity, diffusion in gas mixtures, and the transfer of molecular vibrational energy on the absorption of sound in a gas are considered and compared.

254

Rocard, Y., "Damping of Sound Waves," J. Phys. Radium, 1, 426-437, 1930.

This article discusses the damping of sonorous or ultra-sonorous waves in a homogeneous gaseous medium. It reviews the work of Stokes, Rayleigh, and Chapman on the modifications to be introduced into the fundamental hydrodynamical equations in order to allow for viscosity, the influence of the radiation of heat, and the thermal conductivity of air. It considers the damping due to the reciprocal diffusion in air of its constituent elements. By this the condition of adiabatism is altered, and a new adiabatic equation is deduced. This new equation has a form $PV^{\gamma+i\beta\gamma}$ = const., where the imaginary, i, indicates a displacement of phase between the variations of pressure and volume for the particular frequency used in determining the value of $\Delta\omega$. The value of $\Delta\gamma$ once obtained, it is easy to calculate the amount of damping due to this cause. The same method is used in a revision of the previous work of Stokes, Rayleigh, and Chapman. The relative importance of the different causes of damping is discussed.

255

Rudnick, I., "On the Attenuation of a Repeated Sawtooth Shock Wave," J. Acoust. Soc. Am., 25, 1012-1013, 1953.

A formula which describes the space rate of change of amplitude of a repeated finite amplitude sawtooth wave is derived by applying the Rankine-Hugoniot shock relations. Experimental evidence agrees on the form of the amplitude change but gives lower rates of change than indicated by the formula.

256

Rudnick, I., "Theory of the Attenuation of Very High Amplitude Sound Waves," Tech. Rept. 1, Soundrive Engine Co., Los Angeles, Calif., 21 pp., 1952.
AD-21 268.

The propagation of continuous plane progressive sound waves with pressure variations of the order of one-tenth the average pressure is discussed. Shocks are shown to develop at the leading front of each wave after several wavelengths of propagation regardless of the initial wave form. The attenuation of the repeated shocks was derived from shock wave theory with the assumption that the resulting stable wave form is sawtooth in character. In writing $p_2/p_1 = 1 + \delta$, where $p_1 - p_2$ is the pressure discontinuity at the shock, it is shown that

$$\frac{1}{\delta} - \frac{1}{\delta_0} = \frac{\gamma + 1}{2\gamma} \cdot \frac{X - X_0}{\lambda}$$

where δ_0 is the value of δ at the distance X_0, γ is the ratio of specific heats, and λ is the wavelength of the sound. The result was compatible with previously published studies of the attenuation of single N-shaped waves. Fay's solution (J. Acoust. Soc. Am., 2, 222, 1931) of the hydrodynamic equations, including the effects of viscosity, which shows the stable waveform to be a sawtooth, may be extended to yield the derived attenuation rate.

257

Saxton, H. L., "Mechanical and Electrical Analogies of the Acoustical Path," J. Acoust. Soc. Am., 10, 318-323, 1938-1939.

The infinite acoustical path is treated as a smooth mechanical transmission line, using Firestone's method of drawing schematic diagrams. The method is adopted of translating thermodynamical, hydrodynamical, and collision processes into purely mechanical terms by solving for the circuit elements from their definitions. When representative T sections have been obtained for paths having successive single causes of sound absorption, these are compounded into a T section for the case where all these causes of absorption are present. The electrical analogy follows at once from the mechanical. Input mobilities and complex velocities for the several cases are derived.

258

Skudrzyk, E., "The Theory of Internal Friction in Gases and Liquids, and Sound Absorption" (in German), Acta Phys. Austriaca, 2, 148-181, 1948.

The theories of sound attenuation due to viscosity and heat conduction, developed by Stokes and Kirchhoff, are inadequate to explain the experimental observations. Introducing the Boltzmann fundamental equation for gas theory, equations are derived for wave propagation in a viscous medium, the phase velocity and damping being derived from the complex sound velocity at a wide range of frequencies. Tables compare the "classical" values of sound absorption in various gases and in liquids with the "corrected" values.

259

Smith, D. H., and H. J. Wintle, "The Propagation of Sound in Relaxing Gases in Tubes at Low Frequencies," J. Fluid Mech., 9, 29-38, 1960.

The frequency dependence of the velocity and the attenuation of sound waves in a gas which undergoes vibrational relaxation have been investigated theoretically. At low audible frequencies the attenuations due to viscosity, thermal conduction, and relaxation in the gas add linearly, while the velocity is the relaxation velocity diminished by the Helmholtz-Kirchhoff factor. The relations have been confirmed experimentally, and the free gas velocities of sound at zero frequency, one atm. pressure and 30°C, found for carbon dioxide, air and oxygen, are 270.57 ± 0.04 m/sec^{-1}, 349.18 ± 0.02 m/sec^{-1}, and 331.33 ± 0.03 m/sec^{-1}, respectively. The corresponding specific heats are $C_p/R = 4.537 \pm 0.008$ for carbon dioxide and $C_p/R = 3.547 \pm 0.003$ for oxygen.

260

Smith, P. W., Jr., "Effect of Heat Radiation on Sound Propagation in Gases," J. Acoust. Soc. Am., 29, 693-698, 1957.

The effect is reexamined after considerable modification of the classical analysis. Account is taken of the fact that a gas radiates energy of a given electromagnetic wavelength in proportion to its corresponding coefficient of absorption, which is a strongly varying function of wavelength with a number of isolated peaks. No restriction is placed upon the value of the electromagnetic absorption per acoustic wavelength. The results indicate that the acoustic attenuation, which generally increases with decreasing frequency, will show a plateau of very flat peak near those frequencies at which one of the peaks of electromagnetic absorption reaches a value of 4π nepers per acoustic wavelength. An upper bound for the effect shows that dispersion attenuation will be negligible at all frequencies for gases at atmospheric pressure and room temperature, but may become significant in rarified gases or at elevated temperatures.

261

Stupochenko, E. V., and I. P. Stakhanov, "On the Theory of Non-Stationary Discontinuities in Relaxing Media" (in Russian), Dokl. Akad. Nauk SSSR, 117, 65-67, 1957.

The decay of shock waves in relaxing media is studied in detail. The solution to the hydrodynamical equations supplemented by equations of the relaxation processes is given for the case of small perturbations. Initial conditions are imposed on the disturbance u(x, t) (corresponding, for example, to the instantaneous change of velocity of a piston in a cylindrical pipe containing a yielding medium), and the solution for u(x, t) is expressed first in the form of an integral. The paths of integration are discussed in detail. The final solution shows how the disturbance decays exponentially with distance.

262

Tabuchi, D., "Dispersion and Absorption of Sound in Gases in General Chemical Equilibrium," Mem. Res. Inst. Acoust. Sci., Osaka Univ., Japan, 2, 50-60, 1951.

Gases are considered theoretically which are in general chemical equilibrium, dissociation being included as a special case. It is assumed that the gas is ideal, the absorption of sound due to viscosity, thermal conduction and radiation is negligible, and that the transition between the translational and internal energies of the molecules occurs at infinite speed; that is, the specific heat of the gas is not dependent on the sound frequency. Equations are deduced for the velocity of sound and the absorption coefficient of the gas, and then the complex sound velocity is deduced from the acoustic characteristic equation. The theoretical values obtained by Einstein and Luck for dissociating gases are found in good agreement with those deduced in this paper.

263

Tisza, L., "Supersonic Absorption and Stokes' Viscosity Relation," Phys. Rev., 61, 531-536, 1942.

The reduction of the two viscosity coefficients to one according to Stokes' relation, $2\mu + 3\lambda = 0$, is not justified except for a monatomic gas. The generalization by reintroduction of the second independent viscosity coefficient, $k = 2/3\mu + \lambda$, makes it possible to develop the phenomenological theory of the absorption and dispersion of sound, in agreement with experiment completely analogous to the corresponding optical phenomena. The connection of the relaxation theory with classical hydrodynamics can be established and, in the case of polyatomic gases, k is expressed by the characteristic constant of this theory. The case of liquids is discussed. In polyatomic gases and liquids generally $k >> \mu$. Other hydrodynamical consequences of the introduction of k are discussed.

264

Wei, Y. T., "Theory of Attenuation of Sound in Foggy Air Due to Evaporation and Condensation Processes," Acta Sci. Sinica, 2, 245-268, 1953.

After reviewing previous work on the subject, the author gives a mathematical treatment of a modified procedure. As sound waves traverse clouds or foggy air, the temperature change, which accompanies the pressure variation, causes the water molecules at the surface of a drop to evaporate and those on the surrounding vapor to condense, depending on whether there is condensation or rarefaction in the sound wave. In general, the pressure waves propagate ahead of the density waves since a finite time is required for this evaporation or condensation process to take place. At very high frequencies, however, the pressure varies too fast for this process to occur. Only at very low frequencies are the terms "relaxation-time," dispersion, and absorption significant.

265

Zhumartbaev, M., "Absorption of Sound and the Width of Shock Waves in Relativistic Hydrodynamics," Soviet Phys. JETP, English transl., 37(10), 711-713, 1960.

The absorption coefficient of sound due to viscosity and heat conduction of the medium is derived in relativistic hydrodynamics. The structure of relativistic low-intensity shock waves is considered.

Absorption, Theory
See also—6, 7, 13, 24, 30, 31, 36, 41, 47,52, 54, 59, 60, 62, 64, 86, 90, 92, 96, 100, 101, 140, 161, 171, 182, 183, 187, 190, 195, 202, 206, 269, 283, 296, 322, 430, 445, 463, 471,476,,477, 478, 480, 542, 554, 558, 559, 782, 813, 846, 850, 904, 907, 943, 944, 950, 955, 993, 1018, 3071, 3078, 3091, 3118, 3196, 3205, 3212, 3352, 3550, 3553, 3624, 3634, 3652, 3667, 3711, 4327, 4337, 4381

ABSORPTION, ULTRASONIC

266

Abello, T. P., "Absorption of Ultrasonic Waves by Various Gases," Phys. Rev., 31, 1083-1091, 1928.

Measurements of the absorption coefficient of ultrasonic waves of a 612-km frequency have been made for CO_2, N_2, H_2 and He. The increase in the absorption coefficient (cm^{-1}) at 612 kc, when air was replaced by a mixture containing 1% by volume of the gas, was found to be 0.029 for CO_2; 0.034 for NO_2; 0.014 for H_2; and 0.0025 for He. For argon mixtures no absorption was observed. The fractional part of the beam transmitted by thin celluloid films at the end of the absorption tube increased with increase in percentage of CO_2 and NO_2, but decreased with increase in percentage of H_2 and He, agreeing qualitatively with Rayleigh's theory.

267

Bell, J. F. W., "A Fixed Path Ultrasonic Interferrometer for Absorption Measurements on Gases," J. Acoust. Soc. Am., 25, 96-100, 1963.

A fixed path interferometer, using variable temperature for the measurement of the absorption in gases in the low f/p region, is described. Its use is illustrated by measurements on argon, neon, air, nitrogen, and nitrogen-hydrogen mixtures at 250 kc. The values found for argon and neon were above classical by 40% and 65%, respectively. The discrepancies are ascribed to Rayleigh cross modes in the ultrasonic waves excited by the quartz crystal transducer rather than to any departure from classical theory. Cross modes and their influence on ultrasonic measurements are discussed. Data on the performance of two crystals at 250 and 500 kc are given.

268

Beyer, R. T., "Double Relaxation Effects," J. Acoust. Soc. Am., 29, 243-248, 1957.

Detailed consideration is given to several situations in which two relaxation processes contribute to the absorption of ultrasound. A general but rather involved expression is given for $\alpha\lambda$. From the particular cases examined, it appears that when the relaxation frequencies of the two processes are close together, a single experimental relaxational frequency will be observed, with $(\alpha\lambda)$ maximum somewhat higher than the value obtained by combining the two separate peaks. The observed relaxation frequency will be approximately equal to the lower of the two individual relaxation frequencies.

269

Bommel, H., "The Measurement of the Velocity and Absorption of Ultrasonics by an Optical Method," Helv. Phys. Acta, 18, 3-20, 1945.

The measurement of the velocity of ultrasonics in gases becomes more complex as the frequency increases on account of the interaction between source and receiver and other effects. In the optical method described, the Hg 4358Å line is passed through gas subjected to the action of the ultrasonics, and the diffraction pattern brought to a focus on a photographic plate by a concave mirror. The velocity V is obtained from the separation of the diffraction maxima. A range of 951-4755 kc is covered. A method is worked out theoretically whereby the absorption can be obtained from the separation of the diffraction maxima.

270

Brandt, O., "On the Influence of Water Vapor and Fog Content of the Air on the Absorption of Sound and Ultrasonic Waves" (in German), Meteorol. Z., 55, 350-354, 1938.

This paper stresses the effects of weather conditions on sound absorption, particularly the importance of humidity and fog content. It briefly treats the propagation of ultrasonic waves.

271

Curtis, R. W., "Ultrasonic Absorption and Reflection Coefficients in Air and in Carbon Dioxide," Phys. Rev., 46, 811-815, 1934.

Ultrasonic absorption coefficients in air and in CO_2 have been measured, as well as the coefficients of reflection in these gases at a solid boundary. In the frequency range between 88 and 1000 kcs the absorption in air was found to increase with the square of the wavelength as required by classical theory, but for CO_2 the absorption constant of the classical theory rises to a sharp maximum at about 98 kcs. The reflection coefficient (brass reflector) was found to decrease being of the order of 20% at the higher frequencies. Measurements on an impure sample of helium are included.

272

Dubois, M., "The Absorption of Sound and Ultrasonics in Gases" (in French), J. Phys. Radium, 12, 876-884, 1951.

This article reviews the general problem of the attenuation, of a plane wave during propagation, due to the properties of the medium and the local modifications produced by the passage of the wave. Viscosity, conductivity rise and fall of temperature, and the variations in the translational and vibrational energy of the molecules are considered. Theoretical and experimental results are compared, and an extensive bibliography is given.

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Dutta, A. K., "Molecular Motion in Fluids and Internal Dispersion and Absorption of Elastic and Optical Waves," Sci. Cult. (Calcutta), 16, 576-579, 1951.

Elastic waves have been treated on the same lines as optical waves, on the basis of molecular motion. By starting with the relation, $d\rho/\rho = Kdp/p$, where $K = p/\rho\sqrt{2}$ is the dielastic constant, corresponding to the dielectric constant in the optical case, and by taking the equation of motion for an ideal fluid, with due considerations for the forces of friction and restitution, relations have been obtained for the polarization pressure P and the dielastic constant K. They come out in the form $P = NmR(\gamma - 1)(1 + \alpha)\omega^2\xi$ and $K = 1 - R(1 + a)(\gamma - 1)[(1 + \alpha)\{1 + R(\gamma - 1)\} - f - ig\omega]^{-1}$ where N = number of molecules per cm^2, m = mass of molecule, γ = ratio of sp ht in any gaseous state, R = ratio of densities of the state under consideration to the gaseous state with the particular value of γ, α = excitation constant, ω = wave frequency $\times 2\pi$, ξ = displacement due to pressure variation, f and g = coefficients of restitution and friction, acting on a molecule. The relations explain all the characteristics of supersonic absorption and also an internal dispersion indicated by the author. The effect of molecular motion on optical waves has also been stressed.

274

Ener, C., A. F. Gabrysh, and J. C. Hubbard, "Ultrasonic Velocity, Dispersion, and Absorption in Dry, CO_2-Free Air," J. Acoust. Soc. Am., 24, 474-477, 1952.

The velocity dispersion and absorption of ultrasonic waves in dry, CO_2-free air were measured at 32°C, at 2 and 3 Mcs, at pressures ranging from 0.020 to one atm. Dispersion of the velocity was found beginning at 30 Mc/atm, increasing by 5% at 100 Mc/atm, accompanied by a large increase in absorption such that, at the higher limits of f/p reached, measurements became nearly impossible with the equipment used. The ratio $\alpha_{exp}/\alpha_{class}$ decreased from about 2.4 to 1.3, and C_v/R decreased from 2.5 to nearly 1.5 as f/p increased. The changes in velocity, absorption and internal specific heat are interpreted as the result of the slowing of energy exchange between translational and rotational states. Assuming that relations for relaxation of translational-vibrational exchange also hold for this case, the relaxation time for translational-rotational exchange as derived from the dispersion measurements has been found to be 2.29×10^{-9} sec. This corresponds to a frequency of the midpoint of the dispersion curve of 116 Mc/atm, and to 16 as the number per molecule of collisions required for an energy exchange between translational and rotational states. Absorption results were more difficult to secure; by using low frequency values, a relaxation time of about 3×10^{-9} sec was indicated, giving 87 Mc/atm as the f/p value of the midpoint of the dispersion curve, and 21 as the number of collisions required for the energy exchange.

275

Fricke, E. F., "The Absorption of Sound in Five Triatomic Gases," J. Acoust. Soc. Am., 12, 245-254, 1940.

The sound absorption coefficients have been measured between 8 and 130 kc for the five triatomic gases — CO_2, N_2O, COS, CS_2, and SO_2. The frequencies of maximal absorption for these molecules were found to be 20, 153, 287, 379, and 1040 kc, respectively. For the linear molecules CO_2, N_2O, COS, and CS_2, a linear relationship was found between the maximal absorption coefficients and the frequencies at which these maxima occur. It was also found that the lower the fundamental frequencies of vibration of the 4 linear molecules, the higher are the acoustic frequencies of maximal absorption (i.e., the shorter are the lifetimes of the energy quanta); and that the sonically activated fundamentals and harmonics of each of the above linear molecules commute and have the same lifetime, with the possible exception of CO_2. From the experimental data it was possible to calculate the reaction rates, probabilities of removal of vibrational quanta, the numbers of collisions necessary to remove the quanta of energy, and the numbers of quantum transitions per second. In addition to the above data, a technique is presented which enables one to find the frequencies of maximal absorption for gases when these frequencies occur in a range beyond the scope of the apparatus.

276

Gopalji, "Ultrasonic Absorption of Normal Air at 456 kcs for Different Humidities," Indian J. Phys., 25, 298-304, 1951.

The simplified treatment of the ultrasonic formula

$$\mu = \frac{2.303\,[\log_{10}\Delta\theta_A - \log_{10}\Delta\theta_B]}{n_B - n_A}$$

is demonstrated (at 455.8 kcs) in the case of a mixture of nitrogen, oxygen, and carbon dioxide in normal air proportions with varying water content.

277

Greenspan, M., "Propagation of Sound in Five Monatomic Gases," J. Acoust. Soc. Am., 28, 644-648, 1956.

The speed and attenuation of sound at 11 mcs were measured in He, Ne, A, Kr, and Xe at various pressures between atmospheric and a few mm Hg; the results are compared with existing theories.

278

Greenspan, M., "Rotational Relaxation in Nitrogen, Oxygen, and Air," J. Acoust. Soc. Am., 31, 155-160, 1959.

The speed and attenuation of sound at 11 mcs were measured in N_2, O_2, and dry air at various pressures between atmospheric and a few mm Hg. The rotational collision numbers were found to be: for N_2, 5.26 ± 0.05; for O_2, 4.09 ± 0.08; for air, 4.82 ± 0.18.

279

Grossmann, E., "Absorption of Sound in Gases at High Frequencies," Ann. Physik, 13, 681-702, 1932.

The absorption of sound between 3×10^4 and 3×10^5~ is measured by a new method. Generator and receiver are two piezoelectric quartzes with almost the same resonance frequencies. These are placed in an enclosure containing the gas. The generator is made to vibrate with constant amplitude at its resonance frequency, and the energy in the circuit of the receiving quartz is measured by a thermocouple, when the receiver is at various distances. Disturbing effects of all kinds are investigated. Contrary to the Stokes-Kirchhoff theory, the coefficient of absorption is found to vary with the frequency, particularly in CO_2 and SO_2, and is always far in excess of values predicted by this theory.

280

Hardy, H. C., "Use of the Pierce Interferometer for Measuring the Absorption of Sound in Gases," J. Acoust. Soc. Am., 15, 91-95, 1943.

A rigorous derivation of Pielemeier's empirical equation for the absorption of sound in gases is obtained by making use of the principles of the Pierce ultrasonic interferometer and the quartz oscillator. The Pielemeier method gives a fair approximation when the reaction of the sound wave on the crystal is small; it enables both velocity and absorption to be measured. The limits of precision in its use were tested experimentally and agree with theory.

281

Henderson, M. C., and J. Z. Klose, "Ultrasonic Absorption and Thermal Relaxation in CO_2," J. Acoust. Soc. Am., 31, 29-33, 1959.

Measurements of ultrasonic absorption have been made in dry CO_2, and in CO_2 with hydrogen admixtures, between 19°C and 146°C, at pressures from 0.1 to 650 atm, and at frequencies from 300 kc to 7 Mc. The absorption is described within experimental error by the relaxation formula throughout this range, using either (a) a single relaxation time and a single relaxing specific heat representing the total of the vibrational modes, or (b) two relaxation times somewhat more than a factor of two apart and two relaxing specific heats given by certain combinations of the component vibrations. The relaxation time, or times, varies inversely as the density throughout. The maximum absorption per wavelength comes at 32 kc/atm at 25°C. Addition of hydrogen shifts the CO_2 relaxation time by 110 kc/percent by volume of H_2; this amount agrees with the shift determined by Knudsen and Fricke, provided that their data is interpreted by volume and not by weight. The "classical absorption" at low pressures is 1.5 times the theoretical value.

282

Henderson, M. C., and L. Peselnick, "Ultrasonic Velocity and Thermal Relaxation in Dry CO_2 at Moderate Pressures," J. Acoust. Soc. Am., 29, 1074-1080, 1957.

The velocity and absorption of ultrasound in dry CO_2 were measured along the 50.8° isotherm with a Hubbard-type, variable-path, recording acoustic interferometer at six frequencies from 300 kcs to 7 mcs from 0.3 to 250 atm. (i.e., up to liquid densities). Velocity dispersion is clearly shown, in addition to the change in velocity attributable to the nonideality of the gas. The values of the frequency/density ratio f/ρ, at which the transition from V_0^2 to V_∞^2 is half-completed as the pressure is lowered, and at which the maximum absorption per wavelength occurs, were measured whenever possible. From these determinations the relaxation time of the gas was determined as a function of the density. It proves to be inversely proportional to the density up to the highest density reached (0.8 g/ml), indicating that ternary collisions have not become important and that the number of binary collisions required to excite the internal vibrations does not vary with density. At 50.8° and 1 atm. the relaxation frequency $1/2\pi\tau$ is about 26 kcs and the number of collisions required to excite the molecule is 48,500. The extra absorption (in excess of the classical) remains a consequence of thermal relaxation up to liquid densities, and no new mechanism need be postulated to explain it. Further work at higher densities and other temperatures is in progress.

283

Herzfeld, K. F., and T. A. Litovitz, "Absorption and Dispersion of Ultrasonic Waves," Academic Press, Inc., New York, 535 pp., 1959.

The text is divided into three roughly equal parts: A, the general theory of relaxation in fluids; B, gases; and C, liquids.

Part A begins from the Stokes-Navier equation of hydrodynamics, kinetic theory, and statistics. This part constitutes the mathematical formulation of the macroscopic aspects of the phenomena of absorption and dispersion, and is largely formal in character.

The parts devoted to gases and to liquids follow the same pattern: application of Part A to the particular state; a brief discussion of the appropriate methods of measurements; a summary of experimental results; and, finally, an attempt to survey the studies of the physical origins of the processes formally described in Part A. In many respects, those latter sections of Parts B and C are the most interesting portions of the book.

284

Hubbard, J. C., "Acoustic Resonator Interferometer, Part II. Ultrasonic Velocity and Absorption in Gases," Phys. Rev., 41, 523-535, 1932.

The derivation of the equivalent electric network of the acoustic resonator interferometer in Part I of this paper has made it possible to develop the theory for the current in a simple resonant circuit in which the electrodes of the piezoelectric plate of the interferometer are connected to the terminals of the variable condenser. The special case of this theory is that in which the circuit is excited at a constant frequency determined by the crevasse frequency of the resonator plate in its given situation with respect to electrodes and associated circuit, when the acoustic path in the interferometer is detuned and the resonant circuit is tuned so that its resonant maximum occurs at the same frequency; the special case takes an especially simple form and leads to a direct procedure for determining ultrasonic velocity and absorption in a gas in terms only of current in the resonant circuit and path-length in the interferometer, all circuit and interferometer constants dropping out. The values of current as a function of pathlength obtained experimentally are in complete accord with the theory, and data for ultrasonic absorption in air and in CO_2 so far obtained agree with the meager data available by other methods. The role of the coefficient of reflection at the fluid-reflector surface is discussed.

285

Huetz-Aubert, M., and J. Huetz, "Ultrasonic Absorption and Dispersion in Monatomic Gases: The Three Sources of Classical Irreversibility" (in French), J. Phys. Radium, 20, 7-15, 1959.

The study of dispersion and absorption effects, so called "classical effects" or effects of translation, since they affect the molecular degrees of freedom, is most useful for separating the global effects which are the only ones accessible to experiment, from those which are due to intramolecular relaxation. As this latter cannot affect the behavior of monoatomic gases, the experimental control is easier if it is confined to these gases. Viscosity and conduction are the most important classical effects, but radiation leads to dispersion and absorption equations identical to those which are found by relaxation. Thus, irreversibility does not essentially differ according to its inter- or intramolecular origin. It can be concluded that the theory of effects of translational absorption and dispersion is verified.

286

Keller, H. H., "Absorption of hf Sound Waves in Gases" (in German), Physik. Z., 41, 16, 1940.

The method used by Petersen to measure the absorption of supersonic waves in gases has been further developed. In these measurements a monochromatic, parallel light beam is diffracted by inhomogeneities in density of the gas, which are produced by sound waves traveling through it. The decrease in sound intensity with distance from the source produces a change in the distribution of the light on the photographic plate in the first order. Photometric measurements can therefore be used to determine the absorption coefficient. A classical theory of absorption assumes that the energy absorbed from the sound wave is distributed among the translational degrees of freedom. Measurements of the absorption coefficient as a function of the pressure of the gas were made in A, N, NH_3, CO_2, and CO_2 plus 8% H, at a frequency of 4 Mcs. A theoretical relation was derived which enabled the author to determine the absorption coefficient for these substances as a function of the frequency for atmospheric pressure. This was checked against the results predicted by the classical theory. For A, the experimental results agree with those predicted by the theory. This is taken to be a check on the experimental method and on the way in which the results are interpreted. The absorption coefficients of the other substances are larger than those predicted by the theory. This is taken to mean that in these molecules some of the energy absorbed from the sound wave is distributed among the rotational degrees of freedom. Thus, NH_3 has a higher absorption coefficient than N because it requires higher energies to excite its rotational states than does N. Hence NH_3 should have a longer relaxation time.

287

Knudsen, V. O., and E. F. Fricke, "The Absorption of Sound in CO_2, N_2O, COS, and CS_2, Containing Added Impurities," J. Acoust. Soc. Am., 12, 255-259, 1940.

We have investigated the absorptive characteristics of CO_2, N_2O, COS, and CS_2, as influenced by the addition of certain gases, such as H_2, H_2O, H_2S, CH_3OH, etc., acting as "catalysts." These catalysts shift the absorption bands to higher frequencies; the magnitudes of these shifts yield information respecting (1) the frequency to which each pure gas has its maximal absorption, and (2) the nature of the molecular collisions involved, especially the effectiveness of these collisions in distributing the vibrational states of the absorptive molecules. The results indicate that at atmospheric pressure and 23°C, the absorption maxima for pure CO_2, N_2O, COS, and CS_2 are shifted in each case by amounts proportional to the concentration of the added catalyst. The addition of 1% of H_2O to CO_2 shifts the absorption band for CO_2 2250 kc; similarly, 1% of H_2O shifts the CS_2 band 2460 kc, the COS band 4200 kc, and the N_2O band 427 kc. One percent of the other impurities produced shifts which varied from 20 to 1830 kc. Transition probabilities for the above gases have been calculated. These probabilities are characteristic of the colliding pair of molecules.

288

Knudsen, V. O., and E. F. Fricke, "Absorption of Sound in CO_2 and Other Gases," J. Acoust. Soc. Am., 10, 89-97, 1938.

Sound absorption measurements in pure CO_2 at 1 atm and 22°C have been conducted; together with measurements by others, these confirm the collision theory of anomalous absorption as developed by Einstein, Kneser, and others. The absorption coefficient is appreciable at frequencies as low as 2000 ~, and increases to a maximum of 0.317 per wavelength at 77,000 ~. This maximum is higher than values obtained by previous workers, and indicates that both the deformation and symmetrical valence vibrations participate in the exchanges between translational and vibrational energy. Small impurities, such as water or alcohol vapors, affect the absorption greatly; the entire absorption band is shifted to higher frequencies. Measurements in mixtures of CO_2 in O_2 and CO_2 in N_2 indicate that neither the O_2 nor N_2 is appreciably excited by collisions with CO_2. Measurements in CS_2 reveal an absorption similar to that for CO_2 except that the absorption begins at about 10,000 ~. In mixtures of CS_2 and O_2, the observed absorption at frequencies below 10,000 ~ is accounted for by assuming that only the vibration of O_2 molecules is excited by collisions with CS_2 molecules; at higher frequencies the CS_2 molecules also are excited, principally by collisions with other CS_2 molecules.

289

Knudsen, V. O., and L. Obert, "Absorption of H.F. Sound in Oxygen Containing Small Amount of Water Vapor or Ammonia," J. Acoust. Soc. Am., 7, 249-253, 1935.

Using a new technique, the author has extended his measurements upon the absorption of hf sound in gases to higher frequencies (up to 34,000 ~). The gas is contained in a small steel box and the sound is generated in the box by a magnetostriction oscillator. The intensity of the sound generated in the box is measured, and thus the sound absorption in the gas is determined. The results confirm the earlier results, (i.e., the absorption is a maximum at a certain frequency which depends upon the amount and kind of the gaseous impurity, and this frequency increases almost linearly with the concentration of most impurities, but in the case of water impurity is a quadratic function of the concentration). This latter fact suggests that a collision of an O_2 molecule with two molecules of H_2O is more efficient in producing a transition within the molecule than is a collision with a single H_2O molecule. The theoretical value of the maximum absorption per unit wavelength agrees within experimental error with the measurements. Other measurements have shown that CO_2 and H_2 are also absorptive in the frequency range 7000 ~ to 34,000 ~.

290

Laidler, T. J., and E. G. Richardson, "Supersonic Absorption in Smokes," J. Acoust. Soc. Am., 9, 217-223, 1937.

The attenuation of hf sound in smokes is studied by means of the Pierce acoustic interferometer. Supersonic waves radiated from a quartz crystal are reflected from a movable plane reflector back to the crystal. The reaction on the quartz is detected by a change of current in the crystal circuit. As the reflector is moved parallel to the direction of propagation of the waves, a series of peaks and troughs in the current is recorded. From this the absorption coefficient is calculated. The problems of obtaining reproducible smokes and of measuring the size-distribution curve of the particles are discussed. Precautions are taken to avoid rapid coagulation of the particles under the action of supersonic waves. Absorption coefficients are obtained for smokes of magnesium powder, stearic acid, and lycoperdon (puff-ball) spores. The variation of the absorption coefficient with concentration and with frequency of the supersonic sound is compared with that predicted by a theory of J. T. Sewell. Experiment and theory agree that the attenuation is directly proportional to the concentration, but a considerable increase in attenuation with increasing frequency is reported which is not predicted by theory.

291

Lawley, L. E., "The Absorption of Sound in Carbon Dioxide Contained in Narrow Tubes," Proc. Phys. Soc. (London) B, 67, 65-69, 1954.

Measurements were made with carbon dioxide contained in tubes ~1-mm diameter. Frequencies used were between 40 and 120 kcs. Results showed that over a considerable range of frequency/pressure on either side of the relaxation peak of CO_2, the total absorption was given by the sum of the Helmholtz-Kirchhoff tube absorption and the thermal relaxation absorption of the gas. The tube absorption, however, was found to be a few percent higher than that calculated theoretically.

292

Lawlor, R., "Sound Absorption in Non-Reactive Gas Mixtures," J. Acoust. Soc. Am., 4, 284-287, 1932.

Abello's results for binary gas mixtures may be derived simply if it is assumed that the gases mixed are nonreactive. It is found that if any number of nonreactive gases are mixed, the attenuation constant of the mixture is a linear homogeneous function of the volume percentages of the components. Values of the absorption coefficients of CO_2, N_2O, H_2, He, A, and N_2 at 612 kc are calculated.

293

Leonard, R. W., "The Absorption of Sound in Carbon Dioxide," J. Acoust. Soc. Am., 12, 241-244, 1940.

The absorption was measured by a direct method over frequencies between 22 and 112 kc. A microphone responding to the sound pressure is moved away from a piston source located in a flat surface. The output of the microphone is amplified and recorded photographically. The resulting pressure-distance curve yields the pressure attenuation coefficient. The measurements were made in carbon dioxide which was carefully dried by being passed through phosphorous pentoxide. The results obtained for the frequency at which the absorption per wavelength μ is a maximum was 30 kc. In order to account for the maximal value μ obtained experimentally, it is necessary to assume that both the symmetrical valence vibration and the deformation vibration are effective in producing the absorption; and, in addition, that the second harmonic of the deformation mode also participates in the absorptive process. Velocity measurements made with the same apparatus have shown a reasonable agreement between the dispersion and absorption in carbon dioxide.

294

Meyer, E., and G. Sessler, "Sound Propagation in Gases at High Frequencies (100 to 600 kcs) and Very Low Pressures" (in German), Z. Physik, 149, 15-39, 1957.

Sound absorption and velocity values in argon, air, and hydrogen were measured in the f/p range 10^7 to 10^{11} cycles sec^{-1} atm^{-1}, using an interferometric method with condenser transducers (E. Meyer, Nuovo Cimento Suppl., 7, 248-254, 1950). Between 10^7 and 10^8 cycles sec^{-1} atm^{-1} the values in argon agree with the Stokes-Kirchhoff theory; in air, with the Burnett theory. Between 10^8 and 2×10^9 cycles sec^{-1} atm^{-1}, the values in argon and air and the velocity values in hydrogen agree better with the Burnett theory, and absorption measurements in hydrogen with the "super" Burnett theory. From 10^{10} to 10^{11} cycles sec^{-1} atm^{-1} the values agree with a molecular kinetic theory.

295

Mokhtar, M., and E. G. Richardson, "Supersonic Dispersion in Gases, II. Air Containing Water Vapor," Proc. Roy. Soc. (London) A, 184, 117-128, 1945.

The apparatus and method of measurement are described. Curves are given showing the variation, at various frequencies, of the supersonic absorption coefficient μ and the supersonic velocity with the water vapor pressure. The results deduced are: (1) the velocity in dry air is independent of frequency; (2) the measured values for μ in dry air are several times larger than those calculated from the Stokes-Kirchhoff formula and indicate an approximately linear dependence on the frequency; (3) in humid air μ reaches a maximum, two or three times its value in dry air, at a vapor pressure which decreases as the frequency increases; (4) the maximum of dispersion in velocity decreases as the frequency increases.

296

Naugol'nykh, K. A., "On the Absorption of Sound Waves of Finite Amplitude, A Survey," Soviet Phys. Acoust., English Transl., 4, 115-124, 1958.

Calculation shows that the distortion of wave-shape leads to a notable increase of absorption, e.g., a two-fold increase of the absorption coefficient at 100 kcs in water is easily obtained. The Navier-Stokes' theory is reviewed and deductions from it are compared with experiments.

297

Paolini, E., "Absorption and Diffusion of Ultrasonic Energy," Alta Frequenza, 1, 357-375, 1932.

The emitter of ultrasonic energy is a silvered quartz plate maintained in piezoelectric vibration by an alternating frequency of 267 kc, and the receiver is a radiometer such as was used by Dvorak and by Poynting and Barlow for discovering radiant energy. The law of absorption, $p = p_0 e^{-kx}$, is verified where p_0 is the pressure near the quartz, p is the pressure near the radiometer, x is the distance in cm, and k is the coefficient of absorption in cm^{-1}. Propagation is limited to the solid angle $0.37\pi^2\lambda_r^2$. Solid walls diffuse ultrasonic energy in proportion to their roughness and reflect it regularly if perfectly smooth.

298

Parker, J. G., C. E. Adams, and R. M. Stavseth, "Absorption of Sound in Argon, Nitrogen, and Oxygen at Low Pressures," J. Acoust. Soc. Am., 25, 263-269, 1953.

The amplitude absorption coefficient for pulsed sound waves in argon, nitrogen, and oxygen has been measured over a range of pressure p from 1 to 10 mm Hg for frequencies of between 60 and 70 kc, the temperature in all cases being held nearly constant at 20^oC. For the three gases used, the following experimental values of $(p\alpha/f^2)\,10^7$ (cgs units) were obtained: (1) for argon, 1.86 with an rms deviation of 0.03; (2) for nitrogen, 1.64 with an rms deviation of 0.04, and (3) for oxygen; 1.92 with an rms deviation of 0.03. The corresponding values computed from the classical absorption equation are (1) for argon, 1.87; (2) for nitrogen, 1.31; and (3) for oxygen, 1.61. Thus the absorption in argon is classical, while in nitrogen and oxygen it exceeds the classical value. These excesses are attributed to rotational relaxation, and the associated relaxation times are calculated in accordance with the thermal relaxation theory of Herzfeld and Rice, and Kneser. For nitrogen, the relaxation time (reduced to STP conditions) is 4.85×10^{-10} sec; for oxygen, 4.95×10^{-10} sec. Both these values are significantly smaller than the values obtained by other workers at higher frequencies.

299

Parthasarathy, S., D. S. Guruswamy, and A. P. Deshmukh, "Brillouin Components in Light Scattering in Relation to Sound Absorption," Ann. Physik, 17, 170-177, 1956.

A further study of light scattering in relation to sound absorption has revealed that the ratio of the intensity of the central component to the sum of the intensities of the Brillouin components is a function of total sound absorption, rather than of viscosity as interpreted from observations in liquids; or of γ, the ratio of the specific heats only, as given by Landau-Placzek theory. That it depends on both viscosity and γ has been made clear from an interpretation of the results so far obtained in light scattering. This method enables one to determine the velocity and absorption of ultrasonic waves from light scattering experiments.

300

Perepechko, I. I., and V. F. Yakovlev, "Interferometer Measurement of Ultrasonic Absorption in Gases," Soviet Phys. Acoust. English Transl., 7, 81-82, 1961.

A modified interferometric method for measuring absorption coefficients of sound in various gases at ultrasonic frequencies is described. In this method absorption coefficients are calculated from voltage measurements made at the quartz transducer of an interferometer. The new method is compared to the more conventional technique of measuring current through the quartz transducer.

301

Petralia, S., "Absorption of Ultrasonics in Mixtures of Gas Containing Hydrogen" (in Italian), Nuovo Cimento (Ser. 10), 2, 241-254, 1955.

Absorption measurements were made in pure hydrogen and in mixtures of hydrogen and argon, and hydrogen and oxygen, in order to study the influence of extraneous gases on the rotational relaxation time of hydrogen and to verify that Kohler's theory of the classical type of absorption, holding for mixtures of monatomic gases, could be extended to the case of biatomic gases. The effect of the presence of biatomic impurities in strong concentration is to shorten the relaxation time of hydrogen. This shortening does not exceed 10% for argon and is much greater for oxygen. Here the relaxation time decreases continually from the value applying to hydrogen to that applying to oxygen. The author found a relaxation time for oxygen which is shorter than that given by Thaler, but which agrees with the result of a theoretical calculation by Brout. The conclusion may be drawn that Kohler's theory does not apply to the mixtures studied.

302

Petralia, S., "Effects of Diffusion on the Absorption of Ultrasonics in Gas Mixtures" (in Italian), Nuovo Cimento (Ser. 10), 1, 351-354, 1955.

Continuation of the work described in Nuovo Cimento, 11, 570-571, 1954. Values of α/f^2 as a function of concentration for the mixtures He-Kr, He-Ne, Ne-A, A-Kr and Ne-Kr are shown graphically and tabulated. The values are compared with those calculated from Kohler's relation (Ann. Physik, 39, 209, 1941).

303

Petralia, S., "Velocity and Absorption of Ultrasonics in Gases" (in Italian), Nuovo Cimento, 9 (Suppl. No. 1), 1-58, 1952.

This paper reviews the theory of ultrasonic dispersion, the molecular heats of vibration with reference to the absorption bands, and the experimental arrangements and methods together with results of measurements of the velocity and absorption in the more important gases and vapors. Comprehensive tables of values are given. 178 refs.

304

Pielemeier, W. H., "Observed Classical Sound Absorption in Air," J. Acoust. Soc. Am., 17, 24-28, 1945-1946.

A brief treatment of the theory and methods of measuring absorption of sound in gases precedes graphical data. The measurements were made with a Pierce acoustic interferometer at a frequency of 1927 kcs in air. This frequency is high enough to satisfy Hardy's and Krasnooshkin's required conditions to obtain reliable results. The experimental result agrees with Krasnooshkin's value of $\alpha_0\lambda_0^2 = (225 \pm 5) \times 10^{-6}$ cm.

305

Pielemeier, W. H., "Pierce Acoustic Interferometer for Determining Velocity and Absorption," Phys. Rev., 34, 1184-1203, 1929.

The coefficient of absorption A of sound waves, at a distance x from a source, is contained in the expression: $I I_0 e^{-(A/\lambda^2)x}$. It was determined theoretically by Lebedew and experimentally by Neklapajeff. The paper describes its investigation by means of a quartz oscillator apparatus. The crystal forms part of a thermionic valve circuit, and the interfering sound waves react on it in such a way as to cause periodic changes in the plate current when the reflecting mirror is displaced a half wavelength or more. Several observed facts indicate a variation of wave-velocity with intensity, and measurements in air and CO_2 at frequencies from $3(10)^5$ to $14(10)^5$ give a slightly higher velocity than the commonly accepted value for audible frequencies. The absorption by air and CO_2 increases with frequency through this range, CO_2 being nearly opaque at $14(10)^5$. Lebedew's constant has a value of 0.00037 for air at 20°C. The observed values of A for CO_2 were 0.012 at $3(10)^5$, 0.0096 (by torsion vane) at $6.5(10)^5$, and 0.0073 at $12(10)^5$. The humidity has a marked effect on the absorption in CO_2.

306

Pielemeier, W. H., "Supersonic Dispersion and Absorption in CO_2," Phys. Rev., 41, 833-837, 1932.

Since supersonic velocity determinations in air near a crystal oscillator usually yield values in excess of the accepted value, V_0 = 331.6 m/sec, a similar effect with CO_2 was suspected. The velocity and the absorption coefficient were measured at frequencies beginning in the dispersion region, theoretically and experimentally investigated by Kneser, and extending beyond it to 2.09 megacycles. The author's velocity values are slightly less than Kneser's experimental values, but they fit his theoretically determined dispersion curve equally well. At the lowest frequency tested (303 kc) the absorption coefficient was found to exceed, by the greatest amount, its value computed from Lebedew's formula. This frequency is near the middle of the dispersion region where maximum absorption is expected. According to Pierce, the absorption becomes excessive also when this frequency is approached from lower values. The results are presented in tabular and in graphical form. A sharp absorption maximum appears at 217 kc.

307

Pielemeier, W. H., "Supersonic Measurements in CO_2 at 0° to 100°C," J. Acoust. Soc. Am., 15, 22-26, 1943.

An attempt to harmonize the best data on the velocity and absorption of lf and hf sound waves CO_2. Velocity/temperature graphs are drawn, as are curves to show how the frequency for maximum absorption per wavelength depends on the water vapor concentration in the CO_2 at 1 atm pressure. Two distinct relaxation times are indicated for each concentration, and acetaldehyde is cited as a gas in which three relaxation times have been found.

308

Pielemeier, W. H., "Ultrasonic Velocity and Absorption in Oxygen," Phys. Rev., 36, 1005-1006, 1930.

The velocity and absorption in oxygen at room-temperature were measured at five ultrasonic frequencies located in the two octaves, 316 to 1264 kcs. The observed velocities reduced to 0°C do not differ more than 0.2% from Dulong's observed value of V_0 for audible sound (317.2 Mcs). The theoretical value ($V_0 = (\gamma p/d)^{1/2}$) is 314.76 Mcs. The observed absorption values vary with frequency as expected, but the deviations from the theoretical values are greater than the velocity deviations.

309

Pielemeier, W. H., and W. H. Byers, "Supersonic Measurements in CO_2 and H_2O at 98°C," J. Acoust. Soc. Am., 15, 17-21, 1943.

Following a previous method, the velocity and absorption were measured in CO_2 containing water vapor at 98°C. The apparent change in relaxation times from 28° to 98° was not entirely expected, and the minor absorption peaks were not rendered more prominent. The sp ht of CO_2 calculated from the results agrees with the values obtained from spectroscopic data and with reliable calorimetric results.

310

Railston, W., and E. G. Richardson, "Effect of Pressure on Supersonic Dispersion in Gases,"Proc. Phys. Soc. (London), 47, 533-542, 1935.

Measurements of wavelengths by interferometer and hot-wire methods, and of absorption by hot-wire methods alone, have been made for supersonic radiation at frequencies between 40 and 2000 kcs in CO_2, N_2O and SO_2 at various pressures up to 2 atm. For the hot-wire method, a circuit which gives a linear relation between amplitude or particle velocity and response at constant frequency is described. The velocity-measurements in the two former gases may be reduced to a common curve by plotting them against the parameter (f/p). Although the observed velocity rise in the region where this parameter lies between 100 and 1000 is in accordance with the relaxation-time theory, the decrease in velocity at lower and higher values is not. In SO_2 the rise of velocity is in the neighborhood of 4000. The absorption in all three gases rises sharply at pressures below 400 mm of mercury.

311

Rogers, H. H., "Absorption of Supersonic Waves in Mixtures of Air and Carbon Dioxide at Different Relative Humidities," Phys. Rev., 45, 208-211, 1934.

The absorption of supersonic waves of frequency 409.6 kcs was measured in mixtures of air and CO_2 at eight relative humidities ranging from 10 to 75%. The source of the radiation was a quartz crystal oscillator. The receiver was an acoustic radiometer of the torsion vane type. Curves of the logarithm of the radiometer readings as a function of distance between radiometer and crystal face were straight lines, the slopes of which gave the absorption constant k. The absorption constant k is a linear function of the percent of CO_2. For a given mixture of air and CO_2 it is a non-linear function of the relative humidity increasing to a maximum of 45% and then dropping off rapidly. The values of k are given in a table in the original.

312

Sessler, G., "Sound Absorption and Sound Dispersion in Gaseous Nitrogen and Oxygen at High Frequency Pressure Values," Acoustica, 8, 395-397, 1960.

Sound absorption and dispersion in nitrogen and oxygen at 20°C and at frequency/pressure (f/p) values of 10^6 to 10^9 cycles/atm have been measured. The method used is the interferometric arrangement described in an earlier paper (Meyer, E., and G. Sessler, Z. Physik, 149, 15-39, 1957). Reference is also made to a paper by Greenspan (J. Acoust. Soc. Am., 30, 672, 1958). Experimental values of the ratios of absorption α to dispersion β (α/β) are plotted as a function of the ratio f/p. For nitrogen the ratio α/β falls from 0.3 to 0.01 as the ratio f/p decreases from 10^9 to 10^7. For oxygen the experimental curve is much the same. The experimental results agree well with theory.

313

Shields, F. D., "Measurements of Thermal Relaxation in CO_2 Extended to 300°C," J. Acoust. Soc. Am., 31, 248-249, 1959. AD-219 466.

The tube method has been used to extend measurements of sound absorption in CO_2 to 300°C. Results indicate that all of the vibrational specific heat in CO_2 relaxes with a single relaxation time, which, at 305°C was found to be 3.05×10^{-6} sec.

314

Shields, F. D., "Thermal Relaxation in Carbon Dioxide as a Function of Temperature," J. Acoust. Soc. Am., 29, 450-454, 1957.

Sound absorption and velocity have been measured in carbon dioxide between 0 and 200°C. The relaxation absorption was isolated by subtracting the tube and classical absorptions from the measured absorption. The Kirchhoff equations, which had been justified previously by measurements in A and N_2, were used to make these corrections. From the relaxation absorption were determined the temperature variation of the thermal relaxation time, the transition probability, and the collision efficiency. The results indicate that, for the frequencies and pressures here employed, the relaxation absorption and velocity effects are a function of f/p. This means that only binary collisions are effective in transferring energy between the vibrational and translational modes. The relaxation theory with a single relaxation time for all the vibrational modes adequately predicts the observed absorption and velocity. It is estimated that a separation in the relaxation times of the two lowest modes by a factor of more than two could not have gone undetected at 100°C. The temperature variation of the collision efficiency was adequately predicted by the Landau-Teller equation.

315

Sivian, L. J., "High Frequency Absorption in Air and Other Gases," J. Acoust. Soc. Am., 19, 914-916, 1947.

The absorption coefficients were measured for gases: (a) O_2, (b) N_2, (c) $O_2 + N_2$ in normal air proportions; (d) $O_2 + N_2 + CO_2$ in normal air proportions; (e) $O_2 + N_2 + CO_2$ in normal air proportions, plus H_2O vapor at 37% rh at 26.5°C; (f) $O_2 + N_2$ in normal air proportions, plus a CO_2 content varied from zero to 1.15% by volume. Let R denote the ratio of the measured absorption coefficient to that computed from the Stokes-Kirchhoff equation. For gases (a), (b), (c), and (d), $R \simeq 1.5$. For gas (e), $R \simeq 10$ at 15 kcs, and approaches 1.5 with increasing frequency. For gas (f) at 89 kcs, R increases with rising CO_2 content, attaining $\sim R = 20$ at 1.15% CO_2 content.

316

Solov'ev, V. A., "The Theory of an Ultrasonic Interferometer," Soviet Phys. Acoust., English Transl., 301-306, 1956.

The ultrasonic interferometer is widely used for the measurement of velocity of sound in liquids and gases. Its use can be extended to the measurement of the absorption coefficients, providing that the absorption is not great. The author presents a new computational formula to be applied to the interferometer measurements in order to obtain the absorption coefficients.

317

Stewart, E. S., "Dispersion of the Velocity and Anomalous Absorption of Sound in Hydrogen," Phys. Rev., 69, 632-640, 1946.

The velocity and absorption of sound in hydrogen were measured at 25°C at 3.855 and 6.254 mcs and at pressures of 1.00, 0.83, 0.67 and 0.50 atm. Dispersion of the velocity from 1321.9 m/sec to 1382.0 m/sec and anomalous absorption observed are interpreted as caused by molecular absorption induced by loss of the rotational degrees of freedom. Calculations place the inflection point of the dispersion curve at 10.95 Mcs the peak of the absorption curve at 10.0 Mcs from velocity data, and at 16.1 and 14.8 Mcs, respectively, from absorption data. The relaxation times for pressures of 1 atm. from the two sets of data are 1.9 and 1.7×10^{-8} sec. The f/p law is not strictly obeyed.

318

Stewart, J. L., "A Variable Path Ultrasonic Interferometer for the Four Megacycle Region with Some Measurements in Air, CO_2, and H_2. Rev. Sci. Instr., 17, 59-65, 1946.

Alignment of the piston and crystal to the order of one light fringe was attained and maintained by employing Newton and Haidinger optical fringe systems. Velocities were measured to an accuracy of 0.1%, and absorption and reflection coefficients to 50% in air and CO_2. The limit of accuracy in both cases was determined by the length, as measured to one micron with a micrometer screw. Preliminary measurements on H_2 gave evidence of molecular dispersion between 4 and 8 mcs.

319

Tempest, W., and H. D. Parbrook, "Absorption of Ultrasound in Light Gases," Nature, 177, 181, 1956.

A pulse method is described for measurements at 1 Mcs. Absorption coefficients of 1.240 and 1.235 times the classical value are quoted for oxygen and nitrogen, respectively. The technique is being developed for measurements up to 20 Mcs.

320

Thaler, W. J., "The Absorption and Dispersion of Sound in Oxygen as a Function of the Frequency-Pressure Ratio," J. Acoust. Soc. Am., 24, 15-18, 1952.

The velocity and absorption of ultrasonic waves in oxygen were measured by means of an improved ultrasonic interferometer in the range from 1 to 100 Mcs atm. Dispersion of the velocity ranged from 333.14 m/sec to 357.22 m/sec at 30°C. The ratio ($\alpha_{exper}/\alpha_{class}$) dropped from 3.68 to 2.05, and the corresponding value of C_v/R dropped from 2.50 to 1.61. The increase in velocity and the decrease in ($\alpha_{exper}/\alpha_{class}$) is interpreted as caused by the slow exchange of energy between the translational and rotational degrees of freedom. The relaxation time for the rotation was 5.24×10^{-9} sec.

321

Tisza, L., "Supersonic Absorption and Stokes' Viscosity Relation," Phys. Rev., 61, 531-536, 1942.

The reduction of the two viscosity coefficients to one according to Stokes' relation, $2\mu + 3\lambda = 0$, is not justified except for a monatomic gas. The generalization by reintroduction of the second independent viscosity coefficient, $k = 2/3\mu + \lambda$, makes it possible to develop the phenomenological theory of the absorption and dispersion of sound, in agreement with experiment completely analogous to the corresponding optical phenomena. The connection of the relaxation theory with classical hydrodynamics can be established and, in the case of polyatomic gases, k is expressed by the characteristic constant of this theory. The case of liquids is discussed. In polyatomic gases and liquids generally $k >> \mu$. Other hydrodynamical consequences of the introduction of k are discussed.

322

Truesdell, C., "Nonlinear Absorption and Dispersion of Plane Ultrasonic Waves in Pure Fluids," J. Wash. Acad. Sci., 42, 33-36, 1952.

This paper points out that the mean-free-path argument of previous workers cannot be applied to liquids. While the two-term power series expansion for the absorption and dispersion coefficients is not accurate, the exact solution of the Navier-Stokes equations fits experiments very well.

323

van Itterbeek, A., and P. Mariens, "Absorption of Sound in Carbon Dioxide," Physica, 5, 153-160, 1938.

An earlier paper describes measurements of the absorption of supersonic sound in O_2, H_2, and CO. The experiments are now extended to CO_2. The absorption in this gas is markedly influenced by impurities, especially water vapor. By using the method of preparation described by Eucken, CO_2 is obtained sufficiently pure to avoid marked effects of this kind. The absorption is measured as a function of pressure at four different temperatures between -31.0 and 51.3°C and at frequencies of 304 and 599 kcs. The relaxation time is inversely proportional to the pressure, and the absolute values agree with those of Eucken. It is concluded that the results agree with Kneser's theory. From the values of the relaxation times the number of efficient collisions is calculated.

324

van Itterbeek, A., and P. Mariens, "Velocity and Absorption of Sound at Ordinary and Low Temperatures," Physica, 4, 207-215, 1937.

Experiments with ultrasonics are made on the velocity and absorption of sound in O_2, N_2, and H_2 at ordinary and low temperatures. The influence of a magnetic field perpendicular to the direction of propagation of the velocity and the absorption of sound in O_2 is studied. No influence is found on the velocity; the absorption, however, seems to decrease. At low temperatures, measurements are made at the boiling point of O_2. The dependence of the velocity and absorption of sound on pressure in O_2, N_2, and H_2 is studied. Concerning the velocity in O_2 and N_2, a good agreement with the Leiden measurements if found. The dependence on pressure, found for the absorption coefficient of O_2 and N_2, corresponds fairly well with the classical theoretical absorption. The values found for the absorption coefficient of H_2 show that at the boiling point of O_2 there is still a dispersion effect.

325

Verma, G. S., "Effects of Humidity on Ultrasonic Absorption in Air at 1.46 Megacycles," J. Acoust. Soc. Am., 22, 861-862, 1950.

The absorption coefficient for moist air has been measured at 1.46 Mcs for relative humidities varying from zero to 84%. Maximum absorption at this frequency (α = 0.52 cm^{-1}) is found to occur at 46% relative humidity.

326

Wight, H. M., "Vibrational Relaxation in N_2O-H_2O and N_2O-D_2O Mixtures," J. Acoust. Soc. Am., 28, 459-461, 1956.

Ultrasonic absorption measurements were made to compare the relative effectiveness of H_2O and D_2O molecules in influencing thermal vibrational relaxation in N_2O molecules. The displacement rates of the absorption per wavelength maxima induced by H_2O and D_2O were compared in N_2O-H_2O and N_2O-D_2O mixtures. Experimental apparatus constructed for these measurements utilized the "direct" absorption technique in conjunction with pulsed sound waves having a frequency of approximately 113 kcs. The parameter of frequency/pressure was varied by changing the gas pressure. The data were taken at a temperature of 21°C in the f/p range of of 100-700 kcs per atm. The maximum amplitude of the molecular absorption coefficient per wavelength in dry N_2O was 0.153 and this occurred at 210 kcs per atmos. Measurements were taken in N_2O-H_2O and N_2O-D_2O mixtures at H_2O vapor and D_2O vapor concentrations of 0.39%, 0.77% and 1.14%. The usual single relaxation time theoretical absorption curve could be fitted to the data for dried N_2O. However, in the mixtures there was some evidence of two separate relaxation times, one possibly associated with N_2O-N_2O collisions and the other with N_2O-H_2O or N_2O-D_2O collisions. The maximum absorption coefficient in the mixtures was somewhat less than that observed in the dried N_2O. The H_2O molecules were 1.72 times more effective than the D_2O molecules in shifting the frequency associated with the absorption maximum.

327

Zartman, I. F., "Ultrasonic Velocities and Absorption in Gases at Low Pressures," J. Acoust. Soc. Am., 21, 171-174, 1949.

The improvements on an ultrasonic interferometer are discussed. As a result of these, a greater sensitivity to acoustic reactions is obtained and the reproducibility of the data is greatly improved. Velocity measurements in dried CO_2-free air, dried N_2 and dried H_2 are given. Amplitude absorption coefficients for H_2, N_2 and CO_2 are also included. Measurements are made over the temp. range from 9°C to 36·6°C and over the pressure range from 82.17 cm Hg to 0.45 cm Hg. The frequencies extend from approximately 500 kcs to 2.16 Mcs. A maximum value for the absorption in H, attributed to molecular absorption, is located at an f/p ratio of approximately 10 Mcs/atm.

328

Zmuda, A. J., "Dispersion of Velocity and Anomalous Absorption of Ultrasonics in Nitrogen," J. Acoust. Soc. Am., 23, 472-477, 1951.

By means of the interferometer, the velocity and absorption of ultrasonic waves in N were measured at the frequency of 2.992 Mcs in the pressure range of 2.09 to 76 cm of Hg at a temperature of 29°C. A dispersion of velocity was found ranging from 354.3 m/sec to 364.4 m/sec. The ratio $\alpha_{exp}/\alpha_{class}$ dropped from 1.40 to 1.32, and the corresponding value of C_v/R dropped from 2.50 to 2.08. Theoretical values for the change in velocity and in the absorption ratio, calculated by applying the equations for the exchange of energy between translational and vibrational degrees of freedom, show good agreement with the observed values. The increase in velocity and the decrease in $\alpha_{exp}/\alpha_{class}$ is interpreted as due to the slow exchange of energy between the translational and rotational degrees of freedom. The relaxation time for rotation was found to be 1.2×10^{-9} sec.

Absorption, Ultrasonic
See also—9, 16, 44, 66, 85, 118, 134, 1[illegible]7, 186, 197, 202, 217, 590, 828, 839, 904, 944, 1061, 1134, 1140, 1141, 1143, 1145, 1266, 2184, 2185, 2969, 3118, 3212, 3982, 4385, 4397.

ACOUSTIC EXCITATION

329

Baruch, J. J., G. W. Kamperman, et al., "Acoustic Design of Flight Vehicle Structures Facility," WADC Tech. Note No. 58-189, Bolt, Beranek, and Newman, Inc., Cambridge, Mass., 35 pp., 1958.
AD-204 792.

This paper reports on a proposed facility for studying the effects of sonic fatigue on flight vehicle structures. This facility has been designed to simulate the acoustic environment produced by high performance jet and rocket engines, and to test complete, full-scale flight vehicles and weapons systems. Tests will be performed with either progressive waves or random incident waves at high sound intensities.

330

Bhuta, P. G., "Transient Response of a Thin Elastic Cylindrical Shell to a Moving Shock Wave," Rept. No. TDR-930(2119) TN-4), Aerospace Corp., El Segundo, Calif., 24 pp., 1962.
AD-276 099.

By using the theory of thin elastic shells, the transient response of a finite cylindrical shell of circular cross-section subjected to a moving pressure discontinuity is obtained for the axisymmetric case. The response to a moving shock front with a decaying pressure intensity behind the front may be obtained by using this solution and the superposition integral. From the solution for the moving pressure discontinuity, the response of the shell, when the impulsive load is applied simultaneously over the entire shell, is obtained by a limiting procedure. The analysis of the response of the shell to a moving pressure discontinuity shows that if one-half the period of the fundamental vibration is less than 0.87, equal to 1.12, or greater than 3.4 times the time required by the pressure discontinuity to cross the shell, the corresponding dynamic loading factors based on deflections may be taken as 1.78, 2.50, and approaching 2.0, respectively. The upper bound of the dynamic loading factor is 2.50 for this investigation, and is contrary to the commonly accepted notion that it cannot be greater than 2.0.

331

Bianchi, R. A., R. T. Bradshaw, et al., "Survey and Evaluation of Sonic Fatigue Testing Facilities," Rept. No. ASD TR 61-185, CONESCO, Arlington, Mass., 364 pp., 1962.
AD-277 124.

An evaluation of the sonic-fatigue-testing facilities throughout the country was made to establish present methods and techniques of testing and to determine the necessity of performing other environmental tests in combination with high intensity noise. A general conclusion is that the most economical procedure for developing sonic-fatigue-resistant structures consists of: (a) designing panels with discrete frequency siren methods, (b) performing semi-qualification tests with broad band sources such as broad band sirens or modulated air flow speakers (not jet engines), and (c) performing a full-scale proof test. The effects of temperature and pressure (and perhaps corrosion) can only be assessed by combined tests. Combined tests for nuclear radiation should not be considered in the foreseeable future. In many instances the effects of correlation can be approximated in a discrete frequency siren test by orienting a specimen in a manner determined by considering the sound level contours existing on the aircraft.

332

Borisov, Yu. Ya., and N. M. Gynkina, "On Acoustic Drying in a Standing Sound Wave," Soviet Phys. Acoust., English transl., 8, 95-96, 1962.

An investigation is carried out to determine the effect of sound intensity on the drying rate of porous capillary material.

333

Brandt, O., "Behavior of Suspended Matter in Vibrating Gases at Sonic and Supersonic Frequencies," Kolloid-Z., 76, 272-278, 1936.

A brief survey of previous work in this field is first given and is followed by the description of measurements concerning the velocity of aggregation when influenced by sonic and supersonic vibrations in static and flowing gases containing paraffin particles (i.e., paraffin fogs). Since such particles are undoubtedly spherical, all uncertainty in measurement is removed. The apparatus used and the experimental details are fully described. Separate sections deal with the period of fall of the particles, rate of change of particle size as obtained by optical measurements, and phenomena in flowing fogs of paraffinated gases. Comprehensive tables of data, diagrams and bibliography are included.

334

Clarkson, B. L., "Structural Aspects of Acoustic Loads," AGARDograph No. 65, Paris, France, 115 pp., 1960.
AD-294 146.

A review of the experimental and theoretical work on the various structural aspects of acoustic loads is given. The sound pressure levels in the near field of jets and rockets have been investigated experimentally for a range of operating conditions on a few engines. Extrapolation of these data to other engines shows a rapid decrease in accuracy as the difference in the two engine conditions increases. The considerable amount of data on boundary-layer pressure fluctuations establishes that the skin root-mean-square pressure level up to transonic speeds is approximately equal to 0.006 q and that the spectrum is probably sufficiently well defined for structural response to random pressure fluctuations. Theories have been developed for the response of simple structures to noise, but none is directly applicable to practical structures because of the lack of normal mode and other data. Some limited investigations on the types of modes being excited have begun. The effective use of additional damping compounds and the assessment of basic damping in a structure depend on a knowledge of the modes being excited. A variety of test procedures and design philosophies have been adopted.

335

Clarkson, B. L., and R. D. Ford, "An Experimental Investigation of the Random Excitation of a Tailplane Section by Jet Noise," Rept. No. ASD TDR 62-680, 33 pp., 1962.
AD-286 834.

The response of a section of tailplane structure to both discrete and random noise pressures was studied in detail. Initially the specimen was mounted behind a jet engine and the induced strains were analyzed with the object of determining both the resonant frequencies and the corresponding modes of vibration. During these tests a survey was made of the spectrum and correlation pattern of the jet noise on the surface of the model. Secondly the specimen was mounted in front of a loudspeaker in an acoustics laboratory and the structural resonances were excited by means of discrete frequency sound. The mode shapes were studied in detail with the aid of a stroboscope. The tailplane skin on this particular piece of structure only responds to any significant degree in one structural mode. Although reasonable comparison was obtained between the random and discrete tests, it was not possible to calculate the induced stresses using the observed mode shapes and measured pressure excitation.

336

Clarkson, B. L., and R. D. Ford, "Further Analysis of the Random Vibrations of the Caravelle Test Section," Final Rept. No. ASD TDR 62-681, Southampton Univ., Great Britain, 23 pp., 1962. AD-284 886.

Further tests were made on the Caravelle aircraft test section. The vibrations induced by jet-noise of a row of eight panels in the side of the rear fuselage were analyzed, and it was confirmed that the skin panels tend to vibrate in fundamental modes with adjacent panels out of phase with each other so that the intermediate stringers twist. Because of variations in the panel sizes, presumably, no more than three panels were observed to couple in such a mode. The vibrations of the panels on the upper surface of the outboard elevator were also analyzed. It was found that the ribs act as stiff supports, but the vibrations of the two panels between any pair of ribs are coupled in the lower-frequency modes.

The mode shapes were not satisfactorily determined owing to the lack of sufficient strain-gauges on the panels, but it is deduced that the stresses in the ribs are caused by direct inertia loading from the supported panels.

337

Cox, R. J., H. J. Parry, and J. Clough, "A Study of the Characteristics of Modern Engine Noise and the Response Characteristics of Structures," Rept. No. WADD TR 60-220, Lockheed Aircraft Corp., Burbank, Calif., 154 pp., 1961. AD-272 210.

Jet engine noise and the response of structures to that noise were studied. The near-sound-field characteristics of a jet engine operating on the ground at both military and afterburner thrust were measured. Sound pressure levels were obtained in the near field and within the jet wake, as were pressure levels and cross-correlation coefficients. The latter two were obtained at two locations in the noise field for the free field, a rigid boundary, and a flexible boundary. Several panels, representative of typical airframe structure, were subjected to this jet engine noise. Structural response in terms of strain and accelerations was measured and analyzed. These panels were also subjected to discrete frequency excitation to determine basic response parameters. An analytical method for predicting the response of complex structures in an actual jet noise environment was developed. Predicted and measured responses were compared.

338

Danner, P. A., E. Ackerman, and H. W. Frjngs, "Heating of Haired and Hairless Mice in High Intensity Sound Fields from 6 to 22 KC," J. Acoust. Soc. Am., 26, 731-739, 1954.

Experiments have been conducted to provide a comparison of sound absorption by haired and hairless mice in high intensity airborne sound fields. At 18-20 kc, threshold intensities for heating of the mice are 144 ± 2 db for haired animals and 155 ± 2 db for hairless animals. From 6-22 kc, effectiveness of the sound in heating the mice increased with frequency. Absorption coefficients computed from the data are higher at higher frequencies for both types of animals. Death time depends upon the intensity and frequency of the sound, the external covering of animals, and the portion of the animal exposed to the most intense part of the sound field. The configuration of the sound field and its relation to the results are discussed. Measurements of the field made with and without a hairless mouse showed increased distortion at higher frequencies of the sound field by the body of the mouse.

339

Fitch, G. E., T. R. Dutko, et al., "Establishment of the Approach to, and Development of, Interim Design Criteria for Sonic Fatigue," Final Rept. No. ASD TDR 62-26, North American Aviation, Inc., Los Angeles, Calif., 154 pp., 1962. AD-284 597.

Design criteria for sonic fatigue were developed. The approach was accelerated, discrete-frequency life-testing, the results of which are interpreted by a sine-random equivalence analysis. This approach offers the best compromise between economy, accuracy, and lead time to cover structural design problems for advanced design, design development, and prooftesting of completed vehicle structure. Methods were extracted from the literature with which to predict the acoustic environment and determine the duration of various environments from mission analysis. Fatigue data and an examination of cumulative damage are presented in support of the sine-random equivalence technique. This method takes advantage of the extensive fatigue S-N data available in the industry. Examples of the application of the analytical-empirical techniques are presented.

340

Forney, D. M., Jr., "Acoustical Fatigue Test Procedures," Noise Control, 6, 11, 1960.

This article is a general survey of the test procedures and installations presently in use by various organizations in their investigations of aircraft fatigue failures caused by sound.

341

Friedman, M. B., "Acoustic Pulse Loading on a Two-Dimensional Rigid Box in the Vicinity of a Free Surface," Tech. Rept. No. 22, Inst. of Air Flight Structures, Columbia Univ., New York, 11 pp., 1959. AD-225 335.

The pressure loading on a box-shaped obstacle is determined in the presence of a free surface, produced by the impact of a pulse of constant strength. A period on the order of two transit times is considered. The normal to the incident pulse is inclined at 45° with respect to the sides of the box.

342

Gray, C. L., "Study in the Use of Structural Models for Sonic Fatigue," Final Rept. No. ASD TR 61-547, Northrop Corp., Hawthorne, Calif., 49 pp., 1962. AD-277 186.

The feasibility of employing reduced-scale structural models for sonic-fatigue testing were examined theoretically and experimentally. Scaling laws for structure and for jet noise sources were presented and theoretical fatigue aspects discussed. Application of the theory to simple-flight-vehicle type structure was then investigated. Twenty-five panel specimens in three scales and 18 fatigue coupons in two scales were tested to failure with proportionately scaled forcing functions. The results indicate that an empirical relationship between scale factor and fatigue life exists, and that fatigue modeling techniques are feasible and practical.

343

Jackson, F. J., and M. A. Heckl, "Effect of Localized Acoustic Excitation on the Stability of a Laminar Boundary Layer," Final Tech. Rept. No. ARL 62-362, Bolt, Beranek and Newman, Cambridge, Mass., 56 pp., 1962. AD-278 539.

Investigations were performed by utilizing a localized surface source of acoustic energy to generate disturbances in a laminar boundary layer flow to uncover the influence of induced surface vibrations on the stability of a shear flow boundary layer. Explorations were carried out over a frequency range of from 50 to 10,000 cps, using input sound pressure levels of up to 145 db re 0.0002 dynes/sq cm. Results are presented which indicate the effect of sonic parameters (frequency, amplitude) on both the mean and fluctuating components of the boundary layer flow. Induced boundary layer oscillations are discussed, where appropriate, in terms of the stability theory of Tollmien and Schlichting. Studies of distortion of boundary layer oscillations are described and the role of such distortion in producing transition is discussed. Nonlinear secondary flows (streaming) generated by the localized source are also treated. Exploration of the influence of sonic excitation on premature transition produced both by increasing the free stream turbulence level and by use of a tripping wire is described.

344

Jordan, G. H., N. J. McLeod, and L. D. Guy, "Structural Dynamic Experiences of the X-15 Airplane," NASA Tech. Note No. D-1158, Washington, D. C., 14 pp., 1962.
AD-273 566.

The structural dynamic problems anticipated during the design of the X-15 airplane are reviewed briefly, and the actual flight experiences with the airplane are described. The noise environment, acoustic fatigue problems, and panel-flutter experiences are discussed. Where these problems lead to structural modifications, the modifications are described.

345

Kantarges, G. T., "Some Measurements of Noise Transmission and Stress Response of a 0.020-Inch Duralumin Panel in the Presence of Air Flow," Nat'l. Aeron. Space Admin., Washington, D. C., 25 pp., 1960.
AD-241 931.

Noise transmission measurements were made for a 0.020-inch panel with and without air flow on its surface. Tests were conducted with both an absorbent and reverberant chamber behind the panel. Panel stresses for some of these tests were also determined. Noise spectra obtained inside the absorbent chamber with flow attached and flow not attached to the panel appeared to contain several peaks corresponding in frequency to panel vibration modes. These peaks were notably absent when the chamber was reverberant. These noise reduction through the test panel measured with the aid of an absorbent chamber for the flow-not-attached case is in general agreement with values predicted by the theoretical weight law but indicate rather less noise reduction at the high frequencies. The main stress responses of the panel without air flow occurred at its fundamental vibration mode. In the presence of air flow the main response occurs in a vibration mode having a node line perpendicular to the direction of air flow.

346

Kirchman, E. J., and J. E. Greenspon, "Nonlinear Response of Aircraft Panels in Acoustic Noise," J. Acoust. Soc. Am., 29, 854-857, 1957.

This paper considers the response of thin elastic plates to sinusoidal acoustic excitation. A theoretical method for obtaining the dynamic deflection and stress in the nonlinear region is given. The theory is compared with test results showing rather good agreement. The application of the theory to the design of panels to withstand acoustic fatigue is discussed in the latter part of the paper.

347

Kirchman, E. J., K. Thomas, and J. Greenspon, "Panel Excitation by Acoustic Noise," Rept. No. ER 8673, Martin Co., Baltimore, Md., 23 pp., 1956.
AD-150 890

Flat panel response to sonic excitation was evaluated. A direct copy of the Boeing Aircraft Co. siren with an experimental horn tailored for above 100 c was used. Response curves for 12- × 12-inch panels of 0.051-, 0.072-, 0.041-, and 0.125-inch gage were obtained. None of these panels except the 0.125 gage satisfied the linear theory of plates. The production of noise levels up to 170 db over a 1-sq-foot area with the present sinusoidal horn was possible. The nonlinear response can be computed and a conservative estimate of peak stresses made in the case of the fixed panel. Further investigation revealed that all the panels of less than 0.091 gage could be operated in an unsteady equilibrium area for maximum stress. Testing revealed that for small amplitudes the bending stress is predominant; for higher amplitudes the membrane stress increases rapidly. For a nonlinear system, the panel frequency and the amplification factor can be accurately predicted.

348

Lamb, J. J., and R. A. Ditaranto, "Preliminary Investigation of Hyper Environments and Methods of Simulation, Part II. Simulation Methods," WADC Techn. Rept. No. 57-456, RCA Defense Electronic Products, Camden, N. J., Pt. 2, 79 pp., 1957.
AD-142 167.

The report deals mainly with the problem of simulating the environments and combinations of environments discussed in Part I. Only those environments which would be detrimental to the operational characteristics of subsystems and equipments used in U.S. Air Force weapon systems were considered for simulation. These environments are: (a) high vacuum, (b) temperature, (c) air cooling, (d) solar radiation, (e) vibration, (f) acoustic excitation, (g) shock, (h) acceleration, (i) high-speed particles, (j) explosive decompression, (k) zero gravity, (l) ozone, (m) ionization and (n) reentry environment. Combinations of these environments were also considered for simulation. For each environment, current simulation methods and developments are discussed. Finally, when a method could not be simulated, an attempt was made to simulate the effects of an environment. When neither simulation of the environment nor its effect was possible, the limitations are discussed and/or an area for future investigation is indicated. Included also are discussions of the measurement techniques and the equipment for each simulation method. A technique for recording all the resultant data is suggested and outlined in a section of this report.

349

Maidanik, G., "Response of Ribbed Panels to Reverberant Acoustic Fields," J. Acoust. Soc. Am., 34, 809-826, 1962.

This paper discusses a statistical method for estimating the response of ribbed panels to acoustic excitation. It shows that the acceleration spectrum of the vibrational field is related to the pressure spectrum by a coupling factor, which is a simple function of the radiation and mechanical resistance of the structure. The radiation resistance of a ribbed panel is studied as a function of frequency. The analysis predicts that ribbing increases the radiation resistance of the panel and hence its coupling to the acoustic field. The effect of various panel-rib boundary conditions is also considered. The results of experiments which were conducted to test the theory are reported. The agreement between theory and experiments is shown to be satisfactory.

350

Mangiarotty, R. A., "The Vibration Damping of Complex Structures Subjected to Acoustic Excitation," Aeron. Rept. No. LR-323, Nat'l Aeron. Establishment, Canada, 49 pp., 1961.
AD-276 019.

The acoustic fatigue of structures and the application of damping treatment to complex structures subjected to acoustic excitation forces were studied. Attempts were made to examine the status of the outstanding problems as they appear from available published literature and to discuss possible methods for their solution. Acoustic excitation, dynamic response, and the damping of structures are reviewed and discussed, and possible methods of reducing the laborious effort required to compute the response of complex structures are suggested. The total acoustic radiation damping of a vibrating system, and the effects on the dynamic characteristics of the walls of a structure due to the air enclosed by the structure are discussed. The optimization of damping treatments is discussed in terms of minimum added weight, geometric configuration, and suitable choice of parameters. Also, the effect of damping on acoustically induced structural fatigue is examined.

351

Mayes, W. H., and P. M. Edge, Jr., "Application of a Blowdown Wind Tunnel for Large-Scale Acoustic Environmental Testing," Sound, 1, 8-11, 1962.

The 12-foot-diameter exhaust of a blowdown wind tunnel serves as an intense noise source for the testing of large components or of entire vehicles. Sound pressure levels up to 160 db and a wide range of noise spectra are available. An example of the use of this facility in the environmental testing of a manned space vehicle is cited.

352

McLeod, N. J., "Flight-Determined Aerodynamic-Noise Environment of an Airplane Nose Cone up to a Mach Number of 2," NASA Tech. Note No. D-1160, Washington, D. C., 28 pp., 1962. AD-273 754

The aerodynamic-noise environment of a Fiberglass nose cone for a fighter-type airplane was measured over a Mach number range from 0.8 to 2. The measurements were obtained at altitudes of about 26,000 feet and 40,000 feet for a dynamic-pressure range of approximately 200 lb/sq foot to 1000 lb/sq foot. The data showed that the aerodynamic-noise level on the surface of the cone increased with free-stream dynamic pressure. The average noise pressure varied from approximately 0.001 of the lower dynamic pressures to approximately 0.0005 of the higher dynamic pressures. The noise level in the octave bands below 2400 cps showed large deviations from the mean, which would cause serious error in structural-fatigue tests when such tests are based on the average level. Variations in angle of attack of from 1^{o} to 5^{o} had a negligible effect on the noise levels; however, at an altitude of 40,000 feet and an angle of attack of approximately 0^{o}, intermittent increases in noise levels were measured.

353

National Research Council, Prevention of Deterioration Center, "Environmental Effects on Materials and Equipment, Abstracts, Section B," 2B, Washington, D. C., 1962.

Section B, Volume 2B is a running bibliographical series of documents listing reports and papers that deal with the physical effects of environment on various materials and equipment. Among the many environmental effects considered are shock waves, jet acoustic oscillations, supersonic flows, acoustic excitation, and vibration.

Number 1, 17 pp., AD-283 811
Number 2, 17 pp., AD-283 812
Number 3, 18 pp., AD-283 813
Number 4, 18 pp., AD-283 814
Number 5, 17 pp., AD-283 815
Number 6, 18 pp., AD-283 816
Number 7, 19 pp., AD-283 817

354

Noiseux, D. U., J. J. Coles, et al., "Response of Electronics to Intense Sound Fields," Rept. No. ASD TR 61-391, Bolt, Beranek and Newman, Inc., Cambridge, Mass., 46 pp., 1961. AD-270 457.

The intense sound fields present in missiles and other flight vehicles may cause serious malfunction of electronic equipment. Efforts were made to determine the possible ways in which intense sound can excite electronic equipment, to localize the probable areas of failure or malfunction, and to propose testing procedures for electronic equipment. Two areas of possible malfunction were investigated. The first is the printed circuit board, which serves as the final supporting structure for an electronic component. It was found that the electrical noise output from biased condensers mounted on the printed circuit boards was in the order of 10 μv per g of acceleration. It was found, furthermore, that the usual hard coatings applied to the boards tended to increase the electrical noise output. To some extent this was also observed when a hard plaster damping material was applied to the boards. The second area of investigation was the response of a rectangular box to acoustic and to vibration excitation. It was found that the acoustic transmissibility of the largest panel of the box was about unity at resonance and 20 db below this off resonance. Other tests showed that the coupling of vibration among the sides of the box was predominantly by mechanical paths and, furthermore, that the transmissibility of vibration approached 30 db at certain resonances.

355

Rattayya, J. V., and L. E. Goodman, "Bibliographical Review of Panel Flutter and Effects of Aerodynamic Noise," WADC Tech. Rept. No. 50-70, Inst. of Tech., Univ. of Minn., Minneapolis, 36 pp., 1959. AD-215 448.

The world literature in the field of aircraft panel flutter and aerodynamic noise is critically reviewed and a bibliography of over two hundred references assembled.

356

Regier, A. A., and H. H. Hubbard, "Response of Structures to High Intensity Noise," Noise Control, 5, 13, 1959.

The general problem of aircraft fatigue testing is discussed; this includes energy requirements, simulation of random noise environments, and comparison of acoustic fatigue data with conventional fatigue data.

357

Ruscigno, H. G., "Sonic Fatigue Tests of Thermal Insulation Protection Systems for Mach 3.0 to 4.4 Flight Vehicles," Final Rept. No. GDC 62-62, General Dynamics/Convair, San Diego, Calif., 41 pp., 1962. AD-278 665.

Three panels were evaluated for sonic fatigue. One was a bare aluminum plate, the other two were identical except for the addition of a stitched laminate insulation system. It was shown that the addition of stitched laminate to an aluminum structure did not shorten the sonic fatigue life, and the insulation system was not visibly damaged by sound levels to 170 db at the frequency of maximum strain for the panel.

358

Schjelderup, H. C., "Structural Acoustic Proof Testing," Noise Control, 5, 19, 1959.

The problems of fatigue testing are discussed. Realistic, rather than sinusoidal, excitation is used. Simulation of acoustic environment by various jet engine configurations is described.

359

Secretary of Defense, Assistant, "Shock, Vibration and Associated Environments, Part II, Research and Engineering," Washington, D. C., 25 pp., 1959. AD-212 975.

The 27th Symposium was held at the U. S. Army Air Defense Center, Fort Bliss, El Paso, Texas on Feb. 25-27, 1959.

Contents:
Re-entry simulation
Design philosophy and environmental test
Random and complex-wave vibration testing
High-intensity acoustic noise testing

360

Smith, P. W., "Sound-Induced Vibration," Noise Control, 4, 16, 1958.

The alternating forces of a sound wave upon a flexibly mounted, rigid device can cause significant response motion. In particular cases graphs are given for evaluating the amplitude of response to high intensity sounds of single frequency.

361

Smith, P. W., Jr., and C. I. Malme, "Sonic Fatigue Life Determination by Siren Testing," Rept. No. ASD TR 61-639, Bolt, Beranek, and Newman, Inc., Cambridge, Mass., 87 pp., 1962. AD-278 173.

Experimental and theoretical researches were made on the problem of predicting the fatigue life of a resonant structure exposed to jet noise by testing it with intense sound from a siren. One panel design of Alclad 2024 aluminum was tested to fatigue with constant-amplitude and variable amplitude siren sounds and with jet noise. A close correlation of all three results was found. A comparison was also made of fatigue lifetimes of a resonant cantilever beam of plain 2024 aluminum, measured with constant excitation amplitude (pure tone) and with random excitation. Random lifetimes were shorter than predictions from constant-amplitude data.

362

Stevenson, M., D. Saltus, and R. Taggart, "An Experimental Study of Acoustic Excitation of Flat Plates by Unsteady Flow," Rept. No. RT-1101, Taggart, Robert, Inc., Falls Church, Va., 29 pp., 1961. AD-262 951.

Tests were conducted in a gravity flow tunnel with a thin, flexible plate installed in one wall. Measurements were made of flow velocities and boundary layer characteristics in the tunnel and correlated with acoustic measurements of the test plate vibrations. It is demonstrated that unsteady flow excitation at the boundary causes vibration of the plate at many natural modes. Data on vibration amplitudes are related to the excitation of pressure fluctuations in the boundary layer.

363

Valluri, S. R., "A Theory of Acoustic Fatigue," Rept. No. 3, Graduate Aeron. Labs., Calif. Inst. of Tech., Pasadena, 11 pp., 1962. AD-278 808.

Any theory of acoustic fatigue has three essential aspects. The first is an adequate quantitative description of the acoustic field. The second is the determination of the stress response of the structure to this acoustic input. The third is the estimation of time to failure of the structure for the determined stress response. This report is concerned with the third objective. The theory presented is a forman extension of an engineering theory of fatigue proposed earlier. Representing the result of acoustic input as one of random stress response, expressions are derived for the prediction of time to failure. Indications are that the tail of the distribution function curve associated with the rms stress amplitude peak at any one particular frequency is of considerable importance in determining the time to failure. It appears that one has to talk of the probability of failure at any instant rather than a specific time to failure. A detailed and rigorous treatment of the random loading aspect of the problem of acoustic fatigue appears to be too complex to be of much use at this time since the first two aspects of the problem are not too well understood. Under these conditions, simplifying assumptions indicate that the probability of failure at any time is directly related to the cumulative probability of the distribution function associated with the rms stress response.

Acoustic Excitation—See also High Intensity Sound; Noise; Sound Sources; Wave Propagation, Blast/Detonation, Shock
See also—217, 509, 513, 518, 535, 541, 960, 966, 971, 973, 975, 976, 977, 978, 981, 987, 989, 1266, 1301, 1303, 1343, 1629, 1649, 1650, 1652, 1692, 1716, 1731, 1756, 1757, 2277, 2410, 2585, 2586, 2721, 2809, 3496, 3519, 3801, 3907, 4112, 4385

ANECHOIC CHAMBERS, QUIET ROOMS, ETC.

364

Allen, C. H., and A. C. Potter, "Design and Application of a Semi-Anechoic Sound Test Chamber," Sound, 1, 34-39, 1962.

The noise output of small mechanical devices depends greatly upon the mounting structure and the proximity of hard reflecting surfaces such as walls, ceiling, or floor. Although the operating characteristics may be precisely specified, the acoustical output frequently is neglected and poorly understood. This article describes the use of a semi-anechoic room that provides the working environment for the accurate study of the sound output characteristics of a variety of mechanical devices. The semi-anechoic room permits the measurement of the acoustic power and directivity pattern of the sound generated either by the device itself or by the combination of the device and its total mounting structure considered as a unit. The ability to make meaningful measurements which show directly the effects of design changes has, in particular, permitted improvement of both efficiency and noise characteristics of air impellers.

365

Benoit, A. W., R. T. Hemmes, and M. W. Schulz, Jr., "An Anechoic Chamber for Noise Tests on Large Power Transformers," Trans. Am. Inst. Elect. Engrs. III, 74, 50-56, 1955.

This paper describes some of the details of the design, construction, and operation of the sound laboratory recently completed by the General Electric Co. for testing transformers up to 400 tons and 500 MVA. In addition to acoustic data on the anechoic qualities of the testing room, information is given on the handling arrangements, power supply, and instrumentation.

366

Beranek, L. L., and H. P. Sleeper, Jr., "The Design and Construction of Anechoic Sound Chambers," J. Acoust. Soc. Am., 18, 140-150, 1946.

Data on the performance of five different types of structures for use in echo-free (anechoic) chambers are presented. The best is shaped like a wedge and manufactured from glass fibres held together by a binding agent. When mounted in the room, the wedges are spaced out several inches from the walls, and the dihedrals of adjacent units are turned through 90°. Generalized specifications for the optimal design of structures are presented in terms of either (a) lowest frequency at which 90% absorption is desired or

(b) maximum depth of treatment which may be installed in the room. The application of these specifications to two rectangular rooms is shown, and inverse square law measurements performed in the two completed chambers are presented. In the larger chamber the deviations are with ± 0.3 db out to 10 feet and ± 1.0 db out to 30 feet from a point source of sound. In the smaller, the deviations are within ± 1.0 db out to 10 feet.

367

Berger, R. L., and E. Ackerman, "The Penn State Anechoic Chamber," Noise Control, 2, 16, 1956.

The design and construction of a low-cost anechoic chamber is discussed. Test results indicate that a small chamber built in accordance with the design provides a free field throughout most of the region not occupied by acoustical treatment. Architectural details are presented.

368

Diestel, H. G., "Sound Propagation in an Almost Anechoic Room" (in German), Acustica, 12, 113-118, 1962.

A theoretical investigation is presented of the probable deviations of the sound pressure from the 1/r law in an almost anechoic room. The deviations depend upon the distance from the sound source, the reflection coefficient of the walls, the surface area of the room and the directivity of the sound source. The influence of the directivity of the microphone on the probable accuracy of measurement is calculated.

369

Dombrovskii, R. V., and R. T. Kalust'yan, "An Anechoic Chamber with Sound Absorbers Composed of Stable Fiberglass Wedges," Soviet Phys. Acoust., English transl., 8, 283-286, 1963.

Constructional details, dimensions, and acoustic characteristics of an anechoic chamber at the A. S. Popov Scientific Research Institute are given in this short article. The wedges used are built up of six layers of long staple fiberglass having a specific density of 60 kg/m^3. The coefficient of sound reflection from these wedges is well below 10% for all frequencies above 65 cps. Curves are included which show, for various frequencies, departures from normal spherical divergence of sound propagating from a source in the chamber.

370

Hardy, H. C., F. G. Tyzzer, and H. H. Hall, "Performance of the Anechoic Room of the Parmly Sound Laboratory," J. Acoust. Soc. Am., 19, 992-995, 1947.

The performance has been measured to determine the characteristics of rooms of small volume with wedge-covered walls. The inverse square law holds to within ± 1 db to 6.5 feet from 60 to 24,000 cps, although the theoretical cut-off frequency of the room is 115 cps. At 100 cps the radiation resistance of a loudspeaker placed near the walls was found to be 18% > the free-field value, and the radiation reactance was ~5% > the free-field value. The differences disappeared 2 feet from the wall. The wall transmission has been measured as a function of frequency, and the wedges themselves are found to act similarly to a thin plate in optics, having a maximum transmission at 110 cps.

371

Klimov, B. M., and A. N. Rivin, "Sound Absorbing Phenopolyurethane Wedge Coatings," Soviet Phys. Acoust., English transl., 8, 286-287, 1963.

This brief communication presents test results on the absorptive properties of phenopolyurethane coatings applied to wedges for use in anechoic chambers. This material is of interest because of its great mechanical strength in comparison to the fiberglass materials normally used. Although the polyurethane coatings have almost twice the reflectivity of fiberglass, it nonetheless appears that they can assure absorption of over 99% of incident acoustic energy in a chamber for all frequencies above 200 cps. The coefficient of reflection fluctuates between 10% and 20% for frequencies between 100 and 200 cps.

372

Kushner, S. S., and N. E. Barnett, "Reverberation-Room Anechoic Chamber Transmission-Measurement Technique," WADC Tech. Rept. No. 59-130, Acoust. Lab., Inst. Sci. Tech. Univ. of Mich., Ann Arbor, 1959.
AD-229 870.

A preliminary investigation was undertaken to characterize several parameters involved in a reverberant source room — an anechoic termination method for measuring acoustic transmission. This method appears potentially capable of evaluating the acoustic transmission in great detail of samples possessing widely divergent physical characteristics. Exploratory experimentation included examination of reverberation-room diffusion, termination diffraction and directionality, effects of sample mass on transmission, and transmission of various stiff-panel configurations.

373

Mills, P. J., "Construction and Design of Parmly Sound Laboratory and Anechoic Chamber," J. Acoust. Soc. Am., 19, 988-992, 1947.

The chief feature of the laboratory is an anechoic chamber. The 40-ton chamber of concrete, steel, wood and sheet-rock construction is suspended on Neoprene pads to have a natural frequency of ~4 1/2 cps. Continuous ventilation through ducts of high sound attenuation, 90 db at 128 cps, is provided. The inner surfaces are designed to have 99% absorption or better at 115 cps or above. The Harvard treatment of wedge-shaped Fiberglas is used. The chamber is housed in a concrete block wing whose walls are lined with Fiberglas sheets. Costs in terms of man-hours are given.

374

Olson, N., "Acoustic Properties of Anechoic Chamber," J. Acoust. Soc. Am., 33, 767-770, 1961.

Measurements were made on the performance of an anechoic chamber built for the National Research Council of Canada, with the inverse square law adopted as the criterion of performance. Some deviations from the inverse square law were observed, and these were correlated with vibrational modes in the wedge-bearing inner walls. It was shown that maximum amplitudes of vibration occur in certain regions of the walls and occupy frequency ranges which coincide with frequency ranges for maximum deviations from the inverse square law. The phase of the vibrations along the walls varies in the same manner as the phase of the incident sound wave in the room. Blocking all experimental points in one of the walls improved room response by a small but consistent amount. Treating regions of maximum vibration in the walls as extended sources and combining contributions from these with the sound field of the source in the room made it possible to construct room characteristics similar to those observed.

375

Pronenko, L. Z., and A. N. Rivin, "Absorbant Linings of Glass Staple Fiber for an Anechoic Test Chamber," Soviet Phys. Acoust., English transl., 5, 387-388, 1960.

Absorbent wedges were cut with a band saw from rigidly cemented glass-fiber tile to provide a relatively strong and durable lining for an anechoic chamber. The absorptive quality of the wedges was determined by measuring their reflectivity in a specially-constructed, large, low-frequency interferometer. Reflected energy of less than 5% for frequencies above 60 cps was measured.

376

Rivin, A. N., "An Anechoic Chamber for Acoustical Measurements," Soviet Phys. Acoust., English transl., 7, 258-268, 1962.

The equipment and results of investigations of an anechoic chamber with a working volume of 370 cubic meters are described. Wedges fabricated from plates of fiberglass, specific gravity 150 kg/m^3, cemented firmly together by resins, are used for sound-insulation linings. The nonuniformity of the acoustic field in the working area of the chamber at a distance of 3 to 4 meters from the radiator does not exceed ± 0.5 db over a wide range of frequencies, beginning at about 60 or 70 cps.

377

Robinson, D. W., "Anechoic Chamber for Acoustic Measurements," Elec. Commun., 28, 70-77, 1951.

Design and constructional details are given. Methods of testing the quality of acoustic rooms are discussed and details are given of the tests made in this room. The results emphasize the difficulty of setting up a locally uniform sound field and the care necessary in selecting the sound source appropriate to a particular experimental purpose.

378

Schoch, A., "Theory of Linings for Anechoic Rooms, Based on the Principle of Gradual Transition, 'Noise and Sound Transmission'," Proc. Phys. Soc. (London), 167-173, 1949.

Following a consideration of the reflection of sound waves from uniform plates of porous material, an indication is given of the theoretical approach to the design of pyramid- or wedge-shaped elements of porous material projecting from the boundary surface for minimizing sound reflection. Curves are given for a linear wedge structure showing how the reflection factor depends on the frequency parameter, flow resistance parameter, and on the position in the structure.

379

Specht, T. R., "Facilities for the Westinghouse Power-Transformer Sound Room," Noise Control, 4, 10, 1958.

To test the noise output of large electrical transformers, Westinghouse Electric Corporation has built a 45 × 58 × 50-foot sound room. What it is used for and how it is instrumented are described in this article by one of the men who planned it.

380

Velizhanina, K. A., and S. N. Rzhevkin, "The Investigation of Sound-Absorbent Structures for the Anechoic Chamber of the Physics Department of the Moscow State University," Soviet Phys. Acoust., English transl., 3, 21-26, 1957.

The paper describes an experimental investigation of sound absorbent structures which are shaped in the form of cones and wedges. It proves that the best sound absorption (down to frequencies of 80 cps) is provided by a cone of glass fiber with a packing density of 0.12-0.14 g/cm^3 with an air space between the wall and the base of the cone which is equal to 1/3 of the height of the cone. Data are cited from several experiments on the use of a resonant sound absorber for the correction of the sound-absorption characteristic of a porous wedge in the low-frequency range.

Anechoic Chambers, Quite Rooms, Etc.
See also—35, 36, 118, 345, 529, 992, 1040, 1182, 1638, 1775, 1817, 1990, 2110, 2527, 2706, 2739, 3688

ARRAYS

381

Anderson, V. C., "Arrays for the Investigation of Ambient Noise in the Ocean," J. Acoust. Soc. Am., 30, 470-477, 1958.

A discussion of the important parameters to be considered in the use of directional arrays for the study of noise fields in the ocean leads to specialized array designs. Some properties of circular and spherical arrays composed of omnidirectional elements are presented. Consideration of these properties leads to an optimum selection of geometry and element spacing for each of two cases: a distributed noise source, and a set of point noise sources.

The calculation of directivity index for a spherical array is carried out by the use of the space-correlation functions of an isotropic noise field.

The measured, broad-band directivity pattern of a model circular plane array as a function of frequency is also shown.

382

Anderson, V. C., "Digital Array Phasing," Marine Phys. Lab., Univ. of Calif., San Diego, 4 pp., 1960.
AD-242 717.
See also: J. Acoust. Soc. Am., 32, 867-870, 1960.

The extension of digital techniques to the problem of processing the output of an array of point-receiving elements in an acoustic field has given rise to a method of phasing called DIMUS (digital multibeam steering). This digital technique incorporates the use of shift registers as delay line elements, which results in a number of operational advantages. The DIMUS technique is described. The effects of amplitude and time quantization imposed by the digital circuits are considered in the light of the relative signal processing gain of the array referred to as an exact analog phasing network. The processing gain is compared as a function of sampling frequency for a number of types of signals.

383

Baron, P., and J. Prunieras, "Results Obtained with a Group of Sound Sources," Rept. No. 6-1-8, U. S. Coast Guard, Washington, D. C., 8 pp., 1960.
AD-242 093.

By using n identical vibrators set on a vertical line at intervals of half a wave length and operating in phase, it was possible to obtain a substantial strengthening of the sound in the median horizontal plane; by comparison with a single vibrator with an acoustical power n times greater than that of each vibrator, the resulting level increase was 10 log n. In fact, it is the pressures that are added, in phase, and not the intensities. However, it is not evident that this result, obtained close to the source, will also obtain at a distance, owing to the irregularity of sound propagation in the atmosphere. It may also be expected that, in practice, the equality of power of the vibrators and above all, the phase control, will not be achieved by reason of the very principle of operation of the vibrator, the diaphragm of which is tuned to the excitor frequency (in particular, there is a significant phase variation when it is slightly out of time). An experimental test was conducted on a facility in operation. It was found that the efficiency of the group remains the same at long range. The results obtained in the test are less favorable than expected theoretically, because one of the vibrators is so weak that it contributes nothing to the group, and another is relatively strong.

384

Bellin, J. L. S., and R. T. Beyer, "Experimental Investigation of an End-Fire Array," J. Acoust. Soc. Am., 34, 1051-1054, 1962.

Experiments are reported on the measurement of the scattered pressure from two finite-amplitude, collinear sound beams. The measurements were carried out at a carrier frequency of 13.5 Mc in water and 350 kc in air. The slope of the half-pressure angle vs. difference frequency curve agrees well with that predicted by Westervelt, although the radiation pattern measured experimentally was in each case more directive than predicted by the theory.

385

Berman, A., and C. S. Clay, "Theory of Time-Averaged-Product Arrays," J. Acoust. Soc. Am., 29, 805-812, 1957.

The mathematical analysis of the directional characteristics of linear additive arrays is given in a polynomial representation. The result of multiplying and taking a time average of the outputs of several detectors also has directional characteristics that may be expressed as polynomials. It is shown that the same directional characteristics may be obtained from multiplicative arrays having a small number of detectors as with an additive array with a large number of elements. The length of the multiplicative array is about half the length of the additive array having the same directional characteristics.

386

Berman, H. G., and A. Berman, "Effect of Correlated Phase Fluctuation on Array Performance," J. Acoust. Soc. Am., 34, 555-562, 1962.

The response of a uniform array of point detectors receiving cw signals is computed under the assumption that there are correlations in the fluctuations of the phase of the signals. General formulas are developed for various ranges of correlation. It is shown that the peak response of an array is not appreciably reduced until the magnitude of the fluctuations becomes large. If the fluctuations are strongly correlated over many receiving elements, the main lobe will be broadened.

387

Bordelon, D. J., "Effect of Correlated Phase Fluctuation on Array Performance," J. Acoust. Soc. Am., 34, 1147, 1962.

It is shown that the expectation of the mean-square time-averaged response for a configuration of receivers is immediate from known statistical considerations.

388

Bourret, R. C., "Directivity of a Linear Array in a Random Transmission Medium," J. Acoust. Soc. Am., 33, 1793-1797, 1961.

A simple derivation is given of the phase autocorrelation function of a monochromatic signal during transmission through a medium with random fluctuations of refractive index. The resulting phase coherence function is then applied to the theory of the linear array antenna to yield a formula for the degraded directivity pattern.

The analysis developed here was conceived primarily with reference to acoustic signals and sonar ranging systems, although it may be applied, mutatis mutandis, to a wider variety of acoustic and even electromagnetic problems. For concreteness, however, we shall employ a vocabulary appropriate to the case of sonar signals and antennas.

The problem to be considered is the following: Given a source of monochromatic radiation situated far enough from the receiving antenna to be considered a point source, what will be the response, as a function of bearing angle, of a linear array antenna to the signal if the transmission medium has small random irregularities of its refractive index?

389

Brown, J. L., Jr., "Variation of Array Performance with Respect to Statistical Phase Fluctuations," J. Acoust. Soc. Am., 34, 1927-1928, 1962.

The effect of phase fluctuations on the mean-square time-averaged output of a discrete linear array is considered under the assumption that the fluctuations are governed by a Gaussian joint-probability density function. In particular, a closed-form expression is derived for the variance of the array output over the ensemble of phase variations.

390

Brown, J. L., Jr., and R. O. Rowlands, "Design of Directional Arrays," J. Acoust. Soc. Am., 31, 1638-1643, 1959.

From the application of information theory, it is found that for low s/n the best method of increasing the information content of a signal is to add the outputs of the elements of an array to improve the s/n. When the s/n is already high, however, the array should be designed so that independent information is supplied by each element when associated with a reference element.

The possibility of increasing directionality by nonlinear operations is then discussed. In particular, it is shown that for the noiseless case, a two-element array can be made to yield patterns equivalent to those produced by an n-element linear array. Linear maximum directivity arrays (in the sense of Pritchard) may also be synthesized with three omnidirectional elements and a number of nonlinear operations which remain invariant as the order of the equivalent linear array is increased.

Finally linear methods designed to minimize the mean squared error are considered, and it is found that array rotations are capable of giving optimum results under certain circumstances.

391

Bryn, F., "Optimum Signal Processing of Three-Dimensional Arrays Operating on Gaussian Signals and Noise," J. Acoust. Soc. Am., 34, 289-297, 1962.

The essential function of the optimum detector is that of applying a linear mean-square regression process to the output of the array and measuring the power in the residues thus formed. The elements required for instrumentation of the detector are deduced and numerical examples relating to specific array configurations are presented. At low frequencies the directivity pattern is the one having maximum directivity index.

392

Davids, N., E. G. Thurston, and R. E. Mueser, "The Design of Optimum Directional Acoustic Arrays," J. Acoust. Soc. Am., 24, 50-56, 1952.

A transducer array has been designed according to underlying theory originally applied to broadside electromagnetic antenna arrays by Dolph. The properties of Tschebyscheff polynomials have been employed to obtain an optimized relationship between minor-lobe level and main beam width.

The shading design of a 130-element circular array is carried out by utilizing a distance between stack centers of $5\lambda/8$. Experimental measurements of the resulting transducer give a peak sensitivity of -70 db below 1 volt for a field of 1 dyne per cm^2, 11° main beam width at the 3-db down points, and suppression of side lobes to more than 32 db below peak sensitivity.

393

Embleton, T. F. W., and G. J. Thiessen, "Efficiency of Circular Sources and Circular Arrays of Point Sources with Linear Phase Variation," J. Acoust. Soc. Am., 34, 788-795, 1962.

The intensity and power radiated from circular ring sources and circular arrays of point sources are derived from first principles. The shape of the radiation patterns and efficiency of power output are studied as a function of phase changes between different parts of the source and of the ratio of the over-all source dimensions to the wavelength of the sound field. These expressions are applicable to the reduction of noise from such sources as centrifugal and axial blowers and aircraft propellers. The relationship between the mathematical phase parameter and such mechanical quantities as the number of blades is described. As in the case of the linear source the radiated power drops if the phase parameter exceeds a certain critical value. However, the drop in the power for the circular source is greater than that for the line source. For the circular source alone the anomaly exists wherein the power—at most ratios of the source diameter to sound wavelength greater than about 0.6—is greater for a source "dephased" by a small amount than for one having all elements radiating in phase.

394

Embleton, T. F. W., and G. J. Thiessen, "Efficiency of a Linear Array of Point Sources with Periodic Phase Variation," J. Acoust. Soc. Am., 30, 1124-1127, 1958.

The radiation efficiency of a uniform linear array of point sources with periodic-phase variation is evaluated. Two different types of interference are found, depending on whether the characteristic length of the phase variation is greater or less than the wavelength of the sound radiated. In its application to suction roll silencing in paper mills it is found to be less effective than a linear continuous-phase variation.

395

Fakley, D. C., "Comparison Between the Performances of a Time-Averaged Product Array and an Intraclass Correlator," J. Acoust. Soc. Am., 31, 1307-1314, 1959.

Berman and Clay (J. Acoust. Soc. Am., 29, 7, 1957) have investigated the directional characteristics of a linear array of omnidirectional receiving elements when the output from these elements are multiplied together and time arranged in certain ways. They conclude that the same directional characteristics may be obtained from these "time-averaged product" (TAP) arrays having a small number of detectors as with an additive array having a large number of elements; they also show that there is some economy in terms of the over-all length of the array required to give a specified beam width. Because assessing the characteristics of a TAP array solely on the basis of its polar diagram is impossible, a detailed analysis is necessary to determine its usefulness in applications which require a system with a narrow polar diagram. Three particular applications are investigated: the detection of a point source against a noise background, the resolution of the signals from two closely-spaced point sources, and the exploration of the distribution of power across an extended source. For comparison purposes a parallel analysis is carried out for an intraclass correlation system. For simplicity the analyses are confined to investigating the performance of a four-element linear array with equal spacings between adjacent elements under elementary and idealized conditions. The results so obtained, however, are of general application. Two class-I TAP array systems are compared with the intraclass correlator, whose detection performance was analysed by Faran & Hills (Acous. Res. Lab., Harvard Univ., Tech. Memo No. 28, Nov. 1952). This is believed to be the most "efficient" detector in this application. (A class-I array is defined as one in which the number of time-averaging operations lies between N - 1 and 1/2N(N - 1), where N is the number of receiving elements. A class-II TAP array, which employs true multipliers, is obviously inferior to a class-I array in terms of detection performance and will not be considered. It has been shown by Melton et al. (see B. S. Melton and P. R. Kerr, Geophysics 22, 553, 1957, for example) that a class-II type of array employing coincidence detectors rather than multipliers has some useful properties, but it can be demonstrated that its detection performance is inferior to that of an intraclass correlator. Since class-III TAP arrays have the same detection performance as the system prior to the power and sum circuits, there is no need to analyse such arrays here.)

396

Faran, J. J., Jr., and R. H. Hills, Jr., "Wide-Band Directivity of Receiving Arrays," NR-384-903, Acoustics Res. Lab., Div. of Applied Science, Harvard Univ., Office of Naval Res., 17 pp., 1953.
AD-19 235.

The method of maximizing the directional gain of a receiving array (heretofore useful only at a single frequency) is extended to the case of operation at a finite bandwidth. Also shown is how to design for maximum effective gain in the presence of noise which might arise within the individual transducers or their preamplifiers. Some necessary noise-field correlations are computed, and numerical examples are included to show the effects of bandwidth and self-noise on the over-all gain for reception which can be achieved. The directional gain of a broadside linear array for operation at a finite bandwidth is always less than that for operation at a single frequency, but is always greater, and often considerably greater, than the gain realized by use of the single-frequency design at the finite bandwidth. Unlike the single-frequency design, whose directional gain falls very rapidly as the operating bandwidth is increased from zero, the wide-band designs operate with good gain over a wide range of bandwidths.

397

Federici, M., "The Telemetric Characteristics of a Passive Receiving Apparatus for Measuring the Distance of a Sound Source" (in Italian), Ric. Sci., 30, 2009-2020, 1960.

This paper theoretically investigates the possibility of finding the range of a sound source by means of a linear array of microphones whose outputs are fed to a central amplifier. Because of the phase differences, the amplifier output will depend on the range, and the range can be estimated by the addition of artificial delay lines. The output variation is similar to that obtained when the arrangement is used for direction finding.

398

Feik, K., "Directional Sound" (in German), Hochfrequenztech. u. ElektAkust., 64, 36-62, 1955.

The theory is given of the directional propagation of sound from various types of sound source. Consideration is given to the radiated sound power, the directional characteristics, and the amplification factor of various arrays and combination of sound sources. These include piston sources, line groups, circular groups, spherical groups, single and double radiators, and combinations of these. Diagrams are given of the radiation characteristics of these groups, and three-dimensional models are also reproduced.

399

Groves, G. V., "Trajectory Determination of a Supersonic Body by Acoustical Observations," J. Atmospheric Terrest. Phys., 12, 17-25, 1958.

A theory is developed for deriving the trajectory of a body moving at supersonic speeds through the atmosphere from observations on the times of arrival of its shock wave at a number of microphones at known points on the ground, wind and temperature effects being taken into account. It is shown that with 3n + 4 microphones, the position, velocity, acceleration, etc., up to the nth derivative of the spatial coordinates of the body with respect to time can be found at some determined instant of time. Hence, with seven microphones, the position and velocity of the body at a certain instant of time can be found, although four microphones are seen to be adequate for a more approximate determination of these quantities. Particular consideration is given to the method of solution in the seven-microphone case.

400

Hill, R. S., and C. Armstrong, "Aerodynamic Sound in Tube Banks," Proc. Phys. Soc., Great Britain, 79, 225-227, 1962.

Brief reference is made to experiments on two-dimensional air flow through tube banks having regular geometrical arrangements. At certain well defined velocities through the bank, intense acoustic noise is produced. With the arrangements described, it is shown that the frequencies of these sounds cannot be predicted either by vortex shedding (Lighthill) or in terms of the Strouhal number. It is concluded that the units to be considered for producing the sound are the velocity of the air-flow and space between two consecutive rows of tubes. This conclusion is further supported by the observed absence of sound in a "single-row" experiment.

401

Howard, W. H., "Remote Recording System for Sonic Observation of Trajectory and Impact of Missiles," Army White Sands Signal Agency, White Sands Proving Ground, N. Mex., 18 pp., 1957.
AD-135 449.

The remote recording system of sonic observation of the trajectory and impact of missiles (SOTIM) requires interception of the acoustic front which is generated by a missile in flight. Data is collected by recording the individual outputs of microphones arrayed in clusters. These clusters, separated by distances varying from twenty to one hundred miles, require associated recording equipment, communications equipment, and shelter. A new system of operations for the SOTIM has been designed which offers considerable logistic, equipment, and equipment-maintenance advantages, and which requires fewer personnel. The development and present status of this new operational system are discussed in this report.

402

Jacobson, M. J., "Analysis of a Multiple Receiver Correlation System," J. Acoust. Soc. Am., 29, 1342-1347, 1957.

This is a theoretical study of an acoustic receiving system containing a single correlator whose inputs are obtained from arrays of omnidirectional receivers. Mathematical expressions are developed for the mean system output when the input arises from a distant localized signal source. In addition, two major advantages of multiple receiver correlation as compared with two-receiver correlation are discussed in detail. These are improved directional patterns on narrow-band signals and increased output s/n resulting from the use of more than two receivers.

403

Jacobson, M. J., "Correlation with Similar Uniform Collinear Arrays," J. Acoust. Soc. Am., 30, 1030-1034, 1958.

This report concerns the nature of the mean output of a single correlator receiving system when the input is a narrow-frequency-band signal arising from a localized source in space. The signal is received by two uniform, collinear arrays having an equal number of omnidirectional receivers. The mean output as a function of steering is bounded by the product of the space factors of the two arrays, so that the gross nature of the mean can be determined by investigating the main lobe width and side lobe level of the space-factor product. These two quantities are studied as functions of the number of receivers, the receiver spacing in wavelengths, and source direction.

404

Jacobson, M. J., "Optimum Envelope Resolution in an Array Correlator," J. Acoust. Soc. Am., 33, 1055-1060, 1961.

This paper considers a correlator detector which processes the outputs of two identical collinear arrays of uniformly spaced elements. When the input signal is sinusoidal, the mean system output is bounded by the product of the space factors of the arrays. Complex amplitude factors are introduced following each element, and it is shown how to choose them in order to optimize the main-lobe-width-side-lobe-level relationship of the space-factor product or envelope. In addition, it is proved that the use of amplitude factors for improving envelope resolution gives rise to an s/n degradation relative to the corresponding uniform amplitude system. Various numerical results are given, including the fact that the optimum system provides an envelope main-lobe-width reduction of approximately 30% when 20 or fewer elements appear in each array.

405

Jacobson, M. J., "Optimum Envelope Resolution in an Array Correlator," Math Rept. No. 44, Rensselaer Polytechnic Inst., Troy, N. Y., 6 pp., 1961.
AD-264 432.

This paper considers a correlator detector which processes the outputs of two identical collinear arrays of uniformly spaced elements. When the input signal is sinusoidal, the mean system output is bounded by the product of the space factors of the arrays. Complex amplitude factors are introduced following each element, and it is shown how to choose them in order to optimize the main-lobe-width-side-lobe-level relationship of the space-factor product or envelope. In addition, it is proved that the use of amplitude factors for improving envelope resolution gives rise to an s/n degradation relative to the corresponding uniform amplitude system. Various numerical results are given, including the fact that the optimum system provides an envelope main-lobe-width reduction of approximately 30% when 20 or fewer elements appear in each array.

406

Kennedy, W. B., et al., "Study of Meteorological and Terrain Factors Which Affect Sound Ranging," Denver Research Inst., Univ. of Denver, Colo., 1954-1957.

Qrtrly. Prog. Rept. 1, March-May 1954, AD-38 446
" " " 2, June-August 1954, AD-43 297
" " " 3, September-November 1954, AD-54 480
" " " 4, December 1954-February 1955, AD-61 530
" " " 5, March-May 1955, AD-70 078
" " " 6, June-August 1955, AD-74 855
" " " 7, September-November 1955, AD-95 798
" " " 8, December 1955-February 1956, AD-95 799
Final Report, March 1954-April 1956, AD-139 326
Qrtrly. Prog. Rept. 1, May-July 1956, AD-140 087
" " " 2, August-October 1956, AD-140 088
" " " 3, November 1956-January 1957, AD-140 090
Interim Prog. Rept., February-August 1957, AD-160 696

This series of reports covers four years of intensive theoretical and applied research and development on sound-ranging as influenced by meteorological and terrain factors. The general problem of increasing the accuracy of sound-ranging by means of corrections based on meteorological and topographical conditions is discussed. Equations are presented for applying wind and temperature corrections to reduce error in observed sound-source azimuths. Problems encountered in setting up the field operation to provide data for a study of meteorological and terrain corrections for the whole sound path are analyzed. Proposed methods for time measurement of sound arrivals, temperature measurement, control of field operations, and power distribution are presented in detail.

The firing-recording arrays are described. The results and the methods of reducing data are given. Special investigations include: an analysis of the problem of acoustic ray-tracing in the atmosphere; determinations of the sonic data obtainable with various geometries of detecting arrays; an analysis for determining the velocity of sound; studies of errors generated within the Short-Range Whole-Path Firing-Recording Array by elevation differences, angular errors in placing the sensing microphones, and errors due to the assumption that the wave front is plane; a study determining the effect of oscillogram-reading errors on calculated sound-wave-arrival azimuths; a discussion of methods of removing data from oscillograms; and tests to determine the calibration requirements of the T-23 microphones. Other discussions include microphone-wind-shield development, the surveying program, and the general field operational problem.

The application of a drift correction to the primary sound-ranging information provided results superior to those obtained by standard artillery methods. For these calculations, data were used from an array of 14 microphones arranged in an isosceles-trapezoidal configuration. The arrival azimuth obtained by using this configuration is more representative of the direction of arrival of the acoustic wave front than that obtained by standard methods. The corrections which were applied for the refraction of the wave front along its path do not appear to be greatly significant from a study of the small sample presented.

407

Kirvida, L., and C. M. Harris, "A Study of Phase Characteristics of 45 CPS Sound Propagated in Air," Tech. Rept. No. TR-9, Electronics Res. Labs., Columbia Univ., N. Y., 44 pp., 1958. 1958.
AD-202 835.

An indication of the effect of phase fluctuations, which result from propagation of sound through inhomogeneous atmospheric conditions, was obtained on an acoustic phased array detection system. Sound from a 45-c pure tone source (located on the ground in rather flat terrain) was transmitted to two microphones at ground level, which were some distance away at approximately equal distances from the source. The acoustic signals received at each microphone were recorded on a two-channel magnetic tape as a function of time; for a given set of conditions, one such recording was made for each of five different spacings between the two microphones. Twenty-one sets of data (of five recordings each) were obtained for various atmospheric conditions and for different distances between the sound source and the microphones. These recordings provided a convenient method of storing the information from which the required phase characteristics were obtained. The following information was obtained: (1) the phase difference between the acoustic signals was plotted about the mean value for a 50-sec interval, for each of the 21 runs, (2) the autocorrelation function for each of the graphs was calculated for time intervals between 0 and 20 sec, (3) the mean square value of the phase difference about the mean value was computed, and (4) the rms values of the summed output of ten microphones spaced at half-wavelength intervals in the form of a linear array were computed and are an indication of the effect of atmospheric fluctuations on the operation of an acoustic phased array detection system for the meteorological conditions existing during our tests.

408

Kock, W. E., "Related Experiments with Sound Waves and Electromagnetic Waves," Proc. I.R.E., 47, 1192-1201, 1959.

Various analog situations in acoustic and electromagnetic waves are described. Certain higher order modes of airborne sound waves in tubes possess a transverse or polarized nature, and electromagnetic properties such as cut-off effects, polarization rotation, and circular polarization can be shown for these sound waves. Externally guided sound waves, similar to radio waves guided by a dielectric rod, are also discussed, as are super-directive acoustic and electromagnetic arrays, space-frequency equivalence in arrays, and experiments in wave diffraction.

409

Mangulis, V., "Infinite Array of Circular Pistons on a Rigid Plane Baffle," J. Acoust. Soc. Am., 34, 1558-1563, 1960.

The performance of an array is affected by the interaction of the array elements, expressed as a radiation impedance. For a circular piston in an infinite planar array the radiation impedance is calculated as a function of distance between elements and the angle to which the array is steered.

410

Martin, G. E., and J. S. Hickman, "Directional Properties of Continuous Plane Radiators with Bizonal Amplitude Shading," J. Acoust. Soc. Am., 27, 1120-1127, 1955.

The problem of reducing the levels of the minor lobes of linear, rectangular, and circular radiators is considered theoretically. The shading is accomplished by using equiphase normal-velocity distributions limited to two discrete amplitudes. Relationships are derived for the sound-intensity directivity pattern and the directivity index of each radiator. An exhaustive study of various directional properties of such radiators is undertaken. This information is presented in terms of the behavior of the major-lobe width, minor-lobe levels, and directivity index as functions of (1) the ratio of the two normal-velocity amplitudes and (2) the fraction of the unit having the higher source amplitude. It is shown that linear and rectangular radiators with such source distributions can be designed so that all minor-lobe levels are at least 21 db lower than the major-lobe level; the corresponding value for the circular radiator is 28 db. The resultant increase in major-lobe width is approximately 20%. The results are presented so as to provide criteria for the effective use of this method in transducer design.

411

Olsen, R. O., "Acoustical Determination of Winds by Means of a Circular Microphone Array," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 77-87, 1961.
AD-408 716.

An experimental acoustical circular array was set up to determine the wind field near the surface. The array consists of eight microphones placed in a circle, with a sound source at the center. A wind component is determined for each of the eight points from the time arrivals of sound at the microphone positions. By statistically averaging these components a mean wind vector is derived which best fits the various wind components. The accuracy of the mean wind is determined, and some of the errors inherent in the system are described. This data is also compared to the readings from standard measuring equipment located at the site.

412

Parke, N. G., III., "Mathematical Methods in Acoustic Transducer Array Theory," Final Rept., Parke Mathematical Labs., Carlisle, Mass., 31 pp., 1961.
AD-274 262.

Analytical ideas and calculations are presented with preliminary ideas for analog pressure distribution calculation and display. It is felt that both analogs and mathematical analysis have much to offer in gaining an understanding of various features of the near sound field of transducers and arrays.

413

Pritchard, R. L. "Approximate Calculation of the Directivity Factor of Linear Point Arrays," J. Acoust. Soc. Am., 25, 1010-1011, 1953.

An approximate method of calculation is developed in which the reciprocal of the directivity factor of a linear array of equispaced point elements is interpreted as an area beneath the curve of the square of the directional characteristic (relative sound pressure at a large fixed distance) expressed as a function of an auxiliary variable. Data required for the approximate calculation are the spacing between the elements of the array, their relative excitation, the beam width of the pattern, and the value of the average amplitude of the minor lobes of the pattern. The utility of the method is illustrated by a numerical example: a broadside array of 13 uniformly-excited elements with a relative spacing of $d/\lambda = 7/8$. The directivity index obtained by the approximate method described agrees within 0.3 db of the exact value.

414

Pritchard, R. L., "Maximum Directivity Index of a Linear Point Array," J. Acoust. Soc. Am., 26, 1034-1039, 1954.

The maximum directivity index of a symmetrical, linear point array has been calculated as a function of the number and spacing of the elements in the array. The excitation required to produce a maximum directivity index is not uniform, except for integral-half-wavelength element spacings, and in general the minor lobes of the directional response patterns produced are not of equal or of small amplitude. For element spacings exceeding a half-wavelength, a conventional type of pattern and of excitation is found to produce the maximum directivity index. On the other hand, as the element spacing is reduced below a half-wavelength, the directivity patterns corresponding to the maximum directivity index become superdirective, and the directivity index may be improved relative to the value obtainable with uniform excitation. However, this improvement is obtained only at the expense of requiring large, reversed-phase excitation. Numerical results are presented for three-, five-, and seven-element arrays.

415

Pritchard, R. L. "Optimum Directivity Patterns for Linear Point Arrays," J. Acoust. Soc. Am., 25, 879-891, 1953.

The sharpest major lobe of a directivity pattern due to a linear array of equally-spaced point elements is achieved when the elements are excited in such a manner that all minor lobes in the pattern have the same relative amplitude. Methods of producing such equal-minor-lobe patterns originally given in the radio literature by Dolph and by Riblet are summarized briefly in this paper. In particular, the synthesis method indicated by Riblet is described in general terms, and the effect of the element spacing is discussed in detail. Included in this discussion is the subject of super-directivity. Results of numerical calculations based on these methods are presented as families of curves showing the relationships existing among angular width of the major lobe, relative amplitude of the equal minor lobes, directivity index, and number and spacing of the elements in the array for 5-13 odd numbers of elements. In addition, the synthesis methods are extended to compensated, or steered, arrays.

416

Rhian, E., "An Exact Method for Determining the Directivity Index of a General Three-Dimensional Array," J. Acoust. Soc. Am., 26, 704-706, 1954.

An exact method for determining the directivity index of a general three-dimensional array with phased elements is described. The expression for the reciprocal of the directivity factor is shown to be a sum of terms which are simple functions of the sensitivity, phasing, and location of the elements of the array. As an example, the method is applied to a sixteen-element plane array.

417

Rudnick, P., "Small Signal Detection in the DIMUS Array," J. Acoust. Soc. Am., 32, 871-877, 1960.

In the DIMUS system for steering an acoustic array, the output of each element is reduced to a sequence of polarity samples and delayed by an integral multiple of the sampling period. Calculations are given to show the effect of this process on the passive detection threshold of an array beam (in isotropic Gaussian noise) both generally and numerically for several examples. In these, over-all losses range from 0.5 to 1.5 db.

418

Simmons, B. D., "Radiation Impedance of Arrays of Finite Spherical Sources," Rept. No. 123, Chesapeake Instrument Corp., Maryland, 14 pp., 1960.
AD-243 127.

Calculations were obtained of the radiation impedance of acoustic arrays consisting of simple spherical sources of finite radii. These results apply to arrays at low frequencies such that the dimensions of individual elements are small compared to a wavelength. By varying the radii of the spheres, the overall dimensions of the array can be varied, or, with given dimension of the array, the amount of packing can be varied. Results are given for the radiation resistance of square arrays consisting of 16 and 25 elements.

419

Stone, J., "Problems Associated with the Measurement of Ambient-Noise Directivity by Means of Linear Additive Arrays," J. Acoust. Soc. Am., 34, 328-333, 1962.

The problems associated with determining the angular distribution of continuous and discrete noise sources by means of a linear additive array are discussed. A spatial frequency analysis shows that an array acts as a low-pass filter in the spatial frequency domain and hence cannot distinguish between spatial-noise distributions whose spatial spectra differ outside the spatial bandwidth of the array. It is shown that smoothing due to side-lobe response results in a large reduction in the ability of an array to measure accurately peaks in the angular distribution.

420

Swingle, D. M., "Atmospheric and Geometric Considerations in Sound Location Data Processing," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 162-167, 1961.
AD-408 716.

Several ways of processing data obtainable by two-dimensional square microphone arrays are examined, and the optimum formulation is selected given specified random errors. The role of atmospheric turbulence in base-line length selection is discussed in the light of recent progress in this country and the USSR.

421

Thiessen, G. J., and T. F. W. Embleton, "Efficiency of a Linear Array of Point Sources with Linear Phase Variation," J. Acoust. Soc. Am., 30, 449-452, 1958.

The radiation efficiency of a linear array of point sources with linear phase variation is solved by using different approximations for different ranges of the phase parameter. The results are compared with experimental results on small models and also on full-scale suction rolls in paper mills with different drilling patterns. The experiments agree quite closely with theory and indicate that a noise reduction of 15 to 30 db can be obtained by the choice of a substitute drilling pattern that can easily be drilled by multiple spindle machines. Design charts for choosing and evaluating drilling patterns are given.

422

Thomas, J. B., and T. R. Williams, "On the Detection of Signals in Nonstationary Noise by Product Arrays," J. Acoust. Soc. Am., 31, 453-462, 1959.

Two detection systems having multiple inputs each consisting of nonstationary noise and a stationary random signal are analyzed and compared on an s/n basis. In both systems the inputs are divided into two groups and the sum of each group is formed. In the first system the resulting two wave forms are multiplied directly and the product averaged. In the second system the two wave forms are strongly clipped prior to multiplication, forming a polarity-coincidence correlator. Previous studies have shown the latter system to be slightly inferior for stationary noise. The results of this paper show that the latter system may be quite superior in certain types of nonstationary noise.

423

Tucker, D. G., "The Signal Noise Performance of Electro-Acoustic Strip Arrays," Acustica, 8, 53-62, 1960.

The directional patterns (or directivity curves) and the s/n performance of 14 different arrangements of a strip array are discussed and tabulated. The 14 arrangements include five used for the determination of the direction of a received signal by a null method. The noise concerned includes the thermal-agitation noise of the array, the noise generated in the receiving amplifiers, and to a large extent also noise arising in the medium of transmission. The noise factor used in these calculations is shown to be closely related to the directivity index (or power gain) in ordinary tapered arrays. The paper is written in terms of electro-acoustic arrays, but applies equally in principle to electromagnetic arrays.

424

Tucker, D. G., "Signal Noise Performance of Super-Directive Arrays," Acustica, 8, 112-116, 1960.

A super-directive array is defined as one whose effective aperture exceeds its physical aperture; it is shown that while such an array has a directivity index somewhat better than that of an ordinary array, nevertheless its noise factor is much worse. Consequently, in many receiving systems, the use of super-directivity is not to be recommended. The conception of super-directivity is extended to bearing-determining arrays which give a null response on the axis, and it is shown that the same disadvantage of a bad noise factor applies to them also.

425

Tucker, D. G., "Some Aspects of the Design of Strip Arrays," Acustica, 6, 403-411, 1960.

Gives a simple treatment of the design and performance of strip arrays from the point of view of their far-field directional patterns, including as an important example the determination of the bearing of a received signal. The main principle involved is that of synthesizing any arbitrary pattern by the linear superposition of curves of the $x^{-1} \sin x$ type, having suitable peak amplitudes spaced at intervals of π in the x-scale. The treatment of the design of arrays by this process gives a clear picture of the relationship between the directional pattern and the distribution of excitation or sensitivity (according to whether transmission or reception is concerned) over the length of the array.

426

Welkowitz, W., "Directional Circular Arrays of Point Sources," J. Acoust. Soc. Am., 28, 362-366, 1956.

The Fourier series solution for the radiation field of a circular pressure ring is applied to the synthesis of a sound field expressed in the form of a Tchebyscheff polynomial. This leads to an exact solution in closed form for the amplitude and phase of excitation of point source elements on a circle when the main lobe width of the radiation pattern, the side lobe suppression, and the array circle diameter are specified. Calculations are carried out to two sample beam patterns to show the effects of different choices of array circle diameter and number of point source elements.

427

Westervelt, P. J., "Parametric Acoustic Array," Dept. of Phys., Brown Univ., Providence, R.I., J. Acoust. Soc. Am., 35, 535-537, 1963.

This paper presents the theory of highly directional receivers and transmitters that may be "constructed" with the nonlinearity of the equations of fluid motion.

428

Zimmermann, K. H., "A New Directional Analysis and Its Application to Acoustic Measurements" (in German), Acustica, 12, 206-221, 1962.

This paper describes a directional array which is equivalent to a linear row of microphones with electrically-swept directivity pattern. The arrangement makes use of one microphone only, moved at constant speed on a straight line through a stationary sound field. The array is applied for the measurement of the angular distribution of sound in a flat chamber excited with a narrow band noise with various scattering obstacles brought into the room.

Arrays — See also Correlation
See also — 515, 556, 562, 634, 645, 647, 651, 654, 655, 656, 682, 691, 698, 704, 705, 754, 926, 981, 1086, 1117, 1159, 1160, 1163, 1165, 1180, 1181, 1245, 1249, 1252, 1260, 1363, 1377, 1386, 1425, 1435, 1436, 1437, 1438, 1439, 1443, 1444, 1447, 1459, 1471, 1538, 1602, 1715, 1981, 2118, 2120, 2121, 2125, 2131, 2133, 2288, 2289, 2291, 2297, 2298, 2300, 2301, 2305, 2308, 2309, 2490, 2491, 2581, 2603, 2688, 2700, 2720, 2858, 3237, 3383, 3392, 3831, 3914

ATTENUATION, ATMOSPHERIC

429

Acoustics Lab., Mass. Inst. of Tech., "Quarterly Progress Reports," Cambridge, 1950-1957.

This is a seven-year series of quarterly progress reports on government-sponsored research contracts with the Acoustics Laboratory of MIT. A wide variety of problems in acoustics was investigated. Among a host of miscellaneous items, all issues contain one or more brief reports on research related to the propagation of sound in air. Typical subject headings are: atmospheric acoustics; scattering of sound from a vortex; short range propagation in the atmosphere; propagation of sound waves of finite amplitude; absorption of sound in gases; scattering of sound from turbulence; sound field from a random noise source above ground; wind-created shadow formation over ground; instrumentation for field measurements of sound propagation; scattering of sound by sound; acoustic behavior in moving media; diffraction and scattering into the shadow zone; outdoor sound propagation measurements; the effect of a ground layer with a temperature inversion on the field within an acoustic shadow zone; and, computation of the sound field over an absorbing surface. The following is a complete list of MIT Acoustic Laboratory Quarterly Reports with corresponding DDC Document numbers where applicable.

July-September 1950
October-December 1950
January-March 1951
April-June 1951
July-September 1951
October-December 1951
January-March 1952
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October-December 1952, AD-7 815
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April-June 1953, AD-16 881
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January-March 1954, AD-35 322
April-June 1954, AD-44 511
July-September 1954, AD-49 532
October-December 1954, AD-54 507
January-March 1955, AD-61 541
April-June 1955, AD-70 101
July-September 1955, AD-76 096
October-December 1955, AD-85 884
January-March 1956, AD-102 751
April-June 1956, AD-107 074
July-September 1956, AD-110 161
October-December 1956, AD-117 032
January-March 1957, AD-117 117
April-June 1957, AD-133 735
July-September 1957, AD-133 794

430

Arabadzki, V. I., "Absorption of Acoustic Waves in Humid Air and Fog" (in Russian), Meteorol. i Gidrol., 3, 11-18, 1947.

The paper contains a survey of the present state of knowledge of the theory of absorption of sound waves in clouds and fog. It discusses size of water drops in the atmosphere, frequency of sound waves being propagated, chemical composition, sound, and zones of silence.

431

Arabadzhi, V. I., "Acoustical Characteristics of the Air Layer near the Ground" (in Russian), Uch. Zap., Leningr. Gos. Ped. Inst., 7, 87-91, 1957.

Investigations of sound propagation in the ground layer of the atmosphere over various natural surfaces are described. The measurements were made over a straight road, a flat grass field, a water surface, and a depression, with a microphone joined to an amplifier output by a millivoltmeter. Sound reflection from a dense grass cover, from a surface of cut grass, and from bushes and leaves was recorded at frequencies of 0.2-4.0 kcs. The effect of atmospheric temperature inhomogeneities upon sound attenuation was investigated by means of laboratory apparatus, which is described in detail. In these laboratory experiments attenuation coefficients between 10^{-5} and 10^{-4} cm^{-1} were obtained, which is in fair agreement with investigations made in the free atmosphere.

432

Baron, P., "Propagation of Sound in the Atmosphere and Audibility of Warning Signals in the Presence of Ambient Noise" (in French), Ann. Telecommun., 9, 258-274, 1954.

In an introductory section the author reviews the various factors which affect the long distance propagation of sound in the atmosphere: attenuation (influenced by water vapor content), winds, and temperature gradients. A description follows of experiments carried out in "les vals d'Yonne." Sirens were used as sound sources at different heights above the ground, and wind and temperature gradients were recorded and correlated with the observed signal strengths received. Variations of signal strength were recorded at different distances from the source and at various times of the year. The effects of noise and wind on the audibility of the received signals were studied.

433

Benson, R. W., and H. B. Karplus, "Sound Propagation Near the Earth's Surface as Influenced by Weather Conditions," WADC Tech. Rept. No. 57-353, Armour Research Foundation, Chicago, 1958.
AD-130 793.

The influence of various weather conditions on sound propagation in the atmosphere has been studied. The source was a propeller-type aircraft flown at altitudes up to 4800 feet and at distances up to 9600 feet. The propagation was studied for angles of elevation with respect to the earth's surface of 14-1/2^{o}, 30^{o}, and 90^{o}. Noise data were collected for 1300 passes of the airplane over and around a ground observing point. The weather conditions varied during a year's time to include typical weather conditions available in the Chicago area. The noise propagated to the earth was analyzed to determine the variation in attenuation as a function of frequency and as a function of the relative position of the airborne noise source. A statistical analysis determined the effects of various weather parameters on sound propagation. Average values of sound attenuation were obtained. The effects of temperature, temperature gradient, humidity, wind, and wind gradient are given in an empirical formula. Wind direction was the most important factor for minimizing the noise on the ground on a particular day.

434

Bolt, Beranek, and Newman, Inc., "Investigation of Acoustic Signalling over Water in Fog," Final Rept. on Phase 1, Evaluation of Present U. S. Coast Guard Design Procedure for Fog Signals, Cambridge, Mass., 14 pp., 1960.
AD-236 583.

The present USCG design procedure for fog signals represents considerable progress over previous methods. It is based on the concept of the average audible range and uses a fixed loudness level as the criterion for detection. Sound sources are specified in terms of the on-axis free-field sound pressure level at a distance of 25 feet. The transmission path is described by means of a curve of average sound transmission loss obtained many years ago. The following areas of improvement and refinement are suggested: (1) description of the sound source in terms of acoustic power output and directivity; (2) description of the transmission path by means of sound attenuation functions which take into account, in addition to frequency and distance, such parameters as source and receiver heights, wind direction and speed, and temperature and wind gradients, on a statistical basis; (3) description of the process of signal detection and location by the listener in terms of a detection criterion of minimum s/n, taking account of background noise levels and spectra, signal frequency and duration, and other relevant factors.

435

Bolt, Beranek, and Newman, Inc., "Investigation of the Transmission of Sound Through Fog over Water," Final Rept. on Phase 2, Investigation of Acoustic Signalling over Water in Fog, Cambridge, Mass., 1960.
AD-236 659

The physics of sound propagation along the surface of the earth is discussed with particular attention to the conditions existing where sound is propagated for long distances over ocean waters in fog. The results of an extensive measurement program of sound transmission over water are presented, together with the results of measurements of the relevant micrometeorological parameters and a description of the instrumentation and experimental techniques used. The experimental data are analyzed in the light of available theory with a view of applying the results in generalized form to an improved design procedure for audible fog signals. Among the more important conclusions resulting from the analysis and evaluation of the field studies presented in this report are as follows.

(1) The propagation of audible sound over ocean waters in fog is governed by the same micrometeorological parameters which determine the propagation of audible sound over land. (2) The presence of wind and temperature gradients just above the surface of the ocean causes the sound to be refracted from the normal straight-line path. As a consequence the useful range of a fog signal may be severely limited upwind from the signal. (3) The sound attenuation caused by fog itself is generally too small to be of engineering importance for typical fogs encountered along the Eastern Seaboard.

436

Brandt, O., "On the Influence of Water Vapor and Fog Content of the Air on the Absorption of Sound and Ultrasonic Waves" (in German), Meteorol. Z., 55, 350-354, 1938.

This paper stresses the effects of weather conditions on sound absorption, particularly the importance of humidity and fog content. It briefly treats the propagation of ultrasonic waves.

437

Burkhard, M., H. Karplus, and H. Sabine, "Sound Propagation near the Earth's Surface as Influenced by Weather Conditions," WADC TR 57-353, Armour Research Foundation, Chicago, 1961.
AD-254 670.

The effects of weather on the propagation of sound from an elevated source to the ground were studied. Measurements include weather conditions in Arizona and propagation angles down to 2 degrees elevation above the horizon. Attenuations were correlated with absolute humidity, temperature, temperature gradient, wind velocity, and wind direction. For source elevations of 5 degrees and higher and source altitudes above a few hundred feet, only temperature and absolute humidity have a significant effect on attenuation. For source elevations of less than 5 degrees large attenuations occur in the presence of strong wind and temperature gradients. These are due to upwind refraction of sound and the resulting creation of shadow zones on the ground.

438

Chrisler, V. L., and C. E. Miller, "Factors Which Affect the Measurement of Sound Absorption," Bur. Standards J. Research, 9, 175-185, 1932.

It has been found that air has an appreciable absorption for sound at frequencies as low as 512 ~. This absorption varies with the temperature, the moisture content and the barometric pressure. Curves are given showing such changes in absorption in the reverberation room at the Bureau of Standards. Attention is called to the fact that when a highly absorbent sample is placed in a very reverberant room the decay curve may not be logarithmic.

439

Coast Guard, "General Report on the Attenuation of Sound Transmitted over Water," Rept. No. General-4, Washington, D. C., 23 pp., 1960.
AD-242 003.

Data on fog signal attenuation versus range for various frequencies were processed to permit direct comparison of the shape of the attenuation function. A comparison procedure was devised and applied to a comparison of the signal levels based upon the various attenuation functions for downwind transmission. Attenuation curves for upwind transmission of fog signals is extremely diverse. The Coast Guard data agrees with the attenuation versus range expected from theory.

440

Condron, T. P., and W. S. Ripley, "Acoustic Propagation in the Atmosphere," in Handbook of Geophysics for Air Force Designers, Air Force Cambridge Research Center, U. S. Air Force, Chap. 21, 14 pp., 1957.

Normal propagation of sound in a homogeneous atmosphere is reviewed as an introduction to anomalous propagation and absorption in a realistic atmosphere. Spreading and diffraction losses in a refractive medium are described and followed by a brief treatment on ray geometry as applied to sound in air. Attenuation of sound in air due to classical absorption and molecular absorption is described. Several charts and graphs are included from which absorption per unit distance can be determined as a function of meteorological parameters such as temperature and humidity. A final section on noise sources includes data on sound pressure levels and octave band analyses from jet and reciprocating engines, helicopters, and backgrounds in industrial, residential, and jungle areas.

441

Cox, E. F., "Sound Propagation in Air," in Handbuch der Physik (Encyclopedia of Physics), 48, 455-478, 1957.

This paper begins with a review of the basic laws of propagation of sound energy in air and explains why weak sound waves propagate with negligible distortion, while high amplitude sound waves distort and form shock fronts as they propagate. Expressions for shock wave velocity are given.

Meteorological factors affecting the speed and direction of sound rays are described, and the laws of sound ray refraction and reflection are reviewed. Absorption and dispersion of sound in real atmospheres are described. Formulas and graphs are given for determining attenuation with distance. Propagation of sound to great distances is treated in detail. Refraction in the troposphere and the formation of sound ducts at tropopause heights are described and documented. An excellent bibliography is included.

442

Dahl, H., and O. Devik, "Effect of Turbulence on the Propagation of Sound," Nature, 139, 550-551, 1937.

Results of studying the attenuation of sound at sea surface suggest that studying the attenuation of a sound spectrum in open air might furnish a method for studying air turbulence.

443

Dean, E. A., "Absorption of Low Frequency Sound in a Homogeneous Atmosphere," Schellenger Res. Lab., Texas Western College, El Paso, 1959.

This is a review of the classical and molecular theory of the absorption of sound, with particular attention to the absorption of frequencies less than 1000 cps in the atmosphere from sea level to 50 km. The variation of the theoretically predicted absorption with the meteorological parameters—pressure, temperature, and humidity—is investigated. Recent work involving absorption due to radiation is included. It is found that the absorption can be expressed as:

$$\frac{2.5 \times 10^{-7}(T^*)^{0.3}f^2}{P^*} + \frac{5.3 \times 10^{-5}(T^*)\,f}{P^*} + \frac{1.0 \times 10^2 f}{(T^*)^{2.5}e^{8.3/T^*}}\;\frac{2f_0 f}{f_0^2 + f^2}$$

db/mile, where

$$f_0 = \frac{P^*}{(T^*)^{0.8}}\left[900\left(\frac{wT^*}{P^*}\right)^2 + 500\,\frac{wT^*}{P^*} + 50\right]$$

$T^* = T/273$, $T = {}^{\circ}K$, P^* = pressure in atmospheres, and w is the absolute humidity in gm/m^3.

The absorption has been calculated for various altitudes, humidities, and frequencies. These data are presented in tabular form in the appendix. Although the absorption varies in a rather complicated manner with the meteorological parameters, it is found to be quite small for the very low frequencies, resulting in a predicted long distance propagation with small attenuation if the geometry of propagation is advantageous.

444

Dean, E. A., "Absorption of Sound in the Atmosphere," Proc. Symp. Atmos. Acoust. Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. M., 1, 50-56, 1961.
AD-408 716.

The classical and molecular theories of the absorption of sound for low f/p ratios are reviewed. The absorption is discussed as a function of frequency and atmospheric pressure, temperature, and composition, including recent work on the determination of the vibrational relaxation time due to small amounts of water vapor. The possible importance of absorption due to radiation is mentioned.

445

Dean, E. A., "Sound Transmission Loss for Near-Vertical Atmospheric Propagation," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 224-232, 1962.
AD-408 716.

The sound transmission loss in the upper atmosphere is formulated. It is divided into divergent, refractive, and absorption losses, which are derived for an inhomogeneous, moving, layered medium. This calculated loss is then compared to the measured loss for high-altitude grenade detonations (30-90 km), using the data from rocket-grenade experiments performed at Fort Churchill, Churchill, Canada. As expected, an excess loss is found for the lower altitude grenades; however, the actual loss is less than the calculated loss at the higher altitudes.

446

Delsasso, L. P., "The Attenuation of Sound in the Atmosphere," Dept. of Phys., Univ. of Calif., Los Angeles, 37 pp., 1953.
AD-89 256.

The attenuation of sound at sea level pressures and normal temperatures is extended to pressures and temperatures which may be encountered in acoustical signalling and tracking problems. Measurements were made both in the laboratory and in the field. In the laboratory results are reported for the frequency range 1000 to 6000 cps for a temperature range of from 2° to 35°C and for pressures from 76 to 26 cm of Hg. In the field, measurements have been obtained at an altitude of 10,000 feet for representative variations of meteorological conditions. Limits for the possible absorption coefficients to be met with in practice have been extablished. Progress is reported on the development of instruments to measure more accurately the details of the meteorological conditions excountered, particularly with reference to the accurate description of natural fogs. Instrumentation for measuring the attenuation of sound under laboratory conditions and the attenuation of sound propagating outdoors is described and illustrated.

447

Delsasso, L. P., "The Propagation of Sounds Through Moisture-Laden Atmospheres," Dept. of Phys., Univ. of Calif., Los Angeles, 1956.
AD-82 153.

This report covers the experimental information obtained on the transmission of audio-frequency sounds in moisture-laden atmospheres. It constitutes a progress report on a long-term program aimed at obtaining experimental information of the attenuation and velocity fluctuations of sound in the free atmosphere under normal and extreme meteorological conditions.

The absorption of sound in the free atmosphere in these experiments in determined by observing the reduction in sound intensity with distance from a small explosive source. Absorption coefficients under various meteorological conditions are determined from the expression

$$\alpha = \frac{2\left(\ell n \frac{P_1}{P_2} - \ell n \frac{r_2}{r_1}\right)}{r_2 - r_1}$$

where α = coefficient of absorption
P_1 and P_2 = sound pressures at points 1 and 2
r_1 and r_2 = distances from source to points 1 and 2

Transit times are measured as a basis for determining velocity fluctuations. All transit times and attenuation data are correlated with simultaneously recorded meteorological data. The results are presented as a series of charts or records.

448

Delsasso, L. P., and R. W. Leonard, "The Attenuation of Sound in the Atmosphere—and Appendix A.," Dept. of Phys., Univ. of Calif., Los Angeles, 45 pp., 1949.
ATI-96 177.

Progress is reported on the investigation of the transmission of sound under various atmospheric conditions. Primarily the work deals with laboratory measurements, where conditions can be well controlled, and, secondly, with field measurements under varying atmospheric conditions. The ultimate goal is to correlate the two experiments and make it possible to predict the value of attenuation and velocity for any given set of atmospheric conditions. In general, the laboratory measurements confirm previous findings on the variation of the absorption with the moisture content of the air. These results are plotted. Typical values for open air transmission are shown in a graph. Instrumentation for making acoustic attenuation measurements in the laboratory and in the field is described and illustrated. Circuit diagrams are included.

449

Dneprovskaya, I. A., V. K. Iofe, and F. I. Levitas, "On the Attenuation of Sound as It Propagates Through the Atmosphere," Soviet Phys. Acoust., English Transl., 8, 235-239, 1963.

The attenuation of sound as it propagates through the atmosphere was studied in the 200- to 2000-cps range, both in the presence and in the absence of acoustic shadowing. Measurements were performed at distances from 1.5-5 km in 12 steps (in the Leningrad region). Measurement of the sound level at the acoustic source was conducted with the aid of an objective noise meter and, at the receiving point, with the aid of a subjective noise meter.

The results of the measurements demonstrated the seasonal dependence of the excess attenuation of sound (with molecular attenuation subtracted), as well as the dependence on time of day, nature of the terrain over which the sound propagated, distance, and frequency. No relation was found between attenuation and wind direction or wind velocity. The averaged absolute value of the excess attenuation varies, depending again on the conditions of propagation, from 2-12 db/km for frequency 300 cps and from 5-23 db/km for frequencies ranging from 1800-2000 cps. Acoustic shadowing was observed on an average in 30% of the total number of observations. The averaged absolute magnitude of the excess attenuation in the presence of acoustic shadowing lies within the range from 20 db/km at 300-cps frequency to 50 db/km at 1800-cps frequency.

450

Eagleson, H. V., "Influence of Certain Atmospheric Conditions upon Sound Transmission at Short Ranges," J. Acoust. Soc. Am., 12, 427-435, 1940.

A formula is derived for giving sound intensity as a function of temperature, humidity and barometric pressure. A series of measurements was made of the intensity of sound from constant sources at short fixed distances. Readings were taken in all sorts of weather that can be found in Indiana. In general, the experimental values agree with those calculated from the formula to within 5%.

451

Eckart, G., "Acoustic Characteristics of the Atmosphere" (in French), Rech. Aeron., 21, 59-66, 1951.

The author considers the properties of a stratified atmosphere (i.e., one whose pressure, temperature, and relative humidity are functions only of the height above the surface of the earth). The major portion of the paper is devoted to statements, formulae, graphs, and tables showing the effects of temperature and relative humidity on the velocity, characteristic impedance, and attenuation of sound waves in air. It is a useful summary of this information. The author also presents information on the effects of temperature and humidity on the propagation of electromagnetic waves. He points out that whereas changes in temperature are much more significant than changes in humidity with regard to sound propagation, the reverse is true in the electromagnetic case. The author suggests that simultaneous observations of acoustic and electromagnetic transmissions in the atmosphere may yield useful information about its composition at any given time and place.

452

Eyring, C. F., "Jungle Acoustics," J. Acoust. Soc. Am., 18, 257-270, 1946.

The study of jungle acoustics was carried out during the wet season in Panama. Measurements permit the following conclusions to be drawn. Within a jungle the temperature and wind velocity gradients are so small that the sound refraction they produce may be neglected for all practical purposes. Humidity increases the transmission loss at high frequencies and field measurements of the loss agree with laboratory values reported by others. Terrain loss, measured in db, between any two specified distances from the sound source is defined as the transmission loss between these points less that caused by the geometrical divergence of the sound beam. Terrain loss in the jungle was found to increase linearly with distance. The terrain loss coefficients, in db per foot, were measured for various types of jungle and were found to be a function of frequency and of the density of the terrain, the density of terrain being measured by the difficulty of penetration and the distance that a foreign object may be seen. The level of the ambient noise in the wet-season jungle is very low, especially for the quiet periods between animal calls. At night the low frequencies decrease as the light breezes cease and the high frequencies increase as the insects begin their nocturnal chorus. A jungle is a difficult place in which to judge the direction of a sound—a probable error of 20° is to be expected. The error is found to be smallest when the sound comes from a direction near the axis passing through the two ears, and in the range studied the error decreases as the sound source moves farther away. Reverberation and scattering cause part of the error of judgment, but an improved technique of listening which may increase the observer's accuracy is suggested.

453

Eyring, C. F., "Jungle Acoustics," Rept. No. 4699, Office of Scientific Research and Development, NDRC Div. 17, Washington, D. C., 80 pp., 1945.
ATI-62654.

This study of jungle acoustics and micrometeorology is one of the most comprehensive and useful documents available for anyone concerned with the transmission of sound at the earth's surface in tropical climates. The study was conducted during the wet season in Panama and includes propagation measurements over hard, bare surfaces, short and tall grasslands, and through a variety of tropical forests. Terrain loss coefficients and their variations with acoustic frequency and environment were determined from measurements. Ambient jungle noise levels in the audible and ultrasonic ranges were measured. Acoustical and meteorological measurements were taken concurrently in order to demonstrate their inter-relationships. Refraction and shadow zone formation, as caused by combined wind and temperature effects, were investigated and found to be significant in open, sunny areas, but not significant under a jungle canopy. The report clearly shows the typical variations to be expected throughout the day and night for each acoustic and meteorological parameter investigated. The various instruments that were developed for acoustic detection and measurement are described in detail. Calibration procedures are also described.

454

Ghosh, R. N., "Acoustical Impedance of Fog," Indian J. Phys., 18, 341-346, 1945.

The impedance of air containing water particles in suspension is calculated directly from the hydrodynamical laws. The resulting formula is practically the same as that for solids.

455

Gutenberg, B., "Propagation of Sound Waves in the Atmosphere," J. Acoust. Soc. Am., 14, 151-155, 1942.

The effect of humidity is investigated. The radius of curvature for a sound ray propagated in the direction of the wind is given and discussed. The amplitudes of sound waves as a function of the distance are given, and the relative importance of the quantities involved is discussed.

456

Hayhurst, J. D., "The Attenuation of Sound Propagated Over the Ground," Acustica, 3, 227-232, 1953.

Theoretical calculations by Knudsen, supported by the results of laboratory experiments, have established the attenuation of sound in still air. Little work has hitherto been done out-of-doors because of the difficulty in allowing for the effect of wind on the attenuation. In the course of an aircraft-noise-abatement investigation made recently by the Ministry of Civil Aviation, the effect of wind on the propagation of sound over a dry concerte runway has been explored up to a distance of about half a mile from a source of sound. It was found that the only significant parameter was the component of wind in the direction of propagation, and the values that emerged showed that wind effects cannot be neglected in any acoustic work made out-of-doors. By interpolation the attenuations corresponding to a zero wind component in the direction of propagation were derived and were found to be substantially greater than those previously determined for still air. The attenuations were, however, statistically independent of the absolute wind speed. Repetition of the investigation over grassed areas produced no reliable results.

457

Hirai, S., "Decrease of a Sound Signal on the Sea," Rept. No. 6-1-1, Sixth International Technical Conference on Lighthouses and Other Aids to Navigation, U. S. Coast Guard, Washington, D.C., 10 pp., 1960.
AD-242 086.

Sound signals were projected over the water of Tokyo Bay, Japan, to acoustic receiving equipment located 1200 meters from the source. The transmitted frequency was varied in 50-cycle steps from 100-3000 cps. An assumed inverse-square spreading loss was subtracted from the near-field response of the source. Signal levels actually received at 1200 meters were then subtracted from the preceding result to show atmospheric attenuation-vs-frequency. This was found to increase at a rate of about 10 db/octave for frequencies from 100-1500 cps and at a progressively slower rate from 1500-3000 cps.

458

Hirai, S., "The Rated Range of a Sound Fog Signal," Rept. No. 6-1-6, Coast Guard, Washington, D. C., 10 pp., 1960.
AD-242 091.

The paper, "Defining and Calculating the Rated Range of a Sound Signal" by M. R. Ginoechis, is considered. It was presented to the 5th International Conference on Lighthouses and Other Aids to Navigation. Experiments and observations were conducted on (1) the intensity and stress of a sound signal defined as the sound loudness level at its origin and as measured at 10-m distance directly from the mouth of the horn; (2) the question of whether the value of the atmospheric transmission coefficient, T, used correspondingly to the wavelength, should be regarded as proper (AD-242 086); (3) the question of whether it is proper to consider a decrease in sound to be proportional to the distance to the minus squared; and (4) the accuracy of using the value 70 db as the minimum audible sound among the noises. Results indicated that a distance of 10 m is too near to measure the intensity of the source of sound and that in the case where a larger distance cannot be had because of a topographical situation, a compensating value should be added to the value or the value should be made smaller. Noises from diesel and reciprocal engines were measured on different kinds of vessels for stress and loudness level. For the diesel engines, the average noise values were 100, 76, 97, and 85 phons for the engine room, pilot house, and bridge end at 18% and 6% wind velocity, respectively. In the case of the reciprocal engine, the noise values were 80, 67, and 75 to 85 phons in the engine room, pilot house, and bridge end, respectively. The value of minimum audible sound will be about 70 phons.

459

Ingard, U., "Field Studies of Sound Propagation over Ground," Acoustics Lab., Mass. Inst. Tech., Cambridge, 1954.

The results of two sets of field studies of sound propagation over ground are presented. One study utilized pure tones, the levels of which were measured at various distances and different wind velocities. For the second study an airplane propeller served as the source with octave band levels measured over various ground covers, at different wind velocities and at several distances. The importance of wind is shown by the shadow formation obtained. Fluctuation of sound level was shown to increase with distance and frequency. For propagation over the ground, the effect of turbulence scatter was found to be small.

460

Ingard, U., "The Physics of Outdoor Sound," Proc. Fourth Ann. National Noise Abatement Symp., 4, 11-25, 1953.

The effects of wind and temperature gradients, wind fluctuations, turbulence scattering, and absorption due to humidity are described and explained in this clearly written paper. The formation of shadow zones and the dependence of attenuation upon frequency in the shadow zone is discussed. Illustrative data for each of the meteorological parameters affecting the propagation of sound in a natural atmosphere are presented.

461

Ingard, U., "A Review of the Influence of Meteorological Conditions on Sound Propagation," J. Acoust. Soc. Am., 25, 405-411, 1953.

The study of the different atmospheric effect indicates that in short-range sound propagation the attenuation by irregularities in the wind structure (gustiness) often is of major importance in comparison with humidity, fog, and rain, and ordinary temperature and wind refraction. However, the ground attenuation can be just as important as the gustiness, particularly when the sound source and the receiver are sufficiently close to the ground. The effect on the attenuation of the height of the source and the receiver off the ground is presented as a function of frequency for a typical ground impedance. The attenuation curve exhibits a maximum which in most cases lies at a frequency between 200-500 cps.

462

Ingard, U., S. Oleson, and M. Mintz, "Measurements of Sound Attenuation in the Atmosphere," Final Rept., Res. Lab. Electron., Mass. Inst. Tech., Cambridge, 52 pp., 1961. AD-248 636.

An attempt is made to measure acoustic scatter attenuation produced by atmospheric turbulence. Laboratory experiments on scattering of sound by turbulence are described; in particular, a new experimental technique involving pulse-height analysis of scattered sound.

463

Jorand, M., "Influence of Turbulence on the Attenuation of Sound in Free Air" (in French), Compt. Rend., 248, 1306-1308, 1959.

Classical theories fail to explain the observed sound attenuation. Better agreement is given by replacing the classical viscosity by an appropriate kinematic viscosity.

464

Kalavski, P. Z., and L. Rudin, "The Attenuation of Air Blast by Rain, Part I. The Effect of Water Content in Air on the Peak Shock Overpressures Produced by Small Charges," NAVORD Rept. No. 3646, White Oak, Md., 13 pp., 1959. AD-218 770.

The peak shock overpressures produced by 472-g spheres of pentolite exploded in artificial rains were measured. The water concentrations (grams of water/cubic meter of air) were varied from 10 to 144. Comparison of the measured pressure-distance curves with the free-air curve (in the absence of rain) indicates that the attenuation produced by the rainfalls varies from about 4% to 31% over the water-concentration range employed.

465

Kingery, C. N., J. H. Keefer, and J. D. Day, "Surface Air Blast Measurements from a 100-Ton TNT Detonation," Memo Rept. No. 1410, Ballistic Research Labs., Aberdeen Proving Ground, Md., 46 pp., 1962. AD-285 599.

The free field pressure-time histories measured at selected distances from a 100-ton TNT surface burst are presented. Included are plots of overpressure, duration, impulse, arrival time, and dynamic pressure—all versus distance. The measured values are compared with predicted curves, which were prepared by scaling results from 5-ton and 20-ton surface bursts of the same geometrical shape and fired in the same general area. The geometrical shape is a simulated hemisphere which was constructed by stacking cast TNT blocks in a planned pattern.

466

Kneser, H. O., "A Nomogram for Determination of the Sound Absorption Coefficient in Air" (in German), Akust. Z., 5, 256-257, 1940.

The non-classical or molecular absorption of sound in the earth's atmosphere is usually many orders of magnitude greater than the so-called classical absorption. Molecular absorption is principally due to the exchange of translational and vibrational energy between colliding molecules. In air, it is a function of temperature, humidity, and frequency. Kneser's nomogram combines the several sets of curves for molecular absorption as a function of each variable. By using this nomogram one can quickly and easily determine a value for the attenuation constant in air caused by molecular absorption at any desired frequency from 100 cps to 80 kc, for any temperature from -20^{o} to $+40^{o}C$, and for relative humidities from 10% to 100%.

467

Knudsen, V. O., "The Propagation of Sound in the Atmosphere—Attenuation and Fluctuations," J. Acoust. Soc. Am., 18, 90-96, 1946.

Following a summary of earlier work, experiments in progress to determine the absorption of audible sound in air containing different amounts of water vapour are outlined, and the importance of such data in connection with room acoustics, and public-address and sound-ranging systems is emphasized. Reference is also made to measurements, at frequencies between 500 and 4000 cps, of the attenuation of sound in air containing lycopodium spores, but it is shown that the agreement with values calculated from Epstein's equation is not very satisfactory. A laboratory investigation of previously observed fluctuations in the intensity of sound propagated through the atmosphere is described; the effect is attributed to temperature turbulence of the air. For frequencies between 8 and 16 kcs, the magnitude of the intensity fluctuations is proportional to the square of the sound frequency.

468

Knudsen, V. O., J. V. Wilson, and N. S. Anderson, "The Attenuation of Audible Sound in Fog and Smoke," J. Acoust. Soc. Am., 20, 849-857, 1948.

Measurements of the rate of decay of sound in a reverberation room, first with no fog or smoke in the room and then with fog or smoke of known concentration and particle size added to the room, show that the attenuation of sound in a number of aerosols is in approximate agreement with values predicted by the theories of Sewell, Epstein and Oswatitsch. In a water fog having a concentration of 2.0×10^{-6} g/cm^3 and an average droplet radius of 6.25×10^{-4} cm, the attenuation due to the fog increased from about 5 db/sec at 500 cps to 13 db/sec at 8000 cps. In a very similar fog of mineral oil, the corresponding attenuation increased from 1.6 db/sec at 500 cps to 21 db/sec at 8000 cps. At very low frequencies, a fog of water is much more absorptive than is a fog of oil; the difference is ascribed to a "relaxation" effect of evaporation from and recondensation on the droplets, which is >> for water than for oil. The attenuation of sound in smoke may become rather high, amounting to 58 db/sec at a frequency of 6000 cps for a moderately dense smoke of NH_4Cl (180 g in a volume of 6080 ft^3).

469

Linsay, R. B., "Transmission of Sound Through Air at Low Pressure," Am. J. Phys., 16, 371-377, 1948.

The problem is treated in terms of relaxation dissipation. Consideration is given to (1) wave propagation with relaxation dissipation; (2) viscosity and heat-conduction dissipation; (3) classical approximation for very high frequency. Experiments are described in which transmission loss is measured in a low-pressure tank, at 384-6950 cps. Over the pressure (atmospheric to 5 mm of Hg) and frequency ranges employed, the absorption due to viscosity and heat conduction is negligible (in agreement with the theory). The pressure tank measurements indicate increasing impedance mismatch (transmitter-medium-receiver) with decreasing pressure.

470

Mintz, M. D., "Sound Scattering from Turbulence," S. M. Thesis, Mass. Inst. Tech., Cambridge, 1959.

An explanation and clarification of the experimental problems encountered in investigations of sound scattering from turbulence is presented, after which a brief synopsis of Lighthill's scattering theory of sound and turbulence is given.

The experimental approach is divided into three phases: the design and construction of suitable transducers; investigation of sound attenuation in air in the absence of turbulence; and investigation of the scattering of sound by turbulence. A preliminary investigation of this third phase employing the relatively untried technique of pulse-height analysis is conducted for scattering of a sharp beam of 100-kc sound. Complete details of the experimental circuitry and technique are presented, and the resulting pulse-height spectra for scattering angles between -2.5^o and 15^o are presented and discussed. The broadening of the beam due to interaction with the turbulence is displayed in curves relating sound field pressure and laboratory angle to the incident beam. A brief list of suggestions for further investigation of this problem and possible application of the technique of pulse-height analysis to other statistical acoustics problems is presented in the concluding section.

A feasibility report for application of acoustical interferometric measurements is included in the appendix.

471

Nyborg, W. L., and D. Mintzer, "Review of Sound Propagation in the Lower Atmosphere," WADC TR-54-602, Brown Univ., Providence, R. I., 1955.
AD-67 880.

Available information on sound propagation through the lower atmosphere is critically reviewed. The application is to the prediction of sound fields due to aircraft (in flight or on the ground), especially at distances up to a few miles from the aircraft sound sources. Treatment of the prediction problem requires consideration of a number of topics including absorption processes in the air, boundary effects caused by the earth, and refraction of sound due to spatial variations in air temperature and wind. Although a fair amount of information is now available on these topics, a considerable amount of research remains to be done before practical solutions will be available. Numerous charts and nomograms (for determining absorption losses) and a bibliography containing 92 references are included.

472

Oswatitsch, K., "The Dispersion and Absorption of Sound in Clouds," Physik Z., 42, 365-378, 1941.

A theoretical investigation of the effect on the propagation of sound of the condensation or evaporation of water drops suspended in the atmosphere. At sufficiently low sound frequencies, condensation or evaporation of water vapour in clouds or fog can occur in appreciable quantity, leading to absorption and dispersion phenomena. Whereas in clouds the dispersion region is always below the range of human audibility, in clouds laden with small drops of water the absorption region extends into the range of the deep audible tones in agreement with the known strong absorption of thunder.

473

Parkin, P. H., and W. E. Scholes, "Air-to-Ground Sound Propagation," J. Acoust. Soc. Am., 26, 1021-1023, 1954.

The attenuation of sound in air, in the vertical direction, has been measured on six occasions by using an aircraft flying at various heights over a microphone at ground level. Negligible attenuation was always found at frequencies below 1000 cps even though the air was turbulent; at higher frequencies the attenuation was found to be of the same order as the Knudsen-Kneser results for attenuation due to molecular absorption.

474

Pielemeier, W. H., "Kneser's Sound Absorption Nomogram and Other Charts," J. Acoust. Soc. Am., 16, 273-274, 1944.

The author plots the maximum value of the molecular absorption per wavelength as a function of the temperature, and obtains agreement with the theoretical values found by Kneser, the measured values of Knotzel and Kneser, and those of Knudsen. Kneser's nomogram is modified so that the molecular absorption can be found for ordinary conditions of temperature, humidity, and sound frequency; an example is given.

475

Reed, J. W., "Shock Propagation at Large Distances," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 3-6, 1961.
AD-408 716.

It is usually assumed that weak shock waves (overpressure 1 psi) are propagated adiabatically and acoustically. In a homogeneous atmosphere this gives overpressure inversely proportional to distance from an explosion and inversely proportional to the square root of distance from a supersonic projectile. An opposing theory was proposed by DuMond et al. in 1946 to show that entropy changes in a shock front would cause explosive overpressures to decay like (distance)$^{-3/2}$ and projectile bow waves to decay like (distance)$^{-3/4}$. A few bits of experimental evidence show that neither scheme is exactly correct. Measurements at low overpressures over large distances free of refractive effects are necessary to accurately resolve the true propagation decay laws. This requires vertical shock paths through a real atmosphere. Project Banshee tests will allow measurements where blast pressure differences between the two predictions are more than a factor of ten. High altitude atomic tests have only given a factor-of-two difference, so instrument errors may have obscured correct interpretation. Some preliminary small charge experiments where the difference was a factor of four have just been completed.

476

Rocard, Y., "Absorption of Sound in the Atmosphere," J. Phys. Radium, 4, 118-122, 1933.

The classic causes of absorption of sound in a homogeneous atmosphere are insufficient to explain the facts, since the actual absorption is at least twenty times greater than the calculated value. The large ions of the atmosphere, supposed to be formed of drops of water, appear capable of causing important absorption by the evaporation and condensation of water in places where the sound wave heats or cools the air. According to the author's calculations of the energy required to free a molecule of water from a large ion, and of the speed of evaporation of a large ion when suddenly heated, the absorption of sound thus caused would be independent of the frequency within the audible range and would have a definite relation to the optical transparency of the atmosphere in good weather.

477

Rocard, Y., "On the Subject of the Absorption of Sound in Mists" (in French), Rev. Sci., 89, 42-43, 1951.

It is suggested that drops of water suspended in the air can be set in vibration by the sound wave and therefore contribute to absorption. In particular, the small droplets present in mists would absorb the higher frequencies and so explain the selective absorption experienced under these conditions. A simple calculation showing the order of magnitudes is given.

478

Rudnick, I., "Propagation of Sound in the Open Air," in C. M. Harris, ed, "Handbook of Noise Control," McGraw-Hill, New York, Chap. 3, 17 pp., 1957.

Chapter 3 decribes the propagation of sound in air and the various meteorological factors and boundary conditions that influence otherwise normal propagation. The effect of wind and temperature gradients, of fog and water vapor, and of reflecting and absorbing obstacles and boundaries are concisely treated. Mathematical expressions, graphs, and tabular data for determining divergence, diffraction, refraction, reflection, scattering, and attenuation with distance are presented. Anomalous propagation and shadow zones are investigated and explained in terms of sound-ray equations. In general, the chapter presents the basic results of work done by Kneser, Knudsen, Knotzel, Delsasso, Ingard, Nyborg, and Rudnick.

479

Sabine, H., "Sound Propagation near the Earth's Surface as Influenced by Weather Conditions," WADC TR 57-353, Armour Research Foundation, Chicago, 24 pp., 1961.
AD-254 672.

Engineering procedures are outlined for estimating the atmospheric attenuation of sound propagated from an elevated source to ground as a function of distance, source elevation angle, and meteorological data of the type which would be obtained routinely at an air missile base. These procedures are based on the results of an experimental program which covered distances up to four miles and source altitudes up to 14,000 feet.

480

Sabine, H., V. Raelson, and M. Burkhard, "Sound Propagation near the Earth's Surface as Influenced by Weather Conditions," WADC TR 57-353, Armour Research Foundation, Chicago, Ill., 49 pp., 1961.
AD-254 671.

The effects of weather on the propagation of sound from high-power elevated sources, such as large rockets, were studied at altitudes to 80,000 feet and over horizontal ranges to 15 miles. This study continues work reported in Parts I and II (AD-130 793 and AD-254 670) on short-range propagation. A theoretical analysis is reported of the principal atmospheric factors affecting long-range propagation: molecular absorption as a function of temperature and absolute humidity at various altitudes, variation of the characteristic impedance of air with altitude, and large scale refraction due to wind and temperature gradients. Of these, only molecular absorption at high altitudes significantly affects propagation. Limited measurements of atmospheric attenuation were made by using a propeller airplane sound source at altitudes to 14,000 feet and ranges to four miles. The results agree in general with those predicted by extrapolation of previous data for smaller altitudes and ranges, except that residual attenuation due to scattering is smaller.

481

Sieg, H. "On Sound Transmission in the Open Air and Its Dependence on Weather Conditions," Halstead Exploiting Center, Brit. Intelligence Objective Sub-Committee, London, 1940.
AD-55 755.

Meteorological factors affecting sound transmission in the open air are discussed. Normal sound transmission is mainly disturbed by the influence of temperature and wind, which attenuate sound on its progress through the air. Wind has a far greater effect on transmission than temperature, except in approximately calm weather. "Fine" weather, in an acoustic sense, was found to be nearly calm weather with sky overcast, as well as fog and drizzle; whereas weather was "bad" if the wind velocity was high, with consequent squalliness, especially when the wind blew against the direction of sound transmission. Molecular absorption and height of the transmitter above ground were found to be more conductive to transmission of higher frequencies than to lower frequencies.

482

Skeib, G., "On the Propagation of Sound in Atmospheric Turbulence" (in German), Z. Meteorol., 9, 225-234, 1955.

Measurements of the scatter of sound waves of 100 c to 4 kc from a loudspeaker were made at Lindenberg, with micrometeorological observations for comparison. Absorption and scattering are discussed theoretically and the instrumental set-up is described. At a height of 30 m and distance 150 m, with wind >5 m/s, damping was 13 db, increasing with frequency, and decreasing to half at 3 m/s. At 5 m height and 50 m distance results were similar but the wind effect less.

483

Syono, S., "Anomalous Propagation of Sound at a Short Distance," Geophys. Mag. (Tokyo), 9, 175-194, 1935.

In a former paper the author explained by an approximate method some anomalous sound wave propagation phenomena described by J. Kolzer. The present paper, which is almost entirely mathematical, is concerned with making the treatment more rigorous by taking into account the effects of wind and absorption of the earth's surface.

484

Wei, Y. T., "Theory of Attenuation of Sound in Foggy Air Due to Evaporation and Condensation Processes," Acta Sci. Sinica, 2, 245-268, 1953.

After reviewing previous work on the subject, the author gives a mathematical treatment of a modified procedure. As sound waves traverse clouds or foggy air, the temperature change, which accompanies the pressure variation, causes the water molecules at the surface of a drop to evaporate and those on the surrounding vapor to condense, depending on whether there is condensation or rarefaction in the sound wave. In general, the pressure waves propagate ahead of the density waves since a finite time is required for this evaporation or condensation process to take place. At very high frequencies, however, the pressure varies too fast for this process to occur. Only at very low frequencies are the terms "relaxation-time," dispersion, and absorption significant.

485

Wiener, F. M., "On the Propagation of Audible Sound over Water in Fog," Rept. No. 6-1-2, Coast Guard, Washington, D. C., 14 pp., 1960.
AD-242 087.

Field experiments which consisted of sound transmission measurements over water under a variety of atmospheric conditions, including fog, and of extensive micrometeorological measurements taken, for the most part, simultaneously with the acoustic measurements. The micrometeorological data were obtained to describe, as completely as possible, the properties of the lowest layers of the atmosphere above the ocean through which the acoustical signal was propagated. Representative samples are given of the sound attenuation characteristics obtained in the field. The instrumentation is briefly described, and is followed by a brief analysis of the results. This is preceded by a short discussion of the physics of sound propagation through the lower atmosphere in the light of available theory.

486

Wiener, F. M., "Sound Propagation Outdoors," Noise Control, 4, 16, 1958.

This describes a procedure for estimating the attenuation of sound outdoors near the ground in excess of inverse-square law spreading loss.

487

Wiener, F. M., "Sound Propagation over Ocean Waters in Fog," J. Acoust. Soc. Am., 33, 1200-1205, 1961.

Audible fog signals are extensively used as aids to marine navigation during periods of low visibility. Performance, however, has frequently been inadequate. To obtain a better understanding of the physics of sound propagation over water in fog, a series of field experiments was carried out off the coast of Maine. Signals in the frequency range between about 200 and 2000 cps were employed to measure sound attenuation for distances up to a few miles. Simultaneous micrometeorological measurements were performed to describe the relevant properties of the lowest layers of the atmosphere through which the sound was propagated. This paper describes briefly the measurement techniques used and presents typical samples of the results obtained. Downwind, the average excess attenuation over and above inverse square law can be accounted for principally by molecular absorption. Upwind, large values of excess attenuation were found due to shadow zone formation. This constitutes a severe limitation of the useful range of audible fog signals. Fog itself contributes little to the average excess attenuation.

488

Wiener, F. M., and D. N. Keast, "Experimental Study of the Propagation of Sound over Ground," J. Acoust. Soc. Am., 31, 724-733, 1959.

The attenuation of sound propagated out-of-doors is conveniently separated into attenuation due to spherical divergence and excess attenuation due to atmospheric and terrain effects. This excess attenuation is principally caused by sound absorption in the air, the refractive effects of temperature and wind gradients, turbulence, and terrain and ground cover. To investigate these effects, the propagation of sound over open, level ground, through dense evergreen forests, and between hilltops was studied experimentally in the frequency range between about 300 and 5000 cps. Extensive micrometeorological instrumentation was utilized to measure and record the relevant micrometeorological parameters simultaneously with the acoustic data for a wide variety of weather conditions. Data on the attenuation of the mean sound pressure level as well as on the fluctuations about the mean were obtained and correlated with the state of the atmosphere. Over open, level terrain, the excess attenuation upwind was found to exceed that for downwind propagation by as much as 25-30 db for source and receiver heights of 12 and 5 feet, respectively. Temperature and wind gradients near the ground-air interface largely account for this difference. In hilltop-to-hilltop propagation, wind direction is of secondary importance and in dense woods absorption and scattering control. Empirical functions were derived for the purpose of estimating the mean excess attenuation as a function of frequency and distance, for a given set of micrometeorological conditions. These charts were found useful in many practical problems involving the propagation of sound over open level ground.

Attenuation, Atmospheric
See also—32, 72, 92, 154, 161, 223, 225, 290, 407, 411, 522, 529, 550, 551, 554, 562, 564, 759, 765, 790, 873, 874, 875, 876, 877, 902, 986, 1061, 1081, 1086, 1112, 1122, 1291, 1345, 1354, 1371, 1376, 1427, 1460, 1464, 1465, 1531, 1537, 1545, 1552, 1557, 1565, 1569, 1580, 1690, 1751, 1859, 1863, 1864, 1866, 1867, 1937, 2125, 2151, 2155, 2156, 2183, 2184, 2185, 2213, 2222, 2233, 2244, 2258, 2339, 2817, 2837, 2844, 2848, 2861, 3007, 3023, 3210, 3352, 3358, 3365, 3392, 3463, 3955

BIBLIOGRAPHIES

489

Aerospace Medical Lab., "Bibliography of Research Reports and Publications Issued by the Bio-Acoustics Branch," WADD, Wright-Patterson Air Force Base, Ohio, 28 pp., 1960.
AD-252 734.

Contents:
- Sound sources and noise fields
- Sound propagation
- Acoustic instrumentation
- Noise control—general
- Noise control structures
- Hearing and physiology of the ear
- Speech
- Biological and psychological effects of noise
- Ear protection
- Mechanical characteristics of the human body: Effects of vibrations and shocks
- General noise guides and criteria
- Bionics

490

Armed Services Technical Information Agency, "Protective Construction, an ASTIA Report Bibliography," Arlington, Va., 1960. AD-242 653.

This bibliography comprises a selected list of references related to the construction or hardening of strategic military facilities to resist either nuclear or conventional explosives. References are limited to unclassified reports without specific distribution limitations. Literature coverage was restricted to documents within the ASTIA collection, cataloged from 1952 to September 15, 1960. Entries include references to reports pertaining to characteristics of nuclear explosions, propagation of shock waves, underground explosions, soil mechanics, and response of structures to blast. References are arranged according to these broad categories. (See also AD-318 841.)

491

Chasen, L., "Bibliography on Magnetohydrodynamics," T.I.S. Rept. No. R605D300, General Electric Co., Philadelphia, 1960. AD-235 868.

A bibliography on magnetohydrodynamics is presented, representing a search of open literature and company documentary reports of essential references in the areas of magnetohydrodynamics, plasma physics, electric discharge-plasmas, and high-temperature research published from 1954 to 1959. A total of 195 references are listed alphabetically by author or corporate author.

492

Curry, B., and E. Hsi, "Bibliography on Supersonics or Ultrasonics," Research Foundation, Oklahoma Agricultural and Mechanical College, Stillwater, 1949.

Contains about 650 entries, many with short abstracts, gathered from journals of abstracts in the period 1928-1949. Arranged under 72 subject headings, and also under individual authors. Physical, chemical, biological, and industrial aspects are covered. The bibliography has been deposited at a number of public and university libraries.

493

Curry, B., E. Hsi, J. S. Ambrose, and F. W. Wilcox, "Bibliography, Supersonics or Ultrasonics 1926-1949 with Supplement to 1950," Research Foundation, Oklahoma Agricultural and Mechanical College, Stillwater, 1951.

This bibliography is a reissue (see the preceding abstract), with a supplement to 1950.

494

den Hartog, J. P., "Vibration," J. Appl. Mech., 4, A136-A138, 1937.

This is a bibliography on the subject.

495

Dolder, K., and R. Hide, "Bibliography on Shock Waves, Shock Tubes, and Allied Topics," Rept. No. G/R2055, Atomic Energy Research Establ., 94 pp., 1957. AD 127681.

References have been arranged under subject headings in chronological order. The sections dealing with shock waves and shock tubes include most of the work published in these fields up to the end of 1955. A number of more recent references are also included. Further sections list accounts of related subjects. The bibliographies previously compiled by the National Physical Laboratory and Princeton University are also included.

496

Elder, F. K., Jr., "Shock Wave Bibliography of Periodical Literature," Rept. No. TG 75-3, Applied Physics Lab., Johns Hopkins Univ., Silver Spring, Md., 78 pp., 1953. AD-12 033.

Current periodical literature on the physics of shock waves, published during the period 1920 to 1952, is covered. Reference sources include Physics Abstracts, Engineering Index, the Industrial Arts Index, the bibliography section of the Journal of the Acoustical Society of America, and the volume indexes to the Physical Review. References to contributed papers at the American Physical Society meetings are also given. All references are arranged in alphabetical order, by author. Names of second authors are inserted alphabetically between the references, so that the initial listing constitutes its own complete author index. The title of each reference is given as an indication of the content of the paper. A complete list of the journals cited and their abbreviations is given at the end of the bibliography. A brief subject index, in which the papers are grouped under several general headings, is also supplied.

497

Emmitt, M., "Fundamental Study of Jet Noise Generation and Suppression, Volume II. Bibliography," WADD TR 61-21, Rept. for Feb.-Dec. 1960, Armour Research Foundation, Chicago, 67 pp., 1961. AD-264 682 and AD-264 919.

The bibliography is divided into two parts. The first part (AD-264 919) consists of unannotated references chosen from the 1150 documents which were evaluated during the program, and which are considered to be significant contributions to the basic subject categories mentioned above. These references are arranged chronologically by year and within each year alphabetically according to author. The second part consists of annotated references which were essential to the theoretical discussions to be found in Volume I. They are arranged alphabetically according to author. The name or names of the scientific personnel who selected each reference follows each annotation.

498

Federal Aviation Agency, "Aircraft Noise and Its Problems, Selected References, Bibliographic List No. 6," Washington, D. C., 20 pp., 1962. AD-283 265.

Pertinent readings on the subject of aircraft noise and its inherent problems, of concern to federal, state, and local officials and organizations, are listed. The list is divided into seven parts for the convenience of the reader, including general references, community problems, noise abatement procedures, structural and design problems, legal aspects, helicopters, and alleviation methods.

499

Frings, M., and H. Frings, "Sound Production and Sound Reception by Insects: A Bibliography," Penn. State Univ. Press, University Park, 108 pp., 1960.

This is a compilation of 1752 titles arranged alphabetically by author's name, covering references to insect sounds and hearing from Aristotle to the present, with complete listings through

1957. Particularly valuable are the authors' indications of the nature and subject matter of each reference. After naming the family or order of insects studied, they classify the subject as to sound production or sound reception, approach (morphological, physiological, or behavioral), type of receptor employed, method of study (casual observations, field observations, or experimental results), and whether or not analysis of the sound was performed. Unfortunately, the index incorporates very little of this arduously collected information. The reader interested in a specific topic, is confined either to the taxonomic index, which lists all references by family, or to the partial index based on the distinction between sound production and sound reception. The authors will keep this bibliography up to date with periodic revisions.

500

Heap, J. C., "Bibliography on Various Topics Pertaining to Blast Effects," ANL-5792, Argonne Nat'l. Lab., Lemont, Ill., 23 pp., 1957.
AD-144 450

Contents:
Prevailing containment
Atomic explosions
Blast effects
Explosions
Explosives
Pressure vessels
Shelters
Shock waves
Structures
Submarine intermediate reactor-containers
Tanks

501

Hercules, W. L., "Shock and Vibration Environment, An Astia Report Bibliography," Armed Services Technical Information Agency, Arlington, Va., 1000 Refs., 1962.
AD-277 392.

This bibliography was prepared by ASTIA in response to requests for information concerning shock and vibration environment. Citations are included for unclassified reports cataloged by ASTIA from 1953 to 1 July 1962. Entries are arranged alphabetically by subject area. In general, the references fall within the following broad topic areas: mechanical shock and vibration; application to particular fields such as space technology, naval engineering, military equipment, test facilities; and associated environments. Of special interest under associated environments is the subject area Space Environmental Conditions. A classified volume of the bibliography is issued separately as AD-329 865.

502

Kramer, H. P., and M. Rigby, "Selective Annotated Bibliography on Propagation of Acoustic and Explosion Waves in the Atmosphere," Meteorological Abstracts and Bibliography, 1, 670-686, 1950.

This bibliography contains 112 entries, each with an abstract or annotation, and covers the years from 1883 to 1950 inclusive. Most aspects of the propagation of sound in air are covered, with particular emphasis on anomalous sound propagation, meteorological factors affecting sound propagation, and determination of winds and temperatures from acoustic measurements.

503

Kryter, K. D., "The Effects of Noise on Man," Central Inst. for the Deaf, St. Louis, (J. of Speech and Hearing Disorders. Monograph Suppl. 1, 1950), 95 pp., 1950.
AD-105 339.

This is a review, summary, synthesis, evaluation, and interpretation of the experimental literature on noise as an aspect of man's environment. Its first section is concerned with effects upon behavior, particularly in regard to work output and efficiency. The second part brings together material on auditory damage as the result of noise, and defenses against such damage. The third portion considers noise as a disruptive factor in speech communication. A bibliography on methods of noise measurement and procedures for reduction is added as an appendix. The breadth of the project is indicated by the fact that more than 650 different titles are included in the chapter bibliographies and appendix.

504

Kushner, S. S., "A Review of Nuisance and Hazardous Noise," Rept. No. IP-263, Engineering College Industry Program, Univ. of Mich., Ann Arbor, 1958.

The effects of hazardous and nuisance noise levels are reviewed. A bibliography of 54 entries is included.

505

Medwin, H., "Directory of Acoustical Laboratories in Western Europe," Directory No. D-4, Office of Naval Research, London, 30 pp., 1962.
AD-278 014.

The Directory lists those university, government and industrial laboratories and scientists or engineers known to be performing some work of interest to acousticians. The order of listing is alphabetical, first by country, then by city and finally by laboratory. Normally the laboratory name is given in the native language; when necessary, translations are provided in parentheses. Sections of laboratories are separately identified only if they function in an essentially independent manner. An alphabetical index of all acousticians is included at the end of the Directory. Additional information concerning the work and personnel at those laboratories that have been visited during the past year is given in ONRL Reports 82-61, 33-62, and 45-62.

506

Ministry of Aviation (Great Britian), "A Bibliography on Magnetohydrodynamics, Including Plasmas," Rept. No. TIL/BIB45, 35 pp., 1960.
AD-245 267.

Descriptors: Magnetohydrodynamics; Plasma physics; Bibliography; Great Britain; Hypersonic flow; Shock waves.

507

National Research Council, Prevention of Deterioration Center, "Environmental Effects on Materials and Equipment, Abstracts, Section B," 2B, Washington, D. C., 1962.

Section B, Volume 2B is a running bibliographical series of documents listing reports and papers that deal with the physical effects of environment on various materials and equipment. Among the many environmental effects considered are shock waves, jet acoustic oscillations, supersonic flows, acoustic excitation, and vibration.

Number 1, 17 pp., AD-283 811
Number 2, 17 pp., AD-283 812
Number 3, 18 pp., AD-283 813
Number 4, 18 pp., AD-283 814
Number 5, 17 pp., AD-283 815
Number 6, 18 pp., AD-283 816
Number 7, 19 pp., AD-283 817

508

Oppenheim, A. K., and R. A. Stern, "Development and Structure of Plane Detonation Waves," Techn. Note No. 7, Univ. of Calif., Berkeley, 1960.
AD-233 940.

The current status of knowledge on the development and structure of plane detonation waves is critically reviewed. A comprehensive historical survey includes contemporary studies, current theories concerning the mechanism of the development of the process, and the analysis of the structure of the steady, plane-detonation wave.

509

Pennsylvania State University, "Bibliography on Shock and Shock-Excited Vibrations, Volume I. Introduction and Abstracts of Technical Papers," Tech. Rept. No. 3, Coll. of Engineering and Architecture, University Park, 1957.
AD-200 830.

This bibliography consists of three parts. The main body of the text consists of an introduction and abstracts of 1168 technical papers on subjects related to shock motion and its measurement. This is followed by Part II, which consists of abstracts summarizing six subdivisions of the field: Dynamic Behavior of Materials Under Impulsive Loads; Dynamic Behavior of Structures Under Impulsive Loads; Impact Testing Devices; Instrumentation for Measuring Impulsive Forces and Motions; The Shock-Spectrum Approach to Impact Problems; Mathematical Methods for Investigating Dynamic Behavior of Structures Under Impulsive Loading. The final part consists of an appendix that includes an author index, a subject index, and information concerning the search that resulted in these abstracts. The abstracts are mainly of patents and of papers that have been published in technical journals. A few government reports are also included. Originally, it was planned to include abstracts of all pertinent government documents in this publication. However, it now appears desirable to publish these separately in a subsequent volume, because of the bulk of the material and the necessary time required to process it.

510

Powell, A., and T. J. B. Smith, "A Bibliography on Aerosonics," Rept. No. 62-4, Univ. of Calif., Los Angeles, 138 pp., 1962.
AD-274 208.

This bibliography consists mainly of references to open literature relating to fluid motion and thermal action.

511

Ragazzini, J. R., H. Saks, and M. Kaufman, "Methods for Analyzing Shock and Vibration," Library Rept. No. 1, Gruen Appl. Sci. Labs., Inc., Hempstead, N. Y., 30 pp., 1957.
AD-204 756.

This is a bibliography with abstracts on the following topics:
The filter problem of the power-spectrum analyzer.
Communications applications of correlation analysis.
Methods of obtaining amplitude-frequency spectra.
Short-time autocorrelation functions and power spectra.
The response of a resonant system to a gliding tone.
Response of a linear resonant system to excitation of a frequency varying linearly with time.
Measuring noise color.
The sampling theory of power spectrum estimates.
The principles and practice of panoramic display.
An 8000-c sound spectrograph.
Methods and instruments for the visual analysis of complex audio waveforms.
High-speed, high-resolution spectrum analyzer.
A spectrum analyzer for the 100- to 100,000-c range.
Automatic wave analyzer.
Analog equipment for processing randomly fluctuating data.
A computer for correlation functions.
Shock spectrum computer for frequencies up to 2000-c phenomena.
A high-speed correlator.
An extremely wide-range electronically deviable oscillator.

512

Rattayya, J. V., and L. E. Goodman, "Bibliographical Review of Panel Flutter and Effects of Aerodynamic Noise," WADC Tech. Rept. No. 50-70, Inst. of Tech., Univ. of Minn., Minneapolis, 36 pp., 1959.
AD-215 448.

The world literature in the field of aircraft panel flutter and aerodynamic noise is critically reviewed and a bibliography of over two hundred references assembled.

513

Smith, R. J., and T. W. Scott, "Non-Destructive Testing, a Literature Search," TID-3521, Tech. Inf. Service, Atomic Energy Commission, Oak Ridge, Tenn., 11 pp., 1957.
AD-149 529

Bibliographic and availability information is given for 70 AEC reports and 18 non-AEC reports in which are described the following nondestructive testing techniques: sonic, ultrasonic, radiographic, radioautographic, fluorescent penetrant, electromagnetic, frost, eddy current, and leak testing.

514

Thuronyi, G., "Selective Annotated Bibliography on Propagation of Acoustic and Explosion Waves in the Atmosphere," Meteorol. Abst. and Bibl., 10, 1072-1098, 1959.

This bibliography contains 122 entries, each with an abstract or annotation, and spans the years from 1950 to 1959 inclusive, plus a few entries from 1937 to 1949. Most aspects of the propagation of sound in air are covered. Emphasis is on acoustic propagation as a means for studying various properties of the atmosphere.

515

Thurston, G. B., and R. Stern, "A Bibliography on Acoustic Sources and Their Related Fields," Rept. No. 2784-2-S, Willow Run Labs., Univ. of Mich., Ann Arbor, 65 pp., 1959.
AD-213 504.

A bibliography is presented on acoustic sources and their related fields. Both single sources and arrays of sources are considered. The abstracts are arranged into a detailed subject outline having 4 major topics: single sources and receivers; arrays of sources and receivers; transducer properties; acoustic fields. Articles published during the period from 1935 to 1958 are reviewed.

516

Thurston, G. B., and R. Stern, "A Bibliography on Propagation of Sound Through Plates," Rept. No. 2784-1-S, Willow Run Labs., Univ. of Mich., Ann Arbor, 167 pp., 1959.
AD-213 505.

This is a bibliography on propagation of sound through plates. The abstracted material is organized in accordance with a detailed subject outline having five major topics: transmission through plates; wave propagation; properties of materials; vibrating surfaces and plates; general references. Literature surveyed is principally from 1929 to 1958. Approximately 450 abstracts are given.

517

Trambicki, G. S., "Noise and the Means of Combatting It" (Trans. No. T77R of Zh. Ushnykh, 15, 247-260, 1938), Defense Scientific Inf. Serv., 30 pp., 1954.
AD-26 025.

This report on noise sources, noise control and noise reduction also contains a bibliography with 216 entries.

518

van der Toorn, L. J., "Bibliography, Shock and Vibration Absorption in Packaging (Cushioning)," Rept. No. TDCK 28650, Tech. Doc. Inform. Ctr. Krijgsmacht, Netherlands, 261 pp., 1961.
AD-276 956.

This bibliography contains abstracts of articles and reports on theories of shock, vibration and damping. Attention is paid to the analysis of mechanical influences occurring during shipment, storage and operational conditions. Part of the bibliography deals with test methods and measuring equipment; results are given. Extensive information is gathered on cushioning materials and shock- and vibration-resistant constructions used in packaging techniques. Items on properties of materials are compiled. References on isolators against shock and vibration used for the protection of apparatus aboard ships, aircraft, and guided missiles are also included, as is literature on air drop operations. Prescriptions and military specifications dealing with the above mentioned subjects are surveyed.

519

van Rossum, J. W. M., "Bibliography on Blast, Shock Waves and Allied Topics, Featuring Nuclear Explosions," Rept. No. TDCK 30050, Tech. Doc. Inform. Ctr., Krijgsmacht, Netherlands, 1962.
AD-276 958.

Entries include references to reports pertaining to characteristics of nuclear explosions—air burst, ground burst, and underwater burst—together with the response of structures to blast loading. Attenuation is paid to measurements, experimental techniques, and testing equipment. Many of the references in this report bear only a marginal relationship with the subject mentioned, but their findings are of interest in the over-all picture. References have been arranged chronologically with the latest references placed first. The bibliography is cross-referenced and has an author index.

Bibliographies
See also—32, 47, 246, 441, 471, 522, 556, 557, 581, 585, 590, 885, 992, 1143, 1416, 1431, 1437, 1475, 1624, 1731, 2121, 2186, 2256, 2460, 2957

BOOKS, COMPENDIA, PROCEEDINGS, REVIEWS AND SYMPOSIA

520

Air Force Special Weapons Center, "Proceedings of Second Shock Tube Symposium 5-6 March 1958," Rept. No. SWR TM-58-3, Kirtland Air Force Base, N. Mex., 1958.
AD-211 239.

Contents:
Shock tube wind tunnel research at U. S. Naval Ordnance Laboratory.
Shock tube studies of blast pressures behind frangible wall panels.
A comparison of shock tube and field test data on the pressure buildup behind frangible walls.
Some results of a shock tube for biomedical investigation.
Experimentation with the General Electric six-inch shock tunnel.
Pressure-time history in a chamber subjected to shock wave filling through an orifice.
Determination of the time history of the flow field about blunt bodies in a shock tube.
Some experiments with periodic shocks.
On the effect of attenuation on gas dynamic measurements made in shock tubes.
Generation of pressure wave forms through the detonation of explosive charges.
Problems in the use of piezo-gages for shock tube instrumentation.
Determination of the dynamic response characteristics of pressure-measuring systems utilizing shock tube testing techniques.
High temperature effects in shock structure.
Shock wave calculations for high temperature gases.
Heat transfer measurements on a hemisphere-cylinder in the Lockheed three-inch shock tube.
A particular application of a conventional shock tube for the study of transient ignition and combustion in subsonic flow.
One-dimensional shock waves from an axially symmetric electrical discharge.

521

American Industrial Hygiene Association, "Industrial Noise Manual," Detroit, 166 pp., 1958.

This manual clearly and simply presents the necessary background information and specific instruction to enable skilled technicians from many fields to measure noise and obtain meaningful results. By following the methods of noise evaluation given, it is possible to estimate the hearing damage potential of a given source and to determine the minimum useful noise reduction required. The manual outlines the elementary principles, and includes details on 33 examples, of noise control. Each example is presented on a separate page and is accompanied by sound spectra for the before-and-after conditions. Drawings and photographs clearly show what has been done and how materials or methods are used to reduce the generation, transmission, and radiation of noise. Examples are also given in which process planning has led to noise reduction. The last chapter of the manual discusses methods of personal protection, including elementary but detailed discussions of the theory, potential capabilities, and practical results to be expected from ear muffs and ear plugs.

522

Army Signal Missile Support Agency, "Proceedings of the Symposium on Atmospheric Acoustic Propagation," Headquarters, USA SMSA, Missile Meteorology Div., 1, 268 pp, 1961.
AD-408 716.

This document comprises twenty-five technical papers on various aspects of the propagation of sound in air. It features the results of recent research. These deal with high-altitude acoustic detection from balloons, the sound duct at high altitudes, very-long-range detection of low-frequency sound, atmospheric absorption of sound, sound ray theory, shock wave propagation, sound ranging, and the inter-relationships of meteorological parameters with sound propagation. Some of the papers emphasize theory, others emphasize measurements and experimental results, and some describe special instrumentation. Anyone interested in military applications of sound propagation in the atmosphere will find this document especially useful. Most of the papers include extensive bibliographies.

523

Bendat, J. S., "Principles and Applications of Random Noise Theory," John Wiley, New York, 431 pp., 1958.

Random processes have become most important in our understanding of the performance of physical systems. Those working in noise control, vibration, speech analysis and synthesis, as well as other aspects of acoustics, all have some interest in random processes. This is basically an applied mathematics book dealing with some of the specific problems involving random processes. Of special interest to vibration specialists is chapter 2, on Power Spectra and Relationships. In addition, chapter 10 discusses the Zero Crossing Problem, a method of analysis that can be applied to speech signals. A firm foundation in mathematics is required of the reader, although probability theory and Fourier integrals are treated within the book.

524

Beranek, L. L., "Acoustic Measurements," Chapman and Hall, London; John Wylie, New York, 914 pp., 1950.

The subjects covered are: history of acoustics; terminology; attenuation; scattering and nonlinear distortion in wave propagation; diffraction phenomena around various obstacles (spheres, cylinders, the human body, etc.) and around sources of sound in finite baffles; primary techniques for the measurement of sound pressure and particle velocity and for the absolute calibration of microphones ("reciprocity" technique of calibration, the theory and use of the Rayleigh disc); primary sources of sound (thermophone, pistonphone, and the electrostatic actuator); characteristics of the ear (referring to Fletcher's "equal loudness" curves); microphones (carbon, condenser, piezoelectric types) and their directional properties; primary frequency standards (pendulum clocks, precision forks); ordinary frequency standards (audio-oscillators, electronic meters, Wien bridge, etc.); frequency comparison methods; measurement of acoustic impedance (including motional impedance); the audiometers; sound sources for test purposes (vocal, low intensity, high intensity, and explosive); characteristics of random noise (a statistical study); indicating and integrating instruments for the measurement of complex waves (peak, average, rms, and power meters); analysis of sound waves (steady and transient sounds, calibration of sound analyzers); basic tests for communication systems (the rating of microphones, amplifiers, and loudspeakers); tests for laboratory and studio microphones; tests for loudspeakers; articulation test methods; measurement of acoustic properties of rooms, studios and auditoriums; measurement of acoustical materials, the sound level meter. The book covers a very wide field and is likely to be mainly of interest to acoustical and communication engineers for reference purposes.

525

Beranek, L. L., "Acoustics," McGraw-Hill, New York, 481 pp., 1954.

This is an advanced-level textbook on acoustics. The introduction includes a list of definitions of the more important acoustical terms. The first five chapters and chapter 12 deal with fundamental topics in acoustics, such as solutions to the wave equation, acoustical analogues, radiation, acoustic components, and acoustic measurements. Chapters 6 to 11 deal with applications of the fundamental topics to microphone, loudspeaker systems, sound fields in enclosures, and noise control. The last chapter of the book is concerned with hearing, speech intelligibility and psycho-acoustics.

526

Beranek, L. L., "Noise Reduction," McGraw-Hill, New York, 752 pp., 1960.

This book grew out of the special summer programs on the subject of noise reduction in industry which were held at the the Massachusetts Inst. of Tech., in 1953, 1955, 1957, and 1960.

Each of the 19 authors of the 25 chapters in the book is well known through his original contributions to the field he discusses. Although each chapter stands by itself as an introduction to or an up-to-date review of a certain topic, the continuity in terminology, approach, and presentation is well preserved.

The book is divided into four parts: (1) sound waves and their measurement; (2) fundamentals underlying noise control; (3) criteria for noise and vibration control; (4) practical noise control.

527

Blokhintzev, D., "The Acoustics of an Inhomogeneous Moving Medium," Translated by R. T. Beyer, and D. Mintzer, Research Analysis Group, Brown Univ., Providence, R. I., 161 pp., 1952.
AD-7675.

This is an English translation of a Russian book. It comprises comprehensive mathematical treatments of the following general topics: Chap. I, The acoustic equations for an inhomogeneous moving medium; Chap. II, Propagation of sound in the atmosphere and in water; Chap. III, Moving sound sources; Chap. IV, Sound excitation by flow. Ray acoustics, zones of silence, the effects of atmospheric turbulence, scattering, and shock wave propagation are thoroughly treated within these chapters.

528

Bolt, Beranek, and Newman, Inc., "Handbook of Acoustic Noise Control, Vol. I. Physical Acoustics, Supplement 1," Suppl. 1 to WADC Tech. Rept. No. 52-204, Vol. 1, 308 pp., 1955.
AD-66,250.

Contents (additions and revisions to Volume I):

Propeller noise.
Noise from aircraft reciprocating engines.
Total external noise from aircraft with reciprocating engines.
Noise generating mechanisms in axial flow compressors.
Ventilating fans and ventilating systems.

Insulation of airborne sound by rigid partitions.
Insulation of impact sound.
Transmission of sound through cylindrical shells.
Specification of sound absorptive properties.
Lined ducts.
The resonator as a free-field sound absorber.
Acoustical shielding by structures.

529

Bolt, Beranek, and Newman, Inc., "Handbook of Acoustic Noise Control," WADC Tech. Rept. No. 52-204, Wright-Patterson Air Force Base, Ohio, 1,397 pp., 1952
AD-12,015.

An over-all view is presented of the acoustic noise-control problem. The following noise source characteristics and methods of noise control are discussed: specification of a noise source, aircraft propellers and reciprocating engines, aircraft jet and rocket engines, fluid flow devices, industrial machine noise, physical characteristics of miscellaneous environmental noise, general noise-control panning, noise-control requirements, control of structure-borne noise, control of airborne noise, rooms and special enclosures, and evaluation of sound-control installations.

Chapter 12 describes methods for reducing the propagation of noise through air, indoors and outdoors. Lined ducts, parallel baffles, mufflers, resonators, resonant linings, isolating walls and combined treatments are considered. In covering the subject, the propagation of sound in the atmosphere and the effects of temperature, pressure, wind and ground impedance on propagation are described. The presentation is essentially non-mathematical. Most of the data and design criteria appear in the form of charts, graphs, and tables.

530

Brekhovskikh, L. M., "Waves in Stratified Media" (in Russian), Izd. Akad. Nauk SSSR, Moscow, 502 pp., 1957.

This general but detailed text on wave motions of all types in stratified media treats radio and light (electromagnetic) waves in liquids and gases at great length; reflection and refraction of spherical waves and propagation in stratified media in detail; and sound waves in particular. Sound waves in liquids and gases are treated on a theoretical and empirical basis with numerous nomograms and schematic diagrams (pp. 325-359 and 445-458). The special case of acoustical propagation in a three-layer medium is treated on pp. 343-347 and group velocities on pp. 349-350. Focusing of sound waves is discussed on pages 455-458. Much of the work is based on the author's own research in underwater propagation (1954-56).

531

Burd, A. N., "Symposium on Calibration of Microphones and Hydrophones, London, January 1962," J. Sci. Instr., 39, 185-187, 1962.

A report of a symposium held by the Acoustics Group of The Institute of Physics and the Physical Society on 17 January 1962.

532

Coast Guard, "Proceedings of the Sixth International Technical Conference on Lighthouses and Other Aids to Navigation, September 25-October 7, 1960," Washington, D. C., 245 pp., 1960.
AD-277 064.

Descriptors: Conferences-Lighthouses, Lighthouses, Navigational lights, Symposia-Navigational lights, Indexes, Light homing, Lighting equipment, Navigation, Coast Guard, Signal lights, Fog signals, Power supplies, Electronic equipment, Auditory signals, Ships.

533

Condron, T. P., and W. S. Ripley, "Acoustic Propagation in the Atmosphere," in Handbook of Geophysics for Air Force Designers, Air Force Cambridge Research Center, U. S. Air Force, Chap. 21, 14 pp., 1957.

Normal propagation of sound in a homogeneous atmosphere is reviewed as an introduction to anomalous propagation and absorption in a realistic atmosphere. Spreading and diffraction losses in a refractive medium are described and followed by a brief treatment on ray geometry as applied to sound in air. Attenuation of sound in air due to classical absorption and molecular absorption is described. Several charts and graphs are included from which absorption per unit distance can be determined as a function of meteorological parameters such as temperature and humidity. A final section on noise sources includes data on sound pressure levels and octave band analyses from jet and reciprocating engines, helicopters, and backgrounds in industrial, residential, and jungle areas.

534

Cox, E. F., "Sound Propagation in Air," in Handbuch der Physik (Encyclopedia of Physics), 48, 455-478, 1957.

This paper begins with a review of the basic laws of propagation of sound energy in air and explains why weak sound waves propagate with negligible distortion, while high amplitude sound waves distort and form shock fronts as they propagate. Expressions for shock wave velocity are given.

Meteorological factors affecting the speed and direction of sound rays are described, and the laws of sound ray refraction and reflection are reviewed. Absorption and dispersion of sound in real atmospheres are described. Formulas and graphs are given for determining attenuation with distance. Propagation of sound to great distances is treated in detail. Refraction in the troposphere and the formation of sound ducts at tropopause heights are described and documented. An excellent bibliography is included.

535

Crawford, A. E., "Ultrasonic Engineering," Academic Press, New York, 344 pp., 1955.

After a very brief presentation of the theory of ultrasonic radiation and a chapter on cavitation in liquids, the next 100 pages are devoted to the treatment of the generation of high-intensity and high-frequency sound. The remaining 180-odd pages discuss the specific applications, including precipitation, emulsification, chemical action, metallurgical processing, coating of metals, as well as biological and medical applications. There is a final chapter on ultrasonic instruments and control gear.

The treatment is descriptive throughout, with a minimum of emphasis on analytic detail. For the most part the formulas are introduced from the technical literature without deduction, much of the analysis having been replaced by numerous clear and well-drawn graphs. The bibliography, though not extensive, is adequate for the engineering reader who wishes to follow up some special line. The style is clear and readable. The illustrations of ultrasonic equipment are excellent, as is the typography. The volume should find wide use among acoustical processing engineers.

536

Cremer, L., editor, "Proceedings of the Third International Congress on Acoustics, Stuttgard, 1959, Vol. 1, Principles," Elsevier Publishing Co., Amsterdam (U. S. distributor: D. VanNostrand Company, Inc., Princeton, N. J.), 604 pp., 1961.

This large volume is the first of two covering the proceedings of the Third International Congress on Acoustics held in Stuttgart, West Germany, in September 1959. The first volume deals mainly with principles; the second is intended to concentrate on applications. Of the 160 papers in Vol. I, there are 14 on physiological acoustics, 29 on psychological acoustics, 19 on speech, 28 on propagation in liquids and gases, 18 on vibrations, and 52 on physical acoustics. The second volume will contain 168 papers on the five fields: electroacoustics and measurements, room acoustics, building acoustics, noise control, and ultrasonics. There is no index, in Vol. I; however, a complete index for the whole proceedings is promised for Vol. II.

537

Dubin, M., "Meteor Impacts by Acoustical Techniques," in R. L. F. Boyd and M. J. Seaton (eds.), "Rocket Exploration of the Upper Atmosphere," Pergamon Press, London, 26-27, 1954.

This chapter briefly mentions detection of meteorites by rockets flying in the upper atmosphere. The rockets carry flush-mounted microphones, the diaphragms of which are deflected by impacts of meteoric particles.

538

Eckert, C., "Hydrodynamics of Oceans and Atmospheres," Pergamon Press Inc., New York, 290 pp., 1960.

This book presents a systematic study of the fluid motions in oceans and atmospheres. Proceeding from the equations of hydrodynamic motion in a rotating system under the influence of gravity, the author obtains solutions to these equations to the first and second order of approximation for various model atmospheres and oceans. The propagation of small disturbances in these models is examined in great detail. Of particular interest to the acoustician is the discussion of the interrelation of the gravitational and acoustic modes of motion.

539

Esclangon, E., "Acoustics of Guns and Projectiles," Dept. of Physics, Univ. of Calif., Los Angeles, 1941.

This book is primarily concerned with ballistic acoustics but, considering its introduction in 1925, is also a source of surprisingly accurate and complete information on physical acoustics. It is divided into two sections. The first is concerned with the geometrical acoustics of guns and projectiles and covers in detail muzzle waves, ballistic waves, and hissings. The second is concerned with physical acoustics. Both sonic and subsonic acoustics are discussed, as are physiological acoustics, atmospheric reflection and refraction, zones of silence, and sound ranging.

540

Estermann, I. (ed.), "Methods of Experimental Physics, Vol. I. Classical Methods," Academic Press, New York, 596 pp., 1959.

This book emphasizes method rather than experimental details. It is intended to be "a concise well-illustrated presentation of the most important methods or general principles needed by the experimenter, complete with basic references for further reading."

There are 15 contributors. The chapter headings are Evaluation of Measurement, Fundamental Units and Constants, Mechanics of Solids, Mechanics of Fluids, Sound and Vibration, Heat and Thermodynamics, Optics, Electricity, and Magnetism.

The volume fulfills its aim of being valuable to research workers who use physical methods. The discussion is fundamental, and the reader is prompted throughout to a fresh viewpoint.

541

Etkin, B., and H. S. Ribner, "Canadian Research in Aerodynamic Noise," Review No. 13, Inst. of Aerophysics, Univ. of Toronto, Canada, 1958.
AD-203 662.

Canadian research on flow noise and some aspects of the aircraft noise problem is described. Specific experimental and/or theoretical investigations include: aeolian tones; boundary layer noise (rigid and flexible walls); effects of boundary layers and noise on aircraft structures; distribution of noise sources along a jet; ground run-up mufflers; transmission of sound from, and acoustic energy flow in, a moving medium; sound generated by interaction of a vortex with a shock wave.

542

Flugge, S. (ed.), "Handbuch der Physik, XI, Acoustics I," Springer-Verlag, Berlin, 443 pp., 1961.

This is the first of a series of volumes of the Handbuch der Physik dealing with acoustics. The introductory monograph by Morse and Ingard, "Linear Acoustic Theory," is an exceptionally lucid and elegant presentation of this subject. The authors systematically seek to present equations and boundary conditions in a general, nonspecialized form. As a result, this brief monograph covers an exceptional variety of physical situations generally not treated in textbooks and sometimes not available in periodicals. This is particularly true of the analysis of scattering phenomena. This monograph concludes with a most usable section on coupled acoustic systems.

The remaining four monographs are concerned with sound absorption and dispersion in various media. Each was written by an authority: Kneser deals with gases; Tamm, with electrolytic solutions; Sette, with liquids; and Mason, with high polymers. Their contributions generally start with a review of the theory, followed by a section on experimental techniques and results.

543

Fridman, V. M., "Ultrasonics," Aerospace Tech. Intelligence Center, Wright-Patterson Air Force Base, Ohio, 66 pp., 1961.
AD-264 622.

An extensive study of ultrasonics technology is presented in handbook form. Applications to industrial research are presented and descriptions of equipment are given with photographs of various devices. Discussions of ultrasonics theory and principles of applications are stated at some length.

BOOKS, COMPENDIA, PROCEEDINGS, REVIEWS AND SYMPOSIA

544

Gayford, M. L., "Acoustical Techniques and Transducers," Macdonald and Evans, Ltd., London, England, 372 pp.

This book presents the state of the art and a survey of recent developments in the field of applied acoustics as related to sound reproduction.

The book is introduced by a brief general discussion of physical phenomena encountered in acoustical and mechanical systems and analogies between electrical, mechanical, and acoustical systems. The treatment is advanced enough for the specialist but not enough to discourage the reader who has very little specific training in acoustics.

The major portion of the book is devoted to a survey of recent developments in loudspeakers, microphones, and disk recording and reproducing equipment. The discussions on vibration-measurement equipment and the acoustics of studios and listening rooms are somewhat shorter. For example, the section on microphones covers 30% of the book.

The discussion of each topic is concluded with references to books and journals. The references are well chosen and practically all the references relate to articles or books published in the last decade.

545

Glickstein, C., "Basic Ultrasonics," John F. Rider Publisher, New York, 137 pp., 1960.

This book is divided into three parts: general theory, equipment, and applications, with a short glossary and an index. The "pictured text" method is used, with almost every page having a cartoon-like diagram occupying from about one-quarter to, in a few cases, well over one-half of the page. Scattered throughout the book are six sets of "Questions and Problems," each containing ten or twelve questions.

The book is suitable for technical institute or vocational school use. No mathematical background is required, but a fair knowledge of electronics is needed, especially for the equipment section. The diagrams help not only by enlivening the appearance but also by serving as a very effective means of emphasizing the main points of the textual material. The book could also serve those looking for a good elementary survey of ultrasonic equipment and applications. The section on sound in general physics courses could make stimulating supplementary reading material.

546

Gray, D. E. (ed.), "American Institute of Physics Handbook," McGraw-Hill, New York, 1957.

Eight editors have assembled this volume, which comprises nearly 1500 pages and, in addition, a 48-page index. Over one hundred distinguished specialists have contributed their knowledge.

The section on acoustics, edited by F. A. Firestone, comprises fourteen chapters. It begins with chapters on acoustical quantities. This introductory material is followed by a scholarly exposition on the propagation of sound in fluids which, in turn, is followed by chapters on the acoustic properties of gases, liquids, solids, and transducer materials. There are chapters on the frequencies of simple vibrators and musical scales, on radiation of sound, architectural acoustics, and speech and hearing. The section concludes with two chapters on analogies and a chapter of selected references.

547

Griffin, D. R., "Echoes of Bats and Men," Doubleday Anchor Books, Garden City, N. Y., Science Study Series S4, 156 pp., 1959.

Among the early paperback volumes in the new Science Study Series, growing out of the work of the Physical Sciences Study Committee, the fourth and ninth have to do with acoustics. Griffin's book appears to be of high technical quality and, in addition, reads like a detective story. The basic problems of getting about in dark reaches that preclude the use of vision, whether by bats, fishes, or blind men, are clearly stated by the author, who then proceeds to solve the problems logically. It is an extremely readable volume of bioacoustics.

548

Griffin, D. R., "Listening in the Dark," Yale Univ. Press, New Haven, Conn., 413 pp., 1958.

This book presents the history and results of the author's long and thorough research on "echolocation." Bats, birds, fish, and men were investigated. The work is an excellent example of the application of acoustic methods and instrumentation to biological research. One of the author's major conclusions is that much may be learned from the bat for research on guiding the blind.

549

Gutenberg, B., "Propagation of Sound in the Atmosphere" (in German), Handbuch der Geophysik, 9, 89-145, 1932.

This is a thorough study of instruments, theories, and the relation of atmospheric composition, wind and temperature on normal and anomalous sound propagation. Much data and many illustrations are included, as well as thorough references.

550

Gutenberg, B., "Sound Propagation in the Atmosphere," in T. F. Malone, ed., Compendium Meteorol. Am. Meteorol. Soc., Boston, 366-375, 1951.

This is a detailed study of the theory of sound waves in gases, the equations for velocity of sound in quiet and in moving air, and the energy of sound waves in the atmosphere. Microbarographs and their limitations are discussed. Observations and records from microbarographs of sound propagation through the troposphere and the stratosphere, and abnormal audibility zones are also treated. Numerous illustrations show types of records, areas of abnormal audibility from explosions (Germany, 1925, and Vergiate, Italy, November, 1920), and travel time curves. Cross sections showing typical paths of sound waves, and temperature and sound velocity profiles from V-2 flights and other sound propagation data are included.

551

Harris, C. M. (ed.), "Handbook of Noise Control," McGraw-Hill, New York, 1042 pp., 1957.

This volume in the McGraw-Hill handbook series covers the broad and colorful spectrum of noise and its control. In forty chapters—ranging from physics and engineering, physi ology, and medicine to psychology, economics, and law—it contains, in over 1000 pages, a great amount of information. However, Chapters 2 and 3 will be of particular interest to people concerned with the propagation of sound in air.

Chapter 2, "Physical Properties of Noise and Their Specification," by R. W. Young and Chapter 3, "Propagation of Sound in The Open Air," by I. Rudnick are concerned with physical aspects of noise and sound. The former gives a review of the elementary concepts of sound and noise, particularly its description. A more extensive consideration of statistical aspects and methods would probably be useful for many readers. In Chapter 3 the complex field concerning the influence of outdoor factors on sound propagation is discussed, and the results are represented in many useful graphs.

552

Herzfeld, K. F., and T. A. Litovitz, "Absorption and Dispersion of Ultrasonic Waves," Academic Press, Inc., New York, 535 pp., 1959.

The text is divided into three roughly equal parts: A, the general theory of relaxation in fluids; B, gases; and C, liquids.

Part A begins from the Stokes-Navier equation of hydrodynamics, kinetic theory, and statistics. This part constitutes the mathematical formulation of the macroscopic aspects of the phenomena of absorption and dispersion, and is largely formal in character.

The parts devoted to gases and to liquids follow the same pattern: application of Part A to the particular state; a brief discussion of the appropriate methods of measurements; a summary of experimental results; and, finally, an attempt to survey the studies of the physical origins of the processes formally described in Part A. In many respects, those latter sections of Parts B and C are the most interesting portions of the book.

553

Hunter, J. L., "Acoustics," Prentice-Hall, Englewood Cliffs, N. J., xv+407, 1957.

This book is on the intermediate level, requiring some previous knowledge of calculus and general physics; previous knowledge of electric circuit theory is advantageous.

The book is essentially in two parts. The first part, consisting of four chapters, covers the basic theory, including oscillations of a particle, the vibrating string, and plane and spherical sound waves. Complex numbers, the vector diagram, impedance, and electrical analogs are stressed.

The rest of the book is on applications; the principal topics are loudspeakers, microphones, recording, physiological and psychological acoustics, architectural acoustics, acoustic measurements, ultrasonics, and underwater sound. The material is so presented that one might study these topics in any order after having completed the first four chapters.

554

Ingard, U., "Acoustics," in E. U. Condon, and H. Odishaw, eds., Handbook of Physics, McGraw-Hill, New York, 113-133, 1958.

This concise presentation of acoustic theory and applications discusses the general equations of sound propagation, sound sources and their fields, propagation in the atmosphere and in tubes, absorption of sound, scattering, detection of sound, architectural acoustics, and ultrasonics. The section on atmospheric sound propagation develops the equations pertaining to ray acoustics (phase velocity, group velocity, shadow zones), intensity in the shadow zone, scattering by turbulence, and ground absorption.

555

Jacobs, S. J., and A. D. Solem, "The 1961 International Colloquium on Detonation Waves Sponsored by the French Government," NOLTR 62-27, Naval Ordnance Lab., White Oak, Md., 20 pp., 1962.
AD-276 576.

About 100 scientists from eight countries attended the colloquium; major attendance came from France, Great Britain, and the U. S. Some 40 papers were presented, covering the following fields: initiation and transmission of detonation in solid explosives, detonation of solid explosives, detonation and shocks in gases, and shocks in solids. The general contents of the papers are summarized with comments on their pertinence to detonation studies in the U. S.

556

Kaplan, J., G. F. Schilling, and H. K. Kallman, "Methods and Results of Upper Atmosphere Research," Geophys. Res. Papers No. 43, Cambridge Res. Center, Massachusetts, 162 pp., 1955.
Also as Sci. Rept. No. 3, Inst. of Geophys., Univ. of Calif., Los Angeles, 1954.
AD-101 944.

Chapter 8 reviews temperature and wind velocity determinations between 30- and 180-km altitude by measurements of acoustic propagation. Some of the results reported by various authors (Crary, Kennedy, Cox, Whipple, Gutenberg) are shown in tables and diagrams.

557

Kaplan, J., and H. K. Kallman, "Upper Atmosphere Research," Rept. No. AFCRC-TR 57-213, Inst. of Geophysics, Univ. of Calif., Los Angeles, 250 pp., 1957.
AD-133 688.

Various means of investigating the physical state of the upper atmosphere of the earth are discussed. They are classified according to the sources of information (e.g., rocket flights, meteor observations, sound propagation, etc). Each method is described briefly, and typical results concerning temperature, pressure, density, composition, and winds, etc., are given. A distinction is made between the physical quantities which can be measured directly and those which can only be deduced from observations and theories. Tables, graphs, and references are part of each chapter.

558

Kinsler, L. E., and A. R. Frey, "Fundamentals of Acoustics," John Wiley, New York, 516 pp., 1950.

This is a classroom textbook giving the fundamental principles of the generation, transmission and reception of acoustic waves. The first nine chapters analyze the various types of vibration of solid bodies and the propagation of sound waves through fluids. These chapters discuss simple harmonic motion; the vibration of strings, bars, membranes and plates; plane and spherical waves; transmission phenomena; resonators and filters; and absorption. The remaining seven chapters cover a limited number of applications of acoustics; the close association between acoustics and communications engineering is stressed. These chapters include studies of direct-radiation loudspeakers, horn-type speakers, microphones, human hearing, architectural acoustics, underwater acoustics, and ultrasonics. Frequently mentioned is the point that the mathematical formulation of many acoustical problems is similar to that of the transmission of a-c through lines and networks; much use is made of electrical analogues.

BOOKS, COMPENDIA, PROCEEDINGS, REVIEWS AND SYMPOSIA

559

Kinsler, L. E., and A. R. Frey, "Fundamentals of Acoustics," John Wiley, New York, 2nd ed., 524 pp., 1962.

Some of the advances in acoustics since 1950 are included in this new and revised edition. The chapter headings indicate the scope of the book: 1. Fundamentals of Vibration; 2. Vibrating Strings; 3. Vibration of Bars; 4. Circular Membranes and Plates; 5. Acoustic Plane Waves; 6. Transmission Phenomena; 7. Spherical Acoustic Waves; 8. Resonators and Filters; 9. Absorption of Sound Waves in Fluids; 10. Loudspeakers; 11. Microphones; 12. Ultrasonic and Sonar Transducers; 13. Speech, Hearing, and Noise; 14. Architectural Acoustics; 15. Underwater Acoustics. There are a large number of completely solved numerical examples, and the answers to odd-numbered problems are supplied.

Two changes in this edition which required considerable rewriting are the adoption of mks rather than cgs units and the omission of the concept of velocity potential. Besides these, the major changes are in Chapter 9, which was completely rewritten at a more advanced level; in Chapter 10, which replaces two chapters and results in a unified treatment of loudspeakers with less stress on horn speakers; in Chapter 12, which replaces a chapter on ultrasonics, a field which has become too extensive to be covered in anything but a superficial manner in the space available; and in Chapter 15, which includes a great deal more material.

560

Krasil'nikov, V. A., "The All-Union Acoustics Conference," Soviet Phys. Acoust. English Transl., 4, 106-107, 1958.

The All-Union Acoustics Conference, organized by the Academy of Sciences of the USSR and by Moscow University, was held on 24-29 June 1957 in Moscow. About 150 papers on the following subjects were presented: propagation of sound to nonhomogeneous media, production and diffraction of sound, waves of finite amplitude, physics of the ultrasound, musical acoustics, psysiological acoustics and speech.

561

Krasil'nikov, V. A., "Sound Waves in Air, Water and Solid Bodies" (in Russian), 2nd rev. ed., Gos. Izdat., Moscow, 439 pp., 1954.

A comprehensive and popular text on the propagation of sound and ultrasonic waves in the air (atmospheric acoustics), in water (hydroacoustics) and in the earth (seismology) and their utilization. All questions are treated on the basis of the most recent advances in modern acoustics. Chapter 1 deals with vibrations and waves; Chap. 2, sound waves in the air; Chap. 3, receivers and emitters, and oscillographs; Chap. 4, experiments with sound and sound analysis (speed, temperature effects, propagation, interference, dispersion); Chap. 5, ultrasonic air waves (shock and explosion waves); Chap. 6, propagation of sound in enclosed spaces and in the free atmosphere; Chap. 7, sound and ultrasonic waves in water (sound of the sea); Chap. 8, sound and ultrasonic waves in solid bodies; Chap. 9, propagation of elastic waves in the earth's crust. The manual is intended for high school teachers, college and technical school students, engineers and hydro-acousticians.

562

Leyzorek, M., and M. J. Lun, "Symposium on Target Detection by Acoustic and Seismic Means, at the Operations Research Office, 17 June 1953," ORO T-254, Johns Hopkins Univ., 1953.
AD-32007.

Project TACIT's research into the feasibility of a remotely operated target-detection system using sonic and/or seismic sensing elements is an important part of the effort to develop an all-weather battlefield surveillance system designed for atomic weapons. To learn the current findings of other organizations working in related fields, and to disseminate that knowledge to other researchers, TACIT sponsored a symposium at the Operations Research Office on 17 June 1953. Summarized in this memorandum are papers presented by participants from 22 laboratories, covering problems of acoustic and seismic detection, telemetering systems, recorder-computers, target-signature analysis, and display systems. They conclude that: (1) at long ranges (10,000 yards), ground targets may be detected by airborne sound, but the highly directional sensing elements required are influenced by weather and nearby turbulence, and each is generally limited to one target at a time. (2) Earthborne sound may reveal impulsive sources at long ranges, but nonimpulsive-source detection is limited to about 200 yards. (3) Arrays of omnidirectional acoustic and/or seismic detectors can be used to locate and identify targets within 200 yards. (4) There will soon be components for testing a detection, location, and identification system based on short-range, omnidirectional acoustic and/or seismic sensing elements located up to 10 miles behind enemy lines.

563

Link, F., and L. Neuzil, "Rocket Flight and Exploration of the Upper Atmosphere" (in Czechoslovakian), Cesk. Akad. Ved., Prague, 3rd ed., 235 pp., 1957.

As stated in the introduction to this book, the use of rockets greatly facilitates upper atmospheric research but does not replace other methods of exploration. Accordingly, on the basis of original work and results reported in international literature the authors deal with all available methods of investigating the various properties of the upper atmosphere. The methods described include stratosphere flights, acoustical sounding, photometric and other measurements during lunar eclipses, rocket launchings, artificial satellites, ionospheric sounding, spectroscopy. The upper atmospheric phenomena discussed include twilight phenomena, night sky luminescence, ionospheric phenomena, auroras, meteors, geomagnetism, structure and composition of the atmosphere, etc.

564

Massey, H. S. W., and R. L. F. Boyd, "The Upper Atmosphere," Philosophical Library, New York, 333 pp., 1959.

Of particular interest to acousticians is the chapter on sound transmission in the upper atmosphere. The propagation of explosive sounds originating on the ground, with anomalous transmission and zones of silence, is examined for what it reveals on the variation of temperature with height. Explosions in the upper air itself have been made possible with the use of rockets, and these explosions have been used to chart the distribution of wind and temperature. However, it seems that even more effective use of sound propagation (e.g., sound attenuation studies) could be made.

565

Morse, P. M., and R. H. Bolt, "Sound Waves in Rooms," Revs. Mod. Phys., 16, 69-150, 1944.

This is a critical discourse and survey on the present position of room acoustics. It begins with Sabine's pioneer work, gives an account of progress, and points out where further research is required. It discusses the general principles of wave acoustics and shows how they clarify and supplement the geometrical results of earlier workers. It examines the importance of the reverberation time T, background noise, loudness of source, and shape of room, as they affect the recognizability of speech. The value of T given by Knudsen includes the absorptive effect of the air, for above 4000 cps this absorption may be several times the total absorption at the boundaries of the room. Methods of measuring room acoustics reveal the inadequacies of the geometrical theory. The general aspects of wave acoustics studied are the nature of the reaction between the sound wave and the walls of the room and the natures of the steady-state and transient response to a source of sound. The first of these involves a knowledge of the acoustic impedance of the surface; in the second and third the reverberant sound has the characteristic frequencies of the normal modes of vibration of the room and not necessarily the frequency of the source. In a simple rectangular room, a number of different decay rates exist; thus the decay curve cannot be a straight line, and rooms having smooth, regularly-shaped walls show the greatest divergence of decay rates for different standing waves. In general, wave acoustics will have to be used for small regularly shaped rooms, and geometrical acoustics will be sufficient for the analysis of most large auditoriums. The report ends with a very full bibliography.

566

Nyborg, W. L., and D. Mintzer, "Review of Sound Propagation in the Lower Atmosphere," WADC TR-54-602, Brown Univ., Providence, R. I., 1955.
AD-67 880.

Available information on sound propagation through the lower atmosphere is critically reviewed. The application is to the prediction of sound fields due to aircraft (in flight or on the ground), especially at distances up to a few miles from the aircraft sound sources. Treatment of the prediction problem requires consideration of a number of topics including absorption processes in the air, boundary effects caused by the earth, and refraction of sound due to spatial variations in air temperature and wind. Although a fair amount of information is now available on these topics, a considerable amount of research remains to be done before practical solutions will be available. Numerous charts and nomograms (for determining absorption losses) and a bibliography containing 92 references are included.

567

Olson, H. F., "Acoustical Engineering," D. Van Nostrand, New York, 725 pp., 1957.

This is a new edition of H. F. Olson's book, formerly titled Elements of Acoustical Engineering. It retains the organization of the earlier work, but adds two chapters: Chapter 13, "Complete Sound Reproducing Systems," and Chapter 14, "Means for the Communication of Information."

In addition, the text has been thoroughly brought up to data, recording the developments of the last few years. New and often large sections appear in all chapters. For example, Chapter 5 contains added material on the pulsating cylinder and vibrating strip; Chapter 6, on the theory of the electrostatic loudspeaker; Chapter 7, on the throttled air flow speaker and on the ionophone loudspeaker; Chapter 8, on the theory of the electronic microphone; and Chapter 9, on magnetic tape sound recording and reproducing systems. In the revision of Chapter 10 advantage has been taken of the considerable number of new and revised standards on acoustical measurements published by the American Standards Association since 1945.

568

Parkin, P. H., and H. R. Humphreys, "Acoustics, Noise and Buildings," F. A. Praeger, New York, 331 pp., 1959.

This book is well organized and easy to read. It begins with a good section on the nature of sound, discusses the behavior of sound in rooms and then takes up the specific design of various types of rooms, including rooms for speech, rooms for music, and broadcast studios.

Included is a long educational chapter on sound measurement and on the calculation of (a) sound propagation outdoors and over walls, (b) noise levels in rooms, (c) loudness and loudness level, (d) transmission loss, (e) insulation between inside and outside of buildings, (f) ventilation noise control, and (g) vibration isolation. This chapter is rich in examples.

The final chapter on criteria for noise control and sound isolation draws heavily on American literature, and covers the essential criteria needed in design. The book concludes with a series of appendixes, including tables of sound absorption coefficients, weights of various common building materials, transmission loss data, spectra of some typical noises, and tables of conversion factors, decibels, and logarithms. An index is included at the end.

569

Pennsylvania State University, "Atmospheric Physics and Sound," Final Rept., Dept. of Physics, Acoustics Lab., University Park, 288 pp., 1950.

This voluminous report contains a detailed account of the instrumentation developed, methods used, and results achieved at Pennsylvania State University in a five-year study aimed at investigating the production and propagation of sound, both sonic and ultrasonic, in the lower atmosphere, through the ground, and in other media. Chapter 7 "Micrometeorology and Atmospheric Acoustics," is a summary of results of temperature and wind velocity measurements (mostly with hot wire thermometers and aneomometers) made up to 50 feet from the ground in conjunction with sound intensity measurements. A definite correlation is found between sound signal fluctuations and inhomogeneities of temperature, but not of wind. Likewise no effect of snow cover on sound propagation was noted.

570

The Philosophical Library, Inc., "High Altitude and Satellite Rockets," Proc. of a Symposium at Cranfield, England, July 1957, New York, 136 pp., 1959.

This volume records the proceedings of a three-day symposium on high altitude and satellite rockets sponsored jointly by the Royal Aeronautical Society, the British Interplanetary Society, and the College of Aeronautics.

The British Skylark rocket and the American Vanguard satellite are described; propulsion, design, and instrumentation problems of rockets are considered, together with the guidance of satellites and the problems connected with high altitude flight by humans. Two papers consider aspects of the reentry problem, and there is a paper which entends some previous work on the dynamics of a dissociating gas. The first paper, by H. S. W. Massey on the scientific applications of rockets and satellites, is of most general interest. It includes a short discussion of the determination of the temperature at different heights above the earth by measuring the velocity of sound produced by explosions from grenades expelled from a rocket.

The value of this book is enhanced by the inclusion of the discussions which took place following the delivery of the papers; these make up nearly one-quarter of the text and make very interesting reading.

571

Pierce, J. R., and E. E. David, Jr., "Man's World of Sound," Doubleday, Garden City, N. Y., 287 pp., 1958.

A team of sophisticated authors undertakes the audacious task of explaining the principles of speech and hearing to the intelligent reader who may know little or nothing of science and engineering. This book hits the high spots in every field that is now considered important for an understanding of how men communicate with one another. It considers the physics of sound, the psychophysics of hearing, the anatomy and physiology of the ear and related parts of the nervous system, the articulatory mechanisms of speech and its acoustic parameters, speech intelligibility and musical fidelity, the efficiency of communication channels and the design of machines to generate and recognize speech.

572

Powell, A., "Theory and Experiment in Aerodynamic Noise, with a Critique of Research on Jet Flows in Their Relationship to Sound," 2nd Sympos. on Naval Hydrodynamics, 1958, U. S. Govt. Print. Office, Washington, D. C., 27 pp. 1960.

A survey of recent theoretical and experimental work on sound generation by unsteady flows where boundary effects are not important. After some comments on the basic theory, the author describes phenomena associated with discrete tones—the sensitive flame, edge tones and the sound from a choked jet. Experiments on sound generated by a turbulent jet are reviewed, and it is concluded that the technological demands on the subject considerably exceed the present understanding of it.

573

Predvoditelev, A. S., "Physical Gas Dynamics," Pergamon, New York, 183 pp., 1961.

The use of jet propulsion has naturally stimulated great interest in the properties of gases at extreme temperatures and pressures. This book is a translation of the proceedings of a symposium devoted to research carried out in the Power Engineering Institute of the Academy of Sciences of the USSR. It consists of twelve papers relating to various aspects of gas dynamics and, in particular, to the thermodynamic properties of air between 1000^{o} and $12{,}000^{o}$K, at pressures between 10^{-3} and 1000 atm. There are also papers on the high speed flow of gases in the neighborhood of obstacles with accompanying shock wave phenomena. Several articles deal with the phenomena associated with underwater explosions produced by electrical discharges.

Acousticians will be interested in curves giving the velocity of sound in air as a function of temperature up to $12{,}000^{o}$K and over the pressure range indicated above.

The book is printed by photo-offset and though the text is perfectly legible, many of the mathematical formulas are very difficult to read.

574

Rayleigh, J. W. S., "The Theory of Sound," I, 2nd ed., Dover, 480 pp., 1894.

This highly regarded book, originally published in 1877, remains today the basis for a large part of the science of acoustics. Volume I contains ten chapters, which deal with vibrating systems such as strings, bars, membranes, plates, and shells.

575

Rayleigh, J. W. S., "The Theory of Sound," II, 2nd ed., Dover, 504 pp., 1896.

Volume II of Rayleigh's Theory of Sound was first published in 1878 and contains 13 chapters, which deal principally with vibrations in fluids such as air and water. Much of the theory is as useful today as it was in 1878.

576

Rettinger, M. "Practical Electroacoustics," Chemical Publishing Co., N. Y., 1956.

Mr. Rettinger has compiled a pocket-sized volume on present-day electroacoustic devices and techniques. Throughout eight chapters and a short appendix, he presents several hundred typical handbook figures and formulas in a conversational manner.

The initial chapter deals with microphone types and characteristics, emphasizing placement and directivity. There is also an enlightening discussion on the use of the effective microphone output level in dbm. Following this is a chapter on direct radiator and horn loudspeakers. In addition to some fundamental theory on electromechanical transducer mechanisms, the fine points of enclosures and horns are treated at some length. These chapters, plus one on circuits involving crossover networks, mixers, and attenuators, provide the necessary background for a section on public address systems.

577

Richardson, E. G., "Relaxation Spectrometry," North Holland Publishing Co., Amsterdam (Interscience Publishers, Inc., New York), 140 pp., 1957.

For the most part the author discusses experimental devices for studying the behavior of viscoelastic media in both the sonic and ultrasonic frequency ranges. Much of the work referred to has come out of his own laboratory. For gases, standard elastic liquids, and solids, he confines himself to presenting typical examples of relaxation absorption and dispersion of high-frequency sound. There is a very brief treatment of dielectric relaxation in solids and liquids, with a comparison between it and acoustic relaxation.

578

Richardson, E. G., "Technical Aspects of Sound, Vol. II. Ultrasonic Range, Underwater Acoustics," Elsevier, New York, 412 pp., 1957.

This is the second of two volumes devoted primarily to the technical applications of acoustics with special reference to those in current use. Volume I, published in 1953, covered mainly the audible range and propagation through air. The present work extends the study to ultrasonics, propagation in liquids, and high intensity sound, particularly that produced by aircraft. In the preface the editor admits the possibility, in the light of the rapid development of new fields of acoustical application, of further volumes.

579

Rosenblith, W. A., and N. S. Kenneth (for Bolt, Beranek, and Newman, Inc.), "Handbook of Acoustic Noise Control," WADC Tech. Rept. No. 52-204, Wright-Patterson Air Force Base, Ohio, II, 262 pp., 1953.
AD-18 260.

Volume II, which is intended as a guide in solving the problem of noise control, discusses the ways in which acoustic noise can be undesirable. The topics treated in particular are: basic bio- and psycho-acoustic data; effects of noise on human behavior; and human response criteria for noise control. Several subjective responses were analyzed and correlated with properties of the physical stimuli. Definitions of bio-acoustic terminology are given along with a description of the anatomy of the ear and the properties of aural protective devices.

580

Rudnick, I., "Propagation of Sound in the Open Air," in C. M. Harris, ed, "Handbook of Noise Control," McGraw-Hill, New York, Chap. 3, 17 pp., 1957.

Chapter 3 decribes the propagation of sound in air and the various meteorological factors and boundary conditions that influence otherwise normal propagation. The effect of wind and temperature gradients, of fog and water vapor, and of reflecting and absorbing obstacles and boundaries are concisely treated. Mathematical expressions, graphs, and tabular data for determining divergence, diffraction, refraction, reflection, scattering, and attenuation with distance are presented. Anomalous propagation and shadow zones are investigated and explained in terms of sound-ray equations. In general, the chapter presents the basic results of work done by Kneser, Knudsen, Knotzel, Delsasso, Ingard, Nyborg, and Rudnick.

581

Schoch, A., "Reflection, Refraction and Diffraction of Sound," Trans. by F. J. Berry, Ministry of Supply, Armament Research Establishment, 77 pp., 1953.
AD-116 801.

The present state of theory and experiment on the reflection, refraction, and diffraction of sound is very thoroughly presented in this book-length paper. After a brief introduction, the work begins with a comprehensive review of fundamentals including the dynamics of sound waves in homogeneous media, Huygens' Principle, boundary conditions, and uniqueness of solutions. The various situations involving reflection and refraction are then treated, including plane waves at a plane interface, free boundary layer waves along a plane interface, nonplanar waves at a plane interface, plates, and laminated media. Finally, diffraction is treated as phenomena resulting from the presence of curved boundaries. The diffracting properties of cylindrical, spherical, and more complex obstacle shapes are investigated. An extensive bibliography containing 144 references is included.

582

Secretary of Defense, Assistant, "Shock, Vibration and Associated Environments, Part II, Research and Engineering," Washington, D. C., 25 pp., 1959.
AD-212 975.

The 27th Symposium was held at the U. S. Army Air Defense Center, Fort Bliss, El Paso, Texas on Feb. 25-27, 1959.

Contents:
Re-entry simulation
Design philosophy and environmental test
Random and complex-wave vibration testing
High-intensity acoustic noise testing

583

Staniukovich, K. P., "Unsteady Motion of Continuous Media," Pergamon, New York, 745 pp., 1960.

This translation of a Russian work treats the unsteady flow of inviscid fluids under isentropic conditions. The problems treated involve shock-type phenomena and are necessarily limited to situations involving one spatial variable.

The book begins with the development of the basic equations governing fluid motion. Both the Eulerian and Lagrangian forms are presented, and the equations are given in the cylindrical and spherical coordinate systems as well as in Cartesian form. Following this, a systematic process of development is followed from plane to cylindrical to spherical processes, always with the restriction of one space variable. After an extensive treatment of these problems, the author proceeds to consider topics of a more general nature: propulsion, gravitational fields, rarified and dense media, and relativistic effects.

584

Stenzel, H., "Guide for the Calculation of Sound Processes," Translated by C. E. Mongan, Jr., Bureau of Ships, Navy Dept., Electronics Div., Washington, D. C., 1947.
AD-65 532.

This handbook, translated from the German, undertakes a comprehensive theoretical discussion with related mathematical derivations concerning three types of sound fields: (1) the sound field at large distances from the radiator; (2) the sound field in the neighborhood of the radiator; (3) the sound field of a spherical radiator.

585

Stenzel, H., "Introduction to the Calculation of Sound Phenomena (Sound Fields of Radiators, Piston Diaphragms, Spheres, Etc.)" (in German), 2nd rev. ed., Springer-Verlag, Berlin, 167 pp., 1958.

The purpose of the second edition has been to include an extensive survey of the sound fields of piston-diaphragms and spherical sound-transmitters. The book is mainly theoretical and contains numerous diagrams illustrating the pressure amplitude and phase distributions in the sound-fields around various sound sources and obstacles. It contains also a number of useful mathematical tables and a list of references.

586

Taub, A. H., "Wave Propagation in Fluids," in E. U. Condon and H. Odishaw (eds.), "Handbook of Physics," McGraw-Hill, New York, 50-63, 1958.

This theoretical treatment of wave propagation in ideal fluids develops equations describing fluid wave motion with the help of the laws of conservation of mass, momentum, and energy. The cases of small disturbances (e.g., acoustic waves), interactions of waves of small amplitude, small disturbances in shallow water, plane waves of finite amplitude, formation and decay of shocks in one dimension, spherical waves of finite amplitude, and effects of viscosity and heat conduction are treated analytically.

587

Teel, G. D., "Proceedings of the Fourth Shock Tube Symposium 18-20 April 1961," Rept. No. 1160, Ballistic Res. Labs., Aberdeen Proving Ground, Md., 476 pp., 1962.
AD-274 039.

Contents:

NOL model nuclear airblast simulator.
The soil filled shock tube.
A shock tube modified to produce sharp-rising overpressures of 400-msec duration.
A high-explosive-operated shock tube with facilities for testing structures.

Volume detonation in shock tubes.
High pressure loading device for evaluating blast closure performance.
Techniques for producing long-duration loads in the NCEL blast simulator.
Arc heating technique for shock tube driver.
Pressure and heat-transfer instrumentation used in the NOL hypersonic shock tunnels.
Measurements in the hypersonic shock tunnel at I.S.L.
Shock wave decay in tunnels.
Republic 24-inch hypervelocity wind tunnel.

588

Trendelenburg, F., "Introduction to Acoustics" (in German), 2nd ed., Springer-Verlag, Berlin, 378 pp., 1950.

A modern and highly technical text on acoustics, with great emphasis on the theory of wave propagation in various media. Chapter II discusses variations of wave form and speed with changes in temperature and pressure. Chapter IV, Par. 22, deals with the influence of atmospheric temperature and wind lapse rate or discontinuities on propagation and refraction of sound waves, anomalous zones of audibility, and stratospheric reflection. The text is amply illustrated with schematic diagrams, graphs, and photographs.

589

van Bergeijk, W. A., J. R. Pierce, and E. E. David, Jr., "Waves and the Ear," Doubleday Anchor, Garden City, N. Y., 235 pp., 1960.

This book attempts to cover a broad subject matter, providing an introduction to physical acoustics and to auditory phenomena having to do with tones, noise, and speech. The general organization and some of the chapters are the same as those provided in a previous book by Pierce and David, entitled "Man's World of Sound." Probably because of the new author, the introductory material on hearing is more biologically oriented, and auditory phenomena are clearly not restricted to man.

590

Vigoureux, P., "Ultrasonics," Chapman and Hall, London, 163 pp., 1950.

The technique of generating and receiving ultrasonic waves is introduced, but the discussion is restricted to general principles without details of apparatus and experimental procedure. A simplified theoretical treatment is given of the propagation of ultrasound in liquids; the effects of viscosity, thermal conduction, and scattering are described. Methods of measuring velocity and absorption are discussed, most attention being paid to the interferometer, optical-diffraction, and echo-pulse methods. The more important experiments made on liquids and gases by many experimenters during the past decade are described. Concerning common gases, it is concluded that, apart from heat conduction and viscosity, absorption arises largely from delay in attaining equilibrium between the translational, rotational, and vibrational energies of molecules; the equilibrium between the first pair is rapidly attained, so that vibration accounts for most of the absorption. The relaxation times of gases are not predictable, and can be determined only by investigating absorption peaks by ultrasonic techniques. The causes of absorption by liquids are not well understood, probably because the relaxation times are so short that sufficiently high test frequencies are not yet available. Apart from the references cited in the text, the bibliography is confined to papers published since Bergmann's book in 1937.

591

Wood, A. B., "A Textbook of Sound," Macmillan, New York, 610 pp., 1955.

This new edition of a standard text in acoustics has some new material. It is divided into five parts, which deal with (1) the theory of vibrations, (2) vibrating systems and sources of sound, (3) the transmission of sound, (4) the reception transformation and measurement of sound energy, and, finally, (5) technical applications.

Considering this encyclopedic breadth nothing but a superficial coverage of these topics can be made in the scope of one text. The author has tried to prevent this by means of an elementary theoretical exposition of the subjects discussed in the text.

CALIBRATION AND TEST PROCEDURES

592

Ballard, H., "An Acoustical Technique for Calibrating High Altitude Temperature Sensors," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 88-99, 1961.
AD-409 716.

Bead thermistors were calibrated at various atmospheric pressures by measuring changes in the speed of sound caused by temperature shifts. This was done by pulsing a loudspeaker and the triggered sweep of an oscilloscope while applying the resulting output of a nearby microphone to the vertical input of the oscilloscope. The tests were run in an environmental testing chamber at pressures of 670, 87, 8 and 1 mm Hg, corresponding to altitudes of 4000, 50,000, 100,000, and 150,000 feet, respectively. Temperatures were varied between +20°C and -70°C at each of the above pressures, reproducing as nearly as possible the environmental conditions expected during the descent of a parachute-supported temperature telemetry system. It was found, however, that radiation from the walls of the test chamber prevented the thermistor from reaching an equilibrium temperature with the surrounding air. Air was circulated in the chamber at a velocity of 132 fpm during the tests. This velocity was determined at 670 mm Hg.

593

Benson, R. W., "The Calibration and Use of Probe-Tube Microphones," J. Acoust. Soc. Am., 25, 128-134, 1953.

A study was undertaken to obtain the free-field and the coupler calibrations of several probe-tube microphones with tubes of different sizes and to determine those characteristics of a probe tube which are necessary for accurate measurements in both a free field and in closed couplers. For accurate measurements with a probe-tube microphone, precautionary measures must be taken. The probe tube must be sealed to the frame of the microphone in order to prevent an acoustic leak. Such a leak causes a reduction in the output of the probe-tube microphone at the lower frequencies. A probe tube with a high input impedance should be used for making measurements in a closed coupler. A high input impedance is necessary if the pressure in the coupler is to remain the same as before the insertion of the probe tube. If measurements are to be made with the accuracy of measurements made with a standard laboratory microphone, there is a significant difference between the pressure and the free-field calibrations of probe-tube microphones.

594

Beranek, L. L., "Electroacoustic Measuring Equipment and Techniques," Proc. I.R.E., 50, 762-768, 1962.

This article discusses sound-level measurements and primary techniques for the calibration of microphones. It covers systems and techniques for measuring steady-state and transient response of amplifiers, microphones and loudspeakers. Means for shock-wave calibration of microphones and for measurement of nonlinear distortion and complex waveforms are also described.

595

Burd, A. N., "Symposium on Calibration of Microphones and Hydrophones, London, January 1962," J. Sci. Instr., 39, 185-187, 1962.

A report of a symposium held by the Acoustics Group of The Institute of Physics and the Physical Society on 17 January 1962.

596

Burkhard, M. E. Corless, W. Koidan, and F. Biagi, "Calibration for Carrier Operated Microphones and Other Reversible Transducers," J. Acoust. Soc. Am., 32, 501-504, 1960.

An insert technique described in this paper makes it possible to measure sound pressure by using a microphone operated in a carrier circuit; the accuracy is almost the same as can be achieved with more conventional preamplifiers. The carrier system is modified to include a microphone polarizing voltage if the transducer is not self-polarized. Then a calibrating audio-frequency voltage is used to drive the transducer diaphragm to the same displacement amplitude as that generated by the sound pressure. Instead of matching the open-circuit voltage of the microphone, diaphragm motion is matched. A displacement response constant, independent of frequency, is used to determine sound pressure, in contrast to the usual open-circuit response, which depends on frequency.

In a manner analogous to the determination of open-circuit pressure response by the reciprocity technique, the acoustic admittance of the microphone may be evaluated from a series of three voltage ratio measurements and the calculated acoustical transfer admittance of a calibrating coupler. This result can be combined with the open-circuit pressure response determined by the reciprocity technique to give an explicit evaluation of the electromechanical coupling constant.

597

Chalupnik, J., E. Rule, and F. Suellentrop, "Pressure Response of Condenser Microphones at Low Ambient Pressures," J. Acoust. Soc. Am., 33, 177-178, 1961.

The frequency response characteristics of condenser microphones at low ambient pressures are of interest when such microphones are used to make measurements on high-altitude rockets and capsules. Pressure response curves at a number of ambient pressures in the range 10^6 d/cm^2 (atmospheric pressure at sea level) to 1.7×10^4 d/cm^2 (atmospheric pressure at 90,000 ft alt) have been obtained for two commonly used condenser microphones (Western Electric 640AA, Bruel and Kjaer type 4111). Features of the response curves are discussed from a qualitative point of view.

598

Cox, W. F., "Test Setup for Microphone Calibration," J. Acoust. Soc. Am., 32, 508-509, 1960.

This article describes a unique instrument setup for the calibration of a microphone by the comparison method. Conventional instrumentation for calibration by comparison with the Western Electric #640 or other standard uses two VTVM's to measure outputs. A phase meter or Lissajou pattern may also be used for phase relations. Complete definition of the output of the unknown requires measurement of distortion, however, as well as phase and amplitude. In the method of this article one automated display gives "quick look" data on distortion, phase, and amplitude.

599

Diestel, H., "Reciprocity Calibration of Microphones in a Diffuse Sound Field," J. Acoust. Soc. Am., 33, 514-518, 1961.

Microphones can be calibrated by a primary technique in a diffuse sound field. The formula for the diffuse-field voltage response is derived from the well-known relationship for a reciprocal transducer in free space. It is shown that the reciprocity parameter for a diffuse-sound field follows from that for free space by replacing the distance by the "diffuse-field distance" of a point source. This distance depends only on the total absorption in the reverberation room. The experimental procedure is described in some detail, and the results of the diffuse-field calibration of a Western Electric 640 AA condenser microphone are presented.

600

Embleton, T. F. W., and I. R. Dagg, "Accurate Coupler Pressure Calibration of Condenser Microphones at Middle Frequencies," J. Acoust. Soc. Am., 32, 320-326, 1960.

The technique whereby the reciprocity theorem is applied to the determination of the pressure sensitivities of microphones has been modified to improve the reliability and accuracy of the measurements. Sensitivities are measured in terms of the volume of a cavity, the capacity of a fixed condenser, and the variable setting of an accurate potentiometer. Six different pairs of measurements are made instead of three, which is the minimum possible number: this enables a check to be made on the internal consistency of each calibration. The accuracy of the measured sensitivities is estimated to be 0.05 db on an absolute scale and 0.03 db relative to each other. This technique has been employed to measure the properties of several condenser microphones of each of three well-known types over periods ranging from five months to two years. Results are given for their temperature and pressure coefficients, effective volumes due to nonrigidity of their diaphragms, and drift with the passing of time.

601

Embleton, T. F. W., and I. R. Dagg, "Statistical Detection of Errors in Microphone Calibrations," J. Acoust. Soc. Am., 35, 108-112, 1963.

Microphone sensitivities obtained by reciprocity calibration depend on the measurements of several quantities (e.g., volume of a coupler, electrical capacitance). Errors in the best values of these parameters are systematic and undetectable unless an alternate method of calibration is used. A number of microphones of various types have been measured by both reciprocity and pistonphone methods, and the individual pairs of sensitivities are studied statistically to determine the probable existence and amount of the following classes of errors: (a) those related to constants of the pistonphone or reciprocity apparatus, which affect all microphones, (b) those in any coupler used for the reciprocity calibrations, which affect only the microphones used with this coupler, and (c) those associated with individual microphones.

602

Forney, D. M., Jr., "Acoustical Fatigue Test Procedures," Noise Control, 6, 11, 1960.

This article is a general survey of the test procedures and installations presently in use by various organizations in their investigations of aircraft fatigue failures caused by sound.

603

Goff, K. W., and D. M. A. Mercer, "Probe Microphone Analysis and Testing at High Temperatures and High Intensities," J. Acoust. Soc. Am., 27, 1133-1141, 1955.

A probe microphone has been developed suitable for measuring sound fields within such structures as altitude wind tunnels and jet engine test cells. This paper describes the methods of testing and analyzing the instrument. The microphone consists of a 3/8-inch inside diameter probe tube with a porous metal tip, a condenser microphone, and a spiral resistive termination. It operates at sound-pressure levels up to 170 db with 2% distortion, at ambient pressures down to 0.2 atmosphere, and with probe tip temperatures up to 900°F. The normal incidence response is flat within ±3 db from 10 to 10,000 cps.

An electrical analog of the acoustical system is given as a basis for explaining and predicting the performance of the microphone under varying ambient conditions. It appears that the microphone can be used satisfactorily as a cavity terminated probe microphone for frequencies below the frequency at which the spiral termination ceases to be "anechoic." The required length of the spiral termination is then determined by the probe-tube length rather than the lowest frequency of interest.

Testing methods and apparatus are discussed, including a high-temperature flow resistant apparatus, a low-pressure test chamber, and a resonant tube device for developing sound pressures up to 175 db with low distortion.

604

Hoeft, L. O., "A System for Measuring the High Sound Pressure Levels from Rockets," WADC Tech. Rept. No. 56-655, Aero Medical Lab., WADC, Wright-Patterson AFB, Ohio, 38 pp., 1956.
AD-110 669.

A system for measuring the high intensity noise produced by rockets is described. The system (1) should be capable of measuring sound pressure levels to 195 db (re 0.0002 dynes/sq cm), (2) should have a flat frequency response from 37.5 c to 10 kc (with usable response to 20 kc), and (3) should be reliable. A 21 channel sound recording system was developed to obtain far and near field noise characteristics in the short firing time of rocket engines. The selection of microphones and other components, and testing and calibration of the equipment are discussed. The technique of setting up a noise survey, the procedure for operating the equipment, and the system used to analyze the data are described in detail.

605

Keast, D. N., "Measurement of Rocket Engine Noise," Noise Control, 7, 25, 1961.

This paper presents a general approach to the measurement and analysis of rocket engine noise and illustrates this approach with examples of problems which have been encountered in the past. The approach suggested is intended to provide not only the desired data, but also sufficient information about the instrumentation and measurement techniques so that possible sources of error in the data may be evaluated. The procedures include a detailed laboratory evaluation of the transducer systems, evaluation and calibration of the complete data-acquisition system installed at the test site, various steps in the processing and analysis of tape-recorded data, the eventual estimation of the causes and magnitudes of errors in the measurements, and methods for reducing the possibility of human error by measurement personnel.

606

Knight, A. L., and M. Chapman, "A Shock Tube for the Dynamic Testing of Pressure Transducers," Tech. Note IR 3, Royal Aircraft Establishment, Great Britian, 21 pp., 1962.
AD-282 827.

A simple air-to-air shock tube facility has been constructed to examine the dynamic performance of pressure transducers. The theoretical characteristics and real gas effects that are relevant to the design of such a shock tube are discussed, and consideration is given to the special requirements for the dynamic testing of transducers. The design, construction, instrumentation, and operation of the apparatus are described together with the results of tests made to assess its performance.

607

Koidan, W., "Microphone Diaphragm Null Method for Sound Pressure Measurement," J. Acoust. Soc. Am., 32, 505-507, 1960.

A null technique is described for accurately measuring sound pressure with a condenser microphone while its diaphragm is held stationary. The method is particularly useful when it is desirable that the microphone present an infinite impedance to the medium and absorb no energy from the sound field. Sound pressure is determined by means of the electromechanical coupling constant, defined as $\phi = (p/e)_{u=0}$ where p is the sound pressure, e is the alternating voltage applied to the microphone terminals, and u is the volume velocity of the diaphragm. By using this definition, a concise derivation of an expression for ϕ in terms of measurable quantities is described. The value of ϕ for two Western Electric Company type 640AA condenser microphones was measured as constant with frequency to within ±0.25 db from 500 cps to 20 kc.

The effect of the finite acoustic impedance of a microphone on the magnitude of the incident sound pressure is calculated in terms of quantities obtained by driving the microphone electrically. The measurement of high sound pressure levels in resonant tubes is also discussed.

608

Macpherson, P., and D. Thrasher, "High-Frequency Calibration of an ADP Crystal Microphone," J. Acoust. Soc. Am., 32, 1061-1064, 1960.

The free-field sensitivity of a microphone over the frequency range 10,000 to 100,000 cps is determined by the reciprocity technique, in which the transducers are oriented perpendicular to each other in order to minimize diffraction effects. This orientation introduces a complication when the wavelength of sound is comparable to or smaller than the diameter of the microphone face. On theoretical grounds it is established that the sensitivity of the microphone should fall to zero at a discrete set of frequencies. Experimental minimum responses in reasonable agreement with the theory were observed.

609

Merhaut, J., and M. Vlček, "Pistonphone with Differential Piston," J. Acoust. Soc. Am., 30, 263-266, 1958.

The article first examines the various sources of error in absolute calibration of standard microphones in a pistonphone. A new differential pistonphone has been developed in the Czechoslovak Research Institute for Telecommunications which enables absolute calibration of microphones with the accuracy 0.1 db. The design and properties of the instrument are described.

610

Niemoeller, A. F., "Reciprocity Calibration of Electro-Acoustic Transducers in the Time Domain," J. Acoust. Soc. Am., 33, 1712-1719, 1961.

A method of directly evaluating the impulse response of a reciprocal electroacoustic transducer is presented. The method is essentially the time-domain analog of the conventional (frequency-domain) reciprocity method. The transient response of a coupled pair of identical transducers is used to compute the impulse response of either of the pair. A numerical method of obtaining a solution is presented and is shown to be equivalent to the numerical solution of a real convolution integral equation. First, an approximate solution for one member of the pair of identical transducers is obtained. Then, a more precise solution is generated by minimizing the squared error between the actual response of the coupled pair and the one obtained by convolving the approximate impulse response with itself.

The method was tried on two pairs of condenser microphones, the microphones within each pair being very nearly identical. A pair of Western Electric 640-AA microphones were tested with the grids both on and off, and a pair of Bruel and Kjaer type 4131 microphones were tested with the grids on an off and with grids equivalent to those on the W. E. 640-AA both on and off.

Two unsatisfactory solutions resulted when W. E. 640-AA grids were used on the transducers. Three solutions were satisfactory, even though each contained a slight negative drift for large values of time. One solution contained no appreciable error in its entire time course.

611

Russell, W. A. "Determination of the Dynamic Response Characteristics of Pressure Measuring Systems Utilizing Shock Tube Testing Techniques," Tech. Note No. 58-74, Aircraft Lab., Wright Air Development Center, Wright-Patterson AFB, Ohio, 16 pp., 1958.
AD-151 067.

This paper discusses shock tube testing being conducted by the Aircraft Laboratory, WADC, to determine the dynamic response characteristics of various pressure transducers and installations. In accomplishing this, the pressure measuring system is subjected to a step-function pressure input generated by a shock tube. A Fourier integral method is used to evaluate the sinusoidal frequency response characteristics of the system under investigation to the step pressure wave.

Practical use of the Fourier integral method necessitates the utilization of an electronic computer. It is felt that use of the shock tube as a step function generator and the Fourier integral method for determination of the frequency response curves offers an inexpensive and convenient method for determining the dynamic response characteristics of a high-frequency response pressure measuring system.

612

Sacerdote, C. B., "Detecting Sound Fields," J. Acoust. Soc. Am., 31, 133-136, 1959.

A feedback method is described, permitting a loudspeaker to be driven automatically so that the sound pressure generated at any one point is constant with frequency, independent of the loudspeaker characteristics. Several applications illustrate the success of the method in the calibration of microphones and in the study of diffraction and reflection effects.

613

Sacerdote, G. G., and C. B. Sacerdote, "Panoramic Representation of the Sound Field," J. Acoust. Soc. Am., 29, 1165-1168, 1957.

Recording, by means of a sonagraph, the sound pressure generated by a turning loudspeaker, fed by white noise, one can give a synthetic representation of the directional behavior of the loudspeaker. One can study the behavior of reflecting surfaces and the directivity of a microphone by the same method.

614

Seligson, A. L., "Free-Field Technique for Secondary Standard Calibration of Microphones," J. Audio Eng. Soc., 4, 110-115, 1956.

The acoustic environment required for the performance of free-field secondary standard microphone calibrations is examined. The technique includes automatic compensation for variations in sound output level versus frequency of the sound source. Size and orientation of the standard and object microphones and mounting are considered with a view toward minimizing disturbances in the sound field, and resulting calibration errors, arising from reflections at high frequencies. Maximum and minimum working distances from sound sources of various dimensions necessary to maintain plane-wave free-field conditions are given for a variety of microphone types. The accuracy limits of the calibration method are indicated.

615

Simmons, B. D., and F. Biagi, "Pressure Calibration of Condenser Microphones Above 10,000 cps.," J. Acoust. Soc. Am., 26, 693-695, 1954.

A "plane wave" acoustic coupler and an electrical admittance method are described for the pressure calibration of condenser microphones in the ultrasonic frequency range. Calibration results are given for frequencies to 40 kc.

616

Terry, R. L., and R. B. Watson, "Pulse Technique for the Reciprocity Calibration of Microphones," J. Acoust. Soc. Am., 23, 684-685, 1951.

This paper describes a pulse technique which makes possible a free-field reciprocity calibration of a microphone indoors, without recourse to an anechoic chamber. The method is limited to frequencies above the middle audio range by consideration of the room size and pulse spectrum. An experimental calibration of a microphone is included, and waveforms are presented which demonstrate the validity of the method.

617

Thurston, G. B., and R. L. Heiserman, "Calibration and Free Field Evaluation of a Pressure Gradient Microphone," Oklahoma State Univ. Res. Foundation, Stillwater, 19 pp., 1962.
AD-281 773.

The design, calibration procedure, and evaluation in a free field for a condenser-type pressure gradient microphone are described. Procedures were carried out for determining both magnitude and phase of the pressure gradient. The microphone responded to the differential action of the pressure at two closely spaced field points as communicated by two small probe tubes to either side of a sensing metal diaphragm. By means of a coupling chamber calibration procedure it was possible to obtain a sensitivity factor and an error factor which may be used both to describe the precision of the internal structure of the microphone and to correct for its imperfections. The free field studies analyzed the directional characteristics and resolution capabilities of the microphone. The radiation characteristics of a circular orifice in a plane baffle, as measured with the gradient microphone, are compared with those predicted by simple field theory with regard to the relationship between the pressure gradient magnitude and phase, and the pressure magnitude and phase.

618

Villchur, E., "A Method of Testing Loudspeakers with Random Noise Input," J. Audio Eng. Soc., 10, 306-309, 1962.

A method of obtaining a comparative relation between a given speaker and a standard is demonstrated.

619

Whittemore, M. J., Jr., "Transistorized Tone Burst System for Transient Response Testing of Loudspeakers," J. Audio Eng. Soc., 10, 200-203, 1962.

This paper describes a compact, all solid-state instrument that allows the transient response of a loudspeaker (or system) to be evaluated as the device under test is excited by "trains" of suddenly applied sine waves. The use of standard computer logic modules enables this instrument to produce and read out tone bursts up to 20 kc with relative freedom from spurious, internally generated transients.

620

Young, W., "A Brief Guide to Noise Measurement and Analysis," Navy Electronics Lab., San Diego, Calif., 23 pp., 1955.
AD-66 686.

Basic noise-measurement principles and techniques are treated in Part I by only simple arithmetic. Terms peculiar to noise analysis are explained. Special attention is given to interpreting graphs of noise spectra obtained with analyzers of different bandwidths. Part II describes specific calibration procedures. It also gives the mathematics used in calculating sound-pressure levels, spectrum levels, and combinations of levels.

621

Ziemer, R. E., and R. F. Lambert, "Shock Wave Transducer Calibration," J. Acoust. Soc. Am., 34, 987-988, 1962.

The use of a shock-wave technique to obtain a frequency-response calibration of a small lead zirconate titanate transducer is described. The response curve is obtained through numerical Fourier transformation of the recorded response to a shock-wave excitation. Sources or error and agreement with other methods of calibration are discussed.

Calibration and Test Procedures
See also—96, 406, 453, 524, 637, 717, 839, 968, 1052, 1086, 1115, 1119, 1182, 1190, 1192, 1208, 1224, 1234, 1295, 1306, 1307, 1326, 1629, 1715, 1728, 2256, 2725, 2752, 2763, 2767, 2772, 3076, 4125.

CORRELATION

622

Angell, R. K., "A Two-Level Real-Time Correlator," Master's Thesis, 1957.
AD-162 080.

Some recent developments in the design of correlation computers are described. The theory underlying the correlation function and its calculation is summarized, and the effects of finite averaging time, sampling, and quantization are discussed. A classification of types of correlation computers is introduced and is followed by a detailed survey and description of the many components and circuits which may be used to perform the required mathematical operations. By using the component survey as a basis, two correlator designs for a particular requirement, one analog and the other analog-digital, are outlined and discussed in detail. The design and operation is given for a two-level, real-time correlator which was constructed to experiment with two-level quantization. The correlator is designed around the ability of the magnetic-core shift register to accept and store, in time sequence, information given in the form of binary digits one and zero. The evaluation of the correlator test results indicated the practicality of two-level quantization and the possibilities for real-time electronic correlation.

623

Berman, H. G., and A. Berman, "Effect of Correlated Phase Fluctuation on Array Performance," J. Acoust. Soc. Am., 34, 555-562, 1962.

The response of a uniform array of point detectors receiving cw signals is computed under the assumption that there are correlations in the fluctuations of the phase of the signals. General formulas are developed for various ranges of correlation. It is shown that the peak response of an array is not appreciably reduced until the magnitude of the fluctuations becomes large. If the fluctuations are strongly correlated over many receiving elements, the main lobe will be broadened.

624

Berson, B. E., "Impulse Response of Linear Systems Using Correlation and Direct Measurement," Univ. of Rochester, Rochester, N. Y., 58 pp., 1962.
AD-281 770.

If a pseudo-random noise sequence is used as the input to a linear system, then by suitably correlating the output of the system and a delayed version of the input, one can obtain the impulse response of the system. The effect of the finite size of the sequency auto-correlation function upon the expected results is analytically determined. A system for making the measurements, including a simple method of obtaining a delayed sequence, is described. Measurements were made on low pass RC filters and comparisons made with the predicted results. A polarity-coincidence correlator was used. It was found that best results were obtained when the correlator output vs. normalized correlation coefficient curve was assumed to be linear, although an accurate determination of the correlator characteristic could not be made. Finally, impulse response measurements were made on three speakers using correlation, direct pulsing, and differentiation of the step response; the three methods were compared.

625

Bordelon, D. J., "Effect of Correlated Phase Fluctuation on Array Performance," J. Acoust. Soc. Am., 34, 1147, 1962.

It is shown that the expectation of the mean-square time-averaged response for a configuration of receivers is immediate from known statistical considerations.

626

Brzezenski, D. B., C. Caso, et al., "Research on Correlation Type Data Processing Systems," Final Rept. No. AFCRL 62-711, Wolf Research and Development Corp., West Concord, Mass., 113 pp., 1962.
AD-283 925.

The development of the high speed digital computer made the construction of large scale data processing and large real-time control systems feasible. The improvement of sensor and communication devices led to systems of great sophistication. Improvement must now be made in the machine's ability to work with deteriorated or otherwise more complex data. The example used is textual and spoken data, which are important to system operation in two ways: (1) the communication between systems is largely by these means; and (2) the human being's direct communication with the machine is simplified. The analysis of the data by different statistical methods can be expected to develop better means of deriving information from signals without a prior knowledge of their exact content and to develop more efficient transmission schemes for those signals.

627

Chernov, L. A., "Correlation of Amplitude and Phase Fluctuations for Wave Propagation in a Medium with Random Irregularities," Soviet Phys. Acoust. English Transl., 1, 94-101, 1955.

The coefficient of correlation is calculated for amplitude and phase fluctuations at the reception point. It is shown that if the irregularities are large in scale, the autocorrelation between the amplitude (or phase) fluctuation at different reception points extends over a distance of the same order as the correlation between the fluctuations of the index of refraction in the medium.

628

Chernov, L. A., "Correlation of Field Fluctuations," Soviet Phys. Acoust., English Transl., 3, 203-206, 1958.

Formulas are obtained, establishing a connection between the correlation function for field fluctuations and the self-correlation functions for fluctuations of level and phase.

629

Chernov, L. A., "Correlation Properties of a Wave in a Medium with Random Inhomogeneities," Soviet Phys. Acoust., English Transl., 1956, 2, 221-227.

The work complements that described in an earlier paper. The coefficient of the longitudinal space autocorrelation of amplitude and phase fluctuation is calculated. This autocorrelation is shown to extend to a distance considerably greater than for the transverse case. The coefficient of the time autocorrelation of fluctuations of amplitude and phase is also determined. The paper is entirely theoretical.

630

Cook, R. K., et al., "Measurement of Correlation Coefficients in Reverberant Sound Fields," J. Acoust. Soc. Am., 27, 1072-1077, 1955.

Reverberation chambers used for acoustical measurements should have completely random sound fields. We denote by R the cross-correlation coefficient for the sound pressures at two points a distance r apart.

$$R = \left\langle p_1 p_2 \right\rangle Av \Big/ \left(\left\langle p_1{}^2 \right\rangle Av \left\langle p_2{}^2 \right\rangle Av \right)^{1/2}$$

where p_1 is the sound pressure at one point, p_2 that at the other e, and the angular brackets denote long time averages. In a random sound field, R = (sin kr)/kr, where k = 2/(the wavelength of the sound). An instrument for measuring and recording R as a function of time is described. A feature of this instrument is the use of a recorder's servo-mechanism to measure the ratio of two d-c voltages. The results of correlation measurements in reverberant sound fields are given.

631

Cron, B. F., and C. H. Sherman, "Theoretical Derivation of Spatial Correlation Functions for Various Noise Models," Rept. No. 541, Navy Underwater Sound Lab., Fort Trumbull, New London, Conn., 15 pp., 1962.
AD-275 294.

Observations indicate that noise in the ocean is a superposition of an isotropic noise field and an anisotropic noise field originating at the surface. Models which produce such noise fields are described, and the spatial correlation functions are obtained. The volume noise model, which produces an isotropic noise field, consists of noise sources uniformly distributed within a sphere. A single frequency of each noise source is considered; the frequency and mean square output of each are the same, the relative phases are random, and inverse spreading occurs. For a very large sphere the spatial correlation is the same as that given by Marsh for a homogeneous isotropic noise field and by the Faran and Hills noise model, which consists of noise sources on the surface of a large sphere. The surface noise model consists of noise sources uniformly distributed on a large circular area of a plane. The noise sources are assumed to be directional in addition to having the properties listed above. The spatial correlation is obtained as a function of the directionality of the noise sources, the spacing of the receivers and their orientation with respect to the surface, and the electrical delay. Results for the two noise models are compared in relation to s/n gain of hydrophone arrays.

632

Fakley, D. C., "Comparison Between the Performances of a Time-Averaged Product Array and an Intraclass Correlator," J. Acoust. Soc. Am., 31, 1307-1314, 1959.

Berman and Clay (J. Acoust. Soc. Am., 29, 7, 1957) have investigated the directional characteristics of a linear array of omnidirectional receiving elements when the output from these elements are multiplied together and time arranged in certain ways. They conclude that the same directional characteristics may be obtained from these "time-averaged product" (TAP) arrays having a small number of detectors as with an additive array having a large number of elements; they also show that there is some economy in terms of the over-all length of the array required to give a specified beam width. Because assessing the characteristics of a TAP array solely on the basis of its polar diagram is impossible, a detailed analysis is necessary to determine its usefulness in applications which require a system with a narrow polar diagram. Three particular applications are investigated: the detection of a point source against a noise background, the resolution of the signals from two closely-spaced point sources, and the exploration of the distribution of power across an extended source. For comparison purposes a parallel analysis is carried out for an intraclass correlation system. For simplicity the analyses are confined to investigating the performance of a four-element linear array with equal spacings between adjacent elements under elementary and idealized conditions. The results so obtained, however, are of general application. Two class-I TAP array systems are compared with the intraclass correlator, whose detection performance was analysed by Faran & Hills (Acous. Res. Lab., Harvard Univ., Tech. Memo No. 28, Nov. 1952). This is believed to be the most "efficient" detector in this application. (A class-I array is defined as one in which the number of time-averaging operations lies between N - 1 and 1/2N(N - 1), where N is the number of receiving elements. A class-II TAP array, which employs true multipliers, is obviously inferior to a class-I array in terms of detection performance and will not be considered. It has been shown by Melton et al. (see B. S. Melton and P. R. Kerr, Geophysics 22, 553, 1957, for example) that a class-II type of array employing coincidence detectors rather than multipliers has some useful properties, but it can be demonstrated that its detection performance is inferior to that of an intraclass correlator. Since class-III TAP arrays have the same detection performance as the system prior to the power and sum circuits, there is no need to analyse such arrays here.)

633

Fano, R. M., "Short-Time Autocorrelation Functions and Power Spectra," J. Acoust. Soc. Am., 22, 546-550, 1950.

The reciprocal relations between autocorrelation functions and power spectra, known as Wiener's Theorem, are extended in a modified form to the case of experimental results obtained by means of filters with finite time constants. If the short-time autocorrelation function $\phi_t(\tau)$ and power spectrum $G_t(\omega)$ are properly defined, it is found that

$$\phi_t(\tau) = \frac{e^{\alpha|\tau|}}{2\pi}\int_{-\infty}^{\infty} G_t(\omega)\cos\omega\tau\,d\omega$$

$$G_t(\omega) = \int_{-\infty}^{\infty} e^{-\alpha|\tau|}\phi_t(\tau)\cos\omega\tau\,d\tau$$

where $1/\alpha$ is a time constant. These equations may be used to relate the autocorrelation-function representation of a speech wave to the corresponding spectrographic representation.

634

Faran, J. J., Jr., and R. H. Hills, Jr., "The Application of Correlation Techniques to Acoustic Receiving Systems," Tech. Memo. No. 28, Acoustics Res. Lab., Div. of Applied Science, Harvard Univ., Office of Naval Res., 55 pp., 1952. AD-9425.

The application of correlation techniques to acoustic receiving systems is considered theoretically and experimentally. The study is limited, for the most part, to random signals in a background noise which arises in the signal-bearing medium (not in the receiver amplifiers). For example, cross-correlating the signals received by a two-element array is compared with simply adding these signals and detecting with a square-law detector. In some cases, the correlator can effect an improvement in the s/n of as much as 3 db, while, in other cases, conventional methods result in higher s/n. The systems using correlators, however, usually exhibit a practical advantage which may offset any s/n disadvantage; the average output of the correlator usually contains no large term proportional to the strength of the background noise. This allows the use of much higher gain recording or indicating instruments after the correlator. Several methods of performing multiple correlation for use with arrays of more than two elements are considered; nothing significantly superior to a simple adding of all the signals and detecting has been found.

635

Faran, J. J., Jr., and R. H. Hills, Jr., "Correlators for Signal Reception," Tech. Memo No. 27, Acoustics Res. Lab., Div. of Applied Science, Harvard Univ., Office of Naval Res., 88 pp., 1952. AD-3188.

Correlators (multiplier-averagers) are analyzed and compared with detectors (rectifier-averagers) of various power laws from the point of view of their possible use in signal reception systems. Comparison is made in terms of s/n for the limiting case of small input s/n and long averaging time. Of the detectors, the square-law is found to be slightly superior for determining the presence of a small signal in a noise background; while if two samples of the signal in incoherent background noises are available, although the correlator cannot improve the s/n, it does have the advantage that no constant terms independent of the signal appear at its output. The design of electronic correlators is discussed, and several practical circuits are given. Two other types of circuits, similar in operation to correlators but much simpler to construct, are also analyzed. Both are very slightly inferior to true correlators in output s/n.

636

Gershman, S. G., A. I. Smirnov, and Y. I. Tazhilkin, "A Transposing Arrangement for Generating the Correlation Function of Infrasonic Processes," Soviet Phys. Acoust., English Transl., 7, 336-340, 1962.

An arrangement is described which transposes infrasonic signals to the frequency range of the acoustic correlometer. The correlation functions of the original and the transposed processes are connected by simple relations.

637

Gershman, S. G., and E. L. Feinberg, "Measurement of the Correlation Coefficient," Soviet Phys. Acoust., English Transl., 1, 340-352, 1957. AD-265 021.

An instrument is evolved which is based on the use of the connection between the correlation coefficient of two noises and the probability of the signs of the instantaneous values of these noises coinciding. The output effect of the instrument is the measure of this probability. The electric circuit makes use of the transformation of the input voltages into pulses, the electronic relay, on the output of which pulses of coincidence are obtained, the averaging of these pulses and the indicator. The theory of the instrument is developed, and the results of the theory are used for calibrating and evaluating the measuring errors. It is shown that the instrument may be used not merely for measuring the correlation coefficient, but also for certain other purposes, including various measurements in the acoustic field. The results of the experimental use of the instrument are given.

638

Gilbrech, D. A., and R. C. Binder, "Portable Instrument for Locating Noise Sources in Mechanical Equipment," J. Acoust. Soc. Am., 30, 842-846, 1958.

A portable direction finder utilizing correlation techniques was developed for locating noise sources in mechanical equipment. A description of this instrument and some test results are given. The test results include studies of the direction-finding characteristics of the apparatus and a simple method of determining wave fronts.

639

Goff, K. W., "An Analog Electronic Correlator for Acoustic Measurements," J. Acoust. Soc. Am., 27, 223-236, 1955.

A study has been made of the applicability of correlation techniques to the field of acoustic measurements. The development of an analog electronic correlator for this study is reported here while the application of the correlation technique to some acoustic measurements is reported in a companion paper.

The analog correlator is divided into the following four main components and each one is discussed in detail: (1) variable time delay; (2) quarter-squaring multiplier; (3) continuous and stepping integrators; (4) system for scanning and plotting the cross-correlation function on both linear and logarithmic scales.

The correlator operates over an input frequency range of 100 cps to 10 kcps, a range of relative time delay τ from -15 to 190 msec and RC intergration times of 0.5 to 16 seconds. A dynamic range in the cross-correlation function of approximately 50 db is achieved with ±1 db accuracy.

Special attention has been given to the errors in the cross-correlation function resulting from finite integration time and scanning of the correlation function. A significant increase in permissible scanning speed for a given s/n has been shown to result from "matching" the equivalent integrator pass band to that of the spectrum common to the two signals applied to the correlator. Relations have been derived between scanning speed, s/n, and input signal band width for integration performed by either a low-pass filter or a "matched" filter.

640

Goff, K. W., "The Application of Correlation Techniques to Some Acoustic Measurements," J. Acoust. Soc. Am., 27, 236-246, 1955.

This paper discusses the application of an analogue correlator which computes the cross-correlation function between two sound pressures to such measurement problems as the localization of noise sources, the determination of transmission loss, and the reduction of microphone wind noise. The cross-correlation function $\phi_{21}(\tau)$ between two nonperiodic signals will have a peak in amplitude if a component of each signal originates from a common source. The value of time delay τ for which this peak occurs equals the difference in time required for the individual components to propagate from the common source to the two points under study. An analogue electronic correlator described in the preceding abstract has been constructed which, by employing this property of the cross-correlation function, can separate the acoustic signal at a given point into components according to: (1) their points of origin (assuming independent sources), (2) the transit time from source to the point in question, and (3) frequency. Preliminary experimental results show that correlation provides a practical method for determining the amount of sound contributed to the field at a given point by each of several sources. The correlator, by separating the signal transmitted directly through the structure from the flanking signal on the basis of arrival time, is also a useful tool for measuring the transmission loss of walls.

641

Haberstitch, A., and F. R. Hama, "A Correlation Analyzer," Tech. Note No. BN-125, Inst. for Fluid Dynamics and Applied Mathematics, Univ. of Maryland, College Park, 1958.
AD-154 242.

A detailed description is given of a correlation analyzer which measures the spectral equivalent of a double (time) correlation between any two signals. Actual measurements are made with a few artificial signals in order to determine its reliability. Although it is primarily designed for the direct measurement of the energy transfer function in the spectrum of turbulence, the instrument is considered capable of measuring the transfer function of any "black box." Therefore, it may find versatile applications in buffeting, aerodynamic stability, and aeroelasticity, as well as in electronics and servomechanisms.

642

Harder, J. A., "A Machine for Computing Correlation Functions," Inst. of Engineering Res., Univ. of Calif., Berkeley, 11 pp., 1958.
AD-206 604.

A computer is described which is able to analyze graphically recorded data in a more direct way than previous machines. The method does not require multiplication or integration, but instead uses a zero-one process in which no account is taken of the absolute magnitude of the variables; the only question asked is whether the variable is less than or greater than its temporal mean value. The results of analyzing a pure sine wave are given, on which values of C/N are plotted as a function of phase lag. The failure to achieve either 100% coincidence at zero phase lag or 0% at 180° lag appeared to result from a difference in shrinkage between the 2 prints used. The trace width, about .006 inches, is 0.01% of the record length; a difference of length between the two records of only a fraction of the trace width would have the result observed, that of missing the total coincidence by 1.5%. Another measure of the machine accuracy is the reproducibility of counts with the slide shutter at a fixed position. The variance is within one part in 500 or ±0.1%. The machine appeared to be an order of magnitude more precise than necessary for most measurements it will be called on to analyze.

643

Hass, P. H., "Theory and Applications of Correlation Techniques," Thesis, Rept. No. GE/EE/61-6, Inst. of Technology, Air Univ., U. S. Air Force, Wright-Patterson AFB, 68 pp., 1961.
AD-270 272.

This report is a survey of the important principles of correlation theory, as applicable to the statistical analysis of communication systems. The underlying theory of correlation functions and their relations to the power-density spectrum is presented. Linear systems, excited by random inputs, are analyzed, and describing relations are developed from the correlation functions. Corresponding frequency domain relations in terms of the power-density spectrum are also developed. The mean-square error as a design criterion is presented both from a general and a specific viewpoint. The specific approach is a problem which entails the excitation of a linear system by a message corrupted by noise. It is shown how the general development for the mean-square error reduces to the specific problem presented.

644

Jackson, P. L., "Optical Analysis Techniques Applied to Seismic Data," Acoustics and Seismics Lab., Inst. of Science and Technology, Univ. of Mich., 1962.

An optical system capable of performing multichannel, high-resolution spectral analysis, and auto- and cross-correlation is under development. The series of progress reports listed detail the effort in obtaining accurate time and spectral information from variable density, time history signals.

First Semiannual Technical Summary Report, January 1962, Rept. No. 4596-4-P
Second Semiannual Technical Summary Report, July 1962, Rept. No. 4596-7-P
Third Semiannual Technical Summary Report, January 1963, Rept. No. 4596-13-P
Fourth Semiannual Technical Summary Report, July 1963, Rept. No. 4596-20-P

645

Jackson, P. L., "Signal Enhancement Through an Ensemble Presentation," Bull. Seism. Soc. Am., 53, 1962.

A method of treating array responses is presented. The entire statistical distribution from the array is used for either direct visual estimation, or for processing in a scanning machine. An estimate of a coherent signal and the character of the noise can be made visually. Most correlative techniques, in addition to digitizing, could be performed simultaneously through using the scanning machine.

646

Jacobson, M. J., "Analysis of a Multiple Receiver Correlation System," J. Acoust. Soc. Am., 29, 1342-1347, 1957.

This is a theoretical study of an acoustic receiving system containing a single correlator whose inputs are obtained from arrays of omnidirectional receivers. Mathematical expressions are developed for the mean system output when the input arises from a distant localized signal source. In addition, two major advantages of multiple receiver correlation as compared with two-receiver correlation are discussed in detail. These are improved directional patterns on narrow-band signals and increased output s/n resulting from the use of more than two receivers.

647

Jacobson, M. J., "Correlation of a Finite Distance Point Source," Math Rept. No. 18, Rensselaer Polytechnic Inst., Troy, N. Y., 20 pp., 1958.
AD-202 292.
See Also: J. Acoust. Soc. Am., 31, 448-453, 1959.

A two-receiver correlation system intended to process signals from point sources at a large distance from and in a common plane with the receivers will give a predicted source direction which is generally different from the actual source direction when the source distance from the receivers is not large. The exceptions are broadside or endfire sources for which the predicted and actual directions are equal. Apart from these cases, the predicted direction is always closer to broadside than the actual direction. Other results include the fact that a given predicted direction corresponds to a source location at any point on a corresponding hyperbolic arc.

648

Jacobson, M. J., "Correlation with Similar Uniform Collinear Arrays," J. Acoust. Soc. Am., 30, 1030-1034, 1958.

This report concerns the nature of the mean output of a single correlator receiving system when the input is a narrow-frequency-band signal arising from a localized source in space. The signal is received by two uniform, collinear arrays having an equal number of omnidirectional receivers. The mean output as a function of steering is bounded by the product of the space factors of the two arrays, so that the gross nature of the mean can be determined by investigating the main lobe width and side lobe level of the space-factor product. These two quantities are studied as functions of the number of receivers, the receiver spacing in wavelengths, and source direction.

649

Jacobson, M. J., "Optimum Envelope Resolution in an Array Correlator," J. Acoust. Soc. Am., 33, 1055-1060, 1961.

This paper considers a correlator detector which processes the outputs of two identical collinear arrays of uniformly spaced elements. When the input signal is sinusoidal, the mean system output is bounded by the product of the space factors of the arrays. Complex amplitude factors are introduced following each element, and it is shown how to choose them in order to optimize the main-lobe-width-side-lobe-level relationship of the space-factor product or envelope. In addition, it is proved that the use of amplitude factors for improving envelope resolution gives rise to an s/n degradation relative to the corresponding uniform amplitude system. Various numerical results are given, including the fact that the optimum system provides an envelope main-lobe-width reduction of approximately 30% when 20 or fewer elements appear in each array.

650

Jacobson, M. J., "Optimum Envelope Resolution in an Array Correlator," Math Rept. No. 44, Rensselaer Polytechnic Inst., Troy, N. Y., 6 pp., 1961.
AD-264 432.

This paper considers a correlator detector which processes the outputs of two identical collinear arrays of uniformly spaced elements. When the input signal is sinusoidal, the mean system output is bounded by the product of the space factors of the arrays. Complex amplitude factors are introduced following each element, and it is shown how to choose them in order to optimize the main-lobe-width-side-lobe-level relationship of the space-factor product or envelope. In addition, it is proved that the use of amplitude factors for improving envelope resolution gives rise to an s/n degradation relative to the corresponding uniform amplitude system. Various numerical results are given, including the fact that the optimum system provides an envelope main-lobe-width reduction of approximately 30% when 20 or fewer elements appear in each array.

651

Jacobson, M. J., "The Output Probability Distribution of a Correlation Detector with Signal Plus Noise Imputs," Math Rept. No. 55, Rensselaer Polytechnic Inst., Troy, N. Y., 28 pp., 1962.
AD-276 364.

The problen is studied of determining the probability density function of the output of a correlation detector whose two inputs consist of correlated signal corrupted by uncorrelated noise. The inputs are stationary and Gaussian, one having the characteristics of white noise and the other being RC-filtered white noise. The post-multiplier averager is also an RC filter. The general case of signal plus noise inputs is investigated; the special cases of signal-only and noise-only inputs are also considered. Detailed results are presented when the ratio of the time-constant of the post-multiplier filter to that of the pre-multiplier filter is 1/2 and also in the practical case when this ratio is large. With the probability distribution determined, a statistical theory of signal detection is applied, a major result being the determination of the relationship between detection probability and the classical detection measure, output s/n.

652

Jacobson, M. J., "Space-Time Correlation in Spherical and Circular Noise Fields," J. Acoust. Soc. Am., 34, 971-978, 1962.

In many analyses of systems designed to detect and locate a signal source in a noise field, it is necessary to know the correlation of the noise at two points in the field at different times. While spatial effects have been considered in some studies, temporal effects are usually neglected. In this report, space-time correlation is considered as a function of frequency, point separation, and time difference when the noise is generated by independent noise sources located on a sphere and circle of infinite radius. Numerous results are obtained, the most important being that, in general, noise cross-correlation will be very much greater for certain nonzero time differences than for a zero time difference. The effects of inserted time delay must therefore be considered for systems in which noise cross-correlation may adversely affect performance.

653

Jacobson, M. J., "Space Time Correlation in Spherical and Circular Noise Fields," Math Rept. No. 50, Rensselaer Polytechnic Inst., Troy, N. Y., 24 pp., 1962.
AD-271 675.

In this analysis, space-time correlation will be considered as a function of frequency, point separation, and time difference when the noise is generated by independent noise sources located on a sphere and circle of infinite radius. Numerous results are obtained, the most important being that, in general, noise cross-correlation will be very much greater for certain nonzero time differences than for a zero time difference. The effects of inserted time delay must therefore be considered for systems in which noise cross-correlation may adversely affect performance.

654

Jacobson, M. J., and R. J. Talham, "Angular Deviation in Directional Receiver Correlation," J. Acoust. Soc. Am., 32, 810-820, 1960.

When the axes of two directional pressure gradient receivers providing inputs to a steerable correlator receiving system deviate from the desired broadside direction, the system output is altered. An analysis of the improvement in output s/n shows that, in general, the maximum improvement decreases, the direction of maximum improvement shifts from broadside, and the range of source direction over which there is improvement decreases. Simplified expressions are given for these changes in the important case of small deviation angles. The system output is then studied under the conditions that the deviation angles are random variables, and probability expressions are derived for the maximum improvement and the improvement at a given source direction. An example is included for the case of independent deviation angles having identical, even, uniform distributions.

655

Jacobson, M. J., and R. J. Talham, "Comparison Analysis on Four Directional Receiver Correlators," J. Acoust. Soc. Am., 33, 518-526, 1961.

Four correlation systems are studied which make use of two pressure-gradient receivers having first-order cosine directional characteristics. The systems differ in the methods of steering both the receivers and the receiver baseline. The steering may be accomplished by rotation or by the insertion of appropriate time delays. The mean, variance, and output s/n are computed for each system when a distant localized signal source is present in both circular and spherical noise fields. In addition, the directive properties of the mean outputs are examined. For a signal with rectangular power spectrum, the main lobe widths of the mean output are found, the behavior of the means in the neighborhood of source direction is examined, and an investigation is made of the mean output level for steering directions removed from source direction.

656

Jacobson, M. J., and R. J. Talham, "Use of Pressure Gradient Receivers in a Correlator Receiving System," Math Rept. No. 23, Rensselaer Polytechnic Inst., Troy, N. Y., 52 pp., 1959.
AD-215 950.
See Also: J. Acoust. Soc. Am., 31, 1352-1362, 1959.

An analysis is made of a steerable correlator receiving system which contains two-directional receivers of the pressure gradient type. The axes of the receivers are oriented in the broadside direction. The output s/n is computed and compared with that of a system employing two omnidirectional receivers. The directional receiver system gives a maximum improvement in output ratio for broadside signal sources which increases as the orders of the receivers increase. The range of improvement over source direction is studied. Other results include the fact that the maximum output s/n of the directional receiver system containing two receivers of order 1 (2, 3, 4, . . .) is equal to that of an array correlation system requiring the use of 6 (10, 14, 18, . . .) omnidirectional receivers.

657

Karavainikov, V. N., "Fluctuations of Amplitude and Phase in a Spherical Wave," Soviet Phys. Acoust., English Transl., 3, 175-186, 1958.

The correlation coefficient is established between fluctuations of amplitude and phase occurring in a spherical wave. Also obtained are the coefficients of longitudinal and transverse selfcorrelation of amplitudes and phases.

658

Karr, P. R., Statistical Errors in Measurements of Cross-Correlation Functions," Rept. No. 9867-6002-RU-000, Space Technology Labs., Redondo Beach, Calif., 32 pp., 1962.
AD-277 213.

A collection of short articles dealing with statistical errors encountered in measurements related to correlation functions is presented. Various results having some general interest are given. The work is applied to an estimate of the irreducible mean square error encountered in the measurement of the zero point of the cross-correlation function between voice signal and its derivative.

659

Lyon, R. H., "Propagation of Correlation Functions in Continuous Media," J. Acoust. Soc. Am., 28, 76-79, 1956.

The correlation properties of noise fields when considered as a random superposition of elementary sources are derived as an extension of Rice's work on the shot effect (Bell System Tech. J., 34, 282, 1944; 24, 46, 1945). Next a formalism is derived, which calculates the correlation properties of the response of a continuous, linear system when subject to an applied noise field. The requirements for solution are a knowledge of the impulse response of the system and the correlation function of the source. The latter may be obtained experimentally or from calculation.

660

Middleton, D., "Acoustic Signal Detection by Simple Correlators in the Presence of Non-Gaussian Noise, I. Signal-to-Noise Ratios and Canonical Forms," J. Acoust. Soc. Am., 34, 1598-1609, 1962.

The detection of acoustic signals by simple auto- and cross-correlation receivers in the presence of nonnormal as well as normal background noise is examined on the basis of s/n calculated from a generalized deflection criterion. Particular attention is devoted to the effects of impulse noise and mixtures of impulse and normal noise on system performance. Comparisons between system behavior vis-á-vis the two types of interference are made. For impulse noise equivalent in spectral distribution and average intensity to a Gaussian noise background it is found that the output s/n (power) ratios are related by the canonical expression

$$\left(\frac{S}{N}\right)_I^2 = \frac{(S/N)_G^2}{1 + (1 - \mu)\,\Lambda\,(S/N)_G^2},\ 0 \leq \mu \leq 1,$$

where Λ (≥ 0) is the "impulse factor" and μ is the fraction (in average intensity) of the total noise background that is attributable to normal noise. Impulse noise always degrades system performance vis-á-vis normal noise in the autocorrelation reception of stochastic signals, characteristic of applications where passive receiving methods must be used. This degradation can be considerable [0(10 db or more)] if the noise is highly impulsive (large Λ) and if large values of $(s/n)_{out}^2$ (> 0 db) are required (for high accuracy of decision). On the other hand, when coherent (i.e., deterministic) signals are employed, so that cross-correlation reception is possible, the degradation may be reduced essentially to zero (i.e., $\Lambda \to 0$) under realizable conditions of operation. It is observed for impulsive, as well as normal noise backgrounds, that cross-correlation receivers are linear in their dependence on signal-to-noise ratio, i.e., $(s/n)_{out}^2 \sim (s/n)_{in}^2$ if sufficiently strong injected signals are employed. The analysis is carried out largely in canonical form, so that the general results for $(s/n)_{out}^2$ can be applied to other, special types of nonnormal noise backgrounds. Specific relations are included, along with a detailed summary of the principal results, showing the dependence of $(s/n)_{out}^2$ on $(s/n)_{in}^2$, filtering, delay, noise and signal spectra, etc., for weak and strong inputs, little or heavy postcorrelation smoothing and for Gaussian as well as for impulse noise.

661

Middleton, D., "Acoustic Signal Detection by Simple Correlators in the Presence of Nongaussian Noise, I. Signal-to-Noise Ratios and Canonical Forms," Tech. Rept. No. TR-62-1-BF, Litton Systems, Inc., Waltham, Mass., 48 pp., 1962.
AD-273 639.

The detection of acoustic signals by simple auto- and cross-correlation receivers in the presence of nonnormal, as well as normal background noise is examined on the basis of s/n calculated from a generalized deflection criterion. Particular attention is devoted to the effects of impulse noise and mixtures of impulse and normal noise on system performance. Comparisons between system behavior vis-á-vis the two types of interference are made. For impulse noise equivalent in spectral distribution and av intensity to a gauss noise background, it is found that the output s/n (power) ratios are related by a canonical expression.

662

Pick, L. A., "A Quasi-Linear Correlator Applied to Signal Location," Tech. Rept. No. 2203, Army Signal Research and Development Lab., Fort Monmouth, N. J., 7 pp., 1961.
AD-264 563.

A method of obtaining precise measurement of the time difference between two audio signals in the presence of non-correlated noise by means of a delay mechanism and a quasi-linear correlator used as a sensing element is described. The design philosophy of the equipment is discussed and some of the pitfalls encountered during the construction and testing of an experimental model are pointed out. In evaluation of limited test data, it is shown that measurements with a precision of 0.1 μsec were easily obtainable, and accuracies of 0.5 μsec were obtained from preliminary data taken in experimental field tests. These results are interim, but represent considerable improvement in accuracy at a slight sacrifice in sensitivity over previous systems using a magnetic drum.

663

Ragazzini, J. R., H. Saks, and M. Kaufman, "Methods for Analyzing Shock and Vibration," Library Rept. No. 1, Gruen Appl. Sci. Labs., Inc., Hempstead, N. Y., 30 pp., 1957.
AD-204 756.

This is a bibliography with abstracts on the following topics:
The filter problem of the power-spectrum analyzer.
Communications applications of correlation analysis.
Methods of obtaining amplitude-frequency spectra.
Short-time autocorrelation functions and power spectra.
The response of a resonant system to a gliding tone.
Response of a linear resonant system to excitation of a frequency varying linearly with time.

Measuring noise color.
The sampling theory of power spectrum estimates.
The principles and practice of panoramic display.
An 8000-c sound spectrograph.
Methods and instruments for the visual analysis of complex audio waveforms.
High-speed, high-resolution spectrum analyzer.
A spectrum analyzer for the 100- to 100,000-c range.
Automatic wave analyzer.
Analog equipment for processing randomly fluctuating data.
A computer for correlation functions.
Shock spectrum computer for frequencies up to 2000-c phenomena.
A high-speed correlator.
An extremely wide-range electronically deviable oscillator.

664

Rakowski, A., "The Application of the Autocorrelation Method to the Spectral Analysis of Sound Records," Acustica, 11, 39-45, 1961.

Application of the autocorrelation method is discussed and examples are given of typical stationary functions suitable for analysis by this method. The stationary function is represented in the form of time samples and its autocorrelation coefficients for different delay times are computed. The power density spectrum is calculated as a Fourier transform of the autocorrelation function, represented by a set of separate autocorrelation coefficients. An electronic computer is used in both cases. The results are plotted in graphs and compared with the original time functions.

665

Remley, W. R., "Correlation of Signals Having a Linear Delay," J. Acoust. Soc. Am., 35, 65-69, 1963.

The output signal of a cross-correlation detector is calculated for a general signal spectrum and integration time under the assumption of a constant delay rate but otherwise ideal conditions. The delay-rate degradation of the output signal is shown to be equivalent to passing the ideal cross-correlation function through a low-pass filter. The output s/n is evaluated for the threshold case by introducing straightforward noise statistics. Subsequently, low-pass rectangular signal spectra are assumed, and the output s/n for various delay rates and time-band width products are numerically evaluated. For zero delay rates, the output s/n is a linear function of the time-bandwidth product, but for nonzero delay rates, optimum points exist.

666

Schroeder, M. R., "Frequency-Correlation Functions of Frequency Responses in Rooms," J. Acoust. Soc. Am., 34, 1819-1823, 1962.

A mathematical study of the random interference of sound waves in large rooms requires statistical methods. "Statistical wave acoustics" is based on the random interference of many simultaneously excited normal modes of a room. In general, the random interference takes place for frequencies above 2000 $(T_{60}/V)^{1/2}$, where T_{60} is the reverberation time (in sec) and V is the volume (in m^3) of the room. In the statistical theory, frequency responses between two points in a room are treated as random functions. The probability distributions, correlation functions, and "spectra" of these random functions are determined by physical parameters such as the distance between source and receiver, the volume and reverberation time of the room (or distribution of reverberation times), etc.

In this paper, correlation functions of frequency responses are derived for rooms with uniform reverberation time, and negligible direct-sound transmission between source and receiver. Analytic formulas for the following frequency-correlation functions are found: the autocorrelation functions of the real and imaginary parts, the modulus and the squared modulus of the frequency response, and the cross-correlation function between real and imaginary parts of the frequency response.

The significance of these correlation functions in room acoustics is discussed. Measurement of the autocorrelation function of the real (or imaginary) part of the frequency response allows a precise determination of the distribution of reverberation times. The autocorrelation function of the modulus (or squared modulus) determined the required frequency shift in public address systems to improve their stability. For measurement of electroacoustic transducers in reverberation chambers, optimum bandwidths of noise or warble tones are obtained.

667

Shifrin, Ya. S., "Correlation Characteristics of the Diffraction Image Formed by a Focussing System," Soviet Phys. Acoust., English Transl., 8, 360-363, 1963.

An expression is derived for the correlation function of the diffraction image formed by a paraxial focussing system subject to any fluctuations in the incident wave and to any ratio between the dimensions of the system and the correlation radius. Graphs are given for the correlation function as a function of fluctuation and of this ratio.

668

Smith, M., and R. Lambert, "Acoustical Signal Detection in Turbulent Airflow," J. Acoust. Soc. Am., 32, 858-866, 1960.

Improvement in detected signal-to-noise ratio is obtained for a periodic signal masked by additive noise and turbulent noise backgrounds. Comparisons are made between autocorrelation, cross correlation, and a combination of frequency filtering and cross correlation. Although the latter method provided the greatest improvement, the cross-correlation technique was the most successful single method. It turned out that the maximum improvement obtainable was limited by the dynamic range of the correlator-computer and not by errors due to finite averaging time and scanning the delay. The improvement for signals masked by turbulent noise was found to be about 5 db less than that obtained for additive noise.

669

Thomas, J. B., and T. R. Williams, "On the Detection of Signals in Nonstationary Noise by Product Arrays," J. Acoust. Soc. Am., 31, 453-462, 1959.

Two detection systems having multiple inputs each consisting of nonstationary noise and a stationary random signal are analyzed and compared on an s/n basis. In both systems the inputs are divided into two groups and the sum of each group is formed. In the first system the resulting two wave forms are multiplied directly and the product averaged. In the second system the two wave forms are strongly clipped prior to multiplication, forming a polarity-coincidence correlator. Previous studies have shown the latter system to be slightly inferior for stationary noise. The results of this paper show that the latter system may be quite superior in certain types of nonstationary noise.

670

Weinberg, M., "Digital Comparator, Type I and Laboratory Tests of Multicorrelator-Comparator System," Report No. TR-305, Diamond Ordnance Fuze Labs., Washington, D. C., 27 pp., 1955.
AD-217 141.

The digital comparator described is a cross-correlation device for indicating on an output galvanometer the percentage of correlation between a time-varying ternary signal and a predicted-time stationary signal. The device is used in conjunction with the Type 3 Multicorrelator (DOFL Rept. No. TR-215, 30 November 1955, AD-216 868) and the Comprizor (DOFL Report No. TR-304, 15 December 1955, AD-217 140) in a signal detection system. Laboratory tests of the Multicorrelator-Comprizor-Comparator System were run to determine the effectiveness of the digital comparator as a signal-indicating device under as many different operating conditions as possible, and to determine the effect of operating parameters on the performance of the comparator.

671

Wilmotte, R. M., Inc., "Instantaneous Cross-Correlator," Miami, Fla. (reports available from Rome Air Development Center and Defense Documentation Center only), 1956-1957.

Letter Rept.	9,	RADC TN 56-227
	10,	RADC TN 56-228
	11,	RADC TN 56-416, AD-97930
	12,	RADC TN 56-453, AD-97981
	13,	RADC TN 57-200, AD-114495
	14,	RADC TN 57-346, AD-131306
	15,	RADC TN 57-347, AD-131307
Final Report		RADC TR 59-68, AD-222272

The development, construction and performance of an instantaneous cross-correlator is described in detail. Techniques are presented for: (1) wide-band modulation of a light source or light beam, (2) selecting a transducer and material to produce sonic modulation of the light beam, and (3) determining the accuracy with which an auto- or cross-correlator function can be delineated by the proposed component and the accuracy of the time-delay scale between input functions to produce correlation. Based on measurements at a mid-frequency of 400 kc, the conclusions are that: (1) a high percentage of light modulation is obtainable with low power and voltage, (2) a correlation function is obtainable with wideband noise types of signals, (3) a wide frequency band is practicable, (4) no information is given for the dynamic range, (5) a single optical system is practical for many applications, and (6) the unit is rugged and can be built in a compact form.

672

Young, J. E., "Correlation Functions for Noise Fields," J. Acoust. Soc. Am., 26, 788-789, 1954.

The autocorrelation function for the noise pressure on the continuous space-time representation is discussed. It is shown that this function is determined throughout the space delay domain by the space correlation. This dependence can be formally interpreted on a casual basis where the delay τ is the "casual variable." Specifically, the values of the space correlation and its time derivative at some instant $\tau = 0$ all over space serve to specify the autocorrelation for all later delays $\tau > 0$ throughout the infinite domain. In the closed domain, the boundary values of the space correlation and its normal derivative are also required to complete the description.

Arrays: Data Processing;
Correlation- see also Instrumentation, Correlators
See also—331, 337, 381, 382, 385, 388, 396, 407, 417, 679, 793, 1088, 1117, 1193, 1377, 1398, 1478, 1710, 1715, 1771, 1773, 2423, 2492, 2720, 2845, 2858, 2876, 2877, 2883, 2885, 2891, 2898, 3401, 3682, 3712, 3722, 3739, 3773.

DATA PROCESSING

673

Anderson, V. C., "Digital Array Phasing," Marine Phys. Lab., Univ. of Calif., San Diego, 4 pp., 1960.
AD-242 717.
See also: J. Acoust. Soc. Am., 32, 867-870, 1960.

The extension of digital techniques to the problem of processing the output of an array of point-receiving elements in an acoustic field has given rise to a method of phasing called DIMUS (digital multibeam steering). This digital technique incorporates the use of shift registers as delay line elements, which results in a number of operational advantages. The DIMUS technique is described. The effects of amplitude and time quantization imposed by the digital circuits are considered in the light of the relative signal processing gain of the array referred to as an exact analog phasing network. The processing gain is compared as a function of sampling frequency for a number of types of signals.

674

Brachman, R. J., "Field Artillery Digital Automatic Computer," Tech. Memo. No. M59-5-1, Frankford Arsenal, Philadelphia, Pa., 42 pp., 1958.
AD-209 143.

A universal computer to solve the gunnery problems relating to tube artillery, free rockets, and various types of missiles, as well as problems of field artillery support, such as survey, flash and sound ranging, fire planning, and counter battery, is indicated in FADAC. Its high-speed performance, small size, light weight, computing capacity, ruggedness, accuracy and reliability, ease of maintenance, and minimum training necessary, all appear to meet the severe conditions and requirements of field use by the field artillery.

675

Bryn, F., "Optimum Signal Processing of Three-Dimensional Arrays Operating on Gaussian Signals and Noise," J. Acoust. Soc. Am., 34, 289-297, 1962.

The essential function of the optimum detector is that of applying a linear mean-square regression process to the output of the array and measuring the power in the residues thus formed. The elements required for instrumentation of the detector are deduced and numerical examples relating to specific array configurations are presented. At low frequencies the directivity pattern is the one having maximum directivity index.

676

Brzezenski, D. B., C. Caso, et al., "Research on Correlation Type Data Processing Systems," Final Rept. No. AFCRL 62-711, Wolf Research and Development Corp., West Concord, Mass., 113 pp., 1962.
AD-283 925.

The development of the high speed digital computer made the construction of large scale data processing and large real-time control systems feasible. The improvement of sensor and communication devices led to systems of great sophistication. Improvement must now be made in the machine's ability to work with deteriorated or otherwise more complex data. The example used is textual and spoken data, which are important to system operation in two ways: (1) the communication between systems is largely by these means; and (2) the human being's direct communication with the machine is simplified. The analysis of the data by different statistical methods can be expected to develop better means of deriving information from signals without a prior knowledge of their exact content and to develop more efficient transmission schemes for those signals.

677

Cole, J. N., H. E. von Gierke, et al., "Noise Radiation from Fourteen Types of Rockets in the 1000 to 130,000 Pounds Thrust Range," WADC Tech. Rept. No. 57-354, Aero Medical Lab., Wright Air Development Center, Wright-Patterson AFB, Ohio, 64 pp., 1957.
AD-130 794.

Detailed noise characteristics were measured on fourteen types of rockets, with both solid and liquid propellants, in the thrust range from 1000 to 130,000 lb. Near-field and far-field levels on static-fired and vertical-launched rockets were measured under essentially free-field conditions. Measurements and data reduction methods are described. Final results are given as near-field sound pressure spectra, far-field directivities, acoustic power spectra and pressure-time histories. This noise environment is studied as a function of several nozzle configurations and as a function of flame front action in the jet stream. Generalization and correlation of the data result in a formula for the overall acoustic power level output of rockets, OA PWL 78 + 13.5 $\log_{10} W_m$ db re 10^{-13} watts, where W_m is the rocket jet stream mechanical power in watts. Also given is an approximate generalized power spectrum dependent upon nozzle diameter and jet flow characteristics. These correlations result in procedures for predicting far field noise environments produced by static-fired or launched rockets.

678

Diamond, M., and A. B. Gray, "Accuracy of Missile Sound Ranging," Tech. Rept. No. 110, Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 14 pp., 1961.
AD-264 856.

This report presents a technique for determining the impact point of missiles by the detection of the shock wave generated during a missiles descent. It includes the instrumentation and computations involved and an error analysis.

679

Exner, M. L., "Investigation of Periodic Time Processes with Autocorrelation and Fourier Analysis," Tech. Memo No. TM 1404, Natl. Advisory Comm. Aeron., Washington, D. C., 1958.
AD-154 320.
See also: Trans. of Acoustica, 4, 365-379, 1954.

Autocorrelation and frequency analyses were made of a series of aperiodic time events — in particular, filtered noises and sibilant sounds. The position and bandwidth of the frequency ranges are best obtained from the frequency analysis, but the energies contained in the several bands are most easily obtained from the autocorrelation function. The mean number of zero crossings of the time function was determined from the curvature of the latter function in the vicinity of the zero crossing, and also with the aid of a decimal counter. The second method was found to be more exact.

680

Galloway, W. J., "Frequency Analyses of Short-Duration Random Noise," Sound, 1, 31, 1962.

The validity of frequency analyses of short-duration samples of a random-noise signal has been questioned in recent years. The aim of this article is to meet this problem by providing tables of confidence limits directly in decibels so that no further computation from statistical tables is required and to apply the results to two typical analyzers presently used by acousticians.

681

Gershman, S. G., A. I. Smirnov, and Y. I. Tazhilkin, "A Transposing Arrangement for Generating the Correlation Function of Infrasonic Processes," Soviet Phys. Acoust., English Transl., 7, 336-340, 1962.

An arrangement is described which transposes infrasonic signals to the frequency range of the acoustic correlometer. The correlation functions of the original and the transposed processes are connected by simple relations.

682

Groves, G. V., "A Rigorous Method of Analyzing Data of the Rocket-Grenade Experiment," J. Atmospheric Terrest. Phys., 9, 349-351, 1956.

A set of three equations developed in an earlier paper (Groves, J. Atmospheric and Terrest. Phys., 8, 24-38, 1956) express in integral form the horizontal components of wind velocity and the speed of sound at any desired height up to 90 km in terms of quantities that can be measured at and from the ground. These measurable quantities are the x, y, z coordinates in space of at least two exploding grenades, the x and y components of the velocity of the sound as it passes a detection point 0 on the ground at the origin of the coordinate system, and finally, t, the travel times of the sounds from grenades to point 0. Either graphical or numerical differentiation of the integral equations then yields the desired components of wind velocity and speed of sound. With these quantities determined, the air temperature at the corresponding altitude may be calculated. With three grenades a rough linear variation of wind and temperature with height may be determined, while with four or more, an increasingly accurate variation with height may be determined.

683

Heindsmann, T. E., "Acoustic Spectrum Terminology," J. Acoust. Soc. Am., 25, 1201, 1953.

Terminology used to describe line spectra is discussed. It is proposed that "discrete component" be used to describe the individual elements comprising a line spectrum and that "tonal component" be used to describe its auditory equivalent.

684

Jackson, P. L., "Optical Analysis Techniques Applied to Seismic Data," Acoustics and Seismics Lab., Inst. of Science and Technology, Univ. of Mich., 1962.

An optical system capable of performing multichannel, high-resolution spectral analysis, and auto- and cross-correlation is under development. The series of progress reports listed detail the effort in obtaining accurate time and spectral information from variable density, time history signals.

First Semiannual Technical Summary Report, January 1962, Rept. No. 4596-4-P
Second Semiannual Technical Summary Report, July 1962, Rept. No. 4596-7-P
Third Semiannual Technical Summary Report, January 1963, Rept. No. 4596-13-P
Fourth Semiannual Technical Summary Report, July 1963, Rept. No. 4596-20-P

685

Jackson, P. L., "Signal Enhancement Through an Ensemble Presentation," Bull. Seism. Soc. Am., 53, 1962.

A method of treating array responses is presented. The entire statistical distribution from the array is used for either direct visual estimation, or for processing in a scanning machine. An estimate of a coherent signal and the character of the noise can be made visually. Most correlative techniques, in addition to digitizing, could be performed simultaneously through using the scanning machine.

686

Johannesen, N. H., "Analysis of Vibrational Relaxation Regions by Means of the Rayleigh-Line Method," J. Fluid Mech., 10, 25-32, 1961.

The physics of shock-waves with vibrational relaxation regions is recapitulated; it is shown that exact methods of analysis can be developed from the classical Rayleigh-time equations by treating the real gas as an ideal gas with heat transfer. By using these methods to analyse experimental records of density distributions in relaxation regions, a large number of local values of the relaxation frequency, rather than a single over-all value, may be obtained from each shock-wave record.

687

Marble, G., "T43 Sound Range Plotting Kit," Md. Rept. No. DPS-289, Aberdeen Proving Ground, 1961. AD-260 503.

The T43 sound-range-plotting kit permits experimental determination of the best method of graphically solving the problem of locating a sound source using data obtained from field microphones. A complete kit consists of over 20 components, some of which have been tested at Aberdeen Proving Ground. This report contains the results of tests on 15 components, including plotting fans, nomographs and templates made of plastic. The purpose of this test was to determine the accuracy durability and ease of operation of the kit in normal and simulated extreme environments. Results indicated satisfactory performance at normal and extremely low temperatures, but not in extreme heat.

688

McCracken, C. W., "An Analysis of Rocket and Earth Satellite Measurements of Micrometeoric Influx, Acoustic Detection of Meteoric Particles, Volume II. Appendix B," Final Rept., Oklahoma State Univ., Research Foundation, Stillwater, Master's Thesis, 120 pp., 1960. AD-240 260.

The data obtained through the use of micrometeor detection systems mounted on high-altitude rockets and an Earth satellite are analyzed. The analysis indicates a major deviation from the results expected on the basis of extrapolations of visual and radar meteor data. Other known data on meteoric influx are introduced to support the micrometeor data and to provide a framework onto which the micrometeor data can be added. The micrometeor data and some of the other available data on meteoric influx are plotted together as particle influx versus particle momentum to get a tentatively revised mass distribution curve. An equation is fitted to the curve in order to obtain the corresponding revised mass distribution function for meteoric particles. Some of the implications of the revised mass distribution function are discussed.

689

Morrow, C. T., "Averaging Time and Data-Reduction Time for Random Vibration Spectra, I.," J. Acoust. Soc. Am., 30, 461, 1958.

Most narrow-bandwidth wave analyzers currently available on the market were designed for producing spectra of periodic signals. When they are applied to producing spectra for low-frequency random signals such as occur in vibration, a longer averaging time must be provided on the output side of the detector circuit to average out fluctuations and yield data of statistical significance. The application of standard statistical techniques in relation to the bandwidth of the selective circuit provides design data for averaging circuits to be added as modifications to existing analyzers. Proper averaging time carries with it a requirement of a slower sweep rate and hence greatly increases the time required for producing a spectrum. Techniques and apparatus for producing a spectrum in a decreased time interval are discussed.

690

Morrow, C. T., "Averaging Time and Data-Reduction Time for Random Vibration Spectra, II," J. Acoust. Soc. Am., 30, 572-578, 1958.

In part I, formulas were given for uncertainty when a power-spectral-density plot is estimated from a short sample or random vibration. The relation between this problem and the time required to obtain the spectrum was investigated for the sweeping of a simple analyzer through the frequency band. Other methods of obtaining the spectrum are now discussed.

691

Nordberg, W., "A Method of Analysis for the Rocket-Grenade Experiment," Tech. Memo. M-1856, Army Signal Engineering Labs., Fort Monmouth, N. J., 37 pp., 1957. AD-143 218.

The method of analysis for the rocket-grenade experiment is reviewed. An analytical method is derived to obtain temperature and wind data from sound explosions between 30 and 80 km altitude. Errors stemming from both random measuring errors in the initial parameters and systematic sources in the method are investigated. It is concluded that average temperatures and winds in layers of several kilometer thickness between two successive explosions may generally be determined within $\pm 2.5^{O}$K and ±5 m/sec, respectively.

692

Parker, W.E., and L. V. East, "Automatic Processing System for Acoustical Data," J. Acoust. Soc. Am., 33, 1-6, 1961.

An improved instrumentation system has been developed to analyze the dynamic pressure field produced by jet aircraft. The system is automatic and utilizes analog computer techniques to obtain an accuracy of 0.2 db in its readout. The method used is to secure a true rms value of octave band segments of the jet noise spectrum and to convert this to decibels by the use of a d-c logarithmic amplifier. The transition to acoustical decibels is made by obtaining the difference between this voltage and another voltage obtained from a reference oscillator. The value of this reference oscillator in acoustical decibels is obtained by comparing its output voltage to that of a calibrated microphone. The dynamic range of the system has proved more than adequate for greater than 98% of the data processed by this unit during the time this system has been in operation. The output is in the form of punched cards for utilization with a digital computer.

693

Ragazzini, J. R., H. Saks, and M. Kaufman, "Methods for Analyzing Shock and Vibration," Library Rept. No. 1, Gruen Appl. Sci. Labs., Inc., Hempstead, N. Y., 30 pp., 1957.
AD-204 756.

This is a bibliography with abstracts on the following topics:
The filter problem of the power-spectrum analyzer.
Communications applications of correlation analysis.
Methods of obtaining amplitude-frequency spectra.
Short-time autocorrelation functions and power spectra.
The response of a resonant system to a gliding tone.
Response of a linear resonant system to excitation of a frequency varying linearly with time.
Measuring noise color.
The sampling theory of power spectrum estimates.
The principles and practice of panoramic display.
An 8000-c sound spectrograph.
Methods and instruments for the visual analysis of complex audio waveforms.
High-speed, high-resolution spectrum analyzer.
A spectrum analyzer for the 100- to 100,000-c range.
Automatic wave analyzer.
Analog equipment for processing randomly fluctuating data.
A computer for correlation functions.
Shock spectrum computer for frequencies up to 2000-c phenomena.
A high-speed correlator.
An extremely wide-range electronically deviable oscillator.

694

Ramaswamy, T. K., and B. S. Ramakrishna, "Simple Laboratory Setup for Obtaining Sound Spectrograms," J. Acoust. Soc. Am., 34, 515-517, 1962.

A technique for obtaining sound spectrograms using common laboratory equipment is described. The procedure is to record the signal on a tape loop and reproduce it repeatedly. The tape output is fed successively through different bandpass filters to the intensity electrode of an oscilloscope. The oscilloscope beam is triggered by a 2 kcs pulse inserted ahead of the signal. After each repetition of the signal, the filter selector and the vertical position of the trace on the scope are advanced by one step. An oscilloscope recording camera registers the spectrogram under time exposure. The performance of this setup is improved by using an AVC circuit to accommodate the wide range of intensities encountered in speech within the recording range of the oscilloscope and film.

695

Remillard, W. J., "Method of Obtaining Amplitude and Phase Spectra of a Transient Function Using Graphical Input Data," J. Acoust. Soc. Am., 31, 531-534, 1959.

Both amplitude and phase spectra are needed to characterize transient functions completely. Analysis shows how these spectra can be obtained from the envelopes of the line spectra of the even and odd parts of a transient function made to recur in time. Instrumentation is described for the convenient determination of these line spectra.

696

Schneider, W., "Pressure in Air-Shock Waves," Z. Physik, 74, 66-87, 1932.

In air-shock waves there are great and rapid changes of pressure. It is therefore hardly possible with a membrane apparatus to get a distortionless record of the pressure. The author presents a method of computing the pressures from distorted records by observing the divergences from a standard differential equation of motion and extrapolating.

697

Sommer, J., "Acoustic Analyzer" (in German), Issue 240, Arch. Tech. Messen, 1-4, 1956.

A review of methods of determining frequency spectra and harmonic contents of single tones, complex musical or speech waveforms, noise etc. in the af range. Among the circuits discussed are tunable bridge and switched fixed filter distortion meters, a variable filter analyzer for musical tones in which the component frequencies are measured by a Lissajous figure method against standard frequencies, a stroboscopic disk method in which the disks are illuminated by a gas discharge tube driven by the input signal, and various heterodyne methods in which a fixed intermediate filter is used. One analyzer with extremely high resolution has automatic frequency control. Automatic recording systems are described, and the limitation on the frequency sweep speed due to finite filter response time is discussed. Twenty-five references are given.

698

Stroud, W. G., "The Reduction of Data from the Rocket-Grenade Experiment," Tech. Memo. M-1570, Evans Signal Lab., Signal Corps Engineering Labs., Belmar, N. J., 35 pp., 1954.
AD-34 406.

A summary is presented of the firing of 16 Aerobee rockets at White Sands Proving Ground to measure the temperatures and winds in the region of the atmosphere between 30 to 80 km. Basic data were obtained by measuring the speed of sound in the atmospheric layers defined by the explosions of grenades successively ejected from the rocket along various points in its upward trajectory. An account of the method of analysis of the rocket-grenade experiment is given which covers step-by-step, equation-by-equation, the procedures for deducing the temperatures and winds from the basic field data. A complete set of data tabulation sheets is appended.

699

Swingle, D. M., "Atmospheric and Geometric Considerations in Sound Location Data Processing," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 162-167, 1961.
AD-408 716.

Several ways of processing data obtainable by two-dimensional square microphone arrays are examined, and the optimum formulation is selected given specified random errors. The role of atmospheric turbulence in base-line length selection is discussed in the light of recent progress in this country and the USSR.

700

Young, W., "A Brief Guide to Noise Measurement and Analysis," Navy Electronics Lab., San Diego, Calif., 23 pp., 1955.
AD-66 686.

Basic noise-measurement principles and techniques are treated in Part I by only simple arithmetic. Terms peculiar to noise analysis are explained. Special attention is given to interpreting graphs of noise spectra obtained with analyzers of different bandwidths. Part II describes specific calibration procedures. It also gives the mathematics used in calculating sound-pressure levels, spectrum levels, and combinations of levels.

Data Processing— See also Arrays; Correlation; Instrumentation
See also—406, 407, 411, 488, 562, 601, 604, 605, 611, 639, 640, 642, 664, 670, 709, 716, 902, 1040, 1041, 1052, 1117, 1151, 1152, 1165, 1188, 1260, 1300, 1355, 1370, 1416, 1425, 1436, 1437, 1438, 1471, 1485, 1534, 1629, 1675, 1702, 1777, 1912, 1915, 1921, 1935, 1938, 1942, 2046, 2133, 2151, 2298, 2305, 2308, 2309, 2858, 2867, 2963, 3456, 3473, 3624, 3649, 3990.

DETECTION

701

Aerospace Information Div., "Detection of Nuclear Explosions," Rept. No. 62-117, Washington, D. C., 2 pp., 1962.
AD-284 027.

DESCRIPTORS: Detection, Nuclear explosions, USSR, Acoustic detectors, Radioactive fallout, Seismic waves, Electromagnetic effects, Radio signals, Gamma rays.

702

Anastassiades, M., D. Illias et al., "Observations Made at Athens Ionospheric Institute During the Series of Nuclear Weapon Tests at Novaya Zemlya Between Sept. 10 and Nov. 4, 1961," Sci. Rept. No. 2a 001, Univ. of Athens, Greece, 8 pp., 1962.
AD-283 454.

During the series of Russian nuclear weapon tests in autumn 1961, the Ionospheric Institute of the National Observatory of Athens observed several phenomena in the upper and lower atmosphere over Athens. According to official information, the test range was Novaya Zemlya, a distance of about 4100 km from Athens. Evidently, this long distance creates a state of rather poor hopes for clear observations. In fact, among the nuclear explosions which occurred in the period from September 10, 1961, to November 4, 1961, only two (October 23 and October 30) show a distinct ionospheric disturbance which was measured in Athens. These two explosions were also recorded by microbarographs in Greece. An increase of radioactive fallout due to the nuclear weapon tests is also discussed.

703

Army Airborne and Electronics Board, "Evaluation of the Acoustic-Sonde Dummy for Parachute Delivery," Proj. No. AB-2157, Fort Bragg, N. C., 10 pp., 1958.
AD-160 384.

Tests were conducted to determine the suitability of the acoustic-sonde dummy for parachute delivery from an Army aircraft. The acoustic-sonde dummy is composed of 3 major parts: body, parachute, and tail fin assembly, and simulates a container developed for parachute delivery of the radio transmitter component of a combat surveillance system. Tests were made of (1) 12 drops from the bomb shackles of the L-19 aircraft at 60 to 95 mph IAS, (2) 24 drops from the bomb shackles of the L-20 aircraft at 70 to 125 mph IAS, (3) one drop each from the door of an L-20 and an H-21 helicopter using a safety cord and a static line to prevent premature actuation of the parachute system. Results showed that the acoustic-sonde dummy is suitable for parachute delivery from an Army aircraft.

704

Army Electronic Proving Ground, "Operational Evaluation of Detector Set AN/PSS-2 (XE-2)," Final Rept. No. AEPG-SIG 930-142, Fort Huachuca, Ariz., 27 pp., 1961.
AD-253 161.

Tests were conducted to evaluate the technical and operational capabilities of the AN/PSS-2(XE-2) as a device to extend the listening range of an individual sentry. The Detector Set AN/PSS-2(XE-2) consists of 9 microphones, 3 junction blocks, headset, and a vacuum tube audio amplifier. The set is designed to detect moving personnel or vehicles approximately 50 feet from any microphone. Tests indicated that the AN/PSS-2 (XE-2) is capable of increasing the listening range of the individual sentry.

705

Army Electronic Proving Ground, "Operational Evaluation of Detector Set AN/PSS-2 (XE-2)," Rept. No. AEPG-SIG 930-150, Fort Huachuca, Ariz., 18 pp., 1960.
AD-248 583.

Tests were planned to determine the capabilities of Detector Set AN/PSS-2 (XE-2) for increasing the listening range of individual sentries. The AN/PSS-2 (XE-2) consists of nine microphones, three junction blocks, one headset, and a vacuum tube audio amplifier. Each microphone is equipped with a rain shield and a detachable steel ground stake. The set was designed to detect moving personnel or vehicles about 50 ft from any microphone; the manufacturer specified that a maximum of 3000 ft of field wire can be used effectively between junction and amplifier, thus enabling a sentry to "listen-in" at this range. The sentry, using a headset, can monitor all three groups or any one group of the microphones.

706

Army Signal Missile Support Agency, "Proceedings of the Symposium on Atmospheric Acoustic Propagation," Headquarters, USA SMSA, Missile Meteorology Div., 1, 268 pp, 1961.
AD-408 716.

This document comprises twenty-five technical papers on various aspects of the propagation of sound in air. It features the results of recent research. These deal with high-altitude acoustic detection from balloons, the sound duct at high altitudes, very-long-range detection of low-frequency sound, atmospheric absorption of sound, sound ray theory, shock wave propagation, sound ranging, and the inter-relationships of meteorological parameters with sound propagation. Some of the papers emphasize theory, others emphasize measurements and experimental results, and some describe special instrumentation. Anyone interested in military applications of sound propagation in the atmosphere will find this document especially useful. Most of the papers include extensive bibliographies.

707

Beals, C. S., "Audibility of the Aurora and Its Appearance at Low Atmospheric Levels," J. Roy. Meteorolog. Soc., 59, 71-78, 1933.

The author reviews former reports of these phenomena and analyzes reports he has received from reliable observers in Canada. Two types of sounds, corresponding to swishing and crackling, are distinguished, and the infrequency of the reports is attributed to the phenomenon's being rare and having local variations of audibility, while the acuteness of hearing varies among observers. The sounds are attributed to a form of brush discharge. The existence of low level aurorae is confirmed by trained scientific observers who have seen them against a recognized background.

708

Bertolini, A., "An Ultrasonic Receiver for Detecting Signals of Bats," Rept. No. 47G-0010, Lincoln Lab., Mass. Inst. of Tech., Lexington, Rev. 1, 16 pp., 1961.
AD-268 702.

A portable ultrasonic receiver was designed for detecting the signals of bats and other fauna which may emit ultrasonic sounds. The receiver has a passband extending from 15 to 200 kc, but bandwidth selection within this interval can be obtained with the use of plug-in filters. It has a small-signal voltage gain of 78 db preceding a rectifier which envelope-detects the ultrasonic signal. Following detection is 10 db of audio voltage gain. Additional gain is provided by a preamplifier inserted between the microphone and ultrasonic amplifier. All of the power is supplied by five 1.35-volt mercury cells but D-cell flashlight batteries may be used when necessary. The total weight of the unit is 5 pounds.

709

Bettle, J. F., "Acoustic Disturbances Generated by the Scout ST-1," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 213-223, 1961.
AD-408 716.

This is a preliminary report on the detailed analysis of the Pulsonde operation on the Scout rocket firing of 2 July 1960. It is of primary interest because of the close correlation between actual acoustic events detected and those predicted by a modified form of ray tracing. Also of interest are the frequency and pressure content of the detected events.

710

Bolt, Beranek, and Newman, Inc., "Investigation of Acoustic Signalling over Water in Fog," Final Rept. on Phase 1, Evaluation of Present U. S. Coast Guard Design Procedure for Fog Signals, Cambridge, Mass., 14 pp., 1960.
AD-236 583.

The present USCG design procedure for fog signals represents considerable progress over previous methods. It is based on the concept of the average audible range and uses a fixed loudness level as the criterion for detection. Sound sources are specified in terms of the on-axis free-field sound pressure level at a distance of 25 feet. The transmission path is described by means of a curve of average sound transmission loss obtained many years ago. The following areas of improvement and refinement are suggested: (1) description of the sound source in terms of acoustic power output and directivity; (2) description of the transmission path by means of sound attenuation functions which take into account, in addition to frequency and distance, such parameters as source and receiver heights, wind direction and speed, and temperature and wind gradients, on a statistical basis; (3) description of the process of signal detection and location by the listener in terms of a detection criterion of minimum s/n, taking account of background noise levels and spectra, signal frequency and duration, and other relevant factors.

711

Bradfield, G., "Obstacle Detection Using Ultrasonic Waves in Air," Electron. Eng., 21, 464-468, 1949.

This paper describes the results which have been achieved with simple equipment for use as a safety-in-fog aid to road transport, or blind man's aid, to detect the proximity of oncoming traffic, up- or down-going steps, walls, windows, etc. Expressions are given for determining the optimum frequency for certain conditions (e.g., at 20 ft large objects require a frequency of 23 kcs, but clusters of tiny objects require 50 kcs). A spark transmitter was used with a standard 14-mm sparking plug at the focus of a reflector. The receiving microphone used a double bimorph Rochelle crystal at the focus of a five in paraboloid. The spark rate was 3 to 4 sec, and duration 1 to 1 1/2 μsec. Tables show the amplitude of the reflected signal at various frequencies for different objects.

712

Cook, J. C., "Further Investigations of Geophysical Mine-Detection Methods," Final Tech. Rept., 31 May 57, Southwest Research Inst, San Antiono, Tex., 1957.
AD-202 546.

Activity under this contract has been devoted to perfecting three mine-detection methods: air-to-ground-coupled acoustic methods, surface-temperature methods including those employing the normal thermal radiation from the ground, and a low-frequency electro-magnetic method sensitive to resistivity variations of the soil. The work has included the discovery of new phenomena, efforts to improve the experimental apparatus, and the collection of basic data concerning the physical effects utilized. A successful acoustic air-to-ground-to-air system was developed. However, the previously developed air-to-ground system is superior and is recommended as a basis for practical mine detectors. Efforts to improve acoustic coupling to the earth have not significantly bettered the techniques already in use. The thermal investigations have demonstrated the existence in sand and loam of clear surface-temperature anomalies over large buried mines in the afternoon, which arise from the diurnal cycle of insolation. These anomalies can be detected with suitable radiometers, but there are serious interfering effects. The electromagnetic resistivity method is very sensitive, successful and promising, except for the "tilt effect" which prevents free manipulation of the search head. Two promising approaches for eliminating the tilt effect have been partially investigated.

713

der Agobian, R., "A Method of Detecting Non-Ionizing Shock-Waves and Their Study Through Radioelectric Waves" (in French), Compt. Rend., 248, 1308-1311, 1959.

In order to render detection of non-ionizing shockwaves more perceptible, one allows for the possibility of propagating through a previously ionized gas mass. This method of sensitization consists of creating, through an auxiliary discharge, an "autonomous"gaseous plasma ("autonomous" referring to a plasma abandoned to its spontaneous decrease). One studies jointly, by radioelectric exploration and optical observation, the modifications appearing in a film of plasma when the shockwave is passing. The author gives a description of the equipment used and its functioning.

714

Donn, W. L., and M. Ewing, "Atmospheric Waves from Nuclear Explosions, II. The Soviet Test of 30 October 1961," J. Atmos. Sci., 19, 264-273, 1962.

Atmospheric waves from the Soviet nuclear test of 30 October 1961 are described for nine stations having wide global distribution. The records are characterized by waves which begin with the highest amplitudes and which show normal dispersion. These appear to be superimposed on a lower amplitude, long period train of waves which shows inverse dispersion. As shown on dispersion curves of group velocity against period, a maximum of group velocity is indicated by the Airy phase formed through the merging of the two dispersive trains. A more prolonged train of waves of nearly uniform period is attributed to higher modes. The direct waves from the epicentre to the stations give dispersion curves that indicate significant variation in atmospheric structure along different azimuths and probably along different segments of the same azimuth. The curves for waves which have travelled more than once around the earth represent better sampling of world-wide atmospheric conditions and give better agreement with preliminary theoretical models. The average speed of the first arrivals is 324 m/sec, comparing well with the maximum obtained for the Krakatoa eruption.

715

Faran, J. J., Jr., and R. H. Hills, Jr., "Correlators for Signal Reception," Tech. Memo No. 27, Acoustics Res. Lab., Div. of Applied Science, Harvard Univ., Office of Naval Res., 88 pp., 1952.
AD-3188.

Correlators (multiplier-averagers) are analyzed and compared with detectors (rectifier-averagers) of various power laws from the point of view of their possible use in signal reception systems. Comparison is made in terms of s/n for the limiting case of small input s/n and long averaging time. Of the detectors, the square-law is found to be slightly superior for determining the presence of a small signal in a noise background; while if two samples of the signal in incoherent background noises are available, although the correlator cannot improve the s/n, it does have the advantage that no constant terms independent of the signal appear at its output. The design of electronic correlators is discussed, and several practical circuits are given. Two other types of circuits, similar in operation to correlators but much simpler to construct, are also analyzed. Both are very slightly inferior to true correlators in output s/n.

716

Harrington, H. E., and R. F. Buck, "Acoustic Detection of Meteoric Particles," Final Rept. No. AFCRC TR 60-272, Oklahoma State Univ., Research Foundation, Stillwater, 148 pp., 1960.

An investigation is progressing for detecting the influx of micrometeoritic material. The technique is based on the acoustic activation of suitable devices by the impact of such meteoric material upon the metallic surfaces carried by high altitude rockets. The development of this technique is traced from the early discovery to a definite program of rocket instrumentation. This technique is exploited to an electronic system for installation in satellite and space probe vehicles. Laboratory investigations were concerned with two general aspects: (1) the establishment of a working technique and verification of information, and (2) the establishment of the specific electronic devices. Rocket experimentation and a tabulation of the data are given for a number of rocket flights. A discussion of the problems of interpretation of the information acquired from each specific rocket experiment station accompanies the data.

717

Harrington, H. E., "Research Directed Toward the Design, Development, and Construction of Meteoritic Microphone Detectors of Various Sensitivities for Use in Satellites," Sci. Rept. No. 1, Oklahoma State Univ. Research Foundation, Stillwater, 1960.
AD-233 737.

An electronic system designed for the express purpose of exploiting the data-gathering potential of a specific vehicle in obtaining information regarding the influx of micrometeor material was developed. An acoustic sensing technique is employed, whereby the particulate matter to be detected activates a supersonic microphone device. The resultant electrical signal is amplified to a suitable level, graded as to magnitude, and stored internally by electronic means for subsequent recording and/or telemetering to ground receiving stations by the system inherently available within the chosen vehicle. A brief historical background of the development of the technique is presented, together with details of the specific system evolved for this application. Various design features which are peculiar to this application are presented and discussed. The prototypical equipment which resulted from the development program was subjected to a testing program to verify its suitability for the anticipated use, and several sets are currently under construction.

718

Hofe, C. V., "New Directional Sound Receiver," Z. Instrumentenk., 49, 331-341, 1929.

A new directional receiver for sounds traveling through the atmosphere is described. The principle on which the receiver operates is as follows. Two reflectors in the form of paraboloids of revolution are so arranged that sound received from a direction normal to the line joining their foci is reflected through a pair of ellipsoidal tubes to both ears of the observer. The reflectors and connecting tubes are so arranged that sound coming from a direction on, say, the left of the observer can only enter the left connecting tube, the sound received by the right reflector being reflected outside the entrance to the right connecting tube. Thus an accurate estimate of direction is obtained, only a small angle of rotation of the instrument being sufficient to cut off the sound from one ear or the other. In the actual apparatus two pairs of paraboloidal reflectors are employed, one pair arranged for direction-finding in a horizontal plane, and a second pair, arranged at right angles to the first and connected to the observer's ears by ellipsoidal tubes with a right-angled bend, for direction-finding in a vertical plane. The principles on which the operation of the receiver is based are discussed experimentally, and experimental tests on the apparatus, which is made by Goerz, are described.

719

Hubbard, H. H., and D. J. Maglieri, "An Investigation of Some Phenomena Relating to Aural Detection of Airplanes," Tech. Note 4337, NASA, Washington, D. C., 49 pp., 1958.
AD-205 675.

Conventional noise-level measurements consisting of broad- and narrow-band frequency analyses were made for static ground tests of an unmodified and modified single-engine airplane. Also, listening data with the aid of ground observers were obtained in flight during cruise as well as for take-offs, landings, and power-off glides. The test results indicate that the external noise-level characteristics of the airplane, the propagation phenomena relating to the conditions of the problem, and the ambient or background noise conditions at the location are all significant factors in aural detection by ground observers.

720

Kuhlenkamp, A., "Acoustical Location for Shooting at Invisible Aircraft," Ver. Deut. Ing. Z., 85, 393-400, 1941.

Reasons for the inferiority of sound locating to optical methods are given. The principles of sound locating are discussed, and a mechanism for computing the delay is described. The principle of the cotangent method is explained. Equipment developed in France and Austria is described and illustrated.

721

Leyzorek, M., and M. J. Lun, "Symposium on Target Detection by Acoustic and Seismic Means, at the Operations Research Office, 17 June 1953," ORO T-254, Johns Hopkins Univ., 1953.
AD-32007.

Project TACIT's research into the feasibility of a remotely operated target-detection system using sonic and/or seismic sensing elements is an important part of the effort to develop an all-weather battlefield surveillance system designed for atomic weapons. To learn the current findings of other organizations working in related fields, and to disseminate that knowledge to other researchers, TACIT sponsored a symposium at the Operations Research Office on 17 June 1953. Summarized in this memorandum are papers presented by participants from 22 laboratories, covering problems of acoustic and seismic detection, telemetering systems, recorder-computers, target-signature analysis, and display systems. They conclude that: (1) at long ranges (10,000 yards), ground targets may be detected by airborne sound, but the highly directional sensing elements required are influenced by weather and nearby turbulence, and each is generally limited to one target at a time. (2) Earthborne sound may reveal impulsive sources at long ranges, but nonimpulsive-source detection is limited to about 200 yards. (3) Arrays of omnidirectional acoustic and/or seismic detectors can be used to locate and identify targets within 200 yards. (4) There will soon be components for testing a detection, location, and identification system based on short-range, omnidirectional acoustic and/or seismic sensing elements located up to 10 miles behind enemy lines.

722

McCracken, C. W., "An Analysis of Rocket and Earth Satellite Measurements of Micrometeoric Influx, Acoustic Detection of Meteoric Particles, Volume II. Appendix B," Final Rept., Oklahoma State Univ., Research Foundation, Stillwater, Master's Thesis, 120 pp., 1960.
AD-240 260.

The data obtained through the use of micrometeor detection systems mounted on high-altitude rockets and an Earth satellite are analyzed. The analysis indicates a major deviation from the results expected on the basis of extrapolations of visual and radar meteor data. Other known data on meteoric influx are introduced to support the micrometeor data and to provide a framework onto which the micrometeor data can be added. The micrometeor data and some of the other available data on meteoric influx are plotted together as particle influx versus particle momentum to get a tentatively revised mass distribution curve. An equation is fitted to the curve in order to obtain the corresponding revised mass distribution function for meteoric particles. Some of the implications of the revised mass distribution function are discussed.

723

Middleton, D., "Acoustic Signal Detection by Simple Correlators in the Presence of Non-Gaussian Noise, I. Signal-to-Noise Ratios and Canonical Forms," J. Acoust. Soc. Am., 34, 1598-1609, 1962.

The detection of acoustic signals by simple auto- and cross-correlation receivers in the presence of nonnormal as well as normal background noise is examined on the basis of s/n calculated from a generalized deflection criterion. Particular attention is devoted to the effects of impulse noise and mixtures of impulse and normal noise on system performance. Comparisons between system behavior vis-á-vis the two types of interference are made. For impulse noise equivalent in spectral distribution and average intensity to a Gaussian noise background it is found that the output s/n (power) ratios are related by the canonical expression

$$\left(\frac{S}{N}\right)_I^2 = \frac{(S/N)_G^2}{1 + (1 - \mu)\,\Lambda\,(S/N)_G^2},\ 0 \leq \mu \leq 1,$$

where Λ (≥ 0) is the "impulse factor" and μ is the fraction (in average intensity) of the total noise background that is attributable to normal noise. Impulse noise always degrades system performance vis-á-vis normal noise in the autocorrelation reception of stochastic signals, characteristic of applications where passive receiving methods must be used. This degradation can be considerable [0(10 db or more)] if the noise is highly impulsive (large Λ) and if large values of $(s/n)_{out}^2$ (> 0 db) are required (for high accuracy of decision). On the other hand, when coherent (i.e., deterministic) signals are employed, so that cross-correlation reception is possible, the degradation may be reduced essentially to zero (i.e., $\Lambda \to 0$) under realizable conditions of operation. It is observed for impulsive, as well as normal noise backgrounds, that cross-correlation receivers are linear in their dependence on signal-to-noise ratio, i.e., $(s/n)_{out}^2 \sim (s/n)_{in}^2$ if sufficiently strong injected signals are employed. The analysis is carried out largely in canonical form, so that the general results for $(s/n)_{out}^2$ can be applied to other, special types of nonnormal noise backgrounds. Specific relations are included, along with a detailed summary of the principal results, showing the dependence of $(s/n)_{out}^2$ on $(s/n)_{in}^2$, filtering, delay, noise and signal spectra, etc., for weak and strong inputs, little or heavy postcorrelation smoothing and for Gaussian as well as for impulse noise.

724

Middleton, D., "Acoustic Signal Detection by Simple Correlators in the Presence of Nongaussian Noise, I. Signal-to-Noise Ratios and Canonical Forms," Tech. Rept. No. TR-62-1-BF, Litton Systems, Inc., Waltham, Mass., 48 pp., 1962.
AD-273 639.

The detection of acoustic signals by simple auto- and cross-correlation receivers in the presence of nonnormal, as well as normal background noise is examined on the basis of s/n calculated from a generalized deflection criterion. Particular attention is devoted to the effects of impulse noise and mixtures of impulse and normal noise on system performance. Comparisons between system behavior vis-á-vis the two types of interference are made. For impulse noise equivalent in spectral distribution and av intensity to a gauss noise background, it is found that the output s/n (power) ratios are related by a canonical expression.

725

Pike, E. W., "A Search for Means to Detect Distant, Low-Flying Aircraft," Tech. Rept. No. 161, Lincoln Lab., Mass. Inst. of Tech., 107 pp., 1957. AD-150 868.

The problem set is the detection, by a ground-based observer, of an aircraft 40 miles distant, perhaps 100 feet above the terrain, and at least 1000 feet below the observer's mask. The modes of interaction of the aircraft with its immediate surroundings, and the modes of transmission of this disturbance to the observer, can be listed exhaustively. There are 18 physically possible systems, and each can be evaluated confidently from data in the open literature. Only one, an extremely large uhf radar, has even marginal operational possibilities. The others fail by factors larger than 10^5 to provide adequate clutter rejection or sufficient signal strength to override the unavoidable noise. The probability of overlooked possibilities is negligible. The systems studied are based on the following interactions: static gravitational force; vector gravitational force; scattering of cosmic rays; sound generated by lift forces.

726

Pimonow, L., (1957) "The Detection and Analysis of Infrasounds Propagated in the Air in the Range 2 to 30 cps" (in French), Ann. Telecommun., 12, 419-423, 1957.

Instruments to measure the sound pressure level and to analyze the spectrum of steady and transient infrasounds are described.

727

Rudnick, P., "Small Signal Detection in the DIMUS Array," J. Acoust. Soc. Am., 32, 871-877, 1960.

In the DIMUS system for steering an acoustic array, the output of each element is reduced to a sequence of polarity samples and delayed by an integral multiple of the sampling period. Calculations are given to show the effect of this process on the passive detection threshold of an array beam (in isotropic Gaussian noise) both generally and numerically for several examples. In these, over-all losses range from 0.5 to 1.5 db.

728

Sherwin, C. W., F. Kodman, and others, "Detection of Signals in Noise: A Comparison Between the Human Detector and an Electronic Detector," J. Acoust. Soc. Am., 28, 617-622, 1956.

The observer's responses to aural signals in noise are compared to the output of an electronic detection system whose constants are intended to be close to those of the human auditory detection system.

Of the four variations of an electronic detector tested, the best correlation between the detector and the observer occurred for signals of duration 0.3 second, bandpass 60 cps (single tuned RLC circuit), square law detector, output filter time constant 0.15 second.

The incomplete correlation between the signal responses of the observer and the detector can be explained by assuming either that the observer's threshold fluctuated randomly about a mean value with a dispersion of about 20% of the mean, or that there is internal noise with this dispersion generated inside the observer's detection system.

The observer's false alarms appear to be caused by noise fluctuations (as measured by the electronic detector) of the same average magnitude and dispersion as those calculated for a detector with the same threshold fluctuation. However, the observer's false-alarm rate is about an order or magnitude lower than that calculated for the fluctuating threshold detector; thus it is clear that the model is deficient in some important respects.

729

Slaymaker, F. H., and W. F. Meeker, "Blind Guidance by Ultrasonics," Electronics, 21, 76-80, 1948.

The limitations due to different reflection characteristics of various surfaces and objects and to fluctuations in reflection, when a portable "radar" system is employed, are discussed. Simple pulse, simple FM and pulsed-FM systems, all embodying separate transmitting and receiving magnetostriction transducers, are compared. The latter, which employs an ultrasonic oscillator with sawtooth variation of frequency but has narrow-band transducers, is considered the best because it introduces no contradictory information and permits some distinction between objects at different points. One model, operating at 32 kcs with 10 valves, mainly of the subminiature type, for transmitter and receiver and using headphones, enables the presence of a person to be detected at 30 feet. Later equipment is also described.

730

Smith, M., and R. Lambert, "Acoustical Signal Detection in Turbulent Airflow," J. Acoust. Soc. Am., 32, 858-866, 1960.

Imprbvement in detected signal-to-noise ratio is obtained for a periodic signal masked by additive noise and turbulent noise backgrounds. Comparisons are made between autocorrelation, cross correlation, and a combination of frequency filtering and cross correlation. Although the latter method provided the greatest improvement, the cross-correlation technique was the most successful single method. It turned out that the maximum improvement obtainable was limited by the dynamic range of the correlator-computer and not by errors due to finite averaging time and scanning the delay. The improvement for signals masked by turbulent noise was found to be about 5 db less than that obtained for additive noise.

731

Thomas, J. B., and T. R. Williams, "On the Detection of Signals in Nonstationary Noise by Product Arrays," J. Acoust. Soc. Am., 31, 453-462, 1959.

Two detection systems having multiple inputs each consisting of nonstationary noise and a stationary random signal are analyzed and compared on an s/n basis. In both systems the inputs are divided into two groups and the sum of each group is formed. In the first system the resulting two wave forms are multiplied directly and the product averaged. In the second system the two wave forms are strongly clipped prior to multiplication, forming a polarity-coincidence correlator. Previous studies have shown the latter system to be slightly inferior for stationary noise. The results of this paper show that the latter system may be quite superior in certain types of nonstationary noise.

732

Urick, R. J., and P. L. Stocklin, "A Simple Prediction Method for the Signal Detectability of Acoustic Systems," Rept. No. NOLTR 61-164., Naval Ordn. Lab., White Oak, Md., 18 pp., 1962.
AD-274 500.

A method is given for predicting the s/n to be expected for some simple receiving systems. The method relies heavily on the work of Peterson, Birdsall and Fox, and requires, as a starting point, a specification of detection and false-alarm probabilities as performance criteria. Some sonar examples are indicated, and the validity of the method is demonstrated by comparison with measured recognition differentials for the ear, and with measured detection thresholds for A-scan radar displays. For sinusoidal signals in Gaussian noise, the minimum achievable s/n is shown to be d/2T sub s, where d is determined by the selected probabilities and T sub s is the observation time. This minimum threshold deteriorates whenever the system requirements impose a deterioration of knowledge of the signal. It is clear that in general the only valid approach to improving the detection threshold is to improve the available knowledge concerning the signal and noise.

733

Webb, W. L., J. W. Coffman, and G. Q. Clark, "A High Altitude Acoustic Sensing System," Rept. No. 28, Missile Geophys. Div., U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 38 pp., 1959.
AD-230 726L.

Development of an acoustic sensing and telemetering system for use on constant altitude balloons is described. Evolution of the sensors, amplifiers, telemetry techniques, balloons and surface detectors are outlined and the optimum system thus far obtained is presented. Recording and processing techniques applied to the resultant data are enumerated and samples of the processed information are included. Development of the balloon platform used in this application is outlined.

734

Wescott, J. W., "Balloon-Borne Acoustic Surveillance Subsystem," Rept. No. 2144-126-T, Willow Run Lab., Univ. of Mich., Ann Arbor, 29 pp., 1959.
AD-224 111.

An acoustic surveillance subsystem employing balloons equipped with microphones, radio transmitters, and tracking beacons was developed and tested. Methods for improving subsystem performance are proposed. Balloons were launched, monitored, and tracked from a ground station. Acoustic surveillance was achieved over areas of 10 × 75 mile per balloon. Tracking accuracy was 0.5^{o} in azimuth and 0.5% in range. Redesigned components would extend the range to 100 miles. Multiple-balloon operation would increase surveillance-area coverage. Balloons launched from aircraft would provide surveillance from upwind areas.

The inherent silence of free-floating balloons permitted detection of faint sounds arriving from distant targets. Personnel who monitored and interpreted these sounds were successful in classifying such targets as trucks, tanks, railroad trains, and aircraft. Electronic analysis and reduction of data would improve target identification.

Subsystem security included capabilities for operation at night and in foul weather, miniaturization of airborne equipment to prevent detection by enemy radar, infrared, or optics, and utilization of narrow-beam antennas to minimize radio jamming.

Detection — see also Arrays; Echo Ranging; Sound Ranging; Signaling
See also — 391, 395, 396, 401, 402, 407, 419, 432, 435, 458, 537, 547, 548, 554, 612, 634, 640, 651, 652, 654, 655, 662, 665, 670, 678, 892, 1015, 1108, 1159, 1160, 1187, 1221, 1485, 1498, 1548, 1565, 1665, 1715, 1803, 1857, 1859, 2061, 2125, 2230, 2233, 2298, 2305, 2363, 2374, 2489, 2491, 2533, 2742, 2980, 3279, 3314, 3460, 3758, 4133.

DIFFRACTION

735

Alblas, J. B., "On the Diffraction of Sound Waves in a Heat-Conducting Viscous Medium," Proc. Koninkl. Ned. Akad. Wetenschap., 64, 350-367, 1961.

This paper considers the diffraction by an infinitely thin screen of a sound wave which propagates in a gas of finite viscosity and heat conductivity. The screen is assumed to have an infinite heat conductivity and the sound wave is incident normally on the screen. It is assumed that the disturbance is small and that the equations may be linearized. Fourier transforms are then employed to reduce the boundary value problem to the solution of three pairs of dual integral equations. One of these pairs is such that it is amenable to solution by Wiener-Hopf methods and a formal solution is obtained. The necessary factorization, however, is not such that it can be expressed in terms of known functions. The remaining integral equations are of the type associated with simultaneous Wiener-Hopf integral equations and are not amenable to exact solution in a closed form. An approximate iterative procedure is adopted and the first term in the iterative scheme evaluated. The question of the uniqueness of the solution is examined and it is shown that the approximate solution obtained satisfies all the boundary conditions except that on the tangential velocity on the screen. The author states that this slip velocity will be small everywhere and that it is not necessary to consider the next term in the iterative solution of the intergral equations.

736

Alblas, J. B., "On the Diffraction of Sound Waves in a Viscous Medium," Appl. Sci. Res., Sect. A, 6, 237-262, 1957.

The theory of the diffraction of a sound wave at a half-plane barrier is extended to the case of propagation in a viscous medium. It is shown that the singularity in the velocity near the edge of the barrier, a characteristic feature of the classical second-order theory, disappears. In the neighborhood of the edge the velocity attains its maximum, the value of which is determined by a reciprocal power of the viscosity. In the far field a viscous wave occurs, the amplitude of which is proportional to the square root of the viscosity, in contrast to the second-order theory, where the introduction of a viscosity gives rise to a linear dependence.

737

Barakat, R. G., "Transient Diffraction of Scalar Waves by a Fixed Sphere," J. Acoust. Soc. Am., 32, 61-66, 1960.

Diffraction from a fixed sphere is treated as an initial value problem rather than as a boundary value problem. Since only boundedness of the diffracted wave potential rather than the stronger Sommerfeld radiation condition is required, it is shown via use of the Laplace transform and complete inversion integral that the diffracted wave potential consists of the usual steady-state term plus transient terms. The magnitude of the transient terms are governed by $\beta = ka$, where a is the radius of the sphere and k is the wave number; however, the rate of decay is governed by the dimensionless decay parameter ωt. Both Dirichlet and Neumann boundary conditions are discussed in detail. Finally, the transient force on the sphere is computed in the Neumann case and the behavior examined for the long-wave ($\beta \ll 1$) and short-wave($\beta \gg 1$) approximations.

738

Bekefi, G., "Diffraction of Sound Waves by a Circular Aperture," J. Acoust. Soc. Am., 25, 205-211, 1953.

Diffraction of an acoustic wave by an aperture in a plane reflecting screen has been investigated experimentally at a wavelength of about 3 cm. The pressure amplitude distribution within a circular aperture illuminated by a plane, progressive sound wave exhibits oscillations which do not conform to theoretical requirements. A possible explanation for the disagreement is offered. Diffraction measurements made in the near-field of the circular hole were found to be in fair agreement with the Fresnel-Kirchhoff theory. A modified theoretical expression, valid for apertures large as compared to the wavelength, is also presented. It is concluded that this theory is capable of predicting the diffraction effects to a greater degree of accuracy and over a larger region of space than Kirchhoff's classical formula.

739

Brekhovskikh, L. M., "Diffraction of Sound Waves on an Uneven Surface," Dokl. Akad. Nauk, SSSR, 79, 585-588, 1955; Translated by E. R. Hope, Def. Sci. Infor. Ser., DRB Canada. T-164R
AD-64 763.

If the sum of incident and reflected plane waves at each point of the limit of the sound field is a sufficient basis for calculating ϕ and $\delta\phi/\delta n$, where n is the interior normal to the surfaces at such a limit, and if a shallow, regular ripple of a wavelength less than that of the sound-wave occurs at any considerable inequality on plane surfaces, then supplementary diffusion of sound will ensue. The theory can be generalized to apply equally to the case of electromagnetic waves.

740

Brickl, D. E., and W. Bleakney, "The Diffraction of a Shock Wave over a Three-Dimensional Object," Tech. Rept. No. II-14, Princeton Univ., N. J., 5 pp., 1953.
AD-13 660.

A method for partial solution to the problem of three-dimensional diffraction of shock waves is described. The method applies to any right cylinder and yields the pressure averaged along any generating line but no information concerning the forces on the end. The procedure consists of mounting one glass model of the object, whose end faces are polished to an optical finish, in the test section of the shock tube and mounting an identical model in the analogous position in the compensator of the interferometer so that the light rays are perpendicular to the end faces of the models. Diffraction pictures are taken in the usual manner for two-dimensional work, and a map constructed from the pictures shows contours of constant fringe shift. Analysis of the data obtained will give the distribution of the average change in density in the gas along the top surface of the model in the direction of the ray around the boundary of the object. A preliminary test appeared successful.

741

Bryson, A. E., and R. W. F. Gross, "Diffraction of Strong Shocks by Cones, Cylinders, and Spheres," J. Fluid Mech., 10, 1-16, 1961.

This paper presents experimental investigations of the diffraction of plane strong shocks by several cones, a cylinder, and a sphere. The diffraction pattern, in particular the loci of Mach triple points, and the shape of the diffracted shocks are compared with theoretical results obtained from a diffraction theory proposed by Whitham (1957, 1958, 1959). The agreement between theory and experiment is shown to be good. Also given are extensive numerical results supplementing Whitham's papers and theoretical considerations applying Whitham's theory to very blunt bodies.

742

Duff, R. E., and R. N. Hollyer, Jr., "The Diffraction of Shock Waves Through Obstacles with Various Openings in Their Front and Back Surfaces," Rept. 50-3, Engineering Res. Inst., Univ. of Mich., Ann Arbor, 54 pp., 1950.
ATI-94 435.

The results are presented of a photographic investigation of shock-wave diffraction through models with various openings in their front and back surfaces. A method for determining the strength shock waves by measurements of limiting Mach configurations is discussed.

743

Friedlander, F. G., "The Diffraction of Sound Pulses. III. Note on an Integral Occurring in the Theory of Diffraction by a Semi-Infinite Screen," Proc. Roy. Soc. (London), A, 186, 352-355, 1946.

The integral is

$$P(X, T) = \pi^{-1}X^{1/2}\int_0^T p_0(u)(T + X - u)^{-1}(T - u)^{-1/2}\,du$$

and complete expansions, for large and small X, are given. The magnitudes of the remainders are estimated. An expansion is also given which is valid when T and X are both small.

744

Friedlander, F. G., "The Diffraction of Sound Pulses, IV. On a Paradox in the Theory of Reflexion," Proc. Roy. Soc. (London), A, 186, 356-367, 1946.

A plane sound wave is reflected by an infinite plane reflector, and the "simple" theory indicates that the pressure at the reflector is double that of the incident wave, irrespective of the angle of incidence, θ. As $\theta \to 90^{\circ}$ the doubling persists; but there is no reflection and there should be no doubling of the pressure. To explain this paradox the simple theory is abandoned. The reflection of sound pulses by a semi-infinite screen is examined in detail and it is shown that as $\theta \to 90^{\circ}$ the diffracted pulse which emanates from the edge of the screen must also be considered, so that the region in which the simple approximate theory holds moves away from the edge. In the limit, the simple theory must be abandoned at all points at a finite distance from the edge. Reflection of sound pulses by infinite wedges is also considered.

745

Haskell, N. A., "Diffraction Effects in the Propagation of Compressional Waves in the Atmosphere," Geophys. Res. Papers, Air Force Cambridge Research Lab., Mass., 43 pp., 1950.
ATI-74 515.
See Also: Sci. Abstr., Sect. A, 1951.

Asymptotic methods are used to find approximate solutions of the acoustic wave equation in a medium where the velocity is a continuously variable function of one coordinate. It is shown that, when the velocity function has a minimum, undamped normal mode, solutions exist and that such solutions are closely analogous to the internally reflected waves in the case of a medium made up of discrete layers. By converting the sum of the high-order normal modes into an equivalent integral, it is shown that superposition of these modes leads to geometrical ray theory modified by diffraction in a manner that may be computed from the incomplete Fresnel and Airy integrals.

746

Heaps, H. S., "Diffraction of an Acoustical Wave Obliquely Incident upon a Circular Disk," J. Acoust. Soc. Am., 26, 707-708, 1954.

The calculated diffraction pattern behind a circular disk irradiated by an obliquely incident plane wave of sound is compared with that resulting from a normally incident wave. The total sound pressure received by a line receiver is tabulated in terms of its length and position along a certain line.

747

Horton, C. W., "On the Diffraction of a Plane Sound Wave by a Paraboloid of Revolution, II.," J. Acoust. Soc. Am., 25, 632-637, 1953.

For Part I, see Horton and Karal (J. Acoust. Soc. Am., 22, 855-856, 1950). Some numerical values have been computed for the functions which arise in connection with the scalar wave equation in rotational paraboloidal coordinates. Tables of these values are given, and with their aid the scattering of a plane sound wave by a rigid convex paraboloid of revolution is numerically analyzed. The surface of the paraboloid is defined by $k\xi_0 = 0.25$ and the direction of propagation of the plane wave makes an angle of 36.9° with the axis of symmetry of the paraboloid. The asymptotic expansions of the scattered waves are discussed, and their amplitudes are tabulated. The magnitude and phase angle of the total pressure are evaluated at points on the surface of the paraboloid.

748

Horton, C. W., and F. C. Karal, Jr., "On the Diffraction of a Plane Sound Wave by a Paraboloid of Revolution," J. Acoust. Soc. Am., 22, 855-856, 1950.

An infinite set of equations is obtained for the coefficients of the pressure fields inside of and outside of the paraboloid. For the particular case of a rigid paraboloid the coefficients of the series for the scattered field can be obtained explicitly. The ratio of the total pressure of the incident wave is shown as a function of the shape of the paraboloid for a plane wave whose wave front is perpendicular to the axis of revolution. The same quantity is plotted for the case of a sphere whose radius of curvature is equal to that of the paraboloid at the nose.

749

Kanevskii, I. N., "Analysis of the Diffraction of a Converging Cylindrical Wave by a Cylinder," Soviet Phys. Acoust., English Transl., 5, 152-157, 1959.

The cylinder is coaxial with the wave-front. An expression is obtained for the resulting field, as well as an asymptotic expression for the intensity of the scattered wave and the effective scattering cross-section. The present case is compared with scattering of a plane wave on a cylinder whose perimeter is small compared with the incident wavelength.

750

Karp, S. N., and W. E. Williams, "Equivalence Relations in Difference Theory," Proc. Cambridge Phil. Soc., 53, 683-690, 1957.

Certain equivalence relationships between different problems occurring in diffraction theory of acoustic and electromagnetic waves are established. The method used is essentially Schwarz's principle of analytic continuation by reflection across a straight boundary. An explicit solution is also obtained by this method for a plane wave normally incident on a T-shaped structure.

751

Keller, J. B., "A Geometrical Theory of Diffraction," Res. Rept. No. EM-115, Inst. of Math. Science, New York Univ., New York, 52 pp., 1958.
AD-152 454.

A geometrical theory of diffraction in homogeneous media is developed and applied to optics, although the results are equally applicable to acoustics. Explicit developments for cases such as plane waves striking solid edges or surfaces such as cylinders and cones are presented. A more general development based on an extension of Fermat's principle is also presented. The concept of diffracted wavefronts is introduced as a means for defining an eiconal or phase equation for determining these wavefronts.

752

Khaskind, M. D., "Diffraction and Radiation of Acoustic Waves in Fluids and Gases, I., "Soviet Phys. Acoust., English Transl., 3, 371-384, 1958.

A general theory is presented of the hydrodynamic forces acting on a body during the diffraction and emission of sound waves in liquids and gases. It is shown that the theory developed by the author some time ago (Zhur. Eksp. i Teoret. Fiz., 16, 634-46, 1946) is actually in close agreement with the theory of hydrodynamic forces and momenta in the diffraction problem.

753

Khaskind, M. D., "Diffraction and Radiation of Acoustic Waves in Fluids and Gases, II.," Soviet Phys. Acoust., English Transl., 4, 91-99, 1958.

For Part I, see preceding abstract. General equations are established in the quadratic approximation for the mean values of hydrodynamic forces and moments acting on a body during diffraction and emission of acoustic waves in liquids and gases. The general results are illustrated by concrete examples.

754

Kock, W. E., and F. K. Harvey, "Refracting Sound Waves," J. Acoust. Soc. Am., 21, 471-481, 1949.

Structures which refract and focus sound waves are described. They are similar in principle to certain recently developed electromagnetic wave lenses in that they consist of arrays of obstacles which are small compared to the wavelength. These obstacles increase the effective density of the medium and thus effect a reduced propagation velocity of sound waves passing through the array. This reduced velocity is synonymous with refractive power so that lenses and prisms can be designed. When the obstacles $\approx \lambda/2$ in size, the refractive index varies with wavelength, and prisms then cause a dispersion of the waves (sound spectrum analyzer). Path length delay type lenses for focusing sound waves are also described. A diverging lens is discussed which produces a more uniform angular distribution of high frequencies from a loudspeaker.

755

Levine, H., "Some Methods in the Theory of Diffraction at Short Wavelengths," Tech. Rept. No. ONRL-61-60, ONR, London, 9 pp., 1960.
AD-244 861L.

Some emendations and extensions of the Jones approach (Proc. Roy. Soc. A239, 338, 1957) are described for plane wave scattering by a circular cylinder, along with other techniques for allied problems.

756

Levine, H. "Variational Principles in Acoustic Diffraction Theory," J. Acoust. Soc. Am., 22, 48-55, 1950.

The diffraction of a plane harmonic sound wave by an aperture in an infinitely thin rigid plane screen is investigated theoretically. Variational principles for the diffracted spherical wave amplitude at large distances from the aperture are derived. In the first of these, the stationary property is exhibited for the class of functions comprising the normal derivative of the aperture velocity potentials, whose distributions are governed by a generally insolvable integral equation. The second involves functions which characterize the discontinuity in velocity potentials at the screen (or their deviation from infinite screen distributions) and are specified by another integral equation. A comparison of the two variational principles is given, which indicates that their overall agreement following use of approximate functions, is a measure of the accuracy obtained. The plane wave transmission cross section of the aperture is related to the imaginary part of the diffracted amplitude in the direction of incidence and is cast in stationary forms. Particular attention is given to the low and high frequency behavior of the various forms of cross-section, including comparison with Kirchhoff theory predictions.

757

Lighthill, M. J., "The Diffraction of Blast, I.," Proc. Roy. Soc. (London) A, 198, 454-470, 1949.

The behavior of a plane shock of any strength traveling along a wall, when it reaches a corner where the wall turns through a small angle δ, is investigated mathematically by use of a linearized theory of anisentropic flow. At a convex corner pure diffraction occurs; at a concave corner Mach reflection. The shape of the shock and the pressure distribution over the wall are calculated for a variety of shock Mach numbers from 1 to ∞. The connection for weak shocks with acoustic theory is displayed.

758

Lighthill, M. J., "The Diffraction of Blast, II.," Proc. Roy. Soc. (London) A, 200, 554-565, 1950.

The head-on encounter of a plane shock of any strength with a solid corner of angle $\pi - \delta$ is investigated mathematically, when δ is small, by a method similar to that of Part I.

759

Moore, W. C., "A Demonstration of Wave Fronts, Attenuation, and Diffraction," Am. J. Phys., 20, 61-64, 1952.

The concept of wave fronts, defined as points of like phase, can be demonstrated by the use of an audiofrequency oscillator, a loudspeaker, a microphone and a cathode-ray oscilloscope. The shapes of wave fronts radiated from plane, line, and point sources and the attenuation of intensity with distance can be qualitatively demonstrated. The double slit diffraction pattern can be explored as a function of the wavelength, slit spacing, and distance to the plane of observation in a simple arrangement of equipment.

760

Murty, J. S., "Theoretical Investigation on the Diffraction of Light by Superposed Ultrasonic Waves," J. Acoust. Soc. Am., 26, 970-974, 1954.

An analytical treatment for the calculation of intensities of diffraction orders in a general case of superposed sound waves of frequencies in the ratio of 1:n and having any phase difference Δ is given, proceeding from Raman and Nath's simplified theory for normal incidence. Because of the integral harmonic relationship between the frequencies of the sound waves superposed, a particular order may contain a number of combination ones in addition to the orders due to the individual sound waves. Fues theory, which gives a single expression for the intensity of a combination line, cannot be applied to this case.

Expressions are obtained for the intensities of the diffraction orders in the two specific cases of even and odd values of n. In the case of diffraction by two sound waves of frequencies of the ratio 1:2k + 1, expressions for the intensities of the orders suggest symmetry in diffraction for all values of Δ. But, when the superposed frequencies are in the ratio 1:2k, the expressions suggest asymmetry in diffraction for all values of $\lambda\Delta$, except $\pi/2$. When $\Delta = \pi/2$, the diffraction is, however, symmetrical.

By using the expressions, the intensities of the diffraction orders obtained by two sound waves of frequencies in the ratio 1:3 superposed in three different phases, 0, $\pi/2$, and π, are calculated for the values of $\nu_1 = 1$ and $\nu_3 = 1, 2,$ and 3.

761

Nomura, Y., and T. Osanai, "Diffraction of Plane Sound Wave by Many Equal Circular Holes Arbitrarily Distributed in an Infinitely Large Rigid Plane Plate," J. Phys. Soc. Japan, 16, 819-831, 1961.

The solution of the problem, when the holes do not overlap but are distributed arbitrarily in one plane, is obtained by the method of expansion in hypergeometrical polynomials. Formulae of some physical quantities concerned are given. In the case of normal incidence, approximate formulae are given which are valid when the wavelength is large in comparison with the radius.

762

Oberhettinger, F., "On the Diffraction and Reflection of Waves and Pulses by Wedges and Corners," Tech. Summary Rept. No. 15, Mathematics Research Center, Univ. of Wisconsin, Madison, 48 pp., 1957.
AD-156 733.

Various problems are considered which arise in the theory of the excitation of a perfectly reflecting wedge or corner by a plane, cylindrical, or spherical wave field. The incident cylindrical wave is represented by a (acoustic or electromagnetic) line source parallel to the edge. The spherical wave is emitted by an acoustic point source or by a Hertz dipole with its axis parallel to the edge. The case of an incident plane wave field is obtained as the limiting case (for large distance of the source from the edge) of the cylindrical or spherical wave excitation. Various representations for the time harmonic solution of the problems are given. A straightforward method is applied, based on the representation of the incident field in the form of a Kontorovich-Lebedev transform. The results obtained and the relations to geometric optics are discussed. An asymptotic expansion is given for the far field excited by the incidence of a plane wave on a wedge. Also given are the expressions for the energy radiated from a Hertz dipole in the presence of a perfectly reflecting wedge or corner (antenna and corner reflector), and the pulse or transient solutions corresponding to the time harmonic problems.

763

Papadopoulos, M., "Diffraction by a Refracting Wedge," Tech. Summary Rept. No. 297, Mathematics Research Center, Univ. of Wisconsin, Madison, 45 pp., 1962.
AD-275 795.

The refraction and scattering of acoustic plane waves following their arrival at the tip of a refracting wedge are examined. The scattered field contains not only plane waves reflected from the plane walls of the prisms but also the field diffracted at the sharp edge. It is not necessary to discuss the dominant refraction effects in any detail because they are so well known. The diffraction properties, however, are unknown. To understand these it is necessary to consider the mathematical difficulty of defining a normal derivative on the inside of an acute-angled wedge close to the vertex. It may be that the uniform use of the interaction conditions across the refracting surfaces at all distances from the vertex leads to no solution, and that the only well-set problem of this type may be one where the wedge has a rounded tip (as when the wedge is of hyperbolic section) with large curvature.

764

Papadopoulos, V. M., "The Diffraction of an Acoustic or Electromagnetic Pulse by a Resistive Half-Plane," Sci. Rept. No. AF 4561/6, Brown Univ., Providence, R. I., 35 pp., 1959.
AD-230 080.

The two-dimensional wave-diffraction problem, acoustic or electromagnetic, in which a pulse of step-function time dependence is diffracted by a resistive half-plane, is solved by assuming dynamic similarity in the solution.

765

Pridmore-Brown, D. C., and U. Ingard, "Tentative Method for Calculation of the Sound Field About a Source over Ground Considering Diffraction and Scattering into Shadow Zones," NACA TN 3779, Mass. Inst. of Tech., Cambridge, 1956.

A semiempirical method is given for the calculation of the sound field about a source over ground considering the effects of vertical temperature and wind gradients as well as scattering of sound by turbulence into shadow zones. The diffracted field in a wind-created shadow zone is analyzed theoretically in the two-dimensional case and is shown to be similar to the results obtained for a temperature-created shadow field as given in NACA TN 3494. The frequency and wind-velocity dependence of the scattered field into the shadow zone is estimated from Lighthill's theory, and on the basis of these two field contributions a semiempirical formula is constructed for the total field which contains two adjustable parameters. From this expression a set of charts has been prepared showing equal sound-pressure contours at 10 feet above ground for various source heights, wind velocities, and frequencies.

The two adjustable parameters in the formula were obtained from measurements using a relatively small source height (10 feet). The parameters should actually be a function of height determined by the wind and temperature profiles. However, in these preliminary calculations the parameters have been kept constant, and the fields, particularly for large source heights, must be considered as preliminary estimates to be corrected when more information is available.

766

Schmitt, H., "Diffraction of Electromagnetic Waves by Sound Waves," J. Acoust. Soc. Am., 33, 1288-1292, 1961.

For the diffraction of electromagnetic waves from a standing sound wave, the amplitudes of the first diffraction order are calculated from Born's approximation. If the wavelength of the electromagnetic signal is made comparable to the acoustic wavelength, the first diffraction order vanishes periodically with increasing width of the sound beam because of a destructive interference of scattered waves. The sound-perturbed medium becomes also slightly anisotropic. The diffraction of microwaves by a standing sound wave in oil is measured as a function of sound frequency and polarization of the electromagnetic wave.

767

Schoch, A., "Reflection, Refraction and Diffraction of Sound," Trans. by F. J. Berry, Ministry of Supply, Armament Research Establishment, 77 pp., 1953.
AD-116 801.

The present state of theory and experiment on the reflection, refraction, and diffraction of sound is very thoroughly presented in this book-length paper. After a brief introduction, the work begins with a comprehensive review of fundamentals including the dynamics of sound waves in homogeneous media, Huygens' Principle, boundary conditions, and uniqueness of solutions. The various situations involving reflection and refraction are then treated, including plane waves at a plane interface, free boundary layer waves along a plane interface, nonplanar waves at a plane interface, plates, and laminated media. Finally, diffraction is treated as phenomena resulting from the presence of curved boundaries. The diffracting properties of cylindrical, spherical, and more complex obstacle shapes are investigated. An extensive bibliography containing 144 references is included.

768

Seckler, B. D., and J. B. Keller, "Asymptotic Theory of Diffraction in Inhomogeneous Media," J. Acoust. Soc. Am., 31, 206-216, 1959.

Some boundary value problems are considered for the reduced wave equation in media having planar or cylindrical stratification. They are solved exactly and the solutions are expanded asymptotically for high frequencies by using the method of stationary phase in conjunction with the WKB method and the Watson transformation. The asymptotic expansions are compared with the corresponding diffracted fields found by using the geometrical theory described in the companion article, "Geometrical Theory of Diffraction in Inhomogeneous Media" (see Abstract 770). In all cases the asymptotic expansions agree completely with the corresponding results derived by the geometrical theory, thus verifying this theory.

769

Seckler, B. D., and J. B. Keller, "Diffraction in Inhomogeneous Media," Res. Rept. MME-7, Inst. of Math. Science, New York Univ., New York, 68 pp., 1957.
AD-155 157.

A geometric method is presented for finding the field in inhomogeneous media containing smooth convex bodies. The field due to a plane wave in an unbounded medium is constructed by introducing complex rays in the refraction shadow. Fermat's principle is extended to explain the occurrence of certain diffracted rays in the boundary problems. Then by modifying the law of conservation of energy, the field along the diffracted rays is obtained in addition to the field on the geometric lit region. Certain diffraction coefficients and decay exponents are introduced and general formulas are obtained for them. The theory is then applied to several problems in which the medium is plane or cylindrically stratified, and the boundary is planar or circular. Expressions are determined for the exact solution to various boundary problems corresponding to these special problems. Asymptotic forms are obtained by using the method of stationary phase in conjunction with the WKB method and Watson transformations. The geometrical theory is verified, at least in these cases. Two shorter articles based on this report are in J. Acoust. Soc. Am., 31, 192-205 and 206-216 (see Abstracts 768 and 770).

770

Seckler, B. D., and J. B. Keller, "Geometrical Theory of Diffraction in Inhomogeneous Media," J. Acoust. Soc. Am., 31, 192-205, 1959.

The geometrical theory of diffraction is described. It is used to to determine the diffracted fields in inhomogeneous media. Cases in which such media contain smooth convex bodies are treated. The theory employs an extension of Fermat's principle, which yields diffracted rays. The field associated with each ray is calculated by energy considerations. This requires the introduction of diffraction coefficients and decay exponents. General formulas for these quantities are given in terms of local properties of the medium and of the body.

771

Shenderov, E. L., "Diffraction of a Cylindrical Sound Wave by a Cylinder," Soviet Phys. Acoust., English Transl., 7, 293-296, 1962.

The diffraction of a cylindrical wave by a cylindrical obstacle whose axis is displaced relative to the axis of the wave is considered. By application of the theorem of addition by cylindrical functions expressions are derived for the scattered field and for the force acting on the scatterer from the direction of a zero order cylindrical wave and a general cylindrical wave. The results of a number of calculations of the scattered and complete sound fields are given. The results of some of the calculations are compared with the experimental data.

772

Sivian, L. J., and H. T. O'Neil, "Sound Diffraction by Various Shaped Screens," J. Acoust. Soc. Am., 3, 483-510, 1931-1932.

The author considers the diffraction produced by a circular and a square plate, and a semi-infinite screen, from both the experimental point of view and the theoretical. For the experiments, a point source of sound is used, sometimes in a lagged box and sometimes in the open air. Sound pressure measurements are made with a long narrow search tube connecting with a condenser transmitter. The sound pressure is measured on both sides of the diffracting screen for various azimuth angles, and curves are shown. An approximate theory is given, and theoretical and experimental results are compared graphically, from which it appears that discrepancies occur at the lower frequencies. The special case of a circular plate at the end of a long cylinder is also investigated. The theory of diffraction by a semi-infinite screen is discussed in detail and adapted to easy calculation. Several examples of its use are shown.

773

Tsoi, P. I., "Diffraction of Plane Sound Waves (Long) at a Toroid," Appl. Math. Mech., 25, 1146-1151, 1961.

This paper deals with a system of plane sound waves (long waves) moving in the direction x-negative and falling on a stationary toroid (of section radius a, the toroid radius being 1) whose axis of symmetry coincides with the x-axis of the Oxyz-coordinate system.

774

Tsoi, P. I., "Diffraction of (Short) Sound Waves at an Obstacle (Cylinder, Sphere, Cone and Plane)," Appl. Math. Mech., 25, 536-544, 1961.

In the theory of sound, the solution of different problems of diffraction of sound waves at an obstacle (plane, lattice, slot, cylinder, sphere, ellipsoid, etc.) are studied. The author applies the Poincare method, and presents a new solution to the problem.

775

Urusovskii, I. A., "Sound Diffraction at Periodically Uneven and Inhomogeneous Surfaces," Dokl. Akad. Nauk SSSR, 131, 801-804, 1960.

A theoretical treatment of the subject based on a Fourier transform method is given, and the spectrum of the diffracted waves is derived.

776

Wiener, F. M., "On the Relation Between the Sound Fields Radiated and Diffracted by Plane Obstacles," J. Acoust. Soc. Am., 23, 697-700, 1951.

In the past, acoustic diffraction and radiation problems have been treated separately, although their intimate connection is clear from theory. In the case of plane piston radiators and plane rigid scatterers exposed to a perpendicularly incident plane wave, this connection becomes particularly simple and useful. It is easy to show that the radiated sound field is everywhere the same as the field scattered (diffracted) except for a factor of proportionality. It is also shown that the reaction of the medium on the radiator, as expressed by the mechanical radiation impedance, is equal to the force per unit incident pressure exerted on the same obstacle held rigid as a scatterer, except for a factor of proportionality. By way of illustration, the foregoing principles are applied to the important case of the circular disk.

777

Williams, W. E., "Diffraction by a Disk," Proc. Roy. Soc. (London) A, 267, 77-87, 1962.

The problems of diffraction of sound waves by a perfectly "soft" and a perfectly rigid circular disk are studied. An arbitrary nonaxially symmetric wave is assumed to be incident on the disk. It is shown that both problems can be reduced to the solution of Fredholm integral equations of the second kind. The method of solution seems to be new and does not involve the solving of sets of simultaneous linear equations. The present approach may also be applied to the solution of other problems, such as the transmission of waves through circular holes in parallel screens. The kernels of the integral equations are reasonably elementary functions, and the equations are particularly suitable for obtaining iterative approximate solutions at low frequencies. The special case of an incident plane wave is considered in detail and expansions in powers of frequency × radius are obtained for the respective transmission coefficients.

778

Yildiz, M., and O. Mawardi, "On the Diffraction of Multipole Fields by a Semi-infinite Rigid Wedge," J. Acoust. Soc. Am., 32, 1685-1691, 1960.

A general expression has been derived for the evaluation of the pressure distribution, on the surface of a semi-infinite rigid wedge, due to a multipole point source. The derivation makes use of a Green's function constructed by means of spectral representations. The special cases of dipole and quadripole fields are worked out in detail.

Diffraction — see also Scattering
See also — 223, 269, 408, 478, 560, 581, 590, 612, 667, 975, 1302, 1385, 1390, 1391, 1398, 1401, 1404, 1464, 1560, 1791, 1808, 1810, 1881, 1937, 1965, 2048, 2063, 2174, 2187, 2188, 2220, 2222, 2586, 2592, 2728, 2820, 2944, 3132, 3298, 3329, 3403, 3455, 3555, 3566, 3686, 3691, 3706, 3817, 3974, 4181, 4308, 4312, 4397, 4401.

DIFFUSION

779

Antokolskii, M. L., "Reflection of Waves from a Rough Absolute Reflecting Surface" (in Russian), Dokl. Akad. Nauk SSSR, 62, 203-206, 1948.
ATI-137 914.

Experiments show that during the reflection of a lighter sound wave from a surface there exists not only a regularly reflected wave, but also a diffusion field created by the presence of surface roughness. Complete estimation of both diffusion and reflection fields is made only for the case where the surface roughnesses are small in comparison to the wavelength. This report refers to the regular reflection part of the field. The author determined the conditions at which this regular field has the nature of a normally reflected wave and computed the reflection coefficient in relation to the wavelength and angle of incidence. The transition from diffusion to regular reflection during a specific angle of incidence is a convenient means of determining the qualitative characteristics of a reflecting surface. The Kirchhoff law is the basic simplifying assumption in the calculation of surface characteristics.

780

Balachandran, C. G., "Random Sound Field in Reverberation Chambers," J. Acoust. Soc. Am., 31, 1319-1321, 1959.

A series of experiments were performed to compare the efficiency of different diffusing devices in producing a completely random sound field in a reverberation chamber, and the effectiveness of some of the methods for judging whether a sound field is completely random. An additional experiment was performed to compare two types of test signals — warble tone and the same nominal band width of random noise. Results of these measurements indicate the general superiority of the rotating vane over other diffusing devices and superiority of random noise over warble tone in producing a smooth decay curve. One of the significant conclusions is that, even when the diffusion is reasonably adequate, the measured absorption coefficient of a standard sample appears to vary with the chamber absorption especially at the high frequencies.

781

Campbell, A. J., "Investigation of a Wide Angle Diffuser with Air Augmentation for Use as a Jet Muffler," UTIA Tech. Rept. No. 15, Inst. of Aerophys., Univ. of Toronto, Canada, 11 pp., 1957.
AD-215 974

A wide angle diffuser for reducing the noise of a jet by taking advantage of the AV^8 law was combined with a short length augmentation system, which on a full scale muffler provides cooling air flow to the diffuser. A large reduction in velocity and a small cooling air flow were attained when screens were used to prevent separation of flow in the diffuser. The experimental results indicated that grids of rods or pipes (which could be cooled internally) also provide satisfactory resistance. The experiments indicated a pronounced noise augmentation when rods were used. A theory is developed for predicting qualitatively the induced air flow when a short mixing length is used. In the frequency bands, the noise level of the model was higher than that of the free jet. However, the main noise source was found to be inside the muffler. It is possible to reduce the muffler's output by aerodynamic means, and to decrease the radiated sound by acoustic treatment.

782

Cowling, T. G., "The Influence of Diffusion on the Propagation of Shock Waves," Phil. Mag., 33, 61-67, 1942.

It is shown that, in the propagation of shock waves through a gas-mixture, diffusion produces effects similar to those of viscosity and thermal conduction. If the mol. wts. of the two gases are not very different, the effects are small; when they are as widely different as those of hydrogen and oxygen, the diffusion effects are more important than those of thermal conduction and are comparable with those of viscosity. The velocities of diffusion involved are an appreciable fraction of the velocity of sound in the gas.

783

Furduev, V. V., "Survey of Methods for Evaluating and Measuring the Diffuseness of a Sound Field," Soviet Phys. Acoust., English Transl., 1, 312-326, 1957.

A general review of the topic discussing such matters as statistics of natural oscillations, frequency irregularity, directional diffuseness, diffuseness and clarity, and the role of the measuring signal.

784

Greenberg, O., H. Sen, and M. Treve, "Hydrodynamic Model of Diffusion Effects on Shock Structure in a Plasma," Geophysical Res. Papers No. 66, Air Force Cambridge Research Center, Bedford, Mass., 40 pp., 1960.
AD-234 383.

Diffusion effects on the structure of a steady, plane shock in a protonelectron plasma were studied using a simplified, two-fluid, hydrodynamic model in which diffusion is the only shock-broadening mechanism. Charge separations occur inside the shock because of the mass difference between protons and electrons. The shock is shown to have electric field and density oscillations as a functions of distance through the shock. The peak electric fields are large; the peak electric field inside a weak shock of Mach 1.169 reaches 41,700 v/cm for typical quiescent plasma conditions.

The distance in which electric field changes occur is of the order of the Debye length of the quiescent plasma. The present work is limited to shocks of Mach numbers less than 2.

785

Katsanis, D. J., "Diffusion in Expanding Electrically Neutral Gases with Large Pressure Gradients, Part III: Shock Tube Experiments," Memo Rept. No. M62-4-3, Pitman-Dunn Labs. Group, Frankford Arsenal, Philadelphia, 44 pp., 1962. AD-278 199.

An attempt was made to evaluate, by experiment, the accuracy of theoretical estimates of mass diffusion effects in the expansion of a binary mixture of gases in a shock tube. The results of calculations for mass diffusion effects on ideal shock tube flow of a binary compression chamber gas are compared with experimental data.

786

Kohler, M., "Sound Absorption in Mixtures of Monatomic Gases" (in German), Ann. Physik, 39, 209-225, 1941.

The influence of ordinary diffusion and thermal diffusion on sound absorption in monatomic gases is examined by the use of the Enskog equations. On the basis of the kinetic gas theory, the equations of motion are derived for the monatomic gas mixture. Nine independent equations are obtained for the 9 unknowns u_1, v_1, w_1, u_2, v_2, w_2; ρ_1 and ρ_2; and T. The propagation of density waves of infinitely small amplitude is considered. The three new terms due to diffusion depend on frequency and pressure, as do the Kirchhoff terms arising from friction and heat conduction, and they are fully discussed. The first term is due to the effect of ordinary diffusion and is proportional to the diffusion coefficient D_{12}, to $(M_2 - M_1)^2/M_0^2$ (M = mol. wt.), to the ratio c_p/c_v of the sp. hts. and to the product c_1c_2 of the mol. concentrations. The second is due to thermal diffusion and is proportional to (c_p/c_v) -1, to c_1c_2, to $(M_2 - M_1)/M_0$ and to a coefficient v_{12} which determines the thermal diffusion. The third is occasioned by the increased heat conduction due to thermal diffusion. The possibility of determining thermal-diffusion coefficients from measurements of sound absorption in gas mixtures is mentioned.

787

Konyukov, M. V., and Ya. P. Terletskii, "Electroacoustic Waves in a Gas Discharge Plasma with Consideration of Volume Recombination," Soviet Phys. JETP, English Transl., 2, 742-744, 1956.

This paper deals briefly with the theory of electroacoustic waves in a partially ionized gas, and in particular with the effects of volume recombination and diffusion to the discharge tube wall.

788

Kotin, L., "An Acoustic Model of Diffusion in Gases, I.," Mol. Phys., 4, 401-412, 1961.

Principles of macroscopic acoustic theory are applied to the calculation of the friction constant of a dilute gas of rigid spheres. In the model molecular motions are perturbed by acoustic disturbances arising from the occurrence of density fluctuations in the equilibrium fluid. The friction constant calculated is found to have the same parametric form but a substantially lower numerical coefficient when compared with the result of Chapman and Enskog.

789

Lebedeva, I. V., "Reverberation Chamber Techniques in the Measurement of Acoustic Absorption Coefficient," Soviet Phys. Acoust., English Transl., 8, 258-262, 1963.

An investigation of the sound absorption coefficient of the porous material "Silane" was conducted in line with the program of the International Standards Organization (ISO). The relationship between the measured sound absorption coefficient and the degree of diffuseness of the field, and the relationship between the sound absorption coefficient and the variation in the area presented by the specimen, were investigated. It is demonstrated that inadequate field diffuseness leads to absorption coefficient values which are too low at intermediate and high frequencies, from 300 cps up. Recommendations for achieving a proper degree of field diffuseness in a specific reverberation chamber are given.

790

Lyon, R. H., "On the Diffusion of Sound Waves in a Turbulent Atmosphere," J. Acoust. Soc. Am., 31, 1176-1182, 1959.

The directional and frequency diffusion of a plane monochromatic sound wave in statistically homogeneous, isotropic, and stationary turbulence is analyzed theoretically. The treatment is based on the diffusion equation for the energy density of sound waves, using the scattering cross section derived by Kraichnan for the type of turbulence assumed here. A form for the frequency wave number spectrum of the turbulence is adopted which contains some pertinent parameters of the flow and is adapted to ease of calculation. It is expected that the assumed spectrum is unrealistic at larger wave numbers. A new approach to the evaluation of the characteristic period of the flow is suggested. This spectrum is then related to the scattering cross section. Finally, a diffusion equation is derived as a small-angle scattering approximation to the rigorous transport equation. The rate of spread of the incident wave in frequency and direction is calculated, as well as the power spectrum and autocorrelation functions for the wave.

791

Paolini, E., "Absorption and Diffusion of Ultrasonic Energy," Alta Frequenza, 1, 357-375, 1932.

The emitter of ultrasonic energy is a silvered quartz plate maintained in piezoelectric vibration by an alternating frequency of 267 kc, and the receiver is a radiometer such as was used by Dvorak and by Poynting and Barlow for discovering radiant energy. The law of absorption, $p = p_0e^{-kx}$, is verified where p_0 is the pressure near the quartz, p is the pressure near the radiometer, x is the distance in cm, and k is the coefficient of absorption in cm^{-1}. Propagation is limited to the solid angle $0.37\pi^2\lambda_r^2$. Solid walls diffuse ultrasonic energy in proportion to their roughness and reflect it regularly if perfectly smooth.

792

Petralia, S., "Effects of Diffusion on the Absorption of Ultrasonics in Gas Mixtures" (in Italian), Nuovo Cimento (Ser. 10), 1, 351-354, 1955.

Continuation of the work described in Nuovo Cimento, 11, 570-571, 1954. Values of α/f^2 as a function of concentration for the mixtures He-Kr, He-Ne, Ne-A, A-Kr and Ne-Kr are shown graphically and tabulated. The values are compared with those calculated from Kohler's relation (Ann. Physik, 39, 209, 1941).

793

Schroeder, M. R., "Measurement of Sound Diffusion in Reverberation Chambers," J. Acoust. Soc. Am., 31, 1407-1414, 1959.

This paper describes a variety of methods for the measurement of the diffusion of sound fields in reverberation chambers. Diffusion is defined on the basis of the angular distribution of sound energy flux, in accordance with the definition that has found its visual expression in the "sound hedgehog" of Meyer and Thiele. The theoretical foundations of the methods proposed here are: normal mode expansion, the sampling theorem (both in time and two-dimensional space), and either Fourier or correlation analysis. The quantities to be measured are sound pressures and, in some cases, sound pressure gradients at a number of sampling points on the measuring wall. Results of these measurements are suitably transformed to give the sound energy fluxes for all possible angles of incidence. The accuracy of measurement is determined by the Q (frequency times reverberation time) of the chamber and is typically of the order of 1°. This extraordinary directivity is achieved without substantial perturbation of the sound field. Methods applicable to both single frequencies and finite frequency bands are described.

794

van Itterbeek, A., and W. de Rop, "Measurements on the Velocity of Sound in Air Under Pressures up to 20 ATM Combined with Thermal Diffusion," Appl. Sci. Res. A, 6, 21-28, 1956.

An acoustical interferometer has been constructed to measure the velocity of sound in gases under high pressures and low temperatures. Velocity measurements have been carried out down to the boiling point of liquid propane. During the measurements the influence of thermal diffusion could be observed. A few measurements are done by measuring the change of the velocity as a function of time.

795

Venzke, G., and P. Dammig, "Measurement of Diffuseness in Reverberation Chambers with Absorbing Material," J. Acoust. Soc. Am., 33, 1687-1689, 1961.

The angular distribution of sound traveling in a reverberation chamber in which a certain amount of absorbing material had been installed was measured during the decay phase of sound. Two methods were used: the first with a directional sound source and a nondirectional microphone, the second with a nondirectional source and a directional microphone developed in the PTB. In the latter case, the differences of angular distribution of sound impinging on the absorbing sample could be shown for two different states of diffuseness accomplished in the reverberation chamber by installing different numbers of diffusing elements in the room. The angular distributions were investigated at frequencies of 1.2 and 4 kc.

796

Wetzel, L., "Precursor Effects and Electron Diffusion from a Shock Front," Phys. Fluids, 5, 824-830, 1962.

Experiments disclosed electrical effects well ahead of an advancing shock front. Some of these were attributed to the diffusion of electrons through the shock front from the ionized region behind it. The diffusion hypothesis is examined in terms of a simple heuristic model, in which the diffusion is assumed to take place from a plane electron source moving with the shock velocity. According to this model, there is no true electron "front," as was suggested by some experiments with ionizing shocks. However, a transient in the electron distribution may give rise to a virtual front in certain experimental situations. Under reasonable assumptions, the existing observations of precursor fronts by Weymann are found to be consistent with the predictions of the model.

Diffusion — see also Absorption, Classical
see also — 18, 57, 65, 101, 120, 161, 247, 248, 254, 372, 599, 666, 739, 1585, 1602, 1908, 1965, 2080, 2081, 2090, 2091, 2107, 2174, 2587, 3613, 4077, 4280.

DISPERSION

797

Akasofu, S., "Dispersion Relation of Magneto-Hydrodynamic Waves in the Ionosphere and Its Application to the Shock Wave," Sci. Repts. Tohoku Univ., Fifth Ser., (Geophysics), 8, 24-40, 1956.

In this paper, the dispersion relation for longitudinal and transverse propagation of the magneto-hydrodynamic waves in full ionospheric conditions is obtained according to Schluter's momentum balance equation. Then a retarded sound-type shock wave is studied according to the conclusion given above. It is shown that some rapid varying irregular features of the h'-f curve on the ionograms, which have vertical and horizontal motion, may be attributed to a retarded sound-type shock wave.

798

Ankel, T., "Investigations on the Propagation of Signals in Dispersing Media with an Acoustic Model" (in German), Z. Physik. 144, 120-131, 1956.

The study is based on the theory of Sommerfeld and Brillouin on the propagation of a light signal of specific form through an optically dispersing medium. The theory is dicussed in detail. An acoustic model is constructed; it consists of a long tube to which a Helmholtz resonator can be applied. With this system the theory is tested. There is qualitative agreement with the theoretical prediction. Quantitative agreement is not to be anticipated.

799

Aris, R., "On the Dispersion of Linear Kinematic Waves," Proc. Roy Soc. (London)A, 245, 268-277, 1958.

In 1955 Lighthill and Whitham (Proc. Roy. Soc. (London)A, 229, 281, 318, 1955) drew attention to a class of wave motion which arises from the equation of continuity of a flow q and a concentration k and a functional relation between q and k. In contrast to the motions governed by the classical wave equation these are called kinematic waves (the movements of floods and traffic are examples). The theory of kinematic waves is taken up here for the case when the concentration k and flow q are related by a series of linear equations. If the initial disturbance is hump-like, the resulting kinematic wave can be usefully described by the growth of its mean and variance, the former moving with the kinematic wave velocity and the latter increasing proportionally to the distance travelled. Conditions for these moments to be calculated from the Laplace transform of the solution, without the need of inversion, are obtained, and it is shown that for a large class of waves the ultimate wave form is Gaussian. The power of the method is shown in the analysis of a kinematic temperature wave, where the Laplace transform of the solution cannot be inverted.

800

Brekhovskikh, L. M., "Dispersion Equation for Normal Waves in Laminar Media," Soviet Phys. Acoust., English Transl., 2, 362-374, 1956.

A simple means is indicated for obtaining the dispersion equation for waves in such media and a number of particular cases examined. This is a theoretical paper.

801

Brout, R., "Thermal Relaxation in Gases," J. Chem. Phys., 22, 1500-1502, 1954.

The solution of the linearized equations appropriate for sound dispersion is presented. The limiting cases as the sound frequency becomes large or small are examined. The two-state gas is exhibited as a special case and shown to be equivalent to previous work in the field when the appropriate assumptions are made.

802

Connor, J. V., "Ultrasonic Dispersion in Oxygen," J. Acoust. Soc. Am., 30, 297-300, 1958.

The velocity of ultrasonic waves in oxygen was measured at 40.6°C and 2 Mcs, with pressures ranging from one atm. to 0.35 cm Hg. Velocity dispersion was found at the lower pressures and is accounted for in part by rotational relaxation and at the lower pressures by the onset of the Stokes type of dispersion. The midpoint of the dispersion curve lies at 122 Mcs per atm, which corresponds to a relaxation time of 21.76×10^{-10} sec and to 13 as the average number of collisions necessary for the energy exchange. Consideration of the added translational dispersion effect establishes 12 as the average rotational collision number. A Hubbard-type sonic interferometer was used together with a strip recorder, several different tuning techniques being employed at the lowest pressures.

803

Cox, E. F., "Subsonic Frequency Dispersion in the Upper Atmosphere," J. Acoust. Soc. Am., 20, 549, 1948.

Abstract of paper read at Los Angeles meeting, December 1947. Discussion of abnormal sound data from Helgoland blast 1947.

804

Delsasso, L. P., "Attenuation and Dispersion of Sound by Solid Particles Suspended in a Gas," Univ. of Calif., Los Angeles, 36 pp., 1957.
AD-144 065.

Measurements were made on audio frequency sounds propogating through a gaseous medium containing small solid particles in suspension. Two effects measured were attenuation and dispersion of sound in the dust-filled gas. The measurements were made by sending a short train of sine waves through the dust-filled gas and observing the changes produced in the transmitted sine burst. The velocity shift caused by the suspended dust was determined by the changes in arrival time of the short train of waves. Changes in height of the received sine burst provided a measure of the attenuation. The particles were suspended in air, argon, oxygen, and helium gases. The measured attenuation has been compared with existing theory and found to agree within experimental error. The theory takes into account viscous and thermal losses brought about when particles are present. A theory for the corresponding dispersion is presented. This predicts the change in velocity produced by an alteration of the heat capacity and density of the gas when filled with dust particles. The attenuation dispersion results are shown.

805

Dwyer, R. J., "Persistence of Molecular Vibration in Collisions," J. Chem. Phys., 7, 40-44, 1939.

The dispersion of sound is theoretically interpreted by the idea that the exchange of energy in collisions between molecular translation and rotation on one side and vibration on the other side is much slower than, for example, between the various translational degrees of freedom. It seemed desirable to find a direct optical method of observing this hypothetical effect. Apparatus has been developed for the purpose of investigating molecules present in very small concentration, like radicals, by their absorption spectra; with this method, relative concentrations of molecules are determined by comparing intensities of certain rotational lines. This test was applied to the higher vibrational levels of the I_2 molecule. Their concentration was artificially increased beyond the small amount present in thermal equilibrium by an electric discharge of brief duration. By varying the phase between an electric switch and optical shutter, snapshots of the absorption spectrum could be taken at different intervals after the discharge was interrupted. The result was that I_2 molecules raised from the ground level to the first excited vibrational level are able to persist in this level through several thousand collisions with other I_2 molecules before losing their vibration.

806

Ener, C., A. F. Gabrysh, and J. C. Hubbard, "Ultrasonic Velocity, Dispersion, and Absorption in Dry, CO_2-Free Air," J. Acoust. Soc. Am., 24, 474-477, 1952.

The velocity dispersion and absorption of ultrasonic waves in dry, CO_2-free air were measured at 32°C, at 2 and 3 Mcs, at pressures ranging from 0.020 to one atm. Dispersion of the velocity was found beginning at 30 Mc/atm, increasing by 5% at 100 Mc/atm, accompanied by a large increase in absorption such that, at the higher limits of f/p reached, measurements became nearly impossible with the equipment used. The ratio $\alpha_{exp}/\alpha_{class}$ decreased from about 2.4 to 1.3, and C_v/R decreased from 2.5 to nearly 1.5 as f/p increased. The changes in velocity, absorption and internal specific heat are interpreted as the result of the slowing of energy exchange between translational and rotational states. Assuming that relations for relaxation of translational-vibrational exchange also hold for this case, the relaxation time for translational-rotational exchange as derived from the dispersion measurements has been found to be 2.29×10^{-9} sec. This corresponds to a frequency of the midpoint of the dispersion curve of 116 Mc/atm, and to 16 as the number per molecule of collisions required for an energy exchange between translational and rotational states. Absorption results were more difficult to secure; by using low frequency values, a relaxation time of about 3×10^{-9} sec was indicated, giving 87 Mc/atm as the f/p value of the midpoint of the dispersion curve, and 21 as the number of collisions required for the energy exchange.

807

Eucken, A., and E. Numann, "Excitation of Intramolecular Vibrations in Gases and Gas Mixtures by Collisions, Part IV," Z. Physik. Chem., 36, 163-183, 1937.

Measurements of the dispersion and absorption of sound were made in pure CO_2 and N_2O at temperatures up to 400°C. In these substances, and also when He and H_2O are added to them, the valency vibrations are excited as easily as the deformation vibrations. This effect is supposedly due not to a simple equality of sensitiveness to impact, but to a very rapid adjustment of equilibrium of the energy in the two forms of vibration. In CO_2 the mean number of collisions passes through a minimum value as the temperature rises, whereas in N_2O there is a continuous increase in this number. An explanation of this is suggested.

808

Eucken, A., and H. Jaacks, "Excitation of Intramolecular Vibrations in Gases and Gas Mixtures by Collisions, Based on Measurements of Sound Dispersion, Part III," Z. Physik. Chem., B, 30, 85-112, 1935.

Continuation of a research on the exchange of translational and vibrational energy in N_2O pure and with additions of other gases. The ultrasonic method was employed between -60^{o} and $200^{o}C$, and between 1/3 and 1 atm. pressure. N_2O is deactivated by its own molecules and by those of NH_2, in the same way as CO_2 is deactivated by H_2. A considerable difference between the gases consists in the effect, brought out when investigating the dependence of the heat of vibration on temperature, that on addition of H_2 the valence vibration of N_2O is comparatively strongly excited. Measurement of the collision exchanges of H_2, D_2, and He as added gases indicated the possibility of formulating more precisely the difference between the physical and chemical modes of excitation by collision.

809

Eucken, A., and L. Kuchler, "Excitation of Molecular Vibrations by Collision," Z. Tech. Phys. 19, 517-521, 1938.

It is recalled that from measurements of the dispersion of hf sound in gases the number of collisions which result in a transition of vibrational energy to translational energy can be obtained. Earlier determinations of this collision number Z^* in different pure gases and gas mixtures are tabulated. The authors' determinations of Z^* for CO_2 and N_2O with admixtures of other gases are given for temperatures of 293 and $673^{o}K$. A qualitative explanation of these results is given by means of a theory involving the potential curves of the molecules.

810

Eucken, A., and R. Becker, "Excitation of Intramolecular Vibrations in Gases and Gas Mixtures by Collisions, Based on Measurements of Sound Dispersion," Z. Physik, Chem., B, 27, 219-262, 1934.

The paper is in two parts. The first part describes an apparatus for measuring ultrasonic wavelengths, based on the principle of the acoustic interferometer described by Pierce. The apparatus can also be used in investigating chemically active gases within a temperature range of several hundred degrees. Certain difficulties dealt are those which arise when frequencies of the order of 50 kcs are used. The method of calculation is described by which the values of C_p/C_v at zero pressure for the pure components of a gaseous mixture are determined from the speed of sound in the mixture at a given pressure. In the second part, results are given for the speed of sound and the value of C_p/C_v for Cl_2 and CO_2 for frequencies 58, 145, and 292 kcs. It is deduced that the number of collisions required to withdraw a quantum of energy from the pure gases CO_2 and Cl_2 is 51,000 and 34,000, respectively, at room temperature. Under certain conditions these numbers may be greatly reduced. The effect of temperature is such that a rise from -32^{o} to $+145^{o}$ causes a sevenfold increase in pure Cl_2, a fourfold one in CO_2, and a fivefold one in Cl_2 containing CO. A formula was derived theoretically and was found to agree with experiment, according to which the number of impacts required for the release of one quantum is proportional to $1/T^n$ where n is a number depending on two molecular factors.

811

Eucken, A., S. Aybar, and K. Schafer, "Excitation of Intra-Molecular Vibrations in Gases and Gas Mixtures, VI., Sound-Absorption and Dispersion Measurements on CH_4, COS and Their Mixtures with Other Gases (Eucken and Aybar), VII., Theory of Sound Dispersion in the Presence of Several Normal Vibration (Schafer)" (in German), Z. Physik. Chem. B, 46, 195-228, 1940.

The average time required for the exchange of translational and vibrational energy is investigated between 20^{o} and $400^{o}C$ by the method of sound absorption and dispersion. The results of previous investigations with other gases (Kuchler, Z. Physik. Chem. B, 41, 199-214, 1938) are confirmed: there is no indication of different relaxation times for the single vibrations, a uniform period of adjustment holds for the total heat of vibration, and the additional gases are the more effective the easier they react with the main gas. A higher percentage of additional gas was investigated. A corrected formula for determining the average relaxation time is given. The inert gases are generally more effective than the main gas although less so than chemically active gases. Previous theories of sound dispersion (Rutgers and Kneser, Ann. Physik, 16, 350-361, 1933) were based on the presence of only one normal vibration. The author investigates the case of several vibrations excited simultaneously. Similar dispersion curves are obtained, as in the case of only one normal vibration. From the slight deviation of the experimental dispersion curves from standard type, the ratio of the relaxation times for single normal vibrations may be determined. The necessary equations are derived and an example of the application of the theory is given. The theory provides an explanation of the anomalous temperature coefficients of the relaxation times different from that of other investigators (Eucken and Kuchler, Z. Tech. Phys., 19, 517-521, 1938).

812

Ginsburg, V. L., "Concerning the General Relationship Between Absorption and Dispersion of Sound Waves," Soviet Phys. Acoust., English transl., 1957, 1, 32-41.

This same topic is discussed first in application to the propagation of electromagnetic waves and results known previously are obtained. Next analogous formulas connecting velocity and sound absorption coefficient are derived. Lastly the peculiarities distinguishing the acoustic case from the electromagnetic are discussed.

813

Greenspan, M., "Combined Translational and Relaxational Dispersion of Sound in Gases," J. Acoust. Soc. Am., 26, 70-73, 1954.

It is shown that for a special value of the Prandtl number the Stokes-Kirchhoff equation governing the propagation of sound in a fluid is factorizable even for complex values of the heat conductivity and specific heats. A solution allowing for the dispersion due to both translational and thermal relaxation is thus obtained in simple form for this special case, which, however, is representative of many gases with considerable accuracy.

814

Griffith, W., "Vibrational Relaxation Times in Gases," J. Appl. Phys., 21, 1319-1325, 1950.

Relaxation times for 17 gases have been measured by using a steady-flow method, the velocity field found numerically by Southwell's relaxation method. Where a comparison is possible the results are found to agree well with sound dispersion data. The present state of knowledge about relaxation effects is discussed and a few instances of their possible appearance are cited.

815

Gutowski, F. A., "Ultrasonic Dispersion in a CO_2-H_2O Mixture," J. Acoust. Soc. Am., 28, 478-483, 1956.

The velocity of ultrasonic waves was measured in CO_2 containing 0.01 mole of water vapor at frequencies of 1001.8 kcs and 540.6 kcs in the range from 0.5 Mcs per atm. to 6 Mcs per atm. at $35.1^{o}C$. The mixture was prepared at one fixed CO_2 and H_2O

pressure to give greater assurance of constant composition and was analyzed for water content by gravimetry. Variation of pressure within the interferometer was obtained by varying the rate of flow with a precision needle valve. Complete symmetry of current peak structure and, hence, a more accurate determination of wavelength were obtained by the technique of continually compensating for frequency shift due to the variation of acoustic impedance of the gas column. The velocity was found to vary from 286.2 m/sec at 6 Mcs per atm. to 278.1 m/sec at 0.5 Mcs per atm. The experimental points fit the curve for a single relaxation time of 3.03×10^{-7} sec, corresponding to an inflection frequency of 740 kcs per atm.

816

Herzfeld, K. F., and T. A. Litovitz, "Absorption and Dispersion of Ultrasonic Waves," Academic Press, Inc., New York, 535 pp., 1959.

The text is divided into three roughly equal parts: A, the general theory of relaxation in fluids; B, gases; and C, liquids.

Part A begins from the Stokes-Navier equation of hydrodynamics, kinetic theory, and statistics. This part constitutes the mathematical formulation of the macroscopic aspects of the phenomena of absorption and dispersion, and is largely formal in character.

The parts devoted to gases and to liquids follow the same pattern: application of Part A to the particular state; a brief discussion of the appropriate methods of measurements; a summary of experimental results; and, finally, an attempt to survey the studies of the physical origins of the processes formally described in Part A. In many respects, those latter sections of Parts B and C are the most interesting portions of the book.

817

Huetz-Aubert, M., and J. Huetz, "Ultrasonic Absorption and Dispersion in Monatomic Gases: The Three Sources of Classical Irreversibility" (in French), J. Phys. Radium, 20, 7-15, 1959.

The study of dispersion and absorption effects, so called "classical effects" or effects of translation, since they affect the molecular degrees of freedom, is most useful for separating the global effects which are the only ones accessible to experiment, from those which are due to intramolecular relaxation. As this latter cannot affect the behavior of monatomic gases, the experimental control is easier if it is confined to these gases. Viscosity and conduction are the most important classical effects, but radiation leads to dispersion and absorption equations identical to those which are found by relaxation. Thus, irreversibiltiy does not essentially differ according to its inter- or intramolecular origin. It can be concluded that the theory of effects of translational absorption and dispersion is verified.

818

Isakovich, M. A., "Wave Dispersion from a Randomly Uneven Surface," Transl. No. T-112-R, Translated by E. R. Hope, Defence Scientific Information Service (Canada), 15 pp., 1954. AD-50 279.

A method is proposed for calculating the mean values of the intensity and of the fluctuation of waves scattered from a rough surface, with irregularities which are large as compared with the wavelength. The method is applicable both to the acoustic and to the electromagnetic case.

819

Kneser, H. O., "Theory of Dispersion of Sound and Dispersion of H. F. Sound-Waves in Carbon Dioxide," Ann. Physik, 11, 761-801; and 12, 1015-1016 (1932), 1931.

When a disturbance takes place in a gas, as during an adiabatic compression, a certain very small interval of time elapses before equilibrium of the external and internal energies is restored. The period of readjustment is determined by the life of the energy quantum and is accompanied by an increase in the speed of sound. With certain assumptions as to the exchange of quanta of energy during the collisions of molecules, a dispersion equation is derived for the propagation of sound in a gas. It contains one thermodynamically indeterminate term, namely, the life-period of the exciting energy. In the second paper the experimental measurements are described. The method adopted was that of Pierce. By the use of quartz oscillators with frequencies from 60,930 to 1,480,000, the speed of sound in CO_2 was measured relative to that in A. In the frequency range 10^5 to 6×10^5, the speed increases by 3.7%, and again becomes constant at a frequency of 12×10^5. There is good agreement between theory and experiment, if vibrational energy is taken in place of rotational energy. The life of the vibration quanta is calculated as $(1.0 \pm 1.2)10^{-5}$ sec. Other gases are being investigated.

820

Kneser, H. O., and J. Zuhlke, "Period of Adjustment of Vibrational Energy in CO_2 and N_2O," Z. Physik, 77, 649-652, 1932.

Sound dispersion occurring in N_2O is similar to that observed in CO_2 and is in quantitative agreement with the assumption that the period of adjustment of the heat of vibration is of the order of 10^{-6} sec and, hence, is comparable with the period of the sound vibrations. It may be derived from the dispersion curve of N_2O that the part of the heat of vibration which is caused by transversal deformation of the molecule is alone responsible for the dispersion.

821

Knotzel, H., and L. Knotzel, "Absorption and Dispersion of Sound in Oxygen" (in German), Ann. Physik, 2, 393-403, 1948.

For the frequency range 0.6-4.5 kcs the velocity of sound in O_2 contained in a tube was determined by comparing the resonant frequencies with those obtained with the tube full of dry air free from CO_2. The tests were made at 19°C and at atmospheric pressure. The resonant frequencies for the range from the fundamental up to the 12th harmonic wave were determined and the bandwidths giving 1/2 maximum amplitude were used to compute the absorption coefficients. Absorptions were measured for pure O_2 and O_2 diluted with small amounts of H_2O vapor or NH_3. Definite relations were established between the frequencies giving maximum absorption and the H_2O and NH_3 contents. The precise dispersion measurements agreed well with the theoretical values based on thermodynamics.

822

Kohler, M., "Dispersion of Sound in Rarefied Gases" (in German), Abhandl. Braunschweig. Wiss. Ges., 2, 104-108, 1950.

Dispersion of sound in rarefied monoatomic gases is calculated from a kinetical point of view by using the approximation of Burnett-Chapman. The resulting dispersion effect is greater by about 50%-70% than the hydrodynamical dispersion by viscosity and conduction of heat. This effect, in agreement with similar considerations of Wang Chang and Uhlenbeck, is only slightly sensitive to changes of the model of molecule.

823

Krasil'nikov, V. A., and V. I. Tatarskii, "Dispersion of Sound in Turbulent Flow" (in Russian), Dokl. Akad. Nauk SSSR, 90, 159-162, 1953.
Translation available: U. S. Natl. Sci. Found., NSF-tr-121.

On the assumptions that (1) a turbulent flow can be described by the equations of motion of an incompressible viscous fluid, (2) in an incompressible fluid, the dispersions by temperature irregularities and velocity fluctuations, respectively, are independent, and (3) the fluctuations of the velocity of flow v are considerably smaller than the speed of sound c in the medium, it is shown that the wave equation of sound in the moving medium, neglecting acceleration, can be reduced to $\Delta\psi - \partial^2\psi/c^2\partial t^2 = 2v\partial^2\psi/c^2\partial x_i\partial t$, where ψ is the potential function of the sound field. This equation is solved by the method of successive approximations. Expressions are derived for the effective range of sound dispersion in the solid angle of $d\Omega$ per unit of distance travelled by the incident sound wave and for the dispersion coefficient. The coefficient of "backward dispersion" is constant at high frequencies. It is possible that the dispersion of sound by the acceleration field may afford a better explanation of the damping of infrasonic sound waves in the atmosphere than that afforded by the present theory of dispersion due to viscosity and thermal conductivity.

824

Kuchler, L., "Excitation of Intramolecular Vibrations in Gases and Gas Mixtures by Collisions, Part V," Z. Physik. Chem., 41, Abt. B, 3, 199-214, 1938.

Measurements of sound dispersion were made by a method previously described in CO_2, CO_2-He, CO_2-H_2, and N_2O-He, at different frequencies, pressures and concentrations, and at temperatures between 20° and 400°C. It was again noted that a uniform period of adjustment holds for the total heat of vibration. With rise of temperature the number of collisions diminishes in CO_2-He, but is practically constant in CO_2-H and in N_2O-He. A parallel is shown to hold between the total number of collisions and the gross dependence of this on temperature.

825

Landau, L., and E. Teller, "Theory of Sound Dispersion" (in German), Physik. Z. Sowjetunion, 10, 34-43, 1936.

It is shown that the sound dispersion at temperatures which suffice for the excitation of several vibration quanta is given by the same formula as sound dispersion at temperatures where, at most, one vibration quantum is excited. Investigation is also made of the delivery of vibration energy in its dependence on the molecular velocity. Thus, it is established that only great velocities play a part, with which the pehnomenon proceeds classically. The dependence on temperature of the effect is determined.

826

Levin, M. L., "On the Dispersion of Sound in a Slightly Non-Homogeneous Medium" (in Russian), Zh. Tekhn. Fiz., 21, 937-939, 1951.

The author points out that the theory of sound propagation developed by Rayleigh in paragraph 296 of his Theory of Sound could not be applied to a nonhomogeneous medium because it omits the last term in the continuity equation $\partial\rho/\partial t + \rho \operatorname{div} \vec{v} + \vec{v}\nabla\rho' = 0$, where ρ is the density of the medium, ρ' is a small variation of ρ, and $\vec{v}$ is the velocity of the medium at a given point; and, furthermore, because in the Euler equation $\partial\vec{v}/\partial t = -(\nabla p')/\rho$, where p' is a small variation of the pressure, it assumes that p is proportional to the compression at a given point (the "local" compression) while in actual fact it should be proportional to the compression in a given portion of the moving medium (the "material compression") which differs from the former in a nonhomogeneous medium. The author then gives a wave equation and its solution for a slightly nonhomogeneous medium, and shows that the solution given by Rayleigh is a particular case of this more general solution.

827

Meixner, J., "Absorption and Dispersion of Sound in Gases with Chemically Reacting and Excitable Components, I." (in German), Ann. Physik, 5, 43, 470-478, 1943.

The absorption and dispersion of sound in ideal gases of any composition is mathematically investigated; the component gases may consist of chemically reacting or excited molecules. The irreversible processes of internal friction, heat conduction, diffusion, chemical reaction, and excitation each contribute to the absorption and dispersion. The contributions are not simply additive, however, but are inter-related. The relation between sound absorption and local entropy and energy dissipation is investigated for the case of high frequency and low transformation velocity.

828

Metter, I. M., "Probability of Transfer of Vibration Energy in Collisions of CO_2 Molecules With Other Molecules" (in German), Physik. Z. Sowjetunion, 12, 233-234, 1937.

The dispersion of ultrasonic waves in CO_2 and in mixtures of CO_2 with H_2O, CO, NO_2, and N_2 is measured; from this it is possible to deduce how many collisions are required on the average in each case to transfer vibration energy into translation energy and vice versa. The results are correlated with the dipole moments of the molecules and with the energy balance of the reaction that can take place between the colliding molecules. It is found that both the dipole moment and the possibility of a reaction are of great importance for the probability of energy transfer.

829

Mokhtar, M., and E. G. Richardson, "Supersonic Dispersion in Gases, II. Air Containing Water Vapor," Proc. Roy. Soc. (London) A, 184, 117-128, 1945.

The apparatus and method of measurement are described. Curves are given showing the variation, at various frequencies, of the supersonic absorption coefficient μ and the supersonic velocity with the water vapor pressure. The results deduced are: (1) the velocity in dry air is independent of frequency; (2) the measured values for μ in dry air are several times larger than those calculated from the Stokes-Kirchhoff formula and indicate an approximately linear dependence on the frequency; (3) in humid air μ reaches a maximum, two or three times its value in dry air, at a vapor pressure which decreases as the frequency increases; (4) the maximum of dispersion in velocity decreases as the frequency increases.

830

Nomoto, O., "Phenomenological Theory of the Molecular Absorption and Dispersion of Sound in Fluids and the Relation Between the Relaxation Time of the Internal Energy and the Relaxation Time of the Internal Specific Heat," J. Phys. Soc. Japan, 12, 85-99, 1957.

Molecular absorption and dispersion formulae applicable to both liquids and gases have been derived in a phenomenological manner. It is pointed out that the relaxation time of the molecular internal energy γ must be distinguished from the relaxation time of the internal specific heat β, and the relation between these two quantities is discussed in detail. The relaxation time γ has the advantage of making the dispersion formula simpler and directly comparable with the dispersion formulae in other cases, such as the relaxation of shear viscosity. The relaxation time β on the other hand, is more closely related to the collision excitation probability of the molecules than γ.

831

Olson, J. R., R. R. Boade, and S. Legvold, "Electric Field Effect on Sound Dispersion," J. Chem. Phys., 36, 2233, 1962.

A brief report of an attempt to influence the vibrational relaxation of heavy polar gases by applying an electric field of up to 9 kv/cm in the hope of producing partial alignment of the molecules; a null result was always obtained.

832

Oswatitsch, K., "The Dispersion and Absorption of Sound in Clouds," Physik Z., 42, 365-378, 1941.

A theoretical investigation of the effect on the propagation of sound of the condensation or evaporation of water drops suspended in the atmosphere. At sufficiently low sound frequencies, condensation or evaporation of water vapour in clouds or fog can occur in appreciable quantity, leading to absorption and dispersion phenomena. Whereas in clouds the dispersion region is always below the range of human audibility, in clouds laden with small drops of water the absorption region extends into the range of the deep audible tones in agreement with the known strong absorption of thunder.

833

Pekeris, C. L., "Propagation of Sound in a Rarefied Maxwellian Gas," Inst. of Geophysics, Univ. of Calif., Los Angeles, 7 pp., 1953.
AD-23 611.

A study was made of the dispersion and attenuation of sound in a monoatomic gas with a density for which the mean free path is comparable to or exceeds the wave length of sound. The data on the propagation of sound in He at pressures of 1 mm and less required the solution of Boltzmann's complete transfer equation. Secular determinants of order 5, 8, 12, and 20 were evaluated in an effort to determine the phase velocity and attenuation coefficient. For each determinant order, the propagation constants were solved from the polynomial of the same degree representing the determinant; the polynomial roots were determined numerically. The results appeared to show that with a determinant of order 20, the computed values for the propagation constants is reliable for R greater than about three, where R is proportional to λ/L, the ratio of the wave length of sound to the mean free path. Graphical results are included for the determinant of order eight. Calculations are in progress for the determinant of order 30.

834

Penman, H. L., "Effect of Temperature on Supersonic Dispersion in Gases," Proc. Phys. Soc. (London), 47, 543-548, 1935.

Measurements of wavelengths of supersonic radiation at frequencies between 40 and 140 kc have been made in CO_2, N_2O, and SO_2 at various temperatures from room temperature up to 200°C. The velocities at constant density (i.e., reduced to 0°C) have been calculated. When these are plotted against temperature, supersonic dispersion is shown by a sharp fall of velocity in CO_2 at a temperature which increases with the frequency of the source. The significance of these results in the light of the theories of supersonic dispersion which have been propounded is then discussed.

835

Pielemeier, W. H., "Supersonic Dispersion and Absorption in CO_2," Phys. Rev., 41, 833-837, 1932.

Since supersonic velocity determinations in air near a crystal oscillator usually yield values in excess of the accepted value, V_0 = 331.6 m/sec, a similar effect with CO_2 was suspected. The velocity and the absorption coefficient were measured at frequencies beginning in the dispersion region, theoretically and experimentally investigated by Kneser, and extending beyond it to 2.09 megacycles. The author's velocity values are slightly less than Kneser's experimental values, but they fit his theoretically determined dispersion curve equally well. At the lowest frequency tested (303 kc) the absorption coefficient was found to exceed, by the greatest amount, its value computed from Lebedew's formula. This frequency is near the middle of the dispersion region where maximum absorption is expected. According to Pierce, the absorption becomes excessive also when this frequency is approached from lower values. The results are presented in tabular and in graphical form. A sharp absorption maximum appears at 217 kc.

836

Primakoff, H., "The Translational Dispersion of Sound in Gases," J. Acoust. Soc. Am., 14, 14-18, 1942.

The translational dispersion is discussed from the standpoint of kinetic theory. An explicit relation is derived for the variation of sound velocity with frequency in monatomic gases: $V = V_0(1 - 5{\cdot}4\, \ell^2/\lambda^2)$, where ℓ is the m.f.p. and λ the wavelength. The possibility of experimental observation of translational dispersion is briefly discussed.

837

Proud, J. M., P. Tamarkin, and E. T. Kornhauser, "Propagation of Sound Pulses in a Dispersive Medium," J. Acoust. Soc. Am., 28, 80-85, 1956.

The dispersion of a rectangular pulse with many cycles of carrier frequency propagated along an acoustic waveguide of rectangular cross-section has been observed experimentally. The main signal is propagated with the group velocity and is observed to separate from the initial and final transient portions which travel with the greater, free-medium velocity. In the dispersion process, the beating of the initial transient with the main signal causes fluctuations in the envelope of the carrier which compare favorably with the mathematical formulation given. This experiment serves as a calibration of the waveguide so that it can be used qualitatively as a type of analog computer to predict the effects of similar dispersion on the transmission of pulses of other shapes that are not amenable to actual computation.

838

Richards, W. T., and J. A. Reid, "Dispersion of Sound in Nitrogen Tetroxide," J. Chem. Phys., 1, 114-128, 1933.

Several types of sound dispersion in a dissociating gas are discussed. Einstein's expression for the velocity of sound in a dissociating gas has been modified to include heat-capacity dispersion. Accounts are given of measurements on the velocity of sound in nitrogen tetroxide. The range of temperature studied is 0° to 30°C, the range of pressure 132 mm to 670 mm, and the range of frequency 9 kc to 451 kc. The velocity of sound has been thus defined with an estimated error of ±0.1 m/sec^{-1}. The maximum dispersion observed is about 5 m/sec^{-1}. Hence the rate constant of the dissociation reaction is $4.8 \times 10^4 \pm 0.5 \times 10^4$ at 25°C and 260 mm. The activation energy obtained for the dissociation reaction is 13.9 ± 0.9 kcal. An upper limit for the heat capacity of nitrogen tetroxide being fixed by experiment, the effective molecular diameters for the activation process must be at least three times those for ordinary kinetic collisions.

839

Richardson, E. G., "Supersonic Dispersion in Gases," Proc. Roy. Soc. (London) A, 146, 56-71, 1934.

The propagation through various gases of supersonic radiation emitted by piezoelectrically maintained quartz crystals is examined experimentally. New methods involving the change of resistance of an electrically heated wire exposed to the radiation are developed, enabling the wavelength and amplitude of the gaseous vibration to be measured. The method of calibrating the apparatus is also described, and the results are compared with those obtained by older methods. The anomalous dispersion and absorption shown by certain gases is critically examined, and suggestions put forward to account for it. Evidence is adduced to show that some of the radiation "absorbed" is scattered by the gas.

840

Rose, M. E., "Dispersion of Sound," J. Chem. Phys., 2, 260-263, 1934.

In calculations such as that of Richards dealing with dispersion of sound in a gas with n energy states, the final result should contain no terms of higher order than the (n - 1)th. Richards' calculation on this is criticized, and an alternative method is given. In reply, T. W. Richards maintains that the Boltzmann factor at the basis of Rose's argument is not adequate for completely determining the probability of a transition. The inclusion of higher order terms is an approximation device only.

841

Roy, A. S., and M. E. Rose, "Rotational Dispersion of Sound in Hydrogen," Proc. Roy. Soc. (London), 149A, 511-522, 1935.

The dispersion of sound in hydrogen is investigated. The results show that no variation of velocity occurs below frequencies of the order 10^6 cps. This is to be expected from the classical theory of Jeans as well as from the quantum treatment of the inelastic collision between two hydrogen molecules.

842

Rutgers, A. J., and H. O. Kneser, "Theory of Dispersion of Sound," Ann. Physik, 16, 350-361, 1933.

A theory of dispersion of sound is developed on the same lines as Einstein's, but without the aid of further assumptions. The result as regards dependence on frequency is identical with that of Kneser and of Herzfeld and Rice, and also agrees with the experiments of Kneser and Pielemeier. Kneser's theory is criticized in that their reaction equations are not exactly the same, and Kneser replies in a following note.

843

Sakadi, Z., "Dispersion of Sound Waves, Considering the Effects of Heat Conduction and Viscosity," Proc. Phys.-Math. Soc. Japan, 23, 208-213, 1941.

This is a mathematical analysis in which the following assumptions are made: (1) the disturbance by the sound wave is very small, so that every quantity differs little from that of the static state; (2) there is only one excited state, and the number of excited molecules is very small compared with that of unexcited molecules. An addendum contains numerical data for CO_2 which show that consideration of conduction and viscosity introduces a small correction to the sound dispersion.

844

Scorer, R. S., "The Dispersion of a Pressure Pulse in the Atmosphere," Proc. Roy. Soc. (London) A, 201, 137-157, 1950.

The amplitude and form of a pressure oscillation, as related to the magnitude of and distance from a great explosion, are derived. The solution is compared with actual observations made at varying distances from the Great Siberian Meteorite, 1908, and the Krakatoa eruption, 1883.

845

Sessler, G., "Sound Absorption and Sound Dispersion in Gaseous Nitrogen and Oxygen at High Frequency Pressure Values," Acoustica, 8, 395-397, 1960.

Sound absorption and dispersion in nitrogen and oxygen at 20^oC and at frequency/pressure (f/p) values of 10^6 to 10^9 cycles/atm have been measured. The method used is the interferometric arrangement described in an earlier paper (Meyer, E., and G. Sessler, Z. Physik, 149, 15-39, 1957). Reference is also made to a paper by Greenspan (J. Acoust. Soc. Am., 30, 672, 1958). Experimental values of the ratios of absorption α to dispersion β (α/β) are plotted as a function of the ratio f/p. For nitrogen the ratio α/β falls from 0.3 to 0.01 as the ratio f/p decreases from 10^9 to 10^7. For oxygen the experimental curve is much the same. The experimental results agree well with theory.

846

Sette, D., and J. C. Hubbard, "Note on Thernal Relaxation of CO_2 in Presence of H_2O and D_2O Molecules," J. Acoust. Soc. Am., 25, 994-997, 1953.

The large effect of water vapor on the thermal relaxation of carbon dioxide has not yet been satisfactorily explained. In order to have more information on the characteristics of the phenomena involved, we have tried to compare the effects produced by determining the changes in the dispersion curve. Commercial CO_2 was used. The shape of the dispersion curve shows a departure from the single relaxation time theoretical curve, which increases with the H_2O and D_2O content. If this result is confirmed by others, it would indicate that these impurities strongly affect the mechanism of energy transfer among CO_2 molecules. However, it can be objected that we have assumed that during the experiments the water absorved on the walls of the interferometric system did not vary. In any case the comparison between the effects of H_2O and D_2O can be made. We find the values of 1.86 and 2.50 for the respective ratios of the transition probabilities in the collision H_2O — CO_2 and D_2O — CO_2, the two values being determined from two different sets of mixtures. An approximate theoretical calculation of the ratio of the transition probabilities, considering only the mass change of the added impurity, gives a value of 1.25. The same ratio would instead be less than unity if the important process were the energy exchange between rotation of H_2O or D_2O molecules and vibration of CO_2 molecules. The latter mechanism does not, therefore, seem to be responsible for the large decrease of relaxation time when water is added to carbon dioxide.

847

Sinness, L. S., and W. E. Roseveare, "Dispersion of Sound in Oxygen," J. Chem. Phys., 4, 427-431, 1936.

The velocity of a 1000-cycle sound wave in oxygen of various degrees of humidity at 26.5^oC is measured. The velocity behavior indicates that the water molecules are effective in bringing the heat capacity of the first vibrational state of O_2 into equilibrium with the sound wave. The dispersion change in velocity amounts to 0.16%. Intensity measurements agree with velocity data in fixing the center of the dispersion region between 1 and 3 mm partial pressure of water, which agrees with the values calculated from Knudsen's studies of rates of decay at higher frequencies.

848

Stewart, E. S., "Dispersion of the Velocity and Anomalous Absorption of Sound in Hydrogen," Phys. Rev., 69, 632-640, 1946.

The velocity and absorption of sound in hydrogen were measured at 25°C at 3.855 and 6.254 mcs and at pressures of 1.00, 0.83, 0.67 and 0.50 atm. Dispersion of the velocity from 1321.9 m/sec to 1382.0 m/sec and anomalous absorption observed are interpreted as caused by molecular absorption induced by loss of the rotational degrees of freedom. Calculations place the inflection point of the dispersion curve at 10.95 Mcs the peak of the absorption curve at 10.0 Mcs from velocity data, and at 16.1 and 14.8 Mcs, respectively, from absorption data. The relaxation times for pressures of 1 atm. from the two sets of data are 1.9 and 1.7×10^{-8} sec. The f/p law is not strictly obeyed.

849

Tabuchi, D., "Dispersion and Absorption of Sound in Gases in General Chemical Equilibrium," Mem. Res. Inst. Acoust. Sci., Osaka Univ., Japan, 2, 50-60, 1951.

Gases are considered theoretically which are in general chemical equilibrium, dissociation being included as a special case. It is assumed that the gas is ideal, the absorption of sound due to viscosity, thermal conduction and radiation is negligible, and that the transition between the translational and internal energies of the molecules occurs at infinite speed; that is, the specific heat of the gas is not dependent on the sound frequency. Equations are deduced for the velocity of sound and the absorption coefficient of the gas, and then the complex sound velocity is deduced from the acoustic characteristic equation. The theoretical values obtained by Einstein and Luck for dissociating gases are found in good agreement with those deduced in this paper.

850

Tabuchi, D., "Dispersion and Absorption of Sound in Mixtures of Gases," Mem. Inst. Sci. Ind. Res., Osaka Univ., Japan, 9, 65-73, 1952.

This paper calculates the complex velocity of sound for gas mixtures containing molecules with an arbitrary number of vibrational levels and modes of vibration. Absorption due to viscosity and heat conduction is neglected, and it is assumed that there is no dispersion and absorption due to transitions between rotational quantum states. The results, it is claimed, are obtained in a simple form convenient for comparison with experiment.

851

Thaler, W. J., "The Absorption and Dispersion of Sound in Oxygen as a Function of the Frequency-Pressure Ratio," J. Acoust. Soc. Am., 24, 15-18, 1952.

The velocity and absorption of ultrasonic waves in oxygen were measured by means of an improved ultrasonic interferometer in the range from 1 to 100 Mcs atm. Dispersion of the velocity ranged from 333.14 m/sec to 357.22 m/sec at 30°C. The ratio ($\alpha_{exper}/\alpha_{class}$) dropped from 3.68 to 2.05, and the corresponding value of C_v/R dropped from 2.50 to 1.61. The increase in velocity and the decrease in ($\alpha_{exper}/\alpha_{class}$) is interpreted as caused by the slow exchange of energy between the translational and rotational degrees of freedom. The relaxation time for the rotation was 5.24×10^{-9} sec.

852

Tolstoy, I., "Dispersion and Simple Harmonic Point Sources in Wave Ducts," J. Acoust. Soc. Am., 27, 897-908, 1955.

In a previous article, it was shown that, if plane wave reflection coefficients were written as rotations, the characteristic equation for the normal modes could be expressed very simply by means of the arguments. The method is elaborated here for the case of multilayered media. Also, an exact and general solution for the guided wave terms due to a simple harmonic point source in a duct is obtained. This is done by applying the characteristic equation to an integral solution due to Brekhovskikh. A numerical example is given, illustrating quasi-resonance and anti-resonance phenomena associated with stationary values of the group velocity under simple harmonic conditions.

853

Walch, F. A., "Constancy of Velocity of Sound at Sonic Frequencies," Proc. Phys. Soc. (London), 48, 899-913, 1936.

A method of investigating whether there is any dispersion of sound waves in air at sonic frequency is described. It consists in comparing the waveform of a complex sound at different distances from the source. A technique for making the necessary collodion diaphragms has been worked out, and a simple but effective drum camera has been constructed. A controllable waveform is provided by two oscillators, one tuned to a fundamental and the other to a harmonic, locked into synchronism by close coupling. Frequencies from 250 to 1000 cps have been investigated. Velocities have been proved constant for the lower frequencies to within one in 500 and for the higher frequencies to within one in 1000.

854

Wang Chang, C. S., and G. E. Uhlenbeck, "On the Propagation of Sound in Monatomic Gases," Eng. Res. Inst., Univ. of Mich., Ann Arbor, 52 pp., 1952.
AD-9294.

The Boltzmann equation for a monatomic gas with no external force is stated for a small disturbance h from equilibrium in terms of a collision operator J. From this equation an exact dispersion law is derived for gases. Partial lists of eigenfunctions and eigenvalues are obtained for the collision operator for Maxwell molecules (molecules repelling with a Kr^{-5} force law). A successive approximation method gives the dispersion law as a series in λ/λ, the ratio of mean free path to the wavelength of sound. The extension to molecular models other than Maxwell's is discussed.

855

Wright, W. M., "The use of Amplitude Modulation for the Measurement of Ultrasonic Velocity Dispersion in Gases," Tech. Memo. No. 48, Acoust. Res. Lab., Harvard Univ., Cambridge, Mass., 42 pp., 1962.
AD-285 959.

Ultrasonic velocity dispersion in fluids is usually assessed by direct measurement of the speed of sound as a function of frequency. Greater accuracy might be achieved if a quantity proportional to the change of sound velocity with frequency could be measured. The mathematical theory for a dispersion-measurement method using transmission of an amplitude-modulated acoustic signal through a dispersive medium is examined for an idealized case. It is concluded that the proposed method has serious shortcomings. Two other schemes which might use properties of amplitude-modulated signals to measure acoustic velocity dispersion in gases are also considered briefly.

856

Zink, J. W., and L. P. Delsasso, "Attenuation and Dispersion of Sound by Solid Particles Suspended in a Gas," J. Acoust. Soc. Am., 30, 765-771, 1958.

Observations were made on audio-frequency sounds propagating through a gaseous medium containing small solid particles in suspension. Two effects were observed—the attenuation and the dispersion. The measurements were carried out by sending short trains of sine waves through the particle-filled gas and observing the changes in the transmitted train of waves after the particles settled out of the gas. The variation in arrival time of the pulse was used to determine the velocity change caused by the suspended particles. The variations of the attenuation and velocity with frequency due to the particle-filled gas were obtained and the results compared with theory. The measured attenuation agreed with existing theory. The observed dispersion is satisfactorily accounted for by a theory that is introduced in this paper. The attenuation theory takes into account enhanced viscous and thermal losses caused by the suspended particles. The dispersion theory predicts the velocity shift resulting from changes of the heat capacity and the density of the gas containing the suspended particles.

857

Zmuda, A. J., "Dispersion of Velocity and Anomalous Absorption of Ultrasonics in Nitrogen," J. Acoust. Soc. Am., 23, 472-477, 1951.

By means of the interferometer, the velocity and absorption of ultrasonic waves in N were measured at the frequency of 2.992 Mcs in the pressure range of 2.09 to 76 cm of Hg at a temperature of 29°C. A dispersion of velocity was found ranging from 354.3 m/sec to 364.4 m/sec. The ratio $\alpha_{exp}/\alpha_{class}$ dropped from 1.40 to 1.32, and the corresponding value of C_V/R dropped from 2.50 to 2.08. Theoretical values for the change in velocity and in the absorption ratio, calculated by applying the equations for the exchange of energy between translational and vibrational degrees of freedom, show good agreement with the observed values. The increase in velocity and the decrease in $\alpha_{exp}/\alpha_{class}$ is interpreted as due to the slow exchange of energy between the translational and rotational degrees of freedom. The relaxation time for rotation was found to be 1.2×10^{-9} sec.

Dispersion—see also Velocity
See also—49, 50, 53, 62, 69, 117, 134, 144, 152, 180, 187, 195, 205, 214, 222, 248, 263, 264, 282, 303, 310, 318, 322, 714, 754, 941, 949, 1131, 1141, 1329, 1467, 1849, 1905, 1915, 2170, 2907, 2969, 3036, 3048, 3049, 3082, 3091, 3095, 3115, 3129, 3139, 3142, 3172, 3212, 3223, 3340, 3342, 3403, 3460, 3638, 3652, 3665, 3682, 3710, 3711, 3749, 4340, 4350, 4420.

DOPPLER EFFECT

858

Bateman, H., "Sound Rays as Extremals," J. Acoust. Soc. Am., 2, 468-475, 1930.

This is a mathematical paper in which equations are developed, representing a general form of Doppler's principle, applicable when the source of sound, the receiver and the medium are all in motion.

859

Ernst, P. J., "Preliminary Survey in Connection with Use of Ultrasonic Methods for the Accurate Measurement of Rocket Velocities During the Burning Period," Final Rept., Temple Univ., Philadelphia, Pa., 10 pp., 1953.
AD-11 531.

Tests are reported which indicate the feasibility of using ultrasonic methods to make accurate measurements of rocket velocities during the burning period. Two methods are recommended. The echo-Doppler method uses either a small reflector fixed to the rocket nose or the flattened rocket nose for ultra-sound reflection. This method is considered applicable for velocities as high as half the speed of sound. The second method comprises the transmission of a signal from a sonic generator to a microphone on the rocket and the retransmission of a modulated radio signal to a detector. This method is applicable up to the speed of sound. An 8- to 25-kc range and a 50-w transmitter power appeared adequate. Test data are included as well as photographs of experimental setups.

860

Fleischmann, L., "Generalized Formula for Doppler Effect," J. Opt. Soc. Am., 29, 302-304, 1939.

The formula for the Doppler effect is worked out for the case when source and observer are both moving in any manner in flat space. The change in frequency, when the source is moving along a straight line with constant velocity relative to a fixed observer and when the source passes at a given minimum distance from the latter, is worked out, and it is shown that there is no finite jump of frequency as the point of minimum distance is passed through. Moreover, the change of frequency is not the same as that found on the assumption that the source is at rest and the observer is moving along a straight line passing at a given minimum distance from the source. The case of motion of the observer under gravity relative to a fixed source is also worked out in detail.

861

Heaps, C. W., "Demonstrating the Doppler Effect," Am. J. Phys., 9, 313, 1941.

This is a short discussion of various methods for demonstrating the accoustic Doppler effect by movement of a sound source. The methods thought to be best involve using either one tuning fork and a reflecting wall or two tuning forks at almost the same frequency. In the latter case, the change in pitch of the beat note as one of the forks is moved is dramatically apparent to the student.

862

Hey, J. S., J. T. Pinson, and P. G. Smith, "A Radio Method of Determining the Velocity of a Shock Wave," Nature, 179, 1184-1185, 1957.

A virtually continuous record of velocity relative to distance along the tube is obtained by measuring the change of frequency, due to Doppler effect, of radiowaves reflected from the shock front. A dipole at the downstream end of the tube is used to transmit and receive at a frequency such that the reflection coefficient is increased by ionization in the following flow. A typical frequency for shock Mach numbers exceeding six in argon is 5000 Mcs. A directly calibrated oscillographic display is used.

863

Jensen, A. S., "Doppler Effect—a Lecture Demonstration," Am. J. Phys., 13, 39-40, 1945.

Two loudspeakers emitting notes of different frequency are used. One is stationary; the other may be swung as a pendulum, thereby altering the beat frequency.

864

Koch, B., "Reflection of Microwaves by Explosion Phenomena" (in French), Compt. Rend., 236, 661-663, 1953.

By using the Doppler-Fizeau effect, it is possible to detect the echoes of an electromagnetic wave from the explosive wave front. This method also makes it possible to measure the speed of the explosive wave and the ionization of the gases in the explosion. A table gives seven experimental values of speeds thus determined, showing an average of 7994 ± 47 m/sec or ±0.6%.

865

Lienard, P., "On the Sound Pressures Received by an Observer in Relative Motion with Reference to a Point Source in Uniform Rectilinear Motion at Supersonic Velocity in a Perfect Fluid" (in French), Conpt. Rend., 228, 1108-1110, 1949.

This is an extension of the previous work of G. Richter (Z. Physik, 125, 98-107, 1948). It is shown that, when the source is moving at supersonic velocities, the moving observer receives two distinct waves, which appear to come from opposite directions and whose frequencies are modified by the Doppler effect.

866

McIlwraith, C. G., "Note on the Doppler Effect," Rev. Sci. Instr., 12, 612, 1941.

This presents an interesting use of the Doppler effect, that aids in adjusting the frequency of one tuning fork to be exactly equal to the frequency of a second fork.

867

Michels, W. C., "Phase Shifts and the Doppler Effect," Am. J. Phys., 24, 51-53, 1956.

If the path between a source S and an observer O is changed by an amount Δx, the phase of the wave received by O is shifted by $\Delta n = -\Delta x/\lambda = -f\Delta x/c$, where λ and f are, respectively, the wavelength and frequency of the disturbance, and c is the speed of propagation, all measured by an observer fixed in the medium. The resulting change in observed frequency is $\Delta f = \Delta n/\Delta t$, where Δt is the time taken for the observation of the phase change. It is shown that these two statements are sufficient for the derivation of the acoustic Doppler effect equations in all cases. The extension to the relativistic optical Doppler effect also follows if the Einstein time dilatation is taken into account.

868

Perrine, J. O., "The Doppler and Echo Doppler Effect," Am. J. Phys., 12, 23-28, 1944.

This paper records an occasion in which one observer on a car and another on a puffing train approached each other rapidly on parallel courses. The puffs of the engine were seen and heard, and the frequency of the puffs as heard was noticeably different from the frequency as observed by eye. The author sets out 16 cases of the Doppler effect involving motion of generator, detector and reflector; after solving each case separately, he finds a combined formula adaptable to all 16 cases.

869

Rott, N., "The Acoustic Field of a Rapidly Moving Source of Sound" (in German), Mitt. Inst. Aerodyn. E. T. H., Zurich, 9, 1945.

Following a historical survey, including Doppler's results and the fundamental acoustic equations with their solutions, discussions and formulae are presented on the acoustic field in parallel flow, on the field of a moving source of sound in an emitter-centered coordinate system, and on complete reflection at an infinite plane.

870

Spees, A. H., "Acoustic Doppler Effect and Phase Invariance," Am. J. Phys., 24, 7-10, 1956.

Attention is called to the usefulness of the Doppler effect in introducing the idea of invariance with respect to coordinate transformation. The invariant property of the phase of a sound wave with respect to Galilean transformation is applied to several Doppler effects including that resulting from transverse motion of source and detector in a moving medium.

871

Walters, A. G., "On the Propagation of Disturbances from Moving Sources," Proc. Cambridge Phil. Soc., 47, 109-126, 1951.

The concept of the Green's vibrational function given earlier (Walters, ibid., 45, 69-80, 1949) is used to obtain a general expression for the disturbance from a point source. The potential due to transient sources of sound moving with subsonic and supersonic velocities is derived from this. It is found that the Doppler effect for a supersonic source differs from that for a subsonic source. In the former case it is found that two frequencies are heard simultaneously from a source emitting a note of one frequency. The theory is applied to determine some solutions of the two-dimensional equation of supersonic, irrotational compressible flow, corresponding to the flow around an aerofoil; the entropy changes at the shock wave are taken into consideration.

Doppler Effect—see also Wave Propagation, Moving Source
See also—979, 1152, 1353, 1365, 1377, 1637, 2125, 2146, 2475, 2898, 3651, 3940, 3946.

ECHO RANGING

872

Adolph, R., and H. O. Kneser, "Applications of the Impulse Method to Physical Problems" (in German), Z. Angew. Phys., 1, 382-387, 1949.

The applications of pulse techniques to the measurement of the velocity and absorption of sound waves in solids, liquids and gases are surveyed. In solids, an echo-sounding technique is used for flaw detection, employing ultrasonic waves of frequency 5 mcs. Absorption measurements are made on solids by means of ultrasonic frequencies to develop materials suitable for delay lines and to study the heating effect of ultrasonic vibrations. Very accurate measurements can be made by the echo technique to determine the velocity of ultrasonic waves in liquids. It has been found with liquids that the absorption increases with the square of the frequency, so that some materials become almost impermeable to sound at very high frequencies. The troposphere is studied by echo-sounding with the impulse technique using frequencies of 1-4 kcs.

873

Bellamy, J. C., R. F. Bosshart, et al., "Investigation of the Feasibility of Acoustic Soundings of the Atmosphere," Final Rept., Cook Res. Labs., Skokie, Ill., 1958.
AD-210 659.

Acoustic soundings of the atmosphere offer an indirect technique for obtaining frequent information on weather conditions in the upper air. A feasibility experimental model sounding system for acoustical probing of the atmosphere is described. The system consists of an audio projector unit which beams a short-duration, high-intensity, single-frequency, pulse-modulated audio signal vertically into the atmosphere, and a receiver unit for detecting the sonic reflections and reverberations from the atmosphere. Preliminary results indicate the feasibility of acoustical soundings and more detailed field test information will be required to define explicitly the relationships between acoustic reflections and the corresponding meteorological variables.

874

Bellamy, J. C., R. F. Bosshart, et al., "Investigation of the Feasibility of Acoustic Soundings of the Atmosphere," Rept. No. PR-152-1, Cook Res. Labs., Skokie, Ill., 33 pp., 1957.
AD-212 333.

The feasibility of using acoustic sounding techniques to obtain information concerning the structure of the troposphere and the usefulness of such information for forecasting or operations are to be determined. A sonic sounding device of flexible design is to be constructed, and field tests are to be conducted to study the various aspects of acoustic reflection and ranging. Acoustic phenomena in the atmosphere are discussed, and calculations are presented for estimated signal losses using a 1000-c carrier frequency.

875

Bellamy, J. C., R. F. Bosshart, et al., "Investigation of the Feasibility of Acoustic Soundings of the Atmosphere," Rept. No. PR-152-2, Cook Res. Labs., Skokie, Ill., 1957.
AD-212 334.

Investigations revealed that a frequecy of 1000 c affords the best compromise for the signal carrier frequency. Tests will also be made at 500 and 750 c. To provide a logical basis for the tests at these frequencies, a series of calculations have been made of estimated signal losses. In order to understand better the basis of these calculations, a short review is given. Progress in the construction of an experimental sonic sound device of flexible design is summarized.

876

Bellamy, J. C., R. F. Bosshart, et al., "Investigation of the Feasibility of Acoustic Soundings of the Atmosphere," Rept. No. PR-152-4, Cook Res. Labs., Skokie, Ill., 10 pp., 1958.
AD-210 658.

The evaluation of the experimental meteorological acoustic sounding system was continued. In particular, acoustic soundings are to be conducted under selected weather conditions to ascertain the feasibility of identifying atmospheric characteristics from the sonic reflection data.

877

Bellamy, J. C., S. C. Henjum, et al., "Investigations of the Feasibility of Acoustic Soundings of the Atmosphere," Rept. No. PR-152-3, Cook Res. Labs., Skokie, Ill., 1958.
AD-211 017.

The preliminary system test for the evaluation of the sounding equipment and the start of field testing were planned. The field test was delayed because of the effort required during the preliminary system test to eliminate wind and ambient noises in the signal detector. The noise problem was sufficiently alleviated to allow preliminary analysis of these sample soundings; however, the time required to solve the noise problem has prevented the performance of a sufficiently thorough analysis of the soundings.

878

Bradfield, G., "Obstacle Detection Using Ultrasonic Waves in Air," Electron. Eng., 21, 464-468, 1949.

This paper describes the results which have been achieved with simple equipment for use as a safety-in-fog aid to road transport, or blind man's aid, to detect the proximity of oncoming traffic, up- or down-going steps, walls, windows, etc. Expressions are given for determining the optimum frequency for certain conditions (e.g., at 20 ft large objects require a frequency of 23 kcs, but clusters of tiny objects require 50 kcs). A spark transmitter was used with a standard 14-mm sparking plug at the focus of a reflector. The receiving microphone used a double bimorph Rochelle crystal at the focus of a five in paraboloid. The spark rate was 3 to 4 sec, and duration 1 to 1 1/2 μsec. Tables show the amplitude of the reflected signal at various frequencies for different objects.

879

Bradley, G., "Echo Ranging with Audiofrequencies," Am. J. Phys., 21, 159-161, 1953.

The mathematical form of a propagating wave is discussed, and it is pointed out that it may be misleading to emphasize the harmonic form of a wave in the general physics course. A demonstration piece utilizing a sound pulse is described. The demonstration piece is suitable to illustrate (a) the speed of a sound, (b) reflection methods of ranging, and (c) reverberations in rooms.

880

Eckart, G., "Study of Acoustic Wave Echoes in the Stratified Region of the Troposphere" (in French), Acustica, 2, 256-262, 1962.

This paper uses the methods of Bremmer[1,2] and Schelkunoff.[3] The influence of those terms which spoil the analogy with electric waves[4] becomes apparent.

[1] Philips Research Repts., 4, 1-19 and 189-205, 1949.

[2] Physica, 15, 593-608, 1949.

[3] Quart. Appl. Math., 3, 348-355, 1946.

[4] Eckart and Lienard, Acustica, 2, 157-161, 1952.

881

Eisner, F., and K. Kruger, "Reflecting Power of the Earth's Surface for Sound Waves Incident Normally," Hochfrequenztech. u. ElektAkust., 42, 64-67, 1933.

Sound waves of a frequency of 2900 cps were sent out from a whistle on board an airship and were received at the other side of the gondola by a microphone tuned to the whistle. The received sound was amplified by a three-valve apparatus and the intensity recorded by an impulse-measuring instrument. The reflecting power of water being taken as unity, that of thin ice is 1.07, of meadow land 0.49, and of pine woods from 0.21 for young trees to 0.45 for full-grown trees. With the varying nature of country, the height above the ground for a given intensity of echo varies as the square root of the reflection coefficient.

882

Ewer, D. W., H. Hartridge, and M. Wilkinson, "Acoustic Control in the Flight of Bats," Nature, 156, 692-693, 1946.

This is a group of letters to the editor citing the analogy between radar and the acoustic range and direction-finding ability of bats. The supersonic note emitted lasts about 0.01 sec, during which the leading edge travels about 10 feet on a round trip between a bat and an obstacle. It is suggested that since a bat could not perceive targets at ranges shorter than 5 feet by this process, the trailing edge rather than the leading edge of supersonic pulses may be utilized. It is also suggested that as the pulse repetition increases when a bat approaches an obstacle, the pulse duration time may decrease to much less than 0.01 sec, thereby permitting close range perception.

883

Fetter, R. W., P. L. Smith, Jr., and B. L. Jones, "Investigation of Techniques for Remote Measurement of Atmospheric Wind Fields," Rept. No. 3, Phase 3: Design of Experiments, Midwest Res. Inst., Kansas City, Mo., 15 Feb.-30 June 62, 68 pp., 1962.
AD 283 780.

Experiments were designed to provide information needed to assess the practicability of two possible methods of remote wind measurement: electromagnetic scattering from acoustic waves; and electromagnetic scattering from natural atmospheric turbulence. The electromagnetic-acoustic (EMAC) method was demonstrated previously, and the present experiments have been designed to determine the capabilities of the method in range, accuracy, resolution, response time, and wind field mapping. Use of backscattering from natural turbulence is not practical at the present state of the art, but experiments have been designed to determine scale of turbulence, velocity, intensity, and rate of occurrence at low levels to provide data for better analytical representation of atmospheric turbulence.

884

Fetter, R. W., et al., "Investigation of Techniques for Remote Measurement of Atmospheric Wind Fields," Rept. No. 2, Phase 2: Analysis, Midwest Res. Inst., Kansas City, Mo., 1962.
AD 274 254.

Analyses were made to determine the feasibility of three proposed methods of remote wind measurement using (1) scattering from natural atmospheric turbulence; (2) electromagnetic scattering from acoustic waves; and (3) infrared tracking of an artificially heated volume of air, or "bubble." Use of natural turbulence as a sensor will require (1) additional data on distribution and characteristics of turbulence from ground level to an altitude of one mine, (2) correlation of turbulence motion and wind, and (3) radar state-of-the-art improvement to provide consistent detection and measurement.

Remote wind measurements by microwave reflection from acoustic waves have been demonstrated, but additional experimental data are needed to determine maximum usable range and the effects of turbulence on the acoustic waves.

Remote generation of a heated bubble of air does not appear feasible.

885

Fetter, R. W., et al., "Remote Measurement of Atmospheric Wind Fields," Tech. Rept. No. 1 (large bibliography (163 entries) and survey of related programs), Midwest Res. Inst., Kansas City, Mo., 51 pp., 1961.
AD 270 094.

A survey has been made of literature and current work in the field of remote measurement of atmospheric wind fields. In the present context, the term "remote" indicates that no probe, sensing apparatus, or other extraneous physical material is to be located at the point of measurement and no physical connecting means is to be used between that point and the measuring equipment. Most methods investigated do not conform to the definition of "remote" as given above. The survey has produced only a few methods which appear applicable and therefore merit analysis in Phase II of the program.

886

Florisson, C., "Echo Sounding from Aircraft," Compt. Rend., 194, 1149-1150, 1932.

The author describes an hf echo-sounding system for aircraft analogous to that used in the Iangevin-Chilowsky system for ships. The use of a source of hf sound makes it possible to render the receiving circuit relatively insensitive to the lf (audible) sounds from the propellers and exhaust of the aircraft. The source proposed consists of an air-blown whistle placed at the apex of a conical reflector directed towards the ground. An extremely short signal (to permit of sounding near the ground) is sent out 40 times per minute by means of an electromagnetically operated air valve. The receiver is a similar conical reflector connected by tubes to the ear of the observer. The latter has in front of him a chronometer movement in which the high-speed pointer revolves round the dial in about 0.2 sec. The sound emission occurs when the pointer passes through the zero position, the observer noting repeatedly the position of the pointer at the instant the echo arrives. Soundings between 10 and 240 m have been made from an airplane in this way—the apparatus being described as an acoustic altimeter.

887

Gilman, G. W., H. B. Coxhead, and F. H. Willis, "Reflections of Sound Signals in the Troposphere," J. Acoust. Soc. Am., 18, 274-283, 1945-1946.

Experiments directed toward the detection of nonhomogeneities in the first few hundred feet of the atmosphere were carried out with a low power sonic "radar." The device has been named the sodar. Trains of af sound waves were launched vertically upward from the ground, and echoes of sufficient magnitude to be displayed on an oscilloscope were found. Strong displays tended to accompany strong temperature inversions. During these periods, transmission on a microwave radio path along which the sodar was located tended to be disturbed by fading. In addition, relatively strong echoes were received when the atmosphere was in a state of considerable turbulence. There was a well-defined fine-weather diurnal characteristic. The strength of the echoes led to the conclusion that a more complicated distribution of boundaries than those measured by ordinary meteorological methods is required in the physical picture of the lower troposphere.

888

Gold, L., "Analysis of Multiple-Echo Effect Rising from the Release of a Stored Wave Train," J. Acoust. Soc. Am., 23, 214-218, 1951.

A generalized theoretical treatment is presented of a problem which has direct application to the phenomenon of multiple-echo patterns as employed for propagational studies of hf sound waves in various media. Analyzed are the functional dependence of the number of observable echoes N in terms of a prescribed threshold sensitivity db^* of a detecting device, and the storage medium parameters, which are the effective absorption coefficient a and the boundary reflection coefficient R. The equation derived is:

$$N = \{db^*/10 + \log R - \log (1 - R)\}/\{\log R - \alpha d \log\} e$$

where d is the length of the storage system. This relation has values R_{opt} for which N is a maximum, and it is shown that $N_{max} = 1/(1 - R_{opt})$.

889

Griffin, D. R., "Echoes of Bats and Men," Doubleday Anchor Books, Garden City, N. Y., Science Study Series S4, 156 pp., 1959.

Among the early paperback volumes in the new Science Study Series, growing out of the work of the Physical Sciences Study Committee, the fourth and ninth have to do with acoustics. Griffin's book appears to be of high technical quality and, in addition, reads like a detective story. The basic problems of getting about in dark reaches that preclude the use of vision, whether by bats, fishes, or blind men, are clearly stated by the author, who then proceeds to solve the problems logically. It is an extremely readable volume of bioacoustics.

890

Griffin, D. R., "How Bats Guide Their Flight by Supersonic Echoes," Am. J. Phys., 12, 342-345, 1944.

In the 18th century Jurine found that plugging the ears of bats caused them to lose most of their ability to avoid obstacles in the dark. His explanation was not generally accepted. Hartridge in 1920 suggested that bats made use of supersonic sounds for purposes of safety when flying, and Galambos and the author found that bats emit an intense supersonic cry of frequency varying between 30 and 70 kcs with maximum intensity about 50 kcs. When approaching an obstacle, bats emit cries, but their ability to avoid obstacles is much reduced when their ears are plugged or their mouths are gagged. The term echolocation is suggested for the bats' process, which is compared with the echometer used on a ship for depth-finding or for the location of schools of fish.

891

Griffin, D. R., "Listening in the Dark," Yale Univ. Press, New Haven, Conn., 413 pp., 1958.

This book presents the history and results of the author's long and thorough research on "echolocation." Bats, birds, fish, and men were investigated. The work is an excellent example of the application of acoustic methods and instrumentation to biological research. One of the author's major conclusions is that much may be learned from the bat for research on guiding the blind.

892

Griffin, D. R., "Measurements of the Ultrasonic Cries of Bats," J. Acoust. Soc. Am., 22, 247-255, 1950.

The ultrasonic sounds emitted by bats have been analyzed with a system sensitive to frequencies from 1 to 150 kc. These sounds, used by the bats to detect obstacles by means of their echoes, consist of pulses about two msec long. Most of the measurements were made with the common little brown bat, Myotis 1. lucifugus; with this species the sound pressure at 40 to 55 kc, measured 5 to 10 cm from the animal's mouth, averaged 60 dynes/cm^2 (109 db on the conventional scale of sound pressure levels). The highest recorded intensity was 173 dynes/cm^2 (119 db). The frequency of the ultrasonic sound falls during each pulse by about one octave; the average frequency at the peak amplitude was 47.8 kc, while the average at the beginning of the pulse was 77.9 kc, and at the end 39.1 kc. Low frequency waves (about 10 kc) accompany the pulse, but their amplitude is a very small fraction (1/100 to 1/1000 or less) of the peak sound pressure at ultrasonic frequencies. The envelope form is variable; the emission is directional with most of the energy concentrated into the forward direction; and the pulses are commonly repeated at rates of 20 to 30 per second.

893

Hartridge, H., "Acoustic Control in the Flight of Bats," Nature, 156, 490-494, 1945.

Bats undoubtedly emit sounds of more than one frequency, and it is stated that four different kinds of sound are produced: (1) a buzz, observable only at close quarters; (2) the signaling tone of about 7000 cps, usually having a duration of about 1/4 sec; (3) the supersonic tone, which is usually in the range 40-50 kcs — This sound can be emitted at rest and in flight; it may be emitted in single pulses of about 0.01 sec, or in a number of such pulses; at rest the number may be 5-10 per sec, but in flight it increases to 20-30 per sec — (4) a click. Physical characteristics connected with the production of these sounds and with the hearing of bats are discussed, and a brief comparison is made with radar. In the latter the wavelength goes down to 1 cm and in the bat it is about 0.7 cm. The bat has the further advantage of stereophonic reception to aid in the location of obstacles.

894

Hickling, R., "Frequency Dependence of Echoes from Bodies of Different Shapes," J. Acoust. Soc. Am., 30, 137-139, 1958.

The echo returned by a body is known to be frequency dependent if the incident sound has wavelengths greater than or comparable with the over-all dimensions of the body. This paper presents the results of calculations which determine the echoes from the end-on aspect of a rigid prolate spheroid of fineness ratio 5/3, and from the beam-on aspect of an infinite circular cylinder, the incident sound consisting of plane monochromatic waves. These are compared with similar known results for a sphere. For these examples it is shown that the frequency dependence of the echo varies significantly with the shape of the body which returns the echo. It is suggested that bats use such properties in determining the form of their surroundings.

895

Hori, S., "Study of Meteorological Surveillance Observing System," Quart. Progress Rept. No. 2, Armour Research Foundation, Chicago, Ill., 31 pp., 1959.
AD-272 375.

Several concepts for indirect measurement of atmospheric properties were uncovered. Two of these possess potential as the bases of true surveillance techniques and two others provide path-integrated measures of pertinent parameters. The four concepts discussed are: (1) acoustic sounding, (2) interaction of acoustic and electromagnetic energy, (3) gas emission thermometry, and (4) optical lapse rate observations. (See also Uretz (1960) for more reports in this series.)

896

Kontorovich, V. M., "Reflection and Refraction of Sound by Shock Waves," Soviet Phys. Acoust. English Transl., 5, 320-330, 1960.

This paper considers the reflection and refraction of small perturbations, mainly sound, at surfaces of discontinuity in a liquid or gas in general. At the discontinutiy it is assumed that the Rankine-Hugoniot conditions are satisfied. The coefficients of reflection and transmission of sound are determined and the reflection and refraction laws are given in simple geometric form. The author cites data which can be obtained by means of the acoustic "localization" of discontinuities.

897

Norwood, V. T., "Further Discussion on the Feasibility of Tracking Sound Waves by Electromagnetic Waves — and Appendixes I-IV," Signal Corps Eng. Labs., Fort Monmouth, N. J., 10 pp., 1949.
ATI-64, 904.

ECHO RANGING

The feasibility of tracking vertically propagated sound waves by radar was investigated, in order to obtain a complete time plot of the position. The property of the sound waves to be utilized is that of the dielectric variation, set up by successive pressure bands within the waves, which will reflect an electromagnetic wave. Since the velocity of sound is a function of temperature, valuable atmospheric information may be cheaply obtained. A sound wave of 2500 cycles is shown to be the optimum frequency for purposes of radar tracking. The actual reflectivity of a sound pulse will not be calculable until the solution of a Mathieu equation has been found. Wind considerations alone make the tracking of sound waves unfeasible for general atmospheric uses with the present radar equipment.

898

Perrine, J. O., "The Doppler and Echo Doppler Effect," Am. J. Phys., 12, 23-28, 1944.

This paper records an occasion in which one observer on a car and another on a puffing train approached each other rapidly on parallel courses. The puffs of the engine were seen and heard, and the frequency of the puffs as heard was noticeably different from the frequency as observed by eye. The author sets out 16 cases of the Doppler effect involving motion of generator, detector and reflector; after solving each case separately, he finds a combined formula adaptable to all 16 cases.

899

Slaymaker, F. H., and W. F. Meeker, "Blind Guidance by Ultrasonics," Electronics, 21, 76-80, 1948.

The limitations due to different reflection characteristics of various surfaces and objects and to fluctuations in reflection, when a portable "radar" system is employed, are discussed. Simple pulse, simple FM and pulsed-FM systems, all embodying separate transmitting and receiving magnetostriction transducers, are compared. The latter, which employs an ultrasonic oscillator with sawtooth variation of frequency but has narrow-band transducers, is considered the best because it introduces no contradictory information and permits some distinction between objects at different points. One model, operating at 32 kcs with 10 valves, mainly of the subminiature type, for transmitter and receiver and using headphones, enables the presence of a person to be detected at 30 feet. Later equipment is also described.

900

Strother, G. K., "Note on the Possible Use of Ultrasonic Pulse Compression by Bats," J. Acoust. Soc. Am., 33, 696-697, 1961.

The analogy between echo-location techniques used by bats and those used by radar is extended to the relatively new pulse compression radar technique. The hypothesis that the hearing mechanism of the bat contains a frequency-dependent time-delay network permits explanation of most of the anomalies associated with their behavior, including echo location by pulses which overlap in space.

901

Uretz, E. F., "Study of Meteorological Surveillance Observing System," Quart. Progress Rept. No. 5, Armour Res. Foundation, Chicago, Ill., 34 pp., 1960.
AD-263 684.

Acoustic measurement of wind is described. Block diagrams of the low level wind velocity measuring subsystem are given. The results of the computer simulation of an infrared radiometer and the subsequent reduction computation are presented and discussed. (See also S. Hori (1959) for earlier reports in this series.)

902

Zanotelli, G., "Acoustical Sounding of Clouds" (in Italian), Ann. Geofis. (Rome), 5, 55-76, 1952.

An elaborate analytical method is found for determining reflection indexes of waves at various frequencies in the audible scale, as functions of droplet size and number in the reflecting cloud. Values of audibility of the reflected sound with and without an amplifier are calculated. It is pointed out that this method of estimating drop size and number by recording the intensity of reflected sounds at varying frequencies should be very useful in observing quick changes taking place in a cloud owing to evaporation, condensation, cohesion, etc., particularly during stormy conditions.

Echo Ranging
see also — 590, 859, 864, 1258, 1266, 1348, 1430, 1454, 1455, 1465, 1952, 1968, 2136, 2183, 3351, 3697, 3777.

ENERGY PROPAGATION

903

Andreev, N. N., "Concerning Certain Second-Order Quantities in Acoustics" (in Russian), Soviet Phys. Acoust., English Transl., 1, 2-11, 1957.

Density and flux of sound energy, momentum, and pressure of sound radiation are examined fundamentally. The method of successive approximations for first and second order is the accepted basic process of discussing these problems, but it is considered essential to distinguish between the standpoints of Lagrange and Euler. The views of the author on density and flux of sound energy are at variance with the usual views. It appears that a full solution of these topics requires fuller examination of boundary conditions. The author develops an example at length to illustrate his points.

904

Biquard, P., "Ultrasonic Waves," Rev. Acoust. 1, 93-109, 1932.

A mathematical account of plane wave motion deriving from first principles expressions for the energy transmission associated with a sound wave and the decay of amplitude with distance due to viscosity and heat conduction. At $10^{o}C$ and at a frequency of 160,000 cps, the effect of conduction on damping is, for water, 7000 times less than the effect of viscosity; whereas for air it is only three times less. The paper concludes with Langevin's deduction of the fact that the pressure exerted by sound radiation is equal to the energy density of that radiation.

905

Broer, L. J. F., "On the Propagation of Energy in Linear Conservative Waves," Appl. Sci. Res., A2, 329-344, 1951.

This paper is concerned with the question of when and why the rate of energy propagation in a system of waves equals the group velocity. By the method of stationary phase it is shown that equality holds for traveling waves without dissipation whenever this method applies. Why this result can be obtained by this kinematical method is investigated by a discussion of simple harmonic waves. It is shown that the choice of an expression for the energy density to be used in connection with a given wave equation is restricted by the conservation of energy in such a way that the average rate of work done divided by the average energy density always equals the group velocity. Finally, some examples of wave motion are discussed to illustrate the derived formulae.

906

Cadez, M., "On Currents of Internal and Kinetic Energy in the Atmosphere" (in German), Gerlands Beitr. Geophys., 63, 130-144, 1953.

In addition to material transport of air in one direction (wind), there are innumerable longitudinal wave impulses (compression and rarefaction) radiating in all directions with the velocity of sound (e.g., from the centers of cyclones) and carrying energy. The equations of these energy waves and their decay are set out, but the energy transport is small and cannot be calculated.

907

Chu, B. T., and J. Y. Parlange, "A Macroscopic Theory of Two-Phase Flow with Mass, Momentum and Energy Exchange," Tech. Rept. No. 4, Brown Univ., Providence, R. I., 20 pp., 1962.
AD-277 975.

A macroscopic theory of two-phase flow with mass, momentum, and energy exchange is discussed. The theory is applied to the study of systems which depart only slightly from local thermodynamic equilibrium. An example of wave propagation in a two-phase medium with viscous and thermal relaxation is calculated. It confirms some of the predictions of previous research where a thermodynamic analysis was carried out.

908

Fischer, F. A., "Distribution of Sound from Sources in the Neighborhood of Plane Reflectors," Elek. Nackr.-Tech., 10, 19-24, 1933.

When sound is emitted from a point source near a reflecting surface, the effect at a distance is that of an acoustical doublet composed of the source and its image. Polar diagrams are drawn to show the sound distribution for typical cases when (a) there is no phase change, and (b) the reversal of phase occurs at the reflecting surface. In case (a) a maximum of intensity always occurs in the plane of the reflector, and other maxima and minima occur in directions inclined to this plane. In case (b) a minimum is always found in the plane of the reflector, and provided the source is not more than a quarter wavelength from the reflector, nowhere else. On increasing this distance other maxima and minima appear. If, instead of a single source, a series of equidistant sources on a normal to the surface is used, in case (a) the maximum in the plane of the reflector becomes relatively much greater; similarly the first maximum in (b), which is in a direction inclined to the surface, is more pronounced. Formulae are given in each instance for the acoustical energy of the system; and the application of the results to signalling on land and below the surface of water is discussed.

909

Gavreau, V., "Pressure of Sound Radiation According to the Kinetic Theory of Gases" (in French), J. Phys. Radium, 17, 899-904, 1956.

After referring to Rayleigh's formulae for the pressure of sound radiation, the author shows that it is possible to deduce the same relationships between sound radiation pressure and energy-density (proportional to I/c — where I is the intensity of the sound and c the velocity of propagation) by a direct application of the kinetic theory of gases. This theory explains all the peculiarities of the phenomenon and gives an estimate of the value of the radiation pressure. It is shown experimentally that the coefficient of proportionality between radiation pressure and sound intensity is independent of the nature of the gas.

910

Goulard, R., "The Coupling of Radiation and Convection in Detached Shock Layers," J. Quant. Spectr. Radiative Transfer, 1, 249-257, 1961.

Recent studies have shown that for sufficiently high reentry speeds, radiation energy transfer from high-temperature air becomes an appreciable part of the total energy transfer to the nose of the reentry body. This note is concerned with the effects of this fluid energy loss on the energy distribution in the shock layer and, therefore, on the convective and radiative fluxes at the wall. A nondimensional parameter is shown to govern the resulting coupling between radiative and convective fluxes. The first approximation which consists in assuming a constant stagnation temperature layer is shown to be acceptable for most ballistic and earth satellite reentry problems. For larger velocities or dimensions (e.g., planetary probes and heavy meteors), radiation losses become important, and it is necessary to include the radiation terms into the equations which determine the flow field.

911

Hunt, J. N., R. Palmer, and W. Penney, "Atmospheric Waves Caused by Large Explosions," Phil. Trans. A, 252, 275-315, 1961.

This paper considers the harmonic oscillations of several simple model atmospheres. The oscillations are of two types. In the first, the kinetic energy per unit volume tends to zero at great heights; in the second, the kinetic energy per unit volume remains finite. A large explosion at ground level excites a spectrum of both types of oscillation. The pulse ultimately separates into two parts — a train of traveling waves which can be observed at ground level at great distances, and a train of traveling waves which disappears into the upper atmosphere. The complete range of experimental observations on the pressure oscillations caused by explosions of energies varying between 10^{20} and 10^{24} ergs can only be interpreted with model atmospheres having one or more sound channels (i.e., having at least one minimum in the temperature-height relationship of the atmosphere). In spite of the complexity of the phenomena, the theory throws light on some of the characteristic features of the observations. The average period of the largest waves is roughly proportional to the cube root of the energy released by the explosion. The amplitudes of the waves from large explosions can be calculated. Conversely, good records enable the size of the explosion to be estimated. The energy of the Siberian meteorite of 1908 was about 10^{16} cal, or 10 MT (T signifying a ton of tnt).

912

Kraichnan, R. H., "On the Statistical Mechanics of an Adiabatically Compressible Fluid," J. Acoust. Soc. Am., 27, 438-442, 1955.

The extension of classical statistical mechanical methods to non-Hamiltonian systems is discussed. The statistical equilibrium of a confined adiabatically compressible fluid is examined on the basis of a generalized phase space representation, and it is found that there exists a tendency towards equipartition of energy between compressive and vorticity modes which is modified by the viscous dissipation forces. The application of the method to determining nonequilibrium energy transfers between acoustic modes and vorticity modes is discussed.

913

Lighthill, M. J., "On the Energy Scattered from the Interaction of Turbulence with Sound or Shock Waves," Rept. No. 15, 432, Aeronautical Research Council, Great Britain, 22 pp., 1952.
AD-20 290.

See abstract 914.

914

Lighthill, M. J., "On the Energy Scattered from the Interaction of Turbulence with Sound or Shock Waves," Proc. Cambridge Phil. Soc., 49, 531-551, 1953.
Journal article based on preceding entry.

The energy scattered when a sound wave passes through turbulent fluid flow is studied by means of the author's general theory of sound generated aerodynamically. The energy scattered per unit time from unit volume of turbulence is estimated as

$$(8\pi^2 L_1/\Lambda^2)\cdot I\cdot\left(\overline{v'_1{}^2}/a^2\right)$$

where I is the intensity and Λ the wavelength of the incident sound, and $\overline{v'_1{}^2}$ is the mean square velocity and L_1 the macro-scale of the turbulence in the direction of the incident sound. This formula does not assume any particular kind of turbulence, but does assume that Λ/L_1 is less than about 1. For isotropic and homogeneous turbulence, the energy scattered and its directional distribution are obtained for arbitrary values of Λ/L_1. It is predicted that components of the turbulence with wave-number k will scatter sound of wave-number K at an angle $2 \sin^{-1}$ (k/2K). The statistics of multiple successive scatterings is considered, and it is predicted that sound of wavelength less than the micro-scale of the turbulence will become uniform (i.e., quite random) in its directional distribution in a distance approximately $\lambda a^2/\overline{v'_1{}^2}$. The theory is extended to the case of an incident acoustic pulse. However, this extended theory cannot be applied directly to the case of a shock wave, for which it would predict infinite scattered energy. This is due to the perfect resonance between successive rays emitted forwards which would occur if the shock wave were propagated at the speed of sound. By taking into account the true speed of the shock wave (subsonic relative to the fluid behind it), the theory is improved to give a finite value, 0.8s times the kinetic energy of the turbulence traversed by a weak shock of strength s, for the total energy scattered. However, the greater part of this energy catches up with the shock wave and probably is mostly reabsorbed by it, and only the remainder is freely scattered behind the shock wave as sound. The energy thus freely scattered when turbulence is convected through the stationary shock-wave pattern in a supersonic jet may form an important part of the sound field of the jet.

915

Lindsay, R. B., "High-Frequency Sound Radiation from a Diaphragm," Phys. Rev., 32, 515-519, 1928.

By a hydrodynamical-acoustical method a calculation is made of the intensity of the high-frequency sound radiation from a circular piston-like oscillator at a distance from the oscillator greater than 2a, where a is the radius. It is shown that there is no parallel "beam" of sound of cross-sectional area equal to the area of the oscillator, but that nevertheless most of the sound energy is contained in a cone of solid angle $\pi(0.45\ \lambda/a)^2$ steradians, where λ is the wavelength of the radiation. Solution of the problem for points at great relative distance from the source then yields a result analogous to that obtained for the Fraunhofer diffraction of light through a circular aperture. The corresponding formula is $\pi(0.61\ \lambda/a)^2$. Comparison is made between the two methods and they are shown to be essentially the same, the difference in the formulae being solely due to difference in interpretation.

916

McLachlan, N. W., and A. T. McKay, "Rayleigh Formula for Velocity Potential, J. Franklin Inst., 223, 501 (Reply by S. Ballantine), 1937.

This paper answers a statement by Ballantine that the formula for velocity potential given by Rayleigh cannot properly be used for calculating the radiation from a rigid disc in an infinite baffle. The velocity potential due to a rigid flat disc in an infinite baffle and the velocity potential on one side of a vibrating infinite plane are calculated; it is concluded that Rayleigh's formula can quite properly be used. S. Ballantine (in reply) points out that this is true for a rigid flat disc and a plane baffle, but that for a curved disc and baffle the formula is inapplicable.

917

Molloy, C. T., "Calculation of the Directivity Index for Various Types of Radiators," J. Acoust. Soc. Am., 20, 387-405, 1948.

The "directivity index" is defined as "the ratio of the total acoustic power output of the radiator to the a.p.o. of a point source producing the same pressure at the same point on the axis." The utility of the d.i. concept is that it permits power calculations to be made for all radiators in the same manner as for point sources. D.i. formulae, together with graphs covering practical cases, are given for the following types of radiators: (1) general plane piston in infinite baffle; (2) circular plane piston in infinite baffle; (3) rectangular plane piston in infinite baffle; (4) sectoral horn; (5) multicellular horn; (6) piston set in sphere.

918

Oestreicher, H. L., "Representation of the Field of an Acoustic Source as a Series of Multipole Fields," J. Acoust. Soc. Am., 29, 1219-1222, 1957.

A representation of the field of a sound source of arbitrary shape and size as a series of multipole fields of increasing order is derived. This series is convergent for sources of any size if the surface is sufficiently regular, but its main advantage is for sources small compared to the wavelength. In this case the source has, in general, the directivity pattern of a multipole, the order and strength of which can be determined from the formula. Although the representation is not unique, certain coefficients have physical significance. The presently used definition of "strength of a sound source" is discussed and a modified definition suggested.

919

Ribner, H. S., "Note on Acoustic Energy Flow in a Moving Medium," Tech. Note No. 21, Inst. of Aerophysics, Univ. of Toronto, Canada, 8 pp., 1958.
AD-154 265.

Both acoustic energy density and energy flow are known to be modified by motion of the medium, as in a jet. Similarities and discrepancies in the formulas of three investigators are compared in order to infer a correct formulation. Examples of applications show how variations in the velocity of a stream carrying plane sound waves can change the "linear theory" acoustic energy density from positive through zero to negative, with corresponding changes in the energy flow.

920

Richter, G., "On the Energy Flow in a Sound Field in an Flowing Medium" (in German), Z. Physik, 125, 98-107, 1948.

The energy flow in the medium is studied from two different points of view: (1) following the course of one and the same particle of matter, (2) observing the flow across a fixed surface. The distinction between the two points of view is negligible for small motions, but important in relation to ultrasonic waves near cavitation limit, and to explosive waves of great intensity. The theoretical results worked out are illustrated by an application to plane waves subject to Hookes' pressure law.

921

Rzhevkin, S. N., "Energy Movement in the Field of a Spherical Sound Radiator" (in Russian), J. Tech. Phys. (USSR), 19, 1380-1396, 1949.

A generalized expression is given for the acoustic field of a composite spherical sound radiator, involving spherical Bessel and Neumann functions. The connection is shown between the conventional Stokes-Rayleigh functions f(jkr) and F(jkr) and the new, more convenient functions G(kr), D(kr), ϵ(kr), and δ(kr). The problem of the energy fluxes is investigated, and it is established that in the field of simple radiators tangential energy currents are absent, whereas they are always present with composite radiators. As an example, the field of the radiator of order (0 + 1) is analyzed in detail, general expressions being obtained for the "additive energy" and "additive mass" of zonal and sectorial radiators of any order.

922

Sacerdote, G., "Density of Energy in Acoustic Problems," Pontif. Acad. Sci., Acta, 3, 47-52, 1939.

In many acoustical problems, particularly in those of the distribution of sonorous energy and of the course of the sound wave in a definite medium, the density of energy is taken as fundamental parameter. In fact, the analytical expression of such phenomena as a function of the density of energy has a simpler form than when presented as a function of the pressure. The density of energy may be considered as a parameter to be considered by itself. This density is defined as follows: $E = 1/2 (\rho V^2 + P^2/\rho c^2)$, and it is the sum of the kinetic and potential energies per unit of volume; ρ = density of medium, c = velocity of sound, V = velocity of displacement, P = sonorous pressure. After treating the general equations of propagation, the author deals with certain applications to architectural acoustics which become simpler by means of this method.

923

Schoch, A., "Remarks on the Concept of Acoustic Energy," Acustica, 3, 181-184, 1953.

The conventional expressions for acoustic energy — recently found not to be correct in a strict sense — are shown to have characteristic properties by which their use in acoustics can be justified satisfactorily.

924

Stewart, K. H., "Air Waves from a Volcanic Explosion," Meteorol. Mag., 88, 1-3, 1959.

Explosion of the volcano Bezyymyannaya Sopka in Kamchatka (55°57'N, 160°32'E) at 0611 GMT, March 30, 1956, was reported to have "exceeded several dozen times the strength of an explosion of an ordinary atom bomb." Reexamination of the microbarograph record at Kew Observatory for the day shows the arrival of the air wave, also traceable on the float and on the photo barographs. Eskdalemuir and Lerwick recordings also clearly featured the rapid (about 0.2 mb) pressure fall as tabulated here with clock corrections. Thermonuclear 0.2 mb pressure fall has been recorded at Kew Observatory. The difference between sound waves and "long" waves is considered in relation to propagation influenced by atmospheric temperature, and likewise the wave energy as influenced by elevation. In this case, the energy was found to be 1×10^{21} ergs.

925

Tartakovskii, B. D., "Sound Transmission Layers" (in Russian), Dokl. Akad, Nauk SSSR, 75, 29-32, 1950.

The article works out algebraically and diagrammatically a solution to the problem of rendering the boundaries of different media fully conductive. An examination of the method of propagation of plane waves through similar layers leads to a study of the conditions under which sound energy is transmitted without loss through the boundary separating two different media, between which the sound transmission layers are situated. The formulae advanced are held to prove that, in principle, any medium can be rendered fully conductive by a combination of layers consisting of materials whose applicability can be tested by means of a graph in which coordinates are placed on a logarithmic scale. Graphs are also given illustrating energy-conductivity calculation for a given case and the dependence of conductivity upon angle of incidence. Ernst's conclusions as to the behavior of certain layers independently of the law of distribution of their wave-resistances are incidentally judged to be erroneous.

926

Thiessen, G. J., "On the Efficiency of an Acoustic Line Source with Progressive Phase Shift," Can. J. Phys., 33, 618-621, 1955.

The introduction of a small continuous phase shift along the length of a finite line source does not result in a decrease of energy radiated, but simply causes the directionality pattern to change. When the phase shift is such that it corresponds to the phase shift with distance on a sound wave, the directionality pattern has changed through 90°, and the energy radiated begins to drop rapidly. At this point the slope of the curve of energy vs. phase shift parameter increases with increasing frequency.

927

Thouvenin, J., "Dissociation and Ionization of Air by a Shock Wave" (in French), J. Phys. Radium, 19, 639-648, 1958.

The composition and internal energy of air are computed for a range of temperature from 3500 up to 11,500°K and for a range of density from 4 to 12 times normal density. In another connection, the increase of internal energy of air by a shock wave traveling through it is evaluated in terms of the same parameters. By adjusting both expressions of energy, a relation between the temperature T and the ratio of molecular volumes V_0/V ahead and behind the shock front is obtained. The other physical variables— pressure, front velocity, material velocity, degree of ionization — can then be computed if either of parameters T or V_0/V is known. Conversely, measurement of any one physical variable makes it possible to get values of all the others. Present calculations show the oxygen to be completely dissociated by strong shock waves (velocities above 7000 m/s), the nitrogen by a rate of 50% higher, and the concentration of free electrons to be over 0.1%.

928

Vautier, T., "Dissipation of the Energy Transported by a Sound Wave in Air," Compt. Rend., 189, 1253-1255, 1929.

In previous papers the author has described experiments on explosions in tubes and given waveforms obtained by the interferential method. The surface between the line of equilibrium and the time-pressure curve is proportional to the energy of the wave, and the variation of this surface as the wave travels along the tube makes it possible to follow the dissipation of the energy. A study of the previous results on these lines shows that if the wave is reflected at the end of the tube, ψ, the coefficient of reflection, is equal to 0.92 for short waves and 0.96 for long ones, and σ, a constant in the equation $S = S_0 e^{-\sigma x}$, which shows how the energy diminishes with x, the distance travelled in cm, is equal to 2.2×10^{-7} for short waves and 1.6×10^{-7} for long ones.

929

Weir, R. A., and A. F. Wickersham, Jr., "Small Amplitude Electro-Acoustic Plasma Oscillations," Tech. Memo No. EDL-M488, Electronic Defense Lab., Mountain View, Calif., 6 pp., 1962. AD-285 146.

Electrostatic-acoustic disturbances will propagate with but slight attenuation through an ionized medium, even if the medium includes high concentrations of neutral particles. Thus a propagation mode must exist in which most of the kinetic energy resides in the electrons rather than in the ions. A theory comprising both an ionic and an electronic mode is obtained by deriving a set of differential equations, which describe small-amplitude, longitudinal, coherent oscillations in the plasma. Such a theory is briefly compared with recent observations.

Energy Propagation
see also—28, 69, 550, 569, 759, 793, 839, 962, 968, 984, 1003, 1013, 1018, 1022, 1127, 1250, 1370, 1539, 1817, 1820, 2158, 2519, 2561, 2587, 2603, 2907, 3088, 3094, 3274, 3362, 3443, 3466, 3520, 3538, 3550, 3613, 3656, 3722, 3748, 3903, 3974, 3996, 3999, 4201, 4267, 4344.

HEAT CONDUCTION AND CONVECTION

930

Alleman, R. S., "Heat Conduction Effects in Sound Emission," J. Acoust. Soc. Am., 13, 23-25, 1941.

This article is a mathematical formulation of the heat-conduction phenomena which occur at the surface of a sound emitter, wherein the medium considered to be receiving the sound and impeding the motions of the source is gas. The method is that previously used by Herzfeld. The result is that, due to the rapid, approximately adiabatic, compressions and rarefactions, an alternating temperature gradient is set up in the solid source and in the medium in such a manner as to cause a reduction in the total amount of sound energy radiated from the source. This effect is expressed in terms of ② out-of-phase components of particle velocity amplitude. The results had previously been applied in the revision of Hubbard's theory of the ultrasonic interferometer to take account of these heat conduction effects, and the experimental verification of the predicted reflection coefficients for several gases is taken as experimental justification of the theoretical synthesis given.

931

Biquard, P., "Ultrasonic Waves," Rev. Acoust. 1, 93-109, 1932.

A mathematical account of plane wave motion deriving from first principles expressions for the energy transmission associated with a sound wave and the decay of amplitude with distance due to viscosity and heat conduction. At $10^{o}C$ and at a frequency of 160,000 cps, the effect of conduction on damping is, for water, 7000 times less than the effect of viscosity; whereas for air it is only three times less. The paper concludes with Langevin's deduction of the fact that the pressure exerted by sound radiation is equal to the energy density of that radiation.

932

Bourgin, D. G., "Sound Propagation in Gas Mixtures," Phys. Rev., 34, 521-526, 1929.

An earlier treatment of the propagation of sound in mixtures of two gases is generalized and somewhat simplified. The essential point of the theory is the consideration of the internal energy variations by the assignment of fictitious internal state temperatures which, in the simplest case assumed here, are taken to be constant for each of the component gases. The long-wavelength velocity expression is directly interpretable as a Laplace formula for a gas of mean reciprocal mass and averaged specific heat. From a more general point of view, the velocity of propagation of infinitesimal waves is always given by the Laplace result, provided that a frequency variation of specific heats is recognized. Explicit mention is made of the detailed effect of viscosity and the two conductivities. Experimental data support the theory.

933

Chabai, A. J., "Measurement of Wall Heat Transfer and Transition to Turbulence During Hot Gas and Rarefaction Flows in a Shock Tube," Tech. Rept. No. 12, Inst. of Res., Lehigh Univ., Bethlehem, Pa., 86 pp., 1958. AD-203 835.

A thin film resistance thermometer was developed for the study of transient boundary layer flows in the shock tube. Measurements of wall heat flux during laminar flow are presented and compared with theories for the hot gas, the cold gas, and the rarefaction regions of shock tube flows. The experimental results indicate an excellent agreement with the theories of hot gas flow, a general consistency with the theory of cold gas flow, but some unaccountable deviations from the theoretical expectations for rarefaction flows. A Reynolds number for the hot gas flow was proposed; the critical value of this number predicts the time at which the laminar flow is observed to become turbulent. Several Reynolds numbers for the rarefaction flow are proposed, but no correlation between these numbers and the measured transition times are found to exist. The instrument allows previously unexplored boundary layer phenomena to be investigated.

934

Eastwood, I., T. W. Jackson, et al., "Heat Transfer Threshold Values for Resonant Acoustic Vibrations in a Horizontal Isothermal Tube," Rept. No. ARL 62-326, Rept. on Mechanics of Flight, Georgia Inst. of Tech., Atlanta, 115 pp., 1962. AD-277 993.

Data are reported for experiments conducted to study the effects of a resonant acoustic vibration on the heat transfer coefficient for air flowing through an isothermal tube for Reynolds numbers between 16,000 and 200,000. The local heat-transfer coefficient varies periodically between the nodes and loops of the resonant sound wave. For Reynolds numbers below approximately 20,000, the maximum local Nusselt numbers occur at the velocity loops of the standing wave. Above a Reynolds number of 40,000, the maximum values of the Nusselt numbers shift to the velocity nodes. This shift appears to take place gradually between Reynolds numbers of 20,000 and 40,000. Above a Reynolds number of approximately 40,000, resonant acoustic vibrations tend to suppress the over-all heat transfer rate. Threshold sound-pressure level values for a resonant frequency of 222 cps were obtained for various Reynolds numbers from 16,000 to 80,000. These critical sound pressure level values fell into two distinct regimes when plotted versus the corresponding Reynolds number. In each regime the critical value was directly proportional to the Reynolds number.

935

Fand, R. M., and J. Kaye, "Acoustic Streaming near a Heated Cylinder," J. Acoust. Soc. Am., 32, 579-584, 1960.

A photographic study employing smoke as the indicating medium has shown the existence of a new type of streaming near a heated horizontal cylinder in the presence of a horizontal transverse sound field. This phenomenon, called "thermoacoustic streaming," is characterized by the development of two vortices above the cylinder; the fluid pattern resembles vortex shedding behind a cylinder in forced flow normal to its axis. In the presence of sound waves whose half-wavelength is six or more times greater than the diameter of the heated cylinder, the formation of the vortex flow is a function of the sound intensity only; for such wavelengths the vortices begin to appear at 140 db (re 0.002 μbar) and become fully developed at 146 db. This type of streaming is a flow phenomenon which is much stronger than isothermal streaming for the same geometry and sound intensity. It appears that thermoacoustic streaming will have important practical applications, particularly in the field of heat transfer.

936

Fand, R. M., J. Roos, et al., "The Local Heat Transfer Coefficient Around a Heated Horizontal Cylinder in an Intense Sound Field," Final Tech. Rept. No. ARL-148, Rept. on Research on Aerodynamic Fields, Mass. Inst. of Tech., Cambridge, 25 pp., 1961. AD-275 772.

A study was made of the local heat-transfer coefficient around the circumference of a heated horizontal cylinder, both in the presence and absence of a strong stationary sound field. Superposition of intense sound upon the free-convection temperature-velocity field about a heated horizontal cylinder increases the heat-transfer coefficient on both the under and upper portions of the cylinder's surface. In the presence of a sound field for which SPL = 146 db (re 0.0002 microbar) and f = 1500 cps, the maximum measured increases in the local heat-transfer coefficient on the under and upper portions of a 3/4-inch diameter cylinder—relative to the free convection case at the same temperature potential—were approximately 250% and 1200%, respectively. A comparison of these results with earlier flow-visualization studies indicates that the relatively large percentage increase in the heat-transfer coefficient on the upper portion of the cylinder is caused by the oscillating vortex flow which is characteristic of thermoacoustic streaming.

937

Goulard, R., "The Coupling of Radiation and Convection in Detached Shock Layers," J. Quant. Spectr. Radiative Transfer, 1, 249-257, 1961.

Recent studies have shown that for sufficiently high reentry speeds, radiation energy transfer from high-temperature air becomes an appreciable part of the total energy transfer to the nose of the reentry body. This note is concerned with the effects of this fluid energy loss on the energy distribution in the shock layer and, therefore, on the convective and radiative fluxes at the wall. A nondimensional parameter is shown to govern the resulting coupling between radiative and convective fluxes. The first approximation which consists in assuming a constant stagnation temperature layer is shown to be acceptable for most ballistic and earth satellite reentry problems. For larger velocities or dimensions (e.g., planetary probes and heavy meteors), radiation losses become important, and it is necessary to include the radiation terms into the equations which determine the flow field.

938

Herzfeld, K. F., "Reflection of Sound," Phys. Rev., 53, 899-906, 1938.

The losses in the reflection of sound on solids are investigated. The heat conduction of the solid disturbs the temperature distribution in the gas and sets up a temperature wave. That the pressure in the gas near the wall is no longer in phase with the density results in a heating of the gas on the wall. The effect amounts to a few percent for a million cycles. The scattering of the molecules on the wall, the scattering of the sound waves by uneven places, and the effect of absorption are also investigated. They become important only at higher frequencies.

939

Holman, J. P., "On the Effects of Sound Waves on Heat Transfer," J. Acoust. Soc. Am., 32, 407-408, 1960.

A discussion is presented of the physical mechanism, as proposed by Westervelt, whereby heat transfer rates may be increased in the presence of intense sound fields.

940

Jackson, T. W., K. Purdy, et al., "The Effects of Resonant Acoustic Vibrations on the Local and Overall Heat Transfer Coefficients for Air Flowing Through an Isothermal Horizontal Tube," Georgia Inst. of Tech., Atlanta, 122 pp., 1961. AD-249 451.

Results are presented for a series of experiments conducted to study the local and overall effects of a resonant acoustic vibration on the heat transfer coefficient for air flowing through a constant temperature isothermal tube at Graetz Numbers from 33 to 5400. The local heat transfer coefficient is shown to vary periodically between the nodes and loops of the resonant sound wave. Local heat transfer coefficients up to 3.6 times the no-sound values were obtained. Extensive tables of data are included for possible use in analytical investigations. Sound pressure levels to 162 decibels are reported.

941

Jarvis, S., Jr., "Note on the Papers: I. 'Combined Translational and Relaxational Dispersion of Sound in Gases,' by M. Greenspan; II. 'The Effects of Viscosity and Heat Conduction on the Transmission of Plane Sound Pulses,' by J. R. Knudsen," J. Acoust. Soc. Am., 27, 613, 1955.
See Also: Greenspan, M., J. Acoust. Soc. Am., 26, 70-73, 1954.
See Also: Knudsen, J. R., J. Acoust. Soc. Am., 26, 51-57, 1954.

For the "Becker" gas, the heat conductivity K and viscosities (μ, λ) satisfy $K = (2\mu + \lambda)C_p$; transient three-dimensional acoustic pressure disturbances are propagated according to a third-order equation derivable from the Navier-Stokes equations.

942

Kaspar'iants, A. A., "On the Propagation of Sound Waves in a Viscous Gas in the Presence of Heat Conduction" (in Russian), Prikl. Mat. Meh., 18, 729-734, 1954.
See Also: Translation available from M. D. Friedman, 2 Pine Street, West Concord, Mass.

General solutions are obtained of linearized equations for viscous, thermally conducting perfect gases, assuming the velocity, condensation, etc., are proportional to $e^{i\sigma t}$, where σ is a constant.

943

Keller, J. B., "Decay of Spherical Sound Pulses Due to Viscosity and Heat Conduction," J. Acoust. Soc. Am., 26, 58, 1954.

By combining the results of Kirchhoff and Knudsen, the effect of viscosity and heat conduction on a spherical sound pulse are found. A rectangular pulse becomes Gaussian, its peak moves with sound speed, its width increases proportionally to vt, and its amplitude decreases proportionally to $x^{-3/2}$, where x denotes radial distance from the origin. This behavior is exactly the same as that of a pulse in one dimension, except for an extra factor of 1/x which accounts for the spherical spreading.

944

Kittel, C., "Ultrasonic Research and the Properties of Matter," Repts. Progr. Phys., 11, 205-247, 1946-1947.

HEAT CONDUCTION AND CONVECTION

The theoretical treatment of the propagation of sound waves in gases, liquids, and solids is given and the expressions for the velocity of sound are derived. The theory of absorption in gases and liquids due to heat conduction, viscosity, and thermal relaxation is given. Reference is also made to absorption in solids caused by thermoelastic relaxation, scattering, plastic flow, thermal conductivity, structural relaxation, anharmonic coupling, and magnetic effects. A comprehensive review of the present status of measurements made on gases, liquids, and solids is given. The development of electronic pulsed-circuit techniques in the 1-30 mcs range is described, and the possibilities of extending the upper frequency limit are discussed. The use of ultrasonics in conjunction with radar is mentioned, together with recent industrial applications. A section on propagation in liquid He is included. Over 200 references are quoted.

945

Knudsen, J. R., "The Effects of Viscosity and Heat Conductivity on the Transmission of Plane Sound Pulses," J. Acoust. Soc. Am., 26, 51-57, 1954.

The dissipative effects of viscosity and heat conductivity are studied here in connection with the flow of a compressible fluid in a parallel channel or tube. Two kinds of waves or pulses are considered, and the distortion from the customary square wave is calculated. One observer at a fixed point on the channel, and two travelling with the wave, are seen to give information on the order of decay or dissipation of the wave with increasing time.

946

Kubanskiy, P., "Note on Theory of Acoustic Streams in the Environs of Heated Solids," Aerospace Tecn. Intelligence Center, Wright-Patterson Air Force Base, Ohio, 10 pp., 1961. AD-258 840.

A modified system of equations is presented which describes the phenomenon of acoustic streams distorted by convection; the substantiation of assumptions simplifying the solution of the problem is also given. Formulas are derived for calculation of stream velocities and temperatures in the vicinity of a heated-up solid placed into an acoustic field of a high amplitude. Formulas are obtained for calculation of the heat transfer coefficient. The possibility of applying the superposition principle to acoustic and convective flows at a moderate intensity is noted.

947

Lyubimov, G. A., "The Effect of Viscosity and Heat Conduction on the Flow of a Gas Behind a Severely Curved Shock Wave," Foreign Tech. Div., Air Force Systems Command, Wright-Patterson AFB, Ohio, 5 pp., 1962. AD-270 763

Formulas are derived for the relation of stagnation temperatures and pressures behind and in front of a shock wave of any shape, by taking into account the viscosity and thermal conductivity of a gas.

948

Mawardi, O. K., "On Acoustic Boundary Layer Heating," J. Acoust. Soc. Am., 26, 726-731, 1954.

The conventional investigations of the propagation of sound waves in conduits, when the effect of dissipation through friction and conduction of heat through the walls is taken into account, assume that the fluctuating part of the temperature of the gas vanishes at the boundaries. This is in essence a first-order approximation. Very different effects, however, are expected when sound-order terms are considered. The purpose of the present paper is to discuss in detail the nature of the solution obtained from a second-order approximation.

949

Miles, J. W., "Dispersive Reflection at the Interface Between Ideal and Viscous Media," J. Acoust. Soc. Am., 26, 1015-1018, 1954.

The effects of viscosity and heat conduction (in the reflecting medium) in producing dispersive reflection of a plane wave at the plane interface separating two media are investigated. If the reflecting medium is treated as a condensed fluid, heat conduction is found to have no effect, while in first approximation, viscosity is found to produce no change in amplitude but rather a phase shift proportional to frequency (and therefore no phase distortion) at angles of incidence above critical and to produce no phase shift but amplitude distortion at angles below critical. This amplitude distortion is found to be important only in the neighborhood of a sharp wave front.

950

Naugol'nykh, K. A., "Propagation of Spherical Sound Waves of Finite Amplitude in a Viscous Heat-Conducting Medium," Soviet Phys. Acoust., English Transl., 5, 79-84, 1959.

The form of a finite-amplitude wave alters as it is propagated because non-linear effects increase the steepness of the wave profile. If the medium is viscous and heat-conducting, these two properties tend to smooth out the profile and to decrease the velocity and temperature gradients. The effect of viscosity and heat conduction is, therefore, the opposite of the nonlinearity of the medium. The form of a finite amplitude wave in a viscous and heat-conducting medium will be determined by the ratio of nonlinear and dissipative (viscosity and heat conduction) effects. The author discusses propagation of spherical waves of finite amplitude produced by a harmonically pulsating sphere, whose radius is large compared with the emitted wavelength. The problem is dealt with using the Krylov-Bogolyubov method. Conditions when nonlinear effects become important are found.

951

Powers, W. E., K. F. Stetson, M. C. Adams, "A Shock Tube Investigation of Heat Transfer in the Wake of a Hemisphere-Cylinder, with Application to Hypersonic Flight," Res. Rept. No. 30, AVCO Research Lab., Everett, Mass., 36 pp., 1958. AD-205 513.

Wake-heat transfer experiments were conducted in a constant area shock tube under conditions which simulate hypersonic velocities. The preliminary objective of establishing the utility of the shock tube for wake investigations was verified as steady-state wake-heat transfer rates, and stable wake geometries were obtained in less than 100μsec. The heat transfer coefficients for the wake of a sting-supported hemisphere-cylinder configuration were obtained for laminar and turbulent flow on the body. Laminar heat transfer rates for the wake averaged about two-thirds of the theoretical laminar heat transfer rate to a solid surface replacing the wake mixing line. The magnitude of the turbulent heat transfer rates was about one-third of the turbulent prediction for a solid surface replacing the wake boundary. No distinguishable variations of heat transfer rates to the sting or rear face of the model were observed for sting-to-body diameter ratios of 0.3 and 0.6 and observed variations within the wake were less than the experimental scatter of about ±20%.

952

Rabinowicz, J., "Measurement of Turbulent Heat Transfer Rates on the AFT Portion and Blunt Base of a Hemisphere-Cylinder in the Shock Tube," Memo No. 41, Guggenheim Aeronautical Lab., Calif. Inst. of Tech., Pasadena, 24 pp., 1957. AD-149 977.

Turbulent heat-transfer rates were measured on the aft portion and on the blunt base of a hemisphere cylinder in the Galcit shock tube with a 2 7/8-in. square cross section over a range of shock M 3.25 to 5.1 and initial pressures between 3 and 17 cm Hg. The local Reynolds numbers on the cylindrical afterbody varied between 3.5×10^4 and 3.0×10^5/cm. A side support for the model was used in order to eliminate the disturbing effect of a rear sting support. The measured turbulent heat-transfer rates on the cylindrical portion agreed very well with previous flat plate measurements for small temperature differences, although the ratio of stagnation to surface enthalpy varied between 3 to 8. The measured heat-transfer rate on the base indicated that at the center of the base it is comparable to that on the surface just ahead of the base, while the rate falls off to 1/2 to 1/3 of this value towards the rim of the base. This unexpected distribution of heat-transfer rate over the base, and particularly the high value at the center, shows the necessity for a careful study of wake phenomena.

953

Rocard, Y., "Damping of Sound Waves," J. Phys. Radium, 1, 426-437, 1930.

This article discusses the damping of sonorous or ultrasonorous waves in a homogeneous gaseous medium. It reviews the work of Stokes, Rayleigh, and Chapman on the modifications to be introduced into the fundamental hydrodynamical equations in order to allow for viscosity, the influence of the radiation of heat, and the thermal conductivity of air. It considers the damping due to the reciprocal diffusion in air of its constituent elements. By this the condition of adiabatism is altered, and a new adiabatic equation is deduced. This new equation has a form $PV^{\gamma+i\beta\gamma}$ = const., where the imaginary, i, indicates a displacement of phase between the variations of pressure and volume for the particular frequency used in determining the value of $\Delta\omega$. The value of $\Delta\gamma$ once obtained, it is easy to calculate the amount of damping due to this cause. The same method is used in a revision of the previous work of Stokes, Rayleigh, and Chapman. The relative importance of the different causes of damping is discussed.

954

Sakadi, Z., "Dispersion of Sound Waves, Considering the Effects of Heat Conduction and Viscosity," Proc. Phys.-Math. Soc. Japan, 23, 208-213, 1941.

This is a mathematical analysis in which the following assumptions are made: (1) the disturbance by the sound wave is very small, so that every quantity differs little from that of the static state; (2) there is only one excited state, and the number of excited molecules is very small compared with that of unexcited molecules. An addendum contains numerical data for CO_2 which show that consideration of conduction and viscosity introduces a small correction to the sound dispersion.

955

Sedov, L. I., M. P. Michailova, and G. G. Chernyi, "On the Influence of Viscosity and Heat Conduction on the Gas Flow Behind a Strong Shock Wave," Rept. No. WADC-TN 59-349, 1959. AD-227 413.

The authors investigate, mathematically, the influence of viscosity and heat conduction of a gas in supersonic flow past a small body. The specific case chosen is for the symmetric supersonic flow of a gas past a body of revolution or a planar profile with formation of a frontal detached shock wave.

956

Westervelt, P. J., "Effect of Sound Waves on Heat Transfer," J. Acoust. Soc. Am., 32, 337-338, 1960.

It is suggested that the effect of sound waves on heat transfer is dominantly a result of the modification of the inner streaming boundary layer which is known to occur when the sound particle displacement amplitude exceeds in magnitude the acoustic boundary layer thickness.

957

Wilkes, M. V., "Atmosphere Oscillations," Nature, 164, 281, 1949.

In order to remove certain difficulties in the treatment by Pekeris (Proc. Roy. Soc. A, 158, 650, 1937) of long-period oscillations, the author first discusses the effect of heat conductivity on the damping of atmospheric waves. He shows that the two recognized ways in which damping may arise through heat conductivity do not apply to the same physical system. Accordingly he finds that in the analysis followed by Pekeris there are no general grounds for supposing that the wave will be attenuated in the direction of energy flow. If, however, radiation is taken as the damping agency, the difficulty is removed, and an analysis similar to that of Pekeris gives a wave always attenuated in the direction of propagation.

958

Zhumartbaev, M., "Absorption of Sound and the Width of Shock Waves in Relativistic Hydrodynamics," Soviet Phys. JETP, English transl., 37(10), 711-713, 1960.

The absorption coefficient of sound due to viscosity and heat conduction of the medium is derived in relativistic hydrodynamics. The structure of relativistic low-intensity shock waves is considered.

959

Zoller, K. "On the Structure of the Compression Shock" (in German), Z. Physik, 130, 1-38, 1951.

In a previous treatment by Becker (Z. Physik, 8, 321 (1922)) the contributions of viscosity and thermal conductivity to the equations of conservation of mass, momentum, and energy through a stable plane shock wave were expressed in terms of only the first derivatives of the velocity and temperature of the gas-flow. In the present treatment, the viscosity and thermal conductivity are derived from the kinetic theory of a gas consisting of point-masses having an inverse-fifth-power law of repulsion; this is equivalent to expressing the viscosity and thermal conduction terms in the conservation equations as an infinite series of derivatives and their cross-products. The effects of 2nd-order derivatives and the cross-products of 1st-order derivatives have been taken into account in numerical solutions carried out for pressure-ratios p_1/p_0 = 1.5, 4.0 and 6.5 (where p_1 is the pressure behind the shock and p_0 the pressure before the shock). These calculations show that the thickness of the shock-front for p_1/p_0 = 4.0-6.5 is 2-3 times as large as would be expected on Becker's theory. It is pointed out, however, that for p_1/p_0 = 6.5, and to a lesser extent for p_1/p_0 = 4.0, the results are somewhat unreliable, because in these cases the effects of higher-order derivatives may not be negligible; but the computational labor involved in dealing with derivatives higher than second-order becomes prohibitive.

Heat Conduction and Convection — see also Absorption, Classical

See also — 13, 17, 44, 52, 53, 58, 59, 65, 68, 76, 101, 159, 180, 184, 202, 205, 216, 234, 245, 248, 586, 590, 735, 782, 813, 822, 1057, 1187, 1318, 1537, 1561, 2106, 2866, 3075, 3090, 3099, 3178, 3213, 3352, 3549, 3553, 3622, 3633, 3634, 3663, 3673, 3748, 3752, 3803, 3820, 3821, 4070, 4131, 4209, 4243, 4263, 4266, 4267, 4321, 4337.

HIGH INTENSITY SOUND

960

Alexander, P., "Powerful Acoustic Waves," Research (London), 3, 68-73, 1950.

The present position of ultrasonics is summarized, and the piezoelectric and magnetostriction generators and the Pohlmann whistle are described. The chemical and physiochemical effects of ultrasonic vibrations are ascribed to cavitation or to the accelerations of particles in the sound field, and the results obtained so far are described.

961

Bies, D. A., and O. B. Wilson, Jr., "Acoustic Impedance of a Helmholtz Resonator at Very High Amplitude," J. Acoust. Soc. Am., 29, 711-714, 1957.

The acoustic impedance of a Helmholtz resonator terminating a 10-inch-diameter tube has been investigated for sound pressure levels in the resonator of from 100 db to 170 db and for a range of particle velocities in the neck of from 1.3 cm/sec to 1.2×10^4 cm/sec (rms). Two different mounting orientations showed the same general rise in acoustic resistance and rise in resonant frequency with increasing sound pressure level but gave quite different results in detail.

962

Bocker, P., "Measurements on High Intensity Ultrasonic Fields in Air," Acustica, 11, 31-38, 1961.

By means of a resonance oscillator, a sinusoidal ultrasonic field was produced in air at a frequency of 30 kcs and having an intensity up to 0.25 w/cm^2. At this intensity and frequency the equation of state is no longer linear, and the wave front within a propagation distance of 30 cm becomes completely steepened. This steepness was analyzed, and the radiation pressure in the steep-fronted wave was compared with that of a harmonic wave.

963

Bolt, Beranek, and Newman, Inc., "Wide Band Sound Source for WADD Sonic Facility," Summary Analysis Rept. WADD TR 61-109, Cambridge, Mass., 66 pp., 1961.
AD-266 342.

The following were concluded regarding a wide-band sound source: (a) The gas-fuel-powered wide-band acoustic generator is feasible and probably practical in the 100 kw (net) power range. There is no apparent reason why much higher power ratings could not be considered. (b) The optimum acoustic efficiency is obtained with tandem-type devices operating at high inlet charge density, low fuel energy, and low compression ratio so as to avoid excessive exhaust temperatures. The air-spring device is much less efficient but can use high-energy fuels and high compression ratios. (c) The exhaust temperatures can be lowered by injection of secondary air at low (close-to-atmospheric) pressure. (d) The discussion was based on acetylene, but butane, coke-gas or methane would probably be satisfactory. There appears to be no advantage in the use of hydrogen, which was disqualified because of its detonation characteristics.

964

Borisov, Yu. Ya., and L. O. Makarov, "Certain Records in Ultra-Acoustics," (Trans. No. MCL-1229 from "Ultrasonics in the Technology of the Present and Future," Moscow, 77-80, 1960) 4 pp., 1961
AD-264 498.

These are excerpts from the book "Ultrasonics in the Technology of the Present and Future." Several methods of obtaining high density focused ultrasonic energy are briefly discussed: shaped transducers, passive focusing devices, and a new method of irradiation.

965

Burris-Meyer, H. and V. Mallory, "Psycho-Acoustics, Applied and Misapplied," J. Acoust. Soc. Am., 32, 1568-1574, 1960.

The novel and often amusing experiments with psycho-acoustic phenomena and some of the instruments which were developed in the process are chronicled for the period during and immediately following World War II. The article is both humorous and informative. There are descriptions of high-intensity sirens, aircraft-mounted public address systems, and the biggest "Hi Fi" system in the world up to that point in history. The latter included a loudspeaker the size and shape of a freight car. It was used to reproduce recordings of battle sounds (as a troop training aid) and could match the acoustic intensity of 5-inch guns at a range of two miles.

966

Cole, J. N., R. G. Powell, H. L. Oestreicher, and H. E. von Gierke, "Acoustic Siren for Generating Wide-Band Noise," J. Acoust. Soc. Am., Bio-Acoustics Branch, Aerospace Medical Res. Labs., Wright-Patterson Air Force Base, Ohio, 35, 173-191, 1963.

Principle, theory, and an experimental development program for a new type of siren, capable of generating wide-band noise, are discussed with special emphasis on its application to the economic and realistic simulation of high-intensity jet and rocket-noise environments. In contrast to conventional sirens with a single rotor, this wide-band noise siren uses a series of overlapping, slotted rotors rotating at different speeds to produce the modulation of an air flow through a nozzle. Mathematically, the sound field generated by this siren can best be approximated by an "almost periodic" function; that is, a function whose spectrum is a line spectrum but with infinitely many lines in each interval of frequency. A series for the power spectrum can be derived and used to guide the design. For most practical purposes, the resulting acoustic field radiated by the siren represents random noise. Data on acoustic power, spectrum, efficiency of noise generation, and fine structure of the noise for various experimental siren types are presented. The potential value of this principle for large-scale installations (sonic fatigue and missile-component testing and bio-acoustic applications) is evaluated.

967

Crawford, A. E., "Ultrasonic Engineering," Academic Press, New York, 344 pp., 1955.

After a very brief presentation of the theory of ultrasonic radiation and a chapter on cavitation in liquids, the next 100 pages are devoted to the treatment of the generation of high-intensity and high-frequency sound. The remaining 180-odd pages discuss the specific applications, including precipitation, emulsification, chemical action, metallurgical processing, coating of metals, as well as biological and medical applications. There is a final chapter on ultrasonic instruments and control gear.

The treatment is descriptive throughout, with a minimum of emphasis on analytic detail. For the most part the formulas are introduced from the technical literature without deduction, much of the analysis having been replaced by numerous clear and well-drawn graphs. The bibliography, though not extensive, is adequate for the engineering reader who wishes to follow up some special line. The style is clear and readable. The illustrations of ultrasonic equipment are excellent, as is the typography. The volume should find wide use among acoustical processing engineers.

968

Devik, O., and H. Dahl, "Acoustical Output of Air Sound Senders," J. Acoust. Soc. Am., 10, 50-62, 1938.

The use of the Rayleigh disc for measurement of extremely great sound intensities is discussed; it is stated that the Rayleigh disc may even be used in the open air as part of a pointer instrument when properly shielded, thus giving a means of directly measuring the actual sound intensity (in w/cm^2) of intense sound fields. The measurement also involves determining the direction of propagation of energy. Calculating the total flux over the opening of a sound sender, giving the actual acoustical output in watts, is in that way much simplified. As a secondary instrument a crystal microphone, calibrated by comparison with the Rayleigh disc instrument, was used. When used in extreme sound fields it was directly connected with a rectifier galvanometer. Reports are given of measurements of the total output of a membrane sender and of that of a diaphone. In the first case measurements were also made of the different kinds of losses occurring both in the electrical and the acoustical oscillation circuits, while the vibration losses were determined from the power balance and vibration measurements. Oscillograms of sound wave form are given and discussed.

969

Fand, R. M., and J. Kaye, "Acoustic Streaming near a Heated Cylinder," J. Acoust. Soc. Am., 32, 579-584, 1960.

A photographic study employing smoke as the indicating medium has shown the existence of a new type of streaming near a heated horizontal cylinder in the presence of a horizontal transverse sound field. This phenomenon, called "thermoacoustic streaming," is characterized by the development of two vortices above the cylinder; the fluid pattern resembles vortex shedding behind a cylinder in forced flow normal to its axis. In the presence of sound waves whose half-wavelength is six or more times greater than the diameter of the heated cylinder, the formation of the vortex flow is a function of the sound intensity only; for such wavelengths the vortices begin to appear at 140 db (re 0.002 μbar) and become fully developed at 146 db. This type of streaming is a flow phenomenon which is much stronger than isothermal streaming for the same geometry and sound intensity. It appears that thermoacoustic streaming will have important practical applications, particularly in the field of heat transfer.

970

Fand, R. M., J. Roos, et al., "The Local Heat Transfer Coefficient Around a Heated Horizontal Cylinder in an Intense Sound Field," Final Tech. Rept. No. ARL-148, Rept. on Research on Aerodynamic Fields, Mass. Inst. of Tech., Cambridge, 25 pp., 1961. AD-275 772.

A study was made of the local heat-transfer coefficient around the circumference of a heated horizontal cylinder, both in the presence and absence of a strong stationary sound field. Superposition of intense sound upon the free-convection temperature-velocity field about a heated horizontal cylinder increases the heat-transfer coefficient on both the under and upper portions of the cylinder's surface. In the presence of a sound field for which SPL = 146 db (re 0.0002 microbar) and f = 1500 cps, the maximum measured increases in the local heat-transfer coefficient on the under and upper portions of a 3/4-inch diameter cylinder—relative to the free convection case at the same temperature potential—were approximately 250% and 1200%, respectively. A comparison of these results with earlier flow-visualization studies indicates that the relatively large percentage increase in the heat-transfer coefficient on the upper portion of the cylinder is caused by the oscillating vortex flow which is characteristic of thermoacoustic streaming.

971

Fiala, W. T., and J. K. Hilliard, "High-Intensity Sound Reverberation Chamber and Loudspeaker Noise Generator, J. Acoust. Soc. Am., 31, 269-272, 1959.

A high-intensity sound test chamber capable of producing 145 db and having a working area of 6 × 3 × 1 1/2 ft is described. The chamber uses the principle of reverberant sound to test electronic packages used in aircraft and missiles. Double wall construction and use of Aquaplas for panel damping provides the necessary sound insulation. Complete instrumentation and the loudspeaker generator will be described.

972

Gravitt, J. C., "Frequency Response of an Acoustic Air-Jet Generator," J. Acoust. Soc. Am., 31, 1516-1518, 1959.

The mechanism which gives rise to the intense vibrations of an acoustic air-jet generator is investigated both experimentally and theoretically. The results indicate that the mechanism for establishing the vibrations in the generator consists of pressure instabilities in the nozzle air stream which act as the source of the forced oscillations of an air plug in the resonator cavity.

973

Hilliard, J. K., and W. T. Fiala, "Methods of Generating High-Intensity Sound with Loudspeakers for Environmental Testing of Electronic Components Subjected to Jet and Missile Engine Noise," J. Acoust. Soc. Am., 30, 533-538, 1958.

This paper discusses several methods for generating high-intensity sound in the laboratory. Typical characteristics of the two most promising methods—the plane wave tube and the reverberant box—are discussed. A simple formula for the reverberant box is derived. Measurements on several sound generators commercially built are presented.

974

Holman, J. P., "On the Effects of Sound Waves on Heat Transfer," J. Acoust. Soc. Am., 32, 407-408, 1960.

A discussion is presented of the physical mechanism, as proposed by Westervelt, whereby heat transfer rates may be increased in the presence of intense sound fields.

975

Hopwood, F. L., "High-Frequency Sound Waves," J. Sci. Instr., 6, 34-40, 1929.

High-frequency air waves are produced by Langevin's method, putting a massive electrode of lead and a light electrode of copper foil in contact with the two faces of a quartz disc and applying an alternating potential difference of 20,000 volts. The quartz disc dilates and contracts. A beam of air waves is formed at right angles to the disc. If this is horizontal, the formation of stationary wave-striae can be observed in coke-dust laid on glass in the path of the beam. Interference patterns, diffraction effects, attenuation, and the pressure of sound radiation are also demonstrated. These waves kill fish, as Langevin showed. They also break up red blood corpuscles, inhibit the electrical stimulation of a muscle-nerve preparation, and destroy the structure of fresh-water vegetation. If the beam is directed upwards in oil, a mound of oil is raised on the surface; this is in strong vibration, and this vibration can be communicated to liquids in test-tubes. The air dissolved in these liquids is liberated in bubbles. Calorific effects are easy to obtain.

976

Kamperman, G. W., "Design of the High Intensity Noise Test Facility," Tech. Rept. No. 58-367, Bolt, Beranek, and Newman, Inc., Cambridge, Mass., 99 pp., 1958.
AD-202 561.

The facility described is for performing research and development on the prevention of noise-induced fatigue damage on electronic equipment and structures. The facility has been designed primarily for progressive wave testing at high sound intensities. A special high intensity sound source has been developed for this facility. This sound source will cover the frequency range from 50 to 10,000 cps with a maximum acoustic power output of 22,000 w. The sound source will be programmed to produce pure tones or narrow bands of noise having a controlled peak-to-rms ratio.

977

Kamperman, G. W., C. H. Allen, et al., "Performance of Intense Acoustic Facility for Flight Vehicle and Electronic Research," Bolt, Beranek, and Newman, Inc., Cambridge, Mass. Rept. for May-Oct. 1959 on Aeroelasticity, Vibration and Noise, and Thermionics and Solid State Electronic Technology, 40 pp., 1960.
AD-236 365.

A unique sonic failure research facility was constructed for testing flight vehicle structures and electronic systems in the presence of high intensity sound. The siren sound source will produce pure tones or narrow bands of noise throughout the frequency range from 50 to 10,000 c with controlled amplitude modulation from 0 to 50 c. The maximum acoustic power output is 22,000 w to produce a sound pressure level of approximately 174 db in the 1-ft-square progressive-wave test section. The performance of the facility is discussed.

978

Kamps, E. C., "Statistical Evaluation of Near-Field Sound Pressures Generated by the Exhaust of a High-Performance Jet Engine," J. Acoust. Soc. Am., 31, 65-67, 1959.

The operation of modern, high-performance turbojet engines creates an environment that promoted rapid structural fatigue in many areas in jet aircraft. To facilitate the simulation of a valid test environment and, therefore, enable fatigue-resistant structures to be readily developed, the characteristics of the near-field sound pressures created by the jet stream must be established. This study is concerned with the establishment of the level and the rate of occurrence of peak pressures in relation to the commonly measured rms level. A method is presented which enables the determination of these qualities from rms sound pressures generated by the jet exhaust of a General Electric CJ805 turbojet engine. Noted conclusions: (1) occurrence of peak pressures does not follow a Rayleigh Distribution; (2) peak pressure distribution is not altered by the physical position related to the jet stream nor does it appear to be a function of frequency; (3) a maximum of ratio of peak to rms pressure is shown to exceed four, but a physical limit is not established.

979

Lauvstad, V., and S. Tjtta, "Problem of Sound Scattered by Sound," J. Acoust. Soc. Am., 34, 1045-1050, 1962.

The sound generated by the nonlinear interaction of two sound beams of high intensity, arranged to cross each other perpendicularly, is computed to the first order of interaction. Several of the assumptions and specializations in previous treatments of this problem, whose effects on the result it is hard to estimate, are avoided. The interaction is supposed to take place in the Fraunhofer zone of both beams.

Some results are valid. For instance, the Doppler angles computed and measured by Ingard and Pridmore-Brown are found without any strict specializations of the primary beams and the interaction region.

Estimates of the amplitudes of the generated pressure, governing rather wide ranges of frequencies of the primary beams, seem to agree with the previous apparently strongly differing results. This correspondence is brought forward by an amplitude factor, depending on the frequencies of the primary beams.

In the high-frequency limit, the destructive interference among the quadropoles, which cause the generated sound, dominates the results and gives an over-all zero value of the generated pressure, in accordance with Westervelt's treatment.

980

Lehmann, K. O., "Damping of Large Amplitude Sound Waves," Ann. Physik, 20, 533-552, 1934.

Stationary waves of large amplitude are excited in air of normal density in a tube of 6.7-cm diameter, pressures of 75,000 μbars being obtained at the pressure antinodes. The damping of the vibrations is investigated. The damping constant shows scarcely any change up to pressure amplitudes of 30,000 μbars, but shows increases at greater amplitudes caused by the onset of turbulence. Measurements carried out at pressures up to two atm. show that the damping varies inversely as the square root of the gas pressure for small amplitudes, in agreement with the theory of Helmholtz and Kirchhoff, although the absolute magnitude of the damping constant differs considerably from the theoretical value.

981

Levy, S. E., and R. W. Carlisle, "Generation of Intense Audio Sound Fields Utilizing Arrays of Multiple-Driver Horns," J. Acoust. Soc. Am., 33, 936-940, 1961.

There are several major applications for intense audio sound fields: the outdoor propagation of speech and of warning signals, and the sonic fatigue testing of missile and aircraft components. In these applications, several factors combined make it necessary to limit the portion of the frequency spectrum covered by any one loudspeaker unit. In order to provide adequate power capacity, selection is required between the alternatives of (a) using a large number of identical drivers, (b) using a plurality of drivers each especially designed for a selected portion of the frequency range, and (c) using combinations of these arrangements. In an array currently being used for sonic-fatigue testing, a plurality of large open-cone loudspeakers is used for low frequencies, and a plurality of horns is used for middle and high frequencies. Each horn is driven by several drivers. The driver voice coil and diaphragm proportions have been optimized to withstand fatigue stresses under the thermal conditions encountered. The driver is rated at 50 w input for programme material. Horn assemblies are available having throat arrays for mounting 6, 12, or 24 drivers. Various applications are illustrated.

982

Mickelsen, W. R., and L. V. Baldwin, "Aerodynamic Mixing in a High-Intensity Standing-Wave Sound Field," J. Acoust. Soc. Am., 29, 46-49, 1957.

Aerodynamic mixing is fundamentally important in many fluid flow processes, some of which have intense superimposed sound fields. The effect of a transverse sound field on the temperature field downstream from a line source of heat was investigated both analytically and experimentally. In moderately intense sound fields, the temperature field is affected only in the time-mean sense. In intense sound fields, the heat wake is substantially deformed so that both the time-mean and instantaneous temperatures are considerably reduced.

983

Naugol'nykh, K. A., and L. D. Rozenberg, "The Optimum Working Conditions for a Powerful (Acoustic) Concentrator," Scviet Phys. Acoust., English Transl., 6, 352-355, 1961.

This paper discusses a spherical focusing system when the intensity of the focused sound is high and nonlinear distortions of the waveform are important. Conditions needed to obtain maximum amplitude of the wave velocity at the focus are derived.

984

Neppiras, E. A., "Very High Energy Ultrasonics," Brit. J. Appl. Phys., 11, 143-150, 1960.

The field of high power ultrasonics covers the power region where irreversible changes can be produced in the medium. The more important effects and uses of high energy ultrasonics are listed in tabular form. The field is very large; useful applications now touch almost every industry. Approximate figures are quoted for the order of the ultrasonic intensity required in the various applications. In gases and liquids the intensities obtainable are severely limited. In liquids this limit is fixed by cavitation, which sets in at a rather low level. Cavitation can be avoided by pressurization, and then very high energies can be transmitted. But this is inconvenient and seldom used in practice. The field of very high energy ultrasonics is therefore practically confined to solids, as indicated in the table.

985

Oberst, H., "Method for Generating Extremely Strong Stationary Sound Waves in Air" (in German), Akust. Zh., 5, 27-38, 1940.

A method is described for producing by resonance an acoustic pressure of about 0.1 atm. with purely sinusoidal shape of the pressure/time curve at the antinode formed at the closed end of a thin pipe connected to a pipe of larger diameter. The theory of the system and its experimental examination are discussed, and some hints for its application are given.

986

Oslake, J., N. Haight, and L. Oberste, "Acoustical Hazards of Rocket Boosters, Volume I. Physical Acoustics," Tech. Rept. No. U-108:96, Aeronutronic, Newport Beach, Calif., 328 pp., 1961.
AD-253 234.

The results are presented of a survey and analysis of the acoustical hazards at a missile launch site. Volume I deals with the physical aspects of acoustics, noise sources, means of generation, special characteristics of rocket noise, similarity concepts, and prediction techniques for near and far field sound pressure levels, directivity, and acoustical power levels of large rocket boosters. The influence of clusters and blast deflectors on the generation of rocket noise is considered. Expected differences in noise produced by liquid, solid, and/or nuclear rocket engines are compared. Measured acoustical data are presented of sound attenuation along the surface of the earth and at various elevations from the gound as influenced by varying geographical and weather conditions.

987

Peterson, A., "Noise Measurements at Very High Levels," Noise Control, 2, 20, 1956.

What happens to noise-measuring equipment when it is used to measure very high noise levels? The answer to this question and a discussion of instrumentation and limits for high-level noise measurement are presented.

988

Peterson, A., "Sound Measurements at Very High Levels," I.R.E. Trans. Audio, AU-3, 71-76, 1955.

The behavior of a number of microphones at high sound levels is described. Some of the problems of making measurements at these levels are discussed.

989

Regier, A. A., W. H. Mayes, and P. M. Edge, Jr., "Noise Problems Associated with Launching Large Space Vehicles," Sound, 1, 7, 1962.

Engine-noise data for current large launch vehicles have been reviewed, and extrapolations have been made for future vehicles of the multimillion-pound thrust class. The results indicate that the latter vehicles will generate high sound-pressure levels at large distances from the launch site, and the noise spectra will probably peak in the sub-audible frequency range. With regard to the effects of intense low-frequency noise, reference is made to experience in the operation of a large blow-down wind tunnel and in laboratory studies of building components. A ground-building damage criterion is proposed and a brief description is given of a proposed low-frequency-noise environmental test facility.

990

Sachs, R. G., "Some Properties of Very Intense Shock Waves," Phys. Rev., 69, 514-522, 1946.

Conditions have been obtained for the existence of a steady shock wave of such an intensity that radiation pressure plays a role in determining the properties of the shock. These conditions are completely analogous to the Rankine-Hugoniot equations for ordinary shocks; they are obtained by consideration of the conservation of mass, momentum and energy. The results are applied to hydrogen and other very light gases. The application to other media requires a much more complicated discussion of the equation of state and sp ht under extremely high pressures and temperatures. In the light gases, the thickness of the shock front is extremely large because the radiation free path, which is determined by Comptom scattering, is also large. The velocity of sound in a medium under very high pressures and temperatures is also discussed, and it is found that this velocity continues to increase with increasing pressure, a condition that is necessary for the shock to be stable.

991

St. Clair, H. W., "Agglomeration of Smoke, Fog, or Dust Particles by Sonic Waves," Ind. Eng. Chem., 41, 2434-2438, 1949.

The forces causing sonic agglomeration are discussed. The more important factors seem to be a combination of: (1) covibration of particles in a vibrating gas; (2) attractive and repulsive hydrodynamic forces between neighboring particles; and (3) radiation pressure.

992

Soehngen, E. E., and J. P. Holman, "Experimental Studies on the Interaction of Strong Sound Fields with Free Convection Boundary Layers," ARL TR 60-323, Aeronautical Research Lab., Wright Air Development Div., Wright-Patterson Air Force Base, Ohio, 1961.
AD-249 104.

Experiments were conducted on the interaction of strong sound fields with free convection boundary layers on horizontal, heated cylinders of 0.750-inch diameter. The interaction effects were observed through the measurements of the total heat transfer from the cylinders to air under the influence of different types of sound environments. Three different types of sound fields were employed for the experiments: (1) standing plane waves generated by loudspeakers in an anechoic chamber; (2) traveling plane wave fields generated by a mechanical siren in an anechoic duct; and (3) constant pressure or diffuse sound fields generated by a mechanical siren in a reverberant chamber. In all cases the generated sound was monochromatic. The frequencies covered a range from approximately 1000 to 6000 cps at sound intensities ranging from 0 to 152 db. The temperature difference between the test cylinder and air was varied between 20^{o} and 250^{o}F.

993

Soundrive Engine Co., "High Amplitude Sound Abatement Research Program," Final Rept., Los Angeles, Calif., 27 pp., 1953.
AD-13 144.

A sound source (siren) was developed which is capable of delivering continuous acoustic power into a 10-in.-diameter tube at acoustic levels up to 100 kw, provided the tube temperature does not exceed 170^{o}F. An accurate and reliable condenser microphone system was developed for continuous use in the acoustic field with pressure swings approaching 1 atm. Theories were developed for the attenuation of high-amplitude plane waves; however, the predicted attenuation rates were higher than those obtained experimentally. Preliminary measurements of water-spray influence on attenuation rates indicated no significant attenuation effect due to water spray and no clear evidence of frequency dependance. Measurements of the shunting impedance presented by a Helmholtz resonator placed in the 10-in.-tube wall indicated that, for an approximate 56-c low-amplitude frequency, the combination of the resonator and the downstream portion of the tube appeared resistive when the sound frequency matched the low-amplitude resonator frequency. An analysis of the standing-wave structure at this frequency for six particle-velocity amplitudes established that the impedance was given by $R = 1/2\rho_0 \frac{U_0}{S}$, where ρ_0 is the equilibrium density of air, U is the particle velocity amplitude, and S is the cross-sectional area of the neck of the resonator.

994

Thuras, A. L., R. T. Jenkins, and H. T. O'Neil, "Extraneous Frequencies Generated in Air Carrying Intense Sound Waves," J. Acoust. Soc. Am., 6, 173-180, 1934-1935.

This paper deals with theoretical development and experimental results on the generation of sum and difference frequencies and harmonics in air carrying intense sound waves. Measurements were made at the exits of tubes and horns into which two high-intensity pure tones were introduced. The measurements are cited in support of the theory that the non-linearity of air as a compressible medium is a cause of both intermodulation and harmonic distortion at high levels of acoustic pressure.

995

Westervelt, P. J., "Effect of Sound Waves on Heat Transfer," J. Acoust. Soc. Am., 32, 337-338, 1960.

It is suggested that the effect of sound waves on heat transfer is dominantly a result of the modification of the inner streaming boundary layer which is known to occur when the sound particle displacement amplitude exceeds in magnitude the acoustic boundary layer thickness.

996

Wilson, O. B., Jr., and D. A. Bies, "Studies of High Amplitude Sound. A. Measurements of the Acoustic Impedance of a Resonator at Large Amplitudes. B. Measurements of the Attenuation of Repeated Shock Waves. C. A Logarithmic Amplifiers," Tech. Rept. No. 79, Soundrive Engine Co., Los Angeles, Calif., 21 pp., 1954.
AD-52 274.

The experimental investigation of the acoustic impedance of a Helmholtz-type resonator at very high amplitudes of excitation is presented. Sound levels up to 180 db and particle velocity amplitudes in the neck of the resonator up to 1.5×10^4 cm/sec were used. The results at lower levels are compared with those of previous investigators whose work has been confined to levels below 140 db and particle velocity amplitudes in the resonator neck below 4×10^3 cm/sec. Experimental work on the rate of attenuation of repeated shock waves in a five-inch tube is reported. Qualitative agreement with theory is found but there is at present no adequate explanation of quantitative discrepancies. The design and construction of a logarithmic amplifier is discussed.

997

Wilson, O. B., Jr., and D. A. Bies, "Studies of Very High Amplitude Sound," Tech. Rept. No. 82, Soundrive Engine Co., Los Angeles, Calif., 22 pp., 1955.
AD-72 433.

A standing wave technique was used to investigate the acoustic impedance of a resonator over a wide range of sound levels. At large sound pressure levels, above 150 db, the sound waves propagating down the impedance tube became essentially repeated shock waves, so that it was necessary to use a filter in the monitoring system and to consider only the behavior of the fundamental component in the repeated shock wave. In this way a range of sound pressure levels in the resonator from 100 to 170 db was investigated. Two different methods of mounting the resonator were considered. In one case the resonator was mounted on the side of the impedance tube next to a solid end plate terminating the tube; in the other case, the resonator was mounted on the solid end plate coaxially with the impedance tube. At the higher levels of excitation a rise in resonant frequency and in accoustic resistance was noted in both cases, but the details of the effects in the cases were quite different. With the resonator mounted on the side, the rise in the acoustic resistance followed Sivian's formula (J. Acoust. Soc. Am., 7, 94, 1935) while the mass end correction decreased only at very high sound pressure levels. With the resonator mounted on the end, the rise in acoustic resistance was at first more rapid, then less rapid than Sivian's formula would predict. The decrease in mass end correction with increasing sound pressure level began at a lower level and was more pronounced than in the former case.

High Intensity Sound — see also Acoustic Excitation; Noise Sound Sources; Wave Propagation; Finite Amplitude; Shock
see also — 85, 329, 340, 343, 347, 348, 351, 356, 359, 361, 578, 603, 604, 607, 677, 1000, 1002, 1011, 1044, 1111, 1343, 1376, 1404, 1640, 1661, 1683, 1694, 1718, 1725, 1727, 1748, 1799, 1860, 1878, 1890, 2183, 2399, 2410, 2434, 2443, 2444, 2522, 2523, 2527, 2533, 2535, 2539, 2562, 2711, 2718, 2751, 2796, 3592, 3623, 3647, 3665, 3820, 3821, 4328

HORNS

998

Callaway, D. B., "Spectra and Loudness of Modern Automobile Horns," J. Acoust. Soc. Am., 23, 55-58, 1951.

As one phase of a noise survey of the Chicago area, measurements were made of the acoustic output of commonly used automobile horns. Over-all sound levels on the axis at three feet ranged from 108 to 125 db. Loudness levels ranged from 125 to 140 phons. Fundamental frequencies of all horns ranged between 160 and 380 cps. Two types had approximately harmonic overtones, with large amplitudes below about 2000 cps and smoothly decreasing amplitudes at higher frequencies. A third type, with the most unpleasant sound, had inharmonic overtones, groups of which were greater in amplitude than the fundamental. Sound from a pair of horns at various distances were measured both inside and outside a closed automobile. The over-all level outside was 88 db at 50 feet and 74 db at 300 feet, with corresponding loudness levels of 105 and 82 phons. The over-all level inside was 60 db (loudness level, 72 phons) at 50 feet and 50 db (loudness level, 54 phons) at 300 feet. Filtering out overtones above 1200 cps improved the quality of horn sounds markedly, reducing the loudness level inside the automobile by four phons at 50 feet, but only one phon at 300 feet. Since the typical horn is louder than necessary at close range, use of a low pass acoustic filter on automobile horns appears desirable.

999

Carlisle, R. W., "Method of Improving Acoustic Transmission in Folded Horns," J. Acoust. Soc. Am., 31, 1135-1137, 1959.

A novel principle has been developed, applicable to folded horns, for improving the acoustic transmission around bends having a radius greater than one-quarter wavelength. This consists of the use of a conoidal reflecting type of surface in the outer half of the fold. It is beneficial in the frequency-spatial region between the usual horn wave expansion action and transmission by specular or optical type reflection. A practical application is described.

1000

(U. S.) Coast Guard Testing and Development Division, "Catenoidal Horn for Electric Air Oscillator," Field Testing and Development Unit, U. S. Coast Guard Yard, Curtis Bay, Baltimore, Md., 57 pp., 1959.
AD-225 803.

A set of catenoidal horns was designed, manufactured, installed and tested as a replacement for the conical horns on a Coast Guard Type 1954 Electric Air Oscillator. The design method and calculations are presented in this report together with a detailed description of the testing and evaluation of the catenoidal horn in comparison to the original conical horn. The report also contains pictures of the test facilities employed and circuit diagrams for the eletrical analog of the acoustic system involved. The catenoidal horn was found to be more efficient though less directive than the conical horn. The on-axis sound intensity available with the catenoidal horn was found to be more than double that obtainable from the same air oscillator loaded by the conical horn.

1001

Electronic Eng., "The Design of Acoustic Exponential Horns, Data Sheets on Horns of Square and Circular Cross Section," 19, 286-287, 1947.

Engineering design charts and equations for exponential horns are given. They permit designing a horn by various alternate approaches; for instance, on the bases of a given available area for the horn mouth, a given allowable horn length, or a required low-frequency cutoff. The function of horns as acoustic transformers for coupling large amounts of low impedance air to small, piston-type radiators is briefly described, but the amount of acoustic gain or increase in loudspeaker efficiency provided by horns is not discussed.

1002

Gavreau, V., "Pneumatic Generators of Intense Ultra-Sound," Acustica, 8, 121-130, 1960.

Toroidal whistles derived from the police whistle are described. Their operation at low pressure is discussed: oscillation of the air jet produced by the emitted sound, conditions to obtain high efficiency (30%) and pure sinusoidal tone without harmonics; and at high pressure; oscillations produced by the air jet returning to strike at its base, edge sound superposed on the other components of the emitted complex sound. The equation of whistles and the calculation of their theoretical efficiency are given. A contradiction between the theory of horns and the experimental results is no cutoff frequency. Annular exponential horns for emission of plane waves are calculated. Advantages and disadvantages of whistles and of ultrasonic sirens are given, and applications are described.

1003

Holtsmark, J., J. Lothe, S. Tjtta, and W. Romberg, "A Theoretical Investigation of Sound Transmission Through Horns of Small Flare, with Special Emphasis on the Exponential Horn," Paper No. 8, Arch. Math. Naturvidenshab, 53, 43 pp., 1956.

Because of the complexity of the mathematics involved in a rigorous analysis, most horn problems are solved by means of Webster's approximate wave equation (Proc. Natl. Acad. Sci. U.S., 275, 1919). At low frequencies Webster's wave equation gives fairly accurate results for horns which do not flare too quickly. The main object of the present theoretical paper is to develop equations which may be used at high frequencies, the greater part of the paper being concerned with a discussion of the exponential horn. A theory for horns with arbitrary contour is also developed.

1004

Hoodwin, L. S., "The Compound Diffraction Projector," J. Audio Eng. Soc., 2, 40-44, 1954.

A new horn-type loudspeaker has been developed to provide improved reproduction in public address and multiple-channel loudspeaker installations. The name of this unit is the compound diffraction projector (CDP). Although the qualities desirable in a public address loudspeaker depend on the specific application of the loudspeaker, general requirements may be obtained by considering average applications and the demands those applications make on the five measurements of loudspeaker performance: efficiency, frequency response, polar distribution, distortion, and power handling capacity. These measurements are presented for the CDP.

1005

Jensen, A. O., and R. F. Lambert, "Acoustical Studies of the Tractrix Horn, II," J. Acoust. Soc. Am., 26, 1029-1033, 1954.

Experiments have been carried out on the tractrix horn structure to determine its "free-field" radiation characteristics. Axial, off-axis, and polar-response characteristics, as well as throat impedance data on a single-cell horn, are presented for both small and large baffle mounting. Pertinent data on a two-cell structure are also presented. These data show the tractrix performance to be comparable with that of the well-known exponential horn. A multi-cellular structure, while showing definite improvement in uniformity of angular distribution at high frequencies, exhibits undesirable band rejection characteristics within the useful frequency range of the horn.

1006

Kacprowski, J., "Analysis of the Wave-Parameters of the Exponential Horn" (in Polish, English summary), Arch. Elektrotec., 5, 719-758, 1956.

This is a mathematical paper in which the exponential horn is considered as an acoustic four-terminal network. The equations for the network are set in matrix form and shown to correspond to a cascade connection of three four-terminal networks: an ideal, frequency-independent transformer, a transformer with transformation ratio dependent on frequency, an acoustic filter with alternating transmission and attenuation bands. Wave-parameters are derived from the equations in a formal manner, and their physical interpretation is discussed. The concept of the wave impedance of the horn is analyzed in detail, and the author shows that the horn cannot be considered as an iterative chain of matched elementary networks, but it may be considered as a lossless transmission line with distributed constants which are functions of the distance. The formal analogy with a transmission line is proved. The conditions under which the horn can be used as an ideal matching transformer are analyzed.

1007

Lambert, R. F., "Acoustical Studies of the Tractrix Horn, I.," J. Acoust. Soc. Am., 26, 1024-1028, 1954.

When predicting and comparing the acoustical properties of horns, it is customary to formulate the propagation as a one-parameter plane-wave-front problem. However, when particular attenuation is paid to the rapid flare near the mouth of a horn structure, such as the tractrix, it also seems plausible to formulate the propagation on the basis of a one-parameter spherical-wave-front theory. By visualizing the surfaces of constant phase as spheres of constant radii α and the flow lines as tractixes having a generating arm of length α, a one-parameter wave equation and Ricatti impedance equation may be derived. Solutions to these equations have been obtained by wave perturbation and by analogue computer techniques. Axial response and throat impedance measurements are compared with theoretical calculations postulating first a hemispherical and then a plane piston radiation pattern. The most satisfactory explanation apparently lies somewhere in between these two limiting cases.

1008

Lange, T., "The Natural Frequencies of Horns" (in German), Acustica, 5, 323-330, 1955.

The impedances at the throat and the natural frequencies are calculated for horns which consist of a pressure chamber, a connecting tube of constant cross section, and a terminating Salmon horn (widening in the hyperbolic or catenoidal form). In spite of uncertain end corrections, the calculations agree with more precise measurements. The resonances are inharmonic, because of the pressure chamber as well as of the widening of the horn. In special cases it is possible to offset the two influences so as to produce natural frequencies in harmonic relationship.

1009

Larmor, J., "Gramophone Horn," Proc. Cambridge Phil. Soc., 30, 242-248, 1934.

The paper illustrates the problems of general linear propagation mainly by analysis of the conditions necessary for effective resonance. The type chosen is that of a resonating horn made up of two cones joined together. The result gives a relation between the working alternating pressure of the capsule and the pressure spread over the mouth of the horn and transmitted away in air waves. For efficiency, five quantities are adjustable to give a pressure ratio as nearly constant as possible in the range of frequency utilized. Another theory broached is that of the relation of the arterial pulse to the blood-flow, first explored by Young in 1808.

1010

Mawardi, O. K., "Generalized Solutions of Webster's Horn Theory," J. Acoust. Soc. Am., 21, 323-330, 1949.

Webster's equation for the approximate formulation of the propagation of sound waves in horns is solved by two methods. The first considers a transmission line with variable parameters as the electrical analogue of the horn. This approach is especially useful in yielding generalized solutions for horns of finite length. The second method, based on an investigation of the singularities of Webster's differential equation, leads to the discovery of a great number of new families of horns.

1011

Merkulov, L. G., "Design of Ultrasonic Concentrations," Soviet Phys. Acoust., English Transl., 3, 246-255, 1958.

The horns considered are of conical, exponential and catenoidal form. Equations are derived for the calculation of their resonance dimensions and amplification coefficients. The internal volume of the horn is treated as a longitudinally vibrating rod of variable cross section, and the wavefront is assumed to remain plane during its passage through the horn. Intensity is also assumed to be uniform over the wavefront. For a trumpet long compared with its diameter these assumptions are shown to be valid enough; a catenoidal tube gives the greatest amplification. Experimental tests agree well with theory.

1012

Meyer, E., and E. Schunk, "Investigation of a Model for Rapid Transformation in the Air Chambers of Horn Loudspeakers," Acustica, 11, 248-253, 1961.

An air chamber is always placed between the membrane of the driver system and the entrance plane of the horn throat, which effect a transformation of the particle velocity and thus secures a better matching of the membrane. In order to study the performance of air chambers, model experiments have been made at low frequencies with a large "two-dimensional" chamber. Minute oil drops were blown into the air chamber and the translatory oscillation amplitudes of the droplets in the sound field were measured optically. The spatial distribution of particle velocities in the air chamber was measured with continuous and discontinuous transitions from the large to the small cross sections.

Presents a simple theory of air chambers, tested against results obtained with various air chamber volumes and finding them to agree well.

1013

Mokhtar, M., and M. G. Abdel, "Performance of Conical Horns," Proc. Math. Phys. Soc. Egypt, 4, 27-34, 1949.

The radiational properties of conical horns with small apical angles are studied by the aid of a hot wire anemometer and a pitot pressure tube. The results show that long narrow cones are selective radiators to their resonant frequencies, but the selectivity diminishes as the cone gets shorter or as it resounds to a high overtone. The energy radiated increases with the length of the cone and reaches a maximum at a certain optimum angle depending on the length of the cone.

1014

Molloy, C. T., "Response Peaks in Finite Horns," J. Acoust. Soc. Am., 22, 551-555, 1950.

In this paper the term hyperbolic horn is used to designate those horns whose area law is given by:

$$S(x) = \pi R_0^2 \, [\cosh ax + T \sinh ax]^2$$

where S(x) is the cross-sectional area of the horn at distance (x) from the throat, (a) is the flare constant; (T) is the shape parameter, and (R_0) is the throat radius. The pressure on the axis arising from a loudspeaker's circular-mouth and unbaffled horn is derived, using the recent results of Levine and Schwinger, from whose data some useful additional functions are computed and presented in graphical form. Included are calculations of the frequencies at which peaks occur in frequency response curves of hyperbolic horn loudspeakers, and of the parameters of hyperbolic and exponential horn loudspeakers having pre-determined peaks in their frequency response curves.

1015

Obata, J., and Y. Yosida, "Acoustical Properties of Sound Collectors for Aircraft Sound Locator," Rept. No. 62, Aeron. Res. Inst., Tokyo Imp. Univ., 231-237, 1930.

The properties of two parabolic reflectors (diam 2 m, depth 46 cm and 35 cm) and two exponential horns (openings diam 84 cm and 35 cm, lengths, 300 cm and 100 cm respectively) are investigated. The sources of sound were valve generators for the lower frequencies and a dynamic cone loudspeaker for frequencies above 250. A condenser microphone and string galvanometer are employed in measuring the intensity of the sound. The directive property and magnifying power of the collectors are determined, and, for the parabolic reflectors, the distribution of intensity along the axis. In the case of the parabolic mirrors the directive properties are excellent, but the magnifying power is not large. A single horn is almost nondirective for low-frequency sounds, and for directional work two horns are required. The results are exhibited by means of polar graphs for the frequency range 185 to 485.

1016

Perrin, J., "Sound Receivers," Rev. Acoust., 1, 9-27, 1932.

An account of those sound receivers with whose development the author has been associated together with some notes on the sense of direction of sound and the sensitivity of the ear. The instruments concerned include disc-shaped resonators and geophones, and single and multiple horns.

1017

Plach, D. J., "Design Factors in Horn-Type Speakers," J. Audio Eng. Soc., I, 276-281, 1953.

Maximum efficiency in a horn unit can be achieved only if a conjugate match exists between driver and horn. This match is possible only if the unloaded resonance of the driver is greater than horn cutoff frequency. Since the throat resistance of a finite horn at cutoff is a small fraction of its asymptotic value, the point of reactance annulling is chosen at this frequency.

The use of hyperbolic-exponential horns makes possible practically any desired resistance or reactance characteristic near cutoff. The hyperbolic-exponential horn allows much more uniform transmission nearer to cutoff than is possible with the exponential type.

1018

Rudnick, I., "On the Attenuation of High Amplitude Waves of Stable Saw-Tooth Form Propagated in Horns," J. Acoust. Soc. Am., 30, 339-342, 1958.

The attenuation is studied theoretically. The shock associated with each wave is assumed to be weak. An expression for the power loss for a generalized horn is obtained. Two quantities, the limiting particle velocity amplitude and the limiting power which is transmitted per unit throat area, occur in the solution. For long, gently tapering horns these are the limits toward which the particle velocity and power tend as the input to the throat is increased. Uniform-bore tubes, and exponential and conical horns, are discussed as particular examples of the general case.

1019

Ryffert, H., "On the Propagation of 'Exponentially Bounded' Waves of Finite Amplitude" (in German), Acta Phys. Polon., 14, 435-445, 1955.

Describes a mathematical investigation of the propagation of sound waves in an exponentially bounded medium. The problem is considered as unidimensional, making use of curvilinear coordinates. The sound waves are assumed to be penetrated by a small piston source situated at the narrow part of the exponential boundary. The motion of air in an exponential horn (for waves of infinitesimally small amplitude) is first considered, using conventional methods and equations. The results of the mathematical analysis enable one to estimate the ratio of the intensity of the two waves of frequency ω and 2ω, and the manner in which the amplitude decreases as the wave is propagated along the exponential horn.

1020

Salmon, V., "Generalized Plane Wave Horn Theory," J. Acoust. Soc. Am., 17, 199-211, 1945-1946.

By the use of dimensionaless variables and simplifying transformations, Webster's plane wave horn equation is recast into a form permitting separation of the effects of horn contour and frequency. A generalized expression for the admittance also displays this separation. Further interrelations among the variables are developed which permit the formal synthesis of a horn from a given conductance or susceptance function. The conditions for realizability of the horn thus synthesized are discussed. Several applications of the results are presented, including a comparison with Freehafer's exact theory for the hyperbolic horn.

1021

Salmon, V., "A New Family of Horns," J. Acoust. Soc. Am., 17, 212-218, 1945-1946.

A new family of horns is synthesized in which the exponential forms a central member. This permits the effect of perturbations from the exponential contour to be estimated. From other members of the family unique impedance characteristics are obtained, and are discussed with possible applications in mind.

1022

Sato, K., "Acoustical Properties of Conical Horns," Rept. No. 42, Aeron. Res. Inst., Tokyo Imp. Univ., 19 pp., 1928.

The intensity of sound received through a conical horn with its axis set at different angles Θ to the ray of sound was measured with a Rayleigh disc. The intensity distribution depends mainly upon the wavelength (λ) of the sound and only slightly upon the geometrical shape of the conical horn if the diameter (d) of the opening be the same. If λ be small compared with d, the sound energy is considerable for small values only of Θ. If λ be large compared with d, then the sound energy is nearly equal for all values of Θ. Hence, to get a faithful record of a sound when a conical horn is used as a collector, the source must be set in front of the horn ($\Theta = 0^o$); otherwise all higher overtones will be missing. The distortion of sound by a conical horn is due more to the dependence of intensity on λ than to resonance.

1023

Sato, K., "Acoustical Properties of Conical Horns, II," Rept. No. 64, Aeron. Res. Inst., Tokyo Imp. Univ., 261-285, 1930.

A mathematical and experimental treatment of the sound field due to a conical horn with a simple sound source at its vertex. Numerical results obtained from the equation agree fairly well with experiments in which the measuring apparatus was put at the vertex of the cone and the sound source placed at the point under observation.

1024

Sato, K., "Sound Field Due to a Conical Horn," Proc. Imp. Acad. (Tokyo), 6, 256-259, 1930.

The author has calculated the sound field due to a conical horn with a simple source at its vertex, and here compares the results of the theory with actual measurements. Experiments with the source at the vertex of the cone were unsuccessful, and use was made of the reciprocal theorem, the measuring apparatus being placed at the vertex and the position of the source varied. The results verify the correctness of the theory and the applicability of the reciprocal theorem.

1025

Scibor-Marchocki, R. I., "Analysis of Hypex Horns," J. Acoust. Soc. Am., 27, 939-947, 1955.

Impedance transformations of the "Hypex" horns are derived for all cases of mismatch for both increasing and decreasing characteristic impedance. A method of using a Smith Chart for these transformations is presented. The results are applicable to cases where losses are appreciable.

1026

Smith, B. H., "An Investigation of the Air Chamber of Horn Type Loudspeakers," J. Acoust. Soc. Am., 25, 305-312, 1953.

The air chamber is treated as a boundary value problem which results in the solution of the wave equation for the general case in which the horn throat enters the air chamber in any circumferentially symmetrical manner. The following specific cases are analyzed: (1) the case in which the horn throat enters the air chamber by means of a single orifice, (2) the horn throat enters the air chamber by means of a single annulus of radius r and width w, and (3) the horn throat enters the air chamber in "m" annuluses of radii $r_1 \ldots r_m$ and widths $w_1 \ldots w_m$. The analysis reveals that the radial perturbation caused by the horn throat excites the higher order modes. At the resonant frequencies of these modes the horn throat pressure becomes zero and the loudspeaker does not radiate. By suitable choice of annulus radii and widths the first "m" modes may be suppressed and the corresponding nulls in the output pressure eliminated.

1027

Stevenson, A. F., "Exact and Approximate Equations for Wave Propagation in Acoustic Horns," J. Appl. Phys., 22, 1461-1463, 1951.

Exact equations are given for the propagation of acoustic waves in horns of arbitrary shape. These equations are similar to, though simpler than, the equations previously found for electromagnetic horns, and can be regarded as giving rise to an infinite number of coupled modes of propagation. If the coupling is neglected, the equation for the fundamental mode is the familiar one, but the theory also furnishes equations for the higher modes. The error involved in neglecting coupling is discussed.

1028

Tanaka, S., "On the Acoustic Folded Horns," Sci. Rept., Res. Inst., Tohoku Univ., Ser. A, 1, 243-248, 1949.

Two different types of folded horn ("re-entrant" and "mushroom") are described. These horns have previously been constructed and experimentally tested. Details of these tests and an approximate theory are given.

1029

Thiessen, G. J., "Improved Type B Fog Horn System Using Exponential and Catenoidal Horns," J. Acoust. Soc. Am., 28, 356-362, 1956.

The use of a high impedance acoustical load for the type B diaphone is capable of raising the efficiency of the fog horn system to values of 10% to 16% for normal operating pressures. The high impedance is provided by a resonant exponential or catenoidal horn. To provide the high degree of frequency stability required by high Q resonant loads the mechanical impedance of the diaphone is reduced to permit it to lock in with the horn frequency. The reduction of the mechanical impedance is achieved by reducing the mass of the piston through the use of aluminum and reducing and stabilizing the frictional forces by using a central shaft for supporting the piston instead of allowing it to float in the liner. The resulting frequency stability is such that the efficiency under field conditions equals that obtained in the laboratory. An incidental benefit arises from the fact that the horns are smaller and made of aluminum, reducing the weight by a factor of six.

1030

Thiessen, G. J., "Performance of a Type B Fog Horn," J. Acoust. Soc. Am., 28, 281-285, 1956.

Measurements on a type B fog horn indicate that the nominal frequency of 180 cps is far from any resonance peak in the resistance ratio of the horn. Efficiencies of much less than one percent are therefore commonly encountered. Actual diaphone frequencies in the field range between 180 and 245 cps. The frequency stability with pressure is poor, and large deviations from symmetrical piston movement occur. It can generally be stated that a fog horn that grunts is not operating efficiently.

1031

Thiessen, G. J., "Resonance Characteristics of a Finite Catenoidal Horn," J. Acoust. Soc. Am., 22, 558-562, 1950.

Expressions for the impedance components of a finite catenoidal horn are derived and a comparison made with similar exponential and conical horns. The impedance of a section of a catenoidal horn is also calculated and it is shown how, for the finite as well as the infinite horn, this approaches that of the exponential as more length is trimmed from the throat end. The assumption that the resonance characteristics of a horn are the same as that of a uniform tube, provided the higher velocity of sound for the horn is used, seems to be borne out for the catenoidal horn but for the exponential horn the agreement is not very good except at higher frequencies.

1032

Weibel, E. S., "On Webster's Horn Equation," J. Acoust. Soc. Am., 27, 726-728, 1955.

A wave equation for sound propagation through tubes is derived by means of Hamilton's variational principle. It is assumed that the wave fronts can be approximated by surfaces of constant stream potential; this is the only assumption made. The variational principle insures that the best equation that is compatible with this assumption will be obtained. The equation has the form of Webster's horn equation, but its coefficients are defined differently.

1033

Young, F. J., and B. H. Young, "Impedance of Tapered Structures," J. Acoust. Soc. Am., 33, 1206-1210, 1961.

A general expression for the impedance of acoustical horns and analogous devices is derived by considering a manifold of uniform structures. The impedance of the manifold is obtained by complete mathematical induction and the impedance of a smoothly varying tapered structure is obtained by a limiting process. With the expressions established here the impedances of acoustical horns having mouth-to-throat area ratios ranging from 0.125 to 8 can be calculated with less than 10% error at zero frequency.

Horns
see also—121, 331, 347, 458, 576, 917, 981, 994, 1384, 1817, 1818, 1819, 1821, 1858, 1868, 1872, 1873, 1877, 2035, 2036, 2410, 2434, 2694, 2701, 2718, 2817, 3658.

INSTRUMENTATION, ANALYZERS AND SPECTROMETERS

1034

Austin, W. E., "A Very Low Frequency Recording and Analyzing Instrument," Rept. No. 3615, Naval Ordnance Lab., White Oak, Md., 22 pp., 1954.
AD 208 743

Describes development of an FM system of magnetic tape recording for signals from d-c to 15 cps, with playback apparatus permitting wide band frequency analysis from 0.016 to 4.2 cps. The recorder will operate over 24 hours unattended. The recordings are played back either 30 or 60 times faster than recording speed, producing frequencies great enough to be separated by special octave band pass filters which have been developed. This equipment has been used for recording and analyzing low-frequency geomagnetic data and can readily be adapted for other applications.

1035

Betchov, R., "Spectral Analysis of Turbulence" (in French), Proc. Koninkl. Ned. Akad. Wetenschap., 51, 1063-1072, 1948.

Describes a device that uses a hot-wire anemometer and thermocouple for electronically measuring the velocity fluctuations in a turbulent aerodynamic flow. The electrical signals are applied to the grid of a thermionic valve through a low-pass filter with a very large time constant, thus assuring a strictly linear recording. The theory and layout of the circuit are outlined and test results given.

1036

Bially, T., "Theory and Design of a Subsonic Spectrum Analyzer," Proj. No. 4691, Electronics Res. Directorate, AFCRL, Office of Aerospace Res., 44 pp., 1962.
AD-291 782.

The coherent memory filter is analyzed in its application as a spectrum analyzing device and is shown to be capable of performing a spectrum analysis with a minimum of mean squared error in a minimum of time. The instrument described will provide a visual display of the low frequency spectral components of any arbitrary waveform which is applied to its input terminals. In particular, it will analyze frequencies up to four cycles per second with a resolution, or uncertainty, of better than sixty-seven thousandths of a cycle. The signal must be available for analysis for a period of time of not less than fifteen seconds.

Theoretical and practical considerations in the instrumentation of the device are discussed from the system design viewpoint.

1037

Bonvallet, D. J., "Instrumentation and Techniques for Noise and Vibration Control," Sound, 1, 26, 1962.

This article presents a brief description of some of the instruments and techniques employed in noise and vibration studies of automobiles. A few approaches are discussed to indicate the comparative importance of instruments and experienced vibration engineers. Both are found essential to a successful program.

1038

Davis, R. K., and D. Quick, "ASCH Bearing Analyzer," Rept. No. TR 109, Naval Avionics Facility, Indianapolis, Ind., 23 pp., 1961.
AD-269 925.

A prototype bearing analyzer for measuring torque, vibration, and airborne noise was constructed. The virtues and shortcomings of this instrument are listed with respect to the original design requirements. These design requirements are recapitulated, the problem restated, and a survey of instrumentation having some applicability undertaken. Suggestions are made as to the development of appropriate instrumentation. A comprehensive summary and analysis of parameters pertinent to a realistic assessment of bearing quality is appended.

1039

Ellis, J. F., J. Scrivins, and J. S. Rowlinson, "The Behavior of a Sonic Analyser with Imperfect Gases," Rept. No. R&DB(CA) TN-99, United Kingdom Atomic Energy Authority, Great Britian, 4 pp., 1953.
AD-213 356.

The resonant frequency of a sonic analyser filled with an imperfect gas is found to fall as pressure increases above 250 mm Hg. This is shown to be due to the departure of the gas from the perfect gas laws. At pressures below 200 mm the frequency is lower than would be expected. No explanation of this is given. It is found that the response of the instrument is not truly linear over a frequency range of times 2 or greater.

1040

Hamrick, J. J., "Techniques for Measuring and Evaluating Noise," J. Audio Eng. Soc., 6, 19-25, 1958.

The continually increasing public concern about noise has required the development of improved techniques and procedures, both to measure and also to evaluate the noise environment created by new products. Modifications of existing instruments and improved operational procedures have been developed for stereo tape recorders and reproducing systems, audio spectrum analyzers, graphic level recorders, and frequency analyzers. Correlation of noise levels in data-processing rooms with laboratory measurements in anechoic and reverberant chambers, together with careful selection and qualification of listening-panel members for annoyance evaluations, have insured that both the loudness and the quality of the noise of a new product will be satisfactory.

1041

Harris, C. M., and W. M. Waite, "Gaussian-Filter Spectrum Analyzer," Dept. of Electrical Eng., Columbia Univ., N. Y., J. Acoust. Soc. Am., 35, 447-450, 1963.

A real-time audio-frequency spectrum analyzer is described which consists of a bank of 54 contiguous bandpass filters of the Gaussian type. Up to 1000 cps, the filters have a constant bandwidth of 70 cps; above this frequency the bandwidths increase at a constant percentage of about 6.5%. The output of each filter is rectified and the resulting d-c signals are scanned by a solid-state multiplexer. Thus, a single output, which is a function of the power spectrum, is made available for visual display and/or computer processing. Practical advantages of Gaussian filters are described for the analysis of transients of noise, music, or speech, and examples of the analyzer output are presented.

1042

Jackson, P. L., "Optical Analysis Techniques Applied to Seismic Data," Acoustics and Seismics Lab., Inst. of Science and Technology, Univ. of Mich., 1962.

An optical system capable of performing multichannel, high-resolution spectral analysis, and auto- and cross-correlation is under development. The series of progress reports listed detail the effort in obtaining accurate time and spectral information from variable density, time history signals.

First Semiannual Technical Summary Report, January 1962, Rept. No. 4596-4-P
Second Semiannual Technical Summary Report, July 1962, Rept. No. 4596-7-P
Third Semiannual Technical Summary Report, January 1963, Rept. No. 4596-13-P
Fourth Semiannual Technical Summary Report, July 1963, Rept. No. 4596-20-P

1043

Kamperman, G. W., "Data Sheets," Noise Control, 4, 52, 1958.

Response characteristics for twelve analyzers are supplied in tabular form.

1044

Kobrynski, M., and L. Avezard, "Acoustic Measurements in Aeronautics," Acustica, 11, 151-160, 1961.

After a preliminary review of the conditions which must be satisfied by the methods of acoustic measurement, the resolutions adopted are applied to the study of sound fields of high intensity. The experimental apparatus comprises movable chains of displacement microphones, and a controlled analysis of the noise is effected by automatic commutation of the frequency bands.

1045

Kuchmin, O. I., "On an Acoustical Method of Gas Analysis," Soviet Phys. Acoust., English Transl., 268-271, 1958.

The paper describes an acoustical phasometric method of gas analysis based on a comparison of the phases of a sound generator and receiver placed in a tube with the gas mixture to be analyzed. The example of an oxygen-nitrogen system is used to demonstrate that possible industrial application of this method ensures rapid and sufficiently accurate measurement.

1046

Martin, A. E., "The Sonic Gas Analyser," Nature, 178, 407-408, 1956.

Refers to the successful development of a commercial form of sonic gas analyzer by Dawes, Walton, Lawley and Mounfield. The principle of operation involves the use of two equal tubes (length d) each fitted with a deaf-aid earpiece at each end. At end A of each tube the "earpiece" is used as a sound source (3000 cps) whilst at the opposite end B of each tube the earpiece is used as a microphone. By electronic techniques it is easily possible to measure the phase difference of the sound arriving at the two receivers B_1 and B_2. This is zero when the gases filling the tubes are the same but becomes finite and measurable if one gas is heavier than the other. Expressions are given for the change of phase produced by any given gas mixture in one of the tubes — the gas in the other tube being regarded as "standard." No corrections for variations of pressure are involved and temperature compensation is easily arranged.

1047

Parker, W.E., and L. V. East, "Automatic Processing System for Acoustical Data," J. Acoust. Soc. Am., 33, 1-6, 1961.

An improved instrumentation system has been developed to analyze the dynamic pressure field produced by jet aircraft. The system is automatic and utilizes analog computer techniques to obtain an accuracy of 0.2 db in its readout. The method used is to secure a true rms value of octave band segments of the jet noise spectrum and to convert this to decibels by the use of a d-c logarithmic amplifier. The transition to acoustical decibels is made by obtaining the difference between this voltage and another voltage obtained from a reference oscillator. The value of this reference oscillator in acoustical decibels is obtained by comparing its output voltage to that of a calibrated microphone. The dynamic range of the system has proved more than adequate for greater than 98% of the data processed by this unit during the time this system has been in operation. The output is in the form of punched cards for utilization with a digital computer.

1048

Pimonow, L., (1957) "The Detection and Analysis of Infrasounds Propagated in the Air in the Range 2 to 30 cps" (in French), Ann. Telecommun., 12, 419-423, 1957.

Instruments to measure the sound pressure level and to analyze the spectrum of steady and transient infrasounds are described.

1049

Ragazzini, J. R., H. Saks, and M. Kaufman, "Methods for Analyzing Shock and Vibration," Library Rept. No. 1, Gruen Appl. Sci. Labs., Inc., Hempstead, N. Y., 30 pp., 1957. AD-204 756.

This is a bibliography with abstracts on the following topics:
The filter problem of the power-spectrum analyzer.
Communications applications of correlation analysis.
Methods of obtaining amplitude-frequency spectra.
Short-time autocorrelation functions and power spectra.
The response of a resonant system to a gliding tone.
Response of a linear resonant system to excitation of a frequency varying linearly with time.
Measuring noise color.
The sampling theory of power spectrum estimates.
The principles and practice of panoramic display.
An 8000-c sound spectrograph.
Methods and instruments for the visual analysis of complex audio waveforms.
High-speed, high-resolution spectrum analyzer.
A spectrum analyzer for the 100- to 100,000-c range.
Automatic wave analyzer.
Analog equipment for processing randomly fluctuating data.
A computer for correlation functions.
Shock spectrum computer for frequencies up to 2000-c phenomena.
A high-speed correlator.
An extremely wide-range electronically deviable oscillator.

1050

Ramaswamy, T. K., and B. S. Ramakrishna, "Simple Laboratory Setup for Obtaining Sound Spectrograms," J. Acoust. Soc. Am., 34, 515-517, 1962.

A technique for obtaining sound spectrograms using common laboratory equipment is described. The procedure is to record the signal on a tape loop and reproduce it repeatedly. The tape output is fed successively through different band-pass filters to the intensity electrode of an oscilloscope. The oscilloscope beam is triggered by a 2 kcs pulse inserted ahead of the signal. After each repetition of the signal, the filter selector and the vertical position of the trace on the scope are advanced by one step. An oscilloscope recording camera registers the spectrogram under time exposure. The performance of this setup is improved by using an AVC circuit to accommodate the wide range of intensities encountered in speech within the recording range of the oscilloscope and film.

1051

Remillard, W. J., "Method of Obtaining Amplitude and Phase Spectra of a Transient Function Using Graphical Input Data," J. Acoust. Soc. Am., 31, 531-534, 1959.

Both amplitude and phase spectra are needed to characterize transient functions completely. Analysis shows how these spectra can be obtained from the envelopes of the line spectra of the even and odd parts of a transient function made to recur in time. Instrumentation is described for the convenient determination of these line spectra.

1052

Robinson, A. Z., "A Narrow Band Lock-In Analyzer and Slave Analyzer," Rept. No. 4420, Naval Ordnance Lab., White Oak, Md., 60 pp., 1958.
AD-158 517.

A narrow-band lock-in analyzer which was developed for the purpose of obtaining more precise information on the character of the discrete components in noise signals is described. The main features of this analyzer are: a zero-beat analysis in which the analyzer is designed to obtain frequency selectivity by a heterodyning action followed by a simple one-section RC low pass filter; two quadrature phase channels arranged so that the normal ambiguity that exists in narrow-band analyzers between frequency-modulated and amplitude-modulated components is eliminated by making one of these quadrature phase channels sensitive to frequency variations of discrete input components, and the other channel sensitive to the amplitude and amplitude fluctuations of these input components; and an automatic frequency control circuit which enables the analyzer to hold a discrete component within its passband for as long as desired. The theory behind the analyzer is discussed, and a complete description of the circuits and of the calibration and operation procedures is given. Results of performance tests and conclusions as to the usefulness of the instrument are presented. The operation of this analyzer is described in conjunction with a slave analyzer. The frequency selective circuits of both analyzers are identical, and the heterodyning frequencies for the slave analyzer are furnished from the lock-in analyzer.

1053

Scott, H. H., and D. von Recklinghausen, "A Compact, Versatile Filter-Type Sound Analyzer," J. Acoust. Soc. Am., 25, 727-731, 1953.

Availability of a pocket-sized miniature sound level meter meeting all ASA standards has created demand for a small, equally portable sound analyzer as a companion instrument. The analyzer described surpasses all applicable ASA standards. The separate high and low cut-off filters may be adjusted independently, and the noise pass band may be locked in any band width which is an integral multiple of 1/2 octave, from 1/2 octave through the standard 1 octave band, etc. The range of the filters extends one octave lower and one octave higher than the ASA standards. These features permit considerable added precision and flexibility of analysis.

For protection and ease of carrying, the instrument is housed in a leather case similar to those used for amateur motion picture cameras. The case is equipped with a shoulder strap which allows the analyzer to be carried about easily while in use. It can also be used as a general purpose adjustable filter or as a wide-range amplifier.

1054

Sommer, J., "Acoustic Analyzer" (in German), Issue 240, Arch. Tech. Messen, 1-4, 1956.

A review of methods of determining frequency spectra and harmonic contents of single tones, complex musical or speech waveforms, noise etc. in the af range. Among the circuits discussed are tunable bridge and switched fixed filter distortion meters, a variable filter analyzer for musical tones in which the component frequencies are measured by a Lissajous figure method against standard frequencies, a stroboscopic disk method in which the disks are illuminated by a gas discharge tube driven by the input signal, and various heterodyne methods in which a fixed intermediate filter is used. One analyzer with extremely high resolution has automatic frequency control. Automatic recording systems are described, and the limitation on the frequency sweep speed due to finite filter response time is discussed. Twenty-five references are given.

1055

Webb, E. K., and N. E. Bacon, "A Mechanical Harmonic Analyser," J. Sci. Instr., 39, 500-503, 1962.

An analogue instrument is described which operates by a wheel-on-disk principle. It is relatively simple in construction and is capable of evaluating several harmonic components in one operation.

INSTRUMENTATION, ANALYZERS AND SPECTROMETERS

1056

White, H. E., "An Analog Probability Density Analyzer," Tech. Rept. No. 326, Mass. Inst. Technol., Res. Lab. Electron., Cambridge, 28 pp., 1957.
AD-156 601.

The development and construction of an analog analyzer for determining the first-order probability density function of signal amplitudes of frequencies between 30 cps and 20 kc is described. Values of probability density are determined by averaging a derived random variable that is unity when the signal is in the amplitude interval that is being analyzed and is zero at all other times. It is generated by a diode level-selector circuit that gates a 60-mc carrier to a bandpass amplifier. This level selector eliminates many of the problems of frequency response and drift that are associated with the amplitude discriminators of the conventional level selector. The amplitude range of the signal comprises 50 intervals that are analyzed sequentially and the complete probability density function is plotted by a pen recorder.

The frequency response and drift stability of the analyzer are experimentally evaluated, and examples of experimental probability density functions are given. Block diagrams and descriptions of both digital and analog systems that have been previously developed for determining probability density functions are presented. Definitions and some properties of probability density functions are reviewed.

Instrumentation, Analyzers and Spectrometers
see also—433, 562, 604, 605, 620, 641, 680, 689, 690, 1117, 1123, 1128, 1182, 1354, 1355, 1650, 1702, 2370.

INSTRUMENTATION, ATTENUATION MEASURING

1057

Angona, F. A., "Apparatus and Procedure for Measuring the Absorption of Sound in Gases by the Tube Method," J. Acoust. Soc. Am., 25, 1111-1115, 1953.

An apparatus for measuring the absorption of sound in gas mixtures has been developed and tested. The apparatus consists of a sound tube, a movable ribbon-type speaker, and a fixed condenser microphone. The absorption is determined by recording the sound pressure as the path length between the speaker and the microphone is increased. The measured attenuation coefficient is corrected for the effect of the tube and also for the attenuation due to the viscosity and heat conduction of the gas. Both frequency and pressure are variable and range from 2 to 10 kcs and from 3 to 300 mm of Hg respectively.

1058

Angona, F. A., "Attenuation of Sound in a Tube," J. Acoust. Soc. Am., 25, 336, 1953.

An experimental method of measuring the attenuation of sound in a circular tube for gases at reduced pressures has been developed. Since the tube effect is inversely proportional to the square root of the pressure, a reduction in pressure increases the attenuation and thus increases the experimental accuracy. The tube attenuation was measured for the frequency over pressure ratio of 8 to 2000 kc/atm. The measured attenuation was found to be 4.5% greater than that predicted by the Kirchhoff formula.

1059

Arabadzhi, V. I., "Acoustical Characteristics of the Air Layer near the Ground" (in Russian), Uch. Zap., Leningr. Gos. Ped. Inst., 7, 87-91, 1957.

Investigations of sound propagation in the ground layer of the atmosphere over various natural surfaces are described. The measurements were made over a straight road, a flat grass field, a water surface, and a depression, with a microphone joined to an amplifier output by a millivoltmeter. Sound reflection from a dense grass cover, from a surface of cut grass, and from bushes and leaves was recorded at frequencies of 0.2-4.0 kcs. The effect of atmospheric temperature inhomogeneities upon sound attenuation was investigated by means of laboratory apparatus, which is described in detail. In these laboratory experiments attenuation coefficients between 10^{-5} and 10^{-4} cm^{-1} were obtained, which is in fair agreement with investigations made in the free atmosphere.

1060

Bell, J. F. W., "A Fixed Path Ultrasonic Interferrometer for Absorption Measurements on Gases," J. Acoust. Soc. Am., 25, 96-100, 1963.

A fixed path interferometer, using variable temperature for the measurement of the absorption in gases in the low f/p region, is described. Its use is illustrated by measurements on argon, neon, air, nitrogen, and nitrogen-hydrogen mixtures at 250 kc. The values found for argon and neon were above classical by 40% and 65%, respectively. The discrepancies are ascribed to Rayleigh cross modes in the ultrasonic waves excited by the quartz crystal transducer rather than to any departure from classical theory. Cross modes and their influence on ultrasonic measurements are discussed. Data on the performance of two crystals at 250 and 500 kc are given.

1061

Bohn, J. L., and F. H. Nadig, "Research in the Physical Properties of the Upper Atmosphere with V-2 Rockets," 15 Progress Repts. and 1 Final Rept., Res. Inst., Temple Univ., Philadelphia, Pa., 1948-1951.

This series of reports is on an investigation of most of the physical properties of the upper atmosphere and, therefore, includes work on sound in air. The absorption and velocity of sound in air at high altitudes and at high-frequencies is determined. Missile-generated noise levels are measured. The effects of increasing altitudes on microphone sensitivity and coupling efficiency are investigated. In almost all scientific areas both theoretical and experimental efforts are conducted and the results are compared. The instrumentation designed and constructed for the experimental phases of the project is described in much detail.

Quarterly Progress Repts #	1	Apr-June '48	ATI-55337
	2	Jul-Sept '48	
	3	Oct-Dec '48	
	4	Jan-Mar '49	
	5	Apr-June '49	ATI-71245
	6	July-Sept '49	ATI-73390
	7	Oct-Dec '49	ATI-77197
	8	Jan-Mar '50	ATI-82087
	9	April-June '50	ATI-95353
	10	July-Sept '50	ATI-103254
	11	Oct-Dec '50	ATI-119091
	12	Jan-Mar '51	ATI-128908
	13	Apr-June '51	ATI-140216
	14	Jul-Sept '51	ATI-140217
	15	Oct-Dec '51	ATI-159798
	Final Rept	Apr '48-Feb '52	

1062

Bommel, H., "The Measurement of the Velocity and Absorption of Ultrasonics by an Optical Method," Helv. Phys. Acta, 18, 3-20, 1945.

The measurement of the velocity of ultrasonics in gases becomes more complex as the frequency increases on account of the interaction between source and receiver and other effects. In the optical method described, the Hg 4358Å line is passed through gas subjected to the action of the ultrasonics, and the diffraction pattern brought to a focus on a photographic plate by a concave mirror. The velocity V is obtained from the separation of the diffraction maxima. A range of 951-4755 kc is covered. A method is worked out theoretically whereby the absorption can be obtained from the separation of the diffraction maxima.

1063

Delsasso, L. P., "The Attenuation of Sound in the Atmosphere," Dept. of Phys., Univ. of Calif., Los Angeles, 37 pp., 1953. AD-89 256.

The attenuation of sound at sea level pressures and normal temperatures is extended to pressures and temperatures which may be encountered in acoustical signalling and tracking problems. Measurements were made both in the laboratory and in the field. In the laboratory results are reported for the frequency range 1000 to 6000 cps for a temperature range of from 2° to 35°C and for pressures from 76 to 26 cm of Hg. In the field, measurements have been obtained at an altitude of 10,000 feet for representative variations of meteorological conditions. Limits for the possible absorption coefficients to be met with in practice have been extablished. Progress is reported on the development of instruments to measure more accurately the details of the meteorological conditions excountered, particularly with reference to the accurate description of natural fogs. Instrumentation for measuring the attenuation of sound under laboratory conditions and the attenuation of sound propagating outdoors is described and illustrated.

1064

Delsasso, L. P., and R. W. Leonard, "The Attenuation of Sound in the Atmosphere—and Appendix A.," Dept. of Phys., Univ. of Calif., Los Angeles, 45 pp., 1949. ATI-96 177.

Progress is reported on the investigation of the transmission of sound under various atmospheric conditions. Primarily the work deals with laboratory measurements, where conditions can be well controlled, and, secondly, with field measurements under varying atmospheric conditions. The ultimate goal is to correlate the two experiments and make it possible to predict the value of attenuation and velocity for any given set of atmospheric conditions. In general, the laboratory measurements confirm previous findings on the variation of the absorption with the moisture content of the air. These results are plotted. Typical values for open air transmission are shown in a graph. Instrumentation for making acoustic attenuation measurements in the laboratory and in the field is described and illustrated. Circuit diagrams are included.

1065

Evans, E. J., and E. N. Bazley, "The Absorption of Sound in Air at Audio Frequencies," Acustica, 6, 238-245, 1956.

The sound-absorbing properties of air at frequencies from 1 to 12.5 kcs are determined for values of the relative humidity from about 5% to 85% at 20°C. The measurements were made in a large reverberation chamber, in which the surface absorption was very small. The absorption due to the air was evaluated by an analysis of the results and closely agrees with the relaxation theory. A general expression is derived for the attenuation of sound in air as a function of the frequency, humidity, and temperature.

1066

Fay, R. D., "Attenuation of Sound in Tubes," J. Acoust. Soc. Am., 12, 62-67, 1940.

Refinements in method and apparatus have made possible the precise measurement of attenuation of sound in tubes. Preliminary results strongly substantiate the tube wall effect predicted by Kirchhoff. Also, an unexpectedly large effect has been found, which depends on the first power of the frequency. Further measurements are required to find whether this loss exists in free air or is due in part to the tube walls.

1067

Grossmann, E., "Absorption of Sound in Gases at High Frequencies," Ann. Physik, 13, 681-702, 1932.

The absorption of sound between 3×10^4 and 3×10^5~ is measured by a new method. Generator and receiver are two piezoelectric quartzes with almost the same resonance frequencies. These are placed in an enclosure containing the gas. The generator is made to vibrate with constant amplitude at its resonance frequency, and the energy in the circuit of the receiving quartz is measured by a thermocouple, when the receiver is at various distances. Disturbing effects of all kinds are investigated. Contrary to the Stokes-Kirchhoff theory, the coefficient of absorption is found to vary with the frequency, particularly in CO_2 and SO_2, and is always far in excess of values predicted by this theory.

1068

Hardy, H. C., "Use of the Pierce Interferometer for Measuring the Absorption of Sound in Gases," J. Acoust. Soc. Am., 15, 91-95, 1943.

A rigorous derivation of Pielemeier's empirical equation for the absorption of sound in gases is obtained by making use of the principles of the Pierce ultrasonic interferometer and the quartz oscillator. The Pielemeier method gives a fair approximation when the reaction of the sound wave on the crystal is small; it enables both velocity and absorption to be measured. The limits of precision in its use were tested experimentally and agree with theory.

1069

Harris, C. M., "Absorption of Sound in Air in the Audio-Frequency Range," J. Acoust. Soc. Am., 35, 11-17, 1963.

This paper, concerning the absorption of sound in air as a function of humidity, presents new data in the frequency range between 2000 and 12,500 cps. These data are for air at normal atmospheric pressure and at a temperature of 20°C. First the measurement system is described. Then the data are compared with theory and with other published results in the same frequency range. The data also are presented in a graphical form that is particularly convenient for use in computing the contribution of air absorption to the total absorption of sound in a room. In this form the data are plotted directly in terms of the quantity 4mV as a function of frequency and humidity, where m is the attenuation coefficient and V is the volume of the room.

1070

Hartig, H. E., and R. F. Lambert, "Attenuation in a Rectangular Slotted Tube of (1, 0) Transverse Acoustic Waves," J. Acoust. Soc. Am., 22, 42-47, 1950.

A pickup device for measuring the standing wave ratio of transverse acoustic waves is described. One of the important features of this device is the elimination of interference from the residual plane wave. This paper presents an experimental study of the attenuation characteristics of (1, 0) transverse acoustic waves propagated in air in a rectangular metal tube employing such a pickup device. This study reveals that three losses are important contributors to the attenuation. The results agree well with a tube wall effect predicted by Kirchhoff. In evidence in the medium is a gaseous absorption due to thermal equilibrium adjustments. The remaining attenuation is appreciable and appears to vary with frequency as $f^2[1 - f_c{}^2/f^2]^{-1/2}$. This factor is here attributed to a vibration of the tube walls.

1071

Henderson, M. C., and G. J. Donnelly, "Acoustic Resonance Tube for High Pressures and Low f/p.," J. Acoust. Soc. Am., 34, 779-784, 1962.

Describes an acoustic resonance tube capable of operating at moderately high pressures and elevated temperatures: possibly 1000 atm. and several hundred degrees C. The frequency range is 500 to 15,000 cps, or correspondingly 0.5 to 15,000 cps/atm. or higher, thus filling a significant experimental gap in acoustical instrumentation. The wall absorption in this tube is about 10% above the calculated classical value, and is approximately independent of molecular weight or pressure of the gas.

Details of construction and operation are given, and the application of the tube to problems of relaxation at low frequency/pressure ratios is indicated.

1072

Horiuchi, I., "The Absorption of Sound in Humid Air at Low Audio Frequencies," Tech. Rept. No. 6, Columbia Univ., New York, 48 pp., 1957.
AD-140 786.

The reverberation technique of Kudsen has been applied to the measurement of the absorption of sound in air over the frequencies 300 to 1100 cps with mole ratio concentrations of water vapor ranging from zero to 0.1. Pressures from 20 cm Hg to atmospheric, and temperatures from 0°C to 55°C were employed in the study. With the use of a 66-inch spherical resonator and dry nitrogen gas as reference, following the method of Delsasso and Leonard, it has been possible to observe the anomalous absorption of humid air down to 300 cps. Pertinent graphs, theory, and a detailed description of the experimental apparatus are presented.

1073

Horiuchi, I., "The Temperature and Humidity Dependence of Sound Absorption," Tech. Rept. No. TR-7, Electron. Res. Labs., Columbia Univ., New York, 20 pp., 1957.
AD-155 171.

Results have been obtained for the absorption of low-frequency sound in humid air at temperatures of 0°C and 55°C. The pressure ranged from 20 cm Hg to atmospheric, while the relative humidity was varied from 2% to 80%. The frequencies employed were the first five radial modes of a 66-inch spherical resonator: 300, 500, 700, 900, and 1100 cps, approximately. The experimental results show the absorption to follow the Knudsen-Kneser theory closely, except that under extreme relative humidity, large departures occur.

1074

Hubbard, J. C., "Acoustic Resonator Interferometer, Part II. Ultrasonic Velocity and Absorption in Gases," Phys. Rev., 41, 523-535, 1932.

The derivation of the equivalent electric network of the acoustic resonator interferometer in Part I of this paper has made it possible to develop the theory for the current in a simple resonant circuit in which the electrodes of the piezoelectric plate of the interferometer are connected to the terminals of the variable condenser. The special case of this theory is that in which the circuit is excited at a constant frequency determined by the crevasse frequency of the resonator plate in its given situation with respect to electrodes and associated circuit, when the acoustic path in the interferometer is detuned and the resonant circuit is tuned so that its resonant maximum occurs at the same frequency; the special case takes an especially simple form and leads to a direct procedure for determining ultrasonic velocity and absorption in a gas in terms only of current in the resonant circuit and path-length in the interferometer, all circuit and interferometer constants dropping out. The values of current as a function of pathlength obtained experimentally are in complete accord with the theory, and data for ultrasonic absorption in air and in CO_2 so far obtained agree with the meager data available by other methods. The role of the coefficient of reflection at the fluid-reflector surface is discussed.

1075

Knudsen, V. O., "Effect of Humidity upon Absorption of Sound in a Room, Determination of Coefficients of Absorption," J. Acoust. Soc. Am., 3, 126-138, 1931.

The results of the author's experiments confirm the general findings of Sabine and Meyer and throw further light on points of theoretical and practical interest. The author has taken advantage of the special atmospheric conditions at Los Angeles, where the investigations were carried out in the two test chambers of the acoustical laboratory of the University of California. Each of these rooms is enclosed by two separate walls, 12 inches thick, of reinforced concrete, and the floors rest upon a 6-inch fill of sand and a 2-inch slab of cork, thus being insulated from the effects of external vibration, sound, and heat. Owing to the small temperature changes throughout the seasons of the year, the temperature in the room was never lower than 20°C and never higher than 22°C, and it usually differed by only 0.2 or 0.3 of a degree from 21°C. The relative humidity, on the other hand, followed closely the changes of the outside humidity, and changes from 14% to 70% within a period of 48 hours were not infrequently noted. Thus the effects of relative humidity on sound absorption could easily be investigated within a wide range without resorting to artificial aids. Humidities above 70% were readily obtained by evaporation of water in the room. Reverberation times were measured (1) by obtaining oscillographs of the decay of sound; (2) by measuring the times for specified amounts of decay by means of a microphone pick-up, a five stage amplifier, and a relay-controlled chronograph; and (3) by making reverberation measurements with the ear and a recording chronograph. In the oscillograph and relay methods "warble" tones were used, having a bandwidth of 200 ~ and a frequency of warble of 5 to 7 ~ per sec. The results are given in photographs of oscillograms, curves, and tables; they cannot be stated in a short abstract, but in general the experiments indicate that the absorption of sound in the air is an important factor which must be considered in problems in sound signalling and in architectural acoustics.

1076

Knudsen, V. O., and L. Obert, "Absorption of H. F. Sound in Oxygen Containing Small Amount of Water Vapor or Ammonia," J. Acoust. Soc. Am., 7, 249-253, 1935.

Using a new technique, the author has extended his measurements upon the absorption of hf sound in gases to higher frequencies (up to 34,000 ~). The gas is contained in a small steel box and the sound is generated in the box by a magnetostriction oscillator. The intensity of the sound generated in the box is measured, and thus the sound absorption in the gas is determined. The results confirm the earlier results, (i.e., the absorption is a maximum at a certain frequency which depends upon the amount and kind of the gaseous impurity, and this frequency increases almost linearly with the concentration of most impurities, but in the case of water impurity is a quadratic function of the concentration). This latter fact suggests that a collision of an O_2 molecule with two molecules of H_2O is more efficient in producing a transition within the molecule than is a collision with a single H_2O molecule. The theoretical value of the maximum absorption per unit wavelength agrees within experimental error with the measurements. Other measurements have shown that CO_2 and H_2 are also absorptive in the frequency range 7000 ~ to 34,000 ~.

1077

Lawrie, W. E., "Development of New Sound Absorbing Materials for Noise Suppressors, Part I. Development of Equipment for Evaluating Acoustical and Durability Properties of Sound Absorbing Materials at Elevated Temperatures," WADC Tech. Rept. No. 58-460, Armour Research Foundation, Chicago, Ill., 64 pp., 1959.
AD-215 445.

The report describes the development of equipment and techniques for the measurement of high temperature acoustical and mechanical properties of absorbing materials for use in aircraft engine test cells. An acoustical impedance tube has been constructed to determine the high temperature acoustical properties and the necessary techniques developed to obtain accurate measurements in the presence of the temperature distribution found in the tube. In addition, a test cell has been constructed that simulates the environment to which the acoustical materials will be exposed. This cell is to be used to determine the appropriate mechanical properties of acoustical materials to ascertain that the materials will withstand the environment of the aircraft engine test cells.

1078

Leonard, R. W., "Improved Apparatus for Direct Measurement of Absorption of Sound in Gases," Rev. Sci. Instr., 11, 389-393, 1940.

An improved apparatus has been tested with the highly absorptive gases CO_2 and N_2O. Measurements are made of the sound pressure by a microphone as it is moved away from a piston source vibrating in a large baffle. The resulting pressure/distance curves are recorded photographically and yield the absorption coefficient. Reflections from the walls of the cylindrical measuring chamber are reduced materially by specially designed glass baffles. The source is the end of a magnetostrictive rod driven by an improved Pierce-type oscillator with a frequency range of 11.3 to 112 kc.

1079

Northwood, T. D., and H. C. Pettigrew, "The Horn as a Coupling Element for Acoustic Impedance Measurements," J. Acoust. Soc. Am., 26, 503-506, 1954.

Impedance tube methods of testing acoustical materials are restricted to frequencies below the value for which the wavelength is approximately equal to the largest lateral dimension of the tube. Above this frequency, extraneous modes of propagation interfere with measurements. The restriction is a serious one for typical acoustical materials that cannot adequately be sampled in less than 1 square foot. It has been found that the difficulty may be circumvented by using a horn to couple a large sample to a small impedance tube. Comparisons between horn and tube measurements have been made for a range of absorptive materials.

1080

Oberst, H., "Absorption of Sound in Gases," Z. Tech. Phys., 17, 580-582, 1936.

Measurements are described of the absorption of sound in a gas contained in a tube. The sound is excited by a loudspeaker placed at one end of the tube with a diaphragm so heavy that reaction upon it can be neglected. A condenser microphone at the other end of the tube serves to determine the response. The absorption at various frequencies in the range 700-4000 ~ is deduced from the breadth of selected resonances of the gas contained in the tube. To minimize absorption by the tube walls, tubes of thick brass or glass are used. In one series of measurements, N_2 is used at a range of pressures. Since molecular absorption can be neglected in this gas, the absorption deduced should agree with that predicted from Kirchhoff's formula. Actually, the measured absorption is about 15% higher. Measurements are also made in dry and moist O_2, and results are obtained which agree well with those of Kneser and Knudsen. It is suggested that this experimental method would be suitable for determining molecular absorption in gases.

1081

Richards, R. L., "New Airborne Sound Transmission Loss Measuring Facility at Riverbank," J. Acoust. Soc. Am., 30, 999-1004, 1958.

Reports on a then-new facility for measuring sound transmission loss which, in 1958, had been in use for more than a year at Riverbank Acoustic Laboratories. Describes the two reverberation rooms, installation of the test panel, instrumentation, and measurement technique. The several checks made for measurement accuracy and repeatability are discussed. Test results are given, comparing an old method of test with the new, and results are also given for a folding door measured at four testing laboratories in the United States and Canada.

1082

Richardson, E. G., "Relaxation Spectrometry," North Holland Publishing Co., Amsterdam (Interscience Publishers, Inc., New York), 140 pp., 1957.

For the most part the author discusses experimental devices for studying the behavior of viscoelastic media in both the sonic and ultrasonic frequency ranges. Much of the work referred to has come out of his own laboratory. For gases, standard elastic liquids, and solids, he confines himself to presenting typical examples of relaxation absorption and dispersion of high-frequency sound. There is a very brief treatment of dielectric relaxation in solids and liquids, with a comparison between it and acoustic relaxation.

1083

Rudnick, I., "Measurements of the Attenuation of a Repeated Shock Wave," Tech. Rept. No. 3, Soundrive Engine Co., Los Angeles, Calif., 19 pp., 1953.
AD-10, 268.

The rate of attenuation of large-amplitude sound waves in the 30- to 200-cps range was measured as a function of distance along a tube 10 inches in diameter and 60 feet long connected to a siren. The waves approximated a saw-toothed wave form. Expressions are developed for the attenuation caused by the tube walls and by the shock character of the wave. The effect of dc flow of air through the tube is evaluated.

1084

Shaw, E. A. G., "The Acoustic Wave Guide, I., An Apparatus for the Measurement of Acoustic Impedance Using Plane Waves and Higher Order Mode Waves in Tubes," J. Acoust. Soc. Am., 25, 224-230, 1953.

INSTRUMENTATION, ATTENUATION MEASURING

The (1 0) and (2 0) modes of acoustic waves in rectangular wave guides have been excited to the virtual exclusion of plane waves. The experimental techniques depend on the use of acoustic sources equivalent to two or more pistons with appropriate relative phases and amplitudes, precise adjustment of which is accomplished with the aid of an accurately located probe microphone. The standing wave pattern which arises when the wave guide is terminated by a partially absorbing surface may be used to determine the specific normal impedance of the surface, the value of which is characteristic of waves having a particular oblique angle of incidence and may be compared with normal incidence values obtained from plane-wave measurements in the same wave guide and at the same frequency; the angle of oblique incidence may be varied by changing the frequency. The apparatus operates in the 1- 3-kc/sec frequency region, and the accuracy of impedance measurement with (1 0) and (2 0) waves is comparable to that attainable with the usual plane-wave tube techniques. Equivalent angles of incidence at the absorbing surface of up to 84^{o} have been used. The principles underlying the design of the apparatus and some of the distinctive problems which arise with higher order mode waves are discussed.

1085

Shields, F. D., and R. T. Lagemann, "Tube Corrections in the Study of Sound Absorption," J. Acoust. Soc. Am., 29, 470-475, 1957.

The absorption and velocity of sound in argon, nitrogen, and carbon dioxide have been investigated over a range of frequency, pressure, and temperature conditions. A movable sound source and a stationary microphone were used, both employing the principle of the ribbon microphone, located inside glass tubing 1.73 cm in diameter. It was found that Kirchhoff's equations correctly predicted the absorption and velocity as the temperature was varied from 0 to 200^{o} C for argon and from 0 to 150^{o} C for N_2. Not only did the tube absorption vary as a function of $(f/p)^{1/2}$, but the factor incorporating the physical properties also appears to be valid. Certain earlier experiments have not agreed with the Kirchhoff predictions of the magnitude of the factor which depends on the physical properties, and the success in checking the theory is attributed to the use of improved data for the properties and to the use of precision bore tubing in the apparatus.

1086

Wiener, F. M., K. W. Goff, and D. N. Keast, "Instrumentation for Study of Propagation of Sound over Ground," J. Acoust. Soc. Am., 30, 860-866. 1958.

An instrumentation system has been developed to allow continuous determination of the relevant micrometeorological parameters of the atmosphere near the ground in order to relate them to the measured attenuation of an acoustic signal propagated along the ground. Arrays of precision cup anemometers and shielded thermocouples mounted on a 30 ft tower were used to obtain the mean wind and temperature gradients above the ground. To obtain a measure of the atmospheric turbulence, a high-speed wind vane and a bead thermistor were used. The electrical signals obtained by scanning these transducer arrays were fed into a mobile central recording and control facility. Simultaneously, the information provided by the acoustic signal was recorded there by scanning the output of several microphones placed along two test courses each approximately one mile long. The mobile laboratory also contained the necessary equipment for energizing two loudspeakers, one for each test course.

This paper discusses the micrometeorological instrumentation in some detail, together with the calibration techniques used. Typical mean wind and temperature profiles as well as turbulence spectra are presented. The relation of the micrometeorological data to the propagation of sound along the ground is discussed elsewhere.

Instrumentation, Attenuation Measuring
see also—33, 38, 54, 79, 81, 101, 107, 113, 117, 131, 136, 144, 145, 169, 177, 194, 209, 297, 300, 305, 429, 453, 462, 470, 485, 487, 759, 1122, 1134, 1143, 2097, 2848.

INSTRUMENTATION, CORRELATORS

1087

Angell, R. K., "A Two-Level Real-Time Correlator," Master's Thesis, 1957.
AD-162 080.

Some recent developments in the design of correlation computers are described. The theory underlying the correlation function and its calculation is summarized, and the effects of finite averaging time, sampling, and quantization are discussed. A classification of types of correlation computers is introduced and is followed by a detailed survey and description of the many components and circuits which may be used to perform the required mathematical operations. By using the component survey as a basis, two correlator designs for a particular requirement, one analog and the other analog-digital, are outlined and discussed in detail. The design and operation is given for a two-level, real-time correlator which was constructed to experiment with two-level quantization. The correlator is designed around the ability of the magnetic-core shift register to accept and store, in time sequence, information given in the form of binary digits one and zero. The evaluation of the correlator test results indicated the practicality of two-level quantization and the possibilities for real-time electronic correlation.

1088

Baruch, J. J., "Research in the Field of Acoustical Instrumentation," Final Rept. MITO-ORI-07869, Mass. Inst. of Tech., Cambridge, 1958.
AD-213 648.

Reports study and investigation of several methods and techniques of instrumentation usage, including those of the function recorder, application of correlation techniques, analog simulation, magneto-plastic transduction, and transverse vibration instrumentation.

1089

Cook, R. K., et al., "Measurement of Correlation Coefficients in Reverberant Sound Fields," J. Acoust. Soc. Am., 27, 1072-1077, 1955.

Reverberation chambers used for acoustical measurements should have completely random sound fields. We denote by R the cross-correlation coefficient for the sound pressures at two points a distance r apart.

$$R = \left\langle p_1 p_2 \right\rangle \mathrm{Av} \Big/ \left(\left\langle p_1^{\,2} \right\rangle \mathrm{Av} \left\langle p_2^{\,2} \right\rangle \mathrm{Av} \right)^{1/2}$$

where p_1 is the sound pressure at one point, p_2 that at the other e, and the angular brackets denote long time averages. In a random sound field, R = (sin kr)/kr, where k = 2/(the wavelength of the sound). An instrument for measuring and recording R as a function of time is described. A feature of this instrument is the use of a recorder's servomechanism to measure the ratio of two d-c voltages. The results of correlation measurements in reverberant sound fields are given.

1090

Faran, J. J., Jr., and R. H. Hills, Jr., "Correlators for Signal Reception," Tech. Memo No. 27, Acoustics Res. Lab., Div. of Applied Science, Harvard Univ., Office of Naval Res., 88 pp., 1952.
AD-3188.

Correlators (multiplier-averagers) are analyzed and compared with detectors (rectifier-averagers) of various power laws from the point of view of their possible use in signal reception systems. Comparison is made in terms of s/n for the limiting case of small input s/n and long averaging time. Of the detectors, the square-law is found to be slightly superior for determining the presence of a small signal in a noise background; while if two samples of the signal in incoherent background noises are available, although the correlator cannot improve the s/n, it does have the advantage that no constant terms independent of the signal appear at its output. The design of electronic correlators is discussed, and several practical circuits are given. Two other types of circuits, similar in operation to correlators but much simpler to construct, are also analyzed. Both are very slightly inferior to true correlators in output s/n.

1091

Faran, J. J., Jr., and R. H. Hills, Jr., "The Application of Correlation Techniques to Acoustic Receiving Systems," Tech. Memo. No. 28, Acoustics Res. Lab., Div. of Applied Science, Harvard Univ., Office of Naval Res., 55 pp., 1952.
AD-9425.

The application of correlation techniques to acoustic receiving systems is considered theoretically and experimentally. The study is limited, for the most part, to random signals in a background noise which arises in the signal-bearing medium (not in the receiver amplifiers). For example, cross-correlating the signals received by a two-element array is compared with simply adding these signals and detecting with a square-law detector. In some cases, the correlator can effect an improvement in the s/n of as much as 3 db, while, in other cases, conventional methods result in higher s/n. The systems using correlators, however, usually exhibit a practical advantage which may offset any s/n disadvantage; the average output of the correlator usually contains no large term proportional to the strength of the background noise. This allows the use of much higher gain recording or indicating instruments after the correlator. Several methods of performing multiple correlation for use with arrays of more than two elements are considered; nothing significantly superior to a simple adding of all the signals and detecting has been found.

1092

Gershman, S. G., and E. L. Feinberg, "Measurement of the Correlation Coefficient," Soviet Phys. Acoust., English Transl., 1, 340-352, 1957.
AD-265 021.

An instrument is evolved which is based on the use of the connection between the correlation coefficient of two noises and the probability of the signs of the instantaneous values of these noises coinciding. The output effect of the instrument is the measure of this probability. The electric circuit makes use of the transformation of the input voltages into pulses, the electronic relay, on the output of which pulses of coincidence are obtained, the averaging of these pulses and the indicator. The theory of the instrument is developed, and the results of the theory are used for calibrating and evaluating the measuring errors. It is shown that the instrument may be used not merely for measuring the correlation coefficient, but also for certain other purposes, including various measurements in the acoustic field. The results of the experimental use of the instrument are given.

1093

Gilbrech, D. A., and R. C. Binder, "Portable Instrument for Locating Noise Sources in Mechanical Equipment," J. Acoust. Soc. Am., 30, 842-846, 1958.

A portable direction finder utilizing correlation techniques was developed for locating noise sources in mechanical equipment. A description of this instrument and some test results are given. The test results include studies of the direction-finding characteristics of the apparatus and a simple method of determining wave fronts.

1094

Goff, K. W., "An Analog Electronic Correlator for Acoustic Measurements," J. Acoust. Soc. Am., 27, 223-236, 1955.

A study has been made of the applicability of correlation techniques to the field of acoustic measurements. The development of an analog electronic correlator for this study is reported here while the application of the correlation technique to some acoustic measurements is reported in a companion paper.

The analog correlator is divided into the following four main components and each one is discussed in detail: (1) variable time delay; (2) quarter-squaring multiplier; (3) continuous and stepping integrators; (4) system for scanning and plotting the cross-correlation function on both linear and logarithmic scales.

The correlator operates over an input frequency range of 100 cps to 10 kcps, a range of relative time delay τ from -15 to 190 msec and RC intergration times of 0.5 to 16 seconds. A dynamic range in the cross-correlation function of approximately 50 db is achieved with ±1 db accuracy.

Special attention has been given to the errors in the cross-correlation function resulting from finite integration time and scanning of the correlation function. A significant increase in permissible scanning speed for a given s/n has been shown to result from "matching" the equivalent integrator pass band to that of the spectrum common to the two signals applied to the correlator. Relations have been derived between scanning speed, s/n, and input signal band width for integration performed by either a low-pass filter or a "matched" filter.

1095

Haberstitch, A., and F. R. Hama, "A Correlation Analyzer," Tech. Note No. BN-125, Inst. for Fluid Dynamics and Applied Mathematics, Univ. of Maryland, College Park, 1958.
AD-154 242.

A detailed description is given of a correlation analyzer which measures the spectral equivalent of a double (time) correlation between any two signals. Actual measurements are made with a few artificial signals in order to determine its reliability. Although it is primarily designed for the direct measurement of the energy transfer function in the spectrum of turbulence, the instrument is considered capable of measuring the transfer function of any "black box." Therefore, it may find versatile applications in buffeting, aerodynamic stability, and aeroelasticity, as well as in electronics and servomechanisms.

1096

Harder, J. A., "A Machine for Computing Correlation Functions," Inst. of Engineering Res., Univ. of Calif., Berkeley, 11 pp., 1958.
AD-206 604.

A computer is described which is able to analyze graphically recorded data in a more direct way than previous machines. The method does not require multiplication or integration, but instead uses a zero-one process in which no account is taken of the absolute magnitude of the variables; the only question asked is whether the variable is less than or greater than its temporal mean value. The results of analyzing a pure sine wave are given, on which values of C/N are plotted as a function of phase lag. The failure to achieve either 100% coincidence at zero phase lag or 0% at 180° lag appeared to result from a difference in shrinkage between the 2 prints used. The trace width, about .006 inches, is 0.01% of the record length; a difference of length between the two records of only a fraction of the trace width would have the result observed, that of missing the total coincidence by 1.5%. Another measure of the machine accuracy is the reproducibility of counts with the slide shutter at a fixed position. The variance is within one part in 500 or ±0.1%. The machine appeared to be an order of magnitude more precise than necessary for most measurements it will be called on to analyze.

1097

Jackson, P. L., "Optical Analysis Techniques Applied to Seismic Data," Acoustics and Seismics Lab., Inst. of Science and Technology, Univ. of Mich., 1962.

An optical system capable of performing multichannel, high-resolution spectral analysis, and auto- and cross-correlation is under development. The series of progress reports listed detail the effort in obtaining accurate time and spectral information from variable density, time history signals.

First Semiannual Technical Summary Report, January 1962, Rept. No. 4596-4-P
Second Semiannual Technical Summary Report, July 1962, Rept. No. 4596-7-P
Third Semiannual Technical Summary Report, January 1963, Rept. No. 4596-13-P
Fourth Semiannual Technical Summary Report, July 1963, Rept. No. 4596-20-P

1098

Jackson, P. L., "Signal Enhancement Through an Ensemble Presentation," Bull. Seism. Soc. Am., 53, 1962.

A method of treating array responses is presented. The entire statistical distribution from the array is used for either direct visual estimation, or for processing in a scanning machine. An estimate of a coherent signal and the character of the noise can be made visually. Most correlative techniques, in addition to digitizing, could be performed simultaneously through using the scanning machine.

1099

Pick, L. A., "A Quasi-Linear Correlator Applied to Signal Location," Tech. Rept. No. 2203, Army Signal Research and Development Lab., Fort Monmouth, N. J., 7 pp., 1961. AD-264 563.

A method of obtaining precise measurement of the time difference between two audio signals in the presence of non-correlated noise by means of a delay mechanism and a quasi-linear correlator used as a sensing element is described. The design philosophy of the equipment is discussed and some of the pitfalls encountered during the construction and testing of an experimental model are pointed out. In evaluation of limited test data, it is shown that measurements with a precision of 0.1 μsec were easily obtainable, and accuracies of 0.5 μsec were obtained from preliminary data taken in experimental field tests. These results are interim, but represent considerable improvement in accuracy at a slight sacrifice in sensitivity over previous systems using a magnetic drum.

1100

Ragazzini, J. R., H. Saks, and M. Kaufman, "Methods for Analyzing Shock and Vibration," Library Rept. No. 1, Gruen Appl. Sci. Labs., Inc., Hempstead, N. Y., 30 pp., 1957. AD-204 756.

This is a bibliography with abstracts on the following topics:
The filter problem of the power-spectrum analyzer.
Communications applications of correlation analysis.
Methods of obtaining amplitude-frequency spectra.
Short-time autocorrelation functions and power spectra.
The response of a resonant system to a gliding tone.
Response of a linear resonant system to excitation of a frequency varying linearly with time.
Measuring noise color.
The sampling theory of power spectrum estimates.
The principles and practice of panoramic display.
An 8000-c sound spectrograph.
Methods and instruments for the visual analysis of complex audio waveforms.
High-speed, high-resolution spectrum analyzer.
A spectrum analyzer for the 100- to 100,000-c range.
Automatic wave analyzer.
Analog equipment for processing randomly fluctuating data.
A computer for correlation functions.
Shock spectrum computer for frequencies up to 2000-c phenomena.
A high-speed correlator.
An extremely wide-range electronically deviable oscillator.

1101

Weinberg, M., "Digital Comparator, Type I and Laboratory Tests of Multicorrelator-Comparator System," Report No. TR-305, Diamond Ordnance Fuze Labs., Washington, D. C., 27 pp., 1955. AD-217 141.

The digital comparator described is a cross-correlation device for indicating on an output galvanometer the percentage of correlation between a time-varying ternary signal and a predicted-time stationary signal. The device is used in conjunction with the Type 3 Multicorrelator (DOFL Rept. No. TR-215, 30 November 1955, AD-216 868) and the Comprizor (DOFL Report No. TR-304, 15 December 1955, AD-217 140) in a signal detection system. Laboratory tests of the Multicorrelator-Comprizor-Comparator System were run to determine the effectiveness of the digital comparator as a signal-indicating device under as many different operating conditions as possible, and to determine the effect of operating parameters on the performance of the comparator.

1102

Wilmotte, R. M., Inc., "Instantaneous Cross-Correlator," Miami, Fla. (reports available from Rome Air Development Center and Defense Documentation Center only), 1956-1957.

Letter Rept.	9, RADC TN 56-227	
	10, RADC TN 56-228	
	11, RADC TN 56-416,	AD-97930
	12, RADC TN 56-453,	AD-97981
	13, RADC TN 57-200,	AD-114495
	14, RADC TN 57-346,	AD-131306
	15, RADC TN 57-347,	AD-131307
Final Report	RADC TR 59-68,	AD-222272

The development, construction and performance of an instantaneous cross-correlator is described in detail. Techniques are presented for: (1) wide-band modulation of a light source or light beam, (2) selecting a transducer and material to produce sonic modulation of the light beam, and (3) determining the accuracy with which an auto- or cross-correlator function can be delineated by the proposed component and the accuracy of the time-delay scale between input functions to produce correlation. Based on measurements at a mid-frequency of 400 kc, the conclusions are that: (1) a high percentage of light modulation is obtainable with low power and voltage, (2) a correlation function is obtainable with wideband noise types of signals, (3) a wide frequency band is practicable, (4) no information is given for the dynamic range, (5) a single optical system is practical for many applications, and (6) the unit is rugged and can be built in a compact form.

Instrumentation, Correlators
see also—395, 624, 626, 636, 640, 664, 668, 1113, 1117, 1118.

INSTRUMENTATION, INTENSITY AND PRESSURE MEASURING

1103

Baker, S., "An Acoustic Intensity Meter," J. Acoust. Soc. Am., 27, 269-273, 1955.

Describes a device for measuring the intensity of an acoustic wave at a point. The instrument employs a crystal microphone as a pressure transducer, a directional hot-wire anemometer as a velocity transducer, and an electronic multiplier and integrator. It will directly measure the intensity of any pressure or velocity wave form without assuming any relationship between pressure and velocity.

Reports several types of measurements performed, indicating present capabilities of the instrument.

1104

Bonvallet, D. J., "Instrumentation and Techniques for Noise and Vibration Control," Sound, 1, 26, 1962.

This article presents a brief description of some of the instruments and techniques employed in noise and vibration studies of automobiles. A few approaches are discussed to indicate the comparative importance of instruments and experienced vibration engineers. Both are found essential to a successful program.

1105

Clark, G. Q., "Pulsonde Telemetry System," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, New Mex., 1, 135-140, 1961.
AD-408 716.

Studies of atmospheric acoustic propagation at high altitude necessitated the development of a balloon-borne telemetry system capable of transmitting, with a high degree of fidelity, electronic signals proportional to acoustic pressures which vary in frequency from the sonic to the infrasonic region. Experimentation with several types of systems indicated that a pulse-AM system offered the most potential for the realization of the desired characteristics.

Describes system capable of linear response to below 1 cps, sensitivity to pressure below 1 d/cm^2, and nominal operating life from battery supply of eight hours at temperatures from -40° to -70°C.

1106

Criborn, C. O., "Determination of Pressure-Time Curves of the Shock Wave by a New Method," Appl. Sci. Res., A, 3, 225-236, 1952.

Describes an experimental technique which is based on the dependence upon air pressure of the corona discharge current between a positively charged ring and a pointed probe on its axis. A ring approx. 6 mm dia. at 3-4 kV gives a discharge current of 50-100 μA when the pressure is 1 atm, falling to 10 μA at 2 atm; the time variation of current is recorded on an oscillograph, and hence the pressure variation may be deduced from previous static calibration. The method is capable of accurate measurement of pressures as low as 0.01 atm, and is not very sensitive to changes in atmospheric temperature or humidity. Advantages claimed for this technique are: (a) freedom from shock reflection at the measuring surface ensures direct measurement of static pressure; (b) natural gauge oscillations are unimportant; (c) the dimensions of the gauge can be kept small.

1107

Devik, O., and H. Dahl, "Acoustical Output of Air Sound Senders," J. Acoust. Soc. Am., 10, 50-62, 1938.

The use of the Rayleigh disc for measurement of extremely great sound intensities is discussed; it is stated that the Rayleigh disc may even be used in the open air as part of a pointer instrument when properly shielded, thus giving a means of directly measuring the actual sound intensity (in w/cm^2) of intense sound fields. The measurement also involves determining the direction of propagation of energy. Calculating the total flux over the opening of a sound sender, giving the actual acoustical output in watts, is in that way much simplified. As a secondary instrument a crystal microphone, calibrated by comparison with the Rayleigh disc instrument, was used. When used in extreme sound fields it was directly connected with a rectifier galvanometer. Reports are given of measurements of the total output of a membrane sender and of that of a diaphone. In the first case measurements were also made of the different kinds of losses occurring both in the electrical and the acoustical oscillation circuits, while the vibration losses were determined from the power balance and vibration measurements. Oscillograms of sound wave form are given and discussed.

1108

Eliason, M. C., "A Condenser Microphone for Quantitative Determinations of Ballistic Shock-Wave Intensities," J. Audio Eng. Soc., I, 208-212, 1953.

Presents the design and construction features, testing and operating characteristics of the D-42 Microphone, originally developed for use with an acoustic firing error indicator. Briefly, this equipment consists of two microphones which are mounted at opposite ends of a plastic sphere in a towed sleeve target, and which modulate tiny FM transmitters in response to ballistic shock waves. Two receivers near the gunner actuate indicators that show this distance and inform the gunner whether he is leading or lagging a target.

1109

Estes, N. N., and J. J. Moore, "Development of a Noise Exposure Meter," Rept. No. MRL TDR 62-56, Union Carbide Consumer Products Co., New York, 46 pp., 1962.
AD-283 922.

Describes a small portable noise exposure meter that provides a measure of the total cumulative acoustical energy to which it is exposed during a specified time period. Includes description of associated electronic circuitry (which uses transistorized amplifiers, squaring circuits, rectifying circuits, and coupling circuits), and of the solion-type integrator (which performs the integration and stores the integral until such time as it is read out). Provides data on the performance of the engineering model of the meter (which can be worn without undue discomfort or decreased work productivity).

1110

Eyring, C. F., "Jungle Acoustics," Rept. No. 4699, Office of Scientific Research and Development, NDRC Div. 17, Washington, D. C., 80 pp., 1945.
ATI-62654.

This study of jungle acoustics and micrometeorology is one of the most comprehensive and useful documents available for anyone concerned with the transmission of sound at the earth's surface in tropical climates. The study was conducted during the wet season in Panama and includes propagation measurements over hard, bare surfaces, short and tall grasslands, and through a variety of tropical forests. Terrain loss coefficients and their variations with acoustic frequency and environment were determined from measurements. Ambient jungle noise levels in the audible and ultrasonic ranges were measured. Acoustical and meteorological measurements were taken concurrently in order to demonstrate their inter-relationships. Refraction and shadow zone formation, as caused by combined wind and temperature effects, were investigated and found to be significant in open, sunny areas, but not significant under a jungle canopy. The report clearly shows the typical variations to be expected throughout the day and night for each acoustic and meteorological parameter investigated. The various instruments that were developed for acoustic detection and measurement are described in detail. Calibration procedures are also described.

1111

Gavreau, V., and M. Miane, "Radiation Pressure and the Anisotropy of Acoustic Pressure of Great Intensities" (in French), Compt. Rend., 238, 2148-2150, 1954.

An experimental arrangement designed for determining the pressure of sound radiation is described and illustrated and experiments made with the apparatus are discussed. It is found that sound pressure is anisotropic at high sound intensities. This is attributed to an increase in molecular velocity, which probably also results in an increased speed of propagation of intense sounds. At 145 db, for example, the velocity of 34,700 cm/sec was obtained instead of the theoretical value of 34,000 cm/sec for 20^{o}C.

1112

Grime, G., and H. Sheard, "The Experimental Study of the Blast from Bombs and Bare Charges," Proc. Roy. Soc. (London) A, 187, 357-380, 1946.

An electrical method was used for measuring the pressure in a blast wave, involving the use of piezo-electric gauges with CRO's. A detailed description of the apparatus is given. Measurements were made of the blast pressures produced by bare charges up to 2000 lb in weight, by German bombs and mines weighing from 50 to 1000 kg, and by British bombs of all sizes. The measured and calculated velocities of the blast wave agree well, and the observed and calculated rates of decay of maximum excess pressure agree reasonably well.

1113

Gutenberg, B., "The Velocity of Sound-Waves from Gun-Fire in Southern California," Trans. Am. Geophys. Union, 156, 1938.

Description of a sensitive instrument for recording changes in air pressure. Sound waves recorded by this short period Benioff barograph shown.

1114

Hoeft, L. O., "A System for Measuring the High Sound Pressure Levels from Rockets," WADC Tech. Rept. No. 56-655, Aero Medical Lab., WADC, Wright-Patterson AFB, Ohio, 38 pp., 1956.
AD-110 669.

A system for measuring the high intensity noise produced by rockets is described. The system (1) should be capable of measuring sound pressure levels to 195 db (re 0.0002 dynes/sq cm), (2) should have a flat frequency response from 37.5 c to 10 kc (with usable response to 20 kc), and (3) should be reliable. A 21 channel sound recording system was developed to obtain far and near field noise characteristics in the short firing time of rocket engines. The selection of microphones and other components, and testing and calibration of the equipment are discussed. The technique of setting up a noise survey, the procedure for operating the equipment, and the system used to analyze the data are described in detail.

1115

Johnson, O. T., and W. O. Ewing, Jr., "An Omni-Directional Gage for Measuring the Dynamic Pressure Behind a Shock Front," Memo Rept. No. 1394, Ballistic Research Labs., Aberdeen Proving Ground, Md., 32 pp., 1962.
AD-267 470.

The design of a cantilever gauge for determining the direction of flow and time history of dynamic pressure is described, and the results of both static and shock tube calibration are presented.

1116

Keast, D. N., "Measurement of Rocket Engine Noise," Noise Control, 7, 25, 1961.

This paper presents a general approach to the measurement and analysis of rocket engine noise and illustrates this approach with examples of problems which have been encountered in the past. The approach suggested is intended to provide not only the desired data, but also sufficient information about the instrumentation and measurement techniques so that possible sources of error in the data may be evaluated. The procedures include a detailed laboratory evaluation of the transducer systems, evaluation and calibration of the complete data-acquisition system installed at the test site, various steps in the processing and analysis of tape-recorded data, the eventual estimation of the causes and magnitudes of errors in the measurements, and methods for reducing the possibility of human error by measurement personnel.

1117

Keast, D. N., and G. W. Kamperman, "Acoustic Instrumentation for Measurements in the Minuteman Missile Silo," J. Audio Eng. Soc., 8, 180-184, 1960.

An instrumentation system has been developed to measure, record, and analyze various properties of the dynamic field in the Minuteman launching silo. This system permits the simultaneous recording of up to 13 channels of data from microphones placed in the silo environment. These data may then be processed to obtain frequency spectra, time correlation functions, and space correlation functions. The data acquisition system has a frequency response from 0 to 10,000 cps, a wide dynamic range, and (to permit correlation analyses) a maximum channel-to-channel phase difference of 10^{o}. Various system design problems are discussed. These include the choice of transducers to function in the high-temperature, high-vibration environment of the silo; the equalization of phase shift between the data channels; and the phase matching of filters for space correlation. Representative samples of data obtained with the system are used for illustration.

1118

Kleinschmidt, K., J. V. Rattayya, and A. Silbiger, "Noise Radiation from Submarine Hulls, Part II. Comparison of Theoretical Results with Model Test Data Measurements," Rept. No. U-134-64, Cambridge Acoustical Assoc., Inc., Mass., 1962. AD-278 598.

The design and instrumentation of a suitable model for investigating the vibration and sound radiation from a hull with a symmetrical foundation are described. The test results are explained, and in some respects successfully correlated with the predicted values. Natural frequencies in air and water of the ring-stiffened cylindrical model are in good agreement with the theory. Driving point impedance phase measurements conform to theory. For reasons which are discussed in detail, there is only fair correlation of theoretical and measured far field sound pressures for a 1-lb shaking force applied to the foundation. This correlation is not as good as that obtained earlier for the full-scale data. Longitudinal vibrations of a spheroidal shell are also discussed.

1119

Langmuir, D. B., "A New ASA Standard Sound Level Meter," J. Audio Eng. Soc., 10, 318-323, 1962.

Describes a sound level meter intended for general use and utilizing a self-calibrating technique.

1120

Millar, W., "Theory and Design of an Acoustic Pressure Gauge," Mem. GP/M 190, Atomic Energy Research Establ. (Great Britian, 11 pp., 1956.

In the pressure range 10^{-2} to 10^{3} mm mercury, a number of well-established types of gauge are in use. These include manometers (mercury or oil), McLeod gauges, Pirani gauges, and comparison devices using a mechanical diaphragm. Each of these types has its own limitations in convenience, accuracy or working range. A type of gauge is proposed here in which these limitations could be less serious, and which will cover the whole of the above range. Operation of the instrument depends on the amplitude of received signal at the end of an "acoustic transmission line," which is simply a tube containing gas at the pressure to be measured. A simple form of the gauge, which works well for air, has already been constructed; design proposals are given for a gauge of general applicability.

1121

O'Connell, J., "Sound Survey Meter for Field Tests of Fog Signals," Coast Guard, Washington, D. C., 9 pp., 1961. AD-260 511.

Tests of a small, compact, self-contained sound measuring apparatus with a rated dynamic range of 50 to 146 db (re 0.0002 microbar) are reported. The instrument tested was a General Radio Type 1555-AS3 Sound Survey Meter with a ceramic microphone on an extension cable. Frequency response of the meter was investigated as a function of sound pressure level. Dynamic response at 1000 cps as a function of sound pressure level, and temperature dependence of 1000 cps are also reported. The report concludes the device can measure the output of most Coast Guard fog signals within +2 or -2 db.

1122

Oleson, S. K., "Instrumentation for Field Measurements of Noise Propagation over Ground," Acoustics Lab., Mass. Inst. Tech., Cambridge, Mass., 1956.

Describes an improved method of experimental procedure for studies of sound propagation over varied terrain. The improvements described deal mainly with simultaneous recording of meteoroligical and acoustical data, thus minimizing experimental errors resulting from constantly changing meteorological conditions.

1123

Peterson, A., "The Measurement of Impact Noise," Noise Control, 2, 46, 1956.

The instrumentation for impact noise measurement is considerably simplified with the introduction of the new Impact Noise Analyzer capable of indicating the peak and time-averaged values of the impact sound being studied.

1124

Peterson, A., "Noise Measurements at Very High Levels," Noise Control, 2, 20, 1956.

What happens to noise-measuring equipment when it is used to measure very high noise levels? The answer to this question and a discussion of instrumentation and limits for high-level noise measurement are presented.

1125

Pimonow, L., (1957) "The Detection and Analysis of Infrasounds Propagated in the Air in the Range 2 to 30 cps" (in French), Ann. Telecommun., 12, 419-423, 1957.

Instruments to measure the sound pressure level and to analyze the spectrum of steady and transient infrasounds are described.

1126

Schultz, T. J., "Acoustic Wattmeter," J. Acoust. Soc. Am., 28, 693-699, 1956.

The author has constructed a device which gives pointer indications of acoustic intensity over a 50 db range at frequencies up to 10,000 c/sec.

The signals from a pair of pressure-sensitive condenser microphones, mounted back to back in a space roughly the size of a dime, are treated electronically to provide pressure and velocity signals which are then multiplied and averaged in a specially designed moving-coil dynamometer to give precise pointer readings.

The theory of operation of the apparatus is discussed and the paper concludes with a brief account of the test results of the acoustic wattmeter.

1127

Scott, R. A., "An Investigation of the Performance of the Rayleigh Disc," Proc. Roy. Soc. (London) A, 183, 296-316, 1945.

Describes an investigation of the law which governs the torque on a Rayleigh disc in a sound field. The torque follows an expression of the form obtained theoretically by Konig, provided the finite thickness and inertia of the disc are taken into account. The measurements were made over the range of 250-4000 cps, the correction for thickness of the disc being large and having a sign opposite to that determined theoretically by Konig for ellipsoidal discs. The smoke-particle method of Andrade and of Carriere was adapted to the measurement of the oscillatory velocity of the field, and determinations of oscillatory velocity within 1% for up to 4000 cps were made. The experimental work confirms that the stability of behavior of the Rayleigh disc justifies its continued use as a reference standard of acoustical intensity.

INSTRUMENTATION, INTENSITY AND PRESSURE MEASURING

1128

Snow, W. B., "Instrumentation for Noise Measurements," Noise Control, 1, 16-21, 1955.

The various modern instruments for measuring noise are described and illustrated, and their purposes and ranges of application are outlined.

1129

Snow, W. B., "Rectification in the Sound Level Meter," J. Acoust. Soc. Amer., 28, 1338, 1957.

Current specifications call for a root-mean-square indication, which means the square root of the average square of the instantaneous sound pressures (proportional to voltage) supplied to the metering circuit. In practice, rectification provides squaring action, the dynamic action of the meter movement furnishes the averaging action, and the meter scale's calibrations show the square roots.

Instrumentation, Intensity and Pressure Measuring
see also—103, 379, 509, 520, 549, 550, 569, 594, 1015, 1044, 1086, 1187, 1190, 1222, 1225, 1232, 1254, 1354, 1355, 1364, 1369, 1377, 1629, 1675, 1676, 1702, 1709, 1715, 1817, 2256, 2491, 2855, 2980, 3337, 3445, 3446, 3449, 3463, 3532, 3781.

INSTRUMENTATION, INTERFEROMETERS

1130

Bell, J. F. W., "A Fixed Path Ultrasonic Interferrometer for Absorption Measurements on Gases," J. Acoust. Soc. Am., 25, 96-100, 1963.

A fixed path interferometer, using variable temperature for the measurement of the absorption in gases in the low f/p region, is described. Its use is illustrated by measurements on argon, neon, air, nitrogen, and nitrogen-hydrogen mixtures at 250 kc. The values found for argon and neon were above classical by 40% and 65%, respectively. The discrepancies are ascribed to Rayleigh cross modes in the ultrasonic waves excited by the quartz crystal transducer rather than to any departure from classical theory. Cross modes and their influence on ultrasonic measurements are discussed. Data on the performance of two crystals at 250 and 500 kc are given.

1131

Bender, D., "Ultrasonic Velocity in N_2, NO, and CO Between 20° and 200°C, Measured by a New Method" (in German), Ann. Physik, 38, 199-214, 1940.

The temperature dependence of the velocity of sound at a frequency of 1000 kcs is measured by a modification of the Pierce interferometer in which the piezo-quartz is mounted between two fixed reflectors. The quartz is coupled inductively to the driving oscillator and vibrates at temperatures up to 500°C, but above 200°C the sound intensity is too weak to permit measurements. The results indicate that in N_2, CO, and NO, the region of anomalous dispersion of the sound velocity is shifted with increasing temperature towards higher frequencies.

1132

Borgnis, F. E., "On the Theory of the Fixed-Path Interferometer," J. Acoust. Soc. Am., 24, 19-21, 1952.

Gives a general expression for the electric input impedance of the acoustic interferometer. From this expression formulas are derived for determining the velocity of sound by varying the frequency, or for determining changes in velocity due to variations of pressure, temperature, etc. Theory indicates that there is no need for the correction of the actual path length when the path ends at a nonperfect reflector, although papers dealing with the fixed-path interferometer commonly suggest such a need.

1133

Eucken, A., and R. Becker, "Excitation of Intramolecular Vibrations in Gases and Gas Mixtures by Collisions, Based on Measurements of Sound Dispersion," Z. Physik, Chem., B, 27, 219-262, 1934.

The paper is in two parts. The first part describes an apparatus for measuring ultrasonic wavelengths, based on the principle of the acoustic interferometer described by Pierce. The apparatus can also be used in investigating chemically active gases within a temperature range of several hundred degrees. Certain difficulties dealt are those which arise when frequencies of the order of 50 kcs are used. The method of calculation is described by which the values of C_p/C_v at zero pressure for the pure components of a gaseous mixture are determined from the speed of sound in the mixture at a given pressure. In the second part, results are given for the speed of sound and the value of C_p/C_v for Cl_2 and CO_2 for frequencies 58, 145, and 292 kcs. It is deduced that the number of collisions required to withdraw a quantum of energy from the pure gases CO_2 and Cl_2 is 51,000 and 34,000, respectively, at room temperature. Under certain conditions these numbers may be greatly reduced. The effect of temperature is such that a rise from -32° to +145° causes a sevenfold increase in pure Cl_2, a fourfold one in CO_2, and a fivefold one in Cl_2 containing CO. A formula was derived theoretically and was found to agree with experiment, according to which the number of impacts required for the release of one quantum is proportional to $1/T^n$ where n is a number depending on two molecular factors.

1134

Greenspan, M., and M. C. Thompson, Jr., "An Eleven Megacycle Interferometer for Low Pressure Gases," J. Acoust. Soc. Am., 25, 92-96, 1953.

Describes an automatically recording, double-crystal interferometer which measures the speed and attenuation of sound at about 11 mcs in gases at pressures of a fraction of a mm Hg.

1135

Hodge, A. H., "Ultrasonic Velocity in Gases between 1 and 100 Atmospheres," J. Chem. Phys., 5, 974-977, 1937.

An acoustic interferometer of the resonator, or driven, type has been developed for the study of the behavior of ultrasonic waves in gases under pressures ranging from vacuum to several hundred atm.; measurements of acoustic velocity at several frequencies and in several gases at pressures ranging from 1 to 100 atm. have been made. Increase of velocity with pressure was found for air, N_2, He, and H_2, and a decrease for CO_2, with approximate pressure and velocity ranges as follows: air, 1-101 atm., 347-371 m/sec; N_2, 1-102 atm., 353-380 m/sec; CO_2, 1-63 atm., 270-198 m/sec. The He and H_2 were known to be impure. For them an increase in velocity nearly linear with pressure was found. Using frequencies from 88 to 499 kc, dispersion was found for CO_2, at atmospheric pressure, but almost entirely disappeared above 8 atm.

Demonstrates availability of this method for indirect determination of specific heats.

1136

Hubbard, J. C., "Acoustic Resonator Interferometer, Part I. The Acoustic System and Its Equivalent Electric Network," Phys. Rev. 38, 1011-1019, 1931.

The steady state of motion of a fluid between two infinite plane parallel boundaries is found for the case in which one of the boundaries is given a prescribed periodic motion normal to its surface, the other boundary being infinitely rigid or being assigned to a coefficient of reflection. The excess pressure at any point in the fluid is found, being of particular interest at the boundary of the source where it has a term in phase with the velocity of the source and one in phase with its displacement. These terms pass through cyclical values as the distance between the source and reflector is increased, the first passing through sharp maxima, the second changing rapidly from negative to positive values at reflector distances of an integral number of half wavelengths in the fluid. Application is made to the case in which the source is the surface of a piezoelectric plate maintained in forced vibration. The equivalent electric network of the plate and coupled column is found to be the same as that for the plate alone, with modified resistance and capacity coefficients, making possible consideration of the theory of the acoustic resonator interferometer in conjunction with driving and measuring circuits.

1137

Hubbard, J. C., "Acoustic Resonator Interferometer, Part II. Ultrasonic Velocity and Absorption in Gases," Phys. Rev., 41, 523-535, 1932.

The derivation of the equivalent electric network of the acoustic resonator interferometer in Part I of this paper has made it possible to develop the theory for the current in a simple resonant circuit in which the electrodes of the piezoelectric plate of the interferometer are connected to the terminals of the variable condenser. The special case of this theory is that in which the circuit is excited at a constant frequency determined by the crevasse frequency of the resonator plate in its given situation with respect to electrodes and associated circuit, when the acoustic path in the interferometer is detuned and the resonant circuit is tuned so that its resonant maximum occurs at the same frequency; the special case takes an especially simple form and leads to a direct procedure for determining ultrasonic velocity and absorption in a gas in terms only of current in the resonant circuit and path-length in the interferometer, all circuit and interferometer constants dropping out. The values of current as a function of pathlength obtained experimentally are in complete accord with the theory, and data for ultrasonic absorption in air and in CO_2 so far obtained agree with the meager data available by other methods. The role of the coefficient of reflection at the fluid-reflector surface is discussed.

1138

Itterbeek, A. V., "Measurements with Ordinary Sound and Ultrasonics Carried Out in the Physical Laboratory of the University of Louvain," J. Acoust. Soc. Am., 29, 584-587, 1957.

This paper contains brief résumés of some of the acoustical research carried on at the University of Louvain during the year 1955-1956. Descriptions of apparatus and methods, and some interpretation of the results are given. Two different acoustical interferometers are described and illustrated. Their use for measuring sound speeds in various gases and for measuring extremely low temperatures is explained.

1139

Jatkar, S. K. K., "Supersonic Velocity in Gases, Part I," J. Indian Inst. Sci., 21A, 245-271, 1938.

As a preliminary to the measurement of the velocity of supersonic sound in the vapors of organic compounds, a study is made of the aberrations of supersonic interferometers used to determine wavelengths. Includes curves showing how the anode current of the quartz oscillator varies with the position of the reflector, and mapping irregularity of peak positions (corresponding to nodal planes). Investigates causes of these irregularities, and demonstrates that the best results are obtained when a somewhat narrow interferometer tube is used and the quartz is carefully positioned a short distance from the tube; under these conditions the wavelength is said to be obtainable with an accuracy of 1 in 700.

1140

Krasnooshkin, P. E., "Theory of Ultrasonic Interferometer," J. Phys. (USSR), 7, 80-91, 1943.

Develops a theory which takes into account the lack of uniformity in the distribution of vibration amplitudes over the interferometer radiator. Proposes corrections in existing methods of measuring the absorption and velocity of ultrasonic waves in gases.

1141

Petralia, S., "Ultrasonic Interferometry in Gases, I" (in Italian), Nuovo Cimento, 7, 705-714, 1950.

After referring to the principal questions connected with the scattering of ultrasonic waves in gases, describes a variable-path interferometer which allows the determination of the propagation constants (velocity and absorption coefficients) of ultrasonic waves in gases and vapors, for frequencies between 50 and 2000 kcs, and discusses the experimental technique. Notes some preliminary measurements made in CO_2 (known to be dispersive) and in lighting gas, indicating that there is also velocity dispersion in this latter gas in the frequencies between 58 and 1400 kcs.

1142

Pielemeier, W. H., "Pierce Acoustic Interferometer for Determining Velocity and Absorption," Phys. Rev., 34, 1184-1203, 1929.

The coefficient of absorption A of sound waves, at a distance x from a source, is contained in the expression: $I \; I_0 e^{-(A/\lambda^2)x}$. It was determined theoretically by Lebedew and experimentally by Neklapajeff. The paper describes its investigation by means of a quartz oscillator apparatus. The crystal forms part of a thermionic valve circuit, and the interfering sound waves react on it in such a way as to cause periodic changes in the plate current when the reflecting mirror is displaced a half wavelength or more. Several observed facts indicate a variation of wave-velocity with intensity, and measurements in air and CO_2 at frequencies from $3(10)^5$ to $14(10)^5$ give a slightly higher velocity than the commonly accepted value for audible frequencies. The absorption by air and CO_2 increases with frequency through this range, CO_2 being nearly opaque at $14(10)^5$. Lebedew's constant has a value of 0.00037 for air at 20^oC. The observed values of A for CO_2 were 0.012 at $3(10)^5$, 0.0096 (by torsion vane) at $6.5(10)^5$, and 0.0073 at $12(10)^5$. The humidity has a marked effect on the absorption in CO_2.

1143

Richardson, E. G., "Absorption and Velocity of Sound in Vapors," Rev. Modern Phys., 27, 15-25, 1955.

A review of the work on this subject during the past fifteen years. The paper deals with the theory of interferometers of the Pierce, double-crystal, capillary tube, and hot-wire types. Discusses results of measurements at varying pressures in air, rare gases, triatomic molecules, and polyatomic molecules (organic vapors). Examines effects of temperature and of vapor mixtures.

Observations of velocity and absorption near the critical state for CO_2 as functions of pressure and frequency are dealt with in a later section of the paper, where there are also derivations of thermodynamical relationships that lead to expressions for the propagation of shock waves in vapors.

Concluded with a useful list of 100 references to current literature.

1144

Stewart, J. L., "A Variable Path Ultrasonic Interferometer for the Four Megacycle Region with Some Measurements in Air, CO_2, and H_2," Rev. Sci. Instr., 17, 59-65, 1946.

Alignment of the piston and crystal to the order of one light fringe was attained and maintained by employing Newton and Haidinger optical fringe systems. Velocities were measured to an accuracy of 0.1%, and absorption and reflection coefficients to 50% in air and CO_2. The limit of accuracy in both cases was determined by the length, as measured to one micron with a micrometer screw. Preliminary measurements on H_2 gave evidence of molecular dispersion between 4 and 8 mcs.

1145

Stewart, J. L., and E. S. Stewart, "A Recording Ultrasonic Interferometer and its Alignment," J. Acoust. Soc. Am., 24, 22-26, 1952.

The first part describes a circuit employing rf amplification which converts an ultrasonic interferometer into a sensitive self-recording instrument whose records easily can be analyzed to yield a rapid determination of the attenuation and reflection coefficients of gases at low pressures. The second part summarizes the sources of error in ultrasonic interferometry, their detection and their correction. In the third part, some data on the velocity, attenuation, and reflection in helium between two to sixty Mc/atm are presented to illustrate the range, precision, and absolute errors of the instrument.

1146

van Itterbeek, A., and W. van Doninck, "On the Velocity of Propagation of Sound in Air, and in a Nitrogen-Hydrogen Mixture, at Low Temperatures, Calculation of the Specific Heats," Ann. Phys., 19, 88-104, 1944.

An ultrasonic experimental method is used. The acoustic interferometer and its associated electric circuit, and the apparatus for preparing the H_2-N_2 mixture, are described. A theoretical method is given, based on the equation of state $pv = RT(1 + \frac{B}{v} + \frac{C}{v^2} + \ldots)$. It is shown that the velocity of propagation (W) is given by the linear relation $W = W_0(1 + sp)$ where W_0 is a function of t and $s = \frac{B}{R} + \frac{1}{\lambda R}\frac{dB}{dT} + \frac{1}{2\lambda(\lambda+1)}\frac{T}{R}\frac{d^2B}{dT^2}$.

Numerical results (experimental and theoretical) are presented in graphical and tabular form. For air, the velocity was measured between 79.15°K and 90.10°K (obtained by means of liquid oxygen) at pressures varying between 0.085 and 0.941 atm. The coefficient, B, for air is plotted as a function of T, and numerical values of W_0 are given. The specific heats for air are given as function of the pressure for T = 90°K and T = 80°K. Similar results are given for H_2-N_2.

1147

Zartman, I. F., "Ultrasonic Velocities and Absorption in Gases at Low Pressures," J. Acoust. Soc. Am., 21, 171-174, 1949.

The improvements on an ultrasonic interferometer are discussed. As a result of these, a greater sensitivity to acoustic reactions is obtained and the reproducibility of the data is greatly improved. Velocity measurements in dried CO_2-free air, dried N_2 and dried H_2 are given. Amplitude absorption coefficients for H_2, N_2, and CO_2 are also included. Measurements are made over the temp. range from 9° C to 36·6° C and over the pressure range from 82·17 cm Hg to 0·45 cm Hg. The frequencies extend from approximately 500 kcs to 2·16 Mcs. A maximum value for the absorption in H, attributed to molecular absorption, is located at an f/p ratio of approximately 10 Mcs atm.

Instrumentation, Interferometers
see also—49, 71, 96, 146, 282, 290, 300, 316, 470, 794, 1244, 1278, 1295, 1305, 2625, 3132, 3133, 3545.

INSTRUMENTATION, RANGING AND SOUNDING

1148

Army Artillery Board, "Evaluation of British Recorder, Sound Ranging (Long and Short Base) NR. 5, MK 1," Proj. No. FA 3257, Fort Sill, Okla., 11 pp., 1958.
AD-207 987.

Evaluates the British recorder, sound ranging (long and short base) Nr 5, Mk 1, on a comparative basis with the United States' Sound Ranging Set GR-8. The Nr 5, Mk 1 set is superior to the GR-8 with respect to (1) number of recording channels, (2) design of stylus assemblies, (3) adjustable trace intensity, (4) ease of maintenance, (5) timing circuits, and (6) modular design concepts. The Nr 5, Mk 1 is comparable to the GR-8 with respect to ease of installation and accuracy. The two recorders are comparable and functionally interchangeable.

1149

Army Artillery Board, "Service Test of Sound Ranging Plotting Equipment T43," Fort Sill, Okla., 1960.
AD-240 279.

Describes tests conducted to determine the suitability of the T43 sound ranging plotting equipment for field artillery use (The T43 is used in conjunction with the GR-8 sound ranging set to determine the location of artillery weapons). Concludes that the equipment tested would be suitable for artillery use when discrepancies noted are corrected, provided the modified test item satisfactorily meets the requirements of engineering tests.

1150

Army Artillery Board, "Service Test of Sound Ranging Plotting Equipment T43," Partial Rept. No. 1, Fort Sill, Okla., 7 pp., 1958.
AD-200 905.

Reports an evaluation of the modified M5A2E2 plotting board and string plotting equipment to determine which should be developed for inclusion in the T43 sound-ranging plotting equipment. The string plotting equipment consisted of a jig, pins, strings, and weights, and four-second aluminum curved time scales. The M5A2E2 plotting board consisted of two plotting boards modified by the addition of a four-second time scale and an off-board rest for the drafting machine. The modified M5A2E2 required less time for (1) setting up the equipment, plotting the base, and preparing for plotting, and for (2) plotting a sound source and evaluating the polygon of error. The average plotting error in the location of a sound source by the string plotting equipment was 15.2 meters, compared to 14.3 meters obtained with the modified M5A2E2. The modified M5A2E2 is smaller in size and more easily used in reading the coordinates of plotted points within the masked area.

Two M5A2E1 plotting boards, which are M5A2E2 modified plotting boards, were recommended for service tests as components of the T43 sound-ranging plotting equipment.

1151

Bandeen, W. R., "The Recording of Acoustic Waves From High-Altitude Explosions in the Rocket-Grenade Experiment and Certain Other Related Topics," Tech. Rept. No. 2056, Army Signal Res. and Development Lab., Fort Monmouth, N. J., 72 pp., 1959.
AD-231 943.

Discusses the instrumentation and operation of the sound-ranging installation for the rocket-grenade experiment at Fort Churchill. Applies Schrodinger's equation for the transmissivity of sound in the atmosphere to empirical data, illustrating the upper altitude limit of the experiment, and discusses a modified method of correcting for the test's finite-amplitude-propagation effect. Analyzes the specific problem of measuring arrival angles of sound waves. Examines the effect of the re-entry ballistic wave on grenade-sound arrivals, and presents a method for determining the times of such obscured arrivals, and also of weak sound arrivals.

1152

Bartman, F. L., L. M. Jones, J. Otterman, et al., "Rocket-Grenade Experiment for Upper Atmosphere Temperature and Winds," Proj. No. 2387, Eng. Res. Inst., Univ. of Michigan, Ann Arbor, 1955-1960.

This series of Quarterly Progress Reports and Technical Reports covers the experimental and theoretical results of efforts to adapt the rocket-grenade experiment for use in the Arctic during the IGY. The rocket-grenade system provides an all-weather method for calculating upper atmosphere winds and temperatures from acoustic data. Various methods for computing these temperatures and winds are presented in complete detail. The effects of finite-amplitude acoustic propagation resulting from the use of high-explosive grenades are investigated. Rocket tracking, by the DOVAP method, is described, as are various methods for determining the positions of exploding grenades with respect to the rocket. Sound ranging gear for measuring the arrival times, elevation angles and azimuths of acoustic wavefronts is also described. Abstracts for six technical reports listed in this series are printed separately under appropriate authors and titles.

Qtly. Prog. Rept. 1,	May-July 1955	2387-4-P	AD-95 280
Qtly. Prog. Rept. 2,	August-October 1955	2387-6-P	AD-95 279
Qtly. Prog. Rept. 3,	November-January 1956	2387-10-P	AD-95 278
Qtly. Prog. Rept. 4,	February-April 1956	2387-13-P	AD-118 569
Qtly. Prog. Rept. 5,	May-July 1956	2387-17-P	AD-133 348
Qtly. Prog. Rept. 6,	August-October 1956	2387-19-P	AD-133 347
Qtly. Prog. Rept. 7,	November-January 1957	2387-22-P	AD-133 346
Qtly. Prog. Rept. 8,	February-April 1957	2387-25-P	AD-146 638
Qtly. Prog. Rept. 9,	May-July 1957	2387-27-P	AD-148 199
Qtly. Prog. Rept.10,	August-October 1957	2387-32-P	AD-151 912
Qtly. Prog. Rept.11,	November-January 1958	2387-36-P	AD-162 058
Qtly. Prog. Rept.12,	February-April 1958	2387-39-P	AD-208 805
Qtly. Prog. Rept.13,	May-July 1958	2387-45-P	AD-208 604
Qtly. Prog. Rept.14,	August-October 1958	2387-47-P	AD-213 452
Qtly. Prog. Rept.15,	November-January 1959	2387-51-P	AD-218 341

Tech. Rept. 2387-34-T (1958)	AD-162 059
Tech. Rept. 2387-40-T (1958)	AD-201 454
Tech. Rept. 2387-42-T (1958)	AD-203 897
Tech. Rept. 2387-50-T (1959)	AD-215 303
Tech. Rept. 2387-57-T (1960)	AD-236 213
Tech. Rept. 2387-58-T (1960)	AD-241 362
Final Rept. 2387-59-F (1960)	AD-241 361

1153

Bellamy, J. C., R. F. Bosshart, et al., "Investigation of the Feasibility of Acoustic Soundings of the Atmosphere," Rept. No. PR-152-2, Cook Res. Labs., Skokie, Ill., 1957.
AD-212 334.

Investigations revealed that a frequecy of 1000 c affords the best compromise for the signal carrier frequency. Tests will also be made at 500 and 750 c. To provide a logical basis for the tests at these frequencies, a series of calculations have been made of estimated signal losses. In order to understand better the basis of these calculations, a short review is given. Progress in the construction of an experimental sonic sound device of flexible design is summarized.

1154

Bellamy, J. C., R. F. Bosshart, et al., "Investigation of the Feasibility of Acoustic Soundings of the Atmosphere," Final Rept., Cook Res. Labs., Skokie, Ill., 1958.
AD-210 659.

Acoustic soundings of the atmosphere offer an indirect technique for obtaining frequent information on weather conditions in the upper air. A feasibility experimental model sounding system for acoustical probing of the atmosphere is described. The system consists of an audio projector unit which beams a short-duration, high-intensity, single-frequency, pulse-modulated audio signal vertically into the atmosphere, and a receiver unit for detecting the sonic reflections and reverberations from the atmosphere. Preliminary results indicate the feasibility of acoustical soundings and more detailed field test information will be required to define explicitly the relationships between acoustic reflections and the corresponding meteorological variables.

1155

Belov, A. I., "Theory of the Acoustical Sounding of the Atmosphere and Experimental Material Before 1932" (in Russian), Proc. All-Union Conference of the Study of the Stratosphere, 125-138, 1938.

Reviews observations of sound propagation after powerful explosions from 1920 to 1932. Aerological observations and the propagation of sound analyzed; scheme and instruments for further investigations outlined. Hypotheses suggested in the study of the acoustical phenomena, along with critical consideration of results of investigations.

1156

Bohn, J. L., "Study of Atmospheric Temperature and Meteoric Content by Ultrasonic Techniques and Development of Special Microphones," Final Rept., Res. Inst., Temple Univ., Philadelphia, 9 pp., 1953.
AD 38 283.

Describes the microphones used in making measurements of high-intensity radiation; they are considered superior to previous ones because they are smaller and have a better reflecting diaphragm—the diaphragms are clamped so that they can expand under prolonged heat absorption. Presents complete drawings of the assembly, including the Teflon carriage, which fits into the glass envelope; mounting parts made of Teflon reduce sound transmission, withstand a fairly high temperature for the baking-out process, and have the advantage of low vapor pressure.

Reports an improvement in the transmitter made by loosely coupling the oscillator to a two-tube class C amplifier, which in turn was coupled to the antenna.

Includes a complete schematic of a six-channel magnetic recorder. Four of the channels derive their inputs from the same source; sections of one signal at various amplitude levels may be recorded, permitting the full dynamic range of the recording medium to be utilized. The remaining two channels are conventional in that each gives a record of the signal from an independent unit.

Discusses the use of FM with the condenser microphones.

1157

Brachman, R. J., "Field Artillery Digital Automatic Computer," Tech. Memo. No. M59-5-1, Frankford Arsenal, Philadelphia, Pa., 42 pp., 1958.
AD-209 143.

A universal computer to solve the gunnery problems relating to tube artillery, free rockets, and various types of missiles, as well as problems of field artillery support, such as survey, flash and sound ranging, fire planning, and counter battery, is indicated in FADAC. Its high-speed performance, small size, light weight, computing capacity, ruggedness, accuracy and reliability, ease of maintenance, and minimum training necessary, all appear to meet the severe conditions and requirements of field use by the field artillery.

1158

Bradley, G., "Echo Ranging with Audiofrequencies," Am. J. Phys., 21, 159-161, 1953.

The mathematical form of a propagating wave is discussed, and it is pointed out that it may be misleading to emphasize the harmonic form of a wave in the general physics course. A demonstration piece utilizing a sound pulse is described. The demonstration piece is suitable to illustrate (a) the speed of a sound, (b) reflection methods of ranging, and (c) reverberations in rooms.

1159

Carrell, R. M. and R. Richter, "A Modern Acoustic Missile Launch Locator, the AN/TNS-5," J. Audio Eng. Soc., 9, 208-214, 1961.

Describes design of the azimuth ranging equipment, the Short Range Missile Launch Locator, AN/TNS-5, which determines the azimuth of acoustic signals arriving at a microphone array and permits a fix on a mortar, artillery, or missile site to be obtained by triangulation of the azimuth indications from a number of stations.

(See Erikson, W., and Richter, R., for listing of complete series of progress reports.)

1160

Carrell, R. M., W. Erikson, and R. Richter, "Short Range Missile Launch Locator AN/TNS-5() and Sound Ranging Set AN/TNS-4()," Quart. Progr. Rept. No. 1, RCA Defense Electronic Products, Camden, N. J., 54 pp., 1958.
AD-216 058.

Progress is reported on the development of equipment for locating the source of enemy weapons fire by sound ranging. The equipment consists of microphone arrays; tape recorder-reproducers, which include facilities for timing, monitoring and scanning the signals incident at the microphone arrays; computers and transceivers. (See Erikson, W., and Richter, R., for listing of complete series of progress reports.)

1161

Clark, G. Q., "Pulsonde Telemetry System," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, New Mex., 1, 135-140, 1961.
AD-408 716.

Studies of atmospheric acoustic propagation at high altitude necessitated the development of a balloon-borne telemetry system capable of transmitting, with a high degree of fidelity, electronic signals proportional to acoustic pressures which vary in frequency from the sonic to the infrasonic region. Experimentation with several types of systems indicated that a pulse-AM system offered the most potential for the realization of the desired characteristics.

Describes system capable of linear response to below 1 cps, sensitivity to pressure below 1 d/cm^2, and nominal operating life from battery supply of eight hours at temperatures from -40^oC to -70^oC.

1162

Diamond, M., and A. B. Gray, "Accuracy of Missile Sound Ranging," Tech. Rept. No. 110, Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 14 pp., 1961.
AD-264 856.

This report presents a technique for determining the impact point of missiles by the detection of the shock wave generated during a missiles descent. It includes the instrumentation and computations involved and an error analysis.

1163

Erikson, W., and R. Richter, "Short Range Missile Launch Locator AN/TNS-5() and Sound Ranging Set AN/TNS-4()," Quart. Progr. Rept. No. 2, RCA Defense Electronic Products, Camden, N. J., 62 pp., 1958.
AD-219 010.

Breadboard models of several portions of the AN/TNS-5 were constructed and are described. These include a perforated aluminum tape-storage bin and a transistorized oscilloscope using a three-inch electrostatically deflected cathode ray tube.

Reports on evaluation of samples of magnetic tape with test patterns printed on the Mylar base, using the Diazo process; on the derivation of requirements for the magnetic playback heads and their associated amplifiers, with a one-mcs ultra stable crystal-controlled oscillator, using a proportional controlled oven, selected as a frequency standard; on the testing of several loudspeakers used as microphones; and on a method devised for simulating the alignment of gun signals to determine the effect of microphone phase shift. (See under above authors for listing of complete series of progress reports.)

1164

Erikson, W., and R. Richter, "Short Range Missile Launch Locator AN/TNS-5() and Sound Ranging Set AN/TNS-4()." Quart. Progr. Rept. No. 3, RCA Defense Electronic Products, Camden, N. J., 34 pp., 1959.
AD-227 815.

Describes a powered breadboard of the tape transport, comprising main drive, storage bin, brake and pressure roller assemblies, and dummy recording and erasing heads. Details problems involved in the continuous cycling of oxide-coated Mylar tape, and discusses tape characteristics, including continuity of flow, slippage, speed, friction, effects of folding, and pull-out force required. Evaluates a sample of tape with a Diazo-photo-sensitive coating, and discusses problems peculiar to the playback preamplifier. (See under above authors for listing of complete series of progress reports.)

1165

Erikson, W., and R. Richter, "Short Range Missile Launch Locator AN/TNS-5() and Sound Ranging Set AN/TNS-4()," RCA Defense Electronic Products, Camden, N. J., 1958-1959.

Qtly. Prog. Rept. 1, 15 April-15 July 1958	AD-216 058
Qtly. Prog. Rept. 2, 15 July-15 October 1958	AD-219 010
Qtly. Prog. Rept. 3, 15 October 1958-15 January 1959	AD-227 815
Qtly. Prog. Rept. 4, 15 January-15 April 1959	AD-225 129
Qtly. Prog. Rept. 5, 15 April-15 July 1959	AD-225 976
Qtly. Prog. Rept. 6, 15 July-15 October 1959	AD-230 424

The design, development, and laboratory testing and evaluation of a Sound Ranging Set AN/TNS-4() and a Short Range Missile Launch Locator AN/TNS-5() are described in this series of quarterly progress reports. The purpose of the equipment is to locate rapidly, by electroacoustical means, the source of enemy weapons fire. The sound ranging set consists of three azimuth measuring stations, each employing a four-microphone array plus associated tape recorder, electronic and data-processing components. The missile-launch locator consists of five azimuth measuring stations each equipped as above. (Abstracts for individual reports in this series appear under appropriate authors.)

1166

Florisson, C., "Echo Sounding from Aircraft," Compt. Rend., 194, 1149-1150, 1932.

The author describes an hf echo-sounding system for aircraft analogous to that used in the Iangevin-Chilowsky system for ships. The use of a source of hf sound makes it possible to render the receiving circuit relatively insensitive to the lf (audible) sounds from the propellers and exhaust of the aircraft. The source proposed consists of an air-blown whistle placed at the apex of a conical reflector directed towards the ground. An extremely short signal (to permit of sounding near the ground) is sent out 40 times per minute by means of an electromagnetically operated air valve. The receiver is a similar conical reflector connected by tubes to the ear of the observer. The latter has in front of him a chronometer movement in which the high-speed pointer revolves round the dial in about 0.2 sec. The sound emission occurs when the pointer passes through the zero position, the observer noting repeatedly the position of the pointer at the instant the echo arrives. Soundings between 10 and 240 m have been made from an airplane in this way—the apparatus being described as an acoustic altimeter.

1167

Frazier, W. A., "Sound Range Plotting Kit T-43," Rept. No. 5, Aberdeen Proving Ground, Md., 1958.
AD-201 434.

Effort was made to determine the suitability of the T-43 kit for plotting the geographic position of a sound source after corrected time values are obtained. The T-43 consists of measuring and holding equipment composed of five curved scales, two straight scales, a special plotting fan, and eight strings. The holding equipment consists of eight weights, a jig assembly, and eight hollow plotting pins. Tests were conducted and particular attention was given to the following: (1) the ability of the curved scales to lie flat on a grid plotting paper, (2) binding or fraying of the strings, (3) slippage of the weights, (4) stability of the plotting pins and (5) accuracy of the curved scale graduations. Results indicated that the basic accuracy of the T-43 kit was satisfactory, and is not affected directly by the combinations of equipment used. The stability of the plotting pins and the flatness of the curved scales were satisfactory, the weights did not slip under normal operating conditions, and the five curved scales and jig assembly, together, offered the most efficient combination method of solving the problem.

1168

Gowan, E. H., "Low-Frequency Sound Waves and the Upper Atmosphere," Nature, 124, 452-454, 1929.

Describes instruments for the mechanical registration of sound waves, such as the hot-wire ammeter and the undograph. There are several indications to show that the rate of transmission of low-frequency waves is greater at a level of about 40 km than on the ground. The supposition that above 30 km the temperature of the atmosphere increases again with height until it reaches, or even surpasses, ground temperature, is sufficient to account for the abnormal zone of audibility. The velocity of 340 m/sec at 40 km indicates a temperature of about 15°C there. Such high temperatures in the upper atmosphere were first indicated by a study of meteors, and it has recently been shown that the absorption of solar energy in the ozone layer (center of gravity about 45-50 km) is responsible for their maintenance.

1169

Gutenberg, B., "Propagation of Sound in the Atmosphere" (in German), Handbuch der Geophysik, 9, 89-145, 1932.

This is a thorough study of instruments, theories, and the relation of atmospheric composition, wind and temperature on normal and anomalous sound propagation. Much data and many illustrations are included, as well as thorough references.

1170

Hansen, W. H., and F. F. Fischbach, "The Exos Sounding Rocket," Rept. No. AFCRC TR 59-216, Research Inst., Univ. of Mich., Ann Arbor, 47 pp., 1958.
AD-210 617.

The Exos sounding rocket was developed to fill the needs of upper-air research for an economical vehicle carrying a 40-lb payload to a 300-mile altitude. The report describes the Exos in detail and gives the results of the first two flight tests. The major part of the report is devoted to a manual-type description of the assembly procedures. Part lists and procurement information are included.

1171

Harrington, H. E., "Research Directed Toward the Design, Development, and Construction of Meteoritic Microphone Detectors of Various Sensitivities for Use in Satellites," Sci. Rept. No. 1, Oklahoma State Univ. Research Foundation, Stillwater, 1960.
AD-233 737.

An electronic system designed for the express purpose of exploiting the data-gathering potential of a specific vehicle in obtaining information regarding the influx of micrometeor material was developed. An acoustic sensing technique is employed, whereby the particulate matter to be detected activates a supersonic microphone device. The resultant electrical signal is amplified to a suitable level, graded as to magnitude, and stored internally by electronic means for subsequent recording and/or telemetering to ground receiving stations by the system inherently available within the chosen vehicle. A brief historical background of the development of the technique is presented, together with details of the specific system evolved for this application. Various design features which are peculiar to this application are presented and discussed. The prototypical equipment which resulted from the development program was subjected to a testing program to verify its suitability for the anticipated use, and several sets are currently under construction.

1172

Howard, W. H., "Remote Recording System for Sonic Observation of Trajectory and Impact of Missiles," Army White Sands Signal Agency, White Sands Proving Ground, N. Mex., 18 pp., 1957.
AD-135 449.

The remote recording system of sonic observation of the trajectory and impact of missiles (SOTIM) requires interception of the acoustic front which is generated by a missile in flight. Data is collected by recording the individual outputs of microphones arrayed in clusters. These clusters, separated by distances varying from twenty to one hundred miles, require associated recording equipment, communications equipment, and shelter. A new system of operations for the SOTIM has been designed which offers considerable logistic, equipment, and equipment-maintenance advantages, and which requires fewer personnel. The development and present status of this new operational system are discussed in this report.

1173

Kennedy, W. B., et al., "Study of Meteorological and Terrain Factors Which Affect Sound Ranging," Denver Research Inst., Univ. of Denver, Colo., 1954-1957.

Qrtrly. Prog. Rept. 1, March-May 1954, AD-38 446
" " " 2, June-August 1954, AD-43 297
" " " 3, September-November 1954, AD-54 480
" " " 4, December 1954-February 1955, AD-61 530
" " " 5, March-May 1955, AD-70 078
" " " 6, June-August 1955, AD-74 855
" " " 7, September-November 1955, AD-95 798
" " " 8, December 1955-February 1956, AD-95 799
Final Report, March 1954-April 1956, AD-139 326
Qrtrly. Prog. Rept. 1, May-July 1956, AD-140 087
" " " 2, August-October 1956, AD-140 088
" " " 3, November 1956-January 1957, AD-140 090
Interim Prog. Rept., February-August 1957, AD-160 696

This series of reports covers four years of intensive theoretical and applied research and development on sound-ranging as influenced by meteorological and terrain factors. The general problem of increasing the accuracy of sound-ranging by means of corrections based on meteorological and topographical conditions is discussed. Equations are presented for applying wind and temperature corrections to reduce error in observed sound-source azimuths. Problems encountered in setting up the field operation to provide data for a study of meteorological and terrain corrections for the whole sound path are analyzed. Proposed methods for time measurement of sound arrivals, temperature measurement, control of field operations, and power distribution are presented in detail.

The firing-recording arrays are described. The results and the methods of reducing data are given. Special investigations include: an analysis of the problem of acoustic ray-tracing in the atmosphere; determinations of the sonic data obtainable with various geometries of detecting arrays; an analysis for determining the velocity of sound; studies of errors generated within the Short-Range Whole-Path Firing-Recording Array by elevation differences, angular errors in placing the sensing microphones, and errors due to the assumption that the wave front is plane; a study determining the effect of oscillogram-reading errors on calculated sound-wave-arrival azimuths; a discussion of methods of removing data from oscillograms; and tests to determine the calibration requirements of the T-23 microphones. Other discussions include microphone-wind-shield development, the surveying program, and the general field operational problem.

The application of a drift correction to the primary sound-ranging information provided results superior to those obtained by standard artillery methods. For these calculations, data were used from an array of 14 microphones arranged in an isosceles-trapezoidal configuration. The arrival azimuth obtained by using this configuration is more representative of the direction of arrival of the acoustic wave front than that obtained by standard methods. The corrections which were applied for the refraction of the wave front along its path do not appear to be greatly significant from a study of the small sample presented.

1174

Kuhlenkamp, A., "Acoustical Location for Shooting at Invisible Aircraft," Ver. Deut. Ing. Z., 85, 393-400, 1941.

Reasons for the inferiority of sound locating to optical methods are given. The principles of sound locating are discussed, and a mechanism for computing the delay is described. The principle of the cotangent method is explained. Equipment developed in France and Austria is described and illustrated.

1175

Marble, G., "T43 Sound Range Plotting Kit," Md. Rept. No. DPS-289, Aberdeen Proving Ground, 1961.
AD-260 503.

The T43 sound-range-plotting kit permits experimental determination of the best method of graphically solving the problem of locating a sound source using data obtained from field microphones. A complete kit consists of over 20 components, some of which have been tested at Aberdeen Proving Ground. This report contains the results of tests on 15 components, including plotting fans, nomographs and templates made of plastic. The purpose of this test was to determine the accuracy durability and ease of operation of the kit in normal and simulated extreme environments. Results indicated satisfactory performance at normal and extremely low temperatures, but not in extreme heat.

1176

The Philosophical Library, Inc., "High Altitude and Satellite Rockets," Proc. of a Symposium at Cranfield, England, July 1957, New York, 136 pp., 1959.

This volume records the proceedings of a three-day symposium on high altitude and satellite rockets sponsored jointly by the Royal Aeronautical Society, the British Interplanetary Society, and the College of Aeronautics.

The British Skylark rocket and the American Vanguard satellite are described; propulsion, design, and instrumentation problems of rockets are considered, together with the guidance of satellites and the problems connected with high altitude flight by humans. Two papers consider aspects of the reentry problem, and there is a paper which entends some previous work on the dynamics of a dissociating gas. The first paper, by H. S. W. Massey on the scientific applications of rockets and satellites, is of most general interest. It includes a short discussion of the determination of the temperature at different heights above the earth by measuring the velocity of sound produced by explosions from grenades expelled from a rocket.

The value of this book is enhanced by the inclusion of the discussions which took place following the delivery of the papers; these make up nearly one-quarter of the text and make very interesting reading.

1177

Richter, R., and C. W. Fields, "Short Range Missile Launch Locator AN/TNS-5() and Sound Ranging Set AN/TNS-4()," Quart. Progr. Rept. No. 5, RCA Defense Electronic Products, Camden, N. J., 1959.
AD-225 976.

Reports substantial progress with working models of many contractual items on hand and undergoing tests. Describes and illustrates models of the following: tape drive system using neoprene friction rims, tape storage bin, rotating playback preamplifier, recording capstan servo, trigger head assembly, ultrastable oscillator with voltage regulator and multivibrator circuitry, oscilloscope and skew-corrector, condenser and dynamic microphones, and condenser and dynamic microphone preamplifiers. Items undergoing continuing investigation, development and design are discussed. (See Erikson, W., and Richter, R., for listing of complete series of progress reports.)

1178

Richter, R., and C. W. Fields, "Short Range Missile Launch Locator AN/TNS-5() and Sound Ranging Set AN/TNS-4()," Quart. Progr. Rept. No. 6, RCA Defense Electronic Products, Camden, N. J., 28 pp., 1959.
AD-230 424.

Treats the building of a scale model of the AN/TNS-5 recorder-producer for human engineering evaluation and for the planning of final packaging. Discusses environmental testing of the following models: recorder-reproducer, recording capstan servo, power amplifier for playback drum, most of the oscilloscope skew-corrector circuits alignment circuitry, and condenser microphone with amplifier. Reports beginning of designing of the final versions of the electronic sub-assembly modules, and of evaluation of computer parts and drawings from Frankford Arsenal. (See Erikson, W., and Richter, R., for listing of complete series of progress reports.)

1179

Richter, R., and W. Erikson, "Short Range Missile Launch Locator AN/TNS-5() and Sound Ranging Set AN/TNS-4()," Quart. Progr. Rept. No. 4, RCA Defense Electronic Products, Camden, N. J., 40 pp., 1959.
AD-225 129.

Describes a recording capstan servo, a read channel, and a rotating playback channel—elements added to the tape transport mechanism, and added to the breadboard model. Also describes an optical system for scanning the moving printed tape and the operation of the tape skew-correction circuitry, as well as dynamic and condenser microphone models. (See Erikson, W., and Richter, R., for listing of complete series of progress reports.)

1180

Stroud, W. G., "Meteorological Rocket Soundings in the Arctic," Trans. Am. Geophys. Union, 39, 789-794, 1958.

Various techniques used by the US in IGY meteorological rocket soundings in the Arctic program are made available in this report. Temperature, pressure, density, and winds have been measured by these new devices. Experiments on the freely-falling sphere, rocket-grenade, gage, aerodynamic, and other methods of determining the dynamic processes of the upper atmosphere are discussed. The results achieved are compared with USSR ventures along similar lines.

1181

Stroud, W. G., E. A. Terhune, J. H. Venner, J. R. Walsh, and S. Weiland, "Instrumentation of the Rocket-Grenade Experiment for Measuring Atmospheric Temperatures and Winds," Rev. Sci. Instr., 26, 427-432, 1955.

Analyzes results of 92 grenade explosions from 15 Aerobee rocket firings from March 3, 1950, to September 4, 1953, at White Sands, N. M., to determine efficiency of this method of determining upper air temperatures and winds. From four to eight grenades are exploded on each flight at specified heights (which can be determined to ±1 to 6 ft at 100,000 ft by photographic methods). The formulas $C = kT^{1/2}$ and $V = C + W$ are used, where C is the velocity of sound due to elasticity, k is a constant, T is absolute temperature, V is the velocity of propagation of sound wave, and W is the wind velocity. Timing to 0.1 millisecond is necessary, and the sound detectors are arranged so they are nearly vertically beneath each grenade when it is exploded. The temperatures and wind can be determined for each successive layer (between grenade firings).

The text includes a summary of the fifteen firings; illustrations of equipment and of some of the records; and descriptions of methods, rockets, rocket instrumentation, grenade structure, flash detectors, telemetering system, safety features, sound ranging equipment, and positions of grenade explosions (with ground temperatures).

1182

Temple Univ., Res. Inst., "Research in the Physical Properties of the Upper Atmosphere with V-2 Rockets," Final Rept., 101 pp., 1952.

This report covers work completed during the past four years. In particular it includes work on ion clusters, statistical fluctuation of density at a given point in a gas, and the fall from high altitude of a warhead with a parachute. It also includes work on the measurement of absorption coefficients of air at low pressures and at various frequencies, offering results that fall below the classical at low pressures and are believed to be due to the effective viscosity coefficient. Provides experimental curves and theoretical considerations. Sample calibration curves for microphones and of the anechoic chamber are included as well as photographs and descriptions of various pieces of apparatus such as the wind tunnel, the ultrasonic wave analyzer, the pulser, the apparatus installed in Blossom IV-G, the automatic-feed wire exploder, etc. Results of measurements of noise on the skin of the missile and of meteoritic impacts on the nose obtained during the V-2 flights are given. Various sources of rather intense sound are investigated to determine their suitability for high altitude work, including spark gaps, explosives (primers), and exploding wires. Transient responses of microphones and the velocity of sound in tubes and at various pressures are investigated.

These are theoretical considerations and the original reports should be read for details; only results are given in this report.

1183

Uretz, E. F., "Study of Meteorological Surveillance Observing System," Quart. Progress Rept. No. 5, Armour Res. Foundation, Chicago, Ill., 34 pp., 1960.
AD-263 684.

Acoustic measurement of wind is described. Block diagrams of the low level wind velocity measuring subsystem are given. The results of the computer simulation of an infrared radiometer and the subsequent reduction computation are presented and discussed. (See also S. Hori (1959) for earlier reports in this series.)

1184

Walsh, J. R., G. J. Day, et al., "Description of the Instrumentation and Procedures for the Velocity of Sound (Grenade) Experiment," Eng. Rept. E-1140, Evans Signal Lab., Signal Corps Eng. Labs., Belmar, N. J., 1954.
AD-46 513.

Describes the technique of firing grenades from Aerobee rockets and determining the velocity and the angle at which sound propagating from the grenades arrives at acoustic detectors on the ground. Sound ranging equipment was employed for the system of detectors and the location of grenade explosions was determined by photographing the flashes with fixed plate cameras. Describes and evaluates performance of all equipment used in the experiment.

1185

Webb, W. L., and A. L. McPike, "Sound Ranging Technique for Determining the Trajectory of Supersonic Missiles," Progr. Rept. Nos. 1 and 2, White Sands Signal Corps Agency, White Sands Proving Ground, N. Mex., 6 pp. and 23 pp., 1955.

These two reports are part of a series, the rest of which is classified. These reports describe the application of the Signal Corps GR-8 sound ranging system to the Sonic Observation of the Trajectory and Impact of Missiles (SOTIM). It was found that missiles traveling at supersonic speeds generate shock fronts which are easily observed over wide areas around the missile's trajectory. Analysis of the acoustic signals determined the location and speed of missiles at certain points along their trajectories. Furthermore, this data has been utilized to describe the manner in which pressure waves propagate over long distances through the earth's atmosphere.

1186

See 733

Instrumentation, Ranging and Sounding
see also — 397, 482, 522, 550, 563, 638, 711, 716, 718, 874, 876, 877, 883, 887, 895, 1061, 1113, 1258, 1295, 1300, 1377, 1427, 1430, 1440, 1447, 1451, 1454, 1455, 1467, 1498, 1715, 2124, 2131, 2133, 2298, 2677, 3272, 3392, 4065.

INSTRUMENTATION, SHOCK WAVE

1187

Amster, A. B., and R. L. Beauregard, "Pressure Sensing Probes for Detecting Shock Waves," Rev. Sci. Instr., 30, 942, 1960.

The passage of a shock wave is detected by a probe which closes an electric circuit. Closure occurs when a pressure greater than 12,000 psi acts on the probe, collapsing a thin-walled copper tube onto a copper wire. The response time is of the order of 10^{-7} seconds.

1188

Ballard, H. N., and D. Venable, "Shock-Front-Thickness Measurements by an Electron Beam Technique," Phys. Fluids, 1, 225-229, 1958.

Describes an electron-beam densitometer for investigating the structure of a shock front in low-density gases. The parameters measured by this technique are directly related to those parameters used in the accepted definition of shock front thickness. Hence the interpretation of the data is direct; no model of the shock front structure must be assumed and no theoretical treatment of non-equilibrium flow conditions is needed. An approximate method of data reduction is used for treating preliminary results. The measured value of the thickness of a Mach 4 shock in argon is about three mean free paths, measured in terms of the undisturbed gas. This technique provides a new tool for investigating relaxation phenomena behind shock waves.

1189

Birk, M., A. Erez, Y. Manheimer, and G. Nahmani, "On Electrical Conductivity in Detonation and Shock Waves, and the Measurement of Detonation and Shock Velocities," Bull. Res. Council Israel, 3, 398-413, 1954.

The electrical conductivity between two electrodes on the explosive or in the air close to it is investigated with a view to obtaining data pertaining to the design of probes. The conductivity between two electrodes on an explosive charge as well as the detonation and shock velocities were measured. Theoretically, relations are derived for the electron velocity and the current density; it is deduced that the gas in the detonation zone cannot be in a state of equilibrium.

Describes the apparatus used and the electronic circuit, and mentions a few applications.

1190

Brooks, J. N., "Dri Blast Recording Equipment," Phase Rept. No. 5, Denver Res. Inst., 43 pp., 1957.
AD-132 892.

Impulse is measured by a directly coupled amplifier with a useful response from 0 to 80 kc; for calibration, a known charge on each record is recorded just prior to the shot. Eight to ten impulse measurements are made for each shot. The amplifier output is fed to a CRT and recorded on a drum camera. Impulse is calculated by (1) the use of the gage constant and (2) the dynamic calibration of the gages for each round, by means of the peak-pressure measurement. The amplifier requirements for measuring peak pressures involve measuring the arrival time of the pressure wave; two caps are fired at opposite ends of a string of gages, and the sonic velocity is measured as corrected for wind velocity. The traces of eight CRT's, arranged in banks to present a 19-in. field, are recorded on film at recording speeds from 1 to 5 m/sec. A sequence timer is used to time the sequence of events which occur during the recording of the blast parameters; the timer consists of ten relays with variable time-delay circuits coupled to each other. The sweep circuit is a saw-tooth generator, the voltage of which is applied to the vertical deflection plates of the CRT's so that visual observation is made prior to the shot without burning the scope faces with the bright spot. Intensity and focus adjustments are included in two indicator units, one with eight and one with four 3SP11's. The calibration unit supplies voltage in a sequence of five 0.1-v steps up to 0.5 v. The time base is derived from a 100-c Hewlett-Packard signal generator which supplies a 1000-c sine wave to a pulse shaper. The pulse shaper produces a short pulse which fires a crater tube that is mounted on the indicator unit.

1191

Camm, J. C., and P. H. Rose, "Electric Shock Tube for High Velocity Simulation," Res. Rept. No. 136, AVCO Everett Research Lab., Mass., 61 pp., 1960.
AD-282 729.

Shock tubes were developed capable of producing a gas sample of known conditions at velocities as high as 43,000 ft/sec. The driver of these shock tubes employs a capacitor bank which discharges electrical energy into helium, heating the helium to temperatures of 10,000-20,000^{o}K, and raising the pressure to 10,000-20,000 psi. The high pressure bursts the scribed diaphragm and the resulting shock wave propagates into the test gas.

Extensive diagnostic techniques were employed in the resulting hot gas samples. The growth of these samples was observed optically, and correlations were achieved with theoretical calculations. The observed radiation was compared with and can be used to extend the known radiative properties of high-temperature air. Time-resolved luminous pictures and spectra were also taken to show the purity of the test gas.

The speed and attenuation of the shcok front were measured. The observed operation of this shock tube was compared to theoretical predictions, and although no precise correlation can be made, the driver-gas energy transfer and losses in the shock-tube boundary layer can be accounted for.

1192

Chabai, A. J., "Measurement of Wall Heat Transfer and Transition to Turbulence During Hot Gas and Rarefaction Flows in a Shock Tube," Tech. Rept. No. 12, Inst. of Res., Lehigh Univ., Bethlehem, Pa., 86 pp., 1958. AD-203 835.

A thin film resistance thermometer was developed for the study of transient boundary layer flows in the shock tube. Measurements of wall heat flux during laminar flow are presented and compared with theories for the hot gas, the cold gas, and the rarefaction regions of shock tube flows. The experimental results indicate an excellent agreement with the theories of hot gas flow, a general consistency with the theory of cold gas flow, but some unaccountable deviations from the theoretical expectations for rarefaction flows. A Reynolds number for the hot gas flow was proposed; the critical value of this number predicts the time at which the laminar flow is observed to become turbulent. Several Reynolds numbers for the rarefaction flow are proposed, but no correlation between these numbers and the measured transition times are found to exist. The instrument allows previously unexplored boundary layer phenomena to be investigated.

1193

Clouston, J. G., A. G. Gaydon, and I. I. Glass, "Temperature Measurements of Shock Waves by the Spectrum-Line Reversal Method," Proc. Roy. Soc. (London) A, 248, 429-444, 1958.

By using a photomultiplier and cathode-ray oscillograph responsive only to changes in light signal, the sodium-line reversal technique, commonly used for measurement of flame temperature, has been adapted for time-resolved studies of temperatures behind the shock waves produced by a bursting diaphragm. The sensitivity of the method is discussed; temperatures can be determined to about ±30°C. General agreement between calculated and observed temperatures is obtained, but both air and oxygen show a high-temperature region due to burning at the interface with the hydrogen driver gas. In nitrogen at around 2400°K, a low-temperature region close to the shock front may be attributed to a vibrational energy lag of the order of 100 μsec, the sodium excitation following the effective vibrational temperature rather than the translational temperature of the nitrogen. In oxygen, evidence for a dissociation relaxation effect is obtained for shocks giving temperatures of around 2500°K; this produces an abnormally high temperature near the front. Other irregularities in temperature in the uniform flow is only about half that expected for a real inviscid gas.

1194

Clouston, J. G., A. G. Gaydon, and I. R. Hurle, "Temperature Measurements of Shock Waves by Spectrum-Line Reversal, II. A Double-Beam Method," Proc. Roy. Soc. (London) A, 252, 143-155, 1959.

The sodium-line reversal method previously described (See Entry Number 1193), which uses a photomultiplier and oscillograph, has been modified, producing a system that makes it possible to determine temperatures rather higher than that of the background source. Two light beams are now employed, and interference filters are used in front of the photomultipliers instead of a spectrograph. In one beam the background source is viewed directly, through the shock tube, and in the other beam the background source is viewed through the shock tube by a mirror system with a neutral filter interposed to reduce its effective brightness temperature. With a suitably chosen temperature for the background, one oscillograph trace indicates absorption and the other indicates emission of the sodium lines. It is thus possible, from the records of a single shock, to determine the temperature history of the shock wave to about ±20°C.

Nitrogen and oxygen again show relaxation effects near the front. Temperatures in argon tend to be low, owing to radiative disequilibrium; excitation processes in argon are discussed.

Also reports on experiments employing a single-beam method, using a carbon arc as background and following reversal of the indium blue line. Temperatures up to 3600°K have been measured in shocks through nitrogen, but the time resolution is not good.

1195

Cox, R. N., and D. F. T. Winter, "A Theoretical and Experimental Study of an Intermittent Hypersonic Wind Tunnel Using Free-Piston Compression," ARDE Rept. No. (B) 9/61, Armament Research and Development Establishment, 1961. AD-264 914.

Recounts the development of the hypersonic gun tunnels at ARDE, and studies their performance. Presents calculations of the various phases of piston motion, including the starting motion and shock formation, the multiple shock reflection between the piston and the end of the barrel, and the piston deceleration. Reports the development of an analytical method for calculating the piston motion; this method is compared with a numerical calculation based on the method of characteristics.

Includes estimation of the stagnation enthalpy achieved in the tunnel, and considers real gas effects, bore friction, and boundary layer growth. Presents experimental results of the pressure-time history of the tunnel operation, as well as the results of tunnel stagnation measurements and working section conditions.

1196

Criborn, C. O., "Determination of Pressure-Time Curves of the Shock Wave by a New Method," Appl. Sci. Res., A, 3, 225-236, 1952.

Describes an experimental technique which is based on the dependence upon air pressure of the corona discharge current between a positively charged ring and a pointed probe on its axis. A ring approx. 6 mm dia. at 3-4 kV gives a discharge current of 50-100 μA when the pressure is 1 atm, falling to 10 μA at 2 atm; the time variation of current is recorded on an oscillograph, and hence the pressure variation may be deduced from previous static calibration. The method is capable of accurate measurement of pressures as low as 0.01 atm, and is not very sensitive to changes in atmospheric temperature or humidity. Advantages claimed for this technique are: (a) freedom from shock reflection at the measuring surface ensures direct measurement of static pressure; (b) natural gauge oscillations are unimportant; (c) the dimensions of the gauge can be kept small.

1197

Dawes, J. G., "The Acoustic Blastmeter," J. Sci. Instr., 27, 123-127, 1950.

Describes a method for measuring and recording the speed of a rapidly changing blast of air. The method depends on the change in phase of an acoustic signal received at a point, the phase shift being a function of the velocity of the air between the sound transmitter and receiver. Tested in a laboratory gallery with a series of steady air blasts ranging from 25 to 125 fps, the method gave results closely corresponding to the air velocities measured by an independently calibrated orificemeter. It is capable of rapid response and of dealing with a wide range of air speeds. The article proposes use of the method for recording the changing speed of the air blast which precedes the flame of an explosion traveling along a gallery.

1198

der Agobian, R., "A Method of Detecting Non-Ionizing Shock-Waves and Their Study Through Radioelectric Waves" (in French), Compt. Rend., 248, 1308-1311, 1959.

In order to render detection of non-ionizing shockwaves more perceptible, one allows for the possibility of propagating through a previously ionized gas mass. This method of sensitization consists of creating, through an auxiliary discharge, an "autonomous"gaseous plasma ("autonomous" referring to a plasma abandoned to its spontaneous decrease). One studies jointly, by radioelectric exploration and optical observation, the modifications appearing in a film of plasma when the shock-wave is passing. The author gives a description of the equipment used and its functioning.

1199

Dolder, K., and R. Hide, "Bibliography on Shock Waves, Shock Tubes, and Allied Topics," Rept. No. G/R2055, Atomic Energy Research Establ., 94 pp., 1957.
AD 127681.

References have been arranged under subject headings in chronological order. The sections dealing with shock waves and shock tubes include most of the work published in these fields up to the end of 1955. A number of more recent references are also included. Further sections list accounts of related subjects. The bibliographies previously compiled by the National Physical Laboratory and Princeton University are also included.

1200

Duffy, R. E., and D. F. Rogers, "Design and Characteristics of a Small Hypersonic Shock Tunnel Combustion Driver," Rept. No. ARL 62-307, Rept. on Research on Aerodynamic Flow Fields, Rensselaer Polytechnic Inst., Troy, N. Y., 15 pp., 1962.
AD-277 198.

Reports designing and testing of a combustion driver for a small hypersonic shock tunnel. By its means have been obtained combustion pressure-time histories for stoichiometric hydrogen and oxygen mixtures diluted with varying percentages of helium. Tests indicate that the combustion results are repeatable and peak combustion pressure and temperature are controllable within a wide range. The dimensions of combustion drivers appears to have an important effect in that rough-burning conditions, reported by other investigators, have not been noticeable except at very low concentrations of helium.

1201

Eliason, M. C., "A Condenser Microphone for Quantitative Determinations of Ballistic Shock-Wave Intensities," J. Audio Eng. Soc., I, 208-212, 1953.

Presents the design and construction features, testing and operating characteristics of the D-42 Microphone, originally developed for use with an acoustic firing error indicator. Briefly, this equipment consists of two microphones which are mounted at opposite ends of a plastic sphere in a towed sleeve target, and which modulate tiny FM transmitters in response to ballistic shock waves. Two receivers near the gunner actuate indicators that show this distance and inform the gunner whether he is leading or lagging a target.

1202

Evans, R. C., "Operation and Performance of a Shock Tube with Heated Driver," Memo. No. 48, Guggenheim Aeronautical Lab., Calif. Inst. of Tech., Pasadena, 29 pp., 1959.
AD-216 241.

Reports construction of a shock tube with a driver section which can be heated with Calrod heaters to temperatures of approximately 300°C. This temperature rise increases the shock wave Mach number by about 40%, or from values of 7.7 to 10 for pressure ratios of 20,000 across the diaphragm, an increase sufficient to produce partial dissociation of the oxygen molecules behind the shock wave. The flow behind the shock wave is as uniform as that produced by an unheated driver. There is a transition section designed to enable the major portion of the low pressure changer to be constructed of round Shelby tubing, while the test section still has a flat top and a flat bottom. The flat surfaces are advantageous for optical studies and for convenience in instrumenting the tube. Despite the fact that the transition is gradual, disturbances are present in the flow in the test section, 18 in. downstream of the transition section.

1203

Geiger, F. W., C. W. Mautz, and R. N. Hollyer, Jr., "The Shock Tube as an Instrument for the Investigation of Transonic and Supersonic Flow Patterns—and Appendixes I-IV," Engineering Research Inst., Univ. of Mich., Ann Arbor, 198 pp., 1949.
ATI-63 892.

This book-length report deals with the investigation of the transonic and supersonic flow behind the shock wave, using a shock tube as an instrument. This investigation was motivated by the anticipation that the flow fields produced in the shock tube might render the instrument useful in aerodynamic research, as a kind of intermittent wind tunnel. Chapter I deals with a theoretical discussion of the flow fields produced in the shock tube, in which the diaphragm is assumed to burst instantaneously. Chapter II describes the apparatus, except for the electronic circuits, which are described in Chapter III. In Chapter IV the flow fields in the tube are discussed and compared with theoretical predictions. In Chapter V are given results of certain aerodynamic tests with models. The derivation of some of the formulas are given in the appendixes.

1204

Glass, I. I., "Shock Tubes, Part I. Theory and Performance of Simple Shock Tubes," UTIA Review No. 12, Inst. of Aerophysics, Univ. of Toronto, Canada, 1958.
AD-205 831.

An account is given of flows and wave interactions in simple shock tubes. Tables and graphs are presented for use in the determination of flow quantities in perfect and imperfect inviscid gases. Flow deviations induced by viscosity and heat transfer are considered, and a comparison is made of predicted and observed flows, including consideration of the effects produced by the nonstationary boundary layer. Production of strong shock waves and their application to study of hypersonic shock tunnels and to aerophysical research are also considered, along with shock tube materials, design, construction, and instrumentation.

1205

Grime, G., and H. Sheard, "The Experimental Study of the Blast from Bombs and Bare Charges," Proc. Roy. Soc. (London) A, 187, 357-380, 1946.

An electrical method was used for measuring the pressure in a blast wave, involving the use of piezo-electric gauges with CRO's. A detailed description of the apparatus is given. Measurements were made of the blast pressures produced by bare charges up to 2000 lb in weight, by German bombs and mines weighing from 50 to 1000 kg, and by British bombs of all sizes. The measured and calculated velocities of the blast wave agree well, and the observed and calculated rates of decay of maximum excess pressure agree reasonably well.

1206

Grine, D. R., "Scotchlite Screens for Viewing Shocks," Tech. Rept. No. 003-59, Poulter Labs., Stanford Res. Inst., Menlo Park, Calif., 5 pp., 1959.
AD-217 907.

Scotchlite screens for viewing shocks are compared with the usual shadowgraph method and are found to have the following advantages: (1) the objects or phenomena associated with the shock disturbance can be viewed directly since the screen is photographed from near the light source, (2) black Scotchlite reflects light directly back to its source with a reflectivity on the order of 100 times that of a painted white surface, although its reflectivity falls off as the angle subtended at the screen by source and camera increases, and (3) the Scotchlite screen is fairly inexpensive, so large screens can be used.

1207

Henshall, B. D., "The Use of Multiple Diaphragms in Shock Tubes," Tech. Rept. No. 18,062, Aeronautical Research Council, Great Britain, 1955.
AD-144 058.

Calculations are presented which illustrate the advantages of various types of multiple-diaphragm shock tubes over the conventional single-diaphragm shock tube. Shock tubes having a discontinuous change of cross-section at a diaphragm station or at any other position along the tube are also considered.

1208

Hide, R., N. H. Price, and P. A. Shatford, "The Design, Construction, Instrumentation and Performance of the A.E.R.E. 8 × 2 In. Shock Tube," UK Atomic Energy Authority CLM Rept. R18, Great Britain, 27 pp., 1962.

The theory of gas flow in a shock tube is outlined and augmented by tables of useful numerical data on shocks. Details are given of the special design considerations necessary in the construction of a large shock tube. Instrumentation is discussed in three parts dealing, respectively, with the filling of the tube with gases A and B to the desired pressures, the detection of the shock and the timing of its speed by electronic techniques, and an optical system used for making Toepler-Schieren and shadowgraph observations of the gas flow associated with the shock. A series of calibration experiments is described.

1209

Hufton, P. A., "Hypersonic Facilities in the Aerodynamics Department Royal Aircraft Establishment," Rept. No. 146, Advisory Group for Aeronautical Research and Development, France, 1957.
AD-159 950.

A description is given of the hypersonic facilities at the Royal Aircraft Establishment, and the various problems leading to their development are discussed. Four appendices are included, as follows: (1) A note on multiple diaphragm shock tubes; (2) A note on combustion driven shock tubes; (3) Some methods of evaluating imperfect gas effects in aerodynamic problems; (4) Development of the RAE 6-in. diameter shock tube.

1210

Johnson, O. T., and W. O. Ewing, Jr., "An Omni-Directional Gage for Measuring the Dynamic Pressure Behind a Shock Front," Memo Rept. No. 1394, Ballistic Research Labs., Aberdeen Proving Ground, Md., 32 pp., 1962.
AD-267 470.

The design of a cantilever gauge for determining the direction of flow and time history of dynamic pressure is described, and the results of both static and shock tube calibration are presented.

1211

Jones, W. A., F. L. McCallum, and J. C. Muirhead, "Suffield Experimental Station Shock Tube Instrumentation, IX. The Use of Conventional Shock Tubes for the Generation of Very Low Pressure Waves," Suffield Tech. Note No. 92, Suffield Experimental Station, Canada, 9 pp., 1962.
AD-282 634.

Describes modifications made in conventional shock tubes in order to obtain very low pressure waves. The modifications derive from two different approaches; first, improving the diaphragm-breaking mechanism of a constant cross-section shock tube in order to obtain good wave generation at low pressure, and, second, using a small cross-section compression chamber driving a larger cross-section expansion chamber.

1212

Jones, W. A., F. L. McCallum, and J. C. Muirhead, "Suffield Experimental Station Shock Tube Instrumentation, X. Modification of Shock Wave Valves to Allow Independent Control of Shock Wave Overpressures and Positive Durations," Suffield Tech. Note No. 94, Suffield Experimental Station, Canada, 5 pp., 1962.
AD-284 953.

Describes modifications made in the actuating system of a shock-wave valve to allow independent control of shock wave overpressures and positive durations. By restricting the outward flow of air from the actuating chamber, the main valve piston can be made to re-seal before the compression chamber has been fully exhausted, and by altering the amount of flow restriction from the actuating chamber, the positive duration of the shock wave can be varied. For shock wave overpressures up to 20 psi, variation in the duration can be effected without significantly altering the overpressure of the shock wave. This system has an additional advantage in that it prevents the main piston from striking the end of the actuating chamber, which is a possible source of damage to the valve.

1213

Jones, W. A., F. L. McCallum, and J. C. Muirhead, "Suffield Experimental Station Shock Tube Instrumentation, XI. The Use of Shock Wave Valves with Compression Chamber Overpressures of 100 to 600 psi," Suffield Tech. Note No. 95, Suffield Experimental Station, Canada, 15 pp., 1962.
AD-288 214.

Experiments were conducted to assess the performance of shockwave valves at compression chamber overpressures up to

600 psi. A second shock, apparently caused by wave interactions within the chamber, greatly increased peak shock overpressures obtained from a particular compression chamber overpressure and especially affected the overpressure of reflected waves. However, the second shock can create a wave shape which is undesirable for many purposes, and suggestions for its removal are made. The experiments also showed that excessive restrictions on the flow from the actuating chamber result in decreased shockwave overpressures. While the shock wave valve performed well, as the pressures indicate, the report makes clear that not all aspects of its operation are clearly understood and defined.

1214

Jones, W. A., and J. C. Muirhead, "Suffield Experimental Station Shock Tube Instrumentation, XII. The Generation of Two Distinct Shock Waves in a Single Expansion from a Single Compression Chamber," Tech. Note No. 981, Suffield Experimental Station, Canada, 11 pp., 1962.
AD-288 215.

Describes a method for obtaining from a single compression chamber two or more distinct shock waves in a single expansion chamber. A shock wave valve is used to open, close, re-open, and re-close the compression chamber of a compressed-air-driven shock tube, thus allowing the formation of two or more distinct shock waves.

1215

Klein, E., "Air Shock Wave Velocities over Water," J. Acoust. Soc. Am., 21, 109-115, 1949.

A procedure was devised for determining the air blast pressures of the A-bomb at Bikini. In such a disturbance the air particles move with large and finite amplitudes; hence the propagated waves do not obey the ordinary laws of acoustics. By measuring the ratio of the air shock wave velocity to normal acoustic velocity, an indication may be obtained as to the peak pressure of the explosion. Blast waves in water, on the other hand, follow substantially the familiar acoustic laws and are propagated at a well-known velocity. Measurements of transit times made at identical positions for the air and for the water blast waves immediately yielded the desired air blast velocity in terms of the known velocity of sound in water. This procedure eliminated the need for simultaneous measurement of the continually shifting distances between buoys which carried observational equipment. However, careful positioning of the buoys was necessary in order to avoid their destruction and yet record the maximum possible air blast. These positions were calculated on the basis of an equivalent explosion from 20,000 tons of TNT. Since the measurements had to be made automatically and without human observers, special timing and recording systems were provided. All requirements for gathering the data were successfully met in the assembly of apparatus described herein.

1216

Knight, A. L., and M. Chapman, "A Shock Tube for the Dynamic Testing of Pressure Transducers," Tech. Note IR 3, Royal Aircraft Establishment, Great Britian, 21 pp., 1962.
AD-282 827.

A simple air-to-air shock tube facility has been constructed to examine the dynamic performance of pressure transducers. The theoretical characteristics and real gas effects that are relevant to the design of such a shock tube are discussed, and consideration is given to the special requirements for the dynamic testing of transducers. The design, construction, instrumentation, and operation of the apparatus are described together with the results of tests made to assess its performance.

1217

Knight, H. T., and R. E. Duff, "Precision Measurement of Detonation and Strong Shock Velocity in Gases," Rev. Sci. Instr., 26, 257-260, 1955.

Describes a simple system for determining the detonation velocity of strong shock waves, with temperatures above 3000°K, by using the conductivity behind the wave. Wave contact is made by two 0.036-in. wires set 0.1 in. apart in a Teflon plug mounted in the experimental tube. When a wave passes, signals are produced across a 30kΩ resistor in series with these wires, and a 0.001μf capacitor charged to 300 volts. Any number of circuits may be paralleled across a single-signal resistor if a diode is added to each circuit to prevent signal deterioration. The arrival time of a wave at a pin can be determined, with an accuracy of almost 10^{-8} seconds, from an oscilloscope record of the signals. The principal advantages of this system are excellent space resolution and very simple basic circuitry.

An amplifier is described which can be used with an individual pin circuit to fire a thyratron and extend the range of applicability of the system to waves with temperatures as low as 1000°K.

1218

Lee, J. D., and R. M. Nerem, "Theory and Performance of a Shock Tube Having an Arc-Heated Driver," Aerodynamic Lab., Ohio State Univ. Research Foundation, Columbus, 29 pp., 1962.
AD-277 192.

The pertinent design features, theory of operation, and some initial results are described for a shock tube which utilizes an arc-discharge in the high-pressure driving chamber. The tube has a diameter of four inches, with a 16-inch long driver and a 35-foot driven section. Power stored in a 6000-volt, 200,000-joule capacitor bank is discharged across coaxial electrodes in the pre-pressurized driver chamber. The arrangement is analyzed by assuming perfect gas parameters to obtain driven shock Mach numbers as a function of initial pressures and energy of discharge. Both air and helium are used in the driver while air alone is used in the driven section. Shock Mach numbers up to 33 have been obtained to date. Wave speed is measured through the use of ionization gauges, and pressure by piezo-electric pickups.

1219

Liepmann, H. W., A. Roshko, D. Coles, and B. Sturtevant, "A 17-Inch Diameter Shock Tube for Studies in Rarefied GasDynamics," Rev. Sci. Instr., 33, 625-631, 1962.

A shock tube for studying problems in rarefied gas dynamics is described. The motivation for operating at low density (to increase the length and time scales of certain interesting flows) and the effect of low density on the performance and design of the shock tube are discussed. In order to guarantee uniform and reproducible shock waves of moderate strength, the configuration of the tube is conventional. However, innovations are introduced to simplify the operation of the large facility (for example, in the suspension, the pumping system, and the diaphragm loading and rupturing mechanism). Care in the design of the tube as a vacuum system has resulted in a leak rate of less than 0.01 Hg per hour. A series of shakedown runs at relatively high pressures has shown, for example, that the reproducibility of a given shock Mach number is ±0.6%.

1220

Luthringer, G., "Estimated Performance Characteristics of the ARL 30-inch Hypersonic Wind Tunnel at M 18," Rept. No. ARL-176, Aeronautical Research Lab., Office of Aerospace Research, Wright-Patterson Air Force Base, Ohio, Rept. for July-Aug 61, on Research on Aerodynamic Flow Fields, 14 pp., 1961.
AD-277 952.

Predicted values of the important performance parameters for the Aeronautical Research Laboratory's new thirty-inch (nozzle-exit diameter) hypersonic wind tunnel are discussed. Included are curves giving the tunnel's Reynolds numbers per unit length, flight Reynolds number (with simulation capability indicated), degrees supersaturation, mass flow rates, normal shock recovery pressures, vacuum system characteristics, and running times.

1221

Marshall, J. M., "A Pressure-Sensitive Detector for Use in Shock-Velocity Measurements in Shocktubes and Tunnels," Ballistics Res. Rept. No. 53, Naval Ordnance Lab., White Oak, Md., 4 pp., 1962.
AD-267 059.

A pressure-sensitive detector is described. Two novel features of the design of the detector are the absence of soldered connections to the transducer, and the quick-change components of the working parts. The latter feature enables one to select the type of material and the thickness of the diaphragm to suit anticipated pressure and temperature ranges.

1222

Martin, J. F., G. R. Duryea, and L. M. Stevenson, "Instrumentation for Force and Pressure Measurements in a Hypersonic Shock Tunnel," Rept. No. CAL-113, Cornell Aeronautical Lab., Inc., Buffalo, N. Y., 1962.
AD-281 721.

The instruments described were developed principally for use in the 48-inch hypersonic shock tunnel, which is operated for research and development in hypersonic aerodynamics. The operation of the tunnel encompasses a Mach number range from 5 to 18, temperatures from 2000 to 6000 degrees Rankine, and test section pressures from 200 psi to as low as 0.001 psi. The testing time ranges from 6 to 17 milliseconds. These operating conditions impose severe requirements on the instrumentation in terms of frequency response as well as the magnitude and range of pressures and forces. Transducer development has centered about the use of piezoelectric crystals because of their extreme sensitivity to stress, high natural frequency, wide dynamic range, and adaptability to miniaturization. The objectives have been to develop reliable transducers to perform in the shock tunnel environment with sufficient accuracy to allow meaningful aerodynamic data to be obtained.

1223

Muirhead, J. C., "Shock Tube Studies at Suffield Experimental Station," Suffield Special Pub. No. 10/61, Suffield Experimental Station, Canada, 5 pp., 1961.
AD-272 044.

The functions and responsibilities of the shock tube laboratory at Suffield Experimental Station are presented in this report, with a description of present and proposed facilities. The former include a 2 in. × 1 1/2-in. shock tube and a 12 in. × 2-in. shock tube. Some features of the design of a shock tube 17 inches in diameter are mentioned, as well as proposals for larger tubes. The principal instrumentation methods (including piezoelectric gauges, shadow optics, and smoke stream techniques) are outlined. Experiments to determine the relation between model size and the distribution of wind velocities within them are described. Findings reported indicate that consistent results were obtained over a range of model sizes extending from 1/54 to 1/5 scale, from which it is inferred that air movement observations made in this scale range could be applied to full-scale structures.

1224

Muirhead, J. C., "Suffield Experimental Station Shock Tube Instrumentation, VIII. The 1 1/4 × 1 1/4-in. Shock Tube," Tech. Note No. 69, Suffield Experimental Station, Canada, 5 pp., 1962.
AD-274 234.

The SES 1 1/4 in. × 1 1/4-in. shock tube is described. This tube is driven by a shock wave valve, and the expansion chamber consists of a single length of square cross-section steel tubing. Results are given of calibration experiments using three different shock wave valve pistons.

1225

Muirhead, J. C., and W. M. McMurtry, "A Mercury Surface Tension Gauge for the Measurement of Low Shock Pressures," Suffield Tech. Note No. 93, Suffield Experimental Station, Canada, 5 pp., 1962.
AD-284 952.

Describes the design of a mercury surface tension gauge for the measurement of shock wave overpressures in the 0.05 to 1.2 psi range. Laboratory experiments indicate that this device has a response time of 10 msec or less.

1226

Partlo, F. L., and J. H. Service, "Instantaneous Speeds in Air of Explosion Reports at Short Distances from the Source," Physics, 6, 1-5, 1935.

In the first series of measurements the source was one No. 6 blasting cap, while in the second series 1 lb of 50% nitroglycerin stick dynamite was used as source. A telephone carbon-button microphone was the receiver and was held fixed in location while shots were fired successively at 5, 8, 12.5, 25, 35, 50, 100 and 600-meter distances. A two-element string oscillograph was used for timing, one element recording the instant of firing, the other element recording the arrival of the wave at the microphone. The work was done at a time of no perceptible wind; air temperatures were measured carefully; no humidity measurements were made. Travel times could be read reliably to 10^{-4} sec, and distance measurements were at least correspondingly good. Instantaneous speeds were obtained by plotting time computed minus time observed against distance, and measuring slopes of the resulting curve. Since this work was incidental to seismic prospecting, the observations were not quite as numerous as those of von Angerer and Ladenburg. However, the results are similar, showing abnormally high speeds near the source. Also, the use of instantaneous speeds appears to show abnormally low speeds a little farther from the source, perhaps masked in the work of von Angerer and Ladenburg due to their use of average speeds instead of instantaneous speeds.

1227

Pennsylvania State University, "Bibliography on Shock and Shock-Excited Vibrations, Volume I. Introduction and Abstracts of Technical Papers," Tech. Rept. No. 3, Coll. of Engineering and Architecture, University Park, 1957.
AD-200 830.

This bibliography consists of three parts. The main body of the text consists of an introduction and abstracts of 1168 technical papers on subjects related to shock motion and its measurement. This is followed by Part II, which consists of abstracts summarizing six subdivisions of the field: Dynamic Behavior of Materials Under Impulsive Loads; Dynamic Behavior of Structures Under Impulsive Loads; Impact Testing Devices; Instrumentation for Measuring Impulsive Forces and Motions; The Shock-Spectrum Approach to Impact Problems; Mathematical Methods for Investigating Dynamic Behavior of Structures Under Impulsive Loading. The final part consists of an appendix that includes an author index, a subject index, and information concerning the search that resulted in these abstracts. The abstracts are mainly of patents and of papers that have been published in technical journals. A few government reports are also included. Originally, it was planned to include abstracts of all pertinent government documents in this publication. However, it now appears desirable to publish these separately in a subsequent volume, because of the bulk of the material and the necessary time required to process it.

1228

Peterson, A., "The Measurement of Impact Noise," Noise Control, 2, 46, 1956.

The instrumentation for impact noise measurement is considerably simplified with the introduction of the new Impact Noise Analyzer capable of indicating the peak and time-averaged values of the impact sound being studied.

1229

Resler, E. L., Jr., and M. Scheibe, "Instrument to Study Relaxation Rates Behind Shock Waves," J. Acoust. Soc. Am., 27, 932-939, 1955.

Describes an instrument which combines the schlieren technique, a photomultiplier tube and an oscilloscope in a manner that enables one to measure the density distribution behind shock waves (in gases) produced in a shock tube. From these measured distributions one can determine the way in which the gas or gases relax to equilibrium and the time it takes to reach equilibrium after the gas's enthalpy is suddenly increased a calculable amount in passing through the shock wave. The theory of the instrument is discussed and its predicted performance experimentally verified by measuring vibrational heat capacity relaxation times behind shock waves in CO_2 containing water vapor. The instrument in the reported tests demonstrated a sensitivity sufficient to record a change in atmospheric density of 1/2% over 1 mm distance and a space resolution of the density in the shock tube of 1/10 mm corresponding to times of the order of 1/10 μsec.

1230

Russo, A. L., and A. Hertzberg, "Modifications of the Basic Shock Tube to Improve Its Performance," Rept. No. AD-1052-A-7, Cornell Aeron. Lab., Inc., Buffalo, N. Y., 43 pp., 1958. AD-162 251.

Considers basic modifications which would improve the performance of shock tubes in producing higher shock strengths and extend the use of hydrogen in generating strong shock waves in air. These modifications are the double-diaphragm driver with monatomic buffer gases and an area contraction at the diaphragm station. The results of this investigation indicate that the use of a shock tube with an area contraction and the proper monatomic buffer gas will permit the generation of strong shock waves, using cold hydrogen as a driver gas, with overall pressure ratios comparable to those required for combustion drivers. It is also shown that, by using a buffer gas with the proper atomic weight, the downstream diaphragm pressure ratio may be controlled to minimize the mass of the downstream diaphragm.

1231

Smy, P. R., "Electromagnetic Shock Tube Capable of Producing a Well-Formed Shock Wave of Low Attenuation," Nature, Great Britain, 193, 969-970, 1962.

Description of a variation on the electromagnetically driven shock tube designed to avoid the severe shock attenuation usually encountered. Shock attenuation and secondary shock formation are minimized by using a dense driver gas. Here it is high pressure nitrogen separated from the channel by a plastic diaphragm, and initiated by discharging a condenser bank into the driver section.

1232

Taniguchi, H. H., "Instrumentation for Measurement of Sonic Boom," Noise Control, 7, 43, 1961.

From the Fourier analysis of an N-shaped signature of a sonic boom pressure-time signal, the author derives the frequency and amplitude distribution of the signal, and sets up performance criteria for a transducer and recording system capable of measuring typical sonic boom pressure pulses.

1233

Teel, G. D., "Proceedings of the Fourth Shock Tube Symposium 18-20 April 1961," Rept. No. 1160, Ballistic Res. Labs., Aberdeen Proving Ground, Md., 476 pp., 1962. AD-274 039.

Contents:

NOL model nuclear airblast simulator.
The soil filled shock tube.
A shock tube modified to produce sharp-rising overpressures of 400-msec duration.
A high-explosive-operated shock tube with facilities for testing structures.
Volume detonation in shock tubes.
High pressure loading device for evaluating blast closure performance.
Techniques for producing long-duration loads in the NCEL blast simulator.
Arc heating technique for shock tube driver.
Pressure and heat-transfer instrumentation used in the NOL hypersonic shock tunnels.
Measurements in the hypersonic shock tunnel at I.S.L.
Shock wave decay in tunnels.
Republic 24-inch hypervelocity wind tunnel.

1234

Teng, R. N., "Investigation of Spherical Shock Waves in a Shock Tube," Sci. Rept. No. 62-1, Fluid Dynamics Res. Lab., Mass. Inst. of Tech., Cambridge, 30 pp., 1962. AD-282 372.

A shock tube was constructed for investigating spherical shock waves in various atmospheres. The shock tube was carefully calibrated for its performance throughout the designed operating range. Thin-film heat transfer gauges were employed to measure the speed of the incident shock wave. Shadowgraph technique was used to establish the geometry of the spherical shock waves which were produced either by allowing the center portion of the incident shock to enter an orifice and then to expand into a spherical shock wave at the entrance of the orifice, upon reflection from the end; or by causing the high-temperature, high-enthalpy gas behind the reflected shock wave to expand through a conical nozzle. Attempts were made to measure the speed of the spherical shock waves.

1235

Thomas, R. E., J. D. Lee, and G. L. von Eschen, "Configuration Details and Initial Performance of a Hypersonic Wind Tunnel for the Range of Mach Number 8 to 14," Final Tech. Rept. No. 2, Ohio State Univ. Res. Foundation, Columbus, 14 pp., 1957. AD-146 248.

The report describes the important features of the device used in the second phase of a study to obtain continuous flows of air at Mach numbers up to 14. The initial results have shown that the system is capable of starting and operating continuously within the Mach number range desired. Control features, pressure ratios, cooler performance, and safety requirements have all been satisfactory. The air heater was designed for operation at 4000 psia and 2800 degrees Rankine; initial tests at 2500 degrees Rankine indicated some undesirable features but the main concepts were satisfactory.

1236

Thornton, J. A., and A. B. Cambel, "The Effect of Radiation on Shock Velocity Attenuation in Electromagnetic Shock Tubes," Rept. No. AFOSR-1101, Northwestern Univ., Evanston, Ill., 55 pp., 1961. AD-277 360.

Observations are reported in a study of effects of radiation on shock velocity attenuation in the conical electromagnetic shock tube. Included is a summary of findings which have appeared in the literature along with the approximate blast wave theory, which has become the primary method of making theoretical velocity-attenuation calculations. These published observations lead to the question of the effect of radiation on the velocity attenuation in a tube with highly reflective walls such as might be employed in a propulsion system; the approximate blast wave theory is adapted in developing a modified approximate method for calculating this effect. Approximate radiation equations are combined with the velocity-attenuation equations and a study is made of radiation factors which might influence the velocity attenuation. It is concluded that radiation will be an important factor only for strong shocks moving into a dense gas (approximately 1/10 atmosphere or greater, at room temperature).

A description of the electromagnetic shock tube is given, and a discussion of some velocity-attenuation experiments which are being conducted, in which no attenuation due to radiation has been noted. These experiments conducted at low velocities and densities thus agree with the predictions of the approximate blast wave theory modified to account for radiation effects.

1237

van Rossum, J. W. M., "Bibliography on Blast, Shock Waves and Allied Topics, Featuring Nuclear Explosions," Rept. No. TDCK 30050, Tech. Doc. Inform. Ctr., Krijgsmacht, Netherlands, 1962. AD-276 958.

Entries include references to reports pertaining to characteristics of nuclear explosions—air burst, ground burst, and underwater burst—together with the response of structures to blast loading. Attenuation is paid to measurements, experimental techniques, and testing equipment. Many of the references in this report bear only a marginal relationship with the subject mentioned, but their findings are of interest in the over-all picture. References have been arranged chronologically with the latest references placed first. The bibliography is cross-referenced and has an author index.

1238

Venable, D., "Positive Ion Oscilloscope Trigger for Shocks in Low-Density Gases," Rev. Sci. Instr., 26, 729, 1955.

Positive ions are injected into a shock tube through a hole, 0.5 mm in diam, in the tube wall, and are collected at a needle point approximately one mm from the hole. The ion current passes to earth through an external resistor, across which the voltage varies when a shock wave passes through the ion stream; when amplified, the voltage variation serves as an oscilloscope trigger. The system overlaps conventional methods of detecting shock wave propagation and is applicable at lower pressures; it has been shown to function satisfactorily for shock waves in He, A, and N_2 where the pressure ahead of the shock ranged from 0.05 to 5 mm Hg, and the compression across the disturbance varied from 2 to 3.8.

1239

Wright, H. V., "A Study of Shock-tube Phenomena," Interim Tech. Rept. No. DR-2, Inst. of Eng. Res., Univ. of Calif., Berkeley, 120 pp., 1957. AD-201 390.

Among the most basic studies that can be made with the shock tubes are those of shock-front speed, pressure ratios across a shock front, and interaction of different waves—all which phenomena are most easily described by a wave diagram. This paper presents briefly the basic theory underlying the operation of a shock tube and outlines the procedure for the construction of a wave diagram. Wave diagrams are worked out for the specific cases of an open-ended shock tube and a closed-end shock tube, and are subsequently correlated with experimental results.

1240

Wright, J. K., "The Shock Tube: Aspects of Design and Operations," R & D, Great Britain, 44, 1962.

Gives an elementary account of the theory of shock tubes, and discusses some practical details of their construction.

1241

Wright, J. K., "The Shock Tube: Simple, Cheap and Versatile," R & D, Great Britain, 50-53, 1962.

A review article describing ways in which shock-tube research is applied to physical, chemical and engineering problems.

Instrumentation, Shock Wave
see also—34, 359, 496, 501, 518, 520, 621, 862, 1346, 1372, 1649, 1650, 1790, 1805, 2380, 2381, 2812, 2827, 2978, 2980, 2982, 2983, 3001, 3003, 3010, 3420, 3436, 3445, 3446, 3449, 3454, 3463, 3532, 3533, 3557, 3770, 3846, 3853, 3894, 3895, 4014, 4022, 4027, 4028, 4036, 4037, 4059, 4077, 4084, 4085, 4086, 4087, 4088, 4094, 4101, 4125, 4135, 4138, 4145, 4223.

INSTRUMENTATION, SONIC ANEMOMETERS/THERMOMETERS

1242

Barrett, E. W., and V. E. Suomi, "Preliminary Report on Temperature Measurement by Sonic Means," J. Meteorol., 6, 273-276, 1949.

Following a brief review of the assumptions involved in the Laplacian expression for the speed of sound waves, an instrument, the sonic thermometer, is described which utilizes this relationship to measure the air temperature. The advantages of the sonic thermometer are then discussed; chiefly, they are the absence of radiational errors, and extremely low lag—a result of the fact that the measured variable, the speed of sound, is independent of the properties of the measuring elements.

1243

Bovsheverov, V. M., and V. P. Voronov, "Acoustic Anemometer," Bull. Acad. Sci. USSR, Geophys. Ser. English transl., No. 6, 586-588, 1960.

This paper begins with a review of the theory applicable to sonic anemometry, and then presents the specifications, constructional features and operating characteristics of the precision acoustic anemometer. No circuit diagrams are given, but the operating principles of the instrument are made clear with a block diagram and appropriate text. The instrument contains forty-five vacuum tubes, one sound source and four microphones. The outputs provide both instantaneous and averaged values of the wind velocity vector. The equipment was designed for studying turbulence in the atmosphere near the ground.

1244

Cataland, G., and H. H. Plumb, "Acoustical Interferometer Employed as an Instrument for Measuring Low Absolute Temperatures," J. Acoust. Soc. Am., 34, 1145-1146, 1962.

Values of absolute temperatures at $2^{o}K$ and $20^{o}K$ were determined from experimental measurements of the speed of sound as a function of pressure in helium gas. The acoustical interferometer was the instrument employed in the measurements, and the accuracy achieved in the experiment indicates that sonic thermometry at low temperature may be competitive with other conventional thermometry techniques.

1245

Coffman, J. W., and R. C. Price, "Some Errors Associated with Acoustical Wind Measurements through a Layer," Tech. Rept. No. SELWS-M-12, White Sands Missile Range, N. Mex., 13 pp., 1962.
AD-288 020.

Investigates an acoustic wind-measuring array consisting of a transmitter and two receivers. Finds the error incurred by assuming that the wind component in the line of sensors is dependent solely upon the time delay of the sound front arrival at the two receivers. For an orientation suitable for measuring the horizontal flow through a layer, the error is less than 7%; for crosswind components, less than 30 mph. The temperature through the layer is known to $1^{o}C$.

1246

Cook Research Laboratories, "Research, Design, and Development of Sonic Anemometer-Thermometer," Final Progress Rept. No. FPR 22-1, Cook Electric Co., Chicago, Ill., 44 pp., 1953.
AD-83 722.

Presents the theoretical basis for an instrument to measure the average velocity and direction of wind and average air temperature over fixed distances by means of sound transmission measurements. This instrument is referred to as a sonic anemometer-thermometer.

The experimental setup and testing procedures are presented, as well as recorded and observed results. These results are discussed and an evaluation made in order to establish the feasibility of building a practical sonic anemometer-thermometer. Limitations of such an instrument and pertinent design criteria are discussed.

1247

Corby, R. E., "Acoustic Anemometer-Anemoscope," Electronics, 23, 88-90, 1950.

This article describes an instrument which provides instantaneous visual presentation of wind direction and speed on an oscilloscope screen. The instrument consists of a pulse generator driving a sound projector, four acoustic receivers oriented to the cardinal points of the compass around the projector, an amplifier, a discriminator, and an oscilloscope. The display is a vector line with its origin at the center of the oscilloscope screen and its magnitude and direction correlating with those of the wind.

1248

Dawes, J. G., "The Acoustic Blastmeter," J. Sci. Instr., 27, 123-127, 1950.

Describes a method for measuring and recording the speed of a rapidly changing blast of air. The method depends on the change in phase of an acoustic signal received at a point, the phase shift being a function of the velocity of the air between the sound transmitter and receiver. Tested in a laboratory gallery with a series of steady air blasts ranging from 25 to 125 fps, the method gave results closely corresponding to the air velocities measured by an independently calibrated orificemeter. It is capable of rapid response and of dealing with a wide range of air speeds. The article proposes use of the method for recording the changing speed of the air blast which precedes the flame of an explosion traveling along a gallery.

1249

Gurbitch, A. S., "Acoustic Microanemomometer for Investigating the Microstructure of Turbulence," Soviet Phys. Acoust. English Transl., 5, 375-377, 1960.

Acoustic manometers, as described in the literature, are not too suitable for pulse measurements, since they give a value for the velocity that is averaged over a large base of the order 100 cm. Reduction in the base is limited for the most part by the dimensions of the microphones and the radiators. In this microanemometer design cylindrical condenser transducers having a diameter of 2 mm and a working length of 5 mm are used for the microphones and radiators. A terpilene film with a thickness of 3.5 μ and an external metallic coating serves as the movable electrode. The sensitivity of the microphone is 0.07-0.1 mv/bar at frequencies of 75-100 kcs. The application of high-frequency miniature transducers has made it possible to shorten the base of the microanemometer to 2.5 cm.

1250

Hayashi, T., "Periodic Variation of Temperature Caused by Sound Waves," Electrotech. J., 3, 103-106, 1939.

Two experimental arrangements are described, one for the purpose of indicating the temperature variations due to the adiabatic changes in sound waves sent along a tube by a loudspeaker. The equipment contains a twelve-couple thermopile, the output of which is passed through amplifiers, attenuator and band-pass filter to a valve voltmeter. In the second set a hot wire is in contact with the sound. The hot wire registers the temperature changes which occur at the antinode of the stationary wave. The amplifying and other equipment is similar to that used in the first experiment.

1251

Itterbeek, A. V., "Measurements with Ordinary Sound and Ultrasonics Carried Out in the Physical Laboratory of the University of Louvain," J. Acoust. Soc. Am., 29, 584-587, 1957.

This paper contains brief résumés of some of the acoustical research carried on at the University of Louvain during the year

1955-1956. Descriptions of apparatus and methods, and some interpretation of the results are given. Two different acoustical interferometers are described and illustrated. Their use for measuring sound speeds in various gases and for measuring extremely low temperatures is explained.

1252

Kaimal, J. C., "A Sonic Anemometer for the Study of Turbulent Wind Loading on Missiles," Proj. 7655, Meteorological Res. Lab., AFCRL, Office of Aerospace Res., USAF, L. G. Hanscom Field, Mass., 11 pp., 1962.
AD-294 546.

Describes the design of a sonic wind component meter particularly suited for the study of turbulent wind loading on a stationary missile. The instrument measures eddy fluctuations in the wind along two horizontal axes with an array consisting of one emitter and four receivers. Careful analysis of possible errors shows that measurements should be accurate to within five percent.

1253

Olsen, R. O., "Acoustical Determination of Winds by Means of a Circular Microphone Array," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 77-87, 1961.
AD-408 716.

An experimental acoustical circular array was set up to determine the wind field near the surface. The array consists of eight microphones placed in a circle, with a sound source at the center. A wind component is determined for each of the eight points from the time arrivals of sound at the microphone positions. By statistically averaging these components a mean wind vector is derived which best fits the various wind components. The accuracy of the mean wind is determined, and some of the errors inherent in the system are described. This data is also compared to the readings from standard measuring equipment located at the site.

1254

Pardue, D. R., and A. L. Hedrich, "Absolute Method for Sound Intensity Measurement," Rev. Sci. Instr., 27, 631-632, 1956.

Since sound propagation is an adiabatic process, a temperature fluctuation accompanies the sound wave in media for which the specific heat ratio is greater than unity. If the equation of state and the sound field are known, this temperature fluctuation may be related to the intensity of the sound wave.

Describes a thermometer capable of measuring fast, small-amplitude temperature variations. Its output is calculated for the case of plane, sinusoidal sound waves in an ideal gas. Its uses as a microphone and sound intensity meter are then considered.

1255

Schotland, R. M., "The Measurement of Wind Velocity by Sonic Means," J. Meteorol., 12, 386-390, 1955.

Description of a sonic anemometer operating over one-meter base lines, for measuring horizontal components of the wind. Response time one-fourth second, with accuracy better than ten percent (no standard to check against).

1256

Steward, R. M., Jr., R. E. Post, et al., "Sonic Anemometer Data Acquisition and Analysis System and Calculation of Eulerian Scale of Turbulence from Bivane Data," Iowa Engineering Experiment Station, Ames, AFCRL 62-465, Final Rept., 52 pp., 1962.
AD-284 964.

Describes methods used for measuring wind speed and short-period fluctuations in wind speed. The results are applied to an investigation of atmospheric turbulence. Includes descriptions of the sonic anemometer and of the other instruments used, and explains the methods employed to analyze data.

1257

Suomi, V. E., "Energy Budget Studies at the Earth's Surface and Development of the Sonic Anemometer for Power Spectrum Analysis," Rept. TR-56-274, Univ. of Wisconsin, Dept. of Meteorology, Madison, AFCRL, Bedford, Mass., 1957.
AD-117 197.

Section 2 of this report describes a field-tested model of a sonic anemometer and thermometer which has demonstrated good accuracy (two percent, at less than 50 mph). The systems use two transmitters and two receivers operating in opposite directions. The time delay (with and against wind) between received pulses is directly proportional to wind velocity over a wide range. The sonic thermometer operates on the principal that the average velocity of sound with and against the wind is proportional to the square root of the absolute temperature.

1258

Uretz, E. F., "Study of Meteorological Surveillance Observing System," Final Rept. No. ARF 5125, Armour Res. Foundation, Chicago, Ill., 43 pp., 1960.
AD-263 682.

Describes techniques for passively measuring micrometeorological variables; presents a system for determining temperature, pressure, relative humidity, and wind velocity by passive means; offers a recommendation for the construction and testing of microwave and infrared radiometers as a first step toward implementing the entire system; and discusses acoustic detectors and sonic wind measurements. (See also Hori, S., for earlier reports in this series.)

1259

Uretz, E. F., "Study of Meteorological Surveillance Observing System," Quart. Progress Rept. No. 5, Armour Res. Foundation, Chicago, Ill., 34 pp., 1960.
AD-263 684.

Acoustic measurement of wind is described. Block diagrams of the low level wind velocity measuring subsystem are given. The results of the computer simulation of an infrared radiometer and the subsequent reduction computation are presented and discussed. (See also S. Hori (1959) for earlier reports in this series.)

1260

von dem Borne, H., "Acoustic Wind Measurement" (in German), Meteorol. Rundschau, 7, 217-220, 1954.

Methods are set out, with tables, for determining wind velocity from deformation in the free air of a sound wave, using four microphones placed in four main directions around the source, and timing arrival of the sound or measuring phase changes. The results are said to be accurate if the air temperature is known.

1261

Welshimer, D. E., "The Experimental Application of Sonic-Pneumatic Probe Systems to Temperature Measurement in a Hypersonic Airsteam," Final Tech. Rept. No. ARL 62-364, Ohio State Univ. Res. Foundation, Columbus, 1962.

The feasibility of measuring the total temperature of a low-density hypersonic airstream by using sonic-pneumatic probe systems was investigated. Three successive probe systems were designed and tested at reynolds numbers between 1000 and 100,000 (based upon probe diameter and approaching free-stream conditions). Results showed that the accuracy of the temperatures indicated by a sonic-pneumatic probe system highly depended upon design and that a properly designed sonic-pneumatic probe system yielded, at most, ±3.3% scatter at a total temperature of 2700 degrees Rankine. Furthermore, the magnitude of this maximum error appeared to remain nearly constant throughout the 800 R to 2800 degrees Rankine temperature range of testing. Thus, by the addition of water cooling, it is expected that a sonic-pneumatic probe system could be used in a 5000 degrees Rankine hypersonic airstream with a maximum error of about ±2%.

Instrumentation, Sonic, Anemometers/Thermometers
see also—570, 859, 883, 895, 1321, 1328, 1427, 1430, 1451, 1454, 1455, 1465, 2183, 2749, 2810, 3908.

INSTRUMENTATION, ULTRASONIC

1262

Bender, D., "Ultrasonic Velocity in N_2, NO, and CO Between 20° and 200°C, Measured by a New Method" (in German), Ann. Physik, 38, 199-214, 1940.

The temperature dependence of the velocity of sound at a frequency of 1000 kcs is measured by a modification of the Pierce interferometer in which the piezo-quartz is mounted between two fixed reflectors. The quartz is coupled inductively to the driving oscillator and vibrates at temperatures up to 500°C, but above 200°C the sound intensity is too weak to permit measurements. The results indicate that in N_2, CO, and NO, the region of anomalous dispersion of the sound velocity is shifted with increasing temperature towards higher frequencies.

1263

Bertolini, A., "An Ultrasonic Receiver for Detecting Signals of Bats," Rept. No. 47G-0010, Lincoln Lab., Mass. Inst. of Tech., Lexington, Rev. 1, 16 pp., 1961.
AD-268 702.

A portable ultrasonic receiver was designed for detecting the signals of bats and other fauna which may emit ultrasonic sounds. The receiver has a passband extending from 15 to 200 kc, but bandwidth selection within this interval can be obtained with the use of plug-in filters. It has a small-signal voltage gain of 78 db preceding a rectifier which envelope-detects the ultrasonic signal. Following detection is 10 db of audio voltage gain. Additional gain is provided by a preamplifier inserted between the microphone and ultrasonic amplifier. All of the power is supplied by five 1.35-volt mercury cells but D-cell flashlight batteries may be used when necessary. The total weight of the unit is 5 pounds.

1264

Bommel, H., "The Measurement of the Velocity and Absorption of Ultrasonics by an Optical Method," Helv. Phys. Acta, 18, 3-20, 1945.

The measurement of the velocity of ultrasonics in gases becomes more complex as the frequency increases on account of the interaction between source and receiver and other effects. In the optical method described, the Hg 4358Å line is passed through gas subjected to the action of the ultrasonics, and the diffraction pattern brought to a focus on a photographic plate by a concave mirror. The velocity V is obtained from the separation of the diffraction maxima. A range of 951-4755 kc is covered. A method is worked out theoretically whereby the absorption can be obtained from the separation of the diffraction maxima.

1265

Bradfield, G., "Obstacle Detection Using Ultrasonic Waves in Air," Electron. Eng., 21, 464-468, 1949.

This paper describes the results which have been achieved with simple equipment for use as a safety-in-fog aid to road transport, or blind man's aid, to detect the proximity of oncoming traffic, up- or down-going steps, walls, windows, etc. Expressions are given for determining the optimum frequency for certain conditions (e.g., at 20 ft large objects require a frequency of 23 kcs, but clusters of tiny objects require 50 kcs). A spark transmitter was used with a standard 14-mm sparking plug at the focus of a reflector. The receiving microphone used a double bimorph Rochelle crystal at the focus of a five in paraboloid. The spark rate was 3 to 4 sec, and duration 1 to 1 1/2 μsec. Tables show the amplitude of the reflected signal at various frequencies for different objects.

1266

Bradfield, G., "Summarized Proceedings of Symposium on Applications of Ultrasonics," Proc. Phys. Soc. (London) B, 63, 305-322, 1950.

Recent advances in (a) the investigation of the fundamental structure of matter, (b) telecommunication and allied applications, and (c) use of mechanical forces set up by intense waves are surveyed. Derivation of elastic constants of matter are presented. Losses of energy incurred in propagating waves are surveyed and relaxation phenomena based on Maxwell's hypothesis of shear elasticity as a time function and on Kneser's treatment of loss due to delay in a storage process are represented.

Available sources of ultrasonic power are surveyed and the importance of barium titanate as a powerful and strongly coupled piezoelectric transducer is emphasized.

An expression for the receiver/transmitter power ratio in telecommunications systems is examined and optimum frequencies for various ranges deduced.

Accounts are given of experience with flaw detectors and echo-sounding, showing that these are becoming important industrially and in navigation; work on blind aids is found unpromising.

Advances in timing and time delay devices are described. The importance of the study of cavitation is pointed out. Results are discussed for killing bacteria, disintegrating proteins, emulsifying, soldering aluminum, and refining the crystalline structure in solidification of light alloys.

1267

Capehart Corporation, "RF to Optisonic Bolometer," Final Eng. Tech. Rept. No. 62-8-1, Richmond Hill, N. Y., 82 pp., 1962.
AD-281 915.

The RF to optisonic bolometer system consists of separate transmitting and receiving units operating over an ultrasonic data link. The miniature transmitter is completely self-contained and may be inserted completely within the electroexplosive device; it will transmit through the device by means of an ultrasonic carrier.

Transmitter modulator information is provided by a thermistor which detects and measures the infrared radiation given off by the detonating bridge wires. In operation, the transmitter is substituted for the igniter in an electroexplosive device and the remote receiver monitors the bridge wire temperature as the device is subjected to an electromagnetic radiation environment.

Reports testing of an operational system, and includes compiled data relating bridge wire characteristics to numerous parameters.

1268

Crawford, A. E., "Ultrasonic Engineering," Academic Press, New York, 344 pp., 1955.

After a very brief presentation of the theory of ultrasonic radiation and a chapter on cavitation in liquids, the next 100 pages are devoted to the treatment of the generation of high-intensity and high-frequency sound. The remaining 180-odd pages discuss the specific applications, including precipitation, emulsification, chemical action, metallurgical processing, coating of metals, as well as biological and medical applications. There is a final chapter on ultrasonic instruments and control gear.

The treatment is descriptive throughout, with a minimum of emphasis on analytic detail. For the most part the formulas are introduced from the technical literature without deduction, much of the analysis having been replaced by numerous clear and well-drawn graphs. The bibliography, though not extensive, is adequate for the engineering reader who wishes to follow up some special line. The style is clear and readable. The illustrations of ultrasonic equipment are excellent, as is the typography. The volume should find wide use among acoustical processing engineers.

1269

Eucken, A., and R. Becker, "Excitation of Intramolecular Vibrations in Gases and Gas Mixtures by Collisions, Based on Measurements of Sound Dispersion," Z. Physik, Chem., B, 27, 219-262, 1934.

The paper is in two parts. The first part describes an apparatus for measuring ultrasonic wavelengths, based on the principle of the acoustic interferometer described by Pierce. The apparatus can also be used in investigating chemically active gases within a temperature range of several hundred degrees. Certain difficulties dealt are those which arise when frequencies of the order of 50 kcs are used. The method of calculation is described by which the values of C_p/C_v at zero pressure for the pure components of a gaseous mixture are determined from the speed of sound in the mixture at a given pressure. In the second part, results are given for the speed of sound and the value of C_p/C_v for Cl_2 and CO_2 for frequencies 58, 145, and 292 kcs. It is deduced that the number of collisions required to withdraw a quantum of energy from the pure gases CO_2 and Cl_2 is 51,000 and 34,000, respectively, at room temperature. Under certain conditions these numbers may be greatly reduced. The effect of temperature is such that a rise from -32^o to $+145^o$ causes a sevenfold increase in pure Cl_2, a fourfold one in CO_2, and a fivefold one in Cl_2 containing CO. A formula was derived theoretically and was found to agree with experiment, according to which the number of impacts required for the release of one quantum is proportional to $1/T^n$ where n is a number depending on two molecular factors.

1270

Fridman, V. M., "Ultrasonics," Aerospace Tech. Intelligence Center, Wright-Patterson Air Force Base, Ohio, 66 pp., 1961.
AD-264 622.

An extensive study of ultrasonics technology is presented in handbook form. Applications to industrial research are presented and descriptions of equipment are given with photographs of various devices. Discussions of ultrasonics theory and principles of applications are stated at some length.

1271

Glickstein, C., "Basic Ultrasonics," John F. Rider Publisher, New York, 137 pp., 1960.

This book is divided into three parts: general theory, equipment, and applications, with a short glossary and an index. The "pictured text" method is used, with almost every page having a cartoon-like diagram occupying from about one-quarter to, in a few cases, well over one-half of the page. Scattered throughout the book are six sets of "Questions and Problems," each containing ten or twelve questions.

The book is suitable for technical institute or vocational school use. No mathematical background is required, but a fair knowledge of electronics is needed, especially for the equipment section. The diagrams help not only by enlivening the appearance but also by serving as a very effective means of emphasizing the main points of the textual material. The book could also serve those looking for a good elementary survey of ultrasonic equipment and applications. The section on sound in general physics courses could make stimulating supplementary reading material.

1272

Grossmann, E., "Absorption of Sound in Gases at High Frequencies," Ann. Physik, 13, 681-702, 1932.

The absorption of sound between 3×10^4 and 3×10^5~ is measured by a new method. Generator and receiver are two piezoelectric quartzes with almost the same resonance frequencies. These are placed in an enclosure containing the gas. The generator is made to vibrate with constant amplitude at its resonance frequency, and the energy in the circuit of the receiving quartz is measured by a thermocouple, when the receiver is at various distances. Disturbing effects of all kinds are investigated. Contrary to the Stokes-Kirchhoff theory, the coefficient of absorption is found to vary with the frequency, particularly in CO_2 and SO_2, and is always far in excess of values predicted by this theory.

1273

Hopwood, F. L., "High-Frequency Sound Waves," J. Sci. Instr., 6, 34-40, 1929.

High-frequency air waves are produced by Langevin's method, putting a massive electrode of lead and a light electrode of copper foil in contact with the two faces of a quartz disc and applying an alternating potential difference of 20,000 volts. The quartz disc dilates and contracts. A beam of air waves is formed at right angles to the disc. If this is horizontal, the formation of stationary wave-striae can be observed in coke-dust laid on glass in the path of the beam. Interference patterns, diffraction effects, attenuation, and the pressure of sound radiation are also demonstrated. These waves kill fish, as Langevin showed. They also break up red blood corpuscles, inhibit the electrical stimulation of a muscle-nerve preparation, and destroy the structure of fresh-water vegetation. If the beam is directed upwards in oil, a mound of oil is raised on the surface; this is in strong vibration, and this vibration can be communicated to liquids in test-tubes. The air dissolved in these liquids is liberated in bubbles. Calorific effects are easy to obtain.

1274

Hubbard, J. C., "Acoustic Resonator Interferometer, Part II. Ultrasonic Velocity and Absorption in Gases," Phys. Rev., 41, 523-535, 1932.

The derivation of the equivalent electric network of the acoustic resonator interferometer in Part I of this paper has made it possible to develop the theory for the current in a simple resonant circuit in which the electrodes of the piezoelectric plate of the interferometer are connected to the terminals of the variable condenser. The special case of this theory is that in which the circuit is excited at a constant frequency determined by the crevasse frequency of the resonator plate in its given situation with respect to electrodes and associated circuit, when the acoustic path in the interferometer is detuned and the resonant circuit is tuned so that its resonant maximum occurs at the same frequency; the special case takes an especially simple form and leads to a direct procedure for determining ultrasonic velocity and absorption in a gas in terms only of current in the resonant circuit and path-length in the interferometer, all circuit and interferometer constants dropping out. The values of current as a function of pathlength obtained experimentally are in complete accord with the theory, and data for ultrasonic absorption in air and in CO_2 so far obtained agree with the meager data available by other methods. The role of the coefficient of reflection at the fluid-reflector surface is discussed.

1275

Jatkar, S. K. K., "Supersonic Velocity in Gases, Part I," J. Indian Inst. Sci., 21A, 245-271, 1938.

As a preliminary to the measurement of the velocity of supersonic sound in the vapors of organic compounds, a study is made of the aberrations of supersonic interferometers used to determine wavelengths. Includes curves showing how the anode current of the quartz oscillator varies with the position of the reflector, and mapping irregularity of peak positions (corresponding to nodal planes). Investigates causes of these irregularities, and demonstrates that the best results are obtained when a somewhat narrow interferometer tube is used and the quartz is carefully positioned a short distance from the tube; under these conditions the wavelength is said to be obtainable with an accuracy of 1 in 700.

1276

Mokhtar, M., and E. G. Richardson, "Supersonic Dispersion in Gases, II. Air Containing Water Vapor," Proc. Roy. Soc. (London) A, 184, 117-128, 1945.

The apparatus and method of measurement are described. Curves are given showing the variation, at various frequencies, of the supersonic absorption coefficient μ and the supersonic velocity with the water vapor pressure. The results deduced are: (1) the velocity in dry air is independent of frequency; (2) the measured values for μ in dry air are several times larger than those calculated from the Stokes-Kirchhoff formula and indicate an approximately linear dependence on the frequency; (3) in humid air μ reaches a maximum, two or three times its value in dry air, at a vapor pressure which decreases as the frequency increases; (4) the maximum of dispersion in velocity decreases as the frequency increases.

1277

Pimonow, L., "Modulation of Stationary Ultrasonic Waves in Air" (in French), Ann. Telecommun., 9, 24-28, 1954.

Deals first with the general question of modulation. It points out that superposition of vibrations (electrical or mechanical) signifies an addition of amplitudes, whereas modulation corresponds to a multiplication of amplitudes. Part two deals with the modulation of stationary waves of ultrasound, and in part three an outline is given of a so-called "gaseous microphone." This consists of a 30-kc quartz source which sets up a system of stationary waves between its emitting surface and a rigid reflector a short distance away. The progressive waves from a source of audio-frequency sound cross the track of these stationary waves and produce a modulation which is received by a small Rochelle-salt microphone suitably placed near the stationary wave system. In a particular case mentioned in the paper, the depth of modulation is about 3%. Part four discusses the theory of modulation of stationary waves.

1278

Reid, C. D., "Velocity of Sound at Ultrasonic Frequencies Using Quartz Oscillators," Phys. Rev., 35, 814-831, 1930.

Reports measuring the velocity of sound at frequencies 40 to 216 kcs per sec., using quartz crystals as sound oscillators. The sound emitted travels to a movable reflector and then returns to the source. As the reflector is moved, the phase of the reflected sound changes, causing the plate current of the quartz oscillator to pass through a maximum value each time the reflector is moved a half wavelength (Pierce's method). The velocity was determined in air free from CO_2 at three values of humidity, viz., dry, 45% humidity at 20°C, and in air saturated with water vapor at 20°C. The velocity was found to decrease with increasing distance from the source, approaching asymptotically to a value 331.60 meters per sec at a distance of 45 cm from the source. The effect of humidity was found to be expressible by $V_H = V_O + 0.14H$, where V_O is the velocity in dry air at 20°C, and V_H is the velocity at any relative humidity H at 20°C.

1279

Richardson, E. G., "Supersonic Dispersion in Gases," Proc. Roy. Soc. (London) A, 146, 56-71, 1934.

The propagation through various gases of supersonic radiation emitted by piezoelectrically maintained quartz crystals is examined experimentally. New methods involving the change of resistance of an electrically heated wire exposed to the radiation are developed, enabling the wavelength and amplitude of the gaseous vibration to be measured. The method of calibrating the apparatus is also described, and the results are compared with those obtained by older methods. The anomalous dispersion and absorption shown by certain gases is critically examined, and suggestions put forward to account for it. Evidence is adduced to show that some of the radiation "absorbed" is scattered by the gas.

1280

Romanenko, E. V., "Experimental Investigation of the Propagation of Finite-Amplitude Spherical Waves," Soviet Phys.-Acoust. English Transl., 5, 101-105, 1959.

Gives the designs of the radiator and the receiver built by the author, and some results of an investigation of the propagation of waves with pulsed emission at f = 1.15 mcs and pressure amplitude at the radiator's surface up to 26 atm. The theoretical and the experimental results agree satisfactorily.

For determining the frequency response of receivers, over a wide range of frequencies, the author presents a method based on the change of shape of a finite-amplitude wave during propagation.

1281

Skudrzyk, E., "Acoustic Electronic Pulse Equipment," J. Acoust. Soc. Am., 32, 565-571, 1960.

Gives detailed information for the construction of relatively simple, efficient pulse equipment. The repetition rate of the pulse generator varies between once in ten seconds and 25,000 times a second with a pulse duration from 1/3 second to 100 msec. Pulses of sinusoidal oscillations may be generated in the frequency range from 50 cps to 100 mcs. The circuits are free from ringing at frequencies below 5 mcs. The power output for pulses of less than 2 msec duration is between 50 and 250 watts at frequencies below 10 mcs. A thyratron stage produces a triggering pulse to activate a monostable multivibrator whose adjustable-width pulse passes through a cathode follower and furnishes the screen voltage for the output tube. If the frequency is below a few mcs, the output tube may be used to gate a sinusoidal voltage supplied by a standard signal generator; but for high power or at high frequencies, the output tube is preferably driven as a gated, self-excited oscillator. The receiving amplifier may be connected parrallel to the output of the pulse generator so that the same transducer can be used as both sound projector and microphone. This amplifier limits the large voltage of the driving pulse and is capable of full sensitivity immediately after the pulse has decayed.

Discusses some valuable experiences with acoustic transducers.

1282

Slaymaker, F. H., and W. F. Meeker, "Blind Guidance by Ultrasonics," Electronics, 21, 76-80, 1948.

The limitations due to different reflection characteristics of various surfaces and objects and to fluctuations in reflection, when a portable "radar" system is employed, are discussed. Simple pulse, simple FM and pulsed-FM systems, all embodying separate transmitting and receiving magnetostriction transducers, are compared. The latter, which employs an ultrasonic oscillator with sawtooth variation of frequency but has narrow-band transducers, is considered the best because it introduces no contradictory information and permits some distinction between objects at different points. One model, operating at 32 kcs with 10 valves, mainly of the subminiature type, for transmitter and receiver and using headphones, enables the presence of a person to be detected at 30 feet. Later equipment is also described.

1283

Stewart, J. L., "A Variable Path Ultrasonic Interferometer for the Four Megacycle Region with Some Measurements in Air, CO_2, and H_2. Rev. Sci. Instr., 17, 59-65, 1946.

Alignment of the piston and crystal to the order of one light fringe was attained and maintained by employing Newton and Haidinger optical fringe systems. Velocities were measured to an accuracy of 0.1%, and absorption and reflection coefficients to 50% in air and CO_2. The limit of accuracy in both cases was determined by the length, as measured to one micron with a micrometer screw. Preliminary measurements on H_2 gave evidence of molecular dispersion between 4 and 8 mcs.

1284

Stewart, J. L., and E. S. Stewart, "A Recording Ultrasonic Interferometer and its Alignment," J. Acoust. Soc. Am., 24, 22-26, 1952.

The first part describes a circuit employing rf amplification which converts an ultrasonic interferometer into a sensitive self-recording instrument whose records easily can be analyzed to yield a rapid determination of the attenuation and reflection coefficients of gases at low pressures. The second part summarizes the sources of error in ultrasonic interferometry, their detection and their correction. In the third part, some data on the velocity, attenuation, and reflection in helium between two to sixty Mc/atm are presented to illustrate the range, precision, and absolute errors of the instrument.

1285

Trommler, H., "Ultrasonic Transmitter for Use in Laboratories and Industry" (in German), Carl Zeiss Jena Nachricht (Germany), 9, 93-105, 1961.

After briefly illustrating the various techniques for producing ultrasonic waves, describes and presents the relevant data for several ultrasonic transmitters of 400 kcs and 800 kcs. With reference to a large ultrasonic vessel, discusses the forces produced in the ultrasound field and their effects in liquids.

Instrumentation, Ultrasonic
See also—54, 145, 173, 209, 280, 282, 290, 297, 310, 316, 453, 590, 859, 1134, 1135, 1138, 1156, 1182, 1249, 1369, 2142, 2702, 2749, 2796, 2804, 3132, 3133, 3173, 3647, 3982.

INSTRUMENTATION, UNCLASSIFIED

1286

Antal, J., and A. Konig, "New Acoustical Method of Vacuum Measurement," Periodica Polytech., Elec. Eng., 1, 297-300, 1957.

An approximate theory and brief description are given of a method for measuring pressures between 1 atm and 5×10^{-2} mm Hg using sound energy whose frequency is between 500 and 10,000 cps; it is radiated from a loudspeaker and collected by a microphone provided with a voltmeter. The lowest measurable pressure is limited by the sound energy conducted through the walls of the enclosure.

1287

Army Electronic Proving Ground, "Operational Evaluation of Detector Set AN/PSS-2 (XE-2)," Final Rept. No. AEPG-SIG 930-142, Fort Huachuca, Ariz., 27 pp., 1961. AD-253 161.

Tests were conducted to evaluate the technical and operational capabilities of the AN/PSS-2(XE-2) as a device to extend the listening range of an individual sentry. The Detector Set AN/PSS-2(XE-2) consists of 9 microphones, 3 junction blocks, headset, and a vacuum tube audio amplifier. The set is designed to detect moving personnel or vehicles approximately 50 feet from any microphone. Tests indicated that the AN/PSS-2 (XE-2) is capable of increasing the listening range of the individual sentry.

1288

Army Electronic Proving Ground, "Operational Evaluation of Detector Set AN/PSS-2 (XE-2)," Rept. No. AEPG-SIG 930-150, Fort Huachuca, Ariz., 18 pp., 1960. AD-248 583.

Tests were planned to determine the capabilities of Detector Set AN/PSS-2 (XE-2) for increasing the listening range of individual sentries. The AN/PSS-2 (XE-2) consists of nine microphones, three junction blocks, one headset, and a vacuum tube audio amplifier. Each microphone is equipped with a rain shield and a detachable steel ground stake. The set was designed to detect moving personnel or vehicles about 50 ft from any microphone; the manufacturer specified that a maximum of 3000 ft of field wire can be used effectively between junction and amplifier, thus enabling a sentry to "listen-in" at this range. The sentry, using a headset, can monitor all three groups or any one group of the microphones.

1289

Baruch, J. J., "Research in the Field of Acoustical Instrumentation," Final Rept. MITO-ORI-07869, Mass. Inst. of Tech., Cambridge, 1958.
AD-213 648.

Reports study and investigation of several methods and techniques of instrumentation usage, including those of the function recorder, application of correlation techniques, analog simulation, magneto-plastic transduction, and transverse vibration instrumentation.

1290

Bianchi, R. A., R. T. Bradshaw, et al., "Survey and Evaluation of Sonic Fatigue Testing Facilities," Rept. No. ASD TR 61-185, CONESCO, Arlington, Mass., 364 pp., 1962.
AD-277 124.

An evaluation of the sonic-fatigue-testing facilities throughout the country was made to establish present methods and techniques of testing and to determine the necessity of performing other environmental tests in combination with high intensity noise. A general conclusion is that the most economical procedure for developing sonic-fatigue-resistant structures consists of: (a) designing panels with discrete frequency siren methods, (b) performing semi-qualification tests with broad band sources such as broad band sirens or modulated air flow speakers (not jet engines), and (c) performing a full-scale proof test. The effects of temperature and pressure (and perhaps corrosion) can only be assessed by combined tests. Combined tests for nuclear radiation should not be considered in the foreseeable future. In many instances the effects of correlation can be approximated in a discrete frequency siren test by orienting a specimen in a manner determined by considering the sound level contours existing on the aircraft.

1291

Bolt, Beranek, and Newman, Inc., "Capabilities and Limitations Investigation of Long-Range Public Address Equipment, Construction of Instrumentation Facility," Final Rept. on Phase III, 1956.
AD-125 835.

This report discusses in detail the construction and operation of a transportable instrumentation facility, housed in a standard Army V-51, 26-ft van powered by a standard Army PE-95, 10-kw power unit and a standard Army 2-1/2 ton tractor. It was designed to support a program of gathering fundamental data for study of the transmission of speech over long distances over ground.

Chapter 1 reviews some of the basic considerations and other factors governing the design of the facility. Chapter 2 discusses the complete data-taking facility in more detail. Chapters 3 through 12 describe in detail the various components, such as the Sound Radiating System, the Sound Receiving System, the Temperature and Wind Speed Gradient Measuring Systems, the Thermistor, Vane, and Cup Anemometer Turbulence Measuring Equipment, the 24-Hour-Per-Day Meteorological Equipment, Power Supplies, and Miscellaneous Facilities. Suggested operating procedures for the different systems are given in Chapter 13. Chapter 14 gives technical data such as wiring diagrams, schematics, and maintenance instructions. The techniques used in calibrating the different transducers, such as loudspeakers, microphones and windscreens, weather vanes, and thermistor and cup anemometers are discussed in Appendix A.

1292

Burwen, R. S., "1 Kilowatt Transistor Audio Amplifier," J. Audio Eng. Soc., 11, 34-40, 1963.

A one-kilowatt audio amplifier with 64 germanium power transistors in a Class C, bridge-connected power stage with multiple feedback loops delivers continuous sinewave power.

1293

Cook, J. C., "Further Investigations of Geophysical Mine-Detection Methods," Final Tech. Rept., 31 May 57, Southwest Research Inst, San Antiono, Tex., 1957.
AD-202 546.

Activity under this contract has been devoted to perfecting three mine-detection methods: air-to-ground-coupled acoustic methods, surface-temperature methods including those employing the normal thermal radiation from the ground, and a low-frequency electro-magnetic method sensitive to resistivity variations of the soil. The work has included the discovery of new phenomena, efforts to improve the experimental apparatus, and the collection of basic data concerning the physical effects utilized. A successful acoustic air-to-ground-to-air system was developed. However, the previously developed air-to-ground system is superior and is recommended as a basis for practical mine detectors. Efforts to improve acoustic coupling to the earth have not significantly bettered the techniques already in use. The thermal investigations have demonstrated the existence in sand and loam of clear surface-temperature anomalies over large buried mines in the afternoon, which arise from the diurnal cycle of insolation. These anomalies can be detected with suitable radiometers, but there are serious interfering effects. The electromagnetic resistivity method is very sensitive, successful and promising, except for the "tilt effect" which prevents free manipulation of the search head. Two promising approaches for eliminating the tilt effect have been partially investigated.

1294

Dauphinee, T. M., "Acoustic Pump," Research, 13, 300-303, 1961.

A simply constructed air-circulating pump powered by a loudspeaker is described. The pump has no moving parts other than the speaker cone and can operate at temperatures ranging between room temperature and below that of liquid air, at efficiencies equal to or better than those of conventional blowers.

1295

Dow, W. G., and N. W. Spencer, "Progress Report A2—September, October, November, December, 1949," Eng. Res. Inst., Univ. of Mich., Ann Arbor, 29 pp., 1950.
ATI-75 387.

Instrumentation of Aerobee guided missiles 3 and 4 and flight test of missile No. 3 are described. The missiles were prepared to obtain a definite determination of the differences between ambient pressure and temperature that exist in the upper atmosphere, comparing day and night conditions. Instrumentation construction and calibration are discussed. Conclusions drawn from the flight of missile No. 3 are listed, as well as changes contemplated in instrumentation for the next firing. Possible sensing elements for determining ambient density during flight are considered, including interferometers, deviation of light due to density variations, shadow systems, schlieren systems, absorption of high energy particles as a function of density, and the velocity of sound.

1296

Fiala, W. T., and J. K. Hilliard, "High-Intensity Sound Reverberation Chamber and Loudspeaker Noise Generator, J. Acoust. Soc. Am., 31, 269-272, 1959.

A high-intensity sound test chamber capable of producing 145 db and having a working area of 6 × 3 × 1 1/2 ft is described. The chamber uses the principle of reverberant sound to test electronic packages used in aircraft and missiles. Double wall construction and use of Aquaplas for panel damping provides the necessary sound insulation. Complete instrumentation and the loudspeaker generator will be described.

1297

Goff, K. W., and D. M. A. Mercer, "Probe Microphone Analysis and Testing at High Temperatures and High Intensities," J. Acoust. Soc. Am., 27, 1133-1141, 1955.

A probe microphone has been developed suitable for measuring sound fields within such structures as altitude wind tunnels and jet engine test cells. This paper describes the methods of testing and analyzing the instrument. The microphone consists of a 3/8-inch inside diameter probe tube with a porous metal tip, a condenser microphone, and a spiral resistive termination. It operates at sound-pressure levels up to 170 db with 2% distortion, at ambient pressures down to 0.2 atmosphere, and with probe tip temperatures up to 900°F. The normal incidence response is flat within ±3 db from 10 to 10,000 cps.

An electrical analog of the acoustical system is given as a basis for explaining and predicting the performance of the microphone under varying ambient conditions. It appears that the microphone can be used satisfactorily as a cavity terminated probe microphone for frequencies below the frequency at which the spiral termination ceases to be "anechoic." The required length of the spiral termination is then determined by the probe-tube length rather than the lowest frequency of interest.

Testing methods and apparatus are discussed, including a high-temperature flow resistant apparatus, a low-pressure test chamber, and a resonant tube device for developing sound pressures up to 175 db with low distortion.

1298

Hoeft, L. O., "The Development of a Mobile Acoustics Laboratory," WADC Tech. Rept. No. 56-656, Aero Medical Lab., Wright Air Development Center, Wright-Patterson AFB, Ohio, 25 pp., 1956.
AD-110 670.

The mobile acoustics laboratory built and used by the Bio-Acoustics Branch is described. This laboratory consists of a six-ton semi-trailer equipped with a 15 kilowatt motor generator, relay racks for equipment, and a work bench. It features a custom-built console, UHF radio, air conditioning, heating, and an observation dome to provide an unobstructed view of the surrounding area. The mobile laboratory is completely self-contained and can be moved without dismantling. Storage space is provided for spare parts and non-rack-mountable equipment. Due to the fairly heavy construction and judicious placing of vents, the trailer may be used in moderately high sound fields without difficulty. Although the laboratory was designed primarily to document the sound fields of jet aircraft, it is flexible enough to be used in just about any acoustical measurement problem.

1299

Jones, J. I. P., "The Measurement of Turbulence near the Ground," Porton Tech. Paper No. 786, Chemical Defence Experimental Establishment, Great Britain, 1961.
AD-265 939.

An instrument for measuring vertical and horizontal (lateral) gustiness over frequencies up to 70 cycles is described. Its output voltage is proportional to the angle of the wind over a range of 1-1/2 radians vertically and 6 radians horizontally. This voltage is passed to bandpass filter circuits which automatically provide the major part of the power spectrum of vertical gustiness, and of horizontal gustiness above a frequency of 3.6 cycles per hour. A squaring multiplying circuit is also described and is used to test the method of power measurement. Form factors for turbulence under widely varying conditions are found to be remarkably consistent and indicate a frequency distribution with more peaks than are normal. Use of the equipment in the field is described, and examples of vertical and horizonal spectra at 16 meters are presented.

1300

Lawson, A. W., P. H. Miller, Jr., and L. I. Schiff, "A Device for Plotting Rays in a Stratified Medium," Rev. Sci. Instr., 18, 117-120, 1947.

A device is described which was developed for the rapid computation of rays in a medium in which the index of refraction or speed is a function of only one rectangular coordinate. It was used during the war for the computation of sound fields in water, in the ray-approximation solution to the problem of radar-signal propagation in a stratified atmosphere, since it is possible to transform the curvature of the earth into an additional refractive index that depends only on the height above a plane earth.

1301

Maestrello, L., "UTIA Air Duct Facility for Investigation of Vibration Noise Induced by Turbulent Flow Past a Panel (Boundary-Layer Noise)," UTIA Tech. Note No. 20, Inst. of Aerophysics, Univ. of Toronto, Canada, 20 pp., 1958.
AD-154 263.

An acoustically quieted air-duct facility has been constructed for the purpose of investigating noise generated by turbulent flow past a flexible panel ('boundary layer noise'). The facility is basically an open-circuit wind-tunnel with interchangeable 33-ft rectangular duct sections 12 in. wide and 1 in., 2 in., 4 in., or 8 in. deep. The downstream end of the duct, where fully developed channel flow is obtained, contains the test panel, fitted flush in one wall. Maximum speed (4 in. duct) with the 10 hp blower is 200 fps. Details of design and aerodynamic performance—e.g., velocity profiles and pressure gradient—are given.

1302

Marcley, R. G., "Apparatus Drawings Project, Report Number 27, Apparatus for Investigating the Properties of Sound Waves," Am. J. Phys., 30, 372-379, 1962.

For introduction to this series of reports see Amer. J. Phys., 28, 33, 1960. The apparatus described was developed for undergraduate investigation of some of the properties of waves, such as wavelength, phase, interference, and diffraction, using acoustic waves as the medium of instruction. Thin plates, pierced by various apertures, are irradiated by a beam of essentially plane acoustic waves, at about 15 kcs, obtained from an inexpensive horn-type "hi-fi" tweeter mounted in an enclosure with absorbent interior walls. The radiated energy is examined with a boom-mounted crystal hearing-aid earphone used as a microphone that feeds a tuned preamplifier and cathode-ray oscilloscope. Utilizing undamped resonances, above the normal operating range of the transducers, insures high sensitivity at a trivial cost, while simple phase-measuring techniques further improve resolution and sensitivity. Developed for a 950-student freshman laboratory, five setups of the apparatus can be operated in a room, with completely negligible interaction, and constructed at a low cost for both components and labour. Information on construction is given.

1303

Molella, R. J., "Description and Capability of Environmental Test Facilities at the Aeronautical Structures Laboratory," Rept. No. NAMC-ASL-1042, Aeronautical Structures Lab., Naval Air Material Center, Philadelphia, Pa., 38 pp., 1962.
AD-285 168.

The Aeronautical Structures Laboratory (ASL) has environmental test facilities that can simulate the structural effects of temperature, structural loading, vibration, and acoustic noise. The ASL can simulate these environments simultaneously except for acoustic noise, the facility for which is a separate field site. The power available for heating tests is 4000 kva continuous and 8,000 kva for three minutes. This power is capable of heating areas from 25 to 1000 square feet for respective heating rates of 200 to 5 Btu/sq ft-sec. Automatic control of this power for heating tests is accomplished by 64 channels of control equipment. Other equipment that can be automatically controlled includes a resonance-follower vibration system and a portable temperature chamber, which is capable of steady-state temperatures up to 1200°F and which can be used with either the 5-million-pound or 0.6-million-pound testing machine. The acoustic-noise facility is a field site with a single jet engine and associated acoustic accessories.

1304

Nelson, W. L., and C. M. Alaia, "Aerodynamic Noise and Drag Measurements on a High-Speed Magnetically Suspended Rotor," WADC Tech. Rept. No. 57-339, Acoust. Lab., Columbia Univ., New York, 52 pp., 1958.
AD-142 153.

Measurements were made of the drag torque, temperature rise, and aerodynamic noise produced at the surface of a high-speed, magnetically suspended cylindrical rotor as a function of the surface velocity at normal atmospheric pressure. The primary objective was the measurement of aerodynamic noise. Apparatus and instrumentation were developed for controlled measurement, within the laboratory, of the noise, drag and thermal effects encountered in high-speed atmospheric flight. Results of the study indicated this apparatus, with modifications, can be developed as a fruitful method for the study of boundary layer phenomena. For the measurement of aerodynamic noise, the apparatus should be improved by increases in rotor speed and by enlarging the enclosure to permit acoustic treatment for free-field conditions. In the measurement of drag, the essential frictionless support provided by the magnetic support system would yield accurate drag data, with variations of atmospheric conditions and surface treatment.

1305

Schilling, H. K., and W. Whitson, "Study of Interference Through Acoustics," Am. Phys. Teacher, 4, 27-31, 1936.

The usual approach to the study of interference, in elementary courses, is mainly by way of optics, a procedure that has certain serious drawbacks; to the beginner, it might seem less natural and interesting than the approach through acoustics. This paper describes simple acoustical apparatus for laboratory and demonstration, and the following fundamental experiments on interference of sound waves: double slit; thin films; standing waves; Lloyd's mirror; Fresnel's mirror; effect of plane reflector near point source.

1306

Shattuck, R. D., "Capacitance-Type Displacement Probe," J. Acoust. Soc. Am., 31, 1297-1299, 1959.

Describes a noncontacting displacement probe which is linear throughout the audio-frequency range over a wide displacement-amplitude range. The instrument employs commercially available condenser microphone circuitry to measure the displacement of any conducting surface. Entirely conventional audio-instrumentation may be employed to analyze test data obtained with the probe. A typical output voltage with the gauge located 0.1 in. from the vibrating member is 25 mv for a 0.001-in. displacement amplitude. A simple accessory is described for checking the instrumentation sensitivity.

1307

Wescott, J. W., "Automobile Rear Axle Noise Meter," Rept. No. 2438-1-F, Eng. Res. Inst., Univ. of Mich., 15 pp., 1958.

A portable electroacoustic instrument was developed which compares automobile rear axle noise to automobile background noise, thereby simulating certain human judgment processes. The equipment operates from the front seat of an automobile, where it samples the acoustic environment of a driver or passenger.

Input data obtained with a microphone are processed electronically to drive a large output meter calibrated in axle noise ratings. Human interpretation errors that occur when rating axles by ear are thus avoided.

The instrument is a very sharp-tuning, audio-frequency, superheterodyne receiver with automatic frequency control and automatic gain control. Automatic frequency control continuously adjusts a local oscillator to keep the circuits tuned to axle noise. Automatic gain control establishes wide-band automobile background noise as a dynamic reference against which narrow-band, tone-like axle noise is compared. Calibration of the instrument is described.

Instrumentation, Unclassified
See also—329, 340, 348, 429, 435, 524, 544, 609, 772, 965, 976, 996, 1632, 1657, 1722, 1785, 1863, 1864, 1866, 1868, 1912, 2081, 2181, 2482, 2724, 3245, 3784.

INSTRUMENTATION, VELOCITY MEASURING

1308

Abbey, R. L., and G. E. Barlow, "The Velocity of Sound in Gases," Australian J. Sci. Research, A, 1, 176-189, 1948.

Carefully conducted laboratory measurements of sound speed were made in gases at pressures from one atm. down to 5 mm Hg (air, nitrogen, oxygen, carbon dioxide and methane). Theory, instrumentation, tube correction and results discussed and illustrated by diagrams, charts and tables.

1309

Bender, D., "Ultrasonic Velocity in N_2, NO, and CO Between 20° and 200°C, Measured by a New Method" (in German), Ann. Physik, 38, 199-214, 1940.

The temperature dependence of the velocity of sound at a frequency of 1000 kcs is measured by a modification of the Pierce interferometer in which the piezo-quartz is mounted between two fixed reflectors. The quartz is coupled inductively to the driving oscillator and vibrates at temperatures up to 500°C, but above 200°C the sound intensity is too weak to permit measurements. The results indicate that in N_2, CO, and NO, the region of anomalous dispersion of the sound velocity is shifted with increasing temperature towards higher frequencies.

1310

Bohn, J. L., and F. H. Nadig, "Research in the Physical Properties of the Upper Atmosphere with V-2 Rockets," 15 Progress Repts. and 1 Final Rept., Res. Inst., Temple Univ., Philadelphia, Pa., 1948-1951.

This series of reports is on an investigation of most of the physical properties of the upper atmosphere and, therefore, includes work on sound in air. The absorption and velocity of sound in air at high altitudes and at high-frequencies is determined. Missile-generated noise levels are measured. The effects of increasing altitudes on microphone sensitivity and coupling efficiency are investigated. In almost all scientific areas both theoretical and experimental efforts are conducted and the results are compared. The instrumentation designed and constructed for the experimental phases of the project is described in much detail.

Quarterly Progress Repts #	1	Apr-June '48	ATI-55337
	2	Jul-Sept '48	
	3	Oct-Dec '48	
	4	Jan-Mar '49	
	5	Apr-June '49	ATI-71245
	6	July-Sept '49	ATI-73390
	7	Oct-Dec '49	ATI-77197
	8	Jan-Mar '50	ATI-82087
	9	April-June '50	ATI-95353
	10	July-Sept '50	ATI-103254
	11	Oct-Dec '50	ATI-119091
	12	Jan-Mar '51	ATI-128908
	13	Apr-June '51	ATI-140216
	14	Jul-Sept '51	ATI-140217
	15	Oct-Dec '51	ATI-159798
Final Rept		Apr '48-Feb '52	

1311

Bommel, H., "The Measurement of the Velocity and Absorption of Ultrasonics by an Optical Method," Helv. Phys. Acta, 18, 3-20, 1945.

The measurement of the velocity of ultrasonics in gases becomes more complex as the frequency increases on account of the interaction between source and receiver and other effects. In the optical method described, the Hg 4358Å line is passed through gas subjected to the action of the ultrasonics, and the diffraction pattern brought to a focus on a photographic plate by a concave mirror. The velocity V is obtained from the separation of the diffraction maxima. A range of 951-4755 kc is covered. A method is worked out theoretically whereby the absorption can be obtained from the separation of the diffraction maxima.

1312

Bouchard, J., "On the Determination of the Ratio of Specific Heats of Gases by an Electro-Acoustic Method" (in French), Compt. Rend., 226, 1434-1436, 1948.

A modified electroacoustic method for determining the ratio of specific heats γ from the velocity of sound in a gas is described, resonance in the tube being detected not by ear or microphone but by its reaction on the telephone diaphragm emitting the sound. The impedance of the circuit including the interrupter is a minimum at maximum resonance. A cathode-ray oscillograph gives the waveform and precise frequency and ensures absence of harmonics in determining the half-wavelength. The method is also applicable to free air. Values of γ for air of 1.395 in a 4.5 cm tube and 1.403 in free air were obtained, but the method is of most value in studying variations of γ, by using a closed tube to avoid leakage, determining resonance values for various frequencies, and comparing them with values for a known gas.

1313

Brooks, J. N., "Dri Blast Recording Equipment," Phase Rept. No. 5, Denver Res. Inst., 43 pp., 1957.
AD-132 892.

Impulse is measured by a directly coupled amplifier with a useful response from 0 to 80 kc; for calibration, a known charge on each record is recorded just prior to the shot. Eight to ten impulse measurements are made for each shot. The amplifier output is fed to a CRT and recorded on a drum camera. Impulse is calculated by (1) the use of the gage constant and (2) the dynamic calibration of the gages for each round, by means of the peak-pressure measurement. The amplifier requirements for measuring peak pressures involve measuring the arrival time of the pressure wave; two caps are fired at opposite ends of a string of gages, and the sonic velocity is measured as corrected for wind velocity. The traces of eight CRT's, arranged in banks to present a 19-in. field, are recorded on film at recording speeds from 1 to 5 m/sec. A sequence timer is used to time the sequence of events which occur during the recording of the blast parameters; the timer consists of ten relays with variable time-delay circuits coupled to each other. The sweep circuit is a saw-tooth generator, the voltage of which is applied to the vertical deflection plates of the CRT's so that visual observation is made prior to the shot without burning the scope faces with the bright spot. Intensity and focus adjustments are included in two indicator units, one with eight and one with four 3SP11's. The calibration unit supplies voltage in a sequence of five 0.1-v steps up to 0.5 v. The time base is derived from a 100-c Hewlett-Packard signal generator which supplies a 1000-c sine wave to a pulse shaper. The pulse shaper produces a short pulse which fires a crater tube that is mounted on the indicator unit.

1314

Colwell, R. C., A. W. Friend, and D. A. McGraw, "Velocity of Sound," J. Franklin Inst., 251-255, 1939.

The original apparatus has been improved by the use of two microphones connected in parallel, and it is possible to adjust the pulses so that both peaks on the oscillograph screen appear on the same reference line. Determinations were made over a range from 2.5°C to 29.6°C. An alternative method has also been devised by which accurate measurements are possible over shorter distances. The sound sources employed were an electrically driven tuning fork and a calibrated audio-oscillator. Wavelengths were measured at frequencies 440, 880, 1000, 1320, and 1760. The velocity at 0°C was 331.12 m/sec, and the change of velocity with temperatuer 0.60 m/sec/°C.

1315

Colwell, R. C., A. W. Friend, and D. A. McGraw, "Velocity of Sound in Air," J. Franklin Inst., 225, 579-583, 1938.

A laboratory method. A valve and loudspeaker are worked off mains at 110 v and 60 cps so that each second, 60 short impulses are given to the loudspeaker. The sound impulses are picked up by a microphone, converted, amplified and then observed in a cathode-ray oscilloscope. The position of the microphone near the loudspeaker is adjusted so that the peak pulse falls on a vertical line at the center of the screen, and the position is marked. The microphone is now moved away about 18 feet and again adjusted. The displacement of the microphone is the distance the sound traveled in 1/60 sec. Measurements were made as a test of the method, and the average of 100 measurements, reduced to 0°C was 331.54 m/sec. The walls of the room need to be covered with absorbing material to avoid echo effects.

1316

Colwell, R. C., A.W. Friend, and L. H. Gibson, "Velocity of Sound," J. Franklin Inst., 230, 749-754, 1940.

A new method for measuring the velocity of sound over short distances has been devised in which 60 pulses per second cause a sinusoidal curve to appear upon an oscilloscopic screen. As the receiving microphone is moved away from the sound oscillator, the crest of the sine curve moves across the oscilloscope, completing the circle in 1/60 sec. The actual velocity of the sound is easily calculated after the distance moved by the microphone has been measured. Application of the probability laws and of the error curve show that the method is very accurate, providing the frequency of the a-c supply is constant at 60 cps.

1317

Dawes, J. G., "The Acoustic Blastmeter," J. Sci. Instr., 27, 123-127, 1950.

Describes a method for measuring and recording the speed of a rapidly changing blast of air. The method depends on the change in phase of an acoustic signal received at a point, the phase shift being a function of the velocity of the air between the sound transmitter and receiver. Tested in a laboratory gallery with a series of steady air blasts ranging from 25 to 125 fps, the method gave results closely corresponding to the air velocities measured by an independently calibrated orificemeter. It is capable of rapid response and of dealing with a wide range of air speeds. The article proposes use of the method for recording the changing speed of the air blast which precedes the flame of an explosion traveling along a gallery.

1318

Glass, I. I., "On the Speed of Sound in Gases," J. Aeron. Sci., 19, 286-287, 1952.

The speeds of sound in air, A, and CO_2, are determined by measuring head speed of the rarefaction waves in a shock tube. Results agree well with the values obtained from acoustic methods and from isentropic theory. Experimental arrangement and accuracy of method are briefly described.

1319

Gutenberg, B., "The Velocity of Sound-Waves from Gun-Fire in Southern California," Trans. Am. Geophys. Union, 156, 1938.

Description of a sensitive instrument for recording changes in air pressure. Sound waves recorded by this short period Benioff barograph shown.

1320

Hardy, H. C., "Use of the Pierce Interferometer for Measuring the Absorption of Sound in Gases," J. Acoust. Soc. Am., 15, 91-95, 1943.

A rigorous derivation of Pielemeier's empirical equation for the absorption of sound in gases is obtained by making use of the principles of the Pierce ultrasonic interferometer and the quartz oscillator. The Pielemeier method gives a fair approximation when the reaction of the sound wave on the crystal is small; it enables both velocity and absorption to be measured. The limits of precision in its use were tested experimentally and agree with theory.

1321

Hixson, E. L., J. R. Gerhardt, and A. W. Straiton, "A Device for Continuous and Instantaneous Measurement of the Velocity of Sound Over Considerable Distances," Rept. No. 21, Eng. Res. Lab., Texas Univ., 15 pp., 1948.

Describes an instrument developed for measuring sound propagation velocity by introducing impulses created in a speaker and in a microphone into an oscilloscope, and presents schematic drawings. Measurements using a sound pulse frequency of 1000 cps and a repetition rate of 10 cps are reported and their results presented in terms of temperature and wind velocity components.

1322

Hubbard, J. C., "Acoustic Resonator Interferometer, Part II. Ultrasonic Velocity and Absorption in Gases," Phys. Rev., 41, 523-535, 1932.

The derivation of the equivalent electric network of the acoustic resonator interferometer in Part I of this paper has made it possible to develop the theory for the current in a simple resonant circuit in which the electrodes of the piezoelectric plate of the interferometer are connected to the terminals of the variable condenser. The special case of this theory is that in which the circuit is excited at a constant frequency determined by the crevasse frequency of the resonator plate in its given situation with respect to electrodes and associated circuit, when the acoustic path in the interferometer is detuned and the resonant circuit is tuned so that its resonant maximum occurs at the same frequency; the special case takes an especially simple form and leads to a direct procedure for determining ultrasonic velocity and absorption in a gas in terms only of current in the resonant circuit and path-length in the interferometer, all circuit and interferometer constants dropping out. The values of current as a function of pathlength obtained experimentally are in complete accord with the theory, and data for ultrasonic absorption in air and in CO_2 so far obtained agree with the meager data available by other methods. The role of the coefficient of reflection at the fluid-reflector surface is discussed.

1323

Jatkar, S. K. K., "Supersonic Velocity in Gases, Part I," J. Indian Inst. Sci., 21A, 245-271, 1938.

As a preliminary to the measurement of the velocity of supersonic sound in the vapors of organic compounds, a study is made of the aberrations of supersonic interferometers used to determine wavelengths. Includes curves showing how the anode current of the quartz oscillator varies with the position of the reflector, and mapping irregularity of peak positions (corresponding to nodal planes). Investigates causes of these irregularities, and demonstrates that the best results are obtained when a somewhat narrow interferometer tube is used and the quartz is carefully positioned a short distance from the tube; under these conditions the wavelength is said to be obtainable with an accuracy of 1 in 700.

1324

Knight, H. T., and R. E. Duff, "Precision Measurement of Detonation and Strong Shock Velocity in Gases," Rev. Sci. Instr., 26, 257-260, 1955.

Describes a simple system for determining the detonation velocity of strong shock waves, with temperatures above 3000°K, by using the conductivity behind the wave. Wave contact is made by two 0.036-in. wires set 0.1 in. apart in a Teflon plug mounted in the experimental tube. When a wave passes, signals are produced across a 30kΩ resistor in series with these wires, and a 0.001μf capacitor charged to 300 volts. Any number of circuits may be paralleled across a single-signal resistor if a diode is added to each circuit to prevent signal deterioration. The arrival time of a wave at a pin can be determined, with an accuracy of almost 10^{-8} seconds, from an oscilloscope record of the signals. The principal advantages of this system are excellent space resolution and very simple basic circuitry.

An amplifier is described which can be used with an individual pin circuit to fire a thyratron and extend the range of applicability of the system to waves with temperatures as low as 1000°K.

1325

Lenihan, J. M. A., "The Velocity of Sound in Air," Acustica, 2, 205-212, 1952.

Measurements have been made of the velocity of sound in free air at a frequency of 13,500 cps. A small loudspeaker, connected to an oscillator, emitted sound which was received by a microphone, after travelling a distance determined by an accurate screw. The input waveform of the transmitter and the output waveform of the receiver were passed through pulse-shaping circuits and displayed together on the screen of a double-beam oscillograph. Movement of the transmitter, controlled by rotation of the screw, produced relative motion of the two traces on the oscillograph screen and the wavelength of the sound was determined by measuring the distance at which the two trains of pulses coincided on the screen. Corrections were applied for the effects of temperature, humidity and a number of less important factors. The final value for the velocity of sound at a frequency of 13,500 cps in dry air at a temperature of 273.16°K and a pressure of 1013.2 mb was 331.45 ± 0.04 meters per second.

1326

Matta, K., and M. Mokhtar, "The Velocity of Sound in Vapors," J. Acoust. Soc. Am., 16, 120-122, 1944.

A form of Kundt's tube is employed in which a hot wire records the amplitude in the stationary-wave system. It is calibrated by the use of dry air and of oxygen. The results agree with those determined by other methods.

1327

Maxwell, H. N., and C. C. Alway, "A Determination of the Speed of Sound in Air," Am. J. Phys., 18, 192-193, 1950.

Velocity of sound in free space is measured by means of a loudspeaker emitting short sound pulses at 1/60-sec intervals, the distance to a microphone being adjusted so that the received sound pulse coincides accurately with a time-marker pulse on a cathode-ray oscillator. The distance between "speaker" and the microphone is then adjusted until the sound pulse coincides with another time-marker pulse. If m is the number of marker pulses passed over, the velocity is found by merely multiplying the distance by $\frac{60}{m}$. The results agree well with the generally accepted value of sound velocity in the open air.

1328

McLoughlin, R. C., and J. R. Chiles, Jr., "A Field Meter for Sound Velocity Measurements," J. Acoust. Soc. Am., 25, 732-734, 1953.

The travel time of sound across a fixed gap between diaphragms of transmitting and receiving transducers is recorded each 1/5000 second. From this the interdiaphragm velocity is computed. It is a function of both temperature and wind. Spurious travel time changes introduced by phase shifts in the receiver are minimized by using a 500-cps intelligence-signal amplitude modulating a 10-kcs carrier. Experimental errors when operating in air with interdiaphragm distances of three feet are less than two percent in the temperature range from 70° to 200°F, but the application of the instrument is not restricted to this range. A circuit for recording velocity directly on a paper tape is described. Although designed primarily for air, the unit is adaptable to other media. It should also be of special interest to the micrometeorologist.

1329

Parbrook, H. D., and E. G. Richardson, "The Propagation of Ultrasonics in Gases under Pressure" (in French), Portugaliae Phys., 3, 127-138, 1954.

Measurements of ultrasonic velocity in carbonic acid and ethylene have been made using an interference method. The viscosities have also been measured, using the oscillating cylinder method, and the values compared with ultrasonic viscosities calculated according to the Stokes equation. The velocities at various temperatures show sharp minimal turning points in the region of 60-90 atm. (approx.) while the two viscosities become minimal in roughly the same pressure range. From these and other observations the authors conclude that a thermal relaxation process might account for the anomalous behavior. The paper is noteworthy for the extreme care which has been taken in the experimental work; for instance, the quartz crystal and the reflector are lined up by the Michelson interferometer method, and it is evident that the results are of a high order of accuracy.

1330

Partlo, F. L., and J. H. Service, "Instantaneous Speeds in Air of Explosion Reports at Short Distances from the Source," Physics, 6, 1-5, 1935.

In the first series of measurements the source was one No. 6 blasting cap, while in the second series 1 lb of 50% nitroglycerin stick dynamite was used as source. A telephone carbon-button microphone was the receiver and was held fixed in location while shots were fired successively at 5, 8, 12.5, 25, 35, 50, 100 and 600-meter distances. A two-element string oscillograph was used for timing, one element recording the instant of firing, the other element recording the arrival of the wave at the microphone. The work was done at a time of no perceptible wind; air temperatures were measured carefully; no humidity measurements were made. Travel times could be read reliably to 10^{-4} sec, and distance measurements were at least correspondingly good. Instantaneous speeds were obtained by plotting time computed minus time observed against distance, and measuring slopes of the resulting curve. Since this work was incidental to seismic prospecting, the observations were not quite as numerous as those of von Angerer and Ladenburg. However, the results are similar, showing abnormally high speeds near the source. Also, the use of instantaneous speeds appears to show abnormally low speeds a little farther from the source, perhaps masked in the work of von Angerer and Ladenburg due to their use of average speeds instead of instantaneous speeds.

1331

Patchett, G. N., "An Application of the Cathode-Ray Oscillograph to the Measurement of the Wavelength of Sound," Proc. Phys. Soc. (London) A, 55, 324-325, 1943.

Reports observation of the phase difference between the input to a loudspeaker and the output of a microphone which can be displaced with respect to the loudspeaker. The displacement necessary to change the phase difference by one cycle gives the wavelength, and the displacement is adjusted with the aid of a cathode-ray oscillograph.

1332

Smith, P. W., Jr., "Precision Measurement of the Velocity of Sound in Air," J. Acoust. Soc. of Am., 25, 81-86, 1953.

Describes a method for the precise measurement of the velocity of sound in which the driving-point impedance of a loudspeaker connected to a closed tube of variable length is the frequency-controlling element of a bridge-stabilized oscillator. The operation of the system and the accuracy of measurement are analyzed. Results of measurements in air at 1 kc room temperature, and atmospheric pressure yield, when corrected to standard conditions, a velocity of 331.45 ± 0.05 meters per second.

1333

Tucker, W. S., "The Determination of Velocity of Sound by the Employment of closed Resonators and the Hot-Wire Microphone," Phil. Mag., 34, 217-235, 1943.

A resonator consisting of two cavities connected by a narrow neck is employed. Sound is introduced by a telephone diaphragm forming the boundary of one enclosure, and temperature and response of the resonator to sound are indicated by the change in electrical resistance of a hot wire in the neck of the resonator. Frequency-response curves are obtained from which the true resonance-frequency maximum is obtained. Theoretical support is given to the existence of a linear relationship between velocity and resonance frequency for different gases. Determinations of velocity of sound for air saturated with water vapor were made and data obtained for calculation of γ. From this the velocity of sound in water vapor at 0^oC was deduced. Results were also obtained for the velocity of sound in ether and acetone vapors by a similar process.

1334

van Itterbeek, A., "Velocity of Sound at Low Temperatures," Rev. Acoust., 2, 81-97, 1933.

A detailed description of the experimental methods employed by W. H. Keesom and the author for the determination of the velocity of sound in He, H_2 and O_2 at low temperatures. Temperatures were measured by a platinum thermometer and the frequency of the source was determined by registering on a rotating drum the vibrations of an Einthoven galvanometer, placed in the oscillator circuit, beside those of a tuning fork. For experiments at the boiling point of oxygen a modification of Quincke's method was employed, in which the length of tube is altered until resonance is obtained. While the apparatus was being cooled with liquid hydrogen a spontaneous emission of sound took place, necessitating, for mechanical reasons, the employment at lower temperatures of a resonator of constant length and of a source whose frequency was varied until resonance resulted (Thiessen's method). The modification of the apparatus necessary to determine the theoretically important variation of velocity with pressure is described and the paper concludes with a note on the resonator wall and end corrections.

1335

Walsh, J. R., G. J. Day, et al., "Description of the Instrumentation and Procedures for the Velocity of Sound (Grenade) Experiment," Eng. Rept. E-1140, Evans Signal Lab., Signal Corps Eng. Labs., Belmar, N. J., 1954.
AD-46 513.

Describes the technique of firing grenades from Aerobee rockets and determining the velocity and the angle at which sound propagating from the grenades arrives at acoustic detectors on the ground. Sound ranging equipment was employed for the system of detectors and the location of grenade explosions was determined by photographing the flashes with fixed plate cameras. Describes and evaluates performance of all equipment used in the experiment.

Instrumentation, Velocity Measuring
See also—39, 144, 194, 282, 305, 316, 327, 570, 794, 853, 862, 1045, 1071, 1112, 1134, 1135, 1138, 1143, 1146, 1189, 1215, 1221, 1278, 1295, 1830, 1851, 2124, 2622, 2978, 3024, 3056, 3058, 3132, 3133, 3173.

KEYS, SIGNATURES, SPECTRA, WAVEFORMS, ETC.

1336

Belliveau, L. J., and C. L. Karmel, "Characteristics of Shock Waves from Pentolite Spheres at High Altitudes by Sachs Scaling," Rept. No. 5696, Naval Ordnance Lab., White Oak, Md., 39 pp., 1957.
AD-151 401.

Sachs scaling is used to approximate the shock-wave characteristics from bare 50/50 spherical pentolite charges at the following burst altitudes: 10, 20, 30, 40, 50, 75, 100, and 150 kilofeet. The explosive weights used in compiling the original data at sea level ranged from one-half pound to eight pounds, and the scaled distance from 1.48 to 14.81 ft per $\sqrt[3]{\text{lb}}$. The following characteristics are scaled: peak face-on and peak side-on pressures, face-on and side-on impulses, positive duration, time of arrival, peak face-on minus peak side-on pressure, and the peak dynamic pressure ($1/2\, \rho u^2$). The results are presented as a series of plots for each quantity versus reduced distance, and tables of each quantity at arbitrary distances. Some cross plots are included for illustrative purposes.

1337

Bolt, Beranek, and Newman, Inc., "Characteristics of Noise Produced by Several Contemporary Army Weapons," Rept. No. 630, Cambridge, Mass., 31 pp., 1959.
AD-212 420.

Measurements were made of the noises associated with the firing of an M-1 rifle, 30- and 50-cal. machine guns, a 76-mm gun, a 90-mm gun and a 105-mm howitzer. The noises are described in terms of the maximum instantaneous peak value, the duration, the rise time, and the frequency spectrum. The distributions of these parameters in and around the several weapons are also reported. Recommendations are made concerning efficient data recording techniques.

1338

Bolt, Beranek, and Newman, Inc., "Free-Field Noise Measurements on Carrier-Based Jet Aircraft NATO, Patuxent River, Maryland," Rept. No. 282, 74 pp., 1955.
AD-78 060.

Free-field noise measurements were made on an AJ-2, an F2H-3, an F9F-6, and an F7U-1 for several engine operating conditions. Data obtained are presented in the form of directivity patterns, frequency spectra plots, and tabulated values of acoustic power.

The frequency spectrum of jet noise varies with angle and operating condition. The angular dependence of the frequency spectra can be reduced to a consideration of two angular areas, the regions between 0^o and 120^o and between 130^o and 150^o. For each of the aircraft, the frequency spectrum in each of the angular ranges is relatively constant as a function of angle, and the typical spectrum shape in each range differs from that in the other. The spectrum shape is relatively constant in relation to frequency in the region between 130^o and 150^o, and most of the peak sound-pressure levels occur in this region.

A design procedure for estimating the noise field characteristics of carrier-based planes was developed. The procedure is based primarily on data from planes without afterburners (AJ-2, F9F-6, and the F2H-3). By means of the procedure, it is possible to estimate the acoustic power level, the frequency spectra, and the directivity pattern of the noise field from a knowledge of the jet-engine operating conditions.

1339

Bonvallet, G. L., "Levels and Spectra of Traffic, Industrial, and Residential Area Noise," J. Acoust. Soc. Am., 23, 435-439, 1951.

A survey of city noise in the Chicago area was initiated in 1947. This report describes traffic, industrial, and residential area noise which was investigated as a part of the work. Levels of traffic noise were 35 to 45 db, 45 db to 65 db, and 65 to 75 db in the 400-800-cps band for light, average, and heavy traffic conditions, respectively. Industrial noise ranged from 50 to 60 db in the same band for fifty percent of the cases measured. Ninety percent were below 65 db. A limiting spectrum for noise which is considered not objectionable is presented. Residential area noise ranged from 38 to 47 db in the mentioned band for fifty percent of the cases measured. At night and for winter conditions, traffic noise was 10 db lower in the mentioned band than in the daytime. At night, industrial area noise dropped to levels of existing traffic conditions, and in winter it was lower by about 5 db in octave bands mainly because factory windows were closed. At night, residential area noise was 5 to 10 db less in octave bands than during the day, and for winter conditions there was a drop of 6 to 8 db in octave bands due to the modified character of distant traffic.

1340

Bonvallet, G. L., "Levels and Spectra of Transportation Vehicle Noise," J. Acoust. Soc. Am., 22, 201-205, 1950.

In the recent past a program was initiated to survey vehicle, traffic, and industrial noise in the Chicago area. The phase on noise of vehicles has been completed. The investigation included street, elevated, and subway cars; diesel, steam, and electric trains; and motor buses, trucks, and automobiles.

Measurements were made of over-all and octave band levels. Inside the vehicle, flat network over-all levels ranged from 85 db in a new "L" car to 95 db in subway cars. The readings in the 400-800 cps band ranged from 68 db for automobiles to 91 db in subway cars. Outside and close to vehicles, the flat network cps band ranged from 66 db for automobiles to 87 db for subway trains. Variations in the over-all levels inside of vehicles ranged from ±2 to ±5 db. Outside the vehicles, variations ranged from ±2 to ±6 db in both the over-all and 400-800 cps band levels.

1341

Callaway, D. B., "Spectra and Loudness of Modern Automobile Horns," J. Acoust. Soc. Am., 23, 55-58, 1951.

As one phase of a noise survey of the Chicago area, measurements were made of the acoustic output of commonly used automobile horns. Over-all sound levels on the axis at three feet ranged from 108 to 125 db. Loudness levels ranged from 125 to 140 phons. Fundamental frequencies of all horns ranged between 160 and 380 cps. Two types had approximately harmonic overtones, with large amplitudes below about 2000 cps and smoothly decreasing amplitudes at higher frequencies. A third type, with the most unpleasant sound, had inharmonic overtones, groups of which were greater in amplitude than the fundamental. Sound from a pair of horns at various distances were measured both inside and outside a closed automobile. The over-all level outside was 88 db at 50 feet and 74 db at 300 feet, with corresponding loudness levels of 105 and 82 phons. The over-all level inside was 60 db (loudness level, 72 phons) at 50 feet and 50 db (loudness level, 54 phons) at 300 feet. Filtering out overtones above 1200 cps improved the quality of horn sounds markedly, reducing the loudness level inside the automobile by four phons at 50 feet, but only one phon at 300 feet. Since the typical horn is louder than necessary at close range, use of a low pass acoustic filter on automobile horns appears desirable.

1342

Clark, W. E., A. C. Pietrasanta, and W. J. Galloway, "Noise Produced by Aircraft During Ground Run-up Operations," Bolt, Beranek and Newman, Cambridge, Mass., 142 pp., 1957.
AD-130 763.

Measurements of the noise field around six turbojet aircraft (T33-A, F89-D, F84-G, B-57, F84-F and F86-D) and one propeller aircraft (C-124) during ground run-up operations are reported. Sound pressure levels in octave bands of frequency have been obtained for different operating conditions of the aircraft engines, at distances ranging from 100 to 1600 ft. These data are analyzed and the results reported in terms of acoustic power level, directivity, and noise spectra. An empirical procedure is described for making engineering estimates of the characteristics of the noise field produced during ground run-up operations of jet aircraft.

1343

Cole, J. N., and C. E. Thomas, "Far Field Noise and Vibration Levels Produced During the Saturn SA-1 Launch," Preliminary Rept. No. ASD TR 61-607, Aerospace Medical Div., Wright Air Development Div., Wright-Patterson Air Force Base, Ohio, 22 pp., 1961.
AD-273 666.

Acoustic measurements were made of the sound pressure level-time functions which were produced at six locations on Cape Canaveral Missile Test Annex and at four locations in the surrounding communities during the Saturn SA-1 launch on 27 October 1961. The frequency range of measured data was from the 4.7-to-9.4-cps octave band to the 4800-to-9600-cps octave band. Distances from the launch site to the noise vibration data were measured in three locations at the Tel-2 telemetry site. The frequency range of measured data was from the 4.5-to-9-cps octave band to the 1125-to-2250-cps octave band. The distance from the launch site was 5200 feet. Only the basic sound pressure level-time environments and vibration level-time environments as a function of frequency octave bands are presented in this report.

1344

Cole, J. N., H. E. von Gierke, et al., "Noise Radiation from Fourteen Types of Rockets in the 1000 to 130,000 Pounds Thrust Range," WADC Tech. Rept. No. 57-354, Aero Medical Lab., Wright Air Development Center, Wright-Patterson AFB, Ohio, 64 pp., 1957.
AD-130 794.

Detailed noise characteristics were measured on fourteen types of rockets, with both solid and liquid propellants, in the thrust range from 1000 to 130,000 lb. Near-field and far-field levels on static-fired and vertical-launched rockets were measured under essentially free-field conditions. Measurements and data reduction methods are described. Final results are given as near-field sound pressure spectra, far-field directivities, acoustic power spectra and pressure-time histories. This noise environment is studied as a function of several nozzle configurations and as a function of flame front action in the jet stream. Generalization and correlation of the data result in a formula for the overall acoustic power level output of rockets, OA PWL 78 + 13.5 $\log_{10} W_m$ db re 10^{-13} watts, where W_m is the rocket jet stream mechanical power in watts. Also given is an approximate generalized power spectrum dependent upon nozzle diameter and jet flow characteristics. These correlations result in procedures for predicting far field noise environments produced by static-fired or launched rockets.

1345

DuMond, J. W. M., E. R. Cohen, W. K. H. Panofsky, and E. Deeds, "A Determination of the Wave Forms and Laws of Propagation and Dissipation of Ballistic Shock Waves," J. Acoust. Soc. Am., 18, 97-118, 1946.

Experiments to ascertain the waveforms and laws of propagation and dissipation of ballistic shock waves to large distances (80 yds) from the bullet trajectory are described. Calibres 0.30 and 0.50 in., 20 and 40 mm were studied. In every case an N-shaped wave profile was observed consisting of a sudden rise in pressure ("head discontinuity") followed by an approximately linear decline to a pressure about equally far below atmospheric, and then a second sudden return ("tail discontinuity") to atmospheric pressure. The peak amplitudes of this disturbance are found to diminish about as the inverse 3/4 power of the miss-distance (perpendicular distance from the trajectory) while the period T' (measured between the discontinuous fronts) increases about as the 1/4 power of the miss-distance for calibres 0.30, 0.50, and 20 mm. For 40 mm shells the amplitude decays about as the inverse 0.9 power of miss-distance over the range studied.

A theory taking account of the dissipation of the N-wave energy into heat is developed to explain the observed behavior. A method of measuring absolute N-wave amplitudes by observing the rate of change of period T' with propagation is described. The theory posits that among distance, amplitude, and period at large distances from the bullet trajectory there is an absolute relationship in which no arbitrary constants appear.

1346

Furrer, W., "Acoustics of Detonations and Gunblast" (in German), Schweiz. Arch. Angew. Wis. Tech., 12, 213-219, 1946.

The characteristics of such explosions are discussed and it is shown that the impulse can be calculated from the weight of explosive used. Experimental curves are shown indicating the variation in maximum pressure with distance and with weight of charge. The variation of wave velocity with distance from the muzzle is shown graphically. Very close to the muzzle the velocity is as high as 2000 meters per second, falling rapidly to 340 meters per second at a distance of one meter. Reference is made to the energy in the explosion wave and to the frequency spectrum of explosions. The oscillographic recording apparatus is described.

1347

Griffin, D. R., "Measurements of the Ultrasonic Cries of Bats," J. Acoust. Soc. Am., 22, 247-255, 1950.

The ultrasonic sounds emitted by bats have been analyzed with a system sensitive to frequencies from 1 to 150 kc. These sounds, used by the bats to detect obstacles by means of their echoes, consist of pulses about two msec long. Most of the measurements were made with the common little brown bat, Myotis 1. lucifugus; with this species the sound pressure at 40 to 55 kc, measured 5 to 10 cm from the animal's mouth, averaged 60 dynes/cm^2 (109 db on the conventional scale of sound pressure levels). The highest recorded intensity was 173 dynes/cm^2 (119 db). The frequency of the ultrasonic sound falls during each pulse by about one octave; the average frequency at the peak amplitude was 47.8 kc, while the average at the beginning of the pulse was 77.9 kc, and at the end 39.1 kc. Low frequency waves (about 10 kc) accompany the pulse, but their amplitude is a very small fraction (1/100 to 1/1000 or less) of the peak sound pressure at ultrasonic frequencies. The envelope form is variable; the emission is directional with most of the energy concentrated into the forward direction; and the pulses are commonly repeated at rates of 20 to 30 per second.

1348

Griffin, D. R., and H. Hartridge, "Supersonic Cries of Bats," Nature, 158, 46-48, 135, 1946.

Oscillograph studies have revealed no sign of any low-frequency component, audible to humans, in the bat's cry, so that the audible sounds mentioned by Hartridge are most likely transient components caused by the impulsive nature of the cry, which was found to be only 1-2 msec in duration, with a relatively rapid cut-off. There usually is a fall of frequency of nearly an octave during the pulse. Evidence is presented to show that the cry is not emitted through the nostrils, but that the nasal cavity may play a part in determining the envelope shape of the cry.

Hartridge raises several criticisms to Griffin's interpretations.

1349

Hart, J. C., "Ambient Acoustic Noise at High Altitudes," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 195-212, 1961.
AD-408 716.

Half-octave-band spectra of high-altitude ambient acoustic noise as sampled from more than 60 balloon flights at high altitude have been examined to empirically determine the dependence of both (1) the relative frequency content of the ambient noise and (2) the overall ambient noise level upon (a) the presence of local meteorological disturbances such as thunderstorms, (b) the sound velocity profile with respect to altitude, and (c) the wind structure as a function of altitude.

Man-made acoustics signals, such as those from aircraft, have intentionally been excluded from this study in so far as these signals are strong enough to be identified. The data are believed to be meaningful between 0.1 and about eight cycles per second. Overall levels have been observed within this frequency band as low as approximately 43 db re .0002 d/cm^2 (0.03 d/cm^2); levels in the 0.25-to-8.0-cps band have been observed as low as 35 db (0.01 d/cm^2).

This work was begun with the support of Melpar, Incorporated, Applied Science Division, and completed with the support of Bay State Electronics Corporation.

1350

Hartridge, H., "Acoustic Control in the Flight of Bats," Nature, 156, 490-494, 1945.

Bats undoubtedly emit sounds of more than one frequency, and it is stated that four different kinds of sound are produced: (1) a buzz, observable only at close quarters; (2) the signaling tone of about 7000 cps, usually having a duration of about 1/4 sec; (3) the supersonic tone, which is usually in the range 40-50 kcs — This sound can be emitted at rest and in flight; it may be emitted in single pulses of about 0.01 sec, or in a number of such pulses; at rest the number may be 5-10 per sec, but in flight it increases to 20-30 per sec — (4) a click. Physical characteristics connected with the production of these sounds and with the hearing of bats are discussed, and a brief comparison is made with radar. In the latter the wavelength goes down to 1 cm and in the bat it is about 0.7 cm. The bat has the further advantage of stereophonic reception to aid in the location of obstacles.

1351

Hoover, R. M., and L. N. Miller, "Noise Characteristics of Some Jet Ground Operations," Noise Control, 5, 28, 1959.

Presents results of noise measurements of various ground operations of two-engine Caravelle and four-engine, suppressed, Comet 4 jet airliners. Data include directional characteristics and spectra for static operation at idle, taxi, climb-out, and take-off powers and spectra at side of runway during take-off.

1352

Howes, F. S., and R. R. Real, "Noise Origin, Power, and Spectra of Ducted Centrifugal Fans," J. Acoust. Soc. Am., 30, 714-720, 1958.

Forward and backward curved blade centrifugal fans as noise sources were subjected to an extensive study, measurements being made in a duct with an acoustic termination. The data obtained support the following conclusions:
(1) The noise output from each homologous series of fans can be defined by one V-shaped specific noise power vs log-speed curve, with the minimum close to the maximum static efficiency.
(2) Fan outlet noise power at maximum fan efficiency approximates 10^{-5} times the input fan power.
(3) The noise origin is primarily blade- and air-flow boundary turbulence.

1353

Hubbard, H. H., and D. J. Maglieri, "Noise Characteristics of Helicopter Rotors at Tip Speeds Up to 900 Feet Per Second," J. Acoust. Soc. Am., 32, 1105-1107, 1960.

Evidence is presented which suggests that the noise of full-scale helicopter rotors results mainly from conditions of unsteady flow. Measurements of the sound-pressure levels and spectra are presented for test conditions where gear train, engine, and other propulsion system noises are minimized. These data cover a range of tip speeds from 100 ft/sec to 900 ft/sec for various rotor disk loadings. Results indicate that both tip speed and disk loading have an important influence on the noise radiated from the rotor. During stall, the sound pressure levels increased at all frequencies, but particularly at the high end of the spectrum. As a matter of special interest, a highly-peaked wave form due to possible Doppler effects was noted to be associated with high-tip speed operation.

1354

Hull, G. F., Jr., R. T. Jenkins, et al., "Analysis and Oscillograms of Sounds from Field Artillery and Machine Guns," Rept. No. 4594, National Defense Research Committee, Office of Scientific Research & Development, Vol. 1, 180 pp., Vol. 2, 93 pp., 1945.
ATI-14972.

Volume one describes the equipment, methods of measurement, analysis procedures and spectrum analyses for a detailed study of sounds from field artillery and machine guns. The bulk of the data are of muzzle waves, but there are also data for the sounds of projectiles in flight (ballistic waves) and for shell explosions. In general, the spectrum analyses show maximum acoustic energies at frequencies roughly equal to the reciprocal of the time required for the first compression-rarefaction cycle of the muzzle wave associated with each weapon type.

Volume two is an atlas of oscillograms showing the waveforms and instantaneous acoustic amplitudes of muzzle waves, ballistic waves, and shell explosions as recorded for various weapons and at various distances from the sources of sound. For machine guns, sounds were recorded at ranges of 33, 112, 428, and 648 yards. For large caliber weapons, recordings were made at various ranges from 115 to 14200 yards to show the effects of terrain and atmosphere on sound propagating from firing artillery.

1355

Ingerslev, F., and A. K. Nielsen, "Sound Pressure, Hearing Intensity and Frequency Analysis of Airborne Sound" (in Danish), Ingeniørvidenskab. Skrifter, 2, 26-34, 1947.

Air pressure variations occurring when a car passes close to (50 cm) a column were measured by a crystal microphone coupled through an amplifier to a cathode-ray oscillograph. With a car speed of 100 km/hr an excess pressure of 50 kg occurs when the front of the car meets the front of the column, followed by a pressure deficit of 100 kg at approximately the middle position, then a renewed rise, gradually vanishing.

Routine measurements of pressure and hearing intensity and frequency analysis are carried out by combined motor and band-filter (1/3 octave) and a wave analyzer, which are described. Examples of analysis of some organ-pipe tones and of noise in a canteen are given.

1356

Kingery, C. N., J. H. Keefer, and J. D. Day, "Surface Air Blast Measurements from a 100-Ton TNT Detonation," Memo Rept. No. 1410, Ballistic Research Labs., Aberdeen Proving Ground, Md., 46 pp., 1962.
AD-285 599.

The free field pressure-time histories measured at selected distances from a 100-ton TNT surface burst are presented. Included are plots of overpressure, duration, impulse, arrival time, and dynamic pressure—all versus distance. The measured values are compared with predicted curves, which were prepared by scaling results from 5-ton and 20-ton surface bursts of the same geometrical shape and fired in the same general area. The geometrical shape is a simulated hemisphere which was constructed by stacking cast TNT blocks in a planned pattern.

1357

Kurbjun, M. C., "Noise Survey Under Static Conditions of a Turbine-Driven Transonic Propeller with an Advance Ratio of 4.0," Memo No. 4-18-59L, NASA, Washington, D. C., 14 pp., 1959.
AD-215 388.

Overall sound-pressure levels and frequency spectra of the noise emitted from a three-blade, 6.85-foot-diameter propeller have been measured. The results are compared with similar results obtained from a supersonic propeller having an advance ratio of 2.2 and from a modified supersonic propeller having an advance ratio of 3.2. The effects of power changes on the noise levels and spectra are also shown.

1358

Lee, R., "Free Field Measurements of Sound Radiated by Subsonic Air Jets," Rept. 868, David Taylor Model Basin, Washington, D. C., 15 pp., 1953.
AD-23 417.

Measurements are reported of the sound radiated by small air jets at subsonic velocities. The measurements were made in a free acoustic field to obtain the directional pattern of the radiation in half-octave frequency bands covering the 38- to 13,600-c range. Results indicated that the directivity patterns of the sound depend on the frequency. The sound pressure spectrum at any point in the noise field is dependent upon the jet velocity and azimuth angle; the entire spectrum shifts towards higher frequencies with increase in velocity and azimuth angle. Somewhat smaller values of total acoustic power than previously reported were indicated. Comparison of the present results with those obtained by other workers showed general agrrement with respect to the directional characteristics of the radiated jet noise. Certain differences were attributed to the effect of the length-diameter ratio of the nozzle.

1359

Marsh, A. H., "Noise Measurements Around a Subsonic Air Jet Impinging on a Plane, Rigid Surface," J. Acoust. Soc. Am., 33, 1066, 1961.

Measurements are presented of the noise produced by a 1.5-in. diameter air jet, with an exit Mach number of 0.66, impinging perpendicularly on a plane, rigid plate. The overall sound power output increased rapidly, as the nozzle-to-plate separation distance was decreased. The overall sound power generated, when the plate was two diam. from the nozzle, was ten db greater than that produced with the plate removed. For a two-diam. plate separation the overall sound-pressure levels (SPL's) (measured at a radius of 24 nozzle diameters from the center of the jet exit in the horizontal plane through the jet centerline) were 15 to 18 db greater than those produced at corresponding positions with the plate removed, while for a 20-diam. separation, the increase varied between two and seven db. The spectrum of the noise changed as the separation distance was increased as follows: (a) the peak frequency decreased, (b) the pronounced peak changed to a broad one, and (c) the magnitude of the peak decreased.

1360

Mawardi, O. K., and I. Dyer, "On Noise of Aerodynamic Origin," J. Acoust. Soc. Am., 25, 389-395, 1953.

An attempt is made in this paper to classify noises of various aerodynamic origin by means of an efficiency of conversion from mechanical to acoustical energy, and also by means of representative spectra associated with corresponding characteristic frequencies. The classification has been tried successfully on measurements of wind tunnel noises, turbojet noises, and air jet noises.

1361

Maxfield, J. P., and N. G. Wade, "Energy Distribution in Machine Gun Sounds," Rept. No. 1727, National Defense Research Committee Division 17, Office of Scientific Research and Development, Washington, D. C., 38 pp., 1943. ATI-20592.

The scope of the report is limited to a study of the energy distribution in the sound spectra of 30 to 50 caliber machine guns. The recording system is described. Results of the tests indicate that for distances between 33 and 600 yards, the principal energy of the missile wave lies between 55 and 300 cps. For distances from the gun between 33 and 600 yards, but where the transmitter was directly under the line of fire, the peak energy of the ballistic wave lay between 850 and 1200 cps. The significance of the present data is discussed and a future program is tentatively outlined.

1362

Miller, D. C., "Sound Waves; Their Shape and Speed," Macmillan, New York, 164 pp., 1937.

This description of the phonodeik (an apparatus for photographic recording of sound waves) and its application includes a report on experiments made at Sandy Hook (1918-1919) on acoustical phenomena associated with the firing of large guns (pp. 91-155). Some results are presented in graphical and tabular form on: (1) pressure effects in the air near large guns during firing; (2) wave forms of the sounds; (3) propagation of sound waves from the muzzle of a gun and (4) normal velocity of sound in free air.

1363

Muehl, C. L., and H. Sternfeld, Jr., "Investigation to Determine the Effect of Phasing on the Noise Generated by Spur Gears," TCREC TR 62-49, Vertol Div., Boeing Co., Morton, Pa., 54 pp., 1962. AD-283 757.

A test program was performed to evaluate the effect of relative gear-tooth contact phasing on the acoustical characteristics of a model transmission. It was concluded that within the limitations of the test configuration, the radiated noise frequency characteristics for a constant tooth-contact frequency are a function of the number of gear sets, while the amplitude and directional characteristics are a function of their relative phasing. It was also noted that changes in the torsional elastic properties of the system produced significant changes in radiated noise.

1364

National Defense Research Committee, "Summary Technical Report of Division 17; Compasses, Odographs, Combat Acoustics, and Sonic Deception," Office of Scientific Research & Development, Washington, D. C., 2, 117-130, 1946. ATI-30810.

Oscillographs of the sounds from rifles, machine guns, mortars, and howitzers are shown as sampled at ranges of 1500 feet and 2900 yards. Simulations of these sounds by use of small charges of nitrostarch, Primacord, dynamite, etc., are shown. The general effect of increasing range is atmospheric absorption of the high-frequency content of each sound plus an increase in signal duration.

1365

Obata, J., and Y. Yosida, "Sounds Emitted by Aircraft," Rept. No. 59, Aeron. Res. Inst., Tokyo Imp. Univ., 185 pp., 1930. See Also: Proc. Phys. Math. Soc. Japan, 12, 80-92, 1930.

Describes the electrical methods used for recording the sounds emitted by various types of aircraft. These included a bomber, a chaser, a reconnaissance machine and a small dirigible. Straight-line flights and vertical turns were made. The sounds are generally very complex in nature, overtones being predominant in most cases. At short distances the exhaust sound predominates, while at longer distances the propeller provides the greater part of the sound, the fundamental and second harmonic being predominant. Different aeroplanes equipped with the same kind of engine gave different records. The pitch of the fundamental depends far more on the number of cylinders per bank than on the total number of cylinders in the engine.

A large number of the records obtained are reproduced in the paper.

1366

Oleson, S. K., and U. Ingard, "Acoustic Characteristics of Model Pulsed Jets," J. Acoust. Soc., Am., 29, 1145-1146, 1957.

A note of general interest regarding some of the acoustical properties of model jet engines that have been found to be satisfactory sound sources for certain purposes in connection with studies of sound propagation in the atmosphere.

1367

Pietrasanta, A. C., "Noise Measurements Around Some Jet Aircraft," J. Acoust. Soc. Am., 28, 434-442, 1956.

The noise fields around several jet aircraft have been measured for various engine operating conditions. Directivity patterns as a function of octave bands of frequency are presented. Acoustic power levels have been computed and found to agree with a previously published correlation of power level with engine operating conditions (D. K. Mawardi and I. Dyer, J. Acoust. Soc. Am., 25, 389, 1953). Analysis of these data has led to the development of a procedure for estimating the characteristics of the noise fields around non-afterburner jet aircraft operating at military power.

1368

Romanenko, E. V., "Width of a Sawtooth Wavefront," Soviet Phys. Acoust. English Transl., 7, 82-83, 1961.

The spectrum content of an acoustic saw tooth wave was experimentally determined through the 30th harmonic. The conclusions reached show that the width of a sawtooth wavefront is of the same order of magnitude as that of a weak shock wave. This determination is in contrast dissimilar results obtained by others.

1369

Saby, J. S., and H. A. Thorpe, "Ultrasonic Ambient Noise in Tropical Jungles," J. Acoust. Soc. Am., 18, 271-273, 1946.

A description of equipment, experimental procedure, and data obtained on field trips into the jungles of Panama. The acoustic intensity level of ambient, jungle background noise was monitored and measured for 24-hour periods. Data is reported on an intensity-per-cycle basis (db above 10^{-16} watts per cm^2) for the frequency range of 8-25 kc, and on a broad band basis for the two regions 0-10 kc and 15-25 kc. The band from 0-10 kc varies in intensity from about 50 to 60 db with a slight broad peak at nightfall. The region from 15-25 kc is at a much lower average intensity level, but with a peak rising to 45 to 55 db at nightfall. Observations and analysis of data indicate that most of the ultrasonic noise was made by insects.

1370

Sato, H., "Experimental Study of the Spectrum of Isotropic Turbulence, II," J. Phys. Soc. Japan, 7, 392-396, 1952.

In the isotropic turbulent field, energy spectrum was observed by an improved equipment. The measurements were made in a closed channel which was added to the exit cone of an open-type windtunnel. A voltage integrator was used to read the fluctuating output of lf components. A low-cut filter attached to the input terminal increased the accuracy at hf region.

Measured spectrum curves are nearly the same as previously reported. The decay of spectral components is more severe at high wave-number throughout the decay process. The energy transition is estimated from the measurements mentioned above; the wave-number of zero transition decreases as the turbulence decays. Finally the gradient of spectrum curve is determined by differentiating the spectrum with respect to windspeed. At medium wave-number region the power index is about -5/3. Three-dimensional spectrum is also obtained by this method.

1371

Springer, H. S. and R. O. Olsen, "Launch Noise Distribution of Nike-Zeus Missiles," Special Rept. No. 53, Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 17 pp., 1961.
AD-261 505.

Maximum sound pressure levels averaging 115 decibels, with extreme values of 90 and 128 decibels, were measured about one mile behind the Nike-Zeus Missile Launcher for the variety of meteorological conditions occurring during four monthly tests. Additional small samples of data taken both near the launcher and two miles distant suggest a 20-decibel decline in peak noise level per mile. The decay of the noise level following peak was between two and three decibels per second for the first ten seconds. A frequency analysis of the sound level measured at launch indicates that frequencies below 125 cps are predominant. Under most meteorological conditions, the sound pressure levels at one mile behind the launcher would not be great enough to cause any structural damage or personnel injury. The levels would be above 90 decibels, however, which approach the level at which complaints of annoyance become frequent.

1372

Suffield Experimental Station (Canada), "Scientific Observations on the Explosion of a 20 Ton TNT Charge, Volume Two. Tripartite Blast Measurements," Rept. No. 203, 1961.
AD-272 033.

Air blast data obtained from the detonation of twenty tons of TNT are given. Shock overpressure observations made by the Tripartitite (US-Canada-UK) teams on the airblast are presented, and the various systems for recording the explosive phenomena are compared.

1373

Veneklasen, P. S., "Noise Characteristics of Pulse-Jet Engines," J. Acoust. Soc. Am., 25, 378-380, 1953.

Data obtained as part of a noise control program are presented to show the magnitude, spectral characteristics, directional properties, and variation with operating conditions of the noise produced by two sizes of pulse-jet engines.

1374

von Gierke, H. E., "Physical Characteristics of Aircraft Noise Sources," J. Acoust. Soc. Am., 25, 367-378, 1953.

Available basic characteristics of different aircraft noise sources under the condition of zero forward speed are summarized. Total acoustic power, acoustic mechanical efficiency, directivity and frequency characteristics are given for the rotation and vortex noise of propellers, for the exhaust noise of reciprocating engines, and for different types of jet engines. The physical mechanisms underlying the different noise sources are discussed and the influence of changes in the parameters, such as tip speed or pitch of the propeller, and diameter or velocity of the gas jet, are shown. In cases where measurements on the actual propulsion systems are incomplete, the basic physical conclusions are drawn from experiments on model airscrews and small air jets. The changes in the characteristics of the noise generators during flight are discussed briefly.

1375

von Gierke, H. E., H. O. Parrack, W. J. Gannon, and R. G. Hansen, "The Noise Field of a Turbo-Jet Engine," J. Acoust. Soc. Am., 24, 169-174, 1952.

The noise fields generated by a standard turbo-jet aircraft engine have been measured for three different power settings. Measurements were made at points on circles around the engine having radii of 25 and 50 feet. For the distance of 50 feet, the directional characteristic is presented for the over-all sound pressure and for the noise in the different octave bands, starting at 37.5 cps. From these measurements the total acoustic power radiated from the engine is calculated to be approximately 69 kw at full engine power. The distribution of this power over the different frequency bands and space angles is shown. The highest total energy per cycle and the highest sound levels are found at frequencies near 100 cps for the higher power settings of the engine. Above that frequency range the total energy per cycle drops approximately as the reciprocal of the square of the frequency.

The data should help us understand qualitatively the jet engine as a sound source and are therefore discussed in that respect. On the other hand, the data have practical significance with respect to the design of test facilities for adequate protection of personnel. They are equally important with respect to problems of noise control on an airport.

1376

Waterhouse, R. V., and R. D. Berendt, "A Reverberation Chamber Study of the Sound Power Output of Subsonic Air Jets," Rept. No. 4912, National Bureau of Standards, Washington, D. C., 1956.
AD-156 979.
See Also: J. Acoust. Soc. Am., 30, 114-121, 1958.

The reverberation chamber technique was used to determine the sound spectra and acoustic power radiated by air jets over a range of subsonic velocities. Different air jets were used with round and square velocity profiles; nozzles of circular cross section, and nozzles with sawtooth and corrugated ends were also used. Of these nozzles only the latter type gave a significant (9 db) reduction in sound-power output for a given thrust.

A study was made of the limitations of the reverberation chamber technique caused by the absorption in the chamber. When this absorption became considerable, the measurement of sound levels in a circle around the sound source revealed a directional pattern, and the assumption of uniform energy distribution in the chamber became invalid. This situation was noticeable at frequencies above 5 kc in the National Bureau of Standards chamber, owing to air absorption.

1377

Wescott, J. W., "Acoustic Background at High Altitudes," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 182-194, 1961.
AD-408 716.

The power spectrum of acoustic background noise at altitudes of 60,000 feet has been determined with balloon-borne acoustic detectors, a data link and recording system, and spectrum analyzers. Background levels are surprisingly high with acoustic pressures of 0.2 d/cm^2 persisting at frequencies below 5 cps. The acoustic energy spectrum falls off as the second power of frequency.

Flights have been made with double detectors, one hanging on a long cord below the other. Cross-correlation of the resulting data indicates that a significant portion of it propagates from lower altitudes. The most probable sources of this acoustic energy are turbulent eddies caused by wind shear.

In addition to background noise some specific signals have been detected. Analyzed samples are presented. Some observed Doppler effects suggest a possible method for measuring the absorption of sound in air at low frequencies.

1378

Westley, R., and G. M. Lilley, "An Investigation of the Noise Field from a Small Jet and Methods for its Reduction—and Errata," Rept. No. 53, College of Aeronautics, Cranfield, England, 56 pp., 1952.
ATI-153 224.

Sound measurements are reported which were made on the noise from the jet of a one-inch diameter convergent nozzle at atmospheric temperature and at speeds above and below choking. The noise level and spectrum were investigated in both near and distant fields. Results agree in some measure with the predictions of the Lighthill theory, that the elementary sound radiator is an acoustic quadrupole. The agreement is more marked if attention is confined to the higher frequencies. Simple empirical formulae are derived which give the overall sound intensity and frequency spectrum in terms of the position relative to the jet, the stagnation pressure excess over the atmospheric pressure, and the frequency. Tests on various noise-reduction devices are discussed, which indicate promising lines of investigation. Maximum reduction in total noise level was about 10 db.

1379

Wiener, F. M., "Experimental Study of the Airborne Noise Generated by Passenger Automobile Tires," Noise Control, 6, 13, 1960.

To measure and analyze airborne tire noise, a microphone equipped with a windscreen was mounted near the tire-road interface on the rear fender of a typical passenger automobile. Noise levels were measured for the car coasting from a speed of about 60 mph down to 15 mph with the engine off and the transmission in neutral. Two degrees of road roughness and several different materials of tire construction were used in the tests. Noise levels and noise spectra are given in the paper for several test conditions.

Keys, Signatures, Spectra, Waveforms, Etc.
See also—22, 337, 440, 452, 453, 519, 521, 529, 562, 568, 683, 714, 966, 986, 989, 1232, 1299, 1381, 1445, 1478, 1487, 1584, 1589, 1618, 1621, 1624, 1627, 1628, 1640, 1651, 1652, 1662, 1663, 1665, 1682, 1691, 1692, 1694, 1696, 1704, 1710, 1715, 1718, 1764, 1771, 2293, 2306, 2342, 2370, 2419, 2425, 2440, 2441, 2443, 2444, 2448, 2449, 2456, 2465, 2478, 2490, 2492, 2511, 2810, 2815, 2816, 2817, 2818, 2837, 2858, 2862, 2898, 2901, 2902, 2913, 3362.

LENSES

1380

Augspurger, G. L., "The Acoustical Lens," Electron. World, 68, 34-35, 1962.

This elementary article on acoustical lenses explains the principals of two types of commercially available focusing devices. One is a form of obstacle array within which the velocity of propagation of a wavefront is reduced by diffraction around the obstacles. The other type employs either slanted plates or serpentine ducts of various lengths to delay portions of a wavefront by the amounts required to achieve the desired focusing effect. Photographs of lenses, horns and drivers are included.

1381

Bliakhman, E. A., "Pulsation Spectrum at the Focus of a Lens," Soviet Phys. Acoust. English Transl., 4, 128-130, 1958.

The pulsation spectrum of a field at the focus of a lens is investigated, where the pulsations depend upon the motion of a medium consisting of random inhomogeneities. It is shown that the lens acts as a filter, changing the frequency distribution of energy.

1382

Bliakhman, E. A., and L. A. Chernov, "Dependence of the Pulsation Frequency of a Field at the Focus of a Lens on the Dimensions of the Diaphragm," Soviet Phys. Acoust. English Transl., 5, 20-23, 1959.

The mean-square pulsation frequency of a field at the focus of a lens is determined for waves traversing a medium containing random inhomogeneities. The case of chaotic motion of the inhomogeneities is considered. A comparison is made with the case of ordered motion and with experimental data.

1383

Bondareva, L. N. and M. I. Karnovskii, "Directional Properties of Acoustic Scattering Lenses," Soviet Phys. Acoust. English Transl., 1, 122-140, 1955.

The paper computes the angular distribution of the acoustic pressure created by plane-elliptic and plane-hyperbolic acoustic lenses for various values of the refractive index, the flare angle, and the imaginary focal distance of the lens.

1384

Clark, M. A., "An Acoustic Lens as a Directional Microphone," J. Acoust. Soc. Am., 25, 1152-1153, 1953.

An acoustic lens combined with a conical horn can be used to obtain a highly directional microphone without some of the disadvantages of the parabolic microphone. The directional characteristics can be calculated satisfactorily if one assumes that the horn provides uniform flooding of the lens aperture.

1385

Griffing, Virginia, and F. E. Fox, "Theory of Ultrasonic Intensity Gain due to Concave Reflectors," J. Acoust. Soc. Am., 21, 348-351, 1949.

A concave reflector can be used to concentrate a beam of plane ultrasonic waves in the focal region, where the intensity I_f if much larger than the intensity I_i in the plane wave. When the sound wavelength is small compared to the dimension of the beam and reflector, one can use the well-known Fraunhofer diffraction formulas to calculate the intensity gain, i.e., I_f/I_i. Expressions are derived for the maximum and average intensity gain in the zero-order image when the ultrasonic beam is circular or rectangular, together with formulas giving the total intensity falling upon circular or rectangular areas of arbitrary dimensions in the focal region.

1386

Harvey, F. K., "Focusing Sound with Microwave Lenses," Bell Lab. Record, 27, 349-354, 1949.

This chatty article begins by drawing analogies among optical, microwave and acoustic lenses. A lens that will bring sound (or electromagnetic energy) to a focus is described as a device through which energy travels more slowly at the center than at the edges. An array of small, perfectly reflecting spheres, equally spaced but arranged in the characteristic shape of a convex lens, was found to focus both sound and microwaves of the same wavelength equally well. The wavelength of the sound to be focused must be at least two or three times the diameter of the spheres. A lens of slanted plates, wider at the lens center than at the edges and looking something like a bulgy venetian blind, was also effective in focusing sound. A diffusing lens was constructed with slanted plates wider at the edges than at the center. There are several clear photographs of the lenses presented together with polar diagrams to illustrate directional characteristics.

1387

Kanevskii, I. N., and L. D. Rozenberg, "Computation of the Acoustic Field in the Focal Region of a Cylindrical Focusing System," Soviet Phys. Acoust. English Transl., 3, 46-63, 1957.

By assuming that the wavelength is small in comparison to the focal length of a cylindrical focusing system, a computation is made of the acoustic field in the vicinity of the axis of the system, both for an infinitely long front and for a front of finite length. The results of the computation show that in the focal plane in a direction perpendicular to the axis of the front the potential has systematic nulls, whereas in the direction perpendicular to the same axis but in the axial plane the potential has minimums which do not attain zero. Taking the finite length into account in the cases examined produces small corrections which do not exceed 15-20%.

1388

Karnovskii, M. L., "Work of Soviet Acoustical Engineers in the Study of Directional Properties of Transmitters and Receivers" (in Russian), Izv. Akad. Nauk SSSR, Ser. Fiz., 13, 698-709, 1949.

Enumerates results obtained in investigating the directionality of various geometrical forms of sound transmitting and receiving surfaces.

1389

Kock, W. E., and F. K. Harvey, "Refracting Sound Waves," J. Acoust. Soc. Am., 21, 471-481, 1949.

Structures which refract and focus sound waves are described. They are similar in principle to certain recently developed electromagnetic wave lenses in that they consist of arrays of obstacles which are small compared to the wavelength. These obstacles increase the effective density of the medium and thus effect a reduced propagation velocity of sound waves passing through the array. This reduced velocity is synonymous with refractive power so that lenses and prisms can be designed. When the obstacles $\simeq \lambda/2$ in size, the refractive index varies with wavelength, and prisms then cause a dispersion of the waves (sound spectrum analyzer). Path length delay type lenses for focusing sound waves are also described. A diverging lens is discussed which produces a more uniform angular distribution of high frequencies from a loudspeaker.

1390

Krom, M. N., "Field Fluctuations Near the Focus of a Lens," Soviet Phys. Acoust. English Transl., 5, 43-48, 1959.

The paper considers the distribution of fluctuations near the focus of a large lens, with no limitations on the fluctuations in the incident wave. The dependence of the relative fluctuation at the focus upon the dimensions of the objective is investigated.

1391

Krom, M. N., and L. A. Chernov, "The Effect of Fluctuations in the Incident Wave on the Mean Intensity Distribution in the Vicinity of the Focus of the Lens," Soviet Phys. Acoust. English Transl., 4, 352-358, 1958.

The mean intensity distribution near the focus of the lens for arbitrary fluctuations in the incident wave is obtained in the form of a series. The dependence of the mean intensity at the focus upon the fluctuation is obtained in closed form. The results are presented graphically.

1392

Naugol'nykh, K. A., and E. V. Romanenko, "Amplification Factor of a Focusing System as a Function of Sound Intensity," Soviet Phys. Acoust. English Transl., 5, 191-195, 1959.

The diminution in the amplification factor of focusing systems and radiators due to nonlinear wave form distortions is investigated. A parametric expression is obtained, permitting an evaluation of a focusing system from the point of view of the influence of the nonlinear effects on its amplification factor.

An experimental verification of the results obtained is made. Using miniature pickups, the wave forms near the focus and the amplification factors of three barium-titanate ceramic focusing radiators were investigated. Pulse techniques are applied, with the operating frequency of the radiators at 0.5, 1.4, and 2.2 mc. The maximum amplitude of the pressure at the focus of the radiator was about 200 atm. ± 20%. With the application of pulsing (a continuous impulse of 100 μsec, and a frequency of 1.4 mc) at this pressure cavitation set in.

1393

O'Neil, H. T., "Theory of Focusing Radiators," J. Acoust. Soc. Am., 21, 516-526, 1949.

An approximate theory has been derived describing part of the sound field from a concave spherical radiator, vibrating with normal velocity; the radius a of the circular boundary is assumed to be large relative to the wave-length and large relative to the depth of the concave surface. The theory describes the distribution of pressure, particle velocity, and intensity along the axis of symmetry and in the vicinity of the focal plane, perpendicular to the axis at the center of curvature. It is shown that the ratio of the intensity at the center of curvature to the average intensity at the radiating surface is nearly equal to $(2\pi h/\lambda)^2$ where h is the depth of the concave surface and λ is the wave-length. This ratio can be made very large by suitable choice of dimensions, and the focusing is then very sharp. The point of greatest intensity is not at the center of curvature but approaches it with increasing $kh = 2\pi h/\lambda$, and the greatest intensity is not much greater than the intensity at the center of curvature except when kh is small. In the central part of the focal plane, at angle Θ from the axis, the pressure is approximately proportional to $(2/ka \sin \Theta)J_\ell(ka \sin \Theta)$, which is equivalent to the directivity function of a flat circular piston of radius a, for the region at large distance from the piston.

The calculations are in reasonable agreement with G. W. Willard's experimental data for a 5-mc concave quartz crystal, when allowance is made for the non-uniform normal velocity of the crystal.

1394

Rozenberg, L. D., "Analysis of Gain of Cylindrical Sound-Focusing Systems," Sov. Phys. Acoust. English Transl., 1, 73-81, 1955.

Assuming the length to be small compared with the dimensions of the radiator, general expressions are derived for the amplification coefficients and for the focusing factors of a converging cylindrical front. It is shown that to obtain the maximum value of the focusing factor for the pressure, the optimum distribution function is of the form $\Phi(\alpha) = 1$; and for velocity focusing, of the form $\Phi(\alpha) = \cos \alpha$. The values of K_p, K_b, k, and k' and their dependence on the aperture angle of the front are calculated for several actual cases. The results obtained can be used to calculate actual focusing systems with an error not exceeding 10%, with the exception of edge segments of length $\sqrt{\lambda f}$.

1395

Rozenberg, L. D., "Development of Work on Sound Focusing" (in Russian), Izv. Akad. Nauk SSSR, Ser. Fiz., 13, 710-716, 1949.

Historical résumé of the progress of research on sound focusing, from the early iron hemispherical lenses up to the short-focus, concave and convex types as well as elliptical mirrors.

1396

Sette, D., "Ultrasonic Lenses of Plastic Materials," J. Acoust. Soc. Am., 21, 375-381, 1949.

The properties of certain plastic substances have been examined with the idea of using them to construct solid lenses for focussing ultrasonic radiation. Some experiments are described which illustrate the advantages offered by such lenses. The use of a plano-cylindrical lens permits a reduction to 1/10, and the use of a plano-spherical lens permits a reduction to 1/100 of the energy which must be emitted by a quartz crystal to produce a given intensity of ultrasonic radiation over a given region.

1397

Shifrin, Ya. S., "Correlation Characteristics of the Diffraction Image Formed by a Focussing System," Soviet Phys. Acoust., English Transl., 8, 360-363, 1963.

An expression is derived for the correlation function of the diffraction image formed by a paraxial focussing system subject to any fluctuations in the incident wave and to any ratio between the dimensions of the system and the correlation radius. Graphs are given for the correlation function as a function of fluctuation and of this ratio.

1398

Shifrin, Ja. S., "Effect of Fluctuations in the Incident Wave on the Diffraction Pattern in the Focal Plane of a Lens," Soviet Phys. Acoust. English Transl., 7, 195-200, 1961.

Expressions are obtained for the mean intensity and fluctuations in the focal plane of a lens, given any kind of fluctuation in the incident wave and an arbitrary relation between the lens dimensions and radius of correlation. Graphs are shown characterizing the change in the diffraction pattern as a function of lens dimensions and radius of correlation.

1399

Tartakovskii, B. D., "The Aberrational Characteristics of Acoustic Lenses," Soviet Phys. Acoust. English Transl., 8, 271-277, 1963.

The methods of geometrical optics are used to calculate the focal surfaces and third-order aberration coefficients for planospherical and bispherical acoustic lenses characterized by refractive indices greater than unity (decelerating lenses) and less than unity (accelerating lenses).

Decelerating and accelerating lenses are compared from the viewpoint of the aberrations inherent in them. The comparative advantages and disadvantages of the lenses, and the possibilities of minimizing distortions of the acoustic images by the lenses, are discussed.

1400

Tartakovskii, B. D., "Amplification Factor of a Solid Acoustic Lens with Losses," Soviet Phys. Acoust. English Transl., 8, 176-179, 1962.

As a result of losses in the material of a solid acoustic lens, the lens amplification factor does not indefinitely increase with frequency, but to some maximum value determined by the material of the lens and, in some instances, by its dimensions.

The amplification frequency characteristics are compared for solid acoustic lenses fabricated from materials having linear and square-law relations between the spatial attenuation factor and the frequency (in particular, aluminum and Plexiglas lenses), and recommendations are given for the choice of material to be used in acoustic lenses. As a quantitative measure of the quality of the material that goes into the acoustic lens, a criterion (the "quality rating") is introduced, permitting evaluation of the suitability of various materials.

1401

Tartakovskii, B. D., "On the Diffraction of Sound Waves in Converging Beams," Sov. Phys. Acoust. English Transl., 4, 366-371, 1958.

Approximate equations are found for the sound field near the focal point formed by a converging wave front. The field may be characterized by the nonuniform amplitude distribution over the front and by spherical aberration.

The magnitude of nonuniformity in the amplitude over the wave front is estimated. The amplitudes can be significantly distinguished at a distance which exceeds the wavelength.

Some special cases of the integral equations are investigated; in particular, the equations which describe the field on the axis of the wave beam at an arbitrary distance from the focus are considered and, in connection with these, the results obtained earlier by other authors are subjected to criticism.

1402

Tartakovskii, B. D., "Spherical Aberration of Solid Acoustic Focusing Lenses," Soviet Phys. Acoust. English Transl., 7, 278-283, 1962.

The dependence of the longitudinal aberration (and its associated transverse) of a regular acoustic lens on the index of refraction and shape of the lens is investigated. It is shown that, unlike optical condensing lenses (glass, in air, with an index of refraction 1.4 to 2.0), acoustic lenses with an index of refraction n = 1 (for the image of objects at infinity) can be made aberration-free. The approximate and the trigonometrically exact quantitative dependences of the aberration on n are calculated for solid acoustic lenses in the interval of values of n that are most significant from the viewpoint of designing aberration-free lenses. The role of transverse waves propagating in solid lenses in the formation of an additional focus is explained, and the interference introduced by this focus at the principal focus of the lens (generated by the propagation of longitudinal waves in the lens) is determined.

For selecting the shape and material of the lens, the article offers recommendations promising reductions both in the interference from spherical aberration and in the formation of a secondary, transverse-wave focus.

1403

Tartakovskii, B. D., "Spherical Aberration of Sound Lenses" (in Russian), Dokl. Akad. Nauk SSSR, 69, 29-32, 1949.

The relation of longitudinal aberrations to speeds of sound propagation is expressed algebraically, and it is shown that the aberration is reduced to zero in conformity with the refractive index. Refractive index values corresponding to longitudinal spherical aberrations for various types of lens (optimum curve, concave and convex) are tabulated. Graphs indicate relations between lens aperture and aberration, where the exact magnitude of the latter cannot be otherwise determined; and dependence of lens aperture on refractive index for a given aberration magnitude.

1404

Willard, G. W., "Focusing Ultrasonic Radiators," J. Acoust. Soc. Am., 21, 360, 1949.

Piezoelectric ultrasonic radiators made in the form of a thin spherical shell radiate spherical sound waves which come to a focus at the center of curvature of the shell, thus enabling the production of much greater ultrasonic intensity in a small locality removed from the radiator than it is possible to obtain directly at the surface of a radiator. It is here shown by ultrasonic light-diffraction pictures of the radiated sound field that the sharpness of focus is limited by wave diffraction in the manner well known in astronomical telescopes and may be calculated by optical diffraction formulas. By the same means the radiation efficiency of different areas of the curved surface is explored and the results compared with theory. The variation of efficiency is, of course, due to the variation of the effective elastic and piezoelectric constants of the differently oriented areas.

Calculations are made of the radiation efficiency of a quartz radiator, and it is shown that a greatly improved focusing spherical radiator may be obtained by varying the thickness of the radiator to compensate for the varying frequency constant. Further, cylindrical radiators whose focusing is superior may be obtained by special orientation or by shaping thickness, or by both.

Lenses — see also Parabolic Reflectors
See also — 408, 410, 751, 964, 983, 1784, 1822, 1862, 2190, 3691, 4398, 4399.

METEOROLOGY, DETERMINATIONS FROM ACOUSTIC DATA, MEASUREMENT

1405

auf Kampe, H. J., "Results of Acoustic Measurement at Helogoland" (in German), Meteorol. Rundschau, 5, 99-105, 1952.

On April 18, 1947, 6000 tons of explosive were set off at Helgoland; normal and anomalous waves recorded at German stations are charted up to a distance of 440 km. Results are discussed in the light of upper winds and temperatures and the weather situation, and the paths of anomalous waves plotted, with some alternative solutions. Above tropopause at 10 km a rise of temperature is determined, to a value of nearly 50°C at 50 km.

1406

Bandeen, W. R., R. M. Griffith, et al., "Measurement of Temperatures, Densities, Pressures and Winds over Fort Churchill, Canada, by Means of the Rocket Grenade Experiment," Tech. Rept. No. 2076, Army Signal Res. and Development Lab., Fort Monmouth, N. J., 38 pp., 1959.
AD-288 466.

Ten successful Aerobee rocket firings carrying the Signal Corps-University of Michigan rocket-grenade experiment were conducted at Fort Churchill, Manitoba, Canada (59°N). One hundred and fifty-three values of temperatures and winds between 25 and 94 km were measured in summer and winter, both during the day and at night, using the improved tracking and sound-ranging techniques required to make the grenade experiment an all-weather experiment. New facts about the arctic upper atmosphere were revealed. Temperatures in winter are unexpectedly high above 60 km with a second temperature maximum occurring between 70 to 80 km. Summer temperatures as low as 165°K at 80 km were recorded. The temperature maximum lies at about 50 km and in summer is greater than in White Sands, while in winter these temperatures are lower. Densities and pressures were also calculated from these data. The winds show a pattern similar to that in the middle latitudes: strong and westerly in winter, weaker and easterly in summer.

1407

Bartels, J., "Physics of the High Layers of the Atmosphere" (in Russian), Uspekhi Fiz. Nauk, 13, 689-751, 1933.

Brief summary of knowledge of stratospheric temperatures obtained from acoustical soundings, correlated in this progress report of upper atmospheric knowledge with data obtained by other methods in upper air research. Excellent bibliography of upper air phenomena: aerology, twilight, light of night sky, meteors, ozone, sound, ionization, etc.

1408

Bartman, F. L., V. C. Liu, and E. J. Schaefer, "An Aerodynamic Method of Measuring the Ambient Temperature of Air at High Altitudes," Eng. Res. Inst., Univ. of Mich., Ann Arbor, 64 pp., 1950.
ATI-83, 051.

Describes an aerodynamic method of measuring ambient air temperatures at high altitudes by determination of the shape of the shock cone attached to the nose cone of a missile capable of high supersonic speeds. A trial of this method on V-2 guided missiles, yielded data which are analyzed on the basis of first-order conical shock wave theory. Pirani gauge signals were obtained up to 230,000 ft, indicating that the method may be applicable up to this altitude. Temperatures calculated for altitudes up to 183,000 ft agree fairly well with previously known information about temperatures at high altitudes. The experimental errors are shown to be negligibly small. The possible existence of large systematic errors and plans for investigating them are discussed together with the use of this method for the measurement of winds at high altitudes.

1409

Bellamy, J. C., R. F. Bosshart, et al., "Investigation of the Feasibility of Acoustic Soundings of the Atmosphere," Final Rept., Cook Res. Labs., Skokie, Ill., 1958.
AD-210 659.

Acoustic soundings of the atmosphere offer an indirect technique for obtaining frequent information on weather conditions in the upper air. A feasibility experimental model sounding system for acoustical probing of the atmosphere is described. The system consists of an audio projector unit which beams a short-duration, high-intensity, single-frequency, pulse-modulated audio signal vertically into the atmosphere, and a receiver unit for detecting the sonic reflections and reverberations from the atmosphere. Preliminary results indicate the feasibility of acoustical soundings and more detailed field test information will be required to define explicitly the relationships between acoustic reflections and the corresponding meteorological variables.

1410

Bellamy, J. C., R. F. Bosshart, et al., "Investigation of the Feasibility of Acoustic Soundings of the Atmosphere," Rept. No. PR-152-1, Cook Res. Labs., Skokie, Ill., 33 pp., 1957.
AD-212 333.

The feasibility of using acoustic sounding techniques to obtain information concerning the structure of the troposphere and the usefulness of such information for forecasting or operations are to be determined. A sonic sounding device of flexible design is to be constructed, and field tests are to be conducted to study the various aspects of acoustic reflection and ranging. Acoustic phenomena in the atmosphere are discussed, and calculations are presented for estimated signal losses using a 1000-c carrier frequency.

1411

Bellamy, J. C., R. F. Bosshart, et al., "Investigation of the Feasibility of Acoustic Soundings of the Atmosphere," Rept. No. PR-152-2, Cook Res. Labs., Skokie, Ill., 1957.
AD-212 334.

Investigations revealed that a frequecy of 1000 c affords the best compromise for the signal carrier frequency. Tests will also be made at 500 and 750 c. To provide a logical basis for the tests at these frequencies, a series of calculations have been made of estimated signal losses. In order to understand better the basis of these calculations, a short review is given. Progress in the construction of an experimental sonic sound device of flexible design is summarized.

1412

Bellamy, J. C., R. F. Bosshart, et al., "Investigation of the Feasibility of Acoustic Soundings of the Atmosphere," Rept. No. PR-152-4, Cook Res. Labs., Skokie, Ill., 10 pp., 1958.
AD-210 658.

The evaluation of the experimental meteorological acoustic sounding system was continued. In particular, acoustic soundings are to be conducted under selected weather conditions to ascertain the feasibility of identifying atmospheric characteristics from the sonic reflection data.

1413

Bellamy, J. C., S. C. Henjum, et al., "Investigations of the Feasibility of Acoustic Soundings of the Atmosphere," Rept. No. PR-152-3, Cook Res. Labs., Skokie, Ill., 1958.
AD-211 017.

The preliminary system test for the evaluation of the sounding equipment and the start of field testing were planned. The field test was delayed because of the effort required during the preliminary system test to eliminate wind and ambient noises in the signal detector. The noise problem was sufficiently alleviated to allow preliminary analysis of these sample soundings; however, the time required to solve the noise problem has prevented the performance of a sufficiently thorough analysis of the soundings.

1414

California, Univ. of, "Survey of Data and Theoretical Analysis of the Upper Atmosphere," Final Rept., Inst. of Geophysics, Los Angeles, Pts. I-IV, 1950.

This report is divided into four parts. The first gives methods and results of research into the upper atmosphere; stratospheric winds at various heights were determined by observing noctilucent clouds, gun shell and rocket trajectories, and meteors, and by measuring the propagation of sound and radio waves. Part II, on turbulence in the upper stratosphere, gives evidence of convection currents between 50 and 80 km. Part III proposes a tentative model of stratospheric circulation up to 120 km. Part IV discusses the atmosphere above 100 km.

1415

Coffman, J. W., and R. C. Price, "Some Errors Associated with Acoustical Wind Measurements through a Layer," Tech. Rept. No. SELWS-M-12, White Sands Missile Range, N. Mex., 13 pp., 1962.
AD-288 020.

Investigates an acoustic wind-measuring array consisting of a transmitter and two receivers. Finds the error incurred by assuming that the wind component in the line of sensors is dependent solely upon the time delay of the sound front arrival at the two receivers. For an orientation suitable for measuring the horizontal flow through a layer, the error is less than 7%; for crosswind components, less than 30 mph. The temperature through the layer is known to $1^{o}C$.

1416

Cox, E. F., J. V. Atanasoff, B. L. Snavely, D. W. Beecher, and J. Brown, "Upper-Atmosphere Temperatures from Helgoland Big Bang," J. Meteorol., 6, 300-311, 1949.

Microbarographs situated 66 to 1000 km SSE from Helgoland recorded disturbances initiated by the 5000-ton TNT explosion on that island, April 18, 1947. Special balloons at four meteorological stations obtained weather data to 29.5 km altitude at blast time. Wind velocities are considered negligible up to balloon summits. Assuming negligible winds at higher altitudes, interval velocities of abnormal microbarometric signals permit calculations of upper-atmosphere temperatures. Temperature rises steeply from 221°K at 32 km to 285°K at 42.5 km, then more slowly to 294°K at 55 km, Very long period waves recorded beyond 400 km are believed to have returned from the second high-temperature region of the upper atmosphere. Arrival times are best matched by assuming a cold layer between 55 and 86 km, with lowest temperature 170°K extending from 64 to 79 km. A steep rise to 296°K at 86 km precedes a smaller gradient to 399°K at 172 km.

The authors do not have much confidence in findings for altitudes exceeding 100 km.

1417

Duplicated entry deleted.

1418

Crary, A. P., "Annual Variations of Upper Air Winds and Temperatures in Alaska from Acoustical Measurements," J. Meteorol., 10, 380-389, 1953.

A series of monthly acoustic tests has been made in interior Alaska to obtain upper airwinds and temperatures and their variations during an entire season. Results of these tests show that a temperature maximum of 22 to 36°C exists at about 47 km during the summer months of June, July and August, with the winds between 10 and 47 km averaging about 10 km/sec from the easterly direction. Higher average winds from westerly to northerly directions prevailed during the winter months, with the maximum temperatures probably below 10°C, and at somewhat higher altitudes than were found during the summer months. An exception occurred during the tests in December, when higher temperatures were found, though still at winter altitudes.

1419

Crary, A. P., "Investigation of Stratosphere Winds and Temperature from Acoustical Propagation Studies," Geophys. Res. Papers No. 5, AMC, Cambridge Res. Labs., Mass., 32 pp., 1950.
ATI-84 224.

Reports investigation of velocities of compressional waves at 30 to 60 km height made by sound propagation tests, and knowledge obtained of stratosphere winds and temperatures. Separation of temperature and wind effects is made possible by variations in the distances and azimuths of the recording sites from the source of the waves. Results of summer testing in the Canal Zone, Bermuda, and Alaska, and of winter testing in Alaska, and results of incomplete tests on east coast of the U. S. and in New Mexico, are presented. Temperatures found were lower than those reported in earlier acoustical studies in which winds were assumed to be negligible.

Easterly winds found during summer months for all latitudes, with minimum values in Alaska; high westerly winds found in Alaska in winter. Diurnal effects shown negligible.

Paper summarizes work up to Aug., 1949, by the Terrestrial Sciences Laboratory of the Geophysical Research Directorate on the investigation of stratospheric wind and temperature from acoustical sources. Main features of other reports are included.

1420

Crary, A. P., "Investigation of Stratosphere Winds and Temperatures from Acoustical Propagation Studies," J. Meteorol., 7, 233-242, 1950.

Journal article based on preceding entry.

1421

Crary, A. P., "Stratosphere Winds and Temperatures in Low Latitudes from Acoustical Propagation Studies," J. Meteorol., 9, 93-109, 1952.

Tests of sound-ranging methods near Hawaii, the Canal Zone, Bermuda and Florida are described, and velocity-height curves up to 40-60 km (100-120 km near Florida) are presented. Most probable temperatures and winds are deduced. The results confirm earlier studies, showing light winds over continental areas in low latitudes in winter, and low temperatures and high winds over oceanic areas. The sources of error in this experimental method are discussed.

1422

Crary, A. P., and V. C. Bushnell, "Determination of High-Altitude Winds and Temperatures in the Rocky Mountain Area by Acoustical Soundings, October 1951," J. Meteorol., 12, 463-471, 1955.

On each of ten tests, three 4000-lb bombs were dropped 35 km apart by aircraft, and recordings were made at four listening posts. The winds and temperatures were calculated up to 50 km. At the temperature reversal near 50 km (-55°C at 30 km, -36°C at 45 km) light variable winds were found. Above 50 km wind and temperature effects could not be separated but an assumed temperature curve gave westerly winds up to 100 meters per sec. at 70-80 km with shears up to 10 meters/sec./km.

1423

Crary, A. P., W. B. Kennedy, and V. C. Bushnell, "Atmospheric Winds and Temperatures at Heights up to 60 Kilometres at Determined by Acoustical Propagation Studies," American Meteorological Society and Royal Meteorological Society, Proceedings, Toronto Meteorological Conference, Sept. 9-15, 1953, 9-13, 1954.

Results of measurements of temperature profiles up to 50 km, maximum wind speed and wind azimuth in the Canal Zone, Florida, New Mexico, Bermuda, Colorado and Alaska, from anomalous sound transmission of explosions, are presented in a table and charts, and are discussed.

1424

Dubin, M., "Meteor Impacts by Acoustical Techniques," in R. L. F. Boyd and M. J. Seaton (eds.), "Rocket Exploration of the Upper Atmosphere," Pergamon Press, London, 26-27, 1954.

This chapter briefly mentions detection of meteorites by rockets flying in the upper atmosphere. The rockets carry flush-mounted microphones, the diaphragms of which are deflected by impacts of meteoric particles.

1425

Ference, M., W. G. Stroud, J. R. Walsh, and A. G. Weisner, "Measurements of Temperature at Elevations of 30 to 80 Kilometers by the Rocket Grenade Method," J. Meteorol., 13, 5-12, 1956.
AD-104 510.

The temperatues in the atmospheric region between 30 and 80 km have been determined from measurements of the sound velocity in nearly vertical propagation. The sound sources were grenades consecutively ejected from Aerobee rockets. The method of analysing the data to obtain accurate temperatures is described, and the results are presented.

The temperature data are in good agreement with balloon data near 30 km and show a maximum of about 268°K at 48 km. The probable errors are less than 3%. There are no clear-cut seasonal effects at the latitude of the firings, 32° N, although a number of marked temperature irregularities was noted in individual firings.

1426

Fetter, R. W., et al., "Remote Measurement of Atmospheric Wind Fields," Tech. Rept. No. 1 (large bibliography (163 entries) and survey of related programs), Midwest Res. Inst., Kansas City, Mo., 51 pp., 1961.
AD 270 094.

A survey has been made of literature and current work in the field of remote measurement of atmospheric wind fields. In the present context, the term "remote" indicates that no probe, sensing apparatus, or other extraneous physical material is to be located at the point of measurement and no physical connecting means is to be used between that point and the measuring equipment. Most methods investigated do not conform to the definition of "remote" as given above. The survey has produced only a few methods which appear applicable and therefore merit analysis in Phase II of the program.

1427

Ghosh, S. N., "Methods for the Measurement of Upper Atmospheric Characteristics," J. Sci. Ind. Res. (India), 14A, 277-284, 1955.

A review of methods used. Indirect methods with ground-based apparatus may apply the probe method, as in measuring wind velocity by gunfire, the radar study of meteors, the anomalous propagation of sound, and the use of searchlight beams for air density and temperature. Natural phenomena are used for the spectra and intensity of aurorae, and the height at which meteors appear and disappear. In direct methods instruments are carried into the layers by balloons or rockets. Day and night air-glow may be determined by the Van Rhijn method, which also may be used for ionospheric research into electron density and the fine structure of the ionized layer. Laboratory methods can be combined with theory to investigate collision processes and the recombination coefficients in ionized layers, and to determine photochemical reactions and absorption coefficients. Examples are given.

1428

Gilman, G. W., H. B. Coxhead, and F. H. Willis, "Reflections of Sound Signals in the Troposphere," J. Acoust. Soc. Am., 18, 274-283, 1945-1946.

Experiments directed toward the detection of nonhomogeneities in the first few hundred feet of the atmosphere were carried out with a low power sonic "radar." The device has been named the sodar. Trains of af sound waves were launched vertically upward from the ground, and echoes of sufficient magnitude to be displayed on an oscilloscope were found. Strong displays tended to accompany strong temperature inversions. During these periods, transmission on a microwave radio path along which the sodar was located tended to be disturbed by fading. In addition, relatively strong echoes were received when the atmosphere was in a state of considerable turbulence. There was a well-defined fine-weather diurnal characteristic. The strength of the echoes led to the conclusion that a more complicated distribution of boundaries than those measured by ordinary meteorological methods is required in the physical picture of the lower troposphere.

1429

Gutenberg, B., "Physical Properties of the Atmosphere up to 100 KM," J. Meteorol., 3, 27-30, 1946.

Discusses results of new calculations of temperature, pressure, density, etc., in the stratosphere up to 100 km elevation. Limited treatment and discussion of results of acoustical sounding of the stratosphere.

1430

Hori, S. "Study of Meteorological Surveillance Observing System," Quart. Progress Rept. No. 1, Armour Research Foundation, Chicago, 16 pp., 1959.
AD-272 374.

Investigations are directed toward the design of a system capable of observing, from remote operating locations, fields of meteorological variables in the lowest mile of the atmosphere over areas measuring about 50 × 50 sq mi.

Comprehensively reviews pertinent literature and reports initiation of an analysis of the lower atmosphere which will serve as a guide for the selection of system components. Acoustical, infrared, optical and other measurement techniques are considered. —see also Uretz, E. F. (1960), for more reports in this series.

1431

Jenkins, C. F., "A Survey of Available information on Winds Above 30,000 Feet," U. S. Air Force, Cambridge, Mass., Air Force Surveys in Geophys., 35 pp., 1952.

Includes table of wind direction and speed from 10-50 km, computed from observations of sound propagation made during one year at 40°N.

1432

Kaplan, J., G. F. Schilling, and H. K. Kallman, "Methods and Results of Upper Atmosphere Research," Geophys. Res. Papers No. 43, Cambridge Res. Center, Massachusetts, 162 pp., 1955.
Also as Sci. Rept. No. 3, Inst. of Geophys., Univ. of Calif., Los Angeles, 1954.
AD-101 944.

Chapter 8 reviews temperature and wind velocity determinations between 30- and 180-km altitude by measurements of acoustic propagation. Some of the results reported by various authors (Crary, Kennedy, Cox, Whipple, Gutenberg) are shown in tables and diagrams.

1433

Kaplan, J., and H. K. Kallman, "Upper Atmosphere Research," Rept. No. AFCRC-TR 57-213, Inst. of Geophysics, Univ. of Calif., Los Angeles, 250 pp., 1957.
AD-133 688.

Various means of investigating the physical state of the upper atmosphere of the earth are discussed. They are classified according to the sources of information (e.g., rocket flights, meteor observations, sound propagation, etc). Each method is described briefly, and typical results concerning temperature, pressure, density, composition, and winds, etc., are given. A distinction is made between the physical quantities which can be measured directly and those which can only be deduced from observations and theories. Tables, graphs, and references are part of each chapter.

1434

Kellogg, W. W., and G. F. Schilling, "Survey of Data and Theoretical Analysis of the Upper Atmosphere— Parts I-IV," Final Rept., Inst. of Geophys., Univ. of Calif., Los Angeles, 175 pp., 1950.
ATI-79, 350.

Methods and results of upper-atmosphere research are given together with data on the turbulence in the upper stratosphere, information on the atmosphere above 100 km, and a proposal for a tentative model for the general circulation in the stratosphere. Rocket flights, meteor studies, sound propagation, etc., were used to investigate the physical state of the upper atmosphere. Observational and theoretical evidence is given for the existence of convection currents and turbulence in the upper stratosphere between 50 and 80 km. General considerations of the way in which thermal energy reaches the upper atmosphere are used to estimate temperature and wind distribution at high elevations over the poles. The problem of free electron balance in the various ionospheric layers is also discussed. Results of a study on oxygen afterglow are outlined together with those of Meinel's infrared studies and excitation of water vapor in oxygen afterglow.

1435

Kennedy, W. B., "Atmospheric Winds and Temperatures in the 30-to-60-Kilometer Region over Eastern Colorado as Determined by Acoustical Propagation Studies 31 October 1951 to 28 August 1952," Sci. Rept. No. 3, Denver Res. Inst., Univ. of Denver, Colo., 41 pp., 1954.
AD-28, 523.

Acoustical propagation studies were made to determine the seasonal variation of high-altitude winds and temperatures over eastern Colorado. Measurements were taken once a month during the period from 31 October 1951 through 28 August 1952. Operations were centered at latitude 39° N, longitude 103°40' W (near Limon), and extended radially about 200 km. A variation in the azimuth and distance from sound source to recorder positions permitted the separation of wind and temperature components of the observed upper-atmosphere sonic velocity gradients. The average wind vector obtained from treatment of the azimuth-shift information appeared to move clockwise as the seasons advanced.

1436

Kennedy, W. B., et al., "Atmospheric Winds and Temperatures to 55-Kilometers Altitude over Southwestern New Mexico as Determined by Acoustical Propagation Studies 0600-1020 MST 22 October 1952," Sci. Rept. No. 2, Denver Res. Inst., Univ. of Denver, Colo., 1952.
AD-18, 564.

As part of Operation T-Day, a cooperative effort of a number of agencies, an average of two measurements per day of upper atmosphere winds and temperatures was made during the period 20-24 October. Analyses of a portion of the large amount of data obtained has been completed and results are presented in this paper. The method of calculation employed was generally that synthesized and developed by A. P. Crary; however, a sound-velocity vs altitude model of the atmosphere recently developed at Denver Research Institute was also employed. Methods of calculation are discussed in detail.

Two goals were sought in the performance of this research: the first was to make observations concurrently with other participants in Air Force Operation T-Day for ultimate comparison and correlation; the second, to make observations with sufficient frequency so that the existence and extent of any diurnal variation of high altitude winds and temperatures can be determined.

Calculations of results of the diurnal study are not yet complete since these calculations require the availability of all results of the high-altitude wind and temperature measurements. One set of the ten measurements of upper atmosphere winds and temperatures is presented in this paper.

1437

Kennedy, W. B., and L. Brogan, et al., "Determination of Atmospheric Winds and Temperatures in the 30-60 km Region by Acoustic Means," Denver Res. Inst., Univ. of Denver, Colo., 1950-1954.

Thirteen quarterly progress reports and a final, summarizing report describe four years of experimental and theoretical research on the problem of determining winds and temperatures at high altitudes (30-60 km) from acoustic measurements. Acoustic energy from explosions of 200-lb charges of TNT was recorded at a number of points lying on a circle of 200 km radius around the firing site. From travel time and angle of arrival measurements of the acoustic wave front plus local wind and temperature data, the sound ray paths and the upper-level winds and temperatures, which caused these paths by refraction, were calculated. One method of calculation employed, with certain simplifications, was developed originally by A. P. Crary. Another method used assume that the sound velocity vs altitude structure in the upper air follows a hyperbolic-cosine curve. A new method of treating azimuth-shift data is also presented.

Annual and diurnal variations of high-altitude winds and temperatures were determined in Colorado and New Mexico. Winds were generally westerly and strong during the winter and easterly and of small magnitude during the summer. High-altitude temperatures increased while winds decreased as time advanced during daylight hours. Minimum temperatures and maximum winds generally occurred at about 1000 MST on any given day. As shown below, most of the reports in this series have AD or ATI numbers for use when ordering from DDC (formerly ASTIA).

Qtly. Prog. Rept. 1, June-August, 1950
" " " 2, September-November, 1950
" " " 3, December, 1950-February, 1951, ATI-109, 427
" " " 4, March-May, 1951
" " " 5, June-August, 1951, AD-8 990
" " " 6, September-November, 1951, AD-8 989
" " " 7, December, 1951-February, 1952, AD-38 760
" " " 8, March-May, 1952
" " " 9, June-August, 1952
" " " 10, September-November, 1952, AD-26, 714
" " " 11, December, 1952-February, 1953, AD-20 318
" " " 12, March-May, 1953, AD-31 806
" " " 13, June-August, 1953, AD-36 902
Final Report, 30 June 1954, AD-36 812

1438

Kennedy, W. B., L. Brogan, et al., "The Diurnal Variations of Atmospheric Winds and Temperatures in the 30- to 50-Kilometer Region over Southwestern New Mexico by Acoustical Propagation Studies 20-24 October 1952," Sci. Rept. No. 4, Denver Res. Inst., Univ. of Denver, Colo., 65 pp., 1954.
AD-31 820.

Measurements of upper-atmosphere winds and temperatures were made by means of acoustic propagation studies. Ten measurements were made by employing the method of calculation synthesized and developed by A. P. Crary (J. Meteorol., 7, 233, 1950). A new method discussed by F. J. W. Whipple (Quart. J. Roy. Meteorol. Soc., 61, 285, 1935) is proposed for determining upper-level winds by use of azimuth-shift data. An analysis of results established that the upper atmosphere temperatures increased as the winds decreased with the advance of time of day through the daylight hours.

1439

Kennedy, W. B., L. Brogan, and N. J. Sible, "Further Acoustical Studies of Atmospheric Winds and Temperatures at Elevations of 30-60 Kilometers," J. Meteorol., 12, 519-532, 1955.

Results of firing 200-lb charges of TNT and recording the elevation and the azimuth of the sound wave by an array of microphones are described. Operations in Colorado, 31 October 1951-28 August 1952, confirmed the broad conclusions of the earlier Colorado series. Those conducted in New Mexico bihourly from 20-24 October 1952 (T-day) are fully treated. The winds and temperatures between 25 and 55 km are tabulated and plotted. The average wind was 23-39 meters per sec. from 242-276°, but there were marked fluctuations over very short periods. Temperature increased as wind decreased with advancing time of day.

1440

Machine Design, "Multiple-Explosive Rockets will Measure the North Wind, Spot Checks Under way in Three Spots," Mach. Design, 29, 27-28, 1957.

Refers, briefly, to experiments by Army scientists with Aerobee-Hi rockets, which it is expected will lead to more accurate predictions of cold weather.

1441

Maeda, K., H. Matsumoto, Y. Takeya, and T. Okumoto, "Measurement of Atmospheric Temperature and Wind Velocity by Kappa Rockets," Rep. Ionosphere Space Res. Japan, 14, 385-404, 1960.

Measurements were made in the region ranging from the height readily attainable by radiosonde up to about 60 km. The grenade-explosion method was used. The process of deducing the height distributions of temperature and wind velocity by sound propagation analysis is given. Results are given for Dec., 1958, and March, 1959.

1442

Murgatroyd, R. J., "Anaomalous Sound Reception Experiments," M. R. P. No. 346, Air Ministry, Meteorological Res. Committee, London, 19 pp., 1947.

Results of sixteen experiments in England between April, 1944, and April, 1945, in which recordings of sound received by anomalous paths from large explosions were utilized to obtain data on upper air winds and temperatures. Methods used and their limitations outlined. Results tabulated.

1443

Murgatroyd, R. J., "Wind and Temperature to 50 KM over England, Anomalous Sound Propagation Experiments, 1944-1945," Geophys. Mem. Meteorol. Off. (London), 30 pp., 1955.

The geometry of zones of audibility is set out. In sixteen experiments explosions at seven to ten points in England were recorded on lattices of microphones. Audibility (up to 387 km) and time of travel are tabulated. The experiments gave, with certain assumptions, the vertical distribution of temperature and winds of 18-50 km. Temperature at 50 km varied from 310°K in July and August to 264°K in January. Wind at 30-45 km changed from westerly 40-80 meters per sec. in winter to easterly < 20 meters per sec. in summer. Radiosonde measurements up to 18 km are given for comparison.

1444

Nordberg, W., "Upper Atmosphere Rocket Soundings on the Island of Guam (IGY Project 10.18)," Tech. Rept. 2078, Army Signal Research and Development Lab., Fort Monmouth, N. J., 142 pp., 1959.
AD-228 443.

The performance of the rocket-grenade experiment on Guam during November, 1958, is reviewed. Nine rockets (six Nike-Cajuns and three Aerobee 75's) were launched successfully. A total of 43 data points, each representing one value for temperature, wind speed, and direction, were obtained. The measurements were spread over the period between local sunset and sunrise and cover an altitude range from about 30 to 80 km. Radiosonde data for heights below 30 km are available.

1445

Obukhov, A. M., "Scattering of Waves and Microstructure of Turbulence in the Atmosphere," J. Geophys. Res., 64, 2180-2187, 1960.

A brief survey of the theory of the scattering of waves by turbulent inhomogeneities. Discusses experiments in the study of sound scattering by turbulence in the surface layer of the atmosphere. These experiments were carried out to obtain some information on the turbulent spectrum; their results are compared with the data of meteorological measurements in the surface layer.

Discusses application of scattered radio waves to the study of ionospheric turbulence.

1446

Olsen, R. O., "Acoustical Determination of Winds by Means of a Circular Microphone Array," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 77-87, 1961.
AD-408 716.

An experimental acoustical circular array was set up to determine the wind field near the surface. The array consists of eight microphones placed in a circle, with a sound source at the center. A wind component is determined for each of the eight points from the time arrivals of sound at the microphone positions. By statistically averaging these components a mean wind vector is derived which best fits the various wind components. The accuracy of the mean wind is determined, and some of the errors inherent in the system are described. This data is also compared to the readings from standard measuring equipment located at the site.

1447

Puth, J. W., "Investigation of Stratosphere Compressional Wave Velocities by Studies of Refracted Waves from Explosive Sources," Final Rept., Geophys. Inst., Univ. of Alaska, College, Alaska, 4 pp., 1951.
AD 4 412

In order to investigate the temperature and winds at 30-60 km altitudes, a study of compressional wave velocities was undertaken by firing a series of five two-hundred-pound charges per month for a year and recording the signal received by a five-microphone array utilizing T21-C condenser microphones and a GR-8 sound-ranging recorder.

The conclusions indicate little significant seasonal variation in winds. Azimuth shifts were small, providing little opportunity for resolving a coherent picture of winds aloft. In general, the magnitude of the winds was less than expected. No firm conclusions concerning stratospheric temperature could be obtained.

1448

Regula, H., "Investigation of the High Stratosphere by Explosion Waves" (in German), Meteorol. Rundschau, 2, 263-267, 1949.

Zones of silence and abnormal audibility of explosions point to a strong inversion at 35 to 40 km. This is confirmed by V-2 ascents. The location of zones audibility exceeding 150 km, mainly to west in summer and east in winter, agrees with summer and winter winds, according to Scherhag (1948), from topography of 41 mb surface (ca. 22 km). These winds are considered, therefore, to represent the whole layer from 20-45 km. Further experiments should bring temperatures and winds up to 45 km into discussion of synoptic problems.

1449

Richardson, J. M., and W. B. Kennedy, "Atmospheric Winds and Temperatures to 50-Kilometers Altitude as Determined by Acoustical Propagation Studies—and Appendixes A Thru C—21 July 1950 Thru 31 May 1951," Sci. Rept. No. 1, Univ. of Denver, Colo., 42 pp., 1951.
ATI-171, 410.

During the period 21 July 1950 through 31 May 1951, there were, on the average, three measurements each month of upper-atmosphere winds and temperature were made by means of acoustical propagation studies. Field operations were centered in Wray, Colorado, and extended radially 200 km. A variation in azimuth and distance from sound source to recorder positions permitted the separation of wind and temperature components of the observed upper-atmosphere sonic velocity gradients. It was found that upper winds were generally westerly and of large magnitude during the winter, and easterly and of small magnitude during the summer, with wide fluctuations during the equinoctial periods. Short-term fluctuations in the wind vector were observed to be of the same order of magnitude as the vector itself. Above 25 km altitude, a doubly-periodic annual variation in temperature was observed.

1450

Richardson, J. M., and W. B. Kennedy, "Atmospheric Winds and Temperatures to 50-Kilometers Altitude as Determined by Acoustical Propagation Studies," J. Acoust. Soc. Am., 24, 731-741, 1952.

Between 21 July 1950 and 31 May 1951, upper-atmosphere winds and temperatures were measured three times each month, on the average, by means of acoustical propagation studies. Field operations were centered in Wray, Colorado, (40^{o} N lat, 102^{o} W long) and extended radially 200 km. A variation in azimuth and distance from the sound source to the recorder positions permitted the separation of wind and temperature components of the observed upper-atmosphere sonic velocity gradients. It was found that upper winds were generally westerly and of large magnitude during the winter (autumnal to vernal equinox), and easterly and of small magnitude during the summer, with wide fluctuations during the equinoctial periods. Short-term fluctuations in the wind vector were observed to be of the same order of magnitude as the vector itself. The short-term fluctuation is now well-established. A doubly-periodic annual variation in temperature was observed above 25 km altitude, with mean value in agreement with accepted NACA values.

1451

Rolt, H., "Rockets for Atmospheric Research," Instr. Pract., 9, 427-430, 1955.

Recounts the histories of German war rockets and White Sands research rockets, and the results obtained with the latter, are set out. The thermionic and alphatron ionization gauges are illustrated. The Aerobee, "the rockoon," and methods of measuring temperature and wind velocity by sound waves are described.

1452

Stroud, W. G., E. A. Terhune, J. H. Venner, J. R. Walsh, and S. Weiland, "Instrumentation of the Rocket-Grenade Experiment for Measuring Atmospheric Temperatures and Winds," Rev. Sci. Instr., 26, 427-432, 1955.

Analyzes results of 92 grenade explosions from 15 Aerobee rocket firings from March 3, 1950, to September 4, 1953, at White Sands, N. M., to determine efficiency of this method of determining upper air temperatures and winds. From four to eight grenades are exploded on each flight at specified heights (which can be determined to ±1 to 6 ft at 100,000 ft by photographic methods). The formulas $C = kT^{1/2}$ and $V = C + W$ are used, where C is the velocity of sound due to elasticity, k is a constant, T is absolute temperature, V is the velocity of propagation of sound wave, and W is the wind velocity. Timing to 0.1 millisecond is necessary, and the sound detectors are arranged so they are nearly vertically beneath each grenade when it is exploded. The temperatures and wind can be determined for each successive layer (between grenade firings).

The text includes a summary of the fifteen firings; illustrations of equipment and of some of the records; and descriptions of methods, rockets, rocket instrumentation, grenade structure, flash detectors, telemetering system, safety features, sound ranging equipment, and positions of grenade explosions (with ground temperatures).

1453

Trans. Am. Geophys. Union, "Report of the Committee on the Upper Atmosphere," 38, 954-959, 1957.

A summary of research since 1952 concerned first with that portion of the stratosphere (below 30 km) which has been explored mainly by sounding balloons, and then with the atmosphere above 30 km, which has been investigated mainly by rocket, acoustic, and radio techniques.

1454

Uretz, E. F., "Study of Meteorological Surveillance Observing System," Quart. Progr. Rept. No. 3, Armour Res. Foundation, Chicago, 33 pp., 1960.
AD-269 342.

Analyzes methods, classifying them according to the energy used. Discusses a technique for the measurement of air temperature and water-vapor content by utilizing microwave energy emitted by CO_2 and O_2, and proposes a technique for measuring air temperature by utilizing infrared energy.

Discusses acoustical techniques for measuring wind velocity and a technique for reducing integrated temperature-and-water-vapor data to local data. —see also Hori, S. (1959), for earlier reports in this series.

1455

Uretz, E. F., "Study of Meteorological Surveillance Observing System," Quart. Progr. Rept. No. 4, Armour Res. Foundation, Chicago, Ill., 74 pp., 1960.
AD-272 376.

Intensive investigations were made of techniques involving acoustics, infrared, radar, etc., which appear best suited to measuring temperature, water-vapor pressure, and wind velocity, by passive means. The block diagram for an over-all system to passively determine temperature, pressure, water vapor pressure, and wind velocity was constructed. —see also Hori, S. (1959), for earlier reports in this series.

1456

von dem Borne, H., "Acoustic Wind Measurement" (in German), Meteorol. Rundschau, 7, 217-220, 1954.

Methods are set out, with tables, for determining wind velocity from deformation in the free air of a sound wave, using four microphones placed in four main directions around the source, and timing arrival of the sound or measuring phase changes. The results are said to be accurate if the air temperature is known.

1457

Weisner, A. G., "Measurements of Winds at Elevations of 30 to 80 Kilometers by the Rocket-Grenade Experiment," J. Meteorol., 13, 30-39, 1956.
AD-104 501.

Thirty-two values of wind velocity between 30 and 80 kilometers have been obtained from six Aerobee rocket flights made at night at White Sands Proving Ground, N. Mex. (32° N) between July, 1950, and November, 1951. The average wind velocity in a horizontal layer at a particular altitude was determined from the effect of the wind on a sound wave traveling downward through the layer. The sources of the sound waves were grenades. The travel times of the sound waves to a point of ground almost directly underneath the grenades and the arrival angles of the waves at the ground are the data required for the calculations. The wind directions were found to be easterly in summer and westerly in autumn and winter. The maximum wind speeds were at about 55 km, the largest measured speed having been 104 meters per second.

1458

Whipple, F. J. W., "Propagation to Great Distances of Air Waves from Gunfire," J. Roy. Meteorol. Soc., 60, 80-88, 1934.

The object of the experiments, which are the picking-up by Tucker microphones of the sound from distant firing, usually at Woolwich, is to investigate the properties of the upper air. It is generally found that the waves take so long on their journey that they must have made a long detour through the upper atmosphere. The result of the experiments gives an estimate of the temperature in regions of the atmosphere for which no other method had been found up to the time of this report. Maps show places in England to which sounds have been carried on various occasions, and diagrams show the calculated temperature and velocity of sound with height in the atmosphere.

1459

Whipple, F. J. W., "The Propagation to Great Distances of Air-Waves from Gunfire, Progress of the Investigation During 1931," Quart. J. Roy. Meteorol. Soc., 58, 471-478, 1932.

Earlier gunfire experiments are continued and acoustic data reported. Tables show air temperatures and the velocities of sound as measured on the ground and as calculated for tropopause heights as well as for maximum altitudes of sound-ray paths. The calculations are based on measured travel times and determinations of the arrival angles of sound rays at microphone arrays. Presents several upper air temperature profiles, to altitudes of 50 km, as calculated from acoustic data.

Meteorology, Determinations from Acoustic Data, Measurement
See also—75, 445, 451, 502, 514, 550, 563, 564, 570, 682, 688, 691, 697, 698, 714, 716, 883, 895, 902, 1151, 1152, 1156, 1180, 1182, 1242, 1249, 1252, 1255, 1257, 1321, 1377, 1463, 1465, 1466, 1471, 1475, 1483, 1484, 1487, 1489, 1498, 1515, 1520, 1545, 1557, 1715, 2045, 2046, 2113, 2120, 2124, 2125, 2128, 2131, 2133, 2288, 2817, 2858, 2928, 3028, 3223, 3224, 3231, 3235, 3262, 3271, 3272, 3276, 3358, 3360, 3648, 3649, 3914, 4065, 4084, 4085, 4086, 4087.

METEOROLOGY, DETERMINATIONS FROM ACOUSTIC DATA, THEORY

1460

Andreev, N. N., "The Program of Further Acoustical Investigation of the Stratosphere and the Study of the Acoustics of the Free Atmosphere," Proc. All-Union Conference of the Study of the Stratosphere, Moscow-Leningrad, 105-111, 1938.

General problems of acoustics are discussed. Some supplementary factors to be considered are gravity, rotational forces of the earth, wind, dust, absorption and reflection of sound, and most important, temperature.

1461

Barrett, E. W., and V. E. Suomi, "Preliminary Report on Temperature Measurement by Sonic Means," J. Meteorol., 6, 273-276, 1949.

Following a brief review of the assumptions involved in the Laplacian expression for the speed of sound waves, an instrument, the sonic thermometer, is described which utilizes this relationship to measure the air temperature. The advantages of the sonic thermometer are then discussed; chiefly, they are the absence of radiational errors, and extremely low lag—a result of the fact that the measured variable, the speed of sound, is independent of the properties of the measuring elements.

1462

Belov, A. I., "Theory of the Acoustical Sounding of the Atmosphere and Experimental Material Before 1932" (in Russian), Proc. All-Union Conference of the Study of the Stratosphere, 125-138, 1938.

Reviews observations of sound propagation after powerful explosions from 1920 to 1932. Aerological observations and the propagation of sound analyzed; scheme and instruments for further investigations outlined. Hypotheses suggested in the study of the acoustical phenomena, along with critical consideration of results of investigations.

1463

Benndorf, H., "On Experimental Investigations of the Upper Layers of the Atmosphere, I. Sound of the Atmosphere by Sound Waves" (in German), Physik. Z., 30, 97-115, 1929.

A compact review is given of investigations of the free atmosphere, considering movement, temperature, pressure, thickness, composition, ionization, electrical properties, etc. Indicates that sound propagation could be used for many types of investigations of the atmosphere. Importance of the effect of temperature and wind on velocity and conditions of sound propagation is stressed, and equations are given. A good theoretical article.

1464

Best, A. C., "Physics in Meteorology," Meteorological Acoustics, Pitman Publ. Corp., N. Y., Sec. 49, 123-126, 1957.

The physics of sound propagation in the atmosphere, its velocity, attenuation, diffraction, etc., are discussed. The use of sound propagation (especially from large explosions, accidental or deliberate) for determining temperature and wind in the upper atmosphere is explained.

1465

Cannon, W., and A. Richter, "Low Level Wind Measurement," Quart. Rept. No. 1, Ford Instrument Co., Div. of Sperry Rand Corp., Long Island City, N. Y., 55 pp., 1960.
AD-249 630L.

A literature search has been made to investigate previous methods of measuring the wind.

When two sonic signals of different frequencies are mixed together, the result will be a new signal with a variable amplitude and phase angle. Both the amplitude and phase angle are periodic functions with a frequency equal to the difference between the two original frequencies.

If two sonic signals, focused into beams, intersect at a point in space, a unique volume will exist in which the two signals can join. This volume will reradiate a sonic signal which will be detected by multiple receivers. The difference in the times of arrival at the receivers is used to compute the wind velocity.

Sonic methods using frequency or phase shift can be used to measure wind velocity. If two fixed transmitters are used, a receiver suspended from a balloon moving with the wind will receive signals of slightly different frequency from each transmitter. These signals are sent back to the base station by radio waves which can also be used to locate the receiver. An electrically or pneumatically operated sonic transmitter will send signals from a balloon moving with the wind to two receivers on the ground. The different frequencies received are used to fix the transmitter location and determine the wind velocity. In addition, the mechanisms of energy loss are delineated.

1466

Cox, E. F., "Upper Atmosphere Temperatures from Remote Sound Measurements," Am. J. Phys., 16, 465-474, 1948.

Basic material covered mostly by Cox and others, 1949. Good review of development of theories of acoustical soundings of the atmosphere, determinations of temperature, etc.

1467

Duckert, P., "Dispersion of Explosion Waves in the Atmosphere" (in German), Gerlands Beitr. Geophys., 1, 236-290, 1931.

Various aspects of the theory of longtitudinal waves in the atmosphere are taken up: the propagation speed of longitudinal waves in a gas; the spread of explosion waves in a calm, even, and horizontally stratified medium; in a windy such medium; in any stratified medium. Special solutions, by differential equations, are worked out for determining ray paths. A report is given of research on explosion-wave propagation by systematic detonations, instruments, methods, etc. Practical results of pressure registering and conclusions as to the construction of the atmosphere, including results of pure acoustical observations, are given. A possible explanation for the high speed of sound in the upper stratosphere, and of high temperatures there, is outlined, and the importance of air sounding in aerologic research stressed. A highly theoretical article.

1468

Duckert, P., "The Study of Explosion Waves as Aerological Means for Investigation of the Higher Atmosphere Layers" (in German), Meteorol. Z., 46, 455-461, 1929.

Discussion of acoustical sounding methods, theories, and applications for upper air research. Effects of temperature and wind on speed of sound considered.

1469

Fetter, R. W., P. L. Smith, Jr., and B. L. Jones, "Investigation of Techniques for Remote Measurement of Atmospheric Wind Fields," Rept. No. 3, Phase 3: Design of Experiments, Midwest Res. Inst., Kansas City, Mo., 15 Feb.-30 June 62, 68 pp., 1962.
AD 283 780.

Experiments were designed to provide information needed to assess the practicability of two possible methods of remote wind measurement: electromagnetic scattering from acoustic waves; and electromagnetic scattering from natural atmospheric turbulence. The electromagnetic-acoustic (EMAC) method was demonstrated previously, and the present experiments have been designed to determine the capabilities of the method in range, accuracy, resolution, response time, and wind field mapping. Use of backscattering from natural turbulence is not practical at the present state of the art, but experiments have been designed to determine scale of turbulence, velocity, intensity, and rate of occurrence at low levels to provide data for better analytical representation of atmospheric turbulence.

1470

Fetter, R. W., et al., "Investigation of Techniques for Remote Measurement of Atmospheric Wind Fields," Rept. No. 2, Phase 2: Analysis, Midwest Res. Inst., Kansas City, Mo., 1962.
AD 274 254.

Analyses were made to determine the feasibility of three proposed methods of remote wind measurement using (1) scattering from natural atmospheric turbulence; (2) electromagnetic scattering from acoustic waves; and (3) infrared tracking of an artificially heated volume of air, or "bubble." Use of natural turbulence as a sensor will require (1) additional data on distribution and characteristics of turbulence from ground level to an altitude of one mine, (2) correlation of turbulence motion and wind, and (3) radar state-of-the-art improvement to provide consistent detection and measurement.

Remote wind measurements by microwave reflection from acoustic waves have been demonstrated, but additional experimental data are needed to determine maximum usable range and the effects of turbulence on the acoustic waves.

Remote generation of a heated bubble of air does not appear feasible.

1471

Groves, G. V., "Effect of Experimental Errors on Determination of Wind Velocity, Speed of Sound and Atmospheric Pressure in the Rocket-Grenade Experiment," J. Atmospheric Terrest. Phys., 9, 237-261, 1956.

Expressions are obtained for systematic and random errors in the grenade-experiment determination of wind velocity, speed of sound, and atmospheric pressure, arising from systematic and random errors in the various quantities measured; viz., the coordinates and time of explosion of each grenade and the coordinates of each microphone and the times of arrival of the sound waves.

The theory is first developed for a general distribution of microphones on the ground and of grenade bursts in the air. The results obtained are applied to the special case of four microphones, comprising a central microphone and three symmetrically placed microphones, with grenades bursting vertically above the central microphone. Under certain simplifying assumptions, expressions are obtained to show how the errors in the final determinations are related to the measurement errors, and also to the nature of the atmospheric structure under investigation.

Values are calculated for the errors that would arise in wind velocity, speed of sound, and pressure under certain typical conditions.

METEOROLOGY, DETERMINATIONS FROM ACOUSTIC DATA, THEORY

1472

Groves, G. V., "Introductory Theory for Upper Atmosphere Wind and Sonic Velocity Determination by Sound Propagation," J. Atmospheric Terrest. Phys., 8, 24-38, 1956.

Considers the problem of deriving the mean values of the horizontal wind velocity components u(z), v(z), and the velocity of sound c(z), averaged with respect to height z along a sound ray traveling between two known points in the atmosphere, from measurements of the time of travel of the ray between these points and the coordinates of the ray. It is shown that, for a ray which does not suffer total reflection, expressions can be derived for $\overline{u(z)}$, $\overline{v(z)}$, and $\overline{c(z)}$ in terms of the measured quantities, and the mean value of the vertical component of wind velocity w(z), provided the variations in u(z), v(z), w(z), and c(z) with height are sufficiently small. The theory is carried further by working out in detail the second-order contributions to $\overline{u(z)}$, $\overline{v(z)}$, and $\overline{c(z)}$ which arise from the variations in u(z), v(z), w(z), and c(z). Using typical atmospheric data, the more important of these second-order terms are evaluated numerically for the case of a sound ray received at an observation point on the ground from a source at any height up to 90 km. It is shown that the contributions from these terms to $\overline{u(z)}$, $\overline{v(z)}$, and $\overline{c(z)}$ are less than 0.8 m/sec when the ray lies near the vertical. For a ray which departs appreciably from the vertical (inclination about 45°), the contributions amount to a few meters per second, but are unlikely to exceed about 8 m/sec unless exceptionally large wind velocities are present.

1473

Groves, G. V., "A Rigorous Method of Analyzing Data of the Rocket-Grenade Experiment," J. Atmospheric Terrest. Phys., 9, 349-351, 1956.

A set of three equations developed in an earlier paper (Groves, J. Atmospheric and Terrest. Phys., 8, 24-38, 1956) express in integral form the horizontal components of wind velocity and the speed of sound at any desired height up to 90 km in terms of quantities that can be measured at and from the ground. These measurable quantities are the x, y, z coordinates in space of at least two exploding grenades, the x and y components of the velocity of the sound as it passes a detection point 0 on the ground at the origin of the coordinate system, and finally, t, the travel times of the sounds from grenades to point 0. Either graphical or numerical differentiation of the integral equations then yields the desired components of wind velocity and speed of sound. With these quantities determined, the air temperature at the corresponding altitude may be calculated. With three grenades a rough linear variation of wind and temperature with height may be determined, while with four or more, an increasingly accurate variation with height may be determined.

1474

Gutenberg, B., "With What Accuracy Can the Speed of Sound in the Stratosphere Be Determined?" (in German), Gerlands Beitr. Geophys., 35, 46-50, 1932.

Method for calculating temperature by sound propagation study described; theories of Whipple and Meisser briefly considered and compared.

1475

Harrington, J. B., Jr., "Acoustical Probing of the Upper Atmosphere," Univ. of Mich., 5500 East Engineering, Ann Arbor, 40 pp., 1959.

This paper presents a comprehensive review of historical and current techniques and investigations for accurately determining the propagation characteristics of sound in the atmosphere. Anomolous propagation and the application of Snell's Law of refraction for calculating sound-ray paths are discussed. Gutenberg's approach to measuring upper winds and temperatures using sound rays is described, followed by an account of Richardson's and Kennedy's "Study of Meteorological and Terrain Factors Which Affect Sound Ranging" and "Determination of Atmospheric Winds and Temperatures in the 30 to 60 Kilometer Region by Acoustic Means." The rocket-grenade experiment for determining upper-level wind and temperature profiles is explained as conducted by the Signal Corps and as modified by Groves. A bibliography of more than eighty reports and journal articles on the subject of propagating sound in air is included.

1476

Hori, S., "Study of Meteorological Surveillance Observing System," Quart. Progress Rept. No. 2, Armour Research Foundation, Chicago, Ill., 31 pp., 1959.
AD-272 375.

Several concepts for indirect measurement of atmospheric properties were uncovered. Two of these possess potential as the bases of true surveillance techniques and two others provide path-integrated measures of pertinent parameters. The four concepts discussed are: (1) acoustic sounding, (2) interaction of acoustic and electromagnetic energy, (3) gas emission thermometry, and (4) optical lapse rate observations. (See also Uretz (1960) for more reports in this series.)

1477

Kolzer, J., "Questions of Anomalous Sound Propagation" (in German), Z. Geophysik, 10, 215-221, 1934.

A review of various theories with good references. The high-temperature theory of the upper atmosphere is favored. The importance of studying sound propagation to aerologic research is stressed.

1478

Meecham, W. C., "Theory of Acoustic Propagation at High Altitudes," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 177-181, 1961.
AD-408 716.

Discusses the theory of pressure-fluctuation backgrounds at high altitudes, as observed by freely floating balloon systems. Examines the various possible sources of such backgrounds, and proposes a theoretically predicted level and power spectrum. The pressure levels of local hydrodynamic (incompressible) phenomena and the time characteristics of such effects are considered in particular. Propagated acoustic backgrounds are considered and correlation methods for separating these effects from local hydrodynamic phenomena are reviewed; the characteristics of such backgrounds, if generated by turbulence, are treated with particular emphasis on the sound power-spectrum. Emphasis is placed upon the predicted difference in spectra, from two theories (those of Kraichnan on the one hand and of Meecham and Ford on the other).

These theoretical remarks are examined in the light of actual measurements taken at high altitudes, and tentative conclusions are drawn.

1479

Monin, A. S., and A. M. Obukhov, "Slight Atmospheric Variations and the Adaptation of Meteorological Fields," Am. Meteorol. Soc., Boston, Mass., 18 pp., 1959.
AD-215 605.

On the basis of the solution of the problem of slight variations in a baroclinic atmosphere, a general classification of the main types of dynamic processes in the atmosphere (horizontal vorticity motions, and gravitational and acoustic waves) is given. The work also gives the general form of the invariant, with which the critical stationary state of the atmosphere can be computed, using aribrary initial data, without analyzing the wave processes which cause reorganization of the fields. The filtering role of the quasi-static approximation is explained. Internal acoustic waves are filtered out and somewhat overrate the frequencies of gravitational waves. Only several minutes are required to establish quasistatic equilibrium in the atmosphere.

1480

Nordberg, W., "A Method of Analysis for the Rocket-Grenade Experiment," Tech. Memo. M-1856, Army Signal Engineering Labs., Fort Monmouth, N. J., 37 pp., 1957.
AD-143 218.

The method of analysis for the rocket-grenade experiment is reviewed. An analytical method is derived to obtain temperature and wind data from sound explosions between 30 and 80 km altitude. Errors stemming from both random measuring errors in the initial parameters and systematic sources in the method are investigated. It is concluded that average temperatures and winds in layers of several kilometer thickness between two successive explosions may generally be determined within ±2.5°K and ±5 m/sec, respectively.

1481

Norwood, V. T., "Further Discussion on the Feasibility of Tracking Sound Waves by Electromagnetic Waves — and Appendixes I-IV," Signal Corps Eng. Labs., Fort Monmouth, N. J., 10 pp., 1949.
ATI-64, 904.

The feasibility of tracking vertically propagated sound waves by radar was investigated, in order to obtain a complete time plot of the position. The property of the sound waves to be utilized is that of the dielectric variation, set up by successive pressure bands within the waves, which will reflect an electromagnetic wave. Since the velocity of sound is a function of temperature, valuable atmospheric information may be cheaply obtained. A sound wave of 2500 cycles is shown to be the optimum frequency for purposes of radar tracking. The actual reflectivity of a sound pulse will not be calculable until the solution of a Mathieu equation has been found. Wind considerations alone make the tracking of sound waves unfeasible for general atmospheric uses with the present radar equipment.

1482

Penndorf, R., "Anomalous Sound Propagation and the Ozonosphere" (in German), Z. Geophysik, 12, 315-321, 1936.

The sounding of upper air by anomalous propagation is discussed The effect of ozone on temperature at 35-40 km is pointed out, as are changes in the distribution of temperature (summer and winter) in the stratosphere over Arctic and central Europe, and consequent variations in wind directions.

1483

Penndorf, R., "The Temperature of the Upper Atmosphere" (Translated by C. C. Chapman), Bull. Am. Meteorol. Soc., 27, 331-372, 1946.

A theory of high temperatures in the upper atmosphere is supported by results of anomalous sound propagation (only briefly discussed here), and of research on ozone and meteors, as well as by the theory of atmospheric tides.

1484

Regula, H., "Sound Propagation in the Atmosphere" (in German), Z. Geophys., 10, 167-185, 1934.

Results briefly discussed of sound records of explosions, 1923-1929, at Geophysical Institute, Gottingen. Suggests the possibility of measuring upper air winds by sound measurements. Gives a conception of the construction of the atmosphere, and applies results of the Oldebroek explosion.

1485

Rothwell, P., "Calculation of Sound Rays in the Atmosphere," J. Acoust. Soc. Am., 12, 205-221, 1947.

Highly theoretical work in which methods of tracking sound rays for acoustical location of aircraft are described, with a view to their possible application to other meteorological investigations by acoustical methods. Tables have been constructed for meteorological investigations of the upper atmosphere, covering the range of temperature from ground to stratosphere, the range of angles of descent, and time factors, with respect to equations. The procedure for calculating rays by the use of tables of range and time factors is outlined, and examples are given.

1486

Simpson, G. C., "Physics in Meteorology," Lecture No. 18, Phys. in Ind., 21 pp., 1933.

The author shows by example how various branches of physics — sound, light, heat, magnetism and electricity — may be used to solve problems in meteorology. The zones of audibility and the zones of silence experienced around the position of a large explosion have been used to determine the temperature at heights of 40 to 55 km above the earth's surface. Close investigation of the absorption band due to ozone has been instrumental in determining the seasonal distribution of ozone in the upper atmosphere over the surface of the earth, and likewise its distribution in relation to the cyclones and anti-cyclones of mean latitudes. Proof is given that the effective solar radiation ultimately leaves the earth again as long-wave terrestrial radiation, the author's calculation of the latter agreeing to within 2% of the known incoming radiation.

Curves are drawn for both incoming and outgoing radiation. The curve for outgoing is such that it indicates that the outgoing radiation is the same in all latitudes. This is rendered possible through the transfer of heat from the equator to the poles, a fact long recognized, but only now making possible the use of quantitative values in these problems.

Only a minor part in meteorological problems has been played by magnetism. On the other hand, atmospheric electricity has considerably engaged physicists. The two main problems, (a) the maintenance of the earth's field, and (b) the ionization of the lower atmosphere, are discussed, and the present position as regards the solution of these problems is indicated.

1487

Tverskoi, N. P., "Acoustical Characteristics of Atmospheric Turbulence" (in Russian), Glavnaia Geofizicheskaia Observatoriia, Trudy, 54-60, 1958.

The turbulence of the atmosphere can be studied by observing the propagation of sound waves within it. An indirect means of evaluating atmospheric turbulence is the use of the oscillation of the phase difference of a sound wave passing through an atmospheric layer. The equation for the missing coefficient is

$$K_A = \frac{\sqrt{\overline{\Delta\phi}^2}}{A \frac{\omega}{c^2} \left(\frac{L}{\ell_k}\right)^{1/2}} = \bar{u}_1 \ell_k$$

[$\sqrt{\overline{\Delta\phi^2}}$ = value of phase difference between the sound source and the sound wave, passing through mean characteristic distance (scale of correlation), L = distance covered by the sound wave in the region investigated, $\bar{c}$ = corresponding frequency and mean velocity of sound, $\bar{u}_p$ = mean pulsational velocity of sound].

An experimental design to determine these relationships is described and the results are presented in graphs. The mean square variability of the phase difference depends essentially upon the condition of the atmosphere, wind velocity, gradient wind, temperature, etc. The oscillation of the phase increased sharply with the wind velocity. The phase oscillation diminishes with increased height of wave propagation and of receiver placement.

Registration of pulsations of wind velocity for constant ω, $\bar{c}$, L and $\bar{\ell}$ provided data for determining $\bar{u}_p$ and ultimately A = a dimensionless magnitude which is equal to 5-6. The most characteristic values of turbulent structures occurring under different atmospheric conditions were determined by moving one sound receiver relatively to the other, which remains situated perpendicularly to the sound wave. The value $\bar{\ell}_k$ was found to be an adequate characteristic of the turbulence belonging to an atmospheric state. Further, the oscillation of the phase difference reflects the true turbulence of the atmosphere.

The turbulence coefficients computed by meteorological and acoustical means are compared and a close correlation is observed.

1488

Wegener, K., "Investigation of the Atmosphere by Rockets" (in German), Geofis. Pura Appl., 24, 68-70, 1953.

Rocket measurements of temperature cannot be made accurately by techniques current at the time of this report, but must be based on the propagation of sound. The solar constant and spectrum must also be recalculated considering rocket measurements of the ultrashort waves which are not all intercepted on a normal surface as are larger solar radiations, but are deflected by the earth's magnetic field.

1489

Wexler, H., "Annual and Diurnal Temperature Variations in the Upper Atmosphere," Tellus, 2, 262-274, 1950.

An attempt is made to determine the annual and diurnal variations of temperature to a height of 80 km by knitting together available observations and theoretical results. The observations include radiosonde data, meteor-determined densities, V-2 rocket observations, anomalous propagation of sound, and infrared spectroscopy.

The theory most heavily relied upon is the radiative computation made by Gowan. For the annual temperature range, theory and observations agree reasonably well; in the upper ozonosphere (30 to 55 km), summer temperatures are higher than winter temperatures by amounts equal to or larger than those at the surface. As at lower levels, the annual temperature range aloft increases with latitude. For the diurnal temperature variations there is a large disagreement between the computations of Gowan and Penndorf. However, available evidence appears to favor Gowan's computations, which, together with other considerations, indicate a diurnal temperature range of about 10 to 15°C.

1490

Whipple, F. J. W., "The Detonating Meteor of October 2, 1926," Meteorol. Mag., 61, 253-258, 1926.

Presents details of the occurrence with the idea of investigating upper air temperatures. Some not-completely-satisfactory evidence of audibility in an outer zone is shown.

1491

Whipple, F. J. W., "The Investigation of Air Waves from Explosions, Progress in England," Quart. J. Roy. Meteorol. Soc., 57, 331-335, 1931.

Reports an investigation into the conditions of the upper atmosphere.

Includes two tables: One gives results of observations of air waves from gunfire in England, including distance, time of passage, average angle of descent, etc.; the other shows velocity of transmission of the waves at heights from 40 to 55 km., together with the apparent temperature.

1492

Whipple, F. J. W., "The Propagation to Great Distances of Air-Waves from Gunfire, Progress of the Investigation During 1931," Quart. J. Roy. Meteorol. Soc., 58, 471-478, 1932.

Earlier gunfire experiments are continued and acoustic data reported. Tables show air temperatures and the velocities of sound as measured on the ground and as calculated for tropopause heights as well as for maximum altitudes of sound-ray paths. The calculations are based on measured travel times and determinations of the arrival angles of sound rays at microphone arrays. Presents several upper air temperature profiles, to altitudes of 50 km, as calculated from acoustic data.

1493

Wiechert, E., "Abnormal Propagation of Sound as a Means of Stratosphere Investigation" (in German), Z. Geophysik, 2, 92-101, 1926.

Calculations made on speed of sound at different heights, considering winter and summer temperatures, density of atmospheric layers, wind, etc. Equations formulated and results of research tabulated.

1494

Zanotelli, G., "Acoustical Sounding of Clouds" (in Italian), Ann. Geofis. (Rome), 5, 55-76, 1952.

An elaborate analytical method is found for determining reflection indexes of waves at various frequencies in the audible scale, as functions of droplet size and number in the reflecting cloud. Values of audibility of the reflected sound with and without an amplifier are calculated. It is pointed out that this method of estimating drop size and number by recording the intensity of reflected sounds at varying frequencies should be very useful in observing quick changes taking place in a cloud owing to evaporation, condensation, cohesion, etc., particularly during stormy conditions.

Meteorology, Determinations from Acoustic Data, Theory
See also—451, 502, 514, 522, 557, 873, 874, 875, 885, 1152, 1168, 1181, 1414, 1429, 1434, 1436, 1437, 1438, 1445, 1448, 1458, 1528, 1557, 2118, 2125, 2128, 2288, 2518, 3223, 3235, 3270, 3272, 3327, 3328, 3337, 3366, 3648, 3649

METEOROLOGY, EFFECTS ON SOUND PROPAGATION, MEASUREMENT

1495

Arabadzhi, V. I., "Acoustical Characteristics of the Air Layer near the Ground" (in Russian), Uch. Zap., Leningr. Gos. Ped. Inst., 7, 87-91, 1957.

Investigations of sound propagation in the ground layer of the atmosphere over various natural surfaces are described. The measurements were made over a straight road, a flat grass field, a water surface, and a depression, with a microphone joined to an amplifier output by a millivoltmeter. Sound reflection from a dense grass cover, from a surface of cut grass, and from bushes and leaves was recorded at frequencies of 0.2-4.0 kcs. The effect of atmospheric temperature inhomogeneities upon sound attenuation was investigated by means of laboratory apparatus, which is described in detail. In these laboratory experiments attenuation coefficients between 10^{-5} and 10^{-4} cm^{-1} were obtained, which is in fair agreement with investigations made in the free atmosphere.

1496

Baron, P., "Propagation of Sound in the Atmosphere and Audibility of Warning Signals in the Presence of Ambient Noise" (in French), Ann. Telecommun., 9, 258-274, 1954.

In an introductory section the author reviews the various factors which affect the long distance propagation of sound in the atmosphere: attenuation (influenced by water vapor content), winds, and temperature gradients. A description follows of experiments carried out in "les vals d'Yonne." Sirens were used as sound sources at different heights above the ground, and wind and temperature gradients were recorded and correlated with the observed signal strengths received. Variations of signal strength were recorded at different distances from the source and at various times of the year. The effects of noise and wind on the audibility of the received signals were studied.

1497

Benson, R. W., and H. B. Karplus, "Sound Propagation Near the Earth's Surface as Influenced by Weather Conditions," WADC Tech. Rept. No. 57-353, Armour Research Foundation, Chicago, 1958.
AD-130 793.

The influence of various weather conditions on sound propagation in the atmosphere has been studied. The source was a propeller-type aircraft flown at altitudes up to 4800 feet and at distances up to 9600 feet. The propagation was studied for angles of elevation with respect to the earth's surface of 14-1/2^{o}, 30^{o}, and 90^{o}. Noise data were collected for 1300 passes of the airplane over and around a ground observing point. The weather conditions varied during a year's time to include typical weather conditions available in the Chicago area. The noise propagated to the earth was analyzed to determine the variation in attenuation as a function of frequency and as a function of the relative position of the airborne noise source. A statistical analysis determined the effects of various weather parameters on sound propagation. Average values of sound attenuation were obtained. The effects of temperature, temperature gradient, humidity, wind, and wind gradient are given in an empirical formula. Wind direction was the most important factor for minimizing the noise on the ground on a particular day.

1498

Beyers, N. J., O. W. Thiele, and N. K. Wagner, "Performance Characteristics of Meteorological Rocket Wind and Temperature Sensors," Tech. Rept. No. SELWS-M-4, White Sands Missile Range, N. Mex., 31 pp., 1962.
AD-286 254.

Numerous meteorological rocket firings were conducted at missile ranges to obtain atmospheric data in support of missile tests, and the Meteorological Rocket Network resulted in coordinated firings designed to provide a synoptic picture of the high atmosphere. Rocket-borne inertial systems, consisting of radar chaff and metalized parachutes, were utilized to determine wind flow in the altitude range from 50,000 to 250,000 ft. Fall velocities, parachute oscillations, chaff dispersion, and wind-sensor lag times were examined with radar and radiosonde ground equipment.

Some of the problems involved in the temperature-measuring system (Gamma) are also treated with respect to time constant, radiative effects, compressional and nosecone heating, and internal heating. Typical wind and temperature profiles are presented along with an application of the temperature profile to speed-of-sound and density calculations.

1499

Bolt, Beranek, and Newman, Inc., "Investigation of the Transmission of Sound Through Fog over Water," Final Rept. on Phase 2, Investigation of Acoustic Signalling over Water in Fog, Cambridge, Mass., 1960.
AD-236 659

The physics of sound propagation along the surface of the earth is discussed with particular attention to the conditions existing where sound is propagated for long distances over ocean waters in fog. The results of an extensive measurement program of sound transmission over water are presented, together with the results of measurements of the relevant micrometeorological parameters and a description of the instrumentation and experimental techniques used. The experimental data are analyzed in the light of available theory with a view of applying the results in generalized form to an improved design procedure for audible fog signals. Among the more important conclusions resulting from the analysis and evaluation of the field studies presented in this report are as follows.

(1) The propagation of audible sound over ocean waters in fog is governed by the same micrometeorological parameters which determine the propagation of audible sound over land. (2) The presence of wind and temperature gradients just above the surface of the ocean causes the sound to be refracted from the normal

1500

Burkhard, M., H. Karplus, and H. Sabine, "Sound Propagation near the Earth's Surface as Influenced by Weather Conditions," WADC TR 57-353, Armour Research Foundation, Chicago, 1961.
AD-254 670.

The effects of weather on the propagation of sound from an elevated source to the ground were studied. Measurements include weather conditions in Arizona and propagation angles down to 2 degrees elevation above the horizon. Attenuations were correlated with absolute humidity, temperature, temperature gradient, wind velocity, and wind direction. For source elevations of 5 degrees and higher and source altitudes above a few hundred feet, only temperature and absolute humidity have a significant effect on attenuation. For source elevations of less than 5 degrees large attenuations occur in the presence of strong wind and temperature gradients. These are due to upwind refraction of sound and the resulting creation of shadow zones on the ground.

1501

Chinn, J. E., "Blast Prediction for Small-Scale High-Altitude Experiments," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 168-176, 1961.
AD-408 716.

High-explosive experiments (up to 1000 pounds yield) have been conducted at the test site east of Livermore. Through the study of micrometeorological weather effects upon the resulting sound or pressure waves from such explosions, it has been possible to keep the pressure level below 300 microbars in the populated areas within seven to thirty miles distance.

This paper covers the daily routine of preparing a blast prediction based on a study of temperature, wind direction and velocity through the first 16,000 feet of atmosphere.

1502

Delsasso, L. P., "The Attenuation of Sound in the Atmosphere," Dept. of Phys., Univ. of Calif., Los Angeles, 37 pp., 1953. AD-89 256.

The attenuation of sound at sea level pressures and normal temperatures is extended to pressures and temperatures which may be encountered in acoustical signalling and tracking problems. Measurements were made both in the laboratory and in the field. In the laboratory results are reported for the frequency range 1000 to 6000 cps for a temperature range of from 2^{o} to $35^{o}C$ and for pressures from 76 to 26 cm of Hg. In the field, measurements have been obtained at an altitude of 10,000 feet for representative variations of meteorological conditions. Limits for the possible absorption coefficients to be met with in practice have been extablished. Progress is reported on the development of instruments to measure more accurately the details of the meteorological conditions excountered, particularly with reference to the accurate description of natural fogs. Instrumentation for measuring the attenuation of sound under laboratory conditions and the attenuation of sound propagating outdoors is described and illustrated.

1503

Delsasso, L. P., "The Propagation of Sounds Through Moisture-Laden Atmospheres," Dept. of Phys., Univ. of Calif., Los Angeles, 1956. AD-82 153.

This report covers the experimental information obtained on the transmission of audio-frequency sounds in moisture-laden atmospheres. It constitutes a progress report on a long-term program aimed at obtaining experimental information of the attenuation and velocity fluctuations of sound in the free atmosphere under normal and extreme meteorological conditions.

The absorption of sound in the free atmosphere in these experiments in determined by observing the reduction in sound intensity with distance from a small explosive source. Absorption coefficients under various meteorological conditions are determined from the expression

$$\alpha = \frac{2\left(\ell n \frac{P_1}{P_2} - \ell n \frac{r_2}{r_1}\right)}{r_2 - r_1}$$

where α = coefficient of absorption
P_1 and P_2 = sound pressures at points 1 and 2
r_1 and r_2 = distances from source to points 1 and 2

Transit times are measured as a basis for determining velocity fluctuations. All transit times and attenuation data are correlated with simultaneously recorded meteorological data. The results are presented as a series of charts or records.

1504

Delsasso, L. P., and R. W. Leonard, "The Attenuation of Sound in the Atmosphere—and Appendix A.," Dept. of Phys., Univ. of Calif., Los Angeles, 45 pp., 1949. ATI-96 177.

Progress is reported on the investigation of the transmission of sound under various atmospheric conditions. Primarily the work deals with laboratory measurements, where conditions can be well controlled, and, secondly, with field measurements under varying atmospheric conditions. The ultimate goal is to correlate the two experiments and make it possible to predict the value of attenuation and velocity for any given set of atmospheric conditions. In general, the laboratory measurements confirm previous findings on the variation of the absorption with the moisture content of the air. These results are plotted. Typical values for open air transmission are shown in a graph. Instrumentation for making acoustic attenuation measurements in the laboratory and in the field is described and illustrated. Circuit diagrams are included.

1505

Diamond, M., "Sonic Channels in the Atmosphere," Tech. Rept. No. MM-406, Missile Meteorology Div., U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 27 pp., 1962. AD-289 125.

The mean temperature profile of the atmosphere indicates the probable existence there of two horizontally-distributed sonic waveguides. The lower one usually occurs between the surface and 50 km and the upper one occurs between 50 and 130 km. Wind data above 30 km, which have become available recently through the use of meteorological rockets, have led to revised concepts of atmospheric circulation patterns for the northern hemisphere.

This data has been combined with mean atmospheric temperature data to determine the seasonal sonic patterns of the atmosphere waveguide that can exist between the surface and an altitude of 50 km. These patterns indicate the general existence of a strong waveguide for sound having an eastward propagation component in winter and a westward propagation component in summer.

For other combinations of propagation directions and seasons, a waveguide does not usually exist between the surface and 50 km. The refraction of sound from upper altitudes to the surface generally will occur in winter only at sites located to the east of the source, and in summer, only at sites located to the west of the source.

1506

Duckert, P., "Weather Conditions and Layers of the Atmosphere on December 15, 1932" (in German), Z. Geophysik, 10, 127-144, 1934.

Tables show temperature, pressure, humidity, wind, and upper-air wind measurements at different stations of northwestern Europe, along with sound wave speeds.

1507

Eagleson, H. V., "Influence of Certain Atmospheric Conditions upon Sound Transmission at Short Ranges," J. Acoust. Soc. Am., 12, 427-435, 1940.

A formula is derived for giving sound intensity as a function of temperature, humidity and barometric pressure. A series of measurements was made of the intensity of sound from constant sources at short fixed distances. Readings were taken in all sorts of weather that can be found in Indiana. In general, the experimental values agree with those calculated from the formula to within 5%.

1508

Eyring, C. F., "Jungle Acoustics," J. Acoust. Soc. Am., 18, 257-270, 1946.

The study of jungle acoustics was carried out during the wet season in Panama. Measurements permit the following conclusions to be drawn. Within a jungle the temperature and wind velocity gradients are so small that the sound refraction they produce may be neglected for all practical purposes. Humidity increases the transmission loss at high frequencies and field measurements of the loss agree with laboratory values reported by others. Terrain loss, measured in db, between any two specified distances from the sound source is defined as the transmission loss between these points less that caused by the geometrical divergence of the sound beam. Terrain loss in the jungle was found to increase linearly with distance. The terrain loss coefficients, in db per foot, were measured for various types of jungle and were found to be a function of frequency and of the density of the terrain, the density of terrain being measured by the difficulty of penetration and the distance that a foreign object may be seen. The level of the ambient noise in the wet-season jungle is very low, especially for the quiet periods between animal calls. At night the low frequencies decrease as the light breezes cease and the high frequencies increase as the insects begin their nocturnal chorus. A jungle is a difficult place in which to judge the direction of a sound—a probable error of 20^{0} is to be expected. The error is found to be smallest when the sound comes from a direction near the axis passing through the two ears, and in the range studied the error decreases as the sound source moves farther away. Reverberation and scattering cause part of the error of judgment, but an improved technique of listening which may increase the observer's accuracy is suggested.

1509

Eyring, C. F., "Jungle Acoustics," Rept. No. 4699, Office of Scientific Research and Development, NDRC Div. 17, Washington, D. C., 80 pp., 1945.
ATI-62654.

This study of jungle acoustics and micrometeorology is one of the most comprehensive and useful documents available for anyone concerned with the transmission of sound at the earth's surface in tropical climates. The study was conducted during the wet season in Panama and includes propagation measurements over hard, bare surfaces, short and tall grasslands, and through a variety of tropical forests. Terrain loss coefficients and their variations with acoustic frequency and environment were determined from measurements. Ambient jungle noise levels in the audible and ultrasonic ranges were measured. Acoustical and meteorological measurements were taken concurrently in order to demonstrate their inter-relationships. Refraction and shadow zone formation, as caused by combined wind and temperature effects, were investigated and found to be significant in open, sunny areas, but not significant under a jungle canopy. The report clearly shows the typical variations to be expected throughout the day and night for each acoustic and meteorological parameter investigated. The various instruments that were developed for acoustic detection and measurement are described in detail. Calibration procedures are also described.

1510

Hart, J. C., "Ambient Acoustic Noise at High Altitudes," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 195-212, 1961.
AD-408 716.

Half-octave-band spectra of high-altitude ambient acoustic noise as sampled from more than 60 balloon flights at high altitude have been examined to empirically determine the dependence of both (1) the relative frequency content of the ambient noise and (2) the overall ambient noise level upon (a) the presence of local meteorological disturbances such as thunderstorms, (b) the sound velocity profile with respect to altitude, and (c) the wind structure as a function of altitude.

Man-made acoustics signals, such as those from aircraft, have intentionally been excluded from this study in so far as these signals are strong enough to be identified. The data are believed to be meaningful between 0.1 and about eight cycles per second. Overall levels have been observed within this frequency band as low as approximately 43 db re .0002 d/cm^2 (0.03 d/cm^2); levels in the 0.25-to-8.0-cps band have been observed as low as 35 db (0.01 d/cm^2).

This work was begun with the support of Melpar, Incorporated, Applied Science Division, and completed with the support of Bay State Electronics Corporation.

1511

Hayhurst, J. D., "The Attenuation of Sound Propagated Over the Ground," Acustica, 3, 227-232, 1953.

Theoretical calculations by Knudsen, supported by the results of laboratory experiments, have established the attenuation of sound in still air. Little work has hitherto been done out-of-doors because of the difficulty in allowing for the effect of wind on the attenuation. In the course of an aircraft-noise-abatement investigation made recently by the Ministry of Civil Aviation, the effect of wind on the propagation of sound over a dry concerte runway has been explored up to a distance of about half a mile from a source of sound. It was found that the only significant parameter was the component of wind in the direction of propagation, and the values that emerged showed that wind effects cannot be neglected in any acoustic work made out-of-doors. By interpolation the attenuations corresponding to a zero wind component in the direction of propagation were derived and were found to be substantially greater than those previously determined for still air. The attenuations were, however, statistically independent of the absolute wind speed. Repetition of the investigation over grassed areas produced no reliable results.

1512

Ingard, U., "Field Studies of Sound Propagation over Ground," Acoustics Lab., Mass. Inst. Tech., Cambridge, 1954.

The results of two sets of field studies of sound propagation over ground are presented. One study utilized pure tones, the levels of which were measured at various distances and different wind velocities. For the second study an airplane propeller served as the source with octave band levels measured over various ground covers, at different wind velocities and at several distances. The importance of wind is shown by the shadow formation obtained. Fluctuation of sound level was shown to increase with distance and frequency. For propagation over the ground, the effect of turbulence scatter was found to be small.

1513

Ives, R., "Apparent Relation of Aircraft Noise to Inversions," Bull. Am. Meteorol. Soc., 49, 149-150, 1959.

An investigation is reported in which aircraft noise was recorded in order to determine its relation to meteorological conditions. Under inversion conditions noise was found to be offensive when aircraft flew below the inversion and to be almost indetectable with aircraft above the inversion. Similar conditions were noted with stratus layers.

1514

Kennedy, W. B., et al., "Study of Meteorological and Terrain Factors Which Affect Sound Ranging," Denver Research Inst., Univ. of Denver, Colo., 1954-1957.

Qrtrly. Prog. Rept. 1, March-May 1954, AD-38 446
" " " 2, June-August 1954, AD-43 297
" " " 3, September-November 1954, AD-54 480
" " " 4, December 1954-February 1955, AD-61 530
" " " 5, March-May 1955, AD-70 078
" " " 6, June-August 1955, AD-74 855
" " " 7, September-November 1955, AD-95 798
" " " 8, December 1955-February 1956, AD-95 799

Final Report, March 1954-April 1956, AD-139 326
Qrtrly. Prog. Rept. 1, May-July 1956, AD-140 087
" " " 2, August-October 1956, AD-140 088
" " " 3, November 1956-January 1957, AD-140 090
Interim Prog. Rept., February-August 1957, AD-160 696

This series of reports covers four years of intensive theoretical and applied research and development on sound-ranging as influenced by meteorological and terrain factors. The general problem of increasing the accuracy of sound-ranging by means of corrections based on meteorological and topographical conditions is discussed. Equations are presented for applying wind and temperature corrections to reduce error in observed sound-source azimuths. Problems encountered in setting up the field operation to provide data for a study of meteorological and terrain corrections for the whole sound path are analyzed. Proposed methods for time measurement of sound arrivals, temperature measurement, control of field operations, and power distribution are presented in detail.

The firing-recording arrays are described. The results and the methods of reducing data are given. Special investigations include: an analysis of the problem of acoustic ray-tracing in the atmosphere; determinations of the sonic data obtainable with various geometries of detecting arrays; an analysis for determining the velocity of sound; studies of errors generated within the Short-Range Whole-Path Firing-Recording Array by elevation differences, angular errors in placing the sensing microphones, and errors due to the assumption that the wave front is plane; a study determining the effect of oscillogram-reading errors on calculated sound-wave-arrival azimuths; a discussion of methods of removing data from oscillograms; and tests to determine the calibration requirements of the T-23 microphones. Other discussions include microphone-wind-shield development, the surveying program, and the general field operational problem.

The application of a drift correction to the primary sound-ranging information provided results superior to those obtained by standard artillery methods. For these calculations, data were used from an array of 14 microphones arranged in an isosceles-trapezoidal configuration. The arrival azimuth obtained by using this configuration is more representative of the direction of arrival of the acoustic wave front than that obtained by standard methods. The corrections which were applied for the refraction of the wave front along its path do not appear to be greatly significant from a study of the small sample presented.

1515

Mathur, L. S., "Reflection of Sound Waves from the Stratosphere over India in Different Seasons of the Year," Indian J. Meteorol. Geophys., 1, 24-34, 1950.

Three series of observations were made in India during the summer, fall, and winter of1946-47 to determine the trajectories of sound waves (from explosions) through the stratosphere. Two explosion centers and nine recording stations (in the form of a cross, with the axis along the line joining the two centers) were set up by the Meteorological Department, and their locations shown on a chart. Actual recorder records for ground and reflected waves are reproduced, and derived data are presented in tables and graphs.

In the summer better reception was obtained toward the south; whereas, after the monsoon season, and in the winter, better records were obtained to the north (up to 294 km) of the explosions. Records of the ground wave were obtained even in the "zone of silence." Trajectories are illustrated and temperatures and lapse rates in the stratosphere computed and plotted.

1516

Moies, P. C., "Influence of Wind on Propagation of Loud Sounds," Bull. soc. belge electriciens, 53, 237-240, 1937.

Deals with the propagation of sounds from high-power loudspeakers such as might be used for giving warning signals over a wide area. In calm air the frequency range 1500-2500 is propagated best, a range of about 1500 meters being obtained from a 60-W output. The acoustic efficiency of an ordinary loudspeaker is given as about 0.03%. The results for the influence of wind are given in the form of an empirical formula involving the velocity gradient (with height above the ground) of the wind.

1517

Oleson, S. K., "Instrumentation for Field Measurements of Noise Propagation over Ground," Acoustics Lab., Mass. Inst. Tech., Cambridge, Mass., 1956.

Describes an improved method of experimental procedure for studies of sound propagation over varied terrain. The improvements described deal mainly with simultaneous recording of meteoroligical and acoustical data, thus minimizing experimental errors resulting from constantly changing meteorological conditions.

1518

Pennsylvania State University, "Atmospheric Physics and Sound," Final Rept., Dept. of Physics, Acoustics Lab., University Park, 288 pp., 1950.

This voluminous report contains a detailed account of the instrumentation developed, methods used, and results achieved at Pennsylvania State University in a five-year study aimed at investigating the production and propagation of sound, both sonic and ultrasonic, in the lower atmosphere, through the ground, and in other media. Chapter 7 "Micrometeorology and Atmospheric Acoustics," is a summary of results of temperature and wind velocity measurements (mostly with hot wire thermometers and aneomometers) made up to 50 feet from the ground in conjunction with sound intensity measurements. A definite correlation is found between sound signal fluctuations and inhomogeneities of temperature, but not of wind. Likewise no effect of snow cover on sound propagation was noted.

1519

Reed, J. W. "Weather Determines Blast Prediction for Atom Tests," Weatherwise, 9, 202-204, 1956.

The mechanisms which produce damaging shock waves at a distance from a blast (such as created heavy damage to plaster and windows in Las Vegas, Nevada, 80 miles from point of an atomic bomb explosion in 1951) are outlined and illustrated. Reflection from surface inversions, from strong upper winds, or from the ozonosphere inversion are among the factors discussed. The tests in question produced reflections which hit the earth at 27, 54 and 81 miles, etc., from the nuclear testing site.

Pilot explosions two hours before a test recorded on a network of microbarographs are now used to anticipate dangerous conditions. Actual explosion records are also studied for future use.

1520

Rothwell, P., "Sound Propagation in the Lower Atmosphere," J. Acoust. Soc. Am., 28, 656-665, 1956.

An account is given of experiments carried out in the lower troposphere to compare observations of the audible range and of the angle of sound descent from shell bursts at various heights (up to 10,000 feet) with calculations made from elaborately measured temperatures and winds. In stable conditions they agree satisfactorily.

Several cases were observed of anomalous propagation in which sound rays starting upward from the source are bent back to the earth. These showed the phenomena associated with larger-scale anomalous propagation, namely, inner and outer audibility zones, "zone of silence," and double or multiple reception of the single pulse from the source. From the experience gained in these experiments suggestions are made for (1) observation of the time interval between components of the usual double or multiple bangs from a single pulse-source, and for (2) observation of the sound from explosions in the air as well as on the ground to obtain more information than has been obtained hitherto from sound propagation about temperature and wind in the high atmosphere. Rocket explosions might be used for the latter purpose.

1521

Sabine, H., "Sound Propagation near the Earth's Surface as Influenced by Weather Conditions," WADC TR 57-353, Armour Research Foundation, Chicago, 24 pp., 1961. AD-254 672.

Engineering procedures are outlined for estimating the atmospheric attenuation of sound propagated from an elevated source to ground as a function of distance, source elevation angle, and meteorological data of the type which would be obtained routinely at an air missile base. These procedures are based on the results of an experimental program which covered distances up to four miles and source altitudes up to 14,000 feet.

1522

Skeib, G., "On the Propagation of Sound in Atmospheric Turbulence" (in German), Z. Meteorol., 9, 225-234, 1955.

Measurements of the scatter of sound waves of 100 c to 4 kc from a loudspeaker were made at Lindenberg, with micrometeorological observations for comparison. Absorption and scattering are discussed theoretically and the instrumental set-up is described. At a height of 30 m and distance 150 m, with wind >5 m/s, damping was 13 db, increasing with frequency, and decreasing to half at 3 m/s. At 5 m height and 50 m distance results were similar but the wind effect less.

1523

Webb, W. L., "Detailed Acoustic Structure Above the Tropopause," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 100-118, 1961. AD-408 716.

The general features of atmospheric acoustic structure in the lower mesosphere have been known for several decades. Initial studies were accomplished by surface observations of anomalous propagation of pressure perturbations generated by explosions. Recently the expulsion of explosive grenades from rockets has served to reduce the spatial observation parameter from many miles to the order of 10,000 feet.

The material considered here is based on a resolution of the order of 1,000 feet at the least sensitive point. Data are presented on speed of sound structure evaluated from wind and temperature measurements obtained from meteorological rocket systems. The environment is assumed to be a perfect gas of molecular composition the same as dry air at the earth's surface, and the seasonal course of the general sonic gradient is discussed. The strength and frequency of sub-duct features are presented, and extreme values of the sonic gradient are reviewed for different height intervals. These data are considered in terms of latitude, and the temperature and wind contributions to the sonic gradient are discussed.

1524

Webb, W. L., and K. R. Jenkins, "Sonic Structure of the Mesosphere," J. Acoust. Soc. Am., 34, 193-211, 1962.

Temperature and wind data up to altitudes of 200,000 feet have been obtained with meteorological rockets at various locations over North America during the seasons of 1959 and 1960. Seasonal and geographical variations of the atmosphere's acoustical structure, as derived from these data, are illustrated. The thermal and flow effects on the sonic profiles in the lower mesosphere are pointed out. Data on individual cases of interest and seasonal summaries for several locations are presented.

This article is a condensed version of the report whose abstract follows immediately.

1525

Webb, W. L., and K. R. Jenkins, "Sonic Structure of the Mesosphere," Special Rept. No. 50, Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 56 pp., 1961. AD-255 767.

Temperature and wind data up to altitudes of 200,000 feet were obtained with meteorological rockets at various locations over North America during the seasons of 1959 and 1960. Seasonal and geographical variations of the atmosphere's acoustical structure, as derived from these data, are illustrated. Thermal and flow effects on the sonic profiles in the lower mesosphere are pointed out. Data on individual cases of interest and seasonal summaries for several locations are presented.

1526

Wiener, F. M., "Sound Propagation over Ocean Waters in Fog," J. Acoust. Soc. Am., 33, 1200-1205, 1961.

Audible fog signals are extensively used as aids to marine navigation during periods of low visibility. Performance, however, has frequently been inadequate. To obtain a better understanding of the physics of sound propagation over water in fog, a series of field experiments was carried out off the coast of Maine. Signals in the frequency range between about 200 and 2000 cps were employed to measure sound attenuation for distances up to a few miles. Simultaneous micrometeorological measurements were performed to describe the relevant properties of the lowest layers of the atmosphere through which the sound was propagated. This paper describes briefly the measurement techniques used and presents typical samples of the results obtained. Downwind, the average excess attenuation over and above inverse square law can be accounted for principally by molecular absorption. Upwind, large values of excess attenuation were found due to shadow zone formation. This constitutes a severe limitation of the useful range of audible fog signals. Fog itself contributes little to the average excess attenuation.

1527

Wiener, F. M., and D. N. Keast, "Experimental Study of the Propagation of Sound over Ground," J. Acoust. Soc. Am., 31, 724-733, 1959.

The attenuation of sound propagated out-of-doors is conveniently separated into attenuation due to spherical divergence and excess attenuation due to atmospheric and terrain effects. This excess attenuation is principally caused by sound absorption in the air, the refractive effects of temperature and wind gradients, turbulence, and terrain and ground cover. To investigate these effects, the propagation of sound over open, level ground, through dense evergreen forests, and between hilltops was studied experimentally in the frequency range between about 300 and 5000 cps. Extensive micrometeorological instrumentation was utilized to measure and record the relevant micrometeorological parameters simultaneously with the acoustic data for a wide variety of weather conditions. Data on the attenuation of the mean sound pressure level as well as on the fluctuations about the mean were obtained and correlated with the state of the atmosphere. Over open, level terrain, the excess attenuation upwind was found to exceed that for downwind propagation by as much as 25-30 db for source and receiver heights of 12 and 5 feet, respectively. Temperature and wind gradients near the ground-air interface largely account for this difference. In hilltop-to-hilltop propagation, wind direction is of secondary importance and in dense woods absorption and scattering control. Empirical functions were derived for the purpose of estimating the mean excess attenuation as a function of frequency and distance, for a given set of micrometeorological conditions. These charts were found useful in many practical problems involving the propagation of sound over open level ground.

Meteorology, Effects on Sound Propagation, Measurement
See also—82, 83, 111, 123, 407, 460, 462, 464, 480, 485, 522, 551, 562, 924, 986, 1061, 1086, 1155, 1245, 1364, 1371, 1445, 1690, 1692, 1794, 1859, 1863, 1864, 1866, 1872, 1940, 1947, 2045, 2046, 2069, 2151, 2155, 2184, 2213, 2244, 2309, 2342, 2520, 2677, 2818, 2837, 2844, 2848, 3030, 3066, 3067, 3231, 3236, 3237, 3248, 3263, 3270, 3273, 3337, 3392, 3440, 3445, 3446, 3447, 3448, 3449, 3531, 3532, 3533, 3534, 3535, 3955, 4424

METEOROLOGY, EFFECTS ON SOUND PROPAGATION, THEORY

1528

Aichi, K., "On the Distribution of the Wind Velocity When the Abnormal Propagation of Sound Occurs," Proc. Phys.-Math. Soc. Japan, 2, 63-69, 1920.

Theoretical discussion, and appendix on the velocity of sound propagation in windy atmosphere.

1529

Arabadzhi, V. I., "On Extinction of Sounds in the Atmosphere" (in Russian), Izv. Akad. Nauk SSSR, Ser. Geograf. i Geofiz., 12, 162-164, 1949.

Consideration of the extinction of sound by temperature variations in the lower layers of the atmosphere.

1530

Bergmann, P. G., "The Wave Equation in a Medium with Variable Index of Refraction," J. Acoust. Soc. Am., 17, 329-333, 1945.

The paper deals theoretically with the effects of density gradients in the atmosphere or in large bodies of water on the propagation of sound waves. It is found that the gradient of hydrostatic pressure in water is comparable in effect with a temperature gradient of 0.1^{o}F/ 100 feet. This is negligible if the temperature gradient appreciably exceeds that value. Similar considerations can be applied to the case of sound in air. It is concluded that gravity terms can be disregarded except in certain extreme cases, e.g., at very low frequencies.

1531

Bronstein, I. M., "The Problem of the Extinction of Sound in the Atmosphere" (in Russian), Izv. Akad. Nauk SSSR, Ser. Geograf. i Geofiz., 8, 151-153, 1944.

The author gives a quantitative determination for the coefficient of sound extinction in the atmosphere, and shows the connection between this coefficient and atmospheric turbulence.

1532

Condron, T. P., and W. S. Ripley, "Acoustic Propagation in the Atmosphere," in Handbook of Geophysics for Air Force Designers, Air Force Cambridge Research Center, U. S. Air Force, Chap. 21, 14 pp., 1957.

Normal propagation of sound in a homogeneous atmosphere is reviewed as an introduction to anomalous propagation and absorption in a realistic atmosphere. Spreading and diffraction losses in a refractive medium are described and followed by a brief treatment on ray geometry as applied to sound in air. Attenuation of sound in air due to classical absorption and molecular absorption is described. Several charts and graphs are included from which absorption per unit distance can be determined as a function of meteorological parameters such as temperature and humidity. A final section on noise sources includes data on sound pressure levels and octave band analyses from jet and reciprocating engines, helicopters, and backgrounds in industrial, residential, and jungle areas.

1533

Cox, E. F., "Sound Propagation in Air," in Handbuch der Physik (Encyclopedia of Physics), 48, 455-478, 1957.

This paper begins with a review of the basic laws of propagation of sound energy in air and explains why weak sound waves propagate with negligible distortion, while high amplitude sound waves distort and form shock fronts as they propagate. Expressions for shock wave velocity are given.

Meteorological factors affecting the speed and direction of sound rays are described, and the laws of sound ray refraction and reflection are reviewed. Absorption and dispersion of sound in real atmospheres are described. Formulas and graphs are given for determining attenuation with distance. Propagation of sound to great distances is treated in detail. Refraction in the troposphere and the formation of sound ducts at tropopause heights are described and documented. An excellent bibliography is included.

1534

Cox, E. F., H. J. Plagge, and J. W. Reed, "Meteorology Directs Where Blast Will Strike," Bull. Am. Meteorol. Soc., 35, 95-103, 1954.
See Also: Pack, D. H., "Simplification of Method," Bull. Am. Meteorol. Soc., 39, 364, 1958.

Successful forecasting of the locations where damage may result from blast waves emanating from (a) TNT or (b) atomic explosion must be based on good forecasts of temperature and wind (and, to some extent, humidity) gradients in the troposphere. Ordinarily pressures from shock waves are reduced to ineffective values at 500 feet (a) or 3.7 miles (b), but focusing of ray paths due to inversions of temperature and humidity or wind shear, may give zones of silence and corresponding areas of abnormal shock.

Tables and graphs for computation and illustration of method used by the author and collaborators in New Mexico are presented along with the theoretical basis of their calculations. Criteria for estimating damage to plate glass or ordinary windows are given. Plate glass is subject to long-period oscillations from big blasts as well as to pressures.

Cox, Plagge, and Reed predict the point to which sound will return by elaborate calculation which is greatly facilitated by a simplified mathematical form presented by Pack.

1535

Duncan, L. D., "Revised Ballistic Standard Atmosphere for White Sands Missile Range," Tech. Memo. No. 751, Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 25 pp., 1960.
AD-242 765.

The standard atmosphere formerly used at White Sands Missile Range, New Mexico, was revised by using more recent meteorological data. A yearly standard and standards for each month are developed in equation form.

Equations are given for pressure-height and speed of sound curves, as well as the methods by which these equations were derived.

1536

Eckart, G., "Acoustic Characteristics of the Atmosphere" (in French), Rech. Aeron., 21, 59-66, 1951.

The author considers the properties of a stratified atmosphere (i.e., one whose pressure, temperature, and relative humidity are functions only of the height above the surface of the earth). The major portion of the paper is devoted to statements, formulae, graphs, and tables showing the effects of temperature and relative humidity on the velocity, characteristic impedance, and attenuation of sound waves in air. It is a useful summary of this information. The author also presents information on the effects of temperature and humidity on the propagation of electromagnetic waves. He points out that whereas changes in temperature are much more significant than changes in humidity with regard to sound propagation, the reverse is true in the electromagnetic case. The author suggests that simultaneous observations of acoustic and electromagnetic transmissions in the atmosphere may yield useful information about its composition at any given time and place.

1537

Ertel, H., "Problem in Meteorological Acoustics: The Daily Variation of Sound Intensity" (in German), Akad. Wiss. Wien, 17 pp., 1955.

Humboldt's quantitative explanation of the daily periodic variation in sound intensity is discussed and a quantitative, theoretical treatment of this phenomenon is presented. It is shown that the thermal convective variation of atmospheric temperature causes a daily periodic damping of sound amplitude. Accordingly, the extinction coefficient of sound intensity is directly proportional to the thermal-convective temperature variations, which show a maximum by day and a minimum by night.

1538

Fisher, E. E., R. P. Lee, and H. Rachele, "Meteorological Effects on an Acoustic Wave Within a Sound Ranging Array," Tech. Rept. No. MM-435, Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 20 pp., 1962.
AD-275 415.

Equations are derived for determining the direction cosines of a plane or spherical wave front by assuming the arrival time at each microphone in an array to be an independent observation and requiring a minimum sum of the squares of the corrections to the individual recordings. In addition, the effects on the direction cosines and/ or the time-arrival errors resulting from considering sound-speed variations (profile) with height are also considered. In particular, five examples were considered for different profiles, none of which were extreme, and resulted in direction-angle errors as large as two degrees and apparent time errors on the order of .04 second.

1539

Gazaryan, Yu. L., "Infrasonic Normal Modes in the Atmosphere," Soviet Phys. Acoust. English Transl., 7, 17-22, 1961.

The results are given from numerical calculation of the characteristics of normal modes with periods greater than one minute for models of the atmosphere with one and two temperature minima.

1540

Gutenberg, B., "Effect of Low-Velocity Layers," Geofis. Pura Appl., 29, 1-10, 1954.

Effects of low-velocity channels in the atmosphere, the ocean and the solid earth are discussed. There are two major low-velocity channels in the atmosphere, one with its axis at the tropopause, and another at a height of about 80 km. They produce "zones of silence" and permit the transmission of waves involving the whole atmosphere.

Low-velocity layers in the ocean result from the combined effects of temperature, pressure and salinity. In the earth, the sudden decrease of velocity at the boundary of the core produces a low-velocity channel for elastic waves. In the earth's crust there are two major low velocity channels, one below the Mohorovicic discontinuity, the other at a depth of about 15 km. Misinterpretation of their effects has caused incorrect conclusions concerning the structure of the outer portion of the earth's mantle.

1541

Gutenberg, B., "Propagation of Sound Waves in the Atmosphere," J. Acoust. Soc. Am., 14, 151-155, 1942.

The effect of humidity is investigated. The radius of curvature for a sound ray propagated in the direction of the wind is given and discussed. The amplitudes of sound waves as a function of the distance are given, and the relative importance of the quantities involved is discussed.

1542

Haurwitz, B., "Physical State of the Upper Atmosphere," J. Roy. Astron. Soc. Can., 31, 19-42 & 76-92, 1937.

This continues previous work. The author first discusses atmospheric ozone, its power to absorb solar radiation, its total amount, its annual variation, and its geographical and vertical distributions. Its great absorbing power is seen to determine to a large extent the temperature of the upper atmosphere; the theory of its origin mainly considered is that of Chapman.

In his second section, the author deals with the anomalous propagation of sound, accounting for the varying directions of audibility in summer and winter. The greater velocity of sound in the upper atmosphere, affording an explanation of the zones of audibility, in all probability arises because of the high temperatures of the upper atmosphere. In dealing with the composition of the atmosphere the author points out that this is constant owing to mixing up to heights of about 20 km. Above this, mixing continues to a certain extent and diffusion equilibrium is not to be expected on theoretical grounds below 100 km.

1543

Ingard, U., "The Physics of Outdoor Sound," Proc. Fourth Ann. National Noise Abatement Symp., 4, 11-25, 1953.

The effects of wind and temperature gradients, wind fluctuations, turbulence scattering, and absorption due to humidity are described and explained in this clearly written paper. The formation of shadow zones and the dependence of attenuation upon frequency in the shadow zone is discussed. Illustrative data for each of the meteorological parameters affecting the propagation of sound in a natural atmosphere are presented.

1544

Ingard, U., "A Review of the Influence of Meteorological Conditions on Sound Propagation," J. Acoust. Soc. Am., 25, 405-411, 1953.

The study of the different atmospheric effect indicates that in short-range sound propagation the attenuation by irregularities in the wind structure (gustiness) often is of major importance in comparison with humidity, fog, and rain, and ordinary temperature and wind refraction. However, the ground attenuation can be just as important as the gustiness, particularly when the sound source and the receiver are sufficiently close to the ground. The effect on the attenuation of the height of the source and the receiver off the ground is presented as a function of frequency for a typical ground impedance. The attenuation curve exhibits a maximum which in most cases lies at a frequency between 200-500 cps.

1545

Kallistratova, M. A., and V. I. Tatarskii, "Accounting for Wind Turbulence in the Calculation of Sound Scattering in the Atmosphere," Soviet Phys. Acoust. English Transl., 6, 503-505, 1961.

Gives a mathematical derivation for the scattering of sound waves by turbulent fluctuations. Expressions are derived for the effective-scattering cross section per unit volume; the acoustical pressure of the scattered field, involving the effects of the vertical component of the wind field; and temperature fluctuations. Verification by actual measurements is shown.

1546

Kallmann, H. K., "Physical Properties of the Upper Atmosphere," Rept. No. RM-841, The Rand Corp., Santa Monica, Calif., 19 pp., 1952.
AD-293 673.

Tables have been prepared for the physical properties of the atmosphere at altitudes up to 250 km (156 miles). Among the properties determined are pressure, density, particle density, temperature, and scale height. From 10 km up to 80 km the speed of sound and the coefficient of viscosity have been calculated; for altitudes between 80 km and 250 km, the mean molecular speed and the mean collision frequency of the air particles are given. The properties are tabulated in regular intervals of one, two, and five kilometers up to 30, 80, and 250 km respectively. The decrease of the acceleration g due to gravity with increasing altitude has been taken into account.

1547

Koenuma, K., "Waves Propagated in the Atmosphere," Memo. No. 6, Imp. Marine Obs., Kobe, Japan, 175-212, 1936.

Lamb's treatment is extended to waves of short period, such as a few minutes. Assuming air to be a compressible medium, the propagation of waves in the atmosphere with a uniform temperature gradient is discussed. It is shown that with a given velocity the effect of the temperature gradient is to increase the period and the wave length.

In the second part, waves incident on a discontinuous surface are investigated, and it is shown that at a surface of temperature discontinuity, the periods diminish as the temperature difference increases. Further, the wave length and the velocity increase with the height of the discontinuous surface, although for a height of a few km the period is nearly constant.

1548

Melkas, A., "The Influence of Temperature and Wind on Propagation of Sound in the Air" (in German), Geophysica (Helsinki), 3, 207-219, 1948.

The correction for direction, used in determining the position of aircraft by means of an acoustical sound detector, is based upon ground temperature. In order to secure greater exactness the temperature and wind conditions of the total sound path must be known. The author analyzes mathematically the influence of the temperature gradient alone upon the rate of sound propagation in still air and the combined effect of temperature and horizontal wind movement. Equations are derived for calculating the angles of elevation for the two conditions.

1549

Moies, P. C., "Strong Sound Signals, Effect of the Wind," Tech. Notes No. FRL TN 31, Feltman Res. Labs., Picatinny Arsenal, Dover, N. J., 5 pp., 1961.
AD-253 793.

The range of audibility does not depend on wind velocity as such but on the rate at which the speed increases with height. The effect of a height gradient in wind velocity is to produce curved rays. Equations are given for calculating the radius of curvature from the speed and relative direction of the sound and the gradients in the temperature and velocity of the wind. Sound heard downwind is intensified; that heard upwind is weakened.

1550

Pekeris, C. L., "Free Oscillations of an Atmosphere in Which Temperature Increases Linearly with Height," Tech. Note 2209, Natl. Advisory Comm. Aeron., 26 pp., 1950.

In an atmosphere in which the temperature increases linearly with height and at a constant rate, the acoustical propagation properties are radically different from those hitherto encountered in the theory of atmospheric tides. The phase velocity no longer approaches a limit with increasing period but increases linearly with the period. The region of maximum energy of the oscillation is shifted to increasingly higher elevations as the period is increased.

The bearing of these results on the resonance theory of atmospheric tides is discussed.

1551

Perkins, B., Jr., P. Lorrain, and W. Townsend, "Forecasting the Focus of Air Blasts Due to Meteorological Conditions in the Lower Atmosphere," Rept. No. 1118, Ballistic Research Labs., Aberdeen Proving Ground, Md., 77 pp., 1961.
AD-250 146.

Whenever explosions are used in testing or in experimental procedures, the sound waves that go beyond the limits of the installation may cause annoyance or damage. This is due to the focusing of the sound waves caused by meteorological conditions—atmospheric velocity gradients produced by variations with altitude of humidity, air temperature, and wind velocity.

Briefly, reviews the theory of sound propagation through the atmosphere, and then describes a simple method for evaluating sound-focusing factors and forecasting the location of the focus, if one is to be expected, as well as the intensity of the sound at the focus.

1552

Pridmore-Brown, D. C., "Sound Propagation in a Temperature- and Wind-Stratified Medium," J. Acoust. Soc. Am., 34, 438-443, 1962.

The general linearized equations governing the propagation of sound in a dissipationless temperature- and wind-stratified medium are derived. A formal integral expression is given for the field of a point-source located in such a medium, when it is bounded by an absorbing plane under conditions which lead to the formation of a shadow zone. This integral yields the following approximate (high-frequency) expression for the decay rate within the shadow

$$|p| = (B/r) \exp [-(n/c)f^{1/2}(-c' - U' \cos \phi)^{2/3}r]$$

Here p is the acoustic pressure, r is radial distance from the source, B is independent of r, f is frequency in cps, c is sound speed, c' and U' are sound- and wind-speed gradients at the ground surface, ϕ is the angle between the wind direction and the direction of sound propagation, and n is equal to 5.93 for a pressure-release boundary and to 2.58 for a hard boundary.

1553

Pridmore-Brown, D. C., and U. Ingard, "Tentative Method for Calculation of the Sound Field About a Source over Ground Considering Diffraction and Scattering into Shadow Zones," NACA TN 3779, Mass. Inst. of Tech., Cambridge, 1956.

A semiempirical method is given for the calculation of the sound field about a source over ground considering the effects of vertical temperature and wind gradients as well as scattering of sound by turbulence into shadow zones. The diffracted field in a wind-created shadow zone is analyzed theoretically in the two-dimensional case and is shown to be similar to the results obtained for a temperature-created shadow field as given in NACA TN 3494. The frequency and wind-velocity dependence of the scattered field into the shadow zone is estimated from Lighthill's theory, and on the basis of these two field contributions a semi-empirical formula is constructed for the total field which contains two adjustable parameters. From this expression a set of charts has been prepared showing equal sound-pressure contours at 10 feet above ground for various source heights, wind velocities, and frequencies.

The two adjustable parameters in the formula were obtained from measurements using a relatively small source height (10 feet). The parameters should actually be a function of height determined by the wind and temperature profiles. However, in these preliminary calculations the parameters have been kept constant, and the fields, particularly for large source heights, must be considered as preliminary estimates to be corrected when more information is available.

1554

Richardson, E. G., "Sound and the Weather, Part I," Weather, 2, 169-173, 1947; "Part II," Ibid., 205-210, 1947; Comment by P. Rothwell and reply by E. G. Richardson, Ibid., 3, 1948.

Some of the results of British research. Considers noises caused by meteorological agencies and the propagation of sound, both normal and abnormal.

1555

Rocard, Y., "The Focusing of Energy Caused by Irregular Sound Propagation" (in French), Compt. Rend., 246, 2111-2113, 1958.

Atmospheric temperature and wind speed variations can perturb the wave fronts from a sound source. A formula is developed for this effect and applied to the atmospheric conditions caused by thermonuclear explosions.

1556

Rocard, Y., "Focusing of Sound Energy in the Air Due to Wind Effects" (in French), Compt. Rend., 248, 538-540, 1959.

Theoretical addition to a previous note, to include the effect of large atmospheric disturbances.

1557

Rocard, Y., "Propagation of Sound in a Variable Wind" (in French) Compt. Rend., 244, 1339-1341, 1957.

Sound propagation in a variable wind is shown, theoretically, to consist of ordinary sound waves of amplitude depending upon the wind velocity gradient in the direction of propagation.

Suggests a method for measuring turbulence.

1558

Rudnick, I., "Propagation of Sound in the Open Air," in C. M. Harris, ed, "Handbook of Noise Control," McGraw-Hill, New York, Chap. 3, 17 pp., 1957.

Chapter 3 decribes the propagation of sound in air and the various meteorological factors and boundary conditions that influence otherwise normal propagation. The effect of wind and temperature gradients, of fog and water vapor, and of reflecting and absorbing obstacles and boundaries are concisely treated. Mathematical expressions, graphs, and tabular data for determining divergence, diffraction, refraction, reflection, scattering, and attenuation with distance are presented. Anomalous propagation and shadow zones are investigated and explained in terms of sound-ray equations. In general, the chapter presents the basic results of work done by Kneser, Knudsen, Knotzel, Delsasso, Ingard, Nyborg, and Rudnick.

1559

Sabine, H., V. Raelson, and M. Burkhard, "Sound Propagation near the Earth's Surface as Influenced by Weather Conditions," WADC TR 57-353, Armour Research Foundation, Chicago, Ill., 49 pp., 1961.
AD-254 671.

The effects of weather on the propagation of sound from high-power elevated sources, such as large rockets, were studied at altitudes to 80,000 feet and over horizontal ranges to 15 miles. This study continues work reported in Parts I and II (AD-130 793 and AD-254 670) on short-range propagation. A theoretical analysis is reported of the principal atmospheric factors affecting long-range propagation: molecular absorption as a function of temperature and absolute humidity at various altitudes, variation of the characteristic impedance of air with altitude, and large scale refraction due to wind and temperature gradients. Of these, only molecular absorption at high altitudes significantly affects propagation. Limited measurements of atmospheric attenuation were made by using a propeller airplane sound source at altitudes to 14,000 feet and ranges to four miles. The results agree in general with those predicted by extrapolation of previous data for smaller altitudes and ranges, except that residual attenuation due to scattering is smaller.

1560

Sandmann, B., "Contributions to Propagation of Sound, in Particular to Sound Diffraction and Anomalous Propagation of Sound" (in German, English Summary), Gerlands Beit. Geophys., 28, 241-278, 1930.

The conditions which cause diffraction of sound in the free atmosphere are discussed. Meteorological conditions are treated at length in conjunction with sound propagation. Sections discuss: sound refraction in the air; dependence of sound intensity on meteorological conditions; refraction in relation to a zone of silence; favorable conditions for sound refraction at great heights in the atmosphere; further confirmation of the assumption of sound refractions as cause of anomalous propagation.

1561

Scorer, R. S., "Sonic and Advective Disturbances," Quart. J. Roy. Meteorol. Soc., 78, 76-81, 1952.

An interesting comparison of the atmospheric processes involved in atomic explosions ("little bangs," which are shock waves, "big bangs," like Krakatoa and the Siberian meteorite, which are compression-gravity waves), and slowly distributed heating that gives rise to advective disturbance and mass transport by wind. It is concluded that all meteorological effects are advected with the air, and none propagated through it.

1562

Sieg, H. "On Sound Transmission in the Open Air and Its Dependence on Weather Conditions," Halstead Exploiting Center, Brit. Intelligence Objective Sub-Committee, London, 1940. AD-55 755.

Meteorological factors affecting sound transmission in the open air are discussed. Normal sound transmission is mainly disturbed by the influence of temperature and wind, which attenuate sound on its progress through the air. Wind has a far greater effect on transmission than temperature, except in approximately calm weather. "Fine" weather, in an acoustic sense, was found to be nearly calm weather with sky overcast, as well as fog and drizzle; whereas weather was "bad" if the wind velocity was high, with consequent squalliness, especially when the wind blew against the direction of sound transmission. Molecular absorption and height of the transmitter above ground were found to be more conductive to transmission of higher frequencies than to lower frequencies.

1563

Syono, S., "Anomalous Propagation of Sound at a Short Distance," Geophys. Mag. (Tokyo), 9, 175-194, 1935.

In a former paper the author explained by an approximate method some anomalous sound wave propagation phenomena described by J. Kolzer. The present paper, which is almost entirely mathematical, is concerned with making the treatment more rigorous by taking into account the effects of wind and absorption of the earth's surface.

1564

Trendelenburg, F., "Introduction to Acoustics" (in German), 2nd ed., Springer-Verlag, Berlin, 378 pp., 1950.

A modern and highly technical text on acoustics, with great emphasis on the theory of wave propagation in various media. Chapter II discusses variations of wave form and speed with changes in temperature and pressure. Chapter IV, Par. 22, deals with the influence of atmospheric temperature and wind lapse rate or discontinuities on propagation and refraction of sound waves, anomalous zones of audibility, and stratospheric reflection. The text is amply illustrated with schematic diagrams, graphs, and photographs.

1565

Tucker, W. S., "Meteorological Acoustics," Quart. J. Roy. Meteorol. Soc., 59, 203-216, 1933.

Broad, general article on various aspects of acoustics in relation to meteorology: location of sounds; velocity of sound in still air and the acoustical field; consideration of effects of wind and temperature; anomalous propagation of sound; zones of silence; refraction phenomena based on stratification of the atmosphere; problems of sound attenuation, etc.

1566

Whipple, F. J. W., "Seasonal Variation in the Audibility of Distant Gunfire," Quart. J. Roy. Meteorol. Soc., 44, 285-289, 1918.

Explanations and comments are made on Christy's report (see Ibid., 281-284) on hearing gunfire across the English Channel each year from about May through August. Whipple notes that just the reverse seasonal variation in audibility occurs for listening areas to the east of the same gunfire. He argues that strong winds at very high altitudes (above 20 km) that change regularly with the seasons could cause corresponding variations in the refraction of sound waves, thus accounting for the seasonal shift in zones of audibility.

1567

Wiechert, E., "Remarks on the Abnormal Propagation of Sound in the Air, Part I" (in German), Nachr. Ges. Wiss. Gottingen, Math.-Physik. Kl., 49-69, 1925.

Discusses refraction and differences in speed of sound waves in layers of stratosphere and gives an explanation of abnormal audibility zones depending on actual layers of the stratosphere and wind conditions. Temperature is considered important in view of the new Lindemann-Dobson theory of warm upper-air conditions.

1568

Wiechert, E., "Remarks on the Abnormal Propagation of Sound in the Air, Part II," Nachr. Ges. Wiss. Gottingen, Math.-Physik. Kl., 93-103; "Part III," Ibid., 201-211, 1926.

See preceding abstract.

1569

Zanotelli, G., "Behavior of a Sound Wave When Passing Through a Cloud Layer" (in Italian), Ann. Geofis. 3, 289-301, 1950.

Discusses sound propagation through air that contains uniformly distributed droplets of equal radius, taking into account the viscosity of the air and the motion of the droplets. Small droplets vibrate with low frequencies, but the larger droplets remain stationary with high frequencies. In the first case the greatest values of the extinction coefficient are obtained; in the second, the refraction index is the greater.

Meteorology, Effects on Sound Propagation, Theory
See Also—45, 161, 223, 270, 406, 420, 432, 435, 450, 471, 476, 477, 502, 522, 550, 551, 554, 880, 902, 911, 924, 1445, 1460, 1463, 1464, 1468, 1475, 1477, 1482, 1487, 1493, 1751, 1810, 1867, 1918, 1921, 1937, 1938, 1939, 1942, 1945, 1947, 2074, 2151, 2213, 2269, 2297, 2308, 2309, 2498, 2507, 2520, 2634, 2880, 3210, 3248, 3270, 3298, 3315, 3327, 3331, 3340, 3342, 3344, 3348, 3349, 3351, 3352, 3359, 3361, 3364, 3365, 3366, 3367, 3370, 3391, 3403, 3440, 3460, 3688, 3750, 3883, 3961, 4455.

NOISE, CONTROL

1570

American Industrial Hygiene Association, "Industrial Noise Manual," Detroit, 166 pp., 1958.

This manual clearly and simply presents the necessary background information and specific instruction to enable skilled technicians from many fields to measure noise and obtain meaningful results. By following the methods of noise evaluation given, it is possible to estimate the hearing damage potential of a given source and to determine the minimum useful noise reduction required. The manual outlines the elementary principles, and includes details on 33 examples, of noise control. Each example is presented on a separate page and is accompanied by sound spectra for the before-and-after conditions. Drawings and photographs clearly show what has been done and how materials or methods are used to reduce the generation, transmission, and radiation of noise. Examples are also given in which process planning has led to noise reduction. The last chapter of the manual discusses methods of personal protection, including elementary but detailed discussions of the theory, potential capabilities, and practical results to be expected from ear muffs and ear plugs.

1571

Ancel, J. E., "A Practical Noise Reduction Treatment for Diesel Engines," J. Acoust. Soc. Am., 25, 1163-1166, 1953.

A noise reduction treatment for Diesel engines is described, which, though not the ideal approach to the problem, is practical, economical, and applicable to both new engines and those already in the field. This treatment was designed by making use of the results of a survey of the relative importance of the various noise sources on the Diesel engine. The treatment consisted of a set of sheet metal covers, lined internally with acoustical absorbing material and mounted directly over the noisy areas of the engine by means of built-in vibration isolation. Noise reductions for the direct sound of at least 8 to 12 db were observed at a distance of one foot from the engine. The total loudness of the engine noise at six feet was reduced from 320 to 220 sones. This is a substantial improvement with regard to voice communication in the immediate vicinity. The speech interference level of the engine noise at six feet was reduced from 87 to 82 db.

1572

Apps, D. C., "Quieter Automotive Vehicles," Noise Control, 1, 41, 1955.

The continuing efforts of automotive engineers to design vehicles which are quiet both inside and out has led to attacks on road rumble, axle noise, and tire noises, as well as to increased attention to the reduction of exhaust noise through the use of new muffler design techniques.

1573

Barnett, N. E., "The Efficacy of Damping Submerged Cylindrical Shell," Final Rept. No. 3595-1-F, Acoustics and Seismics Lab., Inst. Sci. Tech., Univ. of Mich., 70 pp., 1962.

An experiment demonstrated that a practical mechanical damping treatment can significantly reduce the resonant vibration (hence radiated energy) of an end-stiffened cylindrical shell in air and water. High-G resonances ranging from about 100 to over 2000 were observed in air and water for selected and identified low-order flexoral modes of vibration ($m = 1, 3; n = 2, ---, 10$). A commercial viscoelastic damping layer applied to the interior of this shell reduced these resonances, in both air and water, to G's of 20 or less; some resonant amplitudes were reduced by as much as a factor of 100. Radiated power measurements in air for both the undamped and damped shell, using the reverberation room technique, were utilized.

1574

Beranek, L. L., "Noise Reduction," McGraw-Hill, New York, 752 pp., 1960.

This book grew out of the special summer programs on the subject of noise reduction in industry which were held at the the Massachusetts Inst. of Tech., in 1953, 1955, 1957, and 1960.

Each of the 19 authors of the 25 chapters in the book is well known through his original contributions to the field he discusses. Although each chapter stands by itself as an introduction to or an up-to-date review of a certain topic, the continuity in terminology, approach, and presentation is well preserved.

The book is divided into four parts: (1) sound waves and their measurement; (2) fundamentals underlying noise control; (3) criteria for noise and vibration control; (4) practical noise control.

1575

Beranek, L. L., S. Labate, and U. Ingard, "Noise Control for NACA Supersonic Wind Tunnel," J. Acoust. Soc. Am., 27, 85-98, 1955.

To reduce an intense noise with frequency components extending from 5 to 10,000 cps due to the burning of a jet engine in the test section of a supersonic wind tunnel, a special muffler was built having an open cross-sectional area of 600 square feet. For frequencies below 11 cps, large Helmholtz type resonators were employed. Between 20 and 800 cps a tuned set of six fiberglas lined square ducts, were constructed. At higher frequencies two lined bends were employed to reduce the noise. Performance data measured in models and in the full scale wind-tunnel are presented. The result is a wind tunnel that is so quiet that nearby listeners are unaware of its operation.

1576

Bies, D. A., J. H. Caffrey, and O. B. Wilson, Jr., "A Study of Internal Acoustic Absorbers as a Technique for Turbojet Engine Noise Reduction," Final Rept. No. 94, Vol. 1, Soundrive Engine Co., Los Angeles, Calif., 192 pp., 1957. AD-150 553.

A comprehensive investigation was begun of several configurations of a modified J34 WE-42 turbojet engine designed for sound suppression. Twenty-two configurations of mild engine changes involving acoustic suppression means were tested, and some of these showed a reduction in particular frequency bands. The sound radiated from a particular configuration was not reduced by more than 1 db. Three tests were made with an untreated engine to establish a standard for comparing the efficacy of the various acoustic absorbers under investigation. Two configurations involving acoustic treatment to the diffuser cone which were not effective in reducing the radiated sound did improve the engine thrust by about 5%. The validity of internal noise measurements was questionable. Possibly less than half of the noise radiated from the turbojet had its origin with the engine.

1577

Bies, D. A., J. H. Caffrey, and O. B. Wilson, Jr., "A Study of Internal Acoustic Absorbers as a Technique for Turbojet Engine Noise Reduction," Final Rept. No. 94, Vol. 2, Soundrive Engine Co., Los Angeles, Calif., 166 pp., 1957
AD-150 554.

Data sheets are presented for the 22 configurations of the modified J34 WE-42 turbojet engine and 3 untreated engines.

1578

Bolt, Beranek, and Newman, Inc., "Handbook of Acoustic Noise Control, Vol. I. Physical Acoustics, Supplement 1," Suppl. 1 to WADC Tech. Rept. No. 52-204, Vol. 1, 308 pp., 1955.
AD-66,250.

Contents (additions and revisions to Volume I):

Propeller noise.
Noise from aircraft reciprocating engines.
Total external noise from aircraft with reciprocating engines.
Noise generating mechanisms in axial flow compressors.
Ventilating fans and ventilating systems.
Insulation of airborne sound by rigid partitions.
Insulation of impact sound.
Transmission of sound through cylindrical shells.
Specification of sound absorptive properties.
Lined ducts.
The resonator as a free-field sound absorber.
Acoustical shielding by structures.

1579

Bolt, Beranek, and Newman, Inc., "Handbook of Acoustic Noise Control," WADC Tech. Rept. No. 52-204, Wright-Patterson Air Force Base, Ohio, 1,397 pp., 1952
AD-12,015.

An over-all view is presented of the acoustic noise-control problem. The following noise source characteristics and methods of noise control are discussed: specification of a noise source, aircraft propellers and reciprocating engines, aircraft jet and rocket engines, fluid flow devices, industrial machine noise, physical characteristics of miscellaneous environmental noise, general noise-control panning, noise-control requirements, control of structure-borne noise, control of airborne noise, rooms and special enclosures, and evaluation of sound-control installations.

Chapter 12 describes methods for reducing the propagation of noise through air, indoors and outdoors. Lined ducts, parallel baffles, mufflers, resonators, resonant linings, isolating walls and combined treatments are considered. In covering the subject, the propagation of sound in the atmosphere and the effects of temperature, pressure, wind and ground impedance on propagation are described. The presentation is essentially non-mathematical. Most of the data and design criteria appear in the form of charts, graphs, and tables.

1580

Bolt, R. H., "The Aircraft Noise Problem," J. Acoust. Soc. Am., 25, 363-366, 1953.

Aircraft noise presents a system problem which to date has been attacked mainly at the level of individual components. The system includes: (a) aircraft as noise sources; (b) atmosphere and terrain as influences on sound propagation; (c) people, under several classes and conditions, as responders to noise; (d) physical components for controlling noise; (e) operating procedures for reducing noise exposure in communities; (f) public relations; (g) aviation planning policies and economics; (h) organizations concerned with characteristics and consequences of aircraft noise.

The nature of these components is reviewed in a general way, with emphasis on their inherent interrelations. This discussion provides a framework for unifying the several subjects included in an aircraft noise symposium.

1581

Callaway, D. B., and R. D. Lemmerman, "A Comparison Between Model Study Tests and Field Measurements on an Aircraft Test-Cell Silencer," J. Acoust. Soc. Am., 25, 429-432, 1953.

An acoustic model study was made of the silencer for a propeller-engine test cell in which the acoustical treatment consisted of conventional splitters for high-frequency silencing and thick splitters designed to give low-frequency reductions. The scale chosen for the model study was 1/8, and absorption coefficients of silencing treatment were simulated at frequencies eight times those of interest in full-scale structure. After construction of the test cell, field measurements were made of the noise reduction provided by the silencing treatment, using as a sound-source both a propeller engine and loudspeakers driven by a thermal noise source.

Measurement of the noise reduction provided in the scale model permitted prediction of a reduction in the full structure which agreed reasonably well with field measurements. On the basis of the model study and field measurements of high-frequency splitters, an empirical relationship between noise reduction and the absorption coefficient was determined.

1582

Campbell, A. J., "Investigation of a Wide Angle Diffuser with Air Augmentation for Use as a Jet Muffler," UTIA Tech. Rept. No. 15, Inst. of Aerophys., Univ. of Toronto, Canada, 11 pp., 1957.
AD-215 974

A wide angle diffuser for reducing the noise of a jet by taking advantage of the AV^8 law was combined with a short length augmentation system, which on a full scale muffler provides cooling air flow to the diffuser. A large reduction in velocity and a small cooling air flow were attained when screens were used to prevent separation of flow in the diffuser. The experimental results indicated that grids of rods or pipes (which could be cooled internally) also provide satisfactory resistance. The experiments indicated a pronounced noise augmentation when rods were used. A theory is developed for predicting qualitatively the induced air flow when a short mixing length is used. In the frequency bands, the noise level of the model was higher than that of the free jet. However, the main noise source was found to be inside the muffler. It is possible to reduce the muffler's output by aerodynamic means, and to decrease the radiated sound by acoustic treatment.

1583

Christman, R. J., and L. R. Pinneo, "Quick-Fix Recommendations for Reduction of Jet Engine Noise in Air Force Control Towers," Rept. No. RADC TR-57-189, Rome Air Development Center, Griffiss AFB, N. Y., 15 pp., 1957.
AD-131 374.

This report presents several techniques which may be employed by local AACS units, in conjunction with their respective Air Installation organizations, for the reduction of jet engine noise in control towers. Suggests minor changes or additions to towers to provide a "quick-fix" relief without the need for immediate tower replacement or major construction.

1584

Cole, J., R. England, and R. Powell, "Effects of Various Exhaust Blast Deflectors on the Acoustic Noise Characteristics of 1,000-Pound-Thrust Rockets," Rept. WADD TR 60-6, Rept. on Definition and Modification of Acoustic and Vibrational Environments, Aerospace Medical Lab., Wright Air Development Div., Wright-Patterson Air Force Base, Ohio, 57 pp., 1961.
AD-251 833.

The sound field produced by rocket engines is affected by exhaust blast deflectors used in test- and launch-site operations. Whether or not these deflectors affect only directivity of the noise radiation or also affect the total acoustic power has gone unanswered.

This report presents the results of a blast-deflector study which employed a 1,000-lb-thrust solid propellant rocket and scaled models of several types of deflector configurations. Changes in acoustic power spectra, directivities, and near-field sound pressure level (SPL) distributions derived from the study are included. Offers evaluations of a number of model diffuser noise suppressors designed for this same rocket, and some limited information on the acoustical effects of firing the rocket into water tanks with and without underwater blast deflectors. The results indicate appreciable reduction of the total power radiated can be achieved to varying degrees with the different deflectors (maximum total power-level reduction of 8 db). However, almost all devices caused increases in the SPL at near-field positions where the missile structure itself is located.

1585

Coles, W. D., J. A. Mihaloew, and E. E. Callaghan, "Turbojet Engine Noise Reduction with Mixing Nozzle-Ejector Combinations," Tech. Note TN 4317, Natl. Advisory Comm. Aeron., Washington, D. C., 33 pp., 1958.
AD-200 740L.

Maximum sound-pressure level reductions of 12 decibels and sound-power level reductions of 8 decibels were obtained with lobe nozzle and ejector combinations on two full-scale engines. The ejectors provided 3 to 5 decibels of the sound-power level reduction. Several combinations of ejectors and nozzles were used, and acoustic and engine-performance data are presented. A study of jet profiles and boundaries at the ejector exit shows the effectiveness of the lobe nozzle and ejector combinations in diffusing the jet to a larger, lower velocity stream. Calculated noise reductions based on ejector exit flow conditions are not realized experimentally, probably because the noise generated inside the ejector is appreciable.

1586

Cook, E. J., J. A. Lee, et al., "Dynamic Mechanical Properties of Materials for Noise and Vibration Control," Rept. No. 101, Chesapeake Instrument Corp., Shadyside, Md., 148 pp., 1960.
AD-236 371.

Dynamic mechanical properties and their relation to wave propagation in viscoelastic media are reviewed. Typical variations with frequency and temperature were studied for amorphous and crystalline polymers. Proposed methods for revising the Fitzgerald apparatus to make possible direct mechanical impedance measurements on resilient mounts and coated panels at audiofrequencies are outlined and compared with present testing procedures. The variations of complex shear compliance ($J^* = J' - iJ''$), sound velocity, and attenuation, at frequencies between 50 and 5000 cps, and at temperatures between 23^oC and 27^oC, were obtained for 15 materials; these included a natural rubber gum stock and a series of six butyl rubber stocks used in resilient mounts.

The variables studied were molecular weight of the butyl rubber and the size and amount of carbon black filler. A series of four polyurethanes was also studied. The dynamic properties of the sample of greatest hardness (Shore A 92) were different from those of the rest of the series; sharp resonances were found at 1550, 2700, and 2950 cps. A sample of polyurethane with 82% lead powder as filler was studied; the shear sound velocity was decreased, and the attenuation was greatly increased in comparison with the unfilled stock. The variation of dynamic properties with frequency is more pronounced for the filled stock than for the unfilled. Polytetrafluorethylene (Teflon) and a copolymer of hexafluoropropylene and vinylidene fluoride (Viton) showed good high-temperature stability, but Viton had a loss factor, or damping, twice to ten times that of Teflon.

1587

Corcos, G. M., "Some Measurements Bearing on the Principle of Operation of Jet Silencing Devices," Rept. No. SM-23114, Douglas Aircraft Co., Santa Monica, Calif., 1958.
AD-159 097.

Recounts an attempt to explain how ejectors corrugated nozzles, and multiple nozzles modify the turbulent mixing of a jet to reduce aerodynamic noise. Ejectors, corrugated and multiple nozzles generate less aerodynamic noise than corresponding plain nozzles because they reduce turbulence levels in the mixing region by accelerating the ambient air before it is mixed with the jet. A sheath of flowing air decreases the lateral jump in the mean axial velocity which is responsible for the turbulence level in the mixing region. Experience with corrugated nozzles and ejectors at low speeds is reported, as are mean velocity profiles and turbulence surveys. The results agree well with the expectations.

1588

Doelling, N., "Acoustical Evaluation of Two Durastack Ground Run-Up Noise Suppressors," Rept. No. WADC TN 57-392, Bolt, Beranek, and Newman, Inc., Cambridge, Mass., 41 pp., 1961.
AD-273 987.

Reports measurements of the noise characteristics of two Durastack noise suppressor systems, between which there is but one difference; the Type A suppressor essentially has no acoustical treatment of the secondary air intake, whereas Type B has it. Measurements in octave bands taken on a 25-foot circle and at close-in positions are presented. Average noise reduction of both suppressors is fairly flat above the first octave band. The average value of the noise reduction between 75 and 10,000 cps is about 14 db for the Type A suppressor, and about 21 db for Type B. No intake suppressor was used.

The relative magnitudes of the major noise sources are also included, and some non-acoustical aspects of the noise suppressors.

1589

Doelling, N., K. S. Pearsons, and others, "Acoustical Evaluation of a B-58 Run-Up Pen at Convair-Fort Worth," WADC Tech. Note No. 57-389, Bolt, Beranek, and Newman, Inc., Cambridge, Mass., 57 pp., 1958.
AD-142 160.

This report describes the acoustical evaluation of the B-58 run-up pen at CONVAIR-Fort Worth. Data are presented which show that the noise reduction in forward quadrants is of the order of 20 or 30 db, while in the aft quadrants it is about 0 db. This pen provides hearing protection to personnel located in adjacent pens.

The noise characteristics of the B-58 are also presented.

1590

Dyer, I., P. A. Franken, et al., "Jet Noise Reduction by Induced Flow," J. Acoust. Soc. Am., 30, 761, 764, 1958.

The secondary air induction of a modified jet nozzle affects the generation of noise, and this report analyzes the effect. It is shown that the combination of the secondary air with the primary jet air creates a new jet stream of larger area, lower velocity, and lower noise generation. The decrease in noise radiation is found in terms of the area of the combined jet streams.

There is no detailed check of the theory because of lack of measurements of the combined jet-stream areas taken with measurements of the noise. However, the upper limit of the appropriate jet-stream area is estimated in order to determine the upper limit on noise reduction; the upper limit on noise reduction obtained from the theory is consistent with existing measurements. The theory allows qualitative conclusions about the spectrum and directivity of the noise radiated by jets with modified nozzles, and these conclusions are in accord with measurements.

1591

Eldred, K., "Acoustic Factors in Jet Airport Design," J. Acoust. Soc. Am., 31, 547-557, 1959.

The advent of commercial jet airline operations called for increased attention to acoustical considerations in airport design. This paper reviews the relationships between the noise resulting from commercial jet and propeller airliner operations, including takeoff, taxi, and idle, for various projected traffic densities and various airport-building functional design criteria. Criteria in force are explained, and new criteria are suggested to fill a gap in the overall evaluation procedure for short-time noises. Methods and examples are presented which expedite initial visualization of the major acoustical factors in an airport-design situation, facilitate decisions for preliminary airport-building layout, and enable evaluation of possible wall and roof structures.

1592

Eldred, K., and J. Ortega, "Acoustical Evaluation of the Air Logistics Corporation Jet Ground Runup Noise Suppressor Model 11000," Final Rept. MRL TDR 62-22, Western Electro-Acoustic Lab., Los Angeles, 41 pp., 1962. AD-285 320L.

Reports on the efficiency and effectiveness of the suppressor named in the title.

1593

Eldred, K., and J. Ortega, "Acoustical Evaluation of the Curtiss-Wright Corporation Jet Ground Runup Noise Suppressor Type 700658," Rept. No. ASD TR 61-542, Western Electro-Acoustic Lab., Los Angeles, 93 pp., 1961. AD-270 879.

Acoustical evaluations were made of a Curtiss-Wright Corporation Type 700658 ground runup noise suppressor. Data were obtained for suppressor operation with J71 and J57 engines with the F8U-1P aircraft. Results give the acoustical performance of the suppressor in both near and far fields, clearly illustrating the effect of aircraft suppressor spacing. The results also demonstrate the dominance of high-frequency noise radiated to the far field by the secondary air intake.

The average noise reduction in the far field for the best engine-suppressor configuration varies from approximately 12 db in the 18.75-37.5 -cps frequency range to about 23 db in the 75-300 -cps range, then decreases rapidly with increasing frequency to 5 db in the 4800-9600-cps octave band. However, this reduction is limited to the aft quadrant of the measurement semicircle, and negative values of noise reduction were found in the forward quadrant.

1594

Eldred, K. and J. Ortega, "Acoustical Evaluation of the Emhart Manufacturing Company, Maxim Division, Portable Ground Runup Suppressor," Rept. No. ASD TR 61-541, Western Electro-Acoustic Lab., Los Angeles, 92 pp., 1961. AD-270 878.

A series of acoustical evaluations were made of a ground runup noise suppressor. Data were obtained for suppressor operation with J57 and J71 engines and with the F8U-1P aircraft. Results give the acoustical performance of the suppressor in both near and far fields, and also show the effects of configuration modifications on the suppressor's overall acoustical performance.

The average (0-180 degrees) far-field noise reduction for the final suppressor configuration varies from about 16 db in the 37.5-75-cps octave band to about 24 db between 75 and 300 cps, tapering off to approximately 5 db in the higher frequencies. Negligible noise reduction is achieved in the near field for maintenance personnel and in some frequency ranges the near-field noise actually increases when the engine is operated with the suppressor.

1595

Eldred, K., and J. Ortega, "Acoustical Evaluation of the General Sound Control, Inc., Class III Jet Ground Runup Noise Suppressor," MRL TDR 62-21, Western Electro-Acoustic Lab., Los Angeles, 49 pp., 1962. AD-285 319L.

Reports on the efficiency and effectiveness of the suppressor named in the title.

1596

Eldred K., and J. Ortega, "Acoustical Evaluation of the General Sound Control, Inc., Jet Ground Runup Noise Suppressor, "Rept. No. ASD TR 61-544, Western Electro-Acoustic Lab., Los Angeles, 87 pp., 1961. AD-270 469.

Acoustical evaluations were made of a General Sound Control, Inc., ground runup noise suppressor. Data were obtained for the suppressor operation with J57 and J71 engines and with the F8U-1P aircraft. Results give the acoustical performance of the suppressor in both near and far fields.

The average noise reduction in the far field for military-power operation ranges between one and 12 db, depending on test configuration and frequency. However, this reduction is limited to the aft quadrant of the measurement semicircle, and negative values of noise reduction were found in the forward quadrant. Furthermore, the noise level in the near field and at the maintenance positions was generally higher with the suppressor than with the unsuppressed engine. The residual far field average SPL was almost identical for both engines and somewhat lower for the F8U (probably resulting from refraction phenomena). The noise reduction for afterburner operation was greater than that achieved for military operation, indicating that the noise generated by the suppressor does not increase as rapidly with an increase in jet flow velocity and temperature as does the noise from the free jet.

1597

Eldred, K., and J. Ortega, "Acoustical Evaluation of the Industrial Acoustics Company, Inc., Jet Ground Runup Noise Suppressor, Model 7043," Rept. No. ASD TR 61-540, Western Electro-Acoustic Lab., Los Angeles, 92 pp., 1961.
AD-273 164.

Presents acoustical evaluations of a ground runup noise suppressor. Data were obtained for suppressor operation with J57 and J71 engines and with the F8U-1P aircraft. Results give the acoustical performance of the suppressor in both near and far fields, showing the effects of several configuration modifications on the suppressor's overall acoustical performance.

The average (0-180 degrees) far-field noise reduction for the final configuration varies from about 11 db at frequencies below 75 cps, to about 19 db between 75 and 300 cps, tapering off to about 7 db at the higher frequencies. Little noise reduction was achieved in the near field for maintenance personnel, and in some frequency ranges the near-field noise actually increased. Estimates of the contributions of various noise sources of the engine suppressor configurations indicate that the far-field average SPL are controlled by exhaust and aerodynamic noise in the frequency range below 600 cps. Above this range, the average levels in the far field result from contributions of exhaust, secondary air, and engine intake noise, the relative levels being dependent on the source and suppressor configuration.

1598

Eldred, K., and J. Ortega, "Acoustical Evaluation of the Industrial Acoustics Company, Inc., Type I Durastack Aircraft Noise Suppressor," Final Rept. No. MRL TDR 62-23, Rept. on Acoustic Energy Control, Western Electro-Acoustic Lab., Los Angeles, 27 pp., 1962.
AD-285 420L.

Reports on the efficiency and effectiveness of the suppressor named in the title.

1599

Eldred, K., and J. Ortega, "Acoustical Evaluation of the Koppers Company, Inc., Class III Jet Ground Runup Noise Suppressor," Final Rept. No. MRL TDR 62-25, Western Electro-Acoustic Lab., Inc., Los Angeles, 49 pp., 1962.
AD-285 587L.

Reports on the efficiency and effectiveness of the suppressor named in the title.

1600

Eldred, K., and J. Ortega, "Accoustical Evaluation of the Koppers Company, Inc., Industrial Sound Control Division Jet Ground Runup Noise Suppressor," Rept No. ASD TR 61-543, Western Electro-Acoustic Lab., Los Angeles, 89 pp., 1961.
AD-270 468.

Acoustical evaluations were made of a Koppers Company, Inc., Industrial Sound Control Division, ground runup noise suppressor. Data were obtained for suppressor operation with J57 and J71 and with the F8U-1P aircraft. Results give the acoustical performance of the suppressor in both the near and the far fields.

The average (0-180 degrees) far-field noise reduction varies from about 5 db in the 18.75-to-37.5 cps octave band to 14 db in the 75-to-150 cps octave band, then decreases to negative values at frequencies above 1200 cps. Little noise reduction was achieved in the near field for maintenance personnel, and in some frequency ranges the near-field noise actually increases when the engine is operated with the suppressor. Estimates of the contributions of various noise sources of the engine-suppressor configuration indicate that the far-field average SPL's are controlled by exhaust, secondary air intake, and aerodynamic noise sources.

1601

Eldred, K., and J. Ortega, "Accoustical Evaluation of the Koppers Company, Inc., Model 30-S Class II Jet Ground Runup Noise Suppressor," Rept. No. MRL TDR 62-24, Western Electro-Acoustic Lab., Inc., Los Angeles, 49 pp., 1962.
AD-285 321L.

Reports on the efficiency and effectiveness of the suppressor named in the title.

1602

Embleton, T. F. W., and I. R. Dagg, "Sound Radiation from a Rectangular Array of Incoherent Sources," Sound, 1, 32-36, 1962.

The use of high-speed digital computers allows the analysis of many acoustical problems, using values of the parameters which closely approximate those found in practice. The result of such an analysis, this paper studies the noise levels in a factory having varying amounts of sound absorption—ranging between perfectly reflecting and perfectly absorbing, from floor to ceiling. The noise source is a rectangular or square array of equally spaced and similar machines. It is found that the sound levels within the boundaries of the machinery array are very little reduced by increasing the amount of sound absorption, though there is a much larger effect outside the array. At large distances from the array, one obtains lower sound levels by the concentration of a given amount of absorption on ceiling alone (rather than distributed between floor and ceiling), but within the array the opposite may be the case, depending upon the size of the array.

1603

Federal Aviation Agency, "Aircraft Noise and Its Problems, Selected References, Bibliographic List No. 6," Washington, D. C., 20 pp., 1962.
AD-283 265.

Pertinent readings on the subject of aircraft noise and its inherent problems, of concern to federal, state, and local officials and organizations, are listed. The list is divided into seven parts for the convenience of the reader, including general references, community problems, noise abatement procedures, structural and design problems, legal aspects, helicopters, and alleviation methods.

1604

Fehr, R. O., "Unsolved Problems in the Field of Aircraft Noise," J. Acoust. Soc. Am., 24, 773-775, 1952.

The testing and operation of turbojet engines offer noise-control problems to the manufacturers of engines and airframes, as well as to the operators of aircraft and airports. Some can be solved by isolation of the noise at the source, while others require reduction of the noise at the source. This report states the important problems remaining to be solved, together with background information that may be helpful to their solution.

1605

Gordon, B. J., "A Review of Work in Jet Engine Noise Control at the General Electric Company," Noise Control 7, 14, 1961.

This paper summarizes the research and development work of the General Electric Company in the field of jet-engine noise control. Noise data are presented for various stages in the development of engine-noise suppressors, and the turbojet engine and the new G.E. turbofan engine are compared.

1606

Hadley, W. C., "Noise Level Studies of Motorcycles in Bermuda," Noise Control, 5, 21, 1959.

This article describes Bermuda's regulations and test facility for control of motorcycle noise. Analysis of results gives variations of levels and shows that the average level is but little affected by normal usage.

1607

Hardy, H. C., "Design Characteristics for Noise Control of Jet Engine Test Cells," J. Acoust. Soc. Am., 24, 185-190, 1952.

Presents an example of the steps in designing the noise-control structure of a jet-engine test cell, from the determination of the goal to the final acoustical treatment of the cell. An arbitrary goal was selected on the basis of an earlier survey of city noise. To achieve the desired noise reduction at a distance of 3000 feet, it is necessary to quiet the noise from ten jet engines having afterburners 50 and 55 db in the 150-300 and 300-600 cps bands, respectively (these two bands are the most difficult to control).

An analysis of the required volume and dependent cost of the structure is given in terms of the amount of quieting needed, the quantity and temperatures of the heated gases exhausted, and the velocity of flow permitted. Two unconventional but economical systems of noise control are recommended: (1) a series of acoustically treated plenums; and (2) a series of acoustical, lined 180-degree turns. Design equations and confirming data from model studies are presented.

1608

Hardy, H. C., "Noise Control Measures for Jet Engine Test Installations," J. Acoust. Soc. Am., 25, 423-428, 1953.

The various schemes currently used for controlling the noise of aircraft engine test-stands and warm-up operations on the ground are briefly surveyed. The first step is to evaluate a design goal for acceptable levels in the neighborhood for the installation. The size of cross section required to handle the intake and exhaust gases is determined from the amount of air consumed, the temperature, acceptable gas velocities, and the aerodynamic pressure drops. The modern trend in engine size requires cross sections of 200 square feet or more. Several different styles of structures have been successful. The various types used — steel mufflers, duct splitters, and plenums and 180-degree bends — are discussed, and typical data are given for each type. Economic considerations are emphasized. The use of scale model acoustic tests for untried acoustic designs is strongly recommeded.

1609

Harris, C. M. (ed.), "Handbook of Noise Control," McGraw-Hill, New York, 1042 pp., 1957.

This volume in the McGraw-Hill handbook series covers the broad and colorful spectrum of noise and its control. In forty chapters — ranging from physics and engineering, physiology, and medicine to psychology, economics, and law — it contains, in over 1000 pages, a great amount of information. However, Chapters 2 and 3 will be of particular interest to people concerned with the propagation of sound in air.

Chapter 2, "Physical Properties of Noise and Their Specification," by R. W. Young and Chapter 3, "Propagation of Sound in The Open Air," by I. Rudnick are concerned with physical aspects of noise and sound. The former gives a review of the elementary concepts of sound and noise, particularly its description. A more extensive consideration of statistical aspects and methods would probably be useful for many readers. In Chapter 3 the complex field concerning the influence of outdoor factors on sound propagation is discussed, and the results are represented in many useful graphs.

1610

Hawley, M. E., "Noise Shield for Microphones Used in Noisy Locations," J. Acoust. Soc. Am., 30, 188-190, 1958.

A rubber noise shield was developed which significantly improves the speech-to-noise ratio at a military microphone. The construction and evaluation techniques are described, and the advantage of introducing acoustic damping material is affirmed.

1611

Hazard, D. M., "Aircraft Engine Noise Control as Viewed by the Engine Manufacturer," J. Acoust. Soc. Am., 25, 412-416, 1953.

In developing and testing engines, the manufacturer has a continuing problem with noise control. Efforts to meet the problem have undergone a manifold growth in scope because of the rapid increase in types and size of military power plants.

This paper presents a review of the overall control procedure, including typical noise sources, control objectives, recent techniques used in the control and attenuation of aircraft power-plant noise, problems associated with the design of noise-control provisions, and limitations in the existing methods. Includes data on reciprocating, turbojet, turboprop, and ram-jet power plants, along with a description of installations used for controlling the noise in both ducted exhaust systems and propeller-type test cells. The discussion cites cost, space, and high tolerance as the major design problems.

The areas needing continued endeavor are outlined for the engine manufacturer, the acoustical consultant, and the manufacturer of noise-control equipment.

1612

Hirschorn, M., "The Jet Aircraft Run-Up Noise Problems," Noise Control, 6, 10, 1960.

The historical development of ground runup mufflers for jet engines is presented. Noise reduction data are given for various suppressors for military and commercial jet engines. A particular series of IAC suppressors is discussed in terms of possible noise specifications delineated in the interests of residential communities near airports.

1613

Hoeft, L. O., "Acoustical Evaluation of the F4D Noise Suppression Run-Up Hangar at Douglas, El Segundo," WADC Tech. Note No. 58-112, Aero Medical Lab., Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, 25 pp., 1958.
AD-203 644.

This report describes the acoustical characteristics of the F4D runup hangar at Douglas Aircraft Company, El Segundo, California. Measurements in three areas are presented: (1) on a circle of 250-foot radius with the engine at military power; (2) around the outside of the runup hangar with the engine at military power; (3) inside the hangar with the engine at idle power. These measurements indicate that at 250 feet this noise suppressor had an average reduction of about 28 db above 300 cps. Some aerodynamic measurements and comments on the construction are included.

1614

Hoeft, L. O., "Proposed Criteria for Acoustical Performance of Noise Suppressors," AMRL Memo. No. M-16, Biomedical Lab., Aerospace Medical Div., Wright-Patterson AFB, Ohio, 30 pp., 1958.
AD-292 702.

The sound-pressure levels which result from using the proposed set of average noise-reduction criteria are compared with those required to provide protection against hazardous noise exposure, communication interference and adverse community response. The comparison demonstrates that noise-control problems can be simplified, standardized, and/or solved satisfactorily through the use of the criteria. Comparison of the noise reduction spectrum required by the proposed criteria with that which has been measured around existing noise suppressors shows that the proposed criteria are practical. These comparisons have been carried out for both the distant and the close fields. The use of the proposed criteria should facilitate the classification of noise suppressors.

1615

Hubbard, H. H., and D. J. Maglieri, "Noise Considerations in the Design and Operations of the Supersonic Transport," Noise Control, 7, 4, 1961.

The main sources of noise from the supersonic transport are the power plants, the aerodynamic boundary layers, and the shock waves. This article discusses the state of knowledge about each of these, and the manner in which noise considerations may affect the design and operation of this type aircraft.

1616

Ingard, U., "Attenuation and Regeneration of Sound in Ducts and Jet Diffusers," J. Acoust. Soc. Am., 31, 1202-1212, 1959.

The effect of noise regeneration by fluid flow on the performance of noise-attenuating structures is examined with special attention to muffler design. The insertion loss of a single element, as well as a continuous distribution of attenuating and noise-regenerating elements, is studied. For example, in a duct with an attenuation constant β per unit length and a regeneration r per unit length, the upper limit of the insertion loss is 10 log $(2\ E\beta/r)$, where E is the source strength. It should be noted that the insertion loss of a noise-regenerating attenuator depends on the sound level to be reduced.

An analysis of experimental data on jet noise indicated that the power spectrum of a circular jet depends on frequency f and Mach number M, approximately, as f^2M^5 at low frequencies, as $f^{-2.5}M^{9.5}$ at high frequencies, and as M^7 at the peak frequency. In terms of the corresponding jet spectrum, for which an empirical analytical expression is given, the maximum attainable insertion loss of a jet muffler diffuser is presented as a function of frequency. The deviation of the characteristics of a lossy diffuser from this upper limit depends on the attenuation and regeneration characteristics of the acoustical elements in the muffler. These characteristics are investigated for the special element consisting of a perforated sheet, and the results are applied to an analysis of the insertion loss of a muffler diffuser of the perforated basket type.

1617

Jackson, R. S., "The Performance of Acoustic Hoods at Low Frequencies," Acustica, 12, 139-152, 1962.

An investigation has been made into the performance of acoustic hoods at low frequencies, in the range where difficulties are often encountered in obtaining adequate attenuation. The problem was analysed for the case of one dimension, and with the aid of small boxes and panels the solution is shown to be of practical value. The importance of having a sealed enclosure with stiff walls is illustrated; several methods of introducing wall rigidity were investigated. When consideration need only be given to higher frequencies, limp wall techniques may be used to advantage, if adequate mechanical damping resides in the system. Methods of introducing wall damping were investigated and discussed, and some further factors influencing the low-frequency performance are included. It is concluded that further research into devising highly-damped stiff structures would be advantageous.

1618

Johnson, J. C., N. E. Barnett, R. N. Hamme, S. S. Kushner, and H. F. Reiher, "Study of Noise-Level Reduction of Aircraft Ground-Support Equipment," Final Rept. No. 2353-8-F, Eng. Res. Inst., Univ. of Mich., 295 pp., 1957.

The report contains a study of nuisance and hazard noise criteria; measurement of the noise characteristic of several types of ground-support equipment; a discussion of experimental studies of the quieting of several ground-equipment units; an analytical and experimental study of exhaust-muffler attenuation characteristics; and a compilation of noise-reduction techniques applicable for quieting ground-support equipment. The results include: a basis for ranking noises of different intensities and frequency composition according to (1) the seriousness of the psychologically disturbing or physically harmful effects which they produce, and (2) the extent to which they mask or interfere with speech communication; information about the sound-pressure levels and the octave-band frequency distributions of the noise of certain typical ground-support units; a demonstration of the application of practical noise-reduction techniques to ground-support equipment; a consideration of the attenuation characteristics of acoustic filter configurations, an examination of the correlation of computed and measured attenuations, and an evaluation of an experimental muffler design; and a compilation of noise-reduction techniques, methods, and measurements.

1619

Kamrass, M., and K. D. Swartzel, "Evaluation of the Noise Field Around Jet-Powered Aircraft," Noise Control, 1, 30, 1955.

Following a review of the factors which affect the ground-level noise from aircraft in flight, a technique is discussed which permits the prediction of ground noise levels, and which indicates flight patterns that will permit minimum noise levels for those areas requiring that such annoyance be held to a minimum.

1620

Keast, D. N., "Acoustical Evaluation of F-102 Production Silencer, Convair, San Diego," Rept. No. WADC TN 57-390 (Rept. on Human Response to Vibratory Energy), Bolt, Beranek, and Newman, Inc., Cambridge, Mass., 47 pp., 1961. AD-273 892.

The F-102 production-silencer enclosure at Convair-San Diego has been evaluated acoustically. This silencer is similar to a turbojet engine test cell, but is designed to enclose a complete aircraft. Measurements of sound-pressure level in and around the silencer are reported; the noise reductions of the various elements of the acoustical treatment, as well as the noise reduction of the silencer as a whole, are determined. The results indicate that the average insertion-loss noise reduction of the silencer at 250 feet increases from about 20 db in the 20-75 cps band to somewhat greater than 50 db for all frequencies above 300 cps.

1621

Koenig, R. J., "Noise Control for Convair 880 and 600 Jets," Noise Control, 5, 23, 1959.

Discusses measures for controlling outdoor noise of these airliners. Data include power levels, directional characteristics, and spectra. The 880 uses GE CJ-805-3 engines and an eight-lobed suppressor nozzle with centerbody and ejector. The 600 uses GE CJ-805-21 engines of aft-fan type, which have markedly different spectrum.

1622

Kurbjun, M. C., "Limited Investigation of Noise Suppression by Injection of Water into Exhaust of Afterburning Jet Engine," Res. Memo. RM L57L05, Natl. Advisory Comm. Aeron., Washington, D. C., 7 pp., 1958. AD-151 945.

A preliminary investigation of the effect of injecting up to 880 gallons of water per minute on the noise production of an afterburning jet engine producing 8,000 pounds of thrust. In the direction of maximum noise radiation, the overall sound-pressure level was reduced two to six decibels. It was noted that the reduction in overall sound pressure was achieved by significant reductions (up to ten decibels) in the range of frequencies below 800 cps, a region where the attenuation due to atmospheric losses is negligible.

1623

Kushner, S. S., and J. C. Johnson, "Determination of the Sound Transmission Characteristics of Various Aircraft Sound-Proofing Materials," Final Rept. No. 2490-1-F, Willow Run Labs. Univ. of Mich., 1958.

Determination of the sound transmission characteristics for various aircraft fuselage acoustic treatments was accomplished utilizing a small sample transmission-loss apparatus. The materials tested were ranked in relation to the theoretical weight-law attenuation of a 0.020-inch-thick dural panel.

1624

Lee, R., R. Kendall, et al., "Research Investigation of the Generation and Suppression of Jet Noise," Final Rept., General Electric Co., Cincinnati, Ohio, 451 pp., 1961. AD-251 887.

Analytical and experimental investigations on jet-noise suppression led to establishment of a new theory relating the sound-power spectra and distribution of mean flows in the jet field. The method is sufficiently general to be applicable to the flow fields of nozzle suppressors, and is found to agree with test results. A computer program was also set up for calculating the mean-flow characteristics of mixer-type suppressors in general.

Scale model testing on various suppressor configurations indicated that further noise reduction may be achieved using suggested optimization techniques. Directivity investigation of jet noise showed that suppressor directivity can be predicted with reasonable accuracy on the basis of sound-power spectrum data alone. Screech phenomena were investigated, including flow interference and temperature effects, leading to formulation of a detailed physical model for their generation.

1625

Lemmerman, R. D., and D. B. Callaway, "Aircraft Run-Up Silencing Design," Noise Control, 2, 10, 1956.

Aircraft run-up silencers are available in a variety of types. Here is a statement of the determining factors in the selection of run-up facilities.

1626

Lodd, K. N., and G. M. Roper, "A Deuce Programme for Propeller Noise Calculations," Tech. Note No. MS 45, Royal Aircraft Establishment, Great Britain, 1958. AD-200 826.

A survey is given of work already performed on propeller noise, and a programme is described for calculating propeller noise on the DEUCE.

1627

Maglieri, D. J., "Shielding Flap Type Jet Engine Noise Suppressor," J. Acoust. Soc. Am., 31, 420-422, 1959.

Far-field noise measurements from model tests of a shielding flap-type jet-noise suppressor are presented in the form of radiation patterns and frequency spectra. The tests used a cold-air jet issuing from the nozzle in such manner that it attached itself to, and flowed along, the surface of a shielding flap. Whereas other proposed noise suppressors provide generally symmetrical noise radiation patterns, the present device skews the pattern beneficially, so that large noise reductions are obtained in the downward direction. These large reductions are thought to result from both the acoustic shielding of the flap and the benefits of flow attachment.

1628

Miller, L. N., L. L. Beranek, and H. Sternfeld, Jr., "Acoustical Design for Transport Helicopters," Noise Control, 5, 6, 1959.

A report of design features for noise reduction on a commercial transport helicopter. Details the treatment of windows, skin, walls, bulkheads, doors, ventilation ducts, etc. Spectra of interior noise levels are given for military and commercial versions.

1629

Mustain, R. W., and B. R. Vernier, "Acoustic and Vibration Data Internal Acoustic Treatment (Firings 4 and 5) Acoustic (Noise) Test Program," Rept. No. NAI-57-582, Northrop Aircraft, Inc., Hawthorne, Calif., 176 pp., 1958. AD-156 121.

This report presents the acoustic and vibration data compiled during a study to determine the capabilities of an internal acoustic treatment as applied to the SM-62 fuselage. These data contain the results of the fourth and fifth firings (internal acoustic treatment) of the Acoustic (Noise) Test Program at AFMTC, and, with the internal acoustic configuration, are discussed and compared with previously published data from the three reference firings.

The data from the five separate firings in the untreated areas correlate well and indicate that these firings are comparable. These data also demonstrate that the internal acoustic treatment provides no consistently significant reduction in the acceleration levels of either the primary structure or the vibration-isolated equipment.

Briefly reviews information on instrumentation characteristics, calibration procedures, and data reduction methods.

1630

O'Bryan, T. C., and J. B. Hammack, "Flight Performance of a Transonic Turbine-Driven Propeller Designed for Minimum Noise," NASA Memo. 4-19-59L , Natl. Aeron. Space Admin., Washington, D. C., 22 pp., 1959. AD-216 733.

Presents results of a flight investigation to determine the aerodynamic characteristics of a transonic-type propeller. This propeller was designed for an advance ratio of 4.0 at a forward Mach number of 0.82 in an effort to limit the noise production. The measured efficiency of the propeller was 68% at the design Mach number of 0.82. This value is to be compared with the as-much-as-15% greater efficiency of a propeller designed with the same Mach number but an optimum advance ratio of about 3.0. This penalty in efficiency must be considered in light of the resulting noise reduction. The noise under static and take-off conditions was measured to be 117.5 decibels, which represents a noise reduction of about five decibels, (at 1400 horsepower) compared with the advance-ratio-three design.

1631

Olesten, N. O., "Saab Silencer System," Noise Control, 5, 15, 1959.

The SAAB Silencer System LJ32, developed for the Swedish Air Force, is described, and performance curves are given. It is a runup muffler for single-engine jets with afterburners.

1632

Olson, H. F., "Electronic Control of Noise, Vibration, and Reverberation," J. Acoust. Soc. Am., 28, 966-972, 1956.

Existing passive materials are inadequate to cope with many problems in the control of noise, vibration, and reverberation. It is only within recent times that active systems have been given consideration for the control of sound.

The electronic sound absorber is an example of an active sound absorber. It consists of a microphone, an amplifier, and a loudspeaker connected in an inverse-feedback manner. The electronic system reduces the effective acoustical impedance in the vicinity of the absorber. As a consequence, this absorber may be used in the manner of a conventional sound absorber or as a zonal sound reducer.

The electronic vibration reducer consists of a sensor, amplifier, and driver connected either in negative or positive feedback fashion, and may be used to isolate vibrating machines or to reduce the vibration of machines.

1633

Paca, F. B., "Reduction of Noise Arising from Demolition Activities," Rept. No. 1703-TR, Army Engineer Research and Development Labs., Fort Belvoir, Va., 44 pp., 1961. AD-276 216.

A study has been made concerning the noise and annoyance arising from detonation of explosive charges at EPG. Damage or noise which is propagated as air blast and methods by which these disturbances can be reduced are analyzed. Response to letters of inquiry dealing with the reduction of air-blast effects is included in the appendices.

1634

Pietrasanta, A. C., and K. N. Stevens, "Guide for the Analysis and Solution of Air Base Noise Problems," Final Rept. No. WADC TR 57-702, Bolt, Beranek, and Newman, Inc., Cambridge, Mass., 163 pp., 1961. AD-278 688.

Detailed engineering procedures for analyzing and solving air base noise problems caused by jet operations are presented. These problems are classified according to activity areas: (a) on- and off-base housing; (b) offices and work areas; (c) group meeting, study, and rest areas; (d) hospitals; and (e) important communication areas. For each of these areas, analysis procedures are described in detail, and several illustrative examples of their application are discussed. The procedures are simplified so that personnel with little or no engineering training can readily apply them to solve air base noise problems. Also, these procedures have been developed so that all noise problems can be solved on paper. No direct measurements of air base noise are required.

The guide is intended to be useful to anyone concerned with air base noise problems. It provides engineering guidance for the solution of a variety of problems, including planning new bases, modifying existing bases, and planning future modifications which may become necessary with newer aircraft.

1635

Powell, A., "Considerations Concerning an Upper Limit to Jet Noise Reduction," J. Acoust, Soc. Am., 31,1138-1140, 1959.

The idea of a theoretical upper limit on jet-noise reduction, put forward by Dyer, Franken, and Westervelt, may prove a profitable one, since it concerns an aspect so much simpler than the question of determining what might be the reduction achieved in practice. Their argument can be greatly strengthened by extending the method to take into account the essential nonuniformity of flow conditions at cross sections away from the jet exit, and also by referring to the physically significant total cross-sectional area of the mixing zone in defining the area ratio, which plays a prominent role in the method. It does not follow that this technique — even as modified — should lead to good extimates of noise reductions achieved in practice; it simply indicates an upper limit which one could not hope to exceed and indeed would be lucky to approach.

1636

Razumov, I. K., "Muffling the Noise of Testing Stations of Aircraft-Engine Factories," Trans. No. FTD-TT 62-1277 from Gigiyena I Sanitariya, 1, 100-104, 1961, Foreign Tech. Div., Air Force Systems Command, Wright-Patterson AFB, Ohio, 8 pp., 1962. AD-288 524.

The combatting of noises at the testing station of aircraft-engine factories is carried on by the method of collective protection against noise, and is accomplished in two ways: muffling the noise emitted from the intake and exhaust channels, and insulating against the noises penetrating through the partitions of the test cabinets.

1637

Regier, A. A., and H. H. Hubbard, "Status of Research on Propeller Noise and its Reduction," J. Acoust. Soc. Am., 25, 395-404, 1953.

Reviews the basic concepts concerning the generation of propeller noise generation, and gives equations for calculating the noise field both near and far from the propeller. Noise from nonsteady airloads on the blades and differences in noise from the approaching and retreating blades are discussed. Effects of tip speed, number of blades, blade thickness, and blade width are considered, and it is shown that reducing the tip speed and increasing the number of blades are probably the most effective means of reducing the efficiency of noise generation and alleviating the noise problem.

Noise characteristics of such special propellers as the supersonic, dual rotating, tandem, and shrouded types are also presented. Studies of propeller weights show that substantial noise reduction on transport propellers would result in a considerable weight penalty. For the propeller-driven aircraft in the 400 to 500 mph speed range, the slower-turning, quieter propeller is likely to have better propulsive efficiency than the noisier high-speed propeller. Hence, in this speed range, the weight penalty of the quiet propeller may be offset by its higher propulsive efficiency.

1638

Reiher, H. F., R. N. Hamme, and R. E. Hamilton, "Tuned Spot Dampers for Aircraft Soundproofing—A Feasibility and Development Study," Rept. No. 2224-24-F, Eng. Res. Inst., Univ. of Mich., 1957.
AD-131 081.

Reports a study in which simulated aircraft panels were excited by an acoustic source mounted in a reverberation room, and transmission was measured in a reverberation-room source-fuselage panel-anechoic chamber configuration. This investigation demonstrates the applicability of tuned spot dampers to aircraft soundproofing by detailed measurement of sound transmission in the range of frequencies potentially resonant for a simulated aircraft fuselage section.

1639

Rettinger, M., "Noise Level Reduction of 'Depressed' Freeways," Noise Control, 5, 12, 1959.

This article explains the method for calculating the reduction of noise to nearby residences achieved by placing highways in depression.

1640

Rollin, V., "Effect of Multiple-Nozzle Geometry on Jet-Noise Generation," NASA Tech. Note No. D-770, Natl. Aeron. Space Admin., Washington, D. C., 17 pp., 1961.
AD-262 410.

An experimental investigation was conducted in order to determine the effect of changes in the geometry of multijet nozzles on noise generation. Jet-pressure ratios of 1.67 and 2.33 were investigated for three-, five-, and seven-nozzle configurations with nozzle widths of 0.5, 0.75, 1.0, and 1.5 inches. Test results showed that minimum power ratios were obtained with spacing ratios of 2.0 and 1.5 at subsonic and supersonic pressure ratios, respectively. Changing the geometrical configuration of multiple nozzles to one with a minimum power ratio produces significant reductions in the intensity of power-spectrum levels at the low- and mid-frequency portions of the spectral distribution curve. Full-scale test results agree well with the established curves.

1641

Schilz, W., "Application of Plate Absorbers to the Acoustic Suppression of Wind Tunnels," Acustica, 12, 202-205, 1962.

Plate absorbers are suitable for acoustic silencing of wind tunnels because of their aerodynamically smooth and tight surfaces. In a wind tunnel of small cross section, several types of plate absorbers were tested. For flow velocities below 20 m/sec absorbers with thin foils and with damped resilient volumes can be used. For greater flow velocities the onset of turbulence necessitates resilient plates. Promising values of attenuation were found for resilient plates with great internal losses (verneer sheet). Special care in the design of plate absorbers must be given to the reduction of the propagation of structure-borne sound.

1642

Schwartz, F. L., N. E. Barnett, et al., "Reduction of Noise Level of Exhaust Gas Ejectors and the Effects of a Ballistic Grill and of Wind Velocities on Ejector Performance, with an AOS-895-3 Engine," Rept. No. 2599-f-F, Eng. Res. Inst., Univ. of Mich., 1957.

This report deals with the silencing of exhaust and gas ejectors in their application to an AOS-895-3 engine. The method of measurement, using both space and time averaging techniques, is given. Various mufflers and absorptive silencers were tested and documented. The possibility of adding a ballistic grill to the ejector system was also investigated.

1643

Trambicki, G. S., "Noise and the Means of Combatting It" (Trans. No. T77R of Zh. Ushnykh, 15, 247-260, 1938), Defense Scientific Inf. Serv., 30 pp., 1954.
AD-26 025.

This report on noise sources, noise control and noise reduction also contains a bibliography with 216 entries.

1644

Tyler, J. and G. Towle, "A jet Exhaust Silencer," Noise Control, 1, 37, 1955.

Describes a jet-exhaust silencer which reduces low-frequency noise and causes the maximum noise to occur at very high audio frequencies. At these high frequencies sound is rapidly absorbed into the atmosphere.

1645

Veneklasen, P. S., "Noise Control for Ground Operation of the F-89 Airplane," J. Acoust. Soc. Am., 25, 417-422, 1953.

Describes a noise-control project that includes a muffler for the ground testing of the F-89 airplane, which is powered by two turbojet engines. Topics discussed include the prediction of performance, acoustical design, correlation of acoustical and thermodynamic requirements, general construction, acoustical tests during construction, surveying the noise around the exposed airplane, and surveying noise in the neighborhood of the completed installation. This noise suppressor is comparatively simple and inexpensive, requires no water cooling even for afterburner operation, and has proved adequate in terms of neighborhood relief and the protection of operating personnel.

1646

Watters, B. G., R. M. Hoover, and P. A. Franken, "Designing a Muffler for Small Engines," Noise Control, 5, 18, 1959.

Describes analysis, test procedure, and some actual designs for mufflers of the cavity-tailpipe type for small two-cycle gasoline engines. Compares predicted and measured attenuations. Pays special attention to steady and alternating components of back pressure. Proposes evaluation procedure for mufflers.

1647

Withington, H. W., "Silencing the Jet Aircraft," Noise Control 2, 46, 1956.

The Boeing 707 Jet Transport incorporates an engine sound-suppression device which substantially reduces the external jet noise. Technical progress has been achieved which makes possible airplanes capable of operating from present airport facilities with no more noise for the surrounding areas than is produced by propeller-driven transport aircraft. This noise reduction has been achieved with only a minor degradation of airplane performance.

Noise Control
See Also—20, 345, 350, 393, 394, 421, 489, 497, 503, 523, 536, 541, 568, 579, 993, 998, 1040, 1077, 1363, 1373, 1376, 1378, 1649, 1651, 1659, 1662, 1673, 1720, 1727, 1728, 1731, 1736, 1740, 1756, 1761, 1774, 2435, 4403.

NOISE, MEASUREMENT

1648

Acustica, "Should Acoustic Power or Acoustic Pressure Level be Be Specified for Machine Noises?", Acustica, 11, 269-276, 1961.

Acoustic power and sound pressure levels may easily be converted into one another. The conversion is conveniently illustrated by plotting a difference curve, the difference depending upon the measuring distance and the acoustic absorptivity of the test room. Possible error in the conversion caused by the idealized assumptions, is certainly smaller than the error of measurement, if measurements are made in different rooms or if the results are to be transferred into other rooms. It is therefore recommended that the acoustic power level be measured and reported for transfer into other rooms or to other measuring distances.

1649

Assistant Secretary of Defense (Research and Engineering), "Shock, Vibration and Associated Environments, Part IV," Bul. No. 30, Part 4, Washington 25, D. C., 203 pp., 1962.
AD-276 198.

Contents:
Saturn telemetry system
Saturn static measurements
Transducer placement program
Saturn vehicle shock and vibration data reduction
Saturn guidance, control, and instrumentation equipment test philosophy
Acoustic and vibration environment for Saturn
Investigation of vibration characteristics of a 1/ 5-scale model of Saturn SA-1
Vibration program on a full-scale vehicle
A comparison of theoretical bending and torsional vibrations with test results of the full-scale Saturn and the 1/ 5-scale test vehicle
Propellant behavior in the tanks of large space vehicles
Thrust buildup and cutoff for the Saturn vehicles
Equivalence of acoustics and mechanical vibrations
The value of acoustical testing of small electronic components
Random versus sinusoidal vibration damage levels
Feasibility of using structural models for acoustic fatigue studies
Control of missile vibration response by additive damping treatments
Structural vibration in space vehicles
Control of missile noise during silo launch
Vibration of a radar nose package using light-weight magnesium

1650

Assistant Secretary of Defense (Research and Engineering), "Shock, Vibration and Associated Environments, Part V," Bul. No. 30, Part 5, Washington 25, D. C., 171 pp., 1962.
AD-267 199.

Contents:
Advanced test and simulation facilities
Survey of large space chambers
Test facility for vibration testing of large packages
A vibration-shock exciter using direct electric-field modulation of hydraulic power
Design and performance data of a unique broadband acoustic test facility
Sonic test facility for aerospace requirements
The Aeronautical Systems Division sonic fatigue facility
The whirl tower
A dynamic analyzer for evaluating reconnaissance systems
Development of a combined environment chamber for physiological testing
Measurement and simulation of space environments
Scientific satellites and the space environment
Micrometeoroid impact damage
Vibration testing of the Mercury capsule
Simulation problems in futuristic space environmental chambers
Vibration at altitude
Solar radiation
Vibrational environment of the Mercury-Redstone vehicle
Simulation of air drops for the Mercury landing system controller
Utility of isolators for protection of equipment

1651

Barnett, N. E., "Preliminary Study of Roller Bearing Noise," Rept. No. 3701-1-F, Acoustics and Seismics Lab., Inst. Sci. Tech., Univ. of Mich., 139 pp., 1962.

A study of roller-bearing noise was conducted with the principal aim of improving quality control in order to reduce noise. The research ranged from consideration of what bearing noise the ear can detect in a given situation to the detailed characteristics of instrumentation used to measure bearing noise and related bearing parameters. A comprehensive formulation of the generalized problem is presented as a conceptual tool for handling information. Various facets of the noise problem are dealt with in numerous specific experiments; it is demonstrated that the noise generated by roller bearings of best current manufacture is essentially caused only by geometrical errors and macroroughness of the bearing surface.

Delineates directions for improving both quality control and research into bearing noise, and suggest necessary concomitant improvements in instrumentation.

1652

Bishop, D. E., "Cruise Flight Noise Levels in a Turbojet Transport Airplane," Noise Control, 7, 37, 1961.

Analysis of noise measurements taken inside a turbojet transport airplane show that at high speeds, boundary-layer excitation of fuselage surfaces is the major source of noise inside the cabin. Changes in noise are correlated with changes in flight conditions through reference to a generalized boundary-layer noise spectrum, derived from flight measurements.

1653

Bolt, Beranek, and Newman, Inc., "Characteristics of Noise Produced by Several Contemporary Army Weapons," Rept. No. 630, Cambridge, Mass., 31 pp., 1959.
AD-212 420.

Measurements were made of the noises associated with the firing of an M-1 rifle, 30- and 50-cal. machine guns, a 76-mm gun, a 90-mm gun and a 105-mm howitzer. The noises are described in terms of the maximum instantaneous peak value, the duration, the rise time, and the frequency spectrum. The distributions of these parameters in and around the several weapons are also reported. Recommendations are made concerning efficient data recording techniques.

1654

Bolt, Beranek, and Newman, Inc., "Free-Field Noise Measurements on Carrier-Based Jet Aircraft NATO, Patuxent River, Maryland," Rept. No. 282, 74 pp., 1955.
AD-78 060.

Free-field noise measurements were made on an AJ-2, an F2H-3, an F9F-6, and an F7U-1 for several engine operating conditions. Data obtained are presented in the form of directivity patterns, frequency spectra plots, and tabulated values of acoustic power.

The frequency spectrum of jet noise varies with angle and operating condition. The angular dependence of the frequency spectra can be reduced to a consideration of two angular areas, the regions between 0° and 120° and between 130° and 150°. For each of the aircraft, the frequency spectrum in each of the angular ranges is relatively constant as a function of angle, and the typical spectrum shape in each range differs from that in the other. The spectrum shape is relatively constant in relation to frequency in the region between 130° and 150°, and most of the peak sound-pressure levels occur in this region.

A design procedure for estimating the noise field characteristics of carrier-based planes was developed. The procedure is based primarily on data from planes without afterburners (AJ-2, F9F-6, and the F2H-3). By means of the procedure, it is possible to estimate the acoustic power level, the frequency spectra, and the directivity pattern of the noise field from a knowledge of the jet-engine operating conditions.

1655

Bonvallet, G. L., "Levels and Spectra of Traffic, Industrial, and Residential Area Noise," J. Acoust. Soc. Am., 23, 435-439, 1951.

A survey of city noise in the Chicago area was initiated in 1947. This report describes traffic, industrial, and residential area noise which was investigated as a part of the work. Levels of traffic noise were 35 to 45 db, 45 db to 65 db, and 65 to 75 db in the 400-800-cps band for light, average, and heavy traffic conditions, respectively. Industrial noise ranged from 50 to 60 db in the same band for fifty percent of the cases measured. Ninety percent were below 65 db. A limiting spectrum for noise which is considered not objectionable is presented. Residential area noise ranged from 38 to 47 db in the mentioned band for fifty percent of the cases measured. At night and for winter conditions, traffic noise was 10 db lower in the mentioned band than in the daytime. At night, industrial area noise dropped to levels of existing traffic conditions, and in winter it was lower by about 5 db in octave bands mainly because factory windows were closed. At night, residential area noise was 5 to 10 db less in octave bands than during the day, and for winter conditions there was a drop of 6 to 8 db in octave bands due to the modified character of distant traffic.

1656

Bonvallet, G. L., "Levels and Spectra of Transportation Vehicle Noise," J. Acoust. Soc. Am., 22, 201-205, 1950.

In the recent past a program was initiated to survey vehicle, traffic, and industrial noise in the Chicago area. The phase on noise of vehicles has been completed. The investigation included street, elevated, and subway cars; diesel, steam, and electric trains; and motor buses, trucks, and automobiles.

Measurements were made of over-all and octave band levels. Inside the vehicle, flat network over-all levels ranged from 85 db in a new "L" car to 95 db in subway cars. The readings in the 400-800 cps band ranged from 68 db for automobiles to 91 db in subway cars. Outside and close to vehicles, the flat network cps band ranged from 66 db for automobiles to 87 db for subway trains. Variations in the over-all levels inside of vehicles ranged from ±2 to ±5 db. Outside the vehicles, variations ranged from ±2 to ±6 db in both the over-all and 400-800 cps band levels.

1657

Borriello, F. F., "Study of Methods for Performing In-Flight Measurements of Acoustic Noise," Rept. No. NAMC-ASL(12)-R360FR101, Aeronautical Structures Lab., Naval Air Material Center, Philadelphia, Pa., 23 pp., 1961.
AD-266 067.

This study was made to determine the feasibility and methods of measuring the boundary-layer acoustical environment during flight. First there is presented a list of the various organizations that have performed work on studies and measurements of either engine noise or boundary-layer noise. Included are descriptions of the acoustic environment, and of equipment and methods for measuring this environment. Important parameters to be measured are stated, and the need for more supersonic data is emphasized. The results indicate that the measurement of boundary-layer noise is feasible, at least up to sonic speeds. Also, it is more fruitful to run a comprehensive flight-test program with one well instrumented airplane than to partially instrument a number of service airplanes and perform statistical surveys.

1658

Bureau of Ships, "Summary of Airborne Noise Levels in Compartments of DD692 Class Destroyers," Rept. No. 371-N-1, Bureau of Ships, Washington, D. C., 13 pp., 1953.
AD-204 927.

The report summarizes the results of airborne-noise surveys conducted aboard DD692 destroyers between January, 1947, and October, 1949, by the Mare Island Naval Shipyard. The data presented consist of noise levels measured on 15 vessels of this class while they were underway during post-repair trial runs. Where a sufficient number of readings have been obtained, curves of noise level are plotted against shaft revolutions.

1659

Callaghan, E. E., and W. D. Coles, "Far Noise Field of Air Jets and Jet Engines," Rept. No. 1329, Natl. Advisory Comm. Aeron., Washington, D. C., 18 pp., 1957.
AD-158 944.

The effect of nozzle-exit shape was studied using a small (four-in. diam.) air jet. Circular, square, rectangular, and elliptical convergent-divergent and plug nozzles were investigated. At low jet-pressure ratios (less than 2.2) the effect of nozzle shape on the sound field was negligible. At high ratios all the nozzles exhibited discrete-frequency noises associated with shock formations in the jet. The convergent-divergent nozzle showed an elimination of such noises at its design pressure ratio. The acoustic power radiated by the engines and air jet was correlated by the Lighthill parameter. The free-field spectral distribution of the sound power agreed well for both engine and air jet.

1660

Callaway, D. B., "Spectra and Loudness of Modern Automobile Horns," J. Acoust. Soc. Am., 23, 55-58, 1951.

As one phase of a noise survey of the Chicago area, measurements were made of the acoustic output of commonly used automobile horns. Over-all sound levels on the axis at three feet ranged from 108 to 125 db. Loudness levels ranged from 125 to 140 phons. Fundamental frequencies of all horns ranged between 160 and 380 cps. Two types had approximately harmonic overtones, with large amplitudes below about 2000 cps and smoothly decreasing amplitudes at higher frequencies. A third type, with the most unpleasant sound, had inharmonic overtones, groups of which were greater in amplitude than the fundamental. Sound from a pair of horns at various distances were measured both inside and outside a closed automobile. The over-all level outside was 88 db at 50 feet and 74 db at 300 feet, with corresponding loudness levels of 105 and 82 phons. The over-all level inside was 60 db (loudness level, 72 phons) at 50 feet and 50 db (loudness level, 54 phons) at 300 feet. Filtering out overtones above 1200 cps improved the quality of horn sounds markedly, reducing the loudness level inside the automobile by four phons at 50 feet, but only one phon at 300 feet. Since the typical horn is louder than necessary at close range, use of a low pass acoustic filter on automobile horns appears desirable.

1661

Callaway, V. E., "Terminal Operations of 707," Noise Control, 5, 42, 1959.

Summarizes, from test measurements, data on noise, blast, and temperature conditions incident to operations at terminals of the Boeing 707 jet transport.

1662

Ciepluch, C. C., W. J. North, et al., "Acoustic, Thrust, and Drag Characteristics of Several Full-Scale Noise Suppressors for Turbojet Engines," Tech. Note TN 4261, Nat'l. Advisory Comm. Aeron., Washington, D. C., 48 pp., 1958. AD-158 880.

An experimental investigation was conducted with an engine in the 10,000-pound-thrust class. The acoustic study was made with an outdoor thrust stand, and the data are presented in terms of sound directionality, spectrum, and sound power. Aerodynamic properties of the suppressors were evaluated over a range of Mach numbers up to 0.5 in an altitude wind tunnel. The most efficient configurations from both acoustic and propulsive thrust considerations were a two-position mixing nozzle with an ejector and a twelve-lobe nozzle; at a Mach number of 0.5 the respective losses in propulsive thrust were about 1% and 3%. Calculations indicate that these two configurations would reduce the noise heard during takeoff by five or six decibels.

1663

Clark, W. E., "Noise from Aircraft Operations," Final Rept. No. ASD TR 61-611, Bolt, Beranek, and Newman, Inc., Cambridge, Mass., 124 pp., 1961. AD-278-625.

Summarizes knowledge of aircraft ground and flight operations in the vicinity of air bases, noise-source characteristics of military aircraft, and propagation of sound from aircraft to observers near or on air bases. Data from earlier Air Force studies, together with new data, have been summarized and incorporated into aircraft noise prediction procedures and descriptions of operations characteristics. The report provides an integrated presentation of available information, techniques, and factors to be considered in determination of noise from aircraft operations that is intermediate in complexity between a simplified "handbook" and detailed source material.

1664

Clark, W. E., A. C. Pietrasanta, and W. J. Galloway, "Noise Produced by Aircraft During Ground Run-up Operations," Bolt, Beranek and Newman, Cambridge, Mass., 142 pp., 1957. AD-130 763.

Measurements of the noise field around six turbojet aircraft (T33-A, F89-D, F84-G, B-57, F84-F and F86-D) and one propeller aircraft (C-124) during ground run-up operations are reported. Sound pressure levels in octave bands of frequency have been obtained for different operating conditions of the aircraft engines, at distances ranging from 100 to 1600 ft. These data are analyzed and the results reported in terms of acoustic power level, directivity, and noise spectra. An empirical procedure is described for making engineering estimates of the characteristics of the noise field produced during ground run-up operations of jet aircraft.

1665

Coast Guard, "Noise Surveys Aboard Ships," Proj. No. CGTD J15-1/ 5-1, Washington, D. C., 1960. AD-246 726.

Ambient background noise-level measurements are presented for twenty-four various type vessels. Noise measurements were made in three shipboard locations: outdoors on the wing of the ship's bridge; outdoors in position of the forward lookout; and inside the pilot house in the position of the conning officer. Octave-band measurements were converted to spectrum levels to allow comparison with 1960 Lighthouse Conference Reports 4-1-4 and 4-1-7.

To describe the average level of masking noise in order to calculate the threshold of audibility of fog signals and of other ships' whistles, this report recommends adopting the data on the spectrum-level analysis of average shipboard background noise at the bridge lookout position.

1666

Cole, J. N., and C. E. Thomas, "Far Field Noise and Vibration Levels Produced During the Saturn SA-1 Launch," Preliminary Rept. No. ASD TR 61-607, Aerospace Medical Div., Wright Air Development Div., Wright-Patterson Air Force Base, Ohio, 22 pp., 1961. AD-273 666.

Acoustic measurements were made of the sound pressure level-time functions which were produced at six locations on Cape Canaveral Missile Test Annex and at four locations in the surrounding communities during the Saturn SA-1 launch on 27 October 1961. The frequency range of measured data was from the 4.7-to-9.4-cps octave band to the 4800-to-9600-cps octave band. Distances from the launch site to the noise vibration data were measured in three locations at the Tel-2 telemetry site. The frequency range of measured data was from the 4.5-to-9-cps octave band to the 1125-to-2250-cps octave band. The distance from the launch site was 5200 feet. Only the basic sound pressure level-time environments and vibration level-time environments as a function of frequency octave bands are presented in this report.

1667

Cole, J. N., H. E. von Gierke, et al., "Noise Radiation from Fourteen Types of Rockets in the 1000 to 130,000 Pounds Thrust Range," WADC Tech. Rept. No. 57-354, Aero Medical Lab., Wright Air Development Center, Wright-Patterson AFB, Ohio, 64 pp., 1957. AD-130 794.

Detailed noise characteristics were measured on fourteen types of rockets, with both solid and liquid propellants, in the thrust range from 1000 to 130,000 lb. Near-field and far-field levels on static-fired and vertical-launched rockets were measured under essentially free-field conditions. Measurements and data reduction methods are described. Final results are given as near-field sound pressure spectra, far-field directivities, acoustic power spectra and pressure-time histories. This noise environment is studied as a function of several nozzle configurations and as a function of flame front action in the jet stream. Generalization and correlation of the data result in a formula for the overall acoustic power level output of rockets, OA PWL 78 + 13.5 $\log_{10} W_m$ db re 10^{-13} watts, where W_m is the rocket jet stream mechanical power in watts. Also given is an approximate generalized power spectrum dependent upon nozzle diameter and jet flow characteristics. These correlations result in procedures for predicting far field noise environments produced by static-fired or launched rockets.

1668

Cole, J. N., and R. G. Powell, "Estimated Noise Produced by Large Space Vehicles as Related to Establishing Tentative Safe Distances to Adjacent Launch Pads and the Community," MRL Memo. No. M-2, 6570th Aerospace Medical Research Labs., Aerospace Medical Div., Wright-Patterson Air Force Base, Ohio, 15 pp., 1962.
AD-276 204.

Sound-pressure environments are presented for 19 sizes of rocket propulsion vehicles covering the pound-thrust range between 1 × 10 to the 6th power and 2.2 × 10 to the 7th power. These environments are specified in simplified form, using overall sound-pressure level as a measure, are given as a function of distance from the launch site for each of the 19 different rocket sizes. Two criteria are assumed and expressed in terms of OASPL: (1) one criterion for maximum levels tolerable by the community; and (2) a criterion for maximum levels tolerable by space vehicle or missile systems (based on Atlas/Titan type) on adjacent pads.

Caution is given that the use of OASPL's as a measure of environment or criteria is only valid on the assumption that pertinent frequency dependencies have been included in the analysis, as they are for the units considered herein. Comparison of estimated levels to assumed criteria resulted in tentative launch-hazard radii for siting of each system. The range of uncertainty in these estimates is also indicated.

1669

Cox, R. J., H. J. Parry, and J. Clough, "A Study of the Characteristics of Modern Engine Noise and the Response Characteristics of Structures," Rept. No. WADD TR 60-220, Lockheed Aircraft Corp., Burbank, Calif., 154 pp., 1961.
AD-272 210.

Jet engine noise and the response of structures to that noise were studied. The near-sound-field characteristics of a jet engine operating on the ground at both military and afterburner thrust were measured. Sound pressure levels were obtained in the near field and within the jet wake, as were pressure levels and cross-correlation coefficients. The latter two were obtained at two locations in the noise field for the free field, a rigid boundary, and a flexible boundary. Several panels, representative of typical airframe structure, were subjected to this jet engine noise. Structural response in terms of strain and accelerations was measured and analyzed. These panels were also subjected to discrete frequency excitation to determine basic response parameters. An analytical method for predicting the response of complex structures in an actual jet noise environment was developed. Predicted and measured responses were compared.

1670

Doelling, N., "Acoustical Evaluation of Two Durastack Ground Run-Up Noise Suppressors," Rept. No. WADC TN 57-392, Bolt, Beranek, and Newman, Inc., Cambridge, Mass., 41 pp., 1961.
AD-273 987.

Reports measurements of the noise characteristics of two Durastack noise suppressor systems, between which there is but one difference; the Type A suppressor essentially has no acoustical treatment of the secondary air intake, whereas Type B has it. Measurements in octave bands taken on a 25-foot circle and at close-in positions are presented. Average noise reduction of both suppressors is fairly flat above the first octave band. The average value of the noise reduction between 75 and 10,000 cps is about 14 db for the Type A suppressor, and about 21 db for Type B. No intake suppressor was used.

The relative magnitudes of the major noise sources are also included, and some non-acoustical aspects of the noise suppressors.

1671

Dyer, I., "Measurement of Noise Sources in Ducts," J. Acoust. Soc. Am., 30, 833-841, 1958.

Recently Kerka, and earlier Beranek, Reynolds, and Wilson, discussed the measurement of sound power radiated by a fan in a straight duct by measuring the sound pressure inside the duct. A difficulty associated with this technique is that above a certain frequency the sound pressure varies markedly across a transverse section of the duct, and the relation between mean square pressure and power is not simple. The transverse variation can be unserstood by application of mode theory to propagation of noise in the duct. In the theory it is assumed that the noise source is purely random and of low internal impedance. Propagation in the various duct modes is shown to be statistically independent, and to give rise to equipartition of energy in the limit of high frequencies.

The theory agrees well with measurements reported by Kerka. With the use of the theory, it is possible to select measurement positions inside the duct so that the mean-square pressure is related to the power flow by the simple plane-wave equation.

1672

Dyer, I., P. A. Franken, and E. E. Ungar, "Noise Environments of Flight Vehicles," Noise Control, 6, 31, 1960.

Article presents estimates of the external noise environments of air- and space-craft based on information currently available. Engine noise, oscillating shocks, surface pressure fluctuations, and wake noise appear most significant. Many more measurements are needed.

1673

Embleton, T. F.W., and G. J. Thiessen, "Train Noises and Use of Adjacent Land," Sound, 1, 10-16, 1962.

This article describes the effect of train noises on the industrial and residential uses of the land adjacent to the railroad right-of-way. Sound pressure levels are given for a variety of train noises as a function of distance from the tracks and the environment (cuts, barriers of various sorts, etc.). Track noise may be reduced to acceptable levels for an urban residential area at a distance to 300 feet from the right-of-way and engine noise at a corresponding distance of 500 feet, if a cut of suitable depth is employed.

1674

Fakan, J. C., and H. R. Mull, "Effect of Forward Velocity on Sound-Pressure Level in the Near Noise Field of a Moving Jet," Tech. Note No. D-61, NASA, 16 pp., 1959.
AD-227 291.

An in-flight investigation of the near-field noise along the boundary of an aircraft-mounted jet engine was conducted over a flight Mach number range of 0.35 to 0.70 at altitudes of 10,000, 20,000, and 30,000 feet, at two and three nozzle-exit diameters downstream of the jet exit. The sound-pressure levels were found to be constant over the full Mach number range. The results of the experiment tend to substantiate predictions of the Mach number effect on jet noise production.

1675

Gales, R. S., "Techniques for Noise Measurement and Evaluation of Data," Noise Control, 1, 22-29, 1955.

To get the most information from a noise measurement it must be taken with care and followed by careful evaluation and clear presentation of the data. Effective methods for these three steps are presented.

1676

Goodfriend, L. S., "Measurement of Noise," Noise Control, 7, 4, 1961.

This review summarizes the essential requirements and performance characteristics of most types of noise-measurement equipment. The environmental conditions under which measurements are made and an appreciation of the characteristics of the noise being measured are also discussed. Decibel notations and the use of units in sound measurements are reviewed.

1677

Hoeft, L. O., "A System for Measuring the High Sound Pressure Levels from Rockets," WADC Tech. Rept. No. 56-655, Aero Medical Lab., WADC, Wright-Patterson AFB, Ohio, 38 pp., 1956.
AD-110 669.

A system for measuring the high intensity noise produced by rockets is described. The system (1) should be capable of measuring sound pressure levels to 195 db (re 0.0002 dynes/sq cm), (2) should have a flat frequency response from 37.5 c to 10 kc (with usable response to 20 kc), and (3) should be reliable. A 21 channel sound recording system was developed to obtain far and near field noise characteristics in the short firing time of rocket engines. The selection of microphones and other components, and testing and calibration of the equipment are discussed. The technique of setting up a noise survey, the procedure for operating the equipment, and the system used to analyze the data are described in detail.

1678

Hoover, R. M., and L. N. Miller, "Noise Characteristics of Some Jet Ground Operations," Noise Control, 5, 28, 1959.

Presents results of noise measurements of various ground operations of two-engine Caravelle and four-engine, suppressed, Comet 4 jet airliners. Data include directional characteristics and spectra for static operation at idle, taxi, climb-out, and take-off powers and spectra at side of runway during take-off.

1679

Howes, F. S., and R. R. Real, "Noise Origin, Power, and Spectra of Ducted Centrifugal Fans," J. Acoust. Soc. Am., 30, 714-720, 1958.

Forward and backward curved blade centrifugal fans as noise sources were subjected to an extensive study, measurements being made in a duct with an acoustic termination. The data obtained support the following conclusions:

(1) The noise output from each homologous series of fans can be defined by one V-shaped specific noise power vs log-speed curve, with the minimum close to the maximum static efficiency.
(2) Fan outlet noise power at maximum fan efficiency approximates 10^{-5} times the input fan power.
(3) The noise origin is primarily blade- and air-flow boundary turbulence.

1680

Hubbard, H. H., "Some Experiments Related to the Noise from Boundary Layers," J. Acoust. Soc. Am., 29, 331-334, 1957.

Presents the main results of several recent experiments relating to the generation of noise in boundary layers. An attempt is made to correlate data obtained from a wind tunnel, a rotating disc, a helicopter rotor, and an aircraft in flight. These data provide evidence about the mechanism of noise generation in the boundary layer and show how the noise varies as a function of velocity, density, and surface roughness. There is also some discussion of the relative importance of the boundary-layer noise and the noise from the power plant in high-speed jet aircraft.

1681

Hubbard, H. H., and D. J. Maglieri, "Noise Characteristics of Helicopter Rotors at Tip Speeds Up to 900 Feet Per Second," J. Acoust. Soc. Am., 32, 1105-1107, 1960.

Evidence is presented which suggests that the noise of full-scale helicopter rotors results mainly from conditions of unsteady flow. Measurements of the sound-pressure levels and spectra are presented for test conditions where gear train, engine, and other propulsion system noises are minimized. These data cover a range of tip speeds from 100 ft/sec to 900 ft/sec for various rotor disk loadings. Results indicate that both tip speed and disk loading have an important influence on the noise radiated from the rotor. During stall, the sound pressure levels increased at all frequencies, but particularly at the high end of the spectrum. As a matter of special interest, a highly-peaked wave form due to possible Doppler effects was noted to be associated with high-tip speed operation.

1682

Hubbard, H. H., and L. W. Lassiter, "Experimental Studies of Jet Noise," J. Acoust. Soc. Am., 25, 381-384, 1953.

The mixing region of a jet is observed to be a complex noise generator. The noise produced is highly directional and is affected by various geometric and flow parameters as well as by conditions in the settling chamber upstream of the nozzle. Noise measurements for a family of circular-model air jets, ranging in diameter from 3/4 to 12 inches, are consistent with available data for a turbojet engine.

The intensity of the fluctuating pressure field near the jet is greatest at an axial distance of approximately two diameters downstream from the nozzle exit, and generally decreases with increasing distance. The frequency spectrums recorded near the jet boundary are usually peaked, the peak frequencies being higher near the jet exit than at points farther downstream. These noise frequencies generally increase with increasing jet fluid velocity and decrease with increasing jet size. Hot-wire surveys of turbulence (axial velocity fluctuation) in the jet stream indicated spectra which were very similar in quality to the noise spectrum recorded outside the jet boundary and at the same axial stations.

1683

Kamperman, G. W., "Measurement of High Intensity Noise," Noise Control, 4, 22, 1958.

A thorough discussion of microphones usable for high-intensity measurement is given along with a discussion of planning an entire measuring system.

1684

Kamps, E. C., "Statistical Evaluation of Near-Field Sound Pressures Generated by the Exhaust of a High-Performance Jet Engine," J. Acoust. Soc. Am., 31, 65-67, 1959.

The operation of modern, high-performance turbojet engines creates an environment that promoted rapid structural fatigue in many areas in jet aircraft. To facilitate the simulation of a valid test environment and, therefore, enable fatigue-resistant structures to be readily developed, the characteristics of the near-field sound pressures created by the jet stream must be established. This study is concerned with the establishment of the level and the rate of occurrence of peak pressures in relation to the commonly measured rms level. A method is presented which enables the determination of these qualities from rms sound pressures generated by the jet exhaust of a General Electric CJ805 turbojet engine. Noted conclusions: (1) occurrence of peak pressures does not follow a Rayleigh Distribution; (2) peak pressure distribution is not altered by the physical position related to the jet stream nor does it appear to be a function of frequency; (3) a maximum of ratio of peak to rms pressure is shown to exceed four, but a physical limit is not established.

1685

Kantarges, G. T., "Some Measurements of Noise Transmission and Stress Response of a 0.020-Inch Duralumin Panel in the Presence of Air Flow," Nat'l. Aeron. Space Admin., Washington, D. C., 25 pp., 1960.
AD-241 931.

Noise transmission measurements were made for a 0.020-inch panel with and without air flow on its surface. Tests were conducted with both an absorbent and reverberant chamber behind the panel. Panel stresses for some of these tests were also determined. Noise spectra obtained inside the absorbent chamber with flow attached and flow not attached to the panel appeared to contain several peaks corresponding in frequency to panel vibration modes. These peaks were notably absent when the chamber was reverberant. These noise reduction through the test panel measured with the aid of an absorbent chamber for the flow-not-attached case is in general agreement with values predicted by the theoretical weight law but indicate rather less noise reduction at the high frequencies. The main stress responses of the panel without air flow occurred at its fundamental vibration mode. In the presence of air flow the main response occurs in a vibration mode having a node line perpendicular to the direction of air flow.

1686

Remillard, W. J., "Method of Obtaining Amplitude and Phase Spectra of a Transient Function Using Graphical Input Data," J. Acoust. Soc. Am., 31, 531-534, 1959.

Both amplitude and phase spectra are needed to characterize transient functions completely. Analysis shows how these spectra can be obtained from the envelopes of the line spectra of the even and odd parts of a transient function made to recur in time. Instrumentation is described for the convenient determination of these line spectra.

1687

Kleinschmidt, K., J. V. Rattayya, and A. Silbiger, "Noise Radiation from Submarine Hulls, Part II. Comparison of Theoretical Results with Model Test Data Measurements," Rept. No. U-134-64, Cambridge Acoustical Assoc., Inc., Mass., 1962.
AD-278 598.

The design and instrumentation of a suitable model for investigating the vibration and sound radiation from a hull with a symmetrical foundation are described. The test results are explained, and in some respects successfully correlated with the predicted values. Natural frequencies in air and water of the ring-stiffened cylindrical model are in good agreement with the theory. Driving point impedance phase measurements conform to theory. For reasons which are discussed in detail, there is only fair correlation of theoretical and measured far field sound pressures for a 1-lb shaking force applied to the foundation. This correlation is not as good as that obtained earlier for the full-scale data. Longitudinal vibrations of a spheroidal shell are also discussed.

1688

Kurbjun, M. C., "Noise Survey Under Static Conditions of a Turbine-Driven Transonic Propeller with an Advance Ratio of 4.0," Memo No. 4-18-59L, NASA, Washington, D. C., 14 pp., 1959.
AD-215 388.

Overall sound-pressure levels and frequency spectra of the noise emitted from a three-blade, 6.85-foot-diameter propeller have been measured. The results are compared with similar results obtained from a supersonic propeller having an advance ratio of 2.2 and from a modified supersonic propeller having an advance ratio of 3.2. The effects of power changes on the noise levels and spectra are also shown.

1689

Lee, R., "Free Field Measurements of Sound Radiated by Subsonic Air Jets," Rept. 868, David Taylor Model Basin, Washington, D. C., 15 pp., 1953.
AD-23 417.

Measurements are reported of the sound radiated by small air jets at subsonic velocities. The measurements were made in a free acoustic field to obtain the directional pattern of the radiation in half-octave frequency bands covering the 38- to 13,600-c range. Results indicated that the directivity patterns of the sound depend on the frequency. The sound pressure spectrum at any point in the noise field is dependent upon the jet velocity and azimuth angle; the entire spectrum shifts towards higher frequencies with increase in velocity and azimuth angle. Somewhat smaller values of total acoustic power than previously reported were indicated. Comparison of the present results with those obtained by other workers showed general agrrement with respect to the directional characteristics of the radiated jet noise. Certain differences were attributed to the effect of the length-diameter ratio of the nozzle.

1690

MacPherson, P. A., D. B. Thrasher, and O. Logan, "A Survey of Noise at RCAF Station Cold Lake and RCAF Station Uplands," Rept. No. 228-1, Defence Research Medical Labs., Canada, 21 pp., 1958.
AD-158 849.

Results of the noise survey indicate that the overall noise levels generated by aircraft during take-off conditions are influenced mainly by ground absorption out to distances of approximately 1000 feet from the aircraft. Beyond this distance the overall noise levels are influenced primarily by temperature conditions. The overall noise levels generated by aircraft under take-off conditions may be predicted. The noise produced by aircraft at RCAF Station Cold Lake and RCAF Station Uplands may result in the deterioration of hearing of exposed personnel. In addition voice communications may be disrupted in areas near where aircraft are being maintained, taxied or taking-off.

1691

Maglieri, D. J., and H. H. Hubbard, "Ground Measurements of the Shock-Wave Noise from Supersonic Bomber Airplanes in the Altitude Range from 30,000 to 50,000 Feet," Tech. Rept. No. D-880, NASA, Washington, D. C., 24 pp., 1961.
AD-260 635.

Shock-wave ground-pressure measurements have been made for supersonic bomber airplanes in the Mach number range between 1.24 and 1.52, for altitudes between 30,000 and 50,000 feet, and for a gross-weight range between 83,000 and 120,000 pounds. The measured overpressures were generally higher than would be predicted by theory, which accounts only for volume effects. There is thus a suggestion that lift effects on sonic-boom intensity may be significant for this type of airplane within the altitude range of the present tests.

1692

Maglieri, D. J., H. H. Hubbard, and D. L. Lansing, "Ground Measurements of the Shock-Wave Noise from Airplanes in Level Flight at Mach Numbers to 1.4 and at Altitudes to 45,000 Feet," Rept. No. NASA TN-D-48, NASA, Washington, D. C., 38 pp., 1959. AD-225 816.

Time histories of noise pressures near ground level were measured during flight tests of fighter-type airplanes over fairly flat, partly wooded terrain for M = 1.13 to 1.4 and at altitudes from 25,000 to 45,000 ft. Atmospheric soundings and radar-tracking studies were made for correlation with the measured noise data. The measured and calculated values of the pressure rise across the shock wave were generally in good agreement. There is a tendency for the theory to over-estimate the pressure at locations remote from the track and to underestimate the pressures for conditions of high tailwind at altitude. The measured values of ground-reflection factor averaged about 1.8 for the surfaces tested as compared to a theoretical value of 2.0. Two booms were measured in all cases. The observers also generally reported two booms; but in some cases, only one boom was reported. The shock-wave noise associated with some of the flight tests was judged to be objectionable by ground observers, and in one case the cracking of a plate-glass store window was correlated in time with the passage of the airplane at an altitude of 25,000 ft.

1693

Marsh, A. H., "Noise Measurements Around a Subsonic Air Jet Impinging on a Plane, Rigid Surface," J. Acoust. Soc. Am., 33, 1066, 1961.

Measurements are presented of the noise produced by a 1.5-in. diameter air jet, with an exit Mach number of 0.66, impinging perpendicularly on a plane, rigid plate. The overall sound power output increased rapidly, as the nozzle-to-plate separation distance was decreased. The overall sound power generated, when the plate was two diam. from the nozzle, was ten db greater than that produced with the plate removed. For a two-diam. plate separation the overall sound-pressure levels (SPL's) (measured at a radius of 24 nozzle diameters from the center of the jet exit in the horizontal plane through the jet centerline) were 15 to 18 db greater than those produced at corresponding positions with the plate removed, while for a 20-diam. separation, the increase varied between two and seven db. The spectrum of the noise changed as the separation distance was increased as follows: (a) the peak frequency decreased, (b) the pronounced peak changed to a broad one, and (c) the magnitude of the peak decreased.

1694

Mayes, W. H., "Some Near- and Far-Field Noise Measurements for Rocket Engines Operating at Different Nozzle Pressure Ratios," J. Acoust. Soc. Am., 31, 1013-1015, 1959.

Measurements of near- and far-field noise pressures are presented for a 1650-lb-thrust engine and for 6000-7500-lb-thrust engines for which the nozzle exit pressure was changed systematically in order to study the effects on the noise level and spectra. Near-field surveys indicated that the highest noise pressure occurred at about 20 exit diameters distance downstream of the nozzle, near the transition from supersonic to subsonic flow. At a radial distance of three exit diameters, the noise pressure levels varied from about 145 db just upstream of the nozzle to about 170 db downstream of the nozzle, and no consistent trends were noted as a function of nozzle-exit pressure. In general, the spectra at points downstream of the nozzle contained considerably more low-frequency noise than those measured upstream of the nozzle. It was noted that the maximum far-field noise was radiated in the downstream direction at angles of 30° to 45° from the jet axis. The acoustical power radiated from all nozzles averaged about 0.5% of the mechanical power of the exhaust stream, the least noise being radiated by the nozzle having an exit pressure less than atmospheric.

1695

Mayes, W. H., D. A. Hilton, and C. A. Hardesty, "In-Flight Noise Measurements for Three Project Mercury Vehicles," Tech. Note D-997, NASA, Washington D. C., 27 pp., 1962. AD-270 809.

In-flight noise measurements have been made for three vehicles of the Project Mercury program. Inside noise measurements have been made for the three vehicles and measurements of external aerodynamic surface-pressure fluctuations have been made for one. The main sources of noise are the rocket engines during the launch phase and the aerodynamic noise during the exit phase of the flight. The rocket noise was maximal at lift-off and decreased rapidly as the vehicle gained altitude and speed. The aerodynamic noise generally increased as the dynamic pressure increased, and was also affected significantly by the Mach number and the external contouring of the vehicle.

1696

Miller, L. N., and L. L. Beranek, "Comparison of the Take-Off Noise Characteristics of the Caravelle Jet Airliner and of Conventional Propeller-Driven Airliners," J. Acoust. Soc. Am., 29, 1169-1179, 1957.

Based upon earlier published information concerning the factors that influence neighborhood response to noise exposure, it is assumed that there are three principal characteristics of noise which must be considered in comparing community response to jet take-offs with that to propeller aircraft take-offs. These three noise factors are: (1) relative noise levels; (2) duration of noise; and (3) frequency distribution of noise.

This paper is devoted to a comparison of the noise produced by the French jet aircraft, the Caravelle, with that produced by conventional propeller-driven airliners in terms of these three factors. Noise-level measurements were made under the take-off path at various distances from the beginning of the runway. The conclusion is drawn that the comparative noise levels of the Caravelle, when considered in terms of probable response of listeners to the spectrum distribution of the noise, are approximately equal to those of large propeller aircraft for similar climb rates when heard out-of-doors. Second, the Caravelle noise levels, based on relative listener response, are somewhat lower than those of propeller aircraft when heard indoors or when the Caravelle is permitted to take off under steep climb conditions. Third, the Caravelle noise persists for longer time intervals than does propeller aircraft noise by a factor of between 1.5 and 3.5, depending upon the distance from the runway.

1697

Miller, L. N. and L. L. Beranek, "Survey of the Take-Off Noise Characteristics of the Caravelle Jet Airliner and of Conventional Propeller-Driven Airplanes," Noise Control, 3, 42, 1956.

Following noise tests, the French Caravelle Airliner was granted permission to land at New York International Airport at Idlewild on May 3, 1957, and to make a series of demonstration flights. The noise tests performed and the methods used for evaluating them are described in this article.

1698

Morgan, W. V., L. C. Sutherland, and K. J. Young, "The Use of Acoustic Scale Models for Investigating Near Field Noise of Jet and Rocket Engines," Rept. No. WADD TR 61-178 (Rept. on Dynamic Problems in Flight Vehicles), Boeing Co., Seattle, Wash., 90 pp., 1961. AD-268 576.

Analytical and experimental studies have been made to examine the feasibility of using acoustic scale models for near-field noise investigations. Analyses show that the important characteristics of noise generation, propagation, and measurement can be scaled. A few deviations from this involve small errors which are negligible in the near field.

The most straightforward model duplicates the gas flow parameters of the full scale engine. The validity of such models has been demonstrated by a series of tests for a wide variety of nozzle-exit conditions, from turbojet through rocket exhausts, and whether in a free field or in the presence of objects which interfere with the flow, such as shaped nozzles and flame deflectors. It is further determined, both analytically and experimentally, that models may be simplified without imparing the results of a scaled test. Considerations in simplifying a model include: reduction of the nozzle size; absence or presence of reflecting surfaces; use of fewer than the full-scale number of engines; and use of a substitute gas which is different from and at a lower temperature than that in the full-scale engine.

1699

Muehl, C. L., and H. Sternfeld, Jr., "Investigation to Determine the Effect of Phasing on the Noise Generated by Spur Gears," TCREC TR 62-49, Vertol Div., Boeing Co., Morton, Pa., 54 pp., 1962.
AD-283 757.

A test program was performed to evaluate the effect of relative gear-tooth contact phasing on the acoustical characteristics of a model transmission. It was concluded that within the limitations of the test configuration, the radiated noise frequency characteristics for a constant tooth-contact frequency are a function of the number of gear sets, while the amplitude and directional characteristics are a function of their relative phasing. It was also noted that changes in the torsional elastic properties of the system produced significant changes in radiated noise.

1700

Nelson, W. L., and C. M. Alaia, "Aerodynamic Noise and Drag Measurements on a High-Speed Magnetically Suspended Rotor," WADC Tech. Rept. No. 57-339, Acoust. Lab., Columbia Univ., New York, 52 pp., 1958.
AD-142 153.

Measurements were made of the drag torque, temperature rise, and aerodynamic noise produced at the surface of a high-speed, magnetically suspended cylindrical rotor as a function of the surface velocity at normal atmospheric pressure. The primary objective was the measurement of aerodynamic noise. Apparatus and instrumentation were developed for controlled measurement, within the laboratory, of the noise, drag and thermal effects encountered in high-speed atmospheric flight. Results of the study indicated this apparatus, with modifications, can be developed as a fruitful method for the study of boundary layer phenomena. For the measurement of aerodynamic noise, the apparatus should be improved by increases in rotor speed and by enlarging the enclosure to permit acoustic treatment for free-field conditions. In the measurement of drag, the essential frictionless support provided by the magnetic support system would yield accurate drag data, with variations of atmospheric conditions and surface treatment.

1701

Peterson, A., "The Measurement of Impact Noise," Noise Control, 2, 46, 1956.

The instrumentation for impact noise measurement is considerably simplified with the introduction of the new Impact Noise Analyzer capable of indicating the peak and time-averaged values of the impact sound being studied.

1702

Peterson, G. E., and G. Raisbeck, "The Measurement of Noise with the Sound Spectrograph," J. Acoust. Soc. Am., 25, 1157-1162, 1953.

The principle of the sound spectrograph may be employed in the quantitative measurement of noise. Measurements may be made with the conventional amplitude-section circuit in which, in the customary use of the sound spectrograph, each section provides observation during a few milliseconds of the signal time. A long integrating time circuit for the amplitude sectioner has been developed which provides integration over a period lasting as long as one or two seconds of signal time. The amplitude sectioning circuit of the sound spectrograph may be employed to determine the relationship between the level of a pure tone and the power-per-cycle of noise. Measurements were made for various types of amplitude analysis with the sound spectrograph. A study was made of the degree to which the section displays conform to the computed values of noise level.

1703

Pietrasanta, A. C., "Noise Measurements Around Some Jet Aircraft," J. Acoust. Soc. Am., 28, 434-442, 1956.

The noise fields around several jet aircraft have been measured for various engine operating conditions. Directivity patterns as a function of octave bands of frequency are presented. Acoustic power levels have been computed and found to agree with a previously published correlation of power level with engine operating conditions (D. K. Mawardi and I. Dyer, J. Acoust. Soc. Am., 25, 389, 1953). Analysis of these data has led to the development of a procedure for estimating the characteristics of the noise fields around non-afterburner jet aircraft operating at military power.

1704

Rosen, M. W., "Noises of Two Spur-Gear Transmissions," Noise Control, 7, 11, 1961.

Two conventional but precision-quality planetary-gear trains have been driven to 20,000 and 27,500-rpm speeds, with as much as 70 hp. Details of the noise measurements and a law of gear noises are given in this paper.

1705

Seltz, R. H., "Aircraft Noise Emission, Survey of A3J-1 Airplane," Interim Rept. No. 6, Naval Air Test Center, Patuxent River, Md., 1961.
AD-264 593.

The Service Test Division conducted a survey of the ground-noise profile of the A3J-1 airplane. Measurements were made with both the airplane engines operating at military thrust and at maximum thrust with full afterburner augmentation (MAX A/B). The maximum overall noise level measured during military thrust operation was 152 db; the maximum overall noise level measured during MAX A/B operations was 156 db. However, at the point where previous experience has indicated that the noise level would be approximately four db higher, no measurements were made because of the danger to personnel from the heat and blast. Data are presented in tabular and graphic form.

1706

Seltz, R. H., "Aircraft Noise Emission, Survey of A4D-2 Airplane," Interim Rept. No. 4, Naval Air Test Center, Patuxent River, Md., 12 pp., 1959.
AD-220 300.

A survey of the ground-noise profile of the A4D-2 airplane was conducted by the Service Test Division. Measurements were made with the engine operating at military power. The maximum overall noise level encountered during these tests was 150 db. Data are presented in tabular and graphic form.

1707

Springer, H. S. and R. O. Olsen, "Launch Noise Distribution of Nike-Zeus Missiles," Special Rept. No. 53, Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 17 pp., 1961.
AD-261 505.

Maximum sound pressure levels averaging 115 decibels, with extreme values of 90 and 128 decibels, were measured about one mile behind the Nike-Zeus Missile Launcher for the variety of meteorological conditions occurring during four monthly tests. Additional small samples of data taken both near the launcher and two miles distant suggest a 20-decibel decline in peak noise level per mile. The decay of the noise level following peak was between two and three decibels per second for the first ten seconds. A frequency analysis of the sound level measured at launch indicates that frequencies below 125 cps are predominant. Under most meteorological conditions, the sound pressure levels at one mile behind the launcher would not be great enough to cause any structural damage or personnel injury. The levels would be above 90 decibels, however, which approach the level at which complaints of annoyance become frequent.

1708

Thiokol Chemical Corp., "Experiments for the Measurement of the Acoustic Impedance of a Burning Solid Propellant," Rept. No. E148-62, Elkton, Md., 18 pp., 1962.
AD-284 888.

Reviews the methods of calculation for measurement (by the Mawardi method) of specific acoustic impedance ratio of passive samples under pressure in chambers with exhaust ports. Equations have been developed for the calculation of impedances from measurements made under pressure in bodies with holes, and have been checked against the same measurement made in solid bodies and found to agree well in the frequency range 500-2000 cps.

The exhaust port area provided in the chamber now in use (0.0984 sq in.) is insufficient to hold within the tolerance of the microphone the pressure differential which accompanies propellant-sample combustion. An increase in the exhaust port area will be necessary to handle full-size samples. Tests were made with samples which have only one-half the burning surface area of the regular samples, and give a tolerable pressure differential. Studies of the propellant combustion noise with such samples showed that both the broad spectrum noise and 1000-cycle component of it are of moderate intensity and must be dealt with if significant acoustic impedance measurements are to be obtained.

1709

Thiokol Corp., "Experiments for the Measurement of the Acoustic Impedance of a Burning Solid Propellant," Rept. No. E194-61, Elkton, Md., 1961.
AD-284 634.

This report describes the research program to measure the acoustic impedance of a burning solid propellant. Based on theoretical evaluation confirmed by experimental studies, a large pressure chamber and a supporting gas pressurizing system were designed.

The acoustic equipment is enclosed in the pressurized chamber to permit better control of the static pressure, and is a simple means of equalizing the static pressure on both faces of the acoustic diaphragm. A chamber volume of approximately 5.5 cu ft was selected. Instrumentation and associated recording equipment for the active tests were incorporated into the experimental setup. Components are being fabricated and assembled. Diagrams of the experimental apparatus are presented, and supporting laboratory studies are described.

1710

Trubert, M. R. P., H. G. Kizner, and W. A. Nash, "Experimental Determination of a Statistical Representation of the Noise Field of a Subsonic Air Jet," Tech. Note No. 3, Engineering and Industrial Experiment Station, Univ. of Florida, Gainesville, 15 pp., 1961.
AD-264 123.

A space-time investigation of the noise field created by a subsonic air jet has been carried out experimentally with a model nozzle 1.4 inches in diameter. The random-noise pressure of the jet has been measured at the surface of a rigid plate placed outside the jet boundary. The cross correlation of the random noise has been chosen to represent the statistical properties of the noise field, and a set of cross-correlation curves has been obtained experimentally.

This investigation presents statistical representations of pressures in an obstructed field, whereas previous studies have pertained only to free fields.

1711

van Niekerk, C. G., "Measurement of the Noise of Ducted Fans," J. Acoust. Soc. Am., 28, 681-687, 1956.

A proposed technique for measuring the noise of a ducted fan by means of a microphone placed inside the duct was evaluated by comparing results so obtained with those obtained by measuring the total sound energy radiated from the duct into a reverberation chamber. A suitable microphone windscreen was developed and was used to reduce the aerodynamic self-noise generated by the microphone to a negligible minimum. Good correlation was obtained, and, by studying transverse resonance conditions in a duct, an attempt was made to discover how suitable microphone stations could be found to eliminate measuring errors caused by the existence of standing waves.

1712

von Gierke, H. E., H. O. Parrack, W. J. Gannon, and R. G. Hansen, "The Noise Field of a Turbo-Jet Engine," J. Acoust. Soc. Am., 24, 169-174, 1952.

The noise fields generated by a standard turbo-jet aircraft engine have been measured for three different power settings. Measurements were made at points on circles around the engine having radii of 25 and 50 feet. For the distance of 50 feet, the directional characteristic is presented for the over-all sound pressure and for the noise in the different octave bands, starting at 37.5 cps. From these measurements the total acoustic power radiated from the engine is calculated to be approximately 69 kw at full engine power. The distribution of this power over the different frequency bands and space angles is shown. The highest total energy per cycle and the highest sound levels are found at frequencies near 100 cps for the higher power settings of the engine. Above that frequency range the total energy per cycle drops approximately as the reciprocal of the square of the frequency.

The data should help us understand qualitatively the jet engine as a sound source and are therefore discussed in that respect. On the other hand, the data have practical significance with respect to the design of test facilities for adequate protection of personnel. They are equally important with respect to problems of noise control on an airport.

1713

Wells, R. J., and B. E. Crocker, "Sound Radiation Patterns of Gas Turbine Exhaust Stacks," J. Acoust. Soc. Am., 25, 44-437, 1953.

Patterns of wide-band noise radiation from gas turbine exhaust stacks have been calculated, assuming negligibly low gas velocities and temperatures. Both the shape of the stack and the band width of the analyzing equipment are considered. Theoretical results are compared with data measured on models and on a proto-type exhaust system.

1714

Wescott, J. W., "Acoustic Background at High Altitudes," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 182-194, 1961.
AD-408 716.

The power spectrum of acoustic background noise at altitudes of 60,000 feet has been determined with balloon-borne acoustic detectors, a data link and recording system, and spectrum analyzers. Background levels are surprisingly high with acoustic pressures of 0.2 d/cm^2 persisting at frequencies below 5 cps. The acoustic energy spectrum falls off as the second power of frequency.

Flights have been made with double detectors, one hanging on a long cord below the other. Cross-correlation of the resulting data indicates that a significant portion of it propagates from lower altitudes. The most probable sources of this acoustic energy are turbulent eddies caused by wind shear.

In addition to background noise some specific signals have been detected. Analyzed samples are presented. Some observed Doppler effects suggest a possible method for measuring the absorption of sound in air at low frequencies.

1715

Wescott, J. W., and S. S. Kushner, "Acoustic Background at the Earth's Surface," Final Rept. No. 3746-35-F, Acoust. and Seismics Lab., Inst. of Sci. and Tech., Univ. of Mich., 30 pp., 1963.
AD-405 837

Acoustic background noise at the earth's surface for frequencies from 0.2 to 100 cps was monitored outdoors with two low-frequency condenser microphones placed 1500 feet apart. The wind speed at each nicrophone was monitored with cup anemometers. Data were transmitted by microwave links to a central receiving station and recorded on magnetic tape. The acoustic data were preemphasized six db/octave before transmission to improve s/ n.

Oscillograms of the multichannel acoustic data show cross-correlations by visual inspection for the sounds radiated from upper-air turbulence and aircraft. Oscillograms of noise generated locally by surface winds show no apparent cross-correlation.

Details of instrumentation are presented. These include a block diagram of the detection, data-link, and recording system and circuit diagrams of components developed for it. A pistonphone calibrator with pushbutton frequencies from 0.125 to 30 cps is described and its use for amplitude and phase calibration of microphones is explained.

1716

Weyers, P. F. R., "Vibration and Near-Field Sound of Thin-Walled Cylinders Caused by Internal Turbulent Flow," NASA, Washington, D. C., 58 pp., 1960.
AD-237 717.

Noise produced by turbulent flow adjacent to the flexible wall was investigated. Measurements were taken of the spectrum and intensity of the pressure field outside thin-walled Mylar cylinders containing turbulent pipe flow. The resulting spectra could be interpreted in relation to the elastic properties of the cylinders and the character of the turbulent fluctuations inside the flow. The eigen frequencies of the cylinders would be identified, and similarity parameters for the spectra were established. The effect of cylinder-wall thickness on the spectrum and intensity of the pressure fluctuations was investigated. It was found that the intensity of the external pressure field scaled with the fifth power of the velocity at the center of the pipe.

For one particular case the spectrum and intensity of the pressure fluctuations exerted by the turbulent flow on the wall were measured. The intensity of the pressure fluctuations at the wall scaled with the fourth power of the velocity, as expected. The ratio of the root-mean-square wall pressure to the dynamic pressure was found to be independent of the Mach number and equal to a constant (0.0078). Similarity laws for the spectra of the wall-pressure fluctuations were also confirmed.

1717

Wiener, F. M., "Experimental Study of the Airborne Noise Generated by Passenger Automobile Tires," Noise Control, 6, 13, 1960.

To measure and analyze airborne tire noise, a microphone equipped with a windscreen was mounted near the tire-road interface on the rear fender of a typical passenger automobile. Noise levels were measured for the car coasting from a speed of about 60 mph down to 15 mph with the engine off and the transmission in neutral. Two degrees of road roughness and several different materials of tire construction were used in the tests. Noise levels and noise spectra are given in the paper for several test conditions.

1718

Wolfe, M. O. W., "Near Field Jet Noise," AGARD Rept. No. 112, Royal Aircraft Establishment, Great Britain, 43 pp., 1957.
AD-154 857.

This paper deals with the subject of jet-engine noise in relation to its effects on aircraft structures. Near-field noise measurements are described for a range of jet-shear velocities on two representative turbo-jet engines, one of them operating with an afterburner. Contours of equal noise pressure in the horizontal plane containing the axis of the jet are presented for a range of shear velocity for overall noise pressure and for noise pressures in 1/ 3-octave frequency bands in the noise spectra. In the velocity range 790 to 1800 feet per second, 400 cps is the dominant frequency. At most velocities the noise pressures at this frequency are about ten decibels less than the corresponding overall noise pressures. The increase in noise level due to reheat is not as great as would have been predicted from a consideration of the noise-level trends at much lower values of velocity without reheat.

1719

Young, W., "A Brief Guide to Noise Measurement and Analysis," Navy Electronics Lab., San Diego, Calif., 23 pp., 1955.
AD-66 686.

Basic noise-measurement principles and techniques are treated in Part I by only simple arithmetic. Terms peculiar to noise analysis are explained. Special attention is given to interpreting graphs of noise spectra obtained with analyzers of different bandwidths. Part II describes specific calibration procedures. It also gives the mathematics used in calculating sound-pressure levels, spectrum levels, and combinations of levels.

Noise Measurement
see also—2, 4, 5, 329, 336, 352, 364, 458, 521, 528, 541, 719, 987, 1038, 1040, 1044, 1061, 1109, 1128, 1301, 1349, 1355, 1365, 1376, 1378, 1532, 1573, 1581, 1584, 1585, 1589, 1592, 1593, 1594, 1595, 1596, 1597, 1598, 1599, 1600, 1601, 1606, 1613, 1620, 1627, 1628, 1645, 1722, 1723, 1724, 1739, 1740, 1775, 1988, 2110, 2339, 2342, 2425, 2435, 2452, 2453, 2474, 2569, 2736, 2826, 2856, 2857

NOISE, PSYCHOPHYSICAL EFFECTS

1720

Baker, J. C., "Aircraft Public Address System Operation Under High-Level Ambient Noise Conditions," J. Audio Engineering Society, 1, 216-220, 1953.

This paper outlines the reasons for and the requirements of good public address systems in airplanes. A résumé of the pertinent characteristics of speech and hearing is provided, as well as a discussion of the sources and characteristics of flight noises and their effects on speech communication, and an outline of the possibilities of noise reduction and developments to date. Presents the necessary qualifications for satisfactory operation of each of the system components in high-level noise fields, and points to the need for further tests and development.

1721

Bolt, R. H., "The Aircraft Noise Problem," J. Acoust. Soc. Am., 25, 363-366, 1953.

Aircraft noise presents a system problem which to date has been attacked mainly at the level of individual components. The system includes: (a) aircraft as noise sources; (b) atmosphere and terrain as influences on sound propagation; (c) people, under several classes and conditions, as responders to noise; (d) physical components for controlling noise; (e) operating procedures for reducing noise exposure in communities; (f) public relations; (g) aviation planning policies and economics; (h) organizations concerned with characteristics and consequences of aircraft noise.

The nature of these components is reviewed in a general way, with emphasis on their inherent interrelations. This discussion provides a framework for unifying the several subjects included in an aircraft noise symposium.

1722

Borsky, P. N., "Community Reactions to Air Force Noise, Part II. Data on Community Studies and Their Interpretation," WADD TR 60-689, Natl. Opinion Res. Center, Univ. of Chicago, 2, 171 pp., 1961.
AD-267 057.

To determine primary relationships among variations in acoustic situations and neighborhood annoyance, personal interviews were held with almost 2500 residents at different air bases. The detailed acoustic conditions at three bases were measured. From these studies, the instruments and procedures for assessing neighborhood reactions were fully developed, pre-tested, and validated. The data provided valuable findings, and facilitated the development of prototypical statistical models for estimating a neighborhood's readiness to complain.

Findings indicate that community reactions are directly related to the intensity of noise levels. Further, a person is more likely to complain if he is fearful of crashes, thinks the air base is not important to the local welfare, or thinks the base is inconsiderate of neighborhood feelings. People who are dissatisfied with the general living conditions of their area, or who are sensitive to the noise of cars and trucks, or who have little experience with flying, tend to be greatly disturbed. Time has not proved itself an automatic cure; some people who have long lived near air bases have become increasingly disturbed by airplane noise.

1723

Callaway, D. B., and H. H. Hall, "Laboratory Evaluation of Field Measurements of the Loudness of Truck Exhaust Noise," J. Acoust. Soc. Am., 26, 216-220, 1954.

Fifteen observers were tested for the correlations of their abilities to discriminate among degrees of loudness of recorded noises made by approximately 100 trucks. The loudness of the noises ranged from about 20 to 200 sones, calculated by a modification of the equivalent-tone method proposed by Beranek and co-workers; the noises were divided into six classes limited by a 40-percent increase in loudness per class. The observers were asked to rank the noises according to these six classes, and were allowed to listen to samples of classes one and six after each twenty recordings.

Although the subjective tests were conducted with no elaborate controls, a correlation coefficient of 0.94 was found between the average judgment of the group and the calculated loudness class. The correlation coefficient between average judgment and total sound-pressure level was 0.78; the correlation coefficient between the average judgment and level on the A-network of the sound-level meter was 0.83.

Experimental techniques and the capabilities and limitations of the loudness-calculation methods are discussed.

1724

Clark, W. E., "Reaction to Aircraft Noise," Final Rept. No. ASD TR 61-610, Bolt, Beranek, and Newman, Inc., Cambridge, Mass., 138 pp., 1961.
AD-278 622

Describes the reactions to aircraft noise of people in communities near air bases and in air base offices. Four kinds of material are offered: (a) summaries of several earlier procedures, studies, and data collections; (b) additional analysis of results from the concurrent sociopsychological interview studies (by the National Opinion Research Center) and noise-environment studies (by the present contractor) in areas near three Air Force bases, highlighting considerations of the physical environment and the aircraft operations; (c) new data, with results from earlier studies, about the reactions of office workers to noise; (d) conclusions regarding the applicability of various available means for predicting reactions to noise intrusion. Several adaptations of the TN 57-10 procedures are derived to incorporate results of NORC work on noise perception and its implications.

This report discusses reactions to noise produced by aircraft in military operations. Although many of the concepts and relationships should be applicable to noise problems in civil aviation and industry, important differences may exist both in noise stimulii and in attitudes towards the noises.

1725

Cole, J. N., and H. E. von Gierke, "Noise from Missile Static Firing and Launch Sites and the Resultant Community Response," WADC TR 57-547, Aerospace Medical Lab., Aeronautical Systems Div., Wright-Patterson AFB, Ohio, 45 pp., 1957.
AD-271 389.

A procedure is given for evaluating areas adjacent to a missile operations site with regard to their suitability for housing. These procedures are applicable to the environs of operations of largest thrust-class rockets which are vertically mounted and statically fired through simple 90-degree bucket deflectors, and those which are vertically launched. Those factors influencing the noise stimulus and the subsequent community response are discussed along with the limitations and sources of error inherent in the prediction procedures. Some conclusions are drawn as to the need for additional information.

1726

Cremer, L., editor, "Proceedings of the Third International Congress on Acoustics, Stuttgart, 1959, Vol. 1, Principles," Elsevier Publishing Co., Amsterdam (U. S. distributor: D. VanNostrand Company, Inc., Princeton, N. J.), 604 pp., 1961.

This large volume is the first of two covering the proceedings of the Third International Congress on Acoustics held in Stuttgart, West Germany, in September 1959. The first volume deals mainly with principles; the second is intended to concentrate on applications. Of the 160 papers in Vol. I, there are 14 on physiological acoustics, 29 on psychological acoustics, 19 on speech, 28 on propagation in liquids and gases, 18 on vibrations, and 52 on physical acoustics. The second volume will contain 168 papers on the five fields: electroacoustics and measurements, room acoustics, building acoustics, noise control, and ultrasonics. There is no index, in Vol. I; however, a complete index for the whole proceedings is promised for Vol. II.

1727

Devaney, R. P., "Intelligibility Test of Communication Ear Defenders in an Area of Extremely High Intensity Noise," J. Audio Eng. Soc., 11, 41-44, 1963.

Many ear defenders, originally designed for protective purposes only, have been used as communication headsets by the installation of acoustic apparatus. Six defender communication headsets in common use and one semi-insert device were tested for intelligibility in a noise environment created by a jet engine. Trained listeners copied prerecorded phonetically balanced (PB) word lists.

This paper details the training and testing procedures, including the monitoring of the noise environment, and the test results, showing the relative performances of the defender headsets.

1728

Fletcher, J. L., and M. Loeb, "Free Field Threshold Shift Reduction as Measures of Efficiency of Ear Protective Devices," Rept. No. 539 (Rept. on Psychophysiological Studies), Army Medical Res. Lab., Fort Knox, Ky., 12 pp., 1962.
AD-283 276.

The protective (attenuation) characteristics of two insert and one helmet ear-protecting device using the free-field threshold shift (FFTS) and temporary threshold-shift reduction (TTSR) techniques were evaluated with both impulse and continuous noise exposure. All devices tested were shown significantly to reduce TTS from impulse and continuous noise exposure. The insert devices were more effective at low frequencies, approximately equal to the helmet at high frequencies. The TTSR technique adds important information regarding the operational efficiency of the ear protectors tested, and because of special problems associated with helmets, it seems particularly desirable to include the TTSR technique in their evaluation. The data suggest that susceptibility to TTS from continuous exposure is not significantly correlated with that from impulse exposure.

1729

Hamrick, J. J., "Techniques for Measuring and Evaluating Noise," J. Audio Eng. Soc., 6, 19-25, 1958.

The continually increasing public concern about noise has required the development of improved techniques and procedures, both to measure and also to evaluate the noise environment created by new products. Modifications of existing instruments and improved operational procedures have been developed for stereo tape recorders and reproducing systems, audio spectrum analyzers, graphic level recorders, and frequency analyzers. Correlation of noise levels in data-processing rooms with laboratory measurements in anechoic and reverberant chambers, together with careful selection and qualification of listening-panel members for annoyance evaluations, have insured that both the loudness and the quality of the noise of a new product will be satisfactory.

1730

Harris, C. M. (ed.), "Handbook of Noise Control," McGraw-Hill, New York, 1042 pp., 1957.

This volume in the McGraw-Hill handbook series covers the broad and colorful spectrum of noise and its control. In forty chapters — ranging from physics and engineering, physiology, and medicine to psychology, economics, and law — it contains, in over 1000 pages, a great amount of information. However, Chapters 2 and 3 will be of particular interest to people concerned with the propagation of sound in air.

Chapter 2, "Physical Properties of Noise and Their Specification," by R. W. Young and Chapter 3, "Propagation of Sound in The Open Air," by I. Rudnick are concerned with physical aspects of noise and sound. The former gives a review of the elementary concepts of sound and noise, particularly its description. A more extensive consideration of statistical aspects and methods would probably be useful for many readers. In Chapter 3 the complex field concerning the influence of outdoor factors on sound propagation is discussed, and the results are represented in many useful graphs.

1731

Hubbard, H. H., "Noise Problems Associated with Ground Operations of Jet Aircraft," Memo No. 3-5-59L, NASA, Washington, D. C., 13 pp., 1959.
AD-213 050.

The nature of the noise-exposure problem for humans and the aircraft-structural-damage problem are each discussed briefly. Some discussion is directed toward available methods of minimizing the effects of noise on ground crews, on the aircraft structure, and on the surrounding community. A bibliography of available papers relating to noise-reduction devices is also included.

1732

Kryter, K. D., "The Effects of Noise on Man," Central Inst. for the Deaf, St. Louis, (J. of Speech and Hearing Disorders. Monograph Suppl. 1, 1950), 95 pp., 1950.
AD-105 339.

This is a review, summary, synthesis, evaluation, and interpretation of the experimental literature on noise as an aspect of man's environment. Its first section is concerned with effects upon behavior, particularly in regard to work output and efficiency. The second part brings together material on auditory damage as the result of noise, and defenses against such damage. The third portion considers noise as a disruptive factor in speech communication. A bibliography on methods of noise measurement and procedures for reduction is added as an appendix. The breadth of the project is indicated by the fact that more than 650 different titles are included in the chapter bibliographies and appendix.

1733

Kryter, K. D., and K. S. Pearsons, "Judgment Tests of the Sound from Piston, Turbojet, and Turbofan Aircraft," Sound, 1, 24-31, 1962.

The authors discuss the results of recent subjective tests on the perceived noisiness of five different aircraft, including piston-engine, turbojet, and turbofan types. The judgments of several subjects are compared with different ways of expressing quantitatively the relative noisiness of the aircraft.

1734

Kushner, S. S., "A Review of Nuisance and Hazardous Noise," Rept. No. IP-263, Engineering College Industry Program, Univ. of Mich., Ann Arbor, 1958.

The effects of hazardous and nuisance noise levels are reviewed. A bibliography of 54 entries is included.

1735

Legget, R. F., and T. D. Northwood, "Noise Surveys of Cocktail Parties," J. Acoust. Soc. Am., 32, 16-18, 1960.

This paper discusses and enlarges on a recent theoretical paper by W. R. MacLean on the acoustics of cocktail parties. The discussion is supported by experimental evidence accumulated during the past two years. MacLean's analysis suggests that there is a critical density of participants above which a quiet cocktail party abruptly becomes noisy. It would appear that one might actually plan a quiet or noisy party as required (assuming control over the number of participants). Unfortunately the cases studied experimentally do not show this quiet-noisy transition, and it is believed that factors not considered in the theory result in a blurring of the distinction. Indications are that there is a gradual increase in sound level to a saturation value that is independent of the properties of the room, the beverages served, and the number of participants. There is, however, dependence on the sex of the participants.

1736

MacLean, W. R., "On the Acoustics of Cocktail Parties," J. Acoust. Soc. Am., 31, 79-80, 1959.

Parties are classified as loud or quiet, and the distinction is shown to depend often upon a critical acoustical relationship rather than upon the guests themselves. An explicit formula is found for the maximum number N of well-mannered quests compatible with the quiet party. When this number is exceeded, the party will become a loud one within a calculable time T.

1737

Maglieri, D. J., and H. W. Carlson, "The Shock-Wave Noise Problem of Supersonic Aircraft in Steady Flight," NASA Memo. No. 3-4-59L, Washington, D. C., 15 pp., 1959.
AD-214 070.

Presents an insight into the nature of the shock-wave noise problem, the significant variables involved, and the manner in which airplane operation may be affected. Flight-test data are compared with the available theory. An attempt is made to correlate the subjective reactions of observers and some physical phenomena associated with the pressure amplitudes during full-scale flight.

1738

Oslake, J., N. Haight, and L. Oberste, "Acoustical Hazards of Rocket Boosters, Volume I. Physical Acoustics," Tech. Rept. No. U-108:96, Aeronutronic, Newport Beach, Calif., 328 pp., 1961.
AD-253 234.

The results are presented of a survey and analysis of the acoustical hazards at a missile launch site. Volume I deals with the physical aspects of acoustics, noise sources, means of generation, special characteristics of rocket noise, similarity concepts, and prediction techniques for near and far field sound pressure levels, directivity, and acoustical power levels of large rocket boosters. The influence of clusters and blast deflectors on the generation of rocket noise is considered. Expected differences in noise produced by liquid, solid, and/or nuclear rocket engines are compared. Measured acoustical data are presented of sound attenuation along the surface of the earth and at various elevations from the gound as influenced by varying geographical and weather conditions.

1739

Parfitt, G. G., "Recent Studies of Noise Problems," Brit. J. Appl. Phys., 11, 53-57, 1960.

Some fairly recent work on various aspects of acoustic noise was reviewed at a half-day symposium held in London in March, 1959, by the Acoustic Group of The Physical Society. One group of papers discussed studies of the parameters of noise which were important in determining the subjective loudness, the possible damaging effects on human hearing, the influence on working efficiency, and the annoyance caused in residential and working communities. Of the more purely technical papers, one considered some of the difficulties in taking measurements of noise from aircraft to the relatively high degree of accuracy often required, while the other described results of measurements and analysis of the noise from automotive diesel engines.

1740

Pietrasanta, A. C., "Jet Noise Problem in Aircraft Carrier Islands," J. Acoust. Soc. Am., 28, 427-433, 1956.

Noise during jet aircraft launching operations seriously interferes with communications in important island spaces aboard aircraft carriers. Measurements of sound-pressure levels made in these spaces during normal jet operations at sea are reported. It was found that these levels could be estimated from a knowledge of jet-engine operating conditions (A. A. Pietrasanta, J. Acoust. Soc. Am., 28, 434, 1956) and the physical properties of the structures involved. The problem of selecting criteria for speech communication is discussed. Noise-reduction requirements for island spaces, based on estimated noise levels of present and future jet aircraft, are presented.

1741

Pietrasanta, A. C., and K. N. Stevens, "Guide for the Analysis and Solution of Air Base Noise Problems," Final Rept. No. WADC TR 57-702, Bolt, Beranek, and Newman, Inc., Cambridge, Mass., 163 pp., 1961.
AD-278 688.

Detailed engineering procedures for analyzing and solving air base noise problems caused by jet operations are presented. These problems are classified according to activity areas: (a) on- and off-base housing; (b) offices and work areas; (c) group meeting, study, and rest areas; (d) hospitals; and (e) important communication areas. For each of these areas, analysis procedures are described in detail, and several illustrative examples of their application are discussed. The procedures are simplified so that personnel with little or no engineering training can readily apply them to solve air base noise problems. Also, these procedures have been developed so that all noise problems can be solved on paper. No direct measurements of air base noise are required.

The guide is intended to be useful to anyone concerned with air base noise problems. It provides engineering guidance for the solution of a variety of problems, including planning new bases, modifying existing bases, and planning future modifications which may become necessary with newer aircraft.

1742

Pollack, I., "Loudness of Periodically Interrupted White Noise," AFCRC TR 57-5, Operational Applications Lab., AF Cambridge Research Center, Washington, D. C., 5 pp., 1960.
AD-247 768.

The burst level of a periodically abruptly interrupted white noise, necessary to match a continuous non-interrupted white noise in loudness, is examined over a wide range of interruption conditions. A procedure for calculating the required burst level, with knowledge of only the time-intensity characteristics of the interrupted noise, is outlined.

1743

Regier, A. A., W. H. Mayes, and P. M. Edge, Jr., "Noise Problems Associated with Launching Large Space Vehicles," Sound, 1, 7, 1962.

Engine-noise data for current large launch vehicles have been reviewed, and extrapolations have been made for future vehicles of the multimillion-pound thrust class. The results indicate that the latter vehicles will generate high sound-pressure levels at large distances from the launch site, and the noise spectra will probably peak in the sub-audible frequency range. With regard to the effects of intense low-frequency noise, reference is made to experience in the operation of a large blow-down wind tunnel and in laboratory studies of building components. A ground-building damage criterion is proposed and a brief description is given of a proposed low-frequency-noise environmental test facility.

1744

Rosenblith, W. A., and N. S. Kenneth (for Bolt, Beranek, and Newman, Inc.), "Handbook of Acoustic Noise Control," WADC Tech. Rept. No. 52-204, Wright-Patterson Air Force Base, Ohio, II, 262 pp., 1953.
AD-18 260.

Volume II, which is intended as a guide in solving the problem of noise control, discusses the ways in which acoustic noise can be undesirable. The topics treated in particular are: basic bio- and psycho-acoustic data; effects of noise on human behavior; and human response criteria for noise control. Several subjective responses were analyzed and correlated with properties of the physical stimuli. Definitions of bio-acoustic terminology are given along with a description of the anatomy of the ear and the properties of aural protective devices.

1745

von Gierke, H. E., "Vibration and Noise Problems Expected in Manned Space Craft," Noise Control, 5, 8, 1959.

The dynamic mechanical environment of space vehicles is reviewed. Noise, vibration, and transient acceleration levels during launch and re-entry are estimated, and their effects on man are discussed. The need for more information in certain areas is pointed out.

1746

Wirt, L., D. Litherland, and Y. Senoo, "Navy Acoustical Gem Study, Volume I," Final Eng. Rept. No. AP-5050-R, Aire-Search Mfg. Co., Phoenix, Ariz., Vol. 1, 185 pp., 1961.
AD-275 126.

Acoustic studies are reported concerning air propeller noise, gas turbine noise, jet-water impingement noise, and lift fan-duct noise. Discussions are included on cabin noise, airborne noise, Hydroskimmer underwater noise, and weight estimates of Hydroskimmer acoustic material.

1747

Wirt, L., D. Litherland, and Y. Senoo, "Navy Acoustical Gem Study, Volume II," Final Eng. Rept. No. AP-5050-R, Airesearch Mfg. Co., Phoenix, Ariz., 201 pp., 1961.
AD-275 090.

This rept. includes: Progress rept., 1 Dec 61 (Rept. No. AP-5046-R, Rev. no. 1).

A study is reported on air propeller noise, lift fan and duct noise, jet water impingement noise, and prime mover (gas turbine trailer) noise. The information contained within this report has been compiled so that the noise levels of air cushion vehicles in general, and the Hydroskimmer research craft specification of the Bureau of Ships in particular, may be estimated.

Noise, Psychophysical Effects
See also—2, 489, 498, 539, 553, 719, 965, 998, 1379, 1591, 1618, 1633, 1650, 1651, 1663, 1665, 1668, 1673, 1690, 1692, 1696, 1697, 1776, 1777, 2426, 2453, 3531, 3533, 3534, 3535.

NOISE, THEORY

1748

Bakken, B. A., "The Sound Intensity of a Shock Wave as Related to Overpressure," Tech. Rept. No. DASA-540, Defense Atomic Support Agency, Washington, D. C., 14 pp., 1961.
AD-266 866.

This report deals with the sound intensity of a blast wave and its noise level, based on the threshold of human hearing. Since the sound level depends on ambient conditions, the effect of altitude was considered by determining the relative change between sea level and 5000 ft. Expressions for sound level as a function of overpressure are presented.

1749

Bies, D. A., and P. Franken, "Notes on Scaling Jet and Rocket Noise," J. Acoust. Soc. Am., 33, 1171-1173, 1961.

For dynamically similar systems it is shown that pressures at similar positions are the same when measured in constant-percentage-frequency bands and when frequency is scaled inversely proportional to a characteristic length. This scaling relationship can be extended to systems containing acoustic liners if the linear flow resistance is held constant. Corrections for small errors in scaling are suggested for the case of rocket engines.

1750

Boyarsky, L. L., "The Calculation of the Thermal Noise in Air," J. Acoust. Soc. Am., 23, 716, 1951.

The basis for the calculation is to consider a cavity containing gas molecules as an acoustic blackbody in which standing waves of sound are set up because of the Brownian movement of the molecules of air.

1751

Chobotov, V., and A. Powell, "On the Prediction of Acoustic Environments from Rockets," Rept. No. GM TR 190, Thompson Ramo Wooldridge, Inc., Los Angeles, 26 pp., 1957.
AD-217 248

Presents a procedure for estimating the far-field acoustical environment generated by rocket engines. Although the problem of estimating far-field noise is complicated by a number of factors, including a scarcity of reliable data, it is believed that the procedure described will predict the over-all sound pressure level to within ±5 db.

Outlines a procedure for estimating the frequency spectrum of the sound pressure. Various factors, such as meteorological conditions, that affect sound-pressure levels at large distances are briefly discussed.

1752

Dyer, I., "Measurement of Noise Sources in Ducts," J. Acoust. Soc. Am., 30, 833-841, 1958.

Recently Kerka, and earlier Beranek, Reynolds, and Wilson, discussed the measurement of sound power radiated by a fan in a straight duct by measuring the sound pressure inside the duct. A difficulty associated with this technique is that above a certain frequency the sound pressure varies markedly across a transverse section of the duct, and the relation between mean square pressure and power is not simple. The transverse variation can be unserstood by application of mode theory to propagation of noise in the duct. In the theory it is assumed that the noise source is purely random and of low internal impedance. Propagation in the various duct modes is shown to be statistically independent, and to give rise to equipartition of energy in the limit of high frequencies.

The theory agrees well with measurements reported by Kerka. With the use of the theory, it is possible to select measurement positions inside the duct so that the mean-square pressure is related to the power flow by the simple plane-wave equation.

1753

Dyer, I., P. A. Franken, et al., "Jet Noise Reduction by Induced Flow," J. Acoust. Soc. Am., 30, 761, 764, 1958.

The secondary air induction of a modified jet nozzle affects the generation of noise, and this report analyzes the effect. It is shown that the combination of the secondary air with the primary jet air creates a new jet stream of larger area, lower velocity, and lower noise generation. The decrease in noise radiation is found in terms of the area of the combined jet streams.

There is no detailed check of the theory because of lack of measurements of the combined jet-stream areas taken with measurements of the noise. However, the upper limit of the appropriate jet-stream area is estimated in order to determine the upper limit on noise reduction; the upper limit on noise reduction obtained from the theory is consistent with existing measurements. The theory allows qualitative conclusions about the spectrum and directivity of the noise radiated by jets with modified nozzles, and these conclusions are in accord with measurements.

1754

Eckart, C., "The Theory of Noise in Continuous Media," J. Acoust. Soc. Am., 25, 195-199, 1953.

It is shown that the mathematical solution of problems involving the propagation of noise is materially aided by the introduction of the space correlation function $\psi(x_1, x_2, \tau)$, defined as the average, over t, of $p(x_1t)p(x_2t - \tau)$, p being the acoustic pressure in the noise field. The differential equations satisfied by ψ are derived. Its relation to $\psi(\alpha, \beta, \gamma)$ is discussed, α, β, γ being the propagation vector of a sinusoidal wave, and $\psi/2c^2$ being the density of potential energy in the α, β, γ space.

The theory of uniform noise fields, both isotropic and anisotropic, is developed in detail. The anisotropy caused by a reflecting plane is discussed.

The radiation of noise by a vibrating plane is discussed, neglecting the reaction of the radiation on the motion of the surface. In particular, it is shown that to this approximation the sea surface cannot radiate subsonic energy into the high atmosphere because the velocity of the surface gravity waves is less than the velocity of sound in air. The theory of noise, as here developed, is analogous to the theory of turbulence, and the relation between noise and turbulence is briefly discussed.

1755

Etkin, B., and H. S. Ribner, "Canadian Research in Aerodynamic Noise," Review No. 13, Inst. of Aerophysics, Univ. of Toronto, Canada, 1958.
AD-203 662.

Canadian research on flow noise and some aspects of the aircraft noise problem is described. Specific experimental and/or theoretical investigations include: aeolian tones; boundary layer noise (rigid and flexible walls); effects of boundary layers and noise on aircraft structures; distribution of noise sources along a jet; ground run-up mufflers; transmission of sound from, and acoustic energy flow in, a moving medium; sound generated by interaction of a vortex with a shock wave.

1756

Franken, P. A., and E. M. Kerwin, Jr., "Methods of Flight Vehicle Noise Prediction," WADC Tech. Rept. No. 58-343, Bolt, Beranek, and Newman, Cambridge, Mass., 1958.
AD-205 776.

Presents detailed engineering procedures for estimating sound-pressure levels on or within a flight vehicle. The report is oriented for use by the aircraft engineer in making preliminary estimates of noise levels on or in a vehicle while the vehicle is still in the design stage. The procedures are expressed in terms of general parameters (such as mechanical power, typical dimensions, forward speed) which may be obtained to a satisfactory degree of accuracy long before flight testing.

The first step is the estimation of noise levels exterior to the vehicle. Next, the basic noise-transmitting properties of panel structures are studied. The effects of coincidences, resonances, damping, etc., are included. Finally, the particular vehicle geometry of interest is considered. The source and transmission properties already determined can then be combined, with appropriate geometrical corrections for the character of the receiving space, to yield the desired estimates of interior noise levels.

Several examples are worked out in detail to illustrate the application of the report procedures to typical vehicle configurations.

1757

Kraichnan, R. H., "Noise Transmission from Boundary Layer Pressure Fluctuations," J. Acoust. Soc. Am., 29, 65-80, 1957.

Reports a theoretical study made of noise spectra radiated by the vibration of thin, stiff, flat plates under the action of turbulent boundary-layer pressure fluctuations. The transmitted radiation investigated arises from the streamwise convection of quasi-static pressure fluctuations by the steady flow, and is critically influenced by the dispersive character of transverse wave porpagation in the plates. For sufficiently thin boundary layers at moderate subsonic Mach numbers and typical parameter values the total transmitted power varies approximately as the fifth power of Mach number. At lower Mach numbers the dependence may be flatter and near-certain transonic velocities should be steeper. The dominant transmitted frequencies increase with Mach number, varying, under certain conditions, as Mach number squared.

Plate parameters which importantly influence sound transmission included mass per unit area, size of independent plate sections, stiffness, and damping factors for the various vibrational modes. For sufficiently thin boundary layers, the transmitted spectrum shape is essentially independent of boundary layer thickness, but the total transmitted power varies approximately as the fourth power of the thickness. For thicker boundary layers, the dependence is flatter and the Mach number dependence is also flattened.

Several possible procedures for reducing the noise transmission are mentioned briefly.

1758

Kramer, H. P., "Note on the Emission of Noise by Supersonic Jets," J. Acoust. Soc. Am., 27, 789-790, 1955.

The sound produced in a supersonic jet issues predominantly at an acute angle θ to the direction of gas flow. This is reminiscent of the Cherenkov effect, in which a charged particle passing through a medium at a speed v greater than the local speed c of propagation of electromagnetic waves, radiates light in a direction $\sec^{-1} v/c$.

The author has applied this method to the acoustical problem and shows that it is essentially equivalent to Lighthill's method (Proc. Roy. Soc. (London) A, 211, 565-87, 1952) since it consists in replacing his quadrupole source distribution in the interior of the jet by the surface pressure distribution.

1759

Lee, R., R. Kendall, et al., "Research Investigation of the Generation and Suppression of Jet Noise," Final Rept., General Electric Co., Cincinnati, Ohio, 451 pp., 1961. AD-251 887.

Analytical and experimental investigations on jet-noise suppression led to establishment of a new theory relating the sound-power spectra and distribution of mean flows in the jet field. The method is sufficiently general to be applicable to the flow fields of nozzle suppressors, and is found to agree with test results. A computer program was also set up for calculating the mean-flow characteristics of mixer-type suppressors in general.

Scale model testing on various suppressor configurations indicated that further noise reduction may be achieved using suggested optimization techniques. Directivity investigation of jet noise showed that suppressor directivity can be predicted with reasonable accuracy on the basis of sound-power spectrum data alone. Screech phenomena were investigated, including flow interference and temperature effects, leading to formulation of a detailed physical model for their generation.

1760

Lighthill, M. J., "On Sound Generated Aerodynamically, II, Turbulence as a Source of Sound," Univ. of Manchester, England, 1953.

The theory of sound generated aerodynamically is extended by taking into account the statistical properties of turbulent airflows, from which the sound radiated (without the help of solid boundaries) is called aerodynamic noise. The theory is developed with special reference to the noise of jets, for which a detailed comparison with experiment is made (Chap. 7 for subsonic, Chap. 8 for supersonic jets).

The quadrupole distribution of Part I (Lighthill, 1952) is shown to behave (see Chap. 3) as if it were concentrated into independent-point quadrupoles, one in each "average eddy volume." The sound field of each of these is distorted, in favor of downstream emission, by the general downstream motion of the eddy, in accordance with the quadrupole convection theory of Part I. This explains, for jet noise, the marked preference for downstream emission, and its increase with jet velocity. For jet velocities considerably greater than the atmospheric speed of sound, the "Mach number of convection" M_c may exceed 1 in parts of the jet, and then the directional maximum for emission from these parts of the jet is at an angle of $\sec^{-1}(M_c)$ to the axis (Chap. 8).

Although turbulence without mean flow has an acoustic power output, which was calculated to a rough approximation from the expressions of Part I by Proudman (1952; see also Chap. 4 below), nevertheless, turbulence of given intensity can generate more sound in the presence of a large mean shear (Chap. 5). This sound has a directional maximum at 45° (or slightly less, due to the quadrupole convection effect) to the shear layer. These results follow from the fact that the most important term in the rate of change of momentum flux is the product of the pressure and the rate of strain. The higher-frequency sound from the heavily sheared mixing region close to the orifice of a jet is found to be of this character. But the lower-frequency sound from the fully turbulent core of the jet, further downstream, can be estimated satisfactorily (Sect. 7) from Proudman's results, which are here reinterpreted (Chap. 5) in terms of sound generated from combined fluctuations of pressure and rate of shear in the turbulence. The acoustic efficiency of the jet is of the order of magnitude $10^{-4}M^5$, where M is the orifice Mach number.

However, the good agreement of total acoustic power output with the dimensional considerations of Part I, is partly fortuitous. The quadrupole convection effect should produce an increase in the dependence of acoustic power on the jet velocity above the predicted U^8 law. Largely cancelling this, the experiments show that some other dependence on velocity is present, tending to reduce the intensity below the U^8 law at the stations where the convection effect would be absent. At these stations (at 90° to the jet) proportionality to about $U^{6.5}$ is more common. A suggested explanation of this, compatible with the existing evidence, is that at higher Mach numbers there may be less turbulence (especially for larger values of nd/U, where n is frequency and d diameter), because as the turbulence builds in the mixing region it loses energy by sound radiation. This would explain also the slow rate at which supersonic mixing regions spread, and, indeed, is notincompatible with existing rough explanations of that phenomenon.

A consideration (Chap. 6) of whether the terms other than momentum flux in the quadrupole strength density might become important in heated jets indicates that they should hardly ever be dominant. Accordingly, the physical explanation (Part I) of aerodynamic sound generation still stands. It is re-emphasized, however, that whenever there is a fluctuating force between the fluid and a solid boundary, a dipole radiation will result which may be more efficient than the quadrupole radiation, at least at low Mach numbers.

1761

Lilley, G. M., "On the Noise from Air Jets," Rept. No. ARC 20, 376, Aeron, Res. Council, Great Britian, 1958. AD-206 360.

Reviews the current position of research into aerodynamic noise. The contents include: (1) Lighthill's theory of aerodynamic noise; (2) Structure of various regions of a turbulent subsonic jet; (3) Sound generated in various regions of a turbulent subsonic jet; (4) Noise emitted by a supersonic jet; (5) Experimental work on noise of subsonic air jets; and (6) Methods of noise reduction.

1762

Lyon, R. H., "Propagation of Correlation Functions in Continuous Media," J. Acoust. Soc. Am., 28, 76-79, 1956.

The correlation properties of noise fields when considered as a random superposition of elementary sources are derived as an extension of Rice's work on the shot effect (Bell System Tech. J., 34, 282, 1944; 24, 46, 1945). Next a formalism is derived, which calculates the correlation properties of the response of a continuous, linear system when subject to an applied noise field. The requirements for solution are a knowledge of the impulse response of the system and the correlation function of the source. The latter may be obtained experimentally or from calculation.

1763

Maidanik, G., "Radiation Efficiency of Panels," J. Acoust. Soc. Am., 35, 115, 1963.

Theoretical predictions are compared with measurements of the radiation efficiencies of gypsum board and concrete panels.

1764

Mawardi, O. K., "On the Spectrum of Noise from Turbulence," J. Acoust. Soc. Am., 27, 442-446, 1955.

Reports development of an approximate method for estimating the acoustical power-frequency spectrum of the sound generated fromisotropic turbulence. The method is based on a hypothetical model for the sound sources, originally produced by Lighthill, consisting of an assembly of quadrupoles extending over the region of turbulence.

1765

Moretti, G., and S. Slutsky, "The Noise Field of a Subsonic Jet," Tech. Rept. No. 150, Gen. Appl. Sci. Labs., Inc., N. Y., 165 pp., 1960. AD-236 386.

The acoustical far field of a singularity is investigated under several different conditions of the medium. The simple cases of a source in an infinite wind, as observed at a fixed or a moving point, are analyzed to permit comparison with physical systems of practical interest, e.g., analysis of jet-engine fly-by noise. Misunderstanding of the Lighthill Mach number dependence was clarified by means of this analysis. The far field of a singularity imbedded in a jet is determined as a function of jet velocity and temperature distribution, with special emphasis on the case of uniform distribution in the jet.

Comparison of experimental results is made and fair agreement noted. Factors involved in failure to obtain complete agreement are discussed.

1766

Mull, H. R., Effect of Jet Structure on Noise Generation by Supersonic Nozzles," J. Acoust. Soc. Am., 31, 147-149, 1959.

In this study the near-noise field of a supersonic jet (Mach 2.87), exhausting into quiescent air, is analyzed with respect to the aerodynamic structure of the jet. The noise field is shown to shift away from the jet exit with the most intense sound near the end of the supersonic portion of the exhaust structure. Downstream of this point, the jet radiates noise in the same manner as a subsonic jet.

1767

Powell, A., "Concerning the Noise of Turbulent Jets," J. Acoust. Soc. Am., 32, 1609-1612, 1960.

The suggestion that the noise generators of turbulent jets undergo convection effects which are limited in such a way as to follow a similarity behavior leads directly to a resolution of Lighthill's paradox, namely, the problem of accounting for the noise power's depending upon the eighth power of the jet velocity simultaneously with the gross directional bias. This hypothesis is shown to be at least plausible to a first approximation because the general velocity field of the jet has typical dimensions comparable to a fraction of a wavelength; an important corollary is the expectation of appreciable refraction effects. Aspects relevant to the higher-frequency directional peaks being less-pronounced and located further from the jet axis, and of the slow frequency rise, and briefly discussed.

1768

Powell, A., "Considerations Concerning an Upper Limit to Jet Noise Reduction," J. Acoust, Soc. Am., 31, 1138-1140, 1959.

The idea of a theoretical upper limit on jet-noise reduction, put forward by Dyer, Franken, and Westervelt, may prove a profitable one, since it concerns an aspect so much simpler than the question of determining what might be the reduction achieved in practice. Their argument can be greatly strengthened by extending the method to take into account the essential nonuniformity of flow conditions at cross sections away from the jet exit, and also by referring to the physically significant total cross-sectional area of the mixing zone in defining the area ratio, which plays a prominent role in the method. It does not follow that this technique — even as modified — should lead to good extimates of noise reductions achieved in practice; it simply indicates an upper limit which one could not hope to exceed and indeed would be lucky to approach.

1769

Powell, A., "On the Effect of Missile Motion on Rocket Noise," J. Acoust. Soc. Am., 30, 1048, 1958.

On the assumption that turbulent mixing accounts for the major part of rocket noise, it is tentatively suggested that the rocket noise intensity at a given point on a missile varies as

$$\left[\frac{M_j - M_m}{M_j}\right]^3 (1 - M_m)^2$$

where M_j is the highly supersonic Mach number of the jet efflux relative to the exit, and M_m is the subsonic Mach number of the missile, both referred to the speed of sound in the external air. The frequency characteristics are little affected.

1770

Regier, A. A., and H. H. Hubbard, "Status of Research on Propeller Noise and its Reduction," J. Acoust. Soc. Am., 25, 395-404, 1953.

Reviews the basic concepts concerning the generation of propeller noise generation, and gives equations for calculating the noise field both near and far from the propeller. Noise from nonsteady airloads on the blades and differences in noise from the approaching and retreating blades are discussed. Effects of tip speed, number of blades, blade thickness, and blade width are considered, and it is shown that reducing the tip speed and increasing the number of blades are probably the most effective means of reducing the efficiency of noise generation and alleviating the noise problem.

Noise characteristics of such special propellers as the supersonic, dual rotating, tandem, and shrouded types are also presented. Studies of propeller weights show that substantial noise reduction on transport propellers would result in a considerable weight penalty. For the propeller-driven aircraft in the 400 to 500 mph speed range, the slower-turning, quieter propeller is likely to have better propulsive efficiency than the noisier high-speed propeller. Hence, in this speed range, the weight penalty of the quiet propeller may be offset by its higher propulsive efficiency.

1771

Slutsky, S., "Acoustic Field of a Cylindrical Jet Due to a Distribution of Random Sources or Quadrupoles," Tech. Rept. No. 281, Gen. Appl. Sci. Labs., Inc., Westbury, New York, 58 pp., 1962.
AD-267 032.

Describes the far field of a random distribution of sources and quadrupoles arising in an axisymmetric field of steady flow. This field is treated as one of a single harmonic oscillator. The random source distribution is described in terms of a spatial and temporal correlation function. Expressions are obtained for the mean square intensity and power spectral density of the acoustic noise field. The effect of eddy convection is not included. It is found that the assumtion of a source mechanism results in a far-field distribution which resembles those experimentally available, whereas the lateral quadrupole mechanism fails in this respect.

1772

Slutsky, S., and J. Tamagno, "Sound Field Distribution About a Jet," Tech. Rept. No. 259, Gen. Appl. Sci. Labs., Inc., Hempstead, New York, 66 pp., 1961.
AD-271 007.

A mathematical model to study the acoustic field generated by a subsonic jet in air at rest was applied to: (1) evaluation of the near-field sound intensity radiated by a source in a jet; (2) effectiveness of shielding around a jet, and its influence on sound-field directionality; and (3) the effect on the far field of nonuniformity in the jet velocity and temperature profiles.

1773

Smith, M. W., and R. F. Lambert, "Propagation of Band Limited Noise," J. Acoust. Soc. Am., 32, 512-514, 1960.

Reports theoretical and experimental work on the propagation of band-limited noise in a plane wave tube. Characteristics of the spatial cross-correlation curve are controlled by the arithmetical mean frequency of the band and the bandwidth of the noise. The amplitude of the correlation function for zero spatial separation is directly proportional to the total power Ak_b, with A the density of the cross power spectra and k_b the bandwidth in wave number. Agreement between theory and experiment is quite good for relatively small spatial separation.

1774

Sperry, W. C., "Fundamental Study of Jet Noise Generation and Suppression," Rept. No. WADD TR 61-21, Armour Res. Foundation, Chicago, Vol. 1, 182 pp., 1961.
AD-264 919.

The fundamental aspects of jet-noise generation and suppression are examined and evaluated. Initially, the basic equations of acoustics and fluid dynamics are considered with respect to the usual simplifying assumptions; the non-linear characteristics that lead to increased generality are emphasized. The Lighthill theory of subsonic jet-stream noise and theories of supersonic jet-stream noise are studied and extended. The sound field surrounding a jet is analytically represented, yielding a solution that provides some insight into noise-generating mechanisms. Finally, the report includes a general review and analysis of experimental studies by others concerning jet-noise generation and suppresion.

Vol. I contains the technical details and Vol. II is a bibliography.

1775

Sperry, W. C., R. Kamo, and A. Peter, "Experimental and Theoretical Studies of Jet Noise Phenomena," Final Rept. No. ASD TDR 62-303, Armour Res. Foundation, Chicago, 163 pp., 1962.
AD 282 273.

Over-all sound pressure levels were measured in an anechoic room for noise generated by cold air flow through more than twenty different nozzle configurations, including converging, converging-diverging, slot, and annular types (the latter with and without center-core flow). The results are examined in terms of over-all acoustic power and directivity versus mass flow, and compared with various eighth-power relations. The acoustic performance of most nozzles was similar in the subsonic region. However, certain annular-type nozzles exhibited a marked superiority in the supersonic region.

Theoretical discussions are presented concerning the generation of sound and the relationship between various turbulence and statistical theories. A modified mixing-length theory is developed, showing its applicability to the generation of turbulence as well as its influence on the general equation for the forcing function. Temperature effects are included. Empirical data are given pertaining to the correlation of jet noise from circular and annular nozzles.

1776

Stevens, S. S., "Calculation of the Loudness of Complex Noise," J. Acoust. Soc. Am., 28, 807-829, 1956.

Presents charts and formulas for the calculation of the loudness of noises having approximately continuous spectra. By means of direct loudness matches it is shown that the loudness in octave bands can be combined according to the formula $S_t = S_m + 0.3 (\Sigma S - S_m)$, where St is the loudness (in sones) of the total noise, S_m is the loudness of the loudest band, and ΣS is the sum of the loudness of all the bands. The loudness of the octave bands can be determined from measurements of their sound-pressure levels by means of a chart based upon a new determination of the equal loudness contours for bands of noise. Other charts and formulas are presented for half- and third-octave band widths.

Measurements were also made of the dependence of loudness on such factors as (a) separation between noncontiguous bands, (b) width of very narrow bands, and (c) rate and level of square wave modulation.

1777

Stevens, S. S., "The Calculation of the Loudness of Noise," Rept. No. PNM-68, Psycho-Acoustic Lab., Harvard Univ., Cambridge, Mass., 5 pp., 1956.
AD-149 464.

This paper discusses the calculation of the apparent loudness (in sones) of the complex noise from measurements of sound-pressure levels in separate frequency bands. From the results of numerous experiments, a practical rule is developed for deriving the total loudness of a noise from measurements based on octave bands. The procedure involves the use of charts and a formula for the addition of loudness. It is also pointed out that experiments designed to determine loudness by means of a rating scale involving categories (e.g., loud, medium, and soft) lead to scales that are nonlinear in sones.

1778

Westley, R., and G. M. Lilley, "An Investigation of the Noise Field from a Small Jet and Methods for its Reduction—and Errata," Rept. No. 53, College of Aeronautics, Cranfield, England, 56 pp., 1952.
ATI-153 224.

Sound measurements are reported which were made on the noise from the jet of a one-inch diameter convergent nozzle at atmospheric temperature and at speeds above and below choking. The noise level and spectrum were investigated in both near and distant fields. Results agree in some measure with the predictions of the Lighthill theory, that the elementary sound radiator is an acoustic quadrupole. The agreement is more marked if attention is confined to the higher frequencies. Simple empirical formulae are derived which give the overall sound intensity and frequency spectrum in terms of the position relative to the jet, the stagnation pressure excess over the atmospheric pressure, and the frequency. Tests on various noise-reduction devices are discussed, which indicate promising lines of investigation. Maximum reduction in total noise level was about 10 db.

Noise Theory
See also—12, 346, 421, 523, 1118, 1377, 1587, 1602, 1629, 1659, 1663, 1698, 1713, 1716, 1722, 1723, 1724, 1735, 1736, 1746, 1747, 1988, 2110, 2413, 2509, 2882, 2905, 3781, 3916

OPTICAL EFFECTS AND TECHNIQUES

1779

Andreev, I. I., "Occurrence of Visible Propagation of Sound Waves in the Air" (in Russian), Priroda, 43, 112-113, 1954.

The reported occurrence was observed by the author in East Prussia during World War II. He describes the sudden appearance, on April 17, 1915, of a huge column of black smoke over the village of Fischhausen. No sound of explosion was to be heard, either at the advent or during the subsequent movement of the wave. At a height of 200-250 m, it took the form of a great mushroom, then the phenomenon began to disperse and spread in the air and finally emitted from its cap a circulatory air wave. The wave passed over a distance to 3-4 km in 10-12 seconds and when it reached the point where the author stood, it disappeared completely.

The origin of this unusual wave and its progress in the air was a heavy explosion at Fischhausen. It was first observed as an optical phenomenon and only later as an acoustical phenomenon, in the form of a loud noise produced by a heavy explosion.

1780

Bennett, F. D., "Cylindrical Shock Waves from Exploding Wires," Rept. No. 1035, Ballistic Res. Labs., Aberdeen Proving Ground, Md., 24 pp., 1958.
AD-162 922.

A simple technique has been found for rendering visible the shock wave formed by an exploding wire after the shock separates from the luminous contact surface. A small, plane mirror is placed just behind the wire so as to be perpendicular to the axis of the optical system. Thus the reflected image of the wire explosion coincides with the disturbance itself when seen through the slit by the camera lens. Rotating mirror pictures taken under these conditions show very clear outlines of the parabolic shock wave as it propagates ahead of the luminous contact surface. The separation of the shock and the contact surface is completed in about one microsecond. Beyond this time the shock is clearly non-luminous and ordinarily would not be visible.

Comparison of shock trajectories with predictions from the similarity solutions for strong shock waves show that the shock receives additional energy while traversing the early part of its path. After this phase both shock and contact surface accurately obey a parabolic law over intervals of several microseconds.

1781

Bennett, F. D., and D. D. Shear, "Shock Waves from Exploding Wires at Low Ambient Densities," Rept. No. 1152, Ballistic Research Labs., Aberdeen Proving Ground, Md., 34 pp., 1961.
AD-271 165.

The recently discovered technique of streak interferometry was applied to study four-mil copper wires exploded into argon at reduced pressures. Typical interferograms at 1/16 atm show an intensely luminous, peripheral arc formed in an annulus several mm from the wire. When filters are used to diminish the diffuse light from the glow, clear fringes can be reduced in the entire glowing region. Near the tip, measured fringe-shifts are negative, indicating the presence of electrons. No shock wave is seen. During an interval of about 1 μsec, fringe-shifts near the periphery of the expanding glow change to positive values and a compressional shock wave can be seen to separate and propagate ahead. Estimates obtained from approximate interferogram reductions indicate electron densities as high as 10^{18}/cc in the annular region of the arc.

A sequence of interferograms at pressures 1/16 atm to 1 atm is presented, and implications for the mechanism of shock production are discussed.

1782

Bennett, F. D., and D. D. Shear, "Visualization of Cylindrical Shock Waves," Memo, Rept. No. 1199, Ballistic Res. Labs., Aberdeen Proving Ground, Md., 12 pp., 1959.
AD-215 122.

Presents a method of streak back-lighting which extends by a factor of two the time interval during which the shock wave from an exploding wire can be made visible.

1783

Bommel, H., "The Measurement of the Velocity and Absorption of Ultrasonics by an Optical Method," Helv. Phys. Acta, 18, 3-20, 1945.

The measurement of the velocity of ultrasonics in gases becomes more complex as the frequency increases on account of the interaction between source and receiver and other effects. In the optical method described, the Hg 4358Å line is passed through gas subjected to the action of the ultrasonics, and the diffraction pattern brought to a focus on a photographic plate by a concave mirror. The velocity V is obtained from the separation of the diffraction maxima. A range of 951-4755 kc is covered. A method is worked out theoretically whereby the absorption can be obtained from the separation of the diffraction maxima.

1784

Clapp, R. E., "The Optical Effect of a Detached Shock Wave in Front of a Rounded Nose Window," Rept. No. AFOSR/DRA 62-8, Air Technology Corp., Cambridge, Mass., 52 pp., 1962.
AD-284 588.

Optical ray-tracing techniques, using air density distributions provided by NASA, have been used to compute the optical distortion introduced by a detached shock wave. A detailed study for the case of a spherical nose window at Mach 2 showed that the central portion of the shock layer was optically equivalent to a thin lens, slightly diverging, located well back of the nose surface. The optical deflection for a ray near the axis was computed as a function of Mach number for several nose shapes (sphere, paraboloid, and oblate ellipsoid). The results showed that over the window aperture the deflection could be kept within a few seconds of angle by a suitable window design.

1785

Fand, R. M., and J. Kaye, "A Hot-Wire Method for Visualizing Intense Stationary Sound Waves," WADC Tech. Note No. 59-74, Heat Transfer Lab., Mass. Inst. of Tech., Cambridge, 6 pp., 1959.
AD-214 148.
See Also: J. Acoust. Soc. Am., 31, 810-811.

A simple method was developed for visualizing intense stationary sound waves, using a thin, electrically heated wire stretched in the direction of sound propagation. The nodes and antinodes of the sound waves appear as a series of alternate incandescent and dark areas on the wire. Photographs of the hot wire indicate the presence of hitherto unreported thermo-acoustic phenomena.

1786

Grine, D. R., "Scotchlite Screens for Viewing Shocks," Tech. Rept. No. 003-59, Poulter Labs., Stanford Res. Inst., Menlo Park, Calif., 5 pp., 1959.
AD-217 907.

Scotchlite screens for viewing shocks are compared with the usual shadowgraph method and are found to have the following advantages: (1) the objects or phenomena associated with the shock disturbance can be viewed directly since the screen is photographed from near the light source, (2) black Scotchlite reflects light directly back to its source with a reflectivity on the order of 100 times that of a painted white surface, although its reflectivity falls off as the angle subtended at the screen by source and camera increases, and (3) the Scotchlite screen is fairly inexpensive, so large screens can be used.

1787

Jackson, P. L., "Optical Analysis Techniques Applied to Seismic Data," Acoustics and Seismics Lab., Inst. of Science and Technology, Univ. of Mich., 1962.

An optical system capable of performing multichannel, high-resolution spectral analysis, and auto- and cross-correlation is under development. The series of progress reports listed detail the effort in obtaining accurate time and spectral information from variable density, time history signals.

First Semiannual Technical Summary Report, January 1962, Rept. No. 4596-4-P
Second Semiannual Technical Summary Report, July 1962, Rept. No. 4596-7-P
Third Semiannual Technical Summary Report, January 1963, Rept. No. 4596-13-P
Fourth Semiannual Technical Summary Report, July 1963, Rept. No. 4596-20-P

1788

Jackson, P. L., "Signal Enhancement Through an Ensemble Presentation," Bull. Seism. Soc. Am., 53, 1962.

A method of treating array responses is presented. The entire statistical distribution from the array is used for either direct visual estimation, or for processing in a scanning machine. An estimate of a coherent signal and the character of the noise can be made visually. Most correlative techniques, in addition to digitizing, could be performed simultaneously through using the scanning machine.

1789

Jarman, P., "Sonoluminescence: A Discussion," J. Acoust. Soc. Am., 32, 1459-1462, 1960.

A brief summary of existing knowledge about sonoluminescence is given. Various theories of the origin of this luminescence are discussed. The author concludes that sonoluminescence is basically thermal in origin and that it might possibly arise from microshocks with collapsing cavities.

1790

Kuznetsov, F. O., N. N. Lebedev, I., Sh. Model, and V. A. Tsukerman "The Use of Coaxial Photocells for Recording Transient Light Phenomena," Instr. Exp. Tech., 5, 953-955 (Sept.-Oct., 1961; publ. Apr. 1962), 1961.

An FEK-01 photocell was used to study light phenomena in shock waves. In an oscillographic record, examples are shown of the propagation velocity and of the change in luminous intensity of the gas in a shock wavefront.

1791

Levine, R. C., "DeForest's Diffraction Microphone—Optical Detection of Sound in Air," J. Acoust. Soc. Am., 33, 1625-1626, 1961.

A theoretical analysis of a microphone which optically detects the changes in air density or index of refraction due to sound waves (Lee DeForest, U. S. Patent, 1,726,289; 1924). A light ray penetrates a thermal gradient in the air, and predicted deflection of the ray is approximately 3×10^{-5} cm per microbar sound pressure for a 300°K temperature change in a centimeter of path length.

1792

Lyon, D. A., "Some Geometry Associated with the Photographic Determination of Shock Front Velocity, I. Calculation of Shock Front Radius, II. A Method of Camera-Projector Calibration along a Single Image Line," Suffield Tech. Note No. 62, Suffield Experimental Station (Canada), 18 pp., 1962. AD-282 635.

Formulae are developed for calculating the radius of shock fronts created by chemical explosions and measured photo-optically, under the assumption that the fronts are spherical. A method is described for simultaneously calculating the shock front radius and calibrating the total optical system, both along the direction of a marker line and both from a single photo frame. No data are included.

1793

Murty, J. S., "Theoretical Investigation on the Diffraction of Light by Superposed Ultrasonic Waves," J. Acoust. Soc. Am., 26, 970-974, 1954.

An analytical treatment for the calculation of intensities of diffraction orders in a general case of superposed sound waves of frequencies in the ratio of 1:n and having any phase difference Δ is given, proceeding from Raman and Nath's simplified theory for normal incidence. Because of the integral harmonic relationship between the frequencies of the sound waves superposed, a particular order may contain a number of combination ones in addition to the orders due to the individual sound waves. Fues theory, which gives a single expression for the intensity of a combination line, cannot be applied to this case.

Expressions are obtained for the intensities of the diffraction orders in the two specific cases of even and odd values of n. In the case of diffraction by two sound waves of frequencies of the ratio 1:2k + 1, expressions for the intensities of the orders suggest symmetry in diffraction for all values of Δ. But, when the superposed frequencies are in the ratio 1:2k, the expressions suggest asymmetry in diffraction for all values of $\lambda\Delta$, except $\pi/2$. When $\Delta = \pi/2$, the diffraction is, however, symmetrical.

By using the expressions, the intensities of the diffraction orders obtained by two sound waves of frequencies in the ratio 1:3 superposed in three different phases, 0, $\pi/2$, and π, are calculated for the values of $\nu_1 = 1$ and $\nu_3 = 1, 2$, and 3.

1794

Ooura, H., "A Study on the Optical and the Acoustical Properties of the Snow Cover," International Union of Geodesy and Geophysics, Assoc. of Sci. Hydrology, Rome, 1954 (Transactions), 4, 71-81, 1956.

The snow cover does not always show perfectly diffused reflection (type E) for the incidence of light. There are the diffused specular reflection (type C) and another reflection (type A) such that the nearer 90° the angle of reflection, the higher the brightness of the snow cover becomes. By quantitative treatment, it was found that in reflection type E, the reflection from the deep places plays the main role while types C and A are due to the reflection from the shallow places whose depth is not more than ten times the size of the snow grain. The degree of polarization of reflected light for the incidence of the linearly polarized light increases with the angle of reflection and is nearly equal to the percentage of light reflected only at the boundary surface of the snow cover. The albedoes are in the range from 40 to 90%. The extinction coefficients in snow are in the range from 0.4 to 1.2/cm.

The relation between these values and the number of snow grains in unit volume was investigated. It was found that the sound wave propagates mainly in air among the snow grains with velocities about 180-300 m/sec. Velocity increases with the temperature and the grain snow surface is about 10-40% of the incident.

1795

Raizer, Yu., P., "On the Brightness of Strong Shock Waves in Air" (in Russian), Zh. Eksperim. i Teor. Fiz., 33, 101-109, 1957.

Considers the emission and absorption of light by a shock-wave front in air at high temperatures. Derives the dependence of its brightness upon the amplitude of the wave front.

1796

Raizer, Yu. P., "Glow of Air During a Strong Explosion and the Minimal Brightness Effect of the Fireball" (in Russian), Zh. Eksperim, i Teor. Fiz., 34, 483-493, 1958.

The optical properties of air below 6000° are considered. It is shown that the absorption and radiation of visible light at temperatures between 6000° and 2000° are due to the presence of the nitrogen dioxide formed in air at these temperatures. Some optical effects observed in strong explosions are explained on this basis, such as the glow of air in a shock wave at low temperatures (down to 2000°), separation of the wave front from the boundary of the fireball when the temperature of the front is close to 2000°, and also the peculiar effect of the fireball's minimal brightness.

1797

Resler, E. L., Jr., and M. Scheibe, "Instrument to Study Relaxation Rates Behind Shock Waves," J. Acoust. Soc. Am., 27, 932-939, 1955.

Describes an instrument which combines the schlieren technique, a photomultiplier tube and an oscilloscope in a manner that enables one to measure the density distribution behind shock waves (in gases) produced in a shock tube. From these measured distributions one can determine the way in which the gas or gases relax to equilibrium and the time it takes to reach equilibrium after the gas's enthalpy is suddenly increased a calculable amount in passing through the shock wave. The theory of the instrument is discussed and its predicted performance experimentally verified by measuring vibrational heat capacity relaxation times behind shock waves in CO_2 containing water vapor. The instrument in the reported tests demonstrated a sensitivity sufficient to record a change in atmospheric density of 1/2% over 1 mm distance and a space resolution of the density in the shock tube of 1/10 mm corresponding to times of the order of 1/10 μsec.

1798

Sanger, R., and F. Springer, "The Propagation of Explosion Waves through Supercooled Clouds" (in German), Z. Angew. Math. Phys., 6, 75-76, 1955.

The concentration of ice-crystals in a supercooled cooled cloud of water droplets was observed optically; no increase in the rate of crystallization occurred during or after the passage of a shock wave from the explosion of a small charge.

1799

Schlemm, H., "Schlieren Optical Investigation on Large-Amplitude Airborne Sound Waves in Tubes," Acustica, 10, 237-245, 1961.

A plane sound wave of large amplitude and low frequency becomes deformed in its passage along a pipe until a weak shock front is set up. The pressure jumps in the shock wave can be photographed by a schlieren method and measured on an oscillograph. The schlieren pictures also enable investigation of the characteristics of the wave front at an obstacle.

1800

Schmauss, A., "Visible Pressure Waves" (in German), Z. Meteorol., 1, 2-14, 1946.

Pressure and sound waves visible in the sky as bright and dark rings and stripes were observed in Germany during the First World War, and again in 1942-3-4. The waves originated in artillery, flak, incendiary bombs and other explosions. A number of accounts of actual cases of this kind observed by meteorologists, together with the accompanying meteorological conditions, are cited for each type of disturbance that would produce pressure waves, including accounts of pressure waves from planes in flight. The thermodynamic theory, the optical theory, the formation of clouds accompanying the waves, and the oscillations of ice crystals, etc., in the field of gravity are considered. The presence of clouds is not necessary, but increases the possibility of viewing the phenomenon.

1801

Tatarskii, V. I., "Criterion of the Applicability of Geometrical Optics to Problems of the Propagation of Waves Through a Medium Characterized by Slight Refractive Index Variations" (in Russian), Zh. Eksperim. i Teor. Fiz., 25, 84-86, 1953.

Ellison's method (J. Atmospheric and Terrest. Phys., 2, 14-21 (1951) is used for obtaining a more general criterion to establish the coincidence of wave-functions resulting from the solutions of the two fundamental equations involved. It is shown that conditions $\lambda << \ell$, and $\lambda L << \ell^2$ (where λ is the length of the propagated wave, ℓ is the mean size of inhomogeneities, and L is the path of wave in the inhomogeneous medium) are sufficient for ensuring the coincidence of both the amplitudes and phases in the geometrical and wave solutions.

1802

Temchenko, P. E., "Another Occurrence of Visible Propagation of Sound Waves in the Air" (in Russian), Priroda, 43, 113, 1954.

Describes a case of visible propagation of a sound wave at a height of 50-100 m produced by the explosion of German bombs and observed by the author, at a distance of 4-5 km, during a raid of enemy bombers on the outskirts of Kerch (S. Crimea) in April, 1944. Air waves, similar to waves produced in water into which an object has been dropped, emanated from the upper cupola-shaped part of a smoke column at the moment of its mushrooming and spreading in concentric circles. The sound of a heavy explosion was heard at the moment when the wave reached the point where the observer stood.

1803

Timnat, Y., and S. H. Bauer, "Investigation of Condensation Processes Behind Normal Shocks by Optical Methods — A Feasibility Analysis," Rept. No. CU-7356, Cornell Univ., Graduate School of Aeronautical Engineering, Ithaca, N. Y., 20 pp., 1962.
AD-274 515.

Detection of solid particles formed by thermal decomposition in a shock tube methods for determining the induction time for the initial condensation, the number of particles formed per unit volume, and their rate of growth are discussed; optical methods of detection seem most promising. The use of the index of refraction, the emissivity of light, and the amount of latent heat released are considered. Examples of substances proposed for study are C6H6, which yields C particles upon thermal decomposition in a mild shock; Pb (C2H5)4, which generated Pb particles as well as some C; and chromium carbonyl, which gives only Cr. The principles of light scattering by small particles, with their application to problems of condensation in a shock tube, are considered.

1804

Tsymbal, A. G., "An Instance of the Visible Propagation of Sound Waves Through the Air" (in Russian), Priroda, 44, 114-115, 1955.

This case of visible sound waves is unique in that it was observed under a cloud-free sky, was associated with reddish light, and the center of the wave was visible not at the place where the explosion had occurred but at points considerably elevated in the free atmosphere.

A diagram of the visible sound waves is presented.

1805

Vasil'ev, L. A., S. S. Semenov, and E. A. Tarantov, "Study of the Physical Processes in a Shock Tube with the Aid of High Speed Photography," Library Transl. No. 817 of Izv. Akad. Nauk SSSR, Otd. Teckn. Nauk, 186-188, 1957, Royal Aircraft Establishment, Great Britain, 7 pp., 1959.
AD-219 518.

A conventional Schlieren system coupled to a high-speed ciné camera is used to picture the flow once every 10 μsec, up to a total of 7600 frames; the frame size is 3.6 min by 4.8 min and the exposure frequency is constant to better than 0.2%. With high contrast film (γ = 0.7), it is shown theoretically and experimentally that effective photographic exposure times down to 5 μsec are possible. Since the transmission loss is 90%, an intense light source is necessary; a momentarily overloaded mercury discharge lamp is satisfactory in the present case.

Flow over a wedge-shaped model in a shock-tube working section is examined. Weak expansion waves are obscured somewhat by the self-luminosity of the flow. While flow is developing, variation of the oblique shock-wave angle occurs, attributable to relaxation processes; further variations are observed on passage of the contact region. The measured-flow Mach number (from shock angle) and measured density ratio across the shock wave may be used to determine the dissociation energy of the gas, and hence the ratio of its specific heats.

1806

Whipple, F. J. W., "On Phenomena Related to the Great Siberian Meteor," Quart. J. Roy. Meteorol. Soc., 60, 505-513, 1934.

Supplementary paper to 1930 work of this author. Air wave records are tabulated for additional European stations, as well as for Batavia and Washington. Barograms are reproduced. Records are discussed and the velocities of propagation of waves travelling in differing directions compared. Additional evidence is given regarding illumination of the sky during the nights following the meteor. A discussion, by S. K. Banerji, of shock waves is included, with equations.

Optical Effects and Techniques
See also—54, 60, 333, 590, 671, 740, 1193, 1194, 1208, 1234, 1305, 2034, 2050, 2376, 2403, 2404, 2412, 2453, 2820, 2827, 2849, 2972, 2982, 2984, 3010, 3023, 3115, 3178, 3272, 3463, 3506, 3512, 3582, 3644, 3765, 3770, 3772, 3787, 3821, 3833, 3853, 3982, 4013, 4032, 4042, 4048, 4051, 4059, 4063, 4079, 4106, 4115, 4118, 4121, 4126, 4127, 4136, 4137, 4138, 4398

PARABOLIC REFLECTORS

1807

Anderson, D. V., "Reflection of a Pulse by a Concave Paraboloid," J. Acoust. Soc. Am., 24, 324-325, 1952.

For the special case of a rectangular pulse, Friedlander has computed the variation in the amplitudes of the pulse reflected from a concave paraboloid, with the distance from the axis. These calculations indicate that, in addition to the maximum on the axis, a secondary pressure maximum is to be found at a distance of approximately 0.75 times the focal length from the axis. The author has observed this phenomenon experimentally, using a pulse frequency of 180 kcs and a repetition rate of 100 cps.

1808

Belle, T. S., V. M. Gorbunkov, and L. D. Rozenberg, "Calculating Amplification Factor in Inclined Incidence of a Sonic Wave on a Parabolic Reflector," Soviet Phys. Acoust., English Transl., 8, 214-219, 1963.

By employing a generalized Debye formula, the geometric aberrations and amplification factors were computed for points lying off the principal optical axis of a parabolic concave reflector. A nonhomocentric converging beam is considered as a homocentric beam, but with a phase aberration equivalent to its violation of homocentricity. Integration of the expression so derived is carried out in two ways: on the BESM-2 computer and on the MFTI analog computer.

1809

Buchholz, H., "Integral and Series Representations for the Different Types of Waves of Mathematical Physics in Axial-Parabolic Coordinates" (in German), Z. Physik, 124, 196-218, 1948.

Representations of the required form are found for standing waves and for outgoing waves of any harmonic type when the source is at the focus of the parabola. Plane waves and cylindrical waves are included as special cases. Representations are also obtained for an arbitrary position of the source.

1810

Chester, W., "The Reflection of a Transient Pulse by a Parabolic Cylinder and a Paraboloid of Revolution," Quart. J. Mech. Appl. Math, 5, 196-205, 1952.

A direct comparison is made between the reflection of a sound-pulse obtained with a body of revolution and the corresponding cylinder. The theoretical treatment yields general information as to the relation between the diffraction effects induced by two-dimensional and axially symmetric barriers. At the common junction of the incident wave front, the reflected front, and the barrier, the pulse discontinuity reproduces the familiar doubling of pressure obtained in regular reflection. In other directions the discontinuity tends toward zero inversely as the square root of the distance from the focus in the case of the parabolic cylinder, and inversely as the distance for the paraboloid of revolution. The excess-pressure distribution along the boundary is calculated when the incident pulse is a simple step function.

1811

Coile, R. C., "Parabolic Sound Concentrators," J. Soc. Motion Picture Television Engrs., 51, 298-311, 1948.

Discusses earlier work and reports on experimental verification of the theoretical acoustical directivity of parabolic concentrators, as well as on further checks of the amplification theory. The sound fields inside parabolic reflectors were also investigated experimentally; agreement was found with theoretical fields calculated by geometrical optics.

1812

Friedlander, F. G., "Reflection of Sound Pulses by Convex Parabolic Reflectors," Proc. Cambridge Phil. Soc., 37, 134-149, 1941.

Lamb's discussion of the reflection of a train of simple harmonic waves by a convex paraboloid of revolution and by a parabolic cylinder is extended to the reflection of the plane waves of arbitrary form. When a suitable time scale is introduced, the reflected wave is the same at all points on any paraboloid (or parabolic cylinder) confocal with the reflector.

1813

Friedlander, F. G., "On the Reflection of a Spherical Sound Pulse by a Parabolic Mirror," Proc. Cambridge Phil. Soc., 38, 383-393, 1942.

An application of a simple series solution of the wave equation to the reflection by a paraboloid of the revolution of a sound pulse coming from the focus of the reflector. Numerical results indicate that the convergence of the series is unsatisfactory except near the vertex of the mirror. The first seven coefficients of the series have been calculated, and investigation of the reflection of the simple rectangular pulse reveals that after some time a secondary pressure maximum is established at some distance from the axis. The results apply, to a certain extent, to a finite parabolic mirror.

1814

Obata, J., and Y. Yosida, "Acoustical Properties of Sound Collectors for Aircraft Sound Locator," Rept. No. 62, Aeron. Res. Inst., Tokyo Imp. Univ., 231-237, 1930.

The properties of two parabolic reflectors (diam 2 m, depth 46 cm and 35 cm) and two exponential horns (openings diam 84 cm and 35 cm, lengths, 300 cm and 100 cm respectively) are investigated. The sources of sound were valve generators for the lower frequencies and a dynamic cone loudspeaker for frequencies above 250. A condenser microphone and string galvanometer are employed in measuring the intensity of the sound. The directive property and magnifying power of the collectors are determined, and, for the parabolic reflectors, the distribution of intensity along the axis. In the case of the parabolic mirrors the directive properties are excellent, but the magnifying power is not large. A single horn is almost nondirective for low-frequency sounds, and for directional work two horns are required. The results are exhibited by means of polar graphs for the frequency range 185 to 485.

1815

Rocard, Y., "Parabolic Surfaces in Acoustics," Rev. Acoust, 1, 222-231, 1932.

A theoretical investigation into the ratio of the sound pressure produced around the focus of a parabolic surface by plane waves incident thereon to that existing at the same point in the absence of the surface. The analysis, which is subject to certain simplifying assumptions, shows that for this amplification to be maximal the aperture of the reflector should be twice its depth. The amplification produced when a source is placed at the focus of a parabola is also considered and a comparison is made between the author's theory and the experimental results obtained by others.

1816

Rozenberg, L. D., "On the Focusing of Sound Waves by a Parabolic Mirror" (in Russian), J. Tech. Phys. (USSR), 20, 385-396, 1950.

It is shown theoretically that for a given radius of the inlet opening of the paraboloid, maximum pressure amplification will be obtained for a mirror whose depth is equal to its radius, and whose focal distance (from the apex) equals 1/4 of its depth. Its absolute value = 2 kf log 5 = 0.8 ky. A further optimum condition is that the focus must be a zero of velocity.

1817

Sato, K., and M. Sasao, "Acoustical Properties of Parabolic Mirrors," Rept. Aeron. Res. Inst., No. 83, Tokyo Imp. Univ., 19-63, 1932.

The experiments were performed in a set of rooms that consisted of one heavily damped room communicating with another in which sound is generated by an organ blown from a constant-pressure device. The range of frequencies used extended from c^1 to a^4. The intensity of sound was determined by a Rayleigh disc with an appropriate resonator to which the sound was conducted by a long rubber tube. Three parabolic mirrors, of different curvatures and of 40 cm dia., constructed from aluminum 2 cm. thick, were used at about 6 m. from the above-mentioned aperture, and the incident waves were assumed to be approximately parallel. The following experiments were performed: (1) the fluctuation of intensity along the axis of the mirror was measured, and shows that very little focussing effect occurred for frequencies below c^4; (2) a determination of the effect of the curvature of the mirror was made; (3) the distribution of intensity in a plane perpendicular to the axis was observed and an involved interference pattern obtained; (4) the contour lines of equal intensity were plotted, and show that while for long wavelengths of interference effects are not very marked, a very complicated pattern could be obtained for such a frequency as c^4. Finally, the magnifying power of the mirrors was determined for different wavelengths; it is shown to increase with decreasing wavelength, and to be much smaller than that of a conical horn of the same opening and depth.

1818

Sato, K., and M. Sasao, "Acoustical Properties of Parabolic Reflectors," Rept. No. 93, Aeron, Res. Inst., Tokyo Imp. Univ., 339-356, 1933.

In continuation of experiments described in an earlier paper the authors have investigated the effect of the shape upon the directive properties of parabolic reflectors. Using several reflectors having different shapes but the same aperture, the variation of the intensity of the collected sound with the angle between the axis and the direction of a parallel beam of sound has been determined. Intensity measurements were made with a Rayleigh disc. It is found that the directive properties are much more marked for high frequencies than for low, and that, for a given diameter, it is little affected by the shape. For the same frequency there is little difference between the directive properties of a conical horn and those of a parabolic mirror. The magnification produced by the mirror is much smaller, however.

1819

Sato. K., and M. Sasao, "Directive Properties of Parabolic Reflectors," Proc. Imp. Acad. (Tokyo), 8, 407-409, 1932.

Reports experiments that used as reflectors three aluminum mirrors whose shapes differed but all of whose apertures were 40 cm in diameter, and as a receiver a small conical horn, three cm in diameter, mounted to a reflector at its focus. The apparatus rotates horizontally about the center of the opening, with a plane wave incident on the reflector.

The results of sound intensity measurements are shown by polar diagrams. For each of the four pitches used, the curves for each reflector are similar. Consequently, the directive property of the reflector depends only slightly on the shape if the diameter of the opening is constant. The effect is similar to that for a conical horn of the same diameter and depth for all the pitches used. The parabolic reflector, however, gives less magnification for a constant depth and opening and is thus, conversely, an inferior collector or radiator of sound.

1820

Sato, K., and M. Sasao, "Sound Field of Parabolic Reflectors," Proc. Phys. Math. Soc. Japan, 14, 363-371, 1932.
See Also: Proc. Imp. Acad. (Tokyo), 8, 281-283.

A train of sound waves was incident normally upon a parabolic mirror, and its field of sound intensity was investigated by means of a Rayleigh disc and resonator. Notes of five different pitches and mirrors of three different shapes were used, the experiments being performed in a soundproof chamber. Curves give the variation in intensity of sound along and at right angles to the axis of the mirror, and for two notes the general field of intensity was explored. It was found that when the wavelength of the note was short compared with the diameter of the opening, the sound energy was concentrated at the focus, while the intensity falls with increasing distance from the focus as the wavelength increases. With shorter wavelengths the pattern is similar to that for diffraction of light with a circular aperture.

1821

Slaymaker, F. H., W. F. Meeker, and L. L. Merrill, "The Directional Characteristics of a Free-Edge Disk Mounted in a Flat Baffle or in a Parabolic Horn," J. Acoust. Soc. Am., 18, 355-370, 1946.

To obtain a sharp supersonic beam with a parabolic horn, it was found desirable for the diaphragm feeding the horn to radiate most of its energy towards the walls of the horn rather than towards the mouth. This was done most effectively by diaphragm vibrating with two concentric circular nodes. An analysis is given of the vibration conditions and radiation diagrams of free-edge diaphragms with one, two, or three circular nodes, and disc diameters and thicknesses can be calculated to give any desired pattern at any frequency. Following these calculations, a one-circle node diaphragm was made which gave a satisfactory directional diagram.

1822

Vollerner, N. F., and M. I. Karnovskii, "Calculating the Concentration Coefficient of Some Directional Acoustical Systems," Soviet Phys. Acoust., English Transl., 5, 24-29, 1959.

Relationships between the coefficient of axial concentration and the coefficient of pressure amplification of acoustical systems possessing directivity, make it possible to calculate one of these coefficients when the other is known. Such relationships are very useful when direct calculation of one of these coefficients is considerably easier. The authors derive these relationships for axi-symmetrical parabolic and cylindrical concentrators.

Parabolic Reflectors —see also Horns; Lenses
see also—711, 718, 747, 748, 873, 1384, 1395, 1859

PRESSURE EFFECTS

1823

Angona, F. A., "Attenuation of Sound in a Tube," J. Acoust. Soc. Am., 25, 336, 1953.

An experimental method of measuring the attenuation of sound in a circular tube for gases at reduced pressures has been developed. Since the tube effect is inversely proportional to the square root of the pressure, a reduction in pressure increases the attenuation and thus increases the experimental accuracy. The tube attenuation was measured for the frequency over pressure ratio of 8 to 2000 kc/atm. The measured attenuation was found to be 4.5% greater than that predicted by the Kirchhoff formula.

1824

Antal, J., and A. Konig, "New Acoustical Method of Vacuum Measurement," Periodica Polytech., Elec. Eng., 1, 297-300, 1957.

An approximate theory and brief description are given of a method for measuring pressures between 1 atm and 5×10^{-2} mm Hg using sound energy whose frequency is between 500 and 10,000 cps; it is radiated from a loudspeaker and collected by a microphone provided with a voltmeter. The lowest measurable pressure is limited by the sound energy conducted through the walls of the enclosure.

1825

Boyer, R. A., "Ultrasonic Velocities in Gases at Low Pressures," J. Acoust. Soc. Am., 23, 176-178, 1951.

An ultrasonic interferometer with high sensitivity is used to measure acoustic velocities in gases at $0^{o}C$, as the wavelength approaches the mean free path of the molecules. Measurements are made of velocity as a function of pressure down to about two mm of Hg, the frequency being kept constant at approximately 970 kcs. The following increases in velocity (at the lowest pressures) over that at standard conditions were observed: A, 27%; N_2, 16%; O_2, 20%; and air free of CO_2, 7%.

1826

Broer, L. J. F., "Pressure Effects of Relaxation and Bulk Viscosity in Gas Motion," Appl. Sci. Res. A, 55-64, 1954.

A comparative study is made of the pressure effect of relaxation and bulk viscosity in stationary flow. It is shown that both stagnation pressure defects (Kantrowitz effect) and pressure distribution in small nozzles in principle constitute methods for distinguishing between the two theories. A discussion of the experimental data on carbon dioxide shows that in this case only the relaxation interpretation is possible.

1827

Caro, D. E., and L. H. Martin, "Velocity of Sound in Air at Low Pressures," Nature, 172, 363-364, 1953.

A significant increase in the velocity of sound has been reported below 15 cm Hg. New experiments are described; after correction, there is no variation of free-space velocity at 1000 and 250 cycles/sec, with pressure down to five mm Hg.

1828

Caro, D. R., and L. H. Martin, "The Velocity of Sound in Air at Low Pressures," Proc. Phys. Soc. (London) B, 66, 760-768, 1953.

Measurements of the velocity of sound in tubes have been made in air over a range of pressures extending down to five mm Hg at frequencies of 250 cps and 1000 cps. The method employed was to measure the time in transit of a sinusoidal pulse between two condenser microphones separated by a distance of approximately four meters. After tube and gas corrections were made it was found that the velocity was independent of pressure between five mm Hg and 760 mm Hg. The mean velocity obtained at $20^{o}C$ is 343.40 ± 0.02 meters per sec^{-1} which is in good agreement with the generally accepted value 343.42 ± 0.07 meters per sec^{-1} obtained by Hardy, et al. (1942), for dry air free from carbon dioxide. No evidence was found of the increase in velocity at low pressures observed by Abbey and Barlow (1948) and by Maulard (1949).

1829

Chalupnik, J., E. Rule, and F. Suellentrop, "Pressure Response of Condenser Microphones at Low Ambient Pressures," J. Acoust. Soc. Am., 33, 177-178, 1961.

The frequency response characteristics of condenser microphones at low ambient pressures are of interest when such microphones are used to make measurements on high-altitude rockets and capsules. Pressure response curves at a number of ambient pressures in the range 10^6 d/ cm^2 (atmospheric pressure at sea level) to 1.7×10^4 d/ cm^2 (atmospheric pressure at 90,000 ft. alt.) have been obtained for two commonly used condenser microphones (Western Electric 640AA, Bruel and Kjaer type 4111). Features of the response curves are discussed from a qualitative point of view.

1830

Colwell, R. C., and L. H. Gibson, "Sound Velocities in Gases Under Different Pressures," J. Acoust. Soc. Am., 12, 436-437, 1940.

With a rapid succession of soundpulses and an oscilloscope it is possible to measure the velocity of sound over short distances. This article reports experiments using a gas-tight metal container enclosing a loudspeaker and a movable microphone. The pulses sent out by the loudspeaker were received by the microphone and translated into a sine wave on the oscillograph. Measurements were made upon air, N, and CO_2 at different pressures. The velocity did not vary with the pressure.

1831

Dean, E. A., "Absorption of Sound in the Atmosphere," Proc. Symp. Atmos. Acoust. Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. M., 1, 50-56, 1961.
AD-408 716.

The classical and molecular theories of the absorption of sound for low f/p ratios are reviewed. The absorption is discussed as a function of frequency and atmospheric pressure, temperature, and composition, including recent work on the determination of the vibrational relaxation time due to small amounts of water vapor. The possible importance of absorption due to radiation is mentioned.

1832

Ellis, J. F., J. Scrivins, and J. S. Rowlinson, "The Behavior of a Sonic Analyser with Imperfect Gases," Rept. No. R&DB(CA) TN-99, United Kingdom Atomic Energy Authority, Great Britian, 4 pp., 1953.
AD-213 356.

The resonant frequency of a sonic analyser filled with an imperfect gas is found to fall as pressure increases above 250 mm Hg. This is shown to be due to the departure of the gas from the perfect gas laws. At pressures below 200 mm the frequency is lower than would be expected. No explanation of this is given. It is found that the response of the instrument is not truly linear over a frequency range of times 2 or greater.

1833

Henderson, M. C., and L. Peselnick, "Ultrasonic Velocity and Thermal Relaxation in Dry CO_2 at Moderate Pressures," J. Acoust. Soc. Am., 29, 1074-1080, 1957.

The velocity and absorption of ultrasound in dry CO_2 were measured along the 50.8^o isotherm with a Hubbard-type, variable-path, recording acoustic interferometer at six frequencies from 300 kcs to 7 mcs from 0.3 to 250 atm. (i.e., up to liquid densities). Velocity dispersion is clearly shown, in addition to the change in velocity attributable to the nonideality of the gas. The values of the frequency/density ratio f/ρ, at which the transition from $V_0{}^2$ to $V_\infty{}^2$ is half-completed as the pressure is lowered, and at which the maximum absorption per wavelength occurs, were measured whenever possible. From these determinations the relaxation time of the gas was determined as a function of the density. It proves to be inversely proportional to the density up to the highest density reached (0.8 g/ml), indicating that ternary collisions have not become important and that the number of binary collisions required to excite the internal vibrations does not vary with density. At 50.8^o and 1 atm. the relaxation frequency $1/2\pi\tau$ is about 26 kcs and the number of collisions required to excite the molecule is 48,500. The extra absorption (in excess of the classical) remains a consequence of thermal relaxation up to liquid densities, and no new mechanism need be postulated to explain it. Further work at higher densities and other temperatures is in progress.

1834

Hodge, A. H., "Ultrasonic Velocity in Gases between 1 and 100 Atmospheres," J. Chem. Phys., 5, 974-977, 1937.

An acoustic interferometer of the resonator, or driven, type has been developed for the study of the behavior of ultrasonic waves in gases under pressures ranging from vacuum to several hundred atm.; measurements of acoustic velocity at several frequencies and in several gases at pressures ranging from 1 to 100 atm. have been made. Increase of velocity with pressure was found for air, N_2, He, and H_2, and a decrease for CO_2, with approximate pressure and velocity ranges as follows: air, 1-101 atm., 347-371 m/sec; N_2, 1-102 atm., 353-380 m/sec; CO_2, 1-63 atm., 270-198 m/sec. The He and H_2 were known to be impure. For them an increase in velocity nearly linear with pressure was found. Using frequencies from 88 to 499 kc, dispersion was found for CO_2, at atmospheric pressure, but almost entirely disappeared above 8 atm.

Demonstrates availability of this method for indirect determination of specific heats.

1835

Horiuchi, I., "Absorption of Sound in Air at Very Low Densities," Tech. Rept. No. 11, Columbia Univ., New York, 1958.
AD-201 133

The "super-Burnett" approximation to the Boltzmann collisional equation has been applied to the evaluation of the absorption of sound in air at low densities. The solutions which were obtained on the REAC analogue computer yield magnitudes somewhat smaller than were obtained by successive approximation methods. A maximum absorption per wavelength of μ = 1.45 was obtained for diatomic molecules. Comparison of the translational absorption with that due to rotational and vibrational degrees of freedom shows that it becomes predominant at ratios of frequency to pressure exceeding 100 Mc/atm.

1836

Hubbard, J. C., and A. H. Hodge, "Ratio of Specific Heats of Air, N_2, and CO_2 as a Function of Pressure by the Ultrasonic Method," J. Chem. Phys., 5, 978-979, 1937.

Hodge has made measurements of ultrasonic velocities at 27^{o}C and pressures from one to 100 atm in air and N_2, and at one to 60 atm in CO_2. The results for air and N_2 combined with the respective compressibility data of Holborn and Otto for air at 27^{o}C give values of γ between 1.406 at one atm and 1.580 at 100 atm, and for N_2, 1.403 at one atm to 1.564 at 100 atm. The acoustic velocities in CO_2 combined with the compressibility data of Amagat, give for γ at 27^{o}C values from 1.304 at one atm to 3.524 at 60 atm. These and the other results between these limits are in excellent general agreement with the few findings available for comparison.

1837

Jha, S., "On the Variation of the Velocity of Sound with the Pressure of the Gas," Bull. Patna Sci. Coll. Phil. Soc., 13, 148-154, 1943.

The velocity of sound in a perfect gas is $(\gamma p/\rho)^{1/2}$, and for real gases this is multiplied by a factor ϕ. Expressions for this factor are derived from the virial equations of state proposed by Kamerlingh Onnes, and values of ϕ are tabulated for H_2, O_2, and C_2H_4 at 0^{o}C.

1838

Keesom, W. H., A. van Itterbeek, and J. A. vanLammeren, "Velocity of Sound in Oxygen Gas," Commun, 216d, Communs, Phys, Lab., Univ. Leiden, 996-1003, 1931.

By a method previously described the velocity of sound in oxygen gas is determined at 0^{o}C and at temperatures between 164.63^{o}K to 77.48^{o}K, and at pressures between 0.1 and 1.0 atm. From the results c_p and c_v and their ratio c_p/c_v are determined. By extrapolation, the value of this ratio at zero pressure is obtained at various temperatures, and is found to be always slightly greater than 1.400. Whether or not this small deviation indicates a departure from classical dynamics cannot, however, be decided at present. If W is the velocity of sound, p the pressure, N, P, Q functions of temperature only, then $W^2 = N(1 + Pp + Qp^2)$. Values of N, P and Q are tabulated. The variation of W with pressure is not so great as in the case of hydrogen. From N is deduced a formula for the temperature variation of the second virial coefficient.

1839

Kneser, H. O., and O. Gauler, "Propagation of Sound in Partly Dissociated Gases," Physik. Z., 37, 677-684, 1936.

The velocity of sound in a partly dissociated gas is calculated, and the influence of pressure, temperature and frequency examined. The results are compared with measurements made upon N_2O_4. It is found that the behavior of this gas depends markedly upon its temperature. The measured and the calculated variations of velocity with pressure are found to agree well.

1840

Linsay, R. B., "Transmission of Sound Through Air at Low Pressure," Am. J. Phys., 16, 371-377, 1948.

The problem is treated in terms of relaxation dissipation. Consideration is given to (1) wave propagation with relaxation dissipation; (2) viscosity and heat-conduction dissipation; (3) classical approximation for very high frequency. Experiments are described in which transmission loss is measured in a low-pressure tank, at 384-6950 cps. Over the pressure (atmospheric to 5 mm of Hg) and frequency ranges employed, the absorption due to viscosity and heat conduction is negligible (in agreement with the theory). The pressure tank measurements indicate increasing impedance mismatch (transmitter-medium-receiver) with decreasing pressure.

1841

Maulard, J., "On the Velocity of Sound in Air at Low Pressures" (in French), Compt. Rend., 229, 25-26, 1949.

It is observed experimentally that below pressures of 15 cm of Hg the velocity of sound in air increases according to an exponential law. The velocity is constant from atmospheric pressure to 15 cm Hg; at ten cm of Hg the velocity is 1.5% higher, and at four cm of Hg it is 4% higher than at atmospheric pressure. The measurements of velocity were made in a steel tube 2,743 cm long and of eight cm internal diameter, buried in the earth at a depth of 50 cm to maintain constant temperature conditions.

1842

Olson, W., J. Patterson, and J. Williams, "The Effect of Atmospheric Pressure on the Reflected Impulse from Air Blast Waves," BRL Memo. Rept. No. 1241, Ballistic Research Laboratories, Aberdeen Proving Ground, Baltimore, 25 pp. 1960.
AD-234 998.

Reports measurements of reflected impulses in air blast waves generated by explosive spheres (up to one pound in weight) detonated under reduced ambient pressures simulating altitudes up to 100,000 ft. (8 mm of mercury). Analysis reveals that the data may be scaled according to Sachs' law.

1843

Parbrook, H. D., and E. G. Richardson, "The Propagation of Ultrasonics in Gases under Pressure" (in French), Portugaliae Phys., 3, 127-138, 1954.

Measurements of ultrasonic velocity in carbonic acid and ethylene have been made using an interference method. The viscosities have also been measured, using the oscillating cylinder method, and the values compared with ultrasonic viscosities calculated according to the Stokes equation. The velocities at various temperatures show sharp minimal turning points in the region of 60-90 atm. (approx.) while the two viscosities become minimal in roughly the same pressure range. From these and other observations the authors conclude that a thermal relaxation process might account for the anomalous behavior. The paper is noteworthy for the extreme care which has been taken in the experimental work; for instance, the quartz crystal and the reflector are lined up by the Michelson interferometer method, and it is evident that the results are of a high order of accuracy.

1844

Pekeris, C. L., "Propagation of Sound in a Rarefied Maxwellian Gas," Inst. of Geophysics, Univ. of Calif., Los Angeles, 7 pp., 1953.
AD-23 611.

A study was made of the dispersion and attenuation of sound in a monoatomic gas with a density for which the mean free path is comparable to or exceeds the wave length of sound. The data on the propagation of sound in He at pressures of 1 mm and less required the solution of Boltzmann's complete transfer equation. Secular determinants of order 5, 8, 12, and 20 were evaluated in an effort to determine the phase velocity and attenuation coefficient. For each determinant order, the propagation constants were solved from the polynomial of the same degree representing the determinant; the polynomial roots were determined numerically. The results appeared to show that with a determinant of order 20, the computed values for the propagation constants is reliable for R greater than about three, where R is proportional to λ / L, the ratio of the wave length of sound to the mean free path. Graphical results are included for the determinant of order eight. Calculations are in progress for the determinant of order 30.

1845

Pekeris, C. L., Z. Alterman, and L. Finkelstein, "Solution of the Boltzmann Hilbert Integral Equation Propagation of Sound in a Rarefied Gas," Tech. Note No. 1, Weizmann Inst. (Isreal), 10 pp., 1961.
AD-268 193.

The Boltzmann-Hilbert integral equation is solved for the problem of propagation of sound in rarefied Maxwell gas, using the eigenfunction method (Uhlenbeck and Wang Chang). Determinants up to order 483 have been solved, and the results converge to wavelengths equal to the mean free path. The results agree with Greenspan's measurements of the propagation of sound in rarefied Helium.

1846

Pumper, E. J., "Change of Velocity of H. F. Sound with Pressure" (in German), Physik. Z. Sowjetunion, 1, 300-310, 1935.

Reports measurements of the variation in the velocity of sound in dry air and CO_2 as the pressure is varied with sound having a frequency of 4.4×10^4~. The velocity increases with decreasing pressure—a change of 0.65% in the case of air and 2.2% in the case of CO_2 for a changein pressure from atmospheric to 1/50 atmosphere. Possible explanations of the results are discussed.

1847

Pusat, N., "The Velocity of Sound in a Real Gas as Function of the Pressure," Rev. Fac. Sci., Univ. Istanbul, Ser. A, 17, 46-60, 1952.

The formula for the velocity of sound in a real gas that shows a relaxation mechanism was calculated as function of pressure and frequency. This formula has been discussed specially for CO_2. The velocity of sound in the vapor of ethyl-formate was measured with an acoustical interferometer, and the theoretical conclusions were applied to the results. A mechanism of relaxation was found with a characteristic time constant of 1.9×10^{-8} sec, calculated for one atm pressure.

1848

Railston, W., and E. G. Richardson, "Effect of Pressure on Supersonic Dispersion in Gases,"Proc. Phys. Soc. (London), 47, 533-542, 1935.

Measurements of wavelengths by interferometer and hot-wire methods, and of absorption by hot-wire methods alone, have been made for supersonic radiation at frequencies between 40 and 2000 kcs in CO_2, N_2O and SO_2 at various pressures up to 2 atm. For the hot-wire method, a circuit which gives a linear relation between amplitude or particle velocity and response at constant frequency is described. The velocity-measurements in the two former gases may be reduced to a common curve by plotting them against the parameter (f/p). Although the observed velocity rise in the region where this parameter lies between 100 and 1000 is in accordance with the relaxation-time theory, the decrease in velocity at lower and higher values is not. In SO_2 the rise of velocity is in the neighborhood of 4000. The absorption in all three gases rises sharply at pressures below 400 mm of mercury.

1849

Richards, W. T., "Acoustical Behavior of a Gas with Several Independent Internal Energy States," J. Chem. Phys., 1, 863-879, 1933.

The method founded by Einstein for the description of the acoustical behavior of a dissociating gas has been extended to cover a nondissociating gas in which five groups of internal energy states have different relaxation times. Since the resulting expressions are unwieldy, approximations based on them, which permit the rough description of experiments, have been given. The study of the variation in the velocity of sound with frequency demonstrates differences in the relaxation times of the various states. The variation in the velocity of sound with pressure shows additional effects from three-body collisions or from radiation from optically active states. It has been suggested that the temperature coefficient of the kinetic relaxation time be treated by introducing an empirical quantity that may be called "the activation energy of collision." By this means a rough kinetic analysis of the probability of transition is possible. In gaseous mixtures, the relative spatial and energetic effectiveness of various types of collisions in exciting internal energy may be compared.

1850

Schultz, T. J., "Effect of Altitude on Output of Sound Sources," Noise Control, 5, 17, 1959.

Curves are presented to show the variation with altitude of the acoustical output of several types of sound source. Theoretical justification of the curves is given.

1851

Smith, P. W., Jr., "The Velocity of Sound at Reduced Pressures," J. Acoust. Soc. Am., 23, 715, 1915.

A summary of a paper by Abbey and Barlow that describes measurements on the sound velocity in gases at one kcs and pressures between atmospheric and several mm of Hg. An acoustical feedback method was used from a dynamic speaker at one end of the tube containing the gas to a movable crystal microphone at the other end. Results are given for air, N_2, CO_2, O_2, and CH_4.

1852

Turner, E. G., "Equilibrium Hydrodynamic Variables Behind a Normal Shock Wave in Hydrogen," Rept. No. GM-TR-0165-00460, Space Tech. Labs., Inc., Los Angeles, Calif., 14 pp., 1958.
AD-265 351.

A complete calculation of the hydrodynamic variables for shock Mach numbers up to and beyond the point at which hydrogen becomes completely ionized is prescribed. A set of curves for initial pressures of 0.001 and 0.01 atm was calculated in February, 1957. Recent experimental work at lower pressures has made it necessary to revise the original calculations with the addition of a set of curves for 0.0001 atm of initial pressure. The curves include density ratio across the shock wave, the temperature behind the shock wave and the degree of ionization. The first graph runs from a shock Mach number of one to 70 while the second graph continues from a shock Mach number of 60 to 200, a region where the hydrogen may be considered completely ionized.

1853

van Itterbeek, A., and J. Zink, "Measurements on the Velocity of Sound in Oxygen Gas Under High Pressure," Appl. Sci. Res. A, 7, 375-385, 1958.

Using the acoustical interferometer for high pressures described in an earlier publication, the velocity of sound in oxygen gas between one and 70 atm was measured as a function of pressure at different temperatures. From the experimental data the change of the ratio of the specific heats and the specific heats themselves, as a function of pressure at the different temperatures, were calculated.

1854

van Itterbeek, A., and P. Mariens, "Velocity and Absorption of Sound at Ordinary and Low Temperatures," Physica, 4, 609-616, 1937.

The absorption and velocity of sound in O_2, and H_2 and, CO have been measured as a function of pressure and temperature. The relaxation time for O_2 is calculated and found to vary inversely as the pressure at a temperature of about 13° C. A departure from this law occurs at higher temperatures; at low temperatures, the absorption coefficients are higher than those predicted by the classical formula. As in earlier measurements, absorption in H_2 is found to be very high. The absorption in this gas is unaffected by increasing the concentration of parahydrogen. Measurements made in CO, for which the vibrational energy is small at ordinary temperatures, also show deviations from the classical formula.

1855

van Itterbeek, A., W. de Rop, and G. Forrez, "Measurements on the Velocity of Sound in Nitrogen Under High Pressure," Appl. Sci. Res. A, 6, 421-432, 1957.

Using an acoustical interferometer for high pressures, the velocity of sound was measured in nitrogen gas between one and 75 atm as a function of pressure and at different temperatures. The experimental data are compared with direct measurements on the equation of state of nitrogen gas. From the experimental results for the velocity, the change of the ratio of the specific heats and the specific heats themselves were calculated as a function of pressure, and at different temperatures.

1856

Vereshchagin, L. F., N. A. Yuzefovich, and A. V. Cheloviskii, "Measurement of the Speed of Ultrasound in Some Gases in a State of High Density," Soviet Phys. Doklady, 1962.

The results of measurements of the speed of ultrasound (3.5 Mc/sec) in nitrogen, argon, and helium at pressures up to 3500 atm are presented graphically. The coefficients of adiabatic heats for nitrogen as a function of pressure, computed from the results, are also shown graphically.

1857

White, C. E., "Report on Effect of Increased Atmospheric Pressures upon Intelligibility of Spoken Words," Memo. Rept. 55-8, Naval Medical Res. Lab., New London, Conn., 8 pp., 1955.
AD-85 597.

An investigation was undertaken to determine the extent of change in the human voice caused by increased atmospheric pressures in the range from 14.7 to 103 psi. Under conditions described in the report, articulation showed a loss of 24.7% using phonetically balanced, monosyballic word lists at a signal-to-noise ratio of 30 db.

Pressure Effects
See also—61, 70, 71, 100, 102, 148, 150, 152, 161, 214, 480, 520, 592, 794, 1071, 1106, 1120, 1134, 1143, 1146, 1244, 1334, 1362, 1708, 1709, 1748, 1800, 1918, 1961, 2277, 2422, 2628, 2677,

PRESSURE EFFECTS

2759, 2983, 3049, 3064, 3135, 3169, 3417, 3456, 3801, 4048, 4082, 4105, 4134, 4248

PUBLIC ADDRESS

1858

Army Airborne, Electronics and Special Warfare Board, "Desert Test of High Powered Voice Amplifier SYS 1492C," Proj. No. CE 2261, Fort Bragg, N. C., 5 pp., 1962. AD-286 406.

High powered Voice Amplifier SYS 1492C, the test item, is a portable, transistorized public address set for distant projection of sound. The system is designed for operation from aircraft to ground and from point to point over land and water. It is packaged for transport by one man and for quick assembly at operational sites. The rated output is 250 watts of audio power from each of the two amplifiers. Two amplifiers are mounted side by side on one-half of a folding aluminum tubular framework. Two nickel-cadmium batteries and a reel of 100-foot cable for remote control are mounted on the other half. This assembly weighs 72 pounds. Four horns are provided with the system. Each horn contains two 75-watt drivers. A remote control is provided for parallel operation of two amplifiers from a single signal source. Power is furnished by the two nickel-cadmium batteries, or a 28-volt aircraft battery, or a 24-volt vehicle battery. The system has a range of approximately one mile.

1859

Army Electronic Proving Ground, "Audio Pickup and Recording," Rept. No. AEPG-SIG 960-34, Army Electronic Proving Ground, Fort Huachuca, Arizona. 46 pp., 1958. AD-215 370.

Presents information on recording public-address system broadcasts at distances beyond those at which intelligibility is possible with the unaided ear. Tests were conducted to determine the factors influencing such recording, and to quantitatively evaluate these factors. Parabolic acoustical reflectors and standard U. S. Army public-address, recording, and test equipments were used. Four major factors were established as affecting long-range recording: broadcast power, propagation-path attenuation, method of signal reception, and background noise. Included are curves that present intelligibility variations with changes in meteorological conditions, distances, public-address radiation patterns, and recorder locations. A method is presented with which to estimate maximum recording distances and minimum intelligibility. It was concluded that intelligible information can be recorded at approximately three times the distance at which intelligibility is possible for the unaided ear, if proper receiving and recording equipment is used.

1860

Arnold, J. S., and A. Picker, "The Modification of a Warning Siren to a Modulated Airstream Loudspeaker," Final Tech. Rept., Stanford Res. Inst., Menlo Park, Calif., 83 pp., 1961. AD-272 937.

The feasibility of modifying a warning siren to add speech capability was demonstrated by adding a modulated airstream loudspeaker to the siren. The siren's air supply and control circuit were used by the loudspeaker, with appropriate auxiliary equipment and minor modifications of the existing siren. Using a recorded-speech input, an average sound pressure level of 117 db was achieved on the horn axis at a distance of 100 ft. At a distance of 675 ft (limited by terrain) observers reported that the sound was loud, clear, and intelligible. Extrapolation of the data indicates that speech is intelligible within a maximum range between one and two miles, depending on ambient noise and other conditions.

1861

Baker, J. C., "Aircraft Public Address System Operation Under High-Level Ambient Noise Conditions," J. Audio Engineering Society, 1, 216-220, 1953.

This paper outlines the reasons for and the requirements of good public address systems in airplanes. A résumé of the pertinent characteristics of speech and hearing is provided, as well as a discussion of the sources and characteristics of flight noises and their effects on speech communication, and an outline of the possibilities of noise reduction and developments to date. Presents the necessary qualifications for satisfactory operation of each of the system components in high-level noise fields, and points to the need for further tests and development.

1862

Beranek, L. L., "Sound Systems for Large Auditoriums," J. Acoust. Soc. Am., 26, 661-675, 1954.

This paper gives a comprehensive review of the design of sound systems for large auditoriums. It covers the following subjects: (a) When is a sound system necessary?; (b) Ambient noise effects; (c) Reverberation effects; (d) Classification of sound systems; (e) Behavior of direct-radiator, multi-cellular, acoustic lens and "column" types of loudspeakers; (f) Psycho-acoustic considerations (g) Naturalness; (h) Loudspeaker arrangements; (i) Sound system in the large hall of the University City in Caracas, Venezuela; (j) Sound system in Plenary Hall of the United Nations Headquarters, New York City; (k) Stereophonic sound system in a municipal theatre; (l) Distributed "column" sound system in the Holy Cross Cathedral; and (m) Tests for evaluating sound systems.

1863

Bolt, Barenek, and Newman, Inc., "Capabilities and Limitations Investigation of Long-Range Public Address Equipment," Rept. No. 466, 1957. AD-136 319.

This report describes an investigation of the several parameters which affect and limit long-range public address. Relevant micrometeorological, terrain and equipment problems are discussed. A careful analysis of experimental and calculated data is presented. This analysis is aimed at developing a standard calculating procedure for use in the field by loudspeaker-team leaders to predict public-address system performance in any given environment.

1864

Bolt, Beranek, and Newman, Inc., "Capabilities and Limitations of Long-Range Public Address Equipment," Rept. No. 493, 1957. AD-136 320.

As the concluding final report, Phase Five of the present study, this report presents a calculation procedure which is basically designed to enable a loudspeaker-team leader in the field to predict with a high degree of probability the success or failure of his assignment to cover a given target area with intelligible speech.

After the introductory material of Chapter 1, there is presented in some detail in Chapter 2, (without justification, for the time being) the proposed Field Calculation System.

In Chapter 3, there is a discussion of the necessary procedures for validating the Calculation System before putting it to use by the military.

Chapter 4 contains recommendations relevant to the set of special micrometeorological instruments which is necessary for using the Calculation System in the field. Chapter 5 discusses the necessary loudspeaker modification.

A detailed justification of the proposed calculation scheme is presented in Appendix A, together with the necessary firing maps, alignment charts and tables..

1865

Bolt, Beranek, and Newman, Inc., "Capabilities and Limitations Investigation of Long-Range Public Address Equipment, Construction of Instrumentation Facility," Final Rept. on Phase III, 1956.
AD-125 835.

This report discusses in detail the construction and operation of a transportable instrumentation facility, housed in a standard Army V-51, 26-ft van powered by a standard Army PE-95, 10-kw power unit and a standard Army 2-1/2 ton tractor. It was designed to support a program of gathering fundamental data for study of the transmission of speech over long distances over ground.

Chapter 1 reviews some of the basic considerations and other factors governing the design of the facility. Chapter 2 discusses the complete data-taking facility in more detail. Chapters 3 through 12 describe in detail the various components, such as the Sound Radiating System, the Sound Receiving System, the Temperature and Wind Speed Gradient Measuring Systems, the Thermistor, Vane, and Cup Anemometer Turbulence Measuring Equipment, the 24-Hour-Per-Day Meteorological Equipment, Power Supplies, and Miscellaneous Facilities. Suggested operating procedures for the different systems are given in Chapter 13. Chapter 14 gives technical data such as wiring diagrams, schematics, and maintenance instructions. The techniques used in calibrating the different transducers, such as loudspeakers, microphones and windscreens, weather vanes, and thermistor and cup anemometers are discussed in Appendix A.

1866

Bolt, Beranek, and Newman, Inc., "Capabilities and Limitations Investigation of Long-Range Public Address Equipment, Establishment of a Test Technique and Instrumentation Complement," Final Rept. on Phase II, 1955.
AD-112 304.

In Chapter 1 are articulation scores directly obtained in the field by a small group of observers. The speech signal was generated by a loudspeaker mounted about ten feet above ground. The speech material consisted of phonetically balanced word lists. To aid in interpreting the data the characteristics of the path of transmission were explored as a function of meteorological conditions and distance, using bands of thermal noise and sweep tones radiated from the loudspeaker.

Chapter 2 contains a critical evaluation of the results of the field tests. The excess attenuation of the path of transmission, measured by using octave bands of noise, is compared with the attenuation predicted by existing transmission theories. Concomitantly, a comparison is made between the measured articulation scores and those predicted from theory using the concept of the Articulation Index.

In Chapter 3 a discussion is presented regarding the relevant parameters describing the state of the atmosphere near the ground and the instruments for their measurement. Based on this discussion, on the experience gained in the preliminary field tests, and on the results obtained from them, detailed design plans for a transportable instrumentation facility are given.

1867

Bolt, Beranek, and Newman, Inc., "Capabilities and Limitations Investigation of Long-Range Public Address Equipment, Literature Search and Preliminary Theoretical Analysis," Final Rept. on Phase I, 15 July 1954-31 May 1955, 126 pp., 1955.
AD-68 943.

Research was undertaken to determine the capabilities and limitations of long-range public address equipment for the transmission of intelligible speech under varied meteorological and terrain conditions for ground psychological warfare operations. Discusses the physics of the propagation of sound through the atmosphere over long distances, the factors affecting the intelligibility of speech (level, bandwidth, masking, and distortion), and the variability of experimental data. Also presents an analysis of long-distance speech transmission over ground; the analysis discusses the source and transmitted signal, the path of transmission through the atmosphere, and the observer and his perception of the received signal. The two bibliographies concern the propagation of sound through the atmosphere and the perception of speech.

1868

Caldwell, J., Jr., and F. C. Fischer, "Design and Development of a Droppable Loudspeaker," Cook Electric Co., Skokie, Ill., 1953-1955.

This series of reports covers the design, development and testing of a high-power speaker-amplifier system capable of being dropped by parachute from high-speed aircraft to radiate intelligible speech to areas on the ground during descent. The complete system is dropped in a bomb-like container which holds brake and final parachutes, a tape playback unit, amplifiers, power supply, horn driver, horn, and deployment control devices. The reports describe in detail the engineering progress, construction and testing that led to the completed system.

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	6 - 1 Apr - 1 May 54	AD-43,137
	7 - 1 May - 1 June 54	AD-48,265
	8 - 1 June - 1 July 54	AD-48,264
	9 - 1 July - 1 Aug 54	AD-50,952
	10 - 1 Aug - 1 Sept 54	AD-56,114
	11 - 1 Sept - 1 Oct 54	AD-55,810
	12 - 1 Oct - 1 Nov 54	AD-60,893
	13 - 1 Nov - 1 Dec 54	AD-60,230
	14 - 1 Dec 54 - 1 Jan 55	AD-66,401
	15 - 1 Jan - 1 Feb 55	AD-66,403
	16 - 1 Feb - 6 Mar 55	AD-66,402
	17 - 6 Mar - 6 Apr. 55	AD-66,531
	18 - 6 Apr - 1 May 55	AD-76,332
	19 - 1 May - 1 June 55	AD-76,333
	20 - 1 June - 1 July 55	AD-76,331
	21 - 1 July - 1 Aug 55	AD-76,334

1869

Densberger, P. J., "Development of a New Flight-Deck Loudspeaker for U. S. Navy Aircraft Carriers," J. Audio Eng. Soc., 4, 138-144, 1956.

A new flight-deck loudspeaker for use in a highly noisy environment was developed, with the following factors as design criteria: (1) Size, weight, number, and configuration of loudspeaker components consistent with ruggedness requirements for shipboard use; (2) the audio-input power required and the manner of distribution of this power to the loudspeaker system; (3) the length of cable runs and the number required; (4) size of the flight deck; (5) a method of installation without jeopardy to flight operations; (6) ease of servicing and reliability.

1870

Hedrick, R. L., "Development of Public Address Set AN/UIH-3 (XC-2)," Quart. Progress Rept. No. 5, Stromberg-Carlson Co., Rochester, N. Y., 11 pp., 1957.
AD-153 979.

A satisfactory breadboard model was constructed of an UIH-3(XC-2). The design employed semiconductor rectifiers and compact output tetrodes. For conversion from dc to ac power, transistorized inverters were used instead of bulky dynamotors. The low harmonic distortion of the model (0.9% at 100 c, 0.7% at 1000 c, and 0.8% at 10,000 c, at full power output) was attributed to the application of a feedback theory in which negative feedback was applied to each stage of the amplifier individually before being applied in multistage feedback loops. The design surpassed all specifications of the plan. A reduction in size and a high reliability were achieved by the exclusive use of silicon power diodes.

1871

Hedrick, R. L., "Development of Public Address Set AN/UIH-3 (XC-2)," Quart. Progress Rept. No. 6, Stromberg-Carlson Co., Rochester, N. Y., 1958.
AD-158 033.

The work accomplished during the period covered by this report is the detailed design of the electrical circuits and mechanical layout of the equipment. In the electrical design of the amplifier, a smooth frequency response and a harmonic distortion below the maximum specified by Technical Requirement SCL-1682 have been achieved. The improved electrical characteristics and the use of fewer components have been achieved by eliminating stages in the power amplifier and in the power supply. Improvements in the blower system design and the reduction of the number of components in the system has eliminated several of the anticipated blowers and reduced the size of those remaining.

Efforts in the design of a transistorized power supply to operate from a DC source has brought to light several very serious and difficult problems to be solved when working at such high levels of power. Considerable success has been achieved in the solution of these problems. Construction of the preliminary service test model is in progress. Modification of the electrical circuits have improved the performance and increased the reliability of the proposed design. The detailed mechanical design is complete.

1872

Hilliard, J. K., and W. T. Fiala, "Electro-Pneumatic Air Modulator for Fog Signals," Rept. No. 6-2-1, United States Coast Guard, Washington, D. C., 11 pp., 1960.
AD-242 094.

A highly directional electro-pheumatic, air-modulated loudspeaker was designed. It is capable of radiating speech or any type of warning signal in the 100-c to 1000-c range. Tests were conducted to delineate the directional qualities of the sound generator, both in absolute terms and in practical navigation. In these tests, 200-c and 400-c warbled tones, plus a voice signal, were compared with a standard diaphone fog signal.

The electro-pneumatic equipment used for the tests included a single unit consisting of four air-modulated loudspeakers driving an exponential horn six ft. in length, with a mouth cross-section of four sq. ft. Voice signals were generated by two air-modulated loudspeakers mounted on an Altec-Lansing 1003 multicell horn with a cutoff of 200 c.

A shadow zone was established in the upwind direction which fully substantiated the effect of sound over water as described by Francis M. Weiner (AD-242 087).

1873

Marine Corps Development Center, "Public Address System AN/TIQ-7 and AN/PIQ-2( )T1," Test Repts., U. S. Marine Corps Development Center, Quantico, Va., 1954.
AD-37 470.

An evaluation was made of the two public address systems. The AN/TIQ-7 is a lightweight, portable, modulated-air-stream sound-amplification system designed for projecting speech over the 300-yd to one-mile range; the set consists of a power unit modified to operate an air compressor in addition to its normal generator load, a small audio amplifier, a speaker head and horn, and accessories. The AN/PIQ-2( )T1 is a portable, electric sound-amplification system designed for field and amphibious use; the set, which operates from either a six-volt battery of a 115-volt, 60-c source, includes a ten-watt amplifier, a storage-battery pack for remote field operation of the amplifier, a loudspeaker, a microphone, and the necessary interconnecting cable. Results of the following tests are compared: physical characteristics, portability, ease of installation, range and directivity, intelligibility, interference, vehicular and helicopter installation, adequacy of power supply, versatility, electrical and mechanical failures, ease of maintenance, spray effects, immersion proofness, high- and frigid-temperature performance, and ruggedness.

The TIQ-7 and PIQ-2 were considered to possess no significant advantages over public-address sets presently available to the Marine Corps.

1874

Oliveros, E. V., "Amplifier-Loudspeaker Equipment Designed for Non-Tactical Applications," Material Lab., New York Naval Shipyard, Brooklyn, 1957.
AD-156 655.

Performance specifications were developed for amplifier loudspeaker equipment for use in protected areas aboard ships or in naval installations ashore. Prototypical equipment constructed to demonstrate the feasibility of the specifications met the requirements in all but two minor respects. The maximum permissible power comsumption was exceeded by 0.4 db. The amplifier was capable of delivering undistorted power of more than six watts with a response well within the desired limits. Amplifier-loudspeaker equipment submitted by two manufacturers did not meet the performance and design requirements of the proposed specification.

1875

Perrigo, W. R., "Air-to-Ground Loudspeaker Equipment," Tech. Rept. No. 59-625, Communication and Navigation Lab., Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, 9 pp., 1959.
AD-227 278.

Describes design, development, and testing of air-to-ground loudspeaker equipment and systems for application in psychological warfare. Presents the development of droppable and fixed airborne loudspeaker systems designed to meet USAF operational requirements, outlined in applicable military characteristics dated 21 Nov 1951. Describes application of the resultant equipment in support of psychological missions of the Strategic and Tactical Air Commands.

It was concluded that the droppable loudspeaker system AN/ANH-4(XA-2 and XA-3) and public address set AN/AIC-11(XA-2) met basic USAF requirements, could be used effectively in psychological warfare, and had potential application in other types of USAF missions.

1876

Rettinger, M. "Practical Electroacoustics," Chemical Publishing Co., N. Y., 1956.

Mr. Rettinger has compiled a pocket-sized volume on present-day electroacoustic devices and techniques. Throughout eight chapters and a short appendix, he presents several hundred typical handbook figures and formulas in a conversational manner.

The initial chapter deals with microphone types and characteristics, emphasizing placement and directivity. There is also an enlightening discussion on the use of the effective microphone output level in dbm. Following this is a chapter on direct radiator and horn loudspeakers. In addition to some fundamental theory on electromechanical transducer mechanisms, the fine points of enclosures and horns are treated at some length. These chapters, plus one on circuits involving crossover networks, mixers, and attenuators, provide the necessary background for a section on public address systems.

1877

Sher, M., "Loudhailer Evaluation for Airborne Use, Phase I," Rept. No. 1606, Central Experimental and Proving Establishment (Canada), 26 pp., 1961.
AD-272 056.

The CMA-402 Canadian Marconi loudhailer was evaluated for use in an airborne public address system to be employed in search, rescue, and survival operations. Order-of-magnitude of ranges was measured by taking readings on a sound level meter at intervals of 100 ft. or more from the loudhailer assembly with a fixed input. Polar patterns were determined with the sound level meter in a fixed position, and the loudhailer assembly rotated through fixed angles on a rotatable table. Distortion and frequency response were measured with a distortion analyzer and power meter.

1878

Webster, J. C., R. G. Klumpp, and A. L. Witchey, "Evaluation of a Modulated Air-Flow Loudspeaker," J. Acoust. Soc. Am., 31, 795-799, 1959.

As part of an overall evaluation of the USNEL Flight Deck Communications System, an RCA modulated-airflow loudspeaker (air speaker) was tried out as an alarm-signalling transducer on the flight deck of an aircraft carrier. Tests with 200-cps to 6000-cps noise showed that the air speaker produced 130 db SPL at optimum points on the deck, as compared to 110 db for the present system. Speech intelligibility and alarm detection tests showed the air speaker to be usable with jet aircraft at idle (30%) power while the present loudspeakers could not be heard. Neither loudspeaker system was adequate with jets at full power.

Public Address
See Also—467, 544, 567, 965, 981, 1004, 1516, 2685, 2700, 2714, 2718, 2724

RADIATION PRESSURE

1879

Awatani, J. "Note on Acoustic Radiation Pressure," J. Acoust. Soc. Am., 29, 392, 1957.

A method for obtaining the acoustical radiation force (i.e., the process of integrating the force on every surface element of the object placed in sound waves) is criticized. This process yields the sum of the contribution of the true radiation pressure and that of the mean pressure. Though there is no effect on plane progressive waves, the mean pressure has a considerable effect on the result obtained in standing plane waves or progressive spherical waves.

1880

Awatani, J., "Studies on Acoustic Radiation Pressure, I, General Considerations," J. Acoust. Soc. Am., 27, 278-281, 1955.

Examines the equation derived by Kotani and King relating to the excess pressure valid to the second order in the acoustical field. It is shown that the solution of the usual wave equation can be used when the radiation pressure in Langevin's sense is derived from this equation. That both the normal and the tangential forces on the nonstiff surface result from the radiational pressure, defined from the viewpoint of the pressure in hydrodynamics, is clarified by considering the motion of the surface. The general expression for the radiational pressure from inertial effect on a rigid object in motion is developed by introducing moving coordinates.

1881

Awatani, J., "Studies on Acoustic Radiation Pressure, II, (Radiation Pressure on a Circular Disk)," J. Acoust. Soc. Am., 27, 282-286, 1955.

A general formula for the radiational pressure acting on a thin, rigid circular disk is derived from the theory of the previous paper. Motion of the disk under action of the wave, and diffraction of the wave due to the disk are taken into account. Constants which may be calculated by the use of the oblate spheroidal functions necessary in obtaining the radiational pressure are given in the table. Numerical calculation for disks of various weight, with the ratio of the circumference of the disk to the wavelength of sound up to 3.5, is carried out.

1882

Borgnis, F. E., "Acoustic Radiation Pressure of Plane-Compressional Waves at Oblique Incidence," J. Acoust. Soc. Am., 24, 468-469, 1952.

The forces due to acoustic radiation in a beam of finite cross section in a nonviscous medium striking a plane reflector at oblique incidence are derived from simple mechanical considerations. The formulas are applied to a wedge-shaped vane. For a vane, the wings of which include an angle of 90°, the force turns out to be quite independent of the coefficient of reflection at the boundary between vane and medium.

1883

Borgnis, F. E., "On the Physics of Sound Radiation Pressure" (in German), Z. Physik, 134, 363-376, 1953.

The paper discusses the radiational pressure on a plane obstacle due to the hydrodynamic impulse of a free stream of plane compressional waves. The expression for the radiational pressure is given in terms of Euler and Lagrange variables. Reference is made to the Rayleigh pressure and to Brillouin's strain tensor, and to the interchange effect between a free acoustic stream and its surrounding medium. The paper concludes with a discussion of the radiational pressure and energy-density relations.

1884

Budal, K., E. Hoy, and others, "Measurements of Acoustic Radiation Force," J. Acoust. Soc. Am., 31, 1536-1538, 1959.

The acoustic radiation force of a plane wave impinging on a rigid sphere, diameter ten cm, and on a circular disk, diameter 7.4 cm, has been measured in the wavelength interval four to 40 cm. The agreement with theory is satisfactory.

1885

Dumezil-Curien, P., "Compression Waves in an Atmosphere at Radiative Equilibrium" (in French), Compt. Rend., 235, 1369-1370, 1952.

Compressional waves generate an acoustic radiational pressure whose variation with depth creates a gravitation greater than the actual gravity in an appreciable portion of the stellar atmosphere.

1886

Embleton, T. F. W., "Mean Force on a Sphere in a Spherical Sound Field, I (Theoretical)," J. Acoust. Soc. Am., 26, 40-45, 1954.

The mean force acting on a rigid sphere placed in a progressive spherical sound field has been obtained by integration of the individual contributions from the velocity-potential and the partile velocity acting on each element of the sphere's surface. Motion of the sphere under the action of the first-order-pressure variations in the sound field has been taken into account. The force of radiation has been expressed as an infinite series of inverse powers of the source distance, each term of which is multiplied by an infinite-power series in terms of sphere radius. At very large distances from the source the force of radiation obeys an inverse-square law of repulsion. As the source of the field is approached, the repulsion decreases to zero and then becomes a force of attraction. The extent of this region of attraction is determined both by the frequency of the sound field and by the size of the detecting sphere; the lower frequencies and smaller spheres both extend the region. Even when allowance is made for an inverse-square law, attractions may be many times greater than the repulsions in the same sound field.

1887

Embleton, T. F. W., "Mean Force on a Sphere in a Spherical Sound Field, II (Experimental)," J. Acoust. Soc. Am., 26, 46-50, 1954.

The theory of the previous paper has been verified by a series of quantitative experiments. Several hollow glass spheres (radius 0.228 to 3.029 cm) were suspended in turn by a fine glass fiber in the sound field in air; the deflection of each was measured at known frequencies (300 to 7000 cps) and amplitudes (0 to 1400 dynes/cm^2) of the sound field. Care was taken to protect the sphere from any gas streaming to or from the source and to insure that the field was accurately spherical. All measurements were made under such conditions that the sound field was substantially sinusoidal.

Theory and experiment agreed well, within the range of the variables investigated. In the region where radiation forces of attraction existed, this agreement was always within a few percent, even though the magnitude of the forces changed by a factor of 100 or even 1000 to one in a single experiment. In the region of repulsion, measurements could not be made with any great accuracy, but even so, the agreement here was within the limits of experimental error.

1888

Gavreau, V., "Pressure of Sound Radiation According to the Kinetic Theory of Gases" (in French), J. Phys. Radium, 17, 899-904, 1956.

After referring to Rayleigh's formulae for the pressure of sound radiation, the author shows that it is possible to deduce the same relationships between sound radiation pressure and energy-density (proportional to I/c—where I is the intensity of the sound and c the velocity of propagation) by a direct application of the kinetic theory of gases. This theory explains all the peculiarities of the phenomenon and gives an estimate of the value of the radiation pressure. It is shown experimentally that the coefficient of proportionality between radiation pressure and sound intensity is independent of the nature of the gas.

1889

Gavreau, V., and M. Miane, "Radiation Pressure and the Anisotropy of Acoustic Pressure of Great Intensities" (in French), Compt. Rend., 238, 2148-2150, 1954.

An experimental arrangement designed for determining the pressure of sound radiation is described and illustrated and experiments made with the apparatus are discussed. It is found that sound pressure is anisotropic at high sound intensities. This is attributed to an increase in molecular velocity, which probably also results in an increased speed of propagation of intense sounds. At 145 db, for example, the velocity of 34,700 cm/sec was obtained instead of the theoretical value of 34,000 cm/sec for 20°C.

1890

Ghiron, E. F., "Acoustic Radiation Pressure and Waves of Large Amplitude," Alta Frequenza, 6, 640-653, 1937.

Phenomena of acoustic radiation are closely connected with anomalous propagation of waves of large amplitude. In the case of plane waves it is found that a fluid carrying a progressive wave is subjected to a variable pressure, the mean value of which differs from the pressure when at rest. If a wall closes the tube in which the fluid moves, it is subject to forces depending upon its orientation, and they are not perpendicular to the surface. The general result may be expressed by a tensor, the terms of which are calculated. Only absorbent walls can be rigorously dealt with; results concerning reflecting walls are approximate.

1891

Kanevskii, I. N., "Steady Forces Arising in a Sound Field," Soviet Phys. Acoust. English Transl., 7, 1-10, 1961.

The hydrodynamic and Bjerknes forces in a sound field are thoroughly discussed. Also discussed are the radiation pressure and that area covered by the Borgnis theorem, although the latter is not discussed with great thoroughness. Included are several methods of calculating radiation pressure in various acoustic environments.

1892

Kubanskiy, P. N., "Coagulating Mechanism of Acoustic Current" (in Russian), Zhur. Tekhn. Fiz., 24, 1049-1054, 1954.

The coagulating effect is not due only to the Bernoulli force and radiation pressure, but also to the acoustic current; i.e., Rayleigh's vortex circulation due to viscosity. Experiments are described to confirm the theoretical calculations.

1893

Lothe, J., "Acoustic Radiation Force on a Uniformly Moving Smooth Body, to the First Order in the Velocity," J. Acoust. Soc. Am., 32, 140-141, 1960.

It is shown that the acoustic force on a uniformly moving smooth body is correct to the third order when given by simple first-order theory, in agreement with a calculation by Nabarro. (Phil. Mag. 41, 1276, 1950.)

1894

Lucas, R., "The Radiation Pressure of Acoustic Waves" (in French), Nuovo Cimento, 7, 236-247, 1950.

The mechanical action of acoustic waves, whether plane or spherical, progressive or stationary, is calculated by various techniques confirming their tensorial character.

1895

Lucas, R., "On the Radiation Pressure of Spherical Waves" (in French), Comp. Rend., 230, 2004-2006, 1950.

Most investigations of radiation pressure caused by sound waves have hitherto been concerned with plane progressive waves and stationary waves. Unlike these cases, with spherical waves near a small pulsating source the density of the kinetic energy is greater than the density of potential energy. It is shown that the radiation pressure for spherical waves $\delta p = W_p \times (1 + 3d \log V/d \log \rho)$ (where W_p is the mean density of potential energy, V is the velocity of sound and ρ the density of the medium. The numerical factor 3, characterizing the problem of spherical symmetry, is significant, for it is here that the result differs from Brillouin's result for plane stationary waves in which this factor is unity. The difference is in effect very small, for in all practical cases $d \log V/d \log \rho$ is insignificant, and $\delta p = W_p$ in all cases.

1896

Lucas, R., "The Tensions of Radiation in Acoustics" (in French), J. Phys. Radium, 17, 395-399, 1956.

Stresses resulting from the propagation of a plane elastic wave through a fluid can be computed by a method similar to the one used in elasticity for stresses in a strained solid body. This discussion proves the anisotropic character of the forces acting on the boundaries and their tensorial nature; the radiation tensor for a spherical wave is different from the tensor for a plane wave. Using the Boltzmann-Ehrenfest adiabatic invariants, it is possible to prove the existence of an isotropic pressure term, which can be discussed experimentally. The method of radiation tensors can be used to compute the pressure in an ideal monatomic gas, or the osmotic pressure in a solution. Both examples are completely discussed.

1897

Maidanik, G., "Acoustical Radiation Pressure Due to Incident Plane Progressive Waves on Spherical Objects," J. Acoust. Soc. Am., 29, 738-742, 1957.

The expression for the force exerted on a scattering sphere by a plane progressive wave is computed by making use of the general formulation derived by P. J. Westervelt. The expression is general in the sense that it allows for complex refractive index and variation of the effective density of the sphere relative to that of the surrounding medium. The numerical calculations are confined to the cases of hard and soft spheres.

1898

Maidanik, G., "Torques Due to Acoustical Radiation Pressure," J. Acoust. Soc. Am., 30, 620-623, 1958.

A general expression for the torque on an object due to acoustical radiation pressure is derived by an approach similar to that used by P. J. Westervelt to derive the general expression for the force.

The general expression is then specialized to plane waves incident in an arbitrary direction. The simplification which is obtainable in the case of disks is also discussed.

1899

Maidanik, G., and P. J. Westervelt, "Acoustical Radiation Pressure Due to Incident Plane Progressive Waves on Spherical Objects," J. Acoust. Soc. Am., 29, 936-940, 1957.

The expression for the force exerted on a rigid sphere by a plane progressive wave is computed by making use of the momentum formulation. The expression is general in the sense that it allows for variation of the density of the sphere relative to that of the surrounding medium, as well as for a wide range of ka (k = wave number, a = radius of sphere). The numerical calculations are confined to the range $ka \leq 10$.

1900

Mawardi, O. K., "On Radiation Pressure in Acoustics" (in French), J. Phys. Radium, 17, 384-390, 1956.

A critical survey for the development of the concept of radiation pressure is presented. In this survey, first restricted to an ideal inviscid fluid, the tensorial character of the radiation pressure is pointed out and its connection with the flux of momentum associated with the wave is studied. It is also shown that the two common definitions of radiation pressure (Langevin and Rayleigh) are closely related and naturally follow from the above mentioned tensor property.

The discussion is then extended to the case of a viscous fluid. The interaction of sound waves and rigid obstacles of simple geometrical shapes is also discussed. The radiation pressure on these obstacles is computed for some limiting cases and the relation between the radiation pressure and the scattering cross-section for the obstacles is investigated.

A review of the better-known methods of experimentally measuring the radiation pressure is next given. The comparative merit of these techniques as far as accuracy of measurement is concerned has been examined in the light of the discussion of this paper. 27 refs.

1901

Mendousse, J., "Acoustic Radiation Pressure," Compt. Rend., 208, 1977-1979, 1939.

It is shown that the mean pressure of sound waves on a boundary wall is equal to the sum of the Eulerian pressure together with twice the mean kinetic energy for the motion normal to the wall. Also shown is a method for calculating the absolute value of the mean pressure.

1902

Olsen, H., and H. Wergeland, "Acoustic Radiation Force," J. Acoust. Soc. Am., 30, 633-634, 1958.

A formula for the force on an arbitrary scatterer is derived without making any assumptions about the scatterer.

1903

Olsen, H., W. Romberg, and others, "Radiation Force on Bodies in a Sound Field," J. Acoust. Soc. Am., 30, 69-76, 1958.

Gives a simple derivation of the force that acts on a body placed in a sound field. The tensor properties of the force are exhibited, but it is also shown that for a rigid body the force may be derived from the scaler pressure alone. It is shown how the time-average force is determined by the momentum lost by the sound wave during the collision with the body. Using this result, the force is related to the scattering amplitude, and a simple expression in terms of the phase shifts is given.

The connection between the force and the scattering cross section is examined. A force factor $k + K_z/(1/2\, p_0 k^2\, \sigma sc)$ is defined. It is shown that k = 1 for plane scattering at perpendicular incidence. A simple general formula for the force in the limit of short wavelengths is derived. It is shown that neither for very long wavelengths nor for very short ones is k in general equal to one.

The case of a rigid sphere is treated in detail. Curves are shown for the force and for the force factor, k.

1904

Post, E. J., "Acoustic Radiation Pressure" (in French), J. Phys. Radium, 17, 391-394, 1956.

In the phenomenological descriptions of classical physics there are three interconnected problems requiring a clear interpretation: (1) acoustic radiation pressure; (2) relations between Euler and Lagrange equations, and their application to turbulent motions; (3) Minkowski's electromagnetic theory for a moving medium, and the definition of momentum and tension or electromagnetic radiation pressure in a material medium. Using the relativistic theory as the most general description, first-order transformations are discussed in the present paper. Transformation equations are independent of the properties of the medium. Physical interpretation suggests semipermeable walls, which lead to a distinction between two terms in acoustic radiation pressure. The nature of phonons or photons is more precisely specified.

1905

Post, E. J., "Radiation Pressure and Dispersion," J. Acoust. Soc. Am., 25, 55-60, 1953.

The paper starts with a brief discussion of the two components of acoustical radiation pressure in contrast to the single component obtained for electromagnetic radiation in vacuum. The two components of acoustical radiation pressure are correlated in a simple manner with the two distinct interaction possibilities of the obstacle and the medium; i.e., interaction with only the wave motion or interaction with the wave motion as well as with the medium itself. This picture appears to be consistent with the earlier conclusions of Brillouin and Richter.

Afterwards the result is generalized for dispersive media. It is shown that the component which is usually stated to be independent of the equation of state in the existing nondispersive theories should contain the time parameters of the equation in the form of a multiplying factor group, velocity over phase velocity. The present paper stresses the basic concepts rather than mathematical detail and concludes with an extensive bibliography and commentary.

1906

Schaefer, C., "Pressure of Sound Radiation," Ann. Physik, 35, 473-491, 1939.

The question of the pressure from a sound wave, investigated by Rayleigh, is taken up and explored by a direct method which leads to results differing from those reached by Rayleigh. It is shown that for feeble but finite sound vibrations the sound pressure is equal to the energy's density, and not as usually quoted from Rayleigh. It is also pointed out that the theory of sound pressure must take into account the unsettled conditions that very intense sound vibrations produce.

1907

Seegall, M., "Acoustic Radiation Pressure Bearing," J. Acoust. Soc. Am., 33, 566-574, 1961.

This paper gives a brief investigation of the concept of the acoustic bearing, the force of which is based on radiation pressure from a resonating sound wave. Of the principal configurations possible, a cylindrical geometry with plates on the ends of the cylinder was considered to be the most suitable. Output ratios of the order of 2640 d/w are shown to be obtainable. Experimentation reached a resonant amplification of 80; ways are shown by which amplifications of around 100 can be achieved. Beyond that internal absorption losses and cavitation present formidable obstacles which, at this point, cannot be overcome.

1908

Sen, H. K., and A. W. Guess, "Radiation Effects in Shock-Wave Structure," Phys. Rev., 108, 560-564, 1957.

The equations for shock-wave structure, with the inclusion of radiation effects, are derived. These radiation effects are radiation pressure, radiation energy density, and radiative transfer of energy. Computations are performed for a diffusion approximation of radiation flux and the neglect of radiation energy density and pressure. The results show that the overall effect of radiation can be taken as a diminution of the Prandtl number, and that the shock width is larger than when viscosity and heat conduction alone are considered. The radiative contribution to the width of the shock is found to depend primarily on the ratio of the mean free path of radiation to that of the material particles. The proportionate increase in shock width is found to be a function of the Mach number and to increase with it. Possible application of these results to shock-wave propagation in a medium of low density is indicated.

1909

Westervelt, P. J., "Acoustic Radiation Pressure," J. Acoust. Soc. Am., 29, 26-29, 1957.
AD-138 859.

The author previously obtained an expression for the force of radiation on a scattering obstacle with arbitrary normal impedance [J. Acoust. Soc. Am., 23, 312-315 (1951)]; he now shows it to be valid for any scattering obstacle. By taking into account the interaction of the incident wave and the scattered wave, he accomplishes the derivation of the final expression for the force in terms of the asymptotic scattering function for the obstacle in the field of an incident plane wave. Thus the former assumption of a perfectly collimated beam (1951) is avoided by considering the incident plane wave to be of infinite extent. The result for the force in the direction of the incident wave is

$$F_{\parallel} = c_o^{-1}\left\{\text{power scattered} + \text{power absorbed} - \int \tau_s \cos\theta \, dA\right\},$$

where c_o is the velocity of sound, τ_s is the magnitude of the mean scattered intensity, θ is the angle formed between the incident and scattered waves. This is the same result as that obtained in 1951. The expression given in 1951 for the force perpendicular to the incident wave is correct only for an object which scatters in a restricted way. The correct general expression for the perpendicular component of the force is $F_1 = -c_o^{-1} \int \tau_s \cos\beta \, dA$ in which β is the angle formed between F_1 and τ_s.

1910

Westervelt, P. J., "The Theory of Steady Forces Caused by Sound Waves," J. Acoust. Soc. Am., 23, 312-315, 1951.

A general expression is derived for the force owing to radiation pressure acting on an object of any shape and having an arbitrary normal boundary impedance. It is shown that boundary layer losses may lead to forces that are several orders of magnitude greater than the forces from classical radiation pressure. Steady forces arising from an asymmetric wave form are compared with the other forces. A sound wave, consisting of equal parts of fundamental and second harmonic components, can cause to be exerted on small particles forces ten or more orders of magnitude greater than the forces from radiation pressure.

1911

Wiener, F. M., "On the Relation Between the Sound Fields Radiated and Diffracted by Plane Obstacles," J. Acoust. Soc. Am., 23, 697-700, 1951.

In the past, acoustic diffraction and radiation problems have been treated separately, although their intimate connection is clear from theory. In the case of plane piston radiators and plane rigid scatterers exposed to a perpendicularly incident plane wave, this connection becomes particularly simple and useful. It is easy to show that the radiated sound field is everywhere the same as the field scattered (diffracted) except for a factor of proportionality. It is also shown that the reaction of the medium on the radiator, as expressed by the mechanical radiation impedance, is equal to the force per unit incident pressure exerted on the same obstacle held rigid as a scatterer, except for a factor of proportionality. By way of illustration, the foregoing principles are applied to the important case of the circular disk.

Radiation Pressure
See Also——341, 384, 752, 753, 903, 904, 916, 962, 975, 990, 991, 1127, 2201, 2202, 2252, 3434, 3632, 3996, 4134, 4183

RAY ACOUSTICS

1912

Barry, G., "Ray Paths of Acoustic Waves in the Ionosphere as Obtained with an Analog Computer," Tech Rept. No. 64, Stanford Electronics Labs., Stanford Univ., Calif., 16 pp., 1962. AD-285 298L.

NOTICE: All requests require approval of Office of Naval Research, Washington 25, D. C., Attn: Code 418.

Utilizes Snell's law and an analog computer to determine the refraction of acoustic waves (and the resulting curved ray paths) propagating in the ionosphere under various typical meteorological conditions.

1913

Bateman, H., "Sound Rays as Extremals," J. Acoust. Soc. Am., 2, 468-475, 1930.

This is a mathematical paper in which equations are developed, representing a general form of Doppler's principle, applicable when the source of sound, the receiver and the medium are all in motion.

1914

Blokhintzev, D., "The Acoustics of an Inhomogeneous Moving Medium," Translated by R. T. Beyer, and D. Mintzer, Research Analysis Group, Brown Univ., Providence, R. I., 161 pp., 1952.
AD-7675.

This is an English translation of a Russian book. It comprises comprehensive mathematical treatments of the following general topics: Chap. I, The acoustic equations for an inhomogeneous moving medium; Chap. II, Propagation of sound in the atmosphere and in water; Chap, III, Moving sound sources; Chap. IV, Sound excitation by flow. Ray acoustics, zones of silence, the effects of atmospheric turbulence, scattering, and shock wave propagation are thoroughly treated within these chapters.

1915

Calvert, J. B., "Progress in the Calculation of the Sound Field in the Atmospheric Acoustic Duct," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 13-23, 1961.
AD-408 716

Calculation of sound intensity by ray-tracing from the source is severely limited in application. At very short ranges (less than 100 km) and for sufficiently short wavelengths ray-tracing methods are useful and simple. As the range and wavelengths increase the method becomes a very poor approximation, complexity of calculation sets in, and even a qualitative calculation of a signal form seems impossible. A more exact treatment by the normal wave analysis becomes necessary.

The signal is composed of a superposition of waves characteristic of the structure of the duct. One must first determine the configuration of the waves, and their dispersion (frequency vs velocity) characteristics. The phenomena are analogous to those in an electromagnetic waveguide. If the amount of excitation of the normal waves is known, the propagation to great distances may be followed with relative ease, since the normal waves propagate in a regular manner. It is therefore important to investigate the method in which acoustic sources excite the normal waves.

First, the field near the source (as if it were in a homogeneous medium) is determined. It may then be simplest to extend this solution by ray-tracing to moderate distances, taking into consideration significant changes in the signal characteristics in this region. Finally, the resulting intermediate signal is expanded in terms of the normal waves. In a practical case, this may be accomplished by numerical integration. A given source will then be specified by its normal-wave frequency spectrum and the times of emission. Reasonable and useful results may well be obtained by this method, even after ruthless simplification to permit a practical solution.

1916

Chernov, L. A., "Propagation of Sound in a Statistically Heterogeneous Medium" (in Russian), Zh. Ekesperim. i Teor. Fiz., 24, 210-213, 1953.
Transl. available from M. D. Friedman, 2 Pine St., West Concord, Mass.

A differential equation is developed for the distribution function of rays in a medium endowed with random inhomogeneities; the medium is considered to be macroscopically homogeneous and isotropic. The irregular variations of the perperties of the medium are assumed to take place at a fairly slow rate. Formulae are derived for the mean square of the deviation of a ray from its original direction.

1917

Cox, E. F., "Sound Propagation in Air," in Handbuch der Physik (Encyclopedia of Physics), 48, 455-478, 1957.

This paper begins with a review of the basic laws of propagation of sound energy in air and explains why weak sound waves propagate with negligible distortion, while high amplitude sound waves distort and form shock fronts as they propagate. Expressions for shock wave velocity are given.

Meteorological factors affecting the speed and direction of sound rays are described, and the laws of sound ray refraction and reflection are reviewed. Absorption and dispersion of sound in real atmospheres are described. Formulas and graphs are given for determining attenuation with distance. Propagation of sound to great distances is treated in detail. Refraction in the troposphere and the formation of sound ducts at tropopause heights are described and documented. An excellent bibliography is included.

1918

Dean, E. A., "The Wavelength Limits of Atmospheric Ray Acoustics," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 7-12, 1961. AD-408 716.

The investigation of the assumptions used in the derivation of the eikonal equation furnishes the wavelength requirements which must be satisfied if the ray description of sound is to be accurate. These requirements are then applied to propagation in a layered inhomogeneous atmosphere of typical structure. It is found that the most exacting requirement, neglecting wind shear and the change in temperature gradient at the tropopause, is the change in pressure due to the gravitational field.

1919

Ellison, T. H., "The Propagation of Sound Waves Through a Medium with Very Small Random Variations in Refractive Index," J. Atmospheric Terrest. Phys., 2, 14-21, 1951.

A theoretical study of scattering in a field having a known, slightly variable refractive index, such as the atmosphere, first of an incident plane wave and secondly of a ray. It is found that "for a wave travelling in a statistically homogeneous medium where the scale of the variations in refractive index is suitably large compared with the wavelength but small compared with the path length, the variations in intensity produced by the medium are proportional to the cube of the path length for short paths, but directly proportional to it for long paths."

1920

Galbrun, H., "Propagation of a Sound Wave in the Atmosphere and the Theory of Zones of Silence" (in French), Gauthier-Villars et Cie, Paris, 352 pp., 1931.

A detailed theoretical work studying the effects of wind on sound propagation. The first part considers discontinuity in the movement of a fluid in relation to propagation of sound. Physics of sound waves and rays are discussed at length. The second part considers zones of silence, giving a detailed analysis and physical and geometrical aspects.

1921

Golden, A., "Evaluation of Meteorological Corrections for Sound Ranging," Proc. of the Symposium on Atmospheric Acoustics Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 149-161, 1961. AD-408 716.

A method for the computation of meteorological corrections is evaluated. The results of a comparison between this method and the standard method of meteorological corrections employed by the U. S. Army artillery are presented. The comparison is made on a ray-by-ray basis.

In the first case tested (consisting of a weighted average of 12 readings), three out of the five rays to the target were more improved by the use of this method than by the artillery method. In the second case tested (also a weighted average of 12 readings), all rays were more improved by this method than by the standard method.

1922

Goodman, R. R., and L. R. B. Duykers, "Calculations of Convergent Zones in a Sound Channel," J. Acoust. Soc. Am., 34, 960-962, 1962.

A simple approximate solution for ray paths near a sound channel with parabolic velocity profile is given for rays crossing the sound-channel axis at small angles. The convergent zone for such rays for a source on the axis is compared with results of Pederson. Two simple straight-line velocity-gradient approximations are compared with the parabolic case for the purpose of observing their accuracy in the prediction of convergent zones. Both cases agree surprisingly well over a range of choices for the gradients.

1923

Groves, G. V., "Geometrical Theory of Sound Propagation in the Atmosphere," J. Atmospheric Terrest. Phys., 7, 113-127, 1955.

Deals with the geometry of sound waves and rays propagated in a moving inhomogeneous medium, with particular reference to the atmosphere. The theory developed is, essentially, a generalization of that in geometrical optics for the propagation of light in an inhomogeneous isotropic medium to the case where the medium is in motion. Differential equations defining the wavefront and rays of a sound propagation in an inhomogeneous moving medium are derived, and then transformed by expressing the unit normal of the wavefront in terms of certain trace velocities.

With the equations in this form, an integral is immediately obtainable for sound propagated in the atmosphere by assuming that the velocity of sound and the wind-velocity vector are functions of height only. From this solution the law of refraction, the condition for total reflection of a sound ray, and the equations for the wavefront at any time are found. By way of example, the theory is applied to a simple velocity of sound vs. height relationship, and expressions are obtained for the range and time at which the abnormal propagation from a ground-level source returns to earth. Numerical results calculated from these formulae are found to be in accord with observations that have been made on this phenomenon.

1924

Groves, G. V., "Introductory Theory for Upper Atmosphere Wind and Sonic Velocity Determination by Sound Propagation," J. Atmospheric Terrest. Phys., 8, 24-38, 1956.

Considers the problem of deriving the mean values of the horizontal wind velocity components u(z), v(z), and the velocity of sound c(z), averaged with respect to height z along a sound ray traveling between two known points in the atmosphere, from measurements of the time of travel of the ray between these points and the coordinates of the ray. It is shown that, for a ray which does not suffer total reflection, expressions can be derived for $\overline{u(z)}$, $\overline{v(z)}$, and $\overline{c(z)}$ in terms of the measured quantities, and the mean value of the vertical component of wind velocity w(z), provided the variations in u(z), v(z), w(z), and c(z) with height are sufficiently small. The theory is carried further by working out in detail the second-order contributions to $\overline{u(z)}$, $\overline{v(z)}$, and $\overline{c(z)}$ which arise from the variations in u(z), v(z), w(z), and c(z). Using typical atmospheric data, the more important of these second-order terms are evaluated numerically for the case of a sound ray received at an observation point on the ground from a source at any height up to 90 km. It is shown that the contributions from these terms to $\overline{u(z)}$, $\overline{v(z)}$, and $\overline{c(z)}$ are less than 0.8 m/sec when the ray lies near the vertical. For a ray which departs appreciably from the vertical (inclination about 45°), the contributions amount to a few meters per second, but are unlikely to exceed about 8 m/sec unless exceptionally large wind velocities are present.

1925

Gutenberg, B., "Propagation of Sound Waves in the Atmosphere," J. Acoust. Soc. Am., 14, 151-155, 1942.

The effect of humidity is investigated. The radius of curvature for a sound ray propagated in the direction of the wind is given and discussed. The amplitudes of sound waves as a function of the distance are given, and the relative importance of the quantities involved is discussed.

1926

Harrington, J. B., Jr., "Acoustical Probing of the Upper Atmosphere," Univ. of Mich., 5500 East Engineering, Ann Arbor, 40 pp., 1959.

This paper presents a comprehensive review of historical and current techniques and investigations for accurately determining the propagation characteristics of sound in the atmosphere. Anomolous propagation and the application of Snell's Law of refraction for calculating sound-ray paths are discussed. Gutenberg's approach to measuring upper winds and temperatures using sound rays is described, followed by an account of Richardson's and Kennedy's "Study of Meteorological and Terrain Factors Which Affect Sound Ranging" and "Determination of Atmospheric Winds and Temperatures in the 30 to 60 Kilometer Region by Acoustic Means." The rocket-grenade experiment for determining upper-level wind and temperature profiles is explained as conducted by the Signal Corps and as modified by Groves. A bibliography of more than eighty reports and journal articles on the subject of propagating sound in air is included.

1927

Ingard, U., "Acoustics," in E. U. Condon, and H. Odishaw, eds., Handbook of Physics, McGraw-Hill, New York, 113-133, 1958.

This concise presentation of acoustic theory and applications discusses the general equations of sound propagation, sound sources and their fields, propagation in the atmosphere and in tubes, absorption of sound, scattering, detection of sound, architectural acoustics, and ultrasonics. The section on atmospheric sound propagation develops the equations pertaining to ray acoustics (phase velocity, group velocity, shadow zones), intensity in the shadow zone, scattering by turbulence, and ground absorption.

1928

Kennedy, W. B., et al., "Study of Meteorological and Terrain Factors Which Affect Sound Ranging," Denver Research Inst., Univ. of Denver, Colo., 1954-1957.

Qrtrly. Prog. Rept. 1, March-May 1954, AD-38 446
" " " 2, June-August 1954, AD-43 297
" " " 3, September-November 1954, AD-54 480
" " " 4, December 1954-February 1955, AD-61 530
" " " 5, March-May 1955, AD-70 078
" " " 6, June-August 1955, AD-74 855
" " " 7, September-November 1955, AD-95 798
" " " 8, December 1955-February 1956, AD-95 799
Final Report, March 1954-April 1956, AD-139 326
Qrtrly. Prog. Rept. 1, May-July 1956, AD-140 087
" " " 2, August-October 1956, AD-140 088
" " " 3, November 1956-January 1957, AD-140 090
Interim Prog. Rept., February-August 1957, AD-160 696

This series of reports covers four years of intensive theoretical and applied research and development on sound-ranging as influenced by meteorological and terrain factors. The general problem of increasing the accuracy of sound-ranging by means of corrections based on meteorological and topographical conditions is discussed. Equations are presented for applying wind and temperature corrections to reduce error in observed sound-source azimuths. Problems encountered in setting up the field operation to provide data for a study of meteorological and terrain corrections for the whole sound path are analyzed. Proposed methods for time measurement of sound arrivals, temperature measurement, control of field operations, and power distribution are presented in detail.

The firing-recording arrays are described. The results and the methods of reducing data are given. Special investigations include: an analysis of the problem of acoustic ray-tracing in the atmosphere; determinations of the sonic data obtainable with various geometries of detecting arrays; an analysis for determining the velocity of sound; studies of errors generated within the Short-Range Whole-Path Firing-Recording Array by elevation differences, angular errors in placing the sensing microphones, and errors due to the assumption that the wave front is plane; a study determining the effect of oscillogram-reading errors on calculated sound-wave-arrival azimuths; a discussion of methods of removing data from oscillograms; and tests to determine the calibration requirements of the T-23 microphones. Other discussions include microphone-wind-shield development, the surveying program, and the general field operational problem.

The application of a drift correction to the primary sound-ranging information provided results superior to those obtained by standard artillery methods. For these calculations, data were used from an array of 14 microphones arranged in an isosceles-trapezoidal configuration. The arrival azimuth obtained by using this configuration is more representative of the direction of arrival of the acoustic wave front than that obtained by standard methods. The corrections which were applied for the refraction of the wave front along its path do not appear to be greatly significant from a study of the small sample presented.

1929

Kennedy, W. B., and L. Brogan, et al., "Determination of Atmospheric Winds and Temperatures in the 30-60 km Region by Acoustic Means," Denver Res. Inst., Univ. of Denver, Colo., 1950-1954.

Thirteen quarterly progress reports and a final, summarizing report describe four years of experimental and theoretical research on the problem of determining winds and temperatures at high altitudes (30-60 km) from acoustic measurements. Acoustic energy from explosions of 200-lb charges of TNT was recorded at a number of points lying on a circle of 200 km radius around the firing site. From travel time and angle of arrival measurements of the acoustic wave front plus local wind and temperature data, the sound ray paths and the upper-level winds and temperatures, which caused these paths by refraction, were calculated. One method of calculation employed, with certain simplifications, was developed originally by A. P. Crary. Another method used assume that the sound velocity vs altitude structure in the upper air follows a hyperbolic-cosine curve. A new method of treating azimuth-shift data is also presented.

Annual and diurnal variations of high-altitude winds and temperatures were determined in Colorado and New Mexico. Winds were generally westerly and strong during the winter and easterly and of small magnitude during the summer. High-altitude temperatures increased while winds decreased as time advanced during daylight hours. Minimum temperatures and maximum winds generally occurred at about 1000 MST on any given day. As shown below, most of the reports in this series have AD or ATI numbers for use when ordering from DDC (formerly ASTIA).

Qtly. Prog. Rept. 1, June-August, 1950
" " " 2, September-November, 1950
" " " 3, December, 1950-February, 1951, ATI-109, 427
" " " 4, March-May, 1951
" " " 5, June-August, 1951, AD-8 990
" " " 6, September-November, 1951, AD-8 989
" " " 7, December, 1951-February, 1952, AD-38 760

Qtly. Prog. Rept. 8, March-May, 1952
" " " 9, June-August, 1952
" " " 10, September-November, 1952, AD-26, 714
" " " 11, December, 1952-February, 1953, AD-20 318
" " " 12, March-May, 1953, AD-31 806
" " " 13, June-August, 1953, AD-36 902
Final Report, 30 June 1954, AD-36 812

1930

Laslett, L. J., "On the Electromagnetic Analogy to Sound Propagation," J. Acoust. Soc. Am., 28, 724, 1956.

Refers to a paper by R. H. Kraichnan, who has drawn attention to an interesting correspondence between the paths of sound rays in fluids undergoing shear flow and the trajectories of charged particles in magnetic fields. To establish the analogy it is assumed (1) that the eddy size is large compared with the sound wavelength, and (2) the velocity of the fluid flow is small by comparison with the velocity of sound. Use is made of the Hamilton-Jacobi theory of particle dynamics, the associated principle of Fermat, and that of least action. Extending Kraichnan's analysis, the auther indicates how sound rays are influenced by the fluid motion.

1931

Lawson, A. W., P. H. Miller, Jr., and L. I. Schiff, "A Device for Plotting Rays in a Stratified Medium," Rev. Sci. Instr., 18, 117-120, 1947.

A device is described which was developed for the rapid computation of rays in a medium in which the index of refraction or speed is a function of only one rectangular coordinate. It was used during the war for the computation of sound fields in water, in the ray-approximation solution to the problem of radar-signal propagation in a stratified atmosphere, since it is possible to transform the curvature of the earth into an additional refractive index that depends only on the height above a plane earth.

1932

Meecham, W. C., "Propagation of Radiation in an Inhomogeneous Medium near an Irregular Surface," J. Acoust. Soc. Am., 25, 1012, 1953.

The intensity of a sound wave propagated in a surface channel is derived, using the concepts of ray acoustics and taking into account the roughness of the surface. The attenuation due to rough-surface scattering is found, and calculations are made for several types of surface reflections.

1933

Mittenthal, L., "Electrostatic Analogy to Sound in a Region of Constant Velocity Gradient," J. Acoust. Soc. Am., 29, 149-150, 1957.

Using ray theory, a wavefront is found for the case of sound from a point source in a medium where sound velocity is proportional to depth. The spreading backwards toward the source is shown to be independent of ray angle. The rays are shown to be harmonic functions similar to lines of flux. The harmonic conjugate to the ray is derived, and shown to resemble an electrostatic potential.

1934

Moies, P. C., "Strong Sound Signals, Effect of the Wind," Tech. Notes No. FRL TN 31, Feltman Res. Labs., Picatinny Arsenal, Dover, N. J., 5 pp., 1961. AD-253 793.

The range of audibility does not depend on wind velocity as such but on the rate at which the speed increases with height. The effect of a height gradient in wind velocity is to produce curved rays. Equations are given for calculating the radius of curvature from the speed and relative direction of the sound and the gradients in the temperature and velocity of the wind. Sound heard downwind is intensified; that heard upwind is weakened.

1935

Mooney, C. S., "Simplified Ray-Tracing Computations," J. Acoust. Soc. Am., 34, 5, 684, 1962.

Most ray-tracing schemes involve many numerical computations. At least one of these calculations can be simplified. The calculation for ray travel through a layer of constant velocity gradient has been performed by calculating the first few terms of an infinite series. This method, in addition to being laborious, can lead to poor approximations. An alternate method employing log tables is suggested.

1936

Poeverlein, H., "Waves in Anisotropic Conditions of Propagation" (in German), Z. Naturforsch., 5a, 492-499, 1950.

A theoretical discussion of the index surface defined by Hamilton and MacCullagh (1837) and the principle that the ray direction is normal to this surface. The ideas are applicable not only in crystal optics but in general to waves in anisotropic media, e.g., radio waves in the ionosphere. Examples treated here are sound waves in air and the motion of electrons in a magnetic field.

1937

Pridemore-Brown, D. C., and U. Ingard, "Sound Propagation into the Shadow Zone in a Temperature-Stratified Atmosphere Above a Plane Boundary," NACA TN 3494, Mass. Inst. of Tech., 1955.

In this report, geometrical ray acoustics are employed to derive the ray paths and the intensity distribution about a sound source located in a uniformly stratified medium. A comparison of the relative effect of the stratification on the intensity from a directive source and from a spherical source is made.

Also presented is a theoretical analysis of the sound field in the "shadow zone" (diffraction region) formed over an absorbing-plane boundary in a temperature-stratified atmosphere. The analysis holds for both two and three dimensions. The boundary condition at the plane is given by a normal acoustic impedance independent of the angle of incidence. As in the corresponding problem of underwater sound, where the boundary is a pressure-release surface, it is found that the major portion of the sound intensity in the shadow region decays exponentially with distance at a rate proportional to the one-third power of frequency and to the two-thirds power of temperature gradient. The effect of ground impedance enters mainly through its resistive component. The rate of sound decay for a pressure-release boundary (zero impedance) is found to be 2.3 times that for a reflecting boundary (infinite impedance).

Finally, the results of measurements of the sound distribution in a two-dimensional laboratory chamber in which a large temperature gradient was created are reported. Measurements were made at various frequencies for both reflecting and absorbing boundaries, and the results are found to agree well with theory.

1938

Rachele, H. "Sound Propagation Through a Windy Atmosphere," Prog. Rept. No. 2, Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 20 pp., 1962. AD-272 644.

Discusses the derivation of two models that can be used for two-dimensional ray-tracing of sound through a windy atmosphere. A procedural outline for calculation and sample calculations are presented. The process takes into account both temperature and wind data.

1939

Rachele, H., "Sound Propagation Through a Windy Atmosphere," Tech. Rept. No. 109, Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 11 pp., 1961.
AD-266 240

Snell's equations, and variations thereof, for the refraction of sound in a temperature-stratified medium are derived from a ballistic standpoint. The equations are then transformed for ray-tracing through a windy atmosphere.

1940

Reynolds, O., "On the Refraction of Sound in the Atmosphere," Phil. Trans. Roy. Soc. London, 166, 315, 1876.

This paper is remarkable for its time (1876). It is one of the earliest attempts at correlating wind and temperature gradients with the apparent refraction of sound rays in the atmosphere. The author writes in narrative style and uses no formal mathematical treatment. The presentation of subjective data from carefully controlled tests on land and sea, however, substantiates the conclusions drawn.

1941

Rothwell, P., "Calculation of Sound Rays in the Atmosphere," J. Acoust. Soc. Am., 12, 205-221, 1947.

Highly theoretical work in which methods of tracking sound rays for acoustical location of aircraft are described, with a view to their possible application to other meteorological investigations by acoustical methods. Tables have been constructed for meteorological investigations of the upper atmosphere, covering the range of temperature from ground to stratosphere, the range of angles of descent, and time factors, with respect to equations. The procedure for calculating rays by the use of tables of range and time factors is outlined, and examples are given.

1942

Saby, J. S., and W. L. Nyborg, "Ray Computation for Non-Uniform Fields," J. Acoust. Soc. Am., 18, 316-322, 1946.

A formula is derived which simplifies computation. A field is first assumed to be equivalent to an array of horizontally homogeneous strata, each with a uniform gradient of the speed of sound, and the range of the ray through the whole array can be computed in one step, to an adequate degree of approximation. Special problems encountered in applying the formula under certain types of conditions are discussed. The method is particularly useful in the study of the propagation of ultrasonic waves through the atmosphere near the ground, where micrometeorological conditions often produce rather complicated gradient conditions.

1943

Seckler, B. D., and J. B. Keller, "Diffraction in Inhomogeneous Media," Res. Rept. MME-7, Inst. of Math. Science, New York Univ., New York, 68 pp., 1957.
AD-155 157.

A geometric method is presented for finding the field in inhomogeneous media containing smooth convex bodies. The field due to a plane wave in an unbounded medium is constructed by introducing complex rays in the refraction shadow. Fermat's principle is extended to explain the occurrence of certain diffracted rays in the boundary problems. Then by modifying the law of conservation of energy, the field along the diffracted rays is obtained in addition to the field on the geometric lit region. Certain diffraction coefficients and decay exponents are introduced and general formulas are obtained for them. The theory is then applied to several problems in which the medium is plane or cylindrically stratified, and the boundary is planar or circular. Expressions are determined for the exact solution to various boundary problems corresponding to these special problems. Asymptotic forms are obtained by using the method of stationary phase in conjunction with the WKB method and Watson transformations. The geometrical theory is verified, at least in these cases. Two shorter articles based on this report are in J. Acoust. Soc. Am., 31, 192-205 and 206-216 (see Abstracts 768 and 770).

1944

Seckler, B. D., and J. B. Keller, "Geometrical Theory of Diffraction in Inhomogeneous Media," J. Acoust. Soc. Am., 31, 192-205, 1959.

The geometrical theory of diffraction is described. It is used to to determine the diffracted fields in inhomogeneous media. Cases in which such media contain smooth convex bodies are treated. The theory employs an extension of Fermat's principle, which yields diffracted rays. The field associated with each ray is calculated by energy considerations. This requires the introduction of diffraction coefficients and decay exponents. General formulas for these quantities are given in terms of local properties of the medium and of the body.

1945

Takesada, Y., "On Sound Channel in Stratosphere," J. Geomagn. Geoelect. (Japan), 12, 171-174, 1961.

The sound channel is formed in accordance with the wind current and temperature distribution. When the sound ray has the same direction of propagation as the jet stream, the velocity minimum in the vertical distribution of the sound velocity exists to about 23 km in height. If the sound ray radiates from the ground, it is refracted at about 13 km in height, and comes back to the ground. When the sound ray has the opposite direction from the wind stream, the velocity minimum of the vertical sound velocity distribution occurs at the altitude of 12 km.

1946

Tolstoy, I., "Modes, Rays, and Travel Times," J. Geophys. Res., 64, 815-821, 1960.

Relationships between the normal-mode and the ray-optical interpretations of seismic and acoustic measurements are discussed, and applications to the theory and practice of refraction techniques are given. The validity of the ray theory is sometimes open to question; that is, the results of travel-time and intercept measurements may be subjected to overinterpretation in terms of rays. Several questions of principle are examined in this connection. It is emphasized that the idea of mode cannot be brought into direct correspondence with the rays and travel-times of the optical, approximate approach, and efforts to interpret mode behavior in terms of rays can lead to paradoxical conclusions. This can be understood in terms of the plane-wave, asymptotic nature of such concepts as phase and group velocity.

1947

Whipple, F. J. W., "Audibility of Explosions and the Constitution of the Upper Atmosphere," Nature, 118, 309-313, 1926.

The results of hundreds of acoustic observations made on a series of four scheduled, experimental explosions are described and presented in map form to show zones of silence and primary and secondary zones of audibility. Corresponding wind and temperature data in the lower atmosphere were taken, but winds and temperatures at higher altitudes were a subject for speculation.

Whipple assumes a negative temperature gradient from 0 to 12 km, an isothermal layer from 12 to about 32 km, and an increasing temperature from 32 km upwards. From this he calculates and shows in graph form a set of sound-ray paths that return to earth at distances comparable to the experimental results. The effects of winds on ray paths are described but not calculated.

1948

Whipple, F. J. W., "The Propagation to Great Distances of Air-Waves from Gunfire, Progress of the Investigation During 1931," Quart. J. Roy. Meteorol. Soc., 58, 471-478, 1932.

Earlier gunfire experiments are continued and acoustic data reported. Tables show air temperatures and the velocities of sound as measured on the ground and as calculated for tropopause heights as well as for maximum altitudes of sound-ray paths. The calculations are based on measured travel times and determinations of the arrival angles of sound rays at microphone arrays. Presents several upper air temperature profiles, to altitudes of 50 km, as calculated from acoustic data.

Ray Acoustics
See also—437, 460, 498, 522, 530, 550, 709, 745, 765, 768, 1405, 1416, 1435, 1436, 1438, 1439, 1442, 1443, 1466, 1467, 1491, 1520, 1534, 1538, 1548, 1556, 1801, 2061, 2090, 2190, 2222, 2297, 2298, 2309, 2413, 2518, 2876, 2944, 3224, 3270, 3298, 3319, 3329, 3331, 3337, 3347, 3349, 3351, 3365, 3366, 3547, 3680, 3735, 3877, 3883, 3898, 3899, 3962, 4210.

REFLECTION

1949

Alpher, R. A., and R. J. Rubin, "Normal Reflection of Shock Waves from Moving Boundaries," J. Appl. Phys., 25, 395-399, 1954.

The problem of the reflection of a shock wave from a moving boundary is examined in an idealized one-dimensional treatment. The headon collision of an incident step shock wave and a piston moving at constant velocity into a gas at rest are considered in detail. The calculation involves the headon collision of two shock waves and the subsequent reflection of an altered transmitted wave from the piston. The reflected pressure is calculated for a range of incident shock strengths and piston speeds. For a stationary piston, both the absolute and excess reflected pressures are at most eight times the absolute or excess pressure of the incident shock wave (with $\gamma = 7/5$).

With a moving piston, however, this limiting factor is greater than eight, but finite for finite piston speed and infinite incident shock strength, and is infinite for infinite piston speed and finite incident shock strength. This last result holds even in the limit of the incident wave's being an acoustic pulse.

The method of solution for shock-wave interaction with a piston receding at constant velocity is also indicated. Although the shock is strengthened on passing through the piston rarefaction wave, the reflected overpressure is less than that resulting from the same initial shock wave reflecting from a stationary piston.

1950

Anderson, D. V., "Reflection of a Pulse by a Concave Paraboloid," J. Acoust. Soc. Am., 24, 324-325, 1952.

For the special case of a rectangular pulse, Friedlander has computed the variation in the amplitudes of the pulse reflected from a concave paraboloid, with the distance from the axis. These calculations indicate that, in addition to the maximum on the axis, a secondary pressure maximum is to be found at a distance of approximately 0.75 times the focal length from the axis. The author has observed this phenomenon experimentally, using a pulse frequency of 180 kcs and a repetition rate of 100 cps.

1951

Antokolskii, M. L., "Reflection of Waves from a Rough Absolute Reflecting Surface" (in Russian), Dokl. Akad. Nauk SSSR, 62, 203-206, 1948.
ATI-137 914.

Experiments show that during the reflection of a lighter sound wave from a surface there exists not only a regularly reflected wave, but also a diffusion field created by the presence of surface roughness. Complete estimation of both diffusion and reflection fields is made only for the case where the surface roughnesses are small in comparison to the wavelength. This report refers to the regular reflection part of the field. The author determined the conditions at which this regular field has the nature of a normally reflected wave and computed the reflection coefficient in relation to the wavelength and angle of incidence. The transition from diffusion to regular reflection during a specific angle of incidence is a convenient means of determining the qualitative characteristics of a reflecting surface. The Kirchhoff law is the basic simplifying assumption in the calculation of surface characteristics.

1952

Arons, A. B., and D. R. Yennie, "Phase Distortion of Acoustic Pulses Obliquely Reflected from a Medium of Higher Sound Velocity," J. Acoust. Soc. Am., 22, 231-237, 1950.

Theoretical analysis predicts the occurrence of phase shifts when harmonic waves are reflected from interfaces of higher sound velocity (such as the sea bed in underwater sound propagation) at angles exceeding the critical angle of total reflection. Since the phase shift depends upon the acoustic parameters of the media forming the interface and upon the angle of incidence, and is independent of the frequency of the incident wave train, one would expect pulses of arbitrary shape to be subjected to distortion upon reflection.

The expected shape of the pressure wave reflected from a semi-solid bottom is derived for the specific case of exponentially decaying shock waves produced in underwater explosions, and the theoretical predictions are found to agree well with the observed pressure-time curves of the first and successively higher order reflections. The theoretical analysis assumes plane waves incident upon an interface between two fluid media. Experimental records were obtained at relatively great distances from the charge so that finite amplitude effects were neglibible and the radius of curvature of the wave front quite large.

1953

Barger, R. L., "Reflection and Transmission of Sound by a Slotted Wall Separating Two Moving Fluid Streams," Rept. No. TN 4295, Natl. Advisory Comm. Aeron., Washington, D. C., 14 pp., 1958.
AD-160 215.

The reflection and transmission coefficients have been determined for a plane sound wave incident on a slotted wall separating two moving fluid streams. This acoustics problem is related to the aerodynamic problem of determining the tunnel-wall interference on an oscillating airfoil in a slotted-throat wind tunnel, in that the same boundary condition is involved, with one of the two streams at the boundary having zero velocity. In analysis, the wall with discrete slots is replaced by an equivalent homogeneous boundary.

1954

Bies, D. A., "Effect of Reflecting Plane on an Arbitrarily Oriented Multipole," J. Acoust. Soc. Am., 33, 286-288, 1961.

Expressions for the power radiated by either a dipole or a quadrupole reflected in an infinite rigid plane are presented. These expressions are perfectly general in that they admit any orientation of the multipole and any kind of a quadrupole. The results include the special cases considered previously by U. Ingard and G. L. Lamb, Jr. (J. Acoust. Soc. Am., 29, 743, 1957). The large variations in radiated power observed for a single multipole tend to diminish when averages over a distribution of such multipoles are considered.

1955

Biot, M. A., "Reflection on a Rough Surface from an Acoustic Point Source," J. Acoust. Soc. Am., 29, 1193-1200, 1957.

A simple solution is developed for the reflected waves on a rough surface from a simple harmonic point source. It is assumed that the roughness is represented by a distribution of hemispherical bosses whose size and mutual distance are small relative to the wavelength. It is shown that under these conditions the effect of the roughness is equivalent to a boundary condition for the wave equation. This boundary condition embodies the surface polarization and the mutual interaction of the bosses. If the generating source lies above the reflecting surface the reflected wave is found to be equivalent to that originating from concentrated and distributed image sources on a line situated below the specular image, with a magnitude decreasing exponentially with depth.

The case of small, vanishing roughness is discussed, together with the field intensity at large distance and grazing incidence. The effect of fluid viscosity is also evaluated.

1956

Bleakney, W., and A. H. Taub, "Interaction of Shock Waves," Rev. Mod. Phys., 21, 584-605, 1949.

The phenomenon considered is the reflection of a plane shock wave from a rigid plane wall. The shock wave may be generated by bursting a plane diaphragm separating a high-pressure chamber from a shock-tube of rectangular section. Propagation of the shock is examined through windows on opposite sides of the tube by shadow-photography, the Schlieren technique, or interferometry. The light source used is a spark of short duration; successive sparks may be used to investigate time-variation of the flow.

The phenomena of reflection depend on the angle of incidence α ($\alpha = 0$ means normal incidence) and the pressure rise P_2/P_1 across the shock wave. For given P_2/P_1, the incident (I) and reflected (R) waves intersect at the wall when $\alpha \leq$ a limiting value α_s; when $\alpha \geq$ another limiting value α_0, I and R intersect at a triple point 0 some distance from the wall. Between 0 and the wall a Mach bridge wave (M) is formed. The theory of regular reflection (when I and R intersect at the wall) is presented: it is shown that for given P_2/P_1 regular reflection can occur only for $\alpha < \alpha_e$. This theoretical value α_e agrees, to within limits of exponential error, with the observed value α_s, but there exists a small range of values $\alpha_e < \alpha < \alpha_0$ for which the reflection phenomena are obscure. Mach reflection can at present be treated theoretically only by making additional assumptions regarding conditions around the point 0. If it is assumed that conditions are uniform in each of the 3 zones (IOR), (IOM), and (ROM), serious discrepancies exist between theory and experiment. These can be overcome by assuming a Prandtl-Meyer (angular) density-variation in the zone (IOM), but it is difficult to see how such a variation could occur ahead of the Mach bridge wave.

In an appendix, recent interferometric studies are reviewed. These show that in the zones (IOM) and (IOR), conditions are very uniform, but that in the zone (ROM) there is a density variation somewhat like the Prandtl-Meyer type.

1957

Brekhovskikh, L. M., "Focusing of Acoustic Waves by Means of Inhomogeneous Media," Soviet Phys. Acoust. English Transl., 2, 124-133, 1956.

The field of a pointed radiator in a lamellar nonuniform medium is represented in an intergral form in which reflection coefficients of plane waves occur. For sufficiently high frequencies coefficients of reflection can be calculated by the V.K.B. method. It is also possible to obtain, by a somewhat simpler procedure Haskell's, the equation for the caustic surfaces and to calculate the sound pressure near the cusp (examples given).

1958

Brekovskikh, L. M., "Reflection of Plane Waves from Inhomogeneous Layered Media" (in Russian), J. Tech. Phys. (USSR), 19, 1126-1135, 1949.

Theoretical. An investigation of the propagation of plane e.m. or acoustic waves in media whose properties depend only on a single Cartesian coordinate z. The treatment is characterized by two special features: (a) it is applicable to an arbitrary variation of the properties of the medium along the coordinate z, provided that the variation is not so rapid as to cause appreciable localized distortion of the plane incident wave; (b) the wave-propatation equations are, at an early stage, transformed into an equation in terms of the local reflection coefficient V(z).

The transformed equation is solved by Picard's method to give a series expansion for V(z). Two different series expansions are given; one in which the successive approximation starts from an initial equation of zero order in V (solution A), and another in which the initial is of first order in V (solution B). Solution B is, of course, much more rapidly convergent than solution A. This is illustrated by an example, dealing with reflection of a plane e.m. wave normally incident upon a medium in which the refractive index n changes from n_0 at $z = 0$, to n_1 at $z = \ell$ according to the law $n = n_0 [1 + (\beta - 1)\zeta]^{-1}$, where $\beta = n_0/n_1$, $\zeta = z/\ell$.

The exact solution of this problem was given by Rayleigh: the second-stage approximation from solution. A gives accurate results only up to $k_0\ell = 0.8$ (k_0 = wave no. in vacuo), but solution B (to the same order of approximation) gives values of the reflection coefficient agreeing with Rayleigh's to better than 1% for all values of $k_0\ell$.

1959

Brillouin, J., "Reflection and Refraction of Acoustic Waves by a Shock Wave" (in French), Acustica, 5, 149-163, 1955.

Investigates the reflection and refraction of acoustic waves incident upon the fluid regions on each side of a shock wave. Reflection occurs in the region of excess pressure, refraction in the region of reduced pressure. The characteristics of these waves are calculated for a plane, progressive, uniform incident wave. In the refracted case, the refracted acoustic wave can, according to the incidence, be plane, progressive and uniform or take the form of an onde d'accompagnement which remains attached to the front of the shock while sliding parallel to it. In each case geometric constructions allow the kinematic characteristics of the reflected or refracted acoustic waves to be determined. Dynamic relationships show that the amplitude of the reflected wave is always less than, but that of the refracted wave in certain cases greater than, the amplitude of the incident wave.

1960

Brillouin, J., "Reflection and Refraction of Acoustic Waves by a Shock Wave," Natl. Advisory Comm. Aeron., 42 pp., 1957. AD-134 968.

This paper treats the problem of reflection and refraction of sound waves by a plane, uniform shock wave separating two regions, in both of which the fluid pressure and temperature are originally in equilibrium. Calculations are made of conditions that prevail in the two regions after the equilibrium in either one or the other region has been upset by incidence of a plane, uniform acoustic wave. Dynamic relationships show that the amplitude of reflected waves is always less than that of the incident wave, but the amplitude of refracted waves may, in certain cases, be greater than that of the incident wave.

1961

Brode, H. L., "Reflection Factors for Normally Reflected Shocks in Air," Res. Memo RM-2211, Rand Corp., Santa Monica, Calif., 8 pp., 1958.
AD-156 025.

An algebraic discussion of shock reflection values in the higher pressure regions is presented. The ideal polytropic gas formulas are not suitable for the treatment of reflections of shock in these regions, since the equation of state for air indicates considerable variance. For simplicity, only the case of the normal reflection is considered.

1962

Cabannes, H., "Laws of Shock Reflection in Nonstationary Flow," Document No. ARA-400, Allied Research Associates, Inc., Boston, Mass., 34 pp., 1957.
AD-150 441.

Several results are given without the use of approximations on the problem of the encounter between a plane shock wave and a wedge. In the case of Mach reflection, the regions of uniform flow are delineated. Approximations are used when (1) the wedge angle is infinitely small and the shock is of any strength, and (2) the shock is infinitely weak and the wedge has any angle. Each of these cases can be treated with linearized equations.

1963

Chernous'ko, F. L., "The Reflection of Weak Converging Shock Waves in a Gas of Variable Density," Appl. Math. Mech., 25, 311-323, 1961.

Considers the effect of nonlinear terms near the centre (or axis of symmetry) on the discussion of the problem in dealing with the reflection of weak converging shock waves in a gas of variable density, and shows that the previous linearized treatment can be qualitatively unsatisfactory.

1964

Chester, W., "The Reflection of a Transient Pulse by a Parabolic Cylinder and a Paraboloid of Revolution," Quart. J. Mech. Appl. Math, 5, 196-205, 1952.

A direct comparison is made between the reflection of a sound-pulse obtained with a body of revolution and the corresponding cylinder. The theoretical treatment yields general information as to the relation between the diffraction effects induced by two-dimensional and axially symmetric barriers. At the common junction of the incident wave front, the reflected front, and the barrier, the pulse discontinuity reproduces the familiar doubling of pressure obtained in regular reflection. In other directions the discontinuity tends toward zero inversely as the square root of the distance from the focus in the case of the parabolic cylinder, and inversely as the distance for the paraboloid of revolution. The excess-pressure distribution along the boundary is calculated when the incident pulse is a simple step function.

1965

Craggs, J. W., "The Oblique Reflexion of Sound Pulses," Proc. Roy. Soc. (London), A, 237, 372-382, 1956.

It is observed that the classical theory of reflection of plane sound waves breaks down in the case in which a sound pulse is incident on a plane surface of separation of two media at such an angle that total reflection is to be expected. A sound wave is imagined to be generated by the supersonic motion of a thin wedge, and the motion when the wave meets the surface of separation is investigated by assuming dynamic similarity in the motion. It is shown that the solution of the problem is not of quasi-steady type, and that there is a diffused wave in the denser medium, with a wave front that preceeds the incident wave near the surface of separation. This wave is due to diffraction in the lighter medium around the edge of the incident wave. A further result is that there is still a reflected wave, and that its amplitude is equal in magnitude but opposite in sign to that of the incident pulse.

1966

Curtis, R. W., "Ultrasonic Absorption and Reflection Coefficients in Air and in Carbon Dioxide," Phys. Rev., 46, 811-815, 1934.

Ultrasonic absorption coefficients in air and in CO_2 have been measured, as well as the coefficients of reflection in these gases at a solid boundary. In the frequency range between 88 and 1000 kcs the absorption in air was found to increase with the square of the wavelength as required by classical theory, but for CO_2 the absorption constant of the classical theory rises to a sharp maximum at about 98 kcs. The reflection coefficient (brass reflector) was found to decrease being of the order of 20% at the higher frequencies. Measurements on an impure sample of helium are included.

1967

Doak, P. E., "The Reflection of a Spherical Acoustic Pulse by an Absorbent Infinite Plane and Related Problems, "Proc. Roy. Soc. (London) A, 215, 233-254, 1952.

Experimental results of the reflection of a short train of sine waves of about 10 m duration by an infinite plane absorption wall are analyzed and discussed theoretically in relation to blast waves and electromagnetic waves. Some possible direct applications are indicated as to reflection of blast waves and waves of transient radiation by an electric dipole.

1968

Dwyer, J., "On the Reflectivity of Materials—and Appendixes A and B," Memo No. 15D, Aero Service Corp., Philadelphia, 27 pp., 1951.
ATI-140 511.

Materials were tested for the efficacy with which they would reflect a sonic beam and for their durability in various water mediums. The tests were part of a program, the purpose of which was to provide data useful primarily to a designer and producer of sonic maps. In the first series of tests the flat material surfaces were positioned perpendicular to the sonic beam, and the percentage of return signal reflected by each surface—relative to the echo returned by hard brass—was recorded. In the second series, the angle of beam incidence was varied, as was also the type and size of surface depression (or proturberance) in the test specimen. The third series consisted of electrolytic tests of metallic materials such as "city" pieces, in pure water and in different kinds of hard water. A visual description of the deposit formed on the materials over a period of four days was recorded. The test procedures employed are described and the results are tabulated.

1969

Eisner, F., and K. Kruger, "Reflecting Power of the Earth's Surface for Sound Waves Incident Normally," Hochfrequenztech. u. ElektAkust., 42, 64-67, 1933.

Sound waves of a frequency of 2900 cps were sent out from a whistle on board an airship and were received at the other side of the gondola by a microphone tuned to the whistle. The received sound was amplified by a three-valve apparatus and the intensity recorded by an impulse-measuring instrument. The reflecting power of water being taken as unity, that of thin ice is 1.07, of meadow land 0.49, and of pine woods from 0.21 for young trees to 0.45 for full-grown trees. With the varying nature of country, the height above the ground for a given intensity of echo varies as the square root of the reflection coefficient.

1970

Embleton, T. F. W., "The Propagation and Reflection of Sound Pulses of Finite Amplitude," Proc. Phys. Soc. (London), B, 69, 382-395, 1956.

Discusses experimental results covering many aspects of the propagation and reflection of finite-amplitude sound pulses and weak shock fronts. These are compared with theory and show amongst other features (a) that an N-shaped wave form tends to shorten on reflection and (b) that a shock front disappears on reflection at an open-ended tube.

1971

Finkelstein, R., "The Normal Reflection of Shock Waves," Phys. Rev., 71, 42-48, 1947.

The problem is solved by an approximate analytical integration of the hydrodynamical equations. It is found that in compressible fluids (gases) the pressure on the reflector is prolonged and the impulse delivered to it is greater than the value predicted by the acoustic theory. In slightly compressible media (liquids and solids), the blow is shorter and the impulse delivered to the reflector is less than predicted.

1972

Fischer, F. A., "Distribution of Sound from Sources in the Neighborhood of Plane Reflectors," Elek. Nackr.-Tech., 10, 19-24, 1933.

When sound is emitted from a point source near a reflecting surface, the effect at a distance is that of an acoustical doublet composed of the source and its image. Polar diagrams are drawn to show the sound distribution for typical cases when (a) there is no phase change, and (b) the reversal of phase occurs at the reflecting surface. In case (a) a maximum of intensity always occurs in the plane of the reflector, and other maxima and minima occur in directions inclined to this plane. In case (b) a minimum is always found in the plane of the reflector, and provided the source is not more than a quarter wavelength from the reflector, nowhere else. On increasing this distance other maxima and minima appear. If, instead of a single source, a series of equidistant sources on a normal to the surface is used, in case (a) the maximum in the plane of the reflector becomes relatively much greater; similarly the first maximum in (b), which is in a direction inclined to the surface, is more pronounced. Formulae are given in each instance for the acoustical energy of the system; and the application of the resultsto signalling on land and below the surface of water is discussed.

1973

Fletcher, C. H., A. H. Taub, and W. Bleakney, "The Mach Reflection of Shock Waves at Nearly Glancing Incidence," Rev. Mod. Phys., 23, 271-286, 1951.

The interaction of a plane shock wave in air with a plane rigid wall involves (1) a regular reflection in which the incident shock is followed by a reflected shock that joins the incident shock wave at the wall; and (2) Mach reflection in which the reflected shock wave meets the incident shock at a triple point or line at some distance from the wall, and is joined to it by a third shock wave (usually curved) called the Mach shock.

The mathematics of the Mach reflection of shock waves at nearly glancing incidence is here developed by linearizing both the differential equation of wave propagation and the boundary condition. The methods employed by Bargmann, by Lighthill, and by Ting and Ludloff (J. Roy. Aeronaut. Soc., 18, 143, 1951) are discussed, and their results compared with experimental results. Preliminary experiments have shown qualitative agreement with Bargmann's results. Experimental evidence indicates that the observed slip streams are density discontinuities, and occur in the reflection of any shock at suitable angles not in the region of near-glancing incidence. For strong incident shocks, there is agreement between the observed shock configuration and that required by the local three-shock theory.

The slip stream in the case of weak incident shocks, where the configuration violates the local three-shock theory, appears, experimentally, to be a sharp density discontinuity; a calculation similar to that of Ting and Ludloff, but for weak shocks, would show a broad region of changing density. The fundamental problem of Mach reflection of weak shocks has not yet been solved.

1974

Franken, P. A., and U. Ingard, "Sound Propagation into a Moving Medium," J. Acoust. Soc. Am., 28, 126-127, 1956.

In the study of transmission of sound into a moving medium, if flow speeds larger than twice that of sound are allowed, the analysis indicates at least formally the existence of two critical angles between which total reflection occurs. A discussion of the corresponding behavior of the angle of refraction and the reflection coefficient is presented.

1975

Friedlander, F. G., "The Diffraction of Sound Pulses, IV. on a Paradox in the Theory of Reflexion," Proc. Roy. Soc. (London), A, 186, 356-367, 1946.

A plane sound wave is reflected by an infinite plan reflector, and the "simple" theory indicates that the pressure at the reflector is double that of the incident wave, irrespective of the angle of incidence, θ. As $\theta \rightarrow 90^{\circ}$ the doubling persists; but there is no reflection and there should be no doubling of the pressure. To explain this paradox the simple theory is abandoned. The reflection of sound pulses by a semi-infinite screen is examined in detail and it is shown that as $\theta \rightarrow 90^{\circ}$ the diffracted pulse which emanates from the edge of the screen must also be considered, so that the region in which the simple approximate theory holds moves away from the edge. In the limit, the simple theory must be abandoned at all points at a finite distance from the edge. Reflection of sound pulses by infinite wedges is also considered.

1976

Friedlander, F. G., "On the Total Reflection of Plane Waves," Quart. J. Mech. Appl. Math., 1, 376-384, 1948.

Considers the reflection and refraction of transverse plane waves at an interface to the direction of polarization when the incident wave is of arbitrary shape and the angle of incidence exceeds the critical angle. It is shown that the solution of this problem depends on the determination of a plane harmonic function $h(\xi, \eta)$ satisfying the condition

$$\left(\frac{\partial h}{\partial \xi}\right)_{\eta=0} - \gamma\left(\frac{\partial h}{\partial \eta}\right)_{\eta=0} = 2f'(\xi),$$

where γ is a known constant and $f'(\xi)$ a given function. By using the 1/2-plane analogue of Poisson's formula, $h(\xi, \eta)$ can be expressed in terms of $f'(\xi)$.

The results show that the reflected and transmitted disturbances exist everywhere at all times even when the incident wave has a well defined front, and that the transmitted disturbance due to an incident simple pulse is of the order of the reciprocal of the distance from the interface, when this distance is large. It is pointed out that the same analysis can be applied to the treatment of the total reflection of electromagnetic waves of arbitrary shape.

Finally, the propagation of waves of arbitrary shape over the surface of a semi-infinite elastic solid is considered, and shown to be possible when the velocity of propagation is that of Rayleigh waves.

1977

Gilman, G. W., H. B. Coxhead, and F. H. Willis, "Reflections of Sound Signals in the Troposphere," J. Acoust. Soc. Am., 18, 274-283, 1945-1946.

Experiments directed toward the detection of nonhomogeneities in the first few hundred feet of the atmosphere were carried out with a low power sonic "radar." The device has been named the sodar. Trains of af sound waves were launched vertically upward from the ground, and echoes of sufficient magnitude to be displayed on an oscilloscope were found. Strong displays tended to accompany strong temperature inversions. During these periods, transmission on a microwave radio path along which the sodar was located tended to be disturbed by fading. In addition, relatively strong echoes were received when the atmosphere was in a state of considerable turbulence. There was a well-defined fine-weather diurnal characteristic. The strength of the echoes led to the conclusion that a more complicated distribution of boundaries than those measured by ordinary meteorological methods is required in the physical picture of the lower troposphere.

1978

Gold, L., "Analysis of Multiple-Echo Effect Rising from the Release of a Stored Wave Train," J. Acoust. Soc. Am., 23, 214-218, 1951.

A generalized theoretical treatment is presented of a problem which has direct application to the phenomenon of multiple-echo patterns as employed for propagational studies of hf sound waves in various media. Analyzed are the functional dependence of the number of observable echoes N in terms of a prescribed threshold sensitivity db^* of a detecting device, and the storage medium parameters, which are the effective absorption coefficient a and the boundary reflection coefficient R. The equation derived is:

$$N = \{db^*/10 + \log R - \log (1 - R)\}/\{\log R - \alpha d \log\} e$$

where d is the length of the storage system. This relation has values R_{opt} for which N is a maximum, and it is shown that $N_{max} = 1/(1 - R_{opt})$.

1979

Goodman, R. R., "Reflection from a Thin Infinite Plate Using the Epstein Method," J. Acoust. Soc. Am., 33, 1096-1098, 1961.

In the calculations concerning the vibrations of thin elastic shells, several approximations called "shell-theories" have been introduced in an attempt to simplify the mathematical formalism. In this paper one of these approximation methods, known as the Epstein method, is used to obtain the reflected field produced by a plane wave impinging on an infinite plane. The results are given to first order in kh, where k is the wave number and 2h is the thickness of the plate. A comparison with the exact results shows exact agreement to first order.

1980

Goodman, R. R., W. Meecham, et al., "The Reflection and Transmission of Sound by Elastic Shells," Rept. No. 2784-5-T, Inst. Sci. Tech., Univ. of Mich., Ann Arbor, 20 pp., 1960.
AD-247 741.

The sound fields resulting from a plane wave incident on a spherical elastic shell are found. Then both the internal and external fields due to the shell are considered. Several limiting cases of the spherical shell are considered and compared with well-known results. The Rayleigh limit is discussed, and it is found that the external field is similar to that produced by a rigid sphere but with more complicated coefficients. The internal field is of a complicated nature but reasonable to consider for numerical computation. The sound fields for a hemispherical shell mounted on a rigid medium are obtained by the image method.

1981

Grace, J. C., "Reflection from a Statistical Array of Scatterers," J. Acoust. Soc. Am., 26, 103, 1954.

The average energy spectrum of the reflection from an array of randomly located point scatterers has been calculated. It is shown that this spectrum is proportional to the square of the sum of the individual scatterer amplitudes for wavelengths that are large compared to the extent of the array, and that it is proportional to the sum of squares of the individual amplitudes for wavelengths that are small compared to the array extent.

1982

Heaps, H. S., "Nonspecular Reflection of Sound from a Sinusoidal Surface," J. Acoust. Soc. Am., 27, 698-705, 1955.

The sound scattered from a sinusoidal surface of zero pressure irradiated by an obliquely incident plane sound wave is obtained as an infinite series of waves whose coefficients may be determined by means of a recurrence relation. The corresponding analysis is presented for the case of a spherical source of radiation. At points sufficiently remote from the surface only a finite number of terms need be included. Each coefficient in the series is itself an infinite series which converges most rapidly when the height of the surface corrugation's is small compared to the wavelength of the incident sound.

Application is made to determine the average intensity and fluctuation of the sound reflected from a travelling sinusoidal boundary. The degree of roughness required to destroy the effect of Lloyd mirror fringes is discussed in terms of the ratio of the surface height and wavelength to the wavelength of the incident sound.

1983

Heaps, H. S., "Reflection of a Plane Acoustic Wave from a Surface of Non-Uniform Impedance," J. Acoust. Soc. Am., 28, 666-671, 1956.

Journal article based on the study covered by the following entry.

1984

Heaps, H. S., "Reflection of a Plane Acoustic Wave from a Surface of Non-Uniform Impedance," Nova Scotia Tech. College, Canada, 6 pp., 1956.
AD-140 841.

A theoretical analysis made of the reflection of a plane wave of sound from a surface whose acoustic impedance is not uniform. The sound pressure received at a distant point consists of a specularly reflected wave plus scattered radiation. The magnitude of the specularly reflected wave is independent of wavelength and depends upon the impedance of the portion of the surface which may be viewed at the specular angle from the receiver. If the impedance differs only slightly from a constant value the directivity pattern of the scattered radiation is determined by the product of three factors. The necessary conditions for the scattered radiation to obey Lambert's cosine law are that the reflecting surface be one of approximately zero pressure and that there be no correlation in the impedance irregularities. The condition for perfectly diffuse scattered radiation is that the surface behave as if approximately rigid, with no correlation in the impedance irregularities.

In the case of a surface whose impedance irregularities have a slow statistical variation with position the scattered radiation is confined to a beam whose axis lies along the direction of specular reflection, but the energy within the beam is not necessarily closely confined to the specular angle.

1985

Heller, G. S., "Reflection of Acoustic Waves from an Inhomogeneous Fluid Medium, I," J. Acoust. Soc. Am., 25, 1104-1106, 1953.

The reflection coefficient for plane waves obliquely incident on a medium in which the velocity exponentially decreases is computed approximately, using the WKB method, and compared with a computation from the rigorous solution. The approximate reflection coefficient $1/[16(\omega/g)^2 \cos^6 \theta + 1]$ where ω is the angular frequency; g is the velocity gradient at the start of the exponential decrease; and θ is the angle of incidence, and is within 0.05 percent of the rigorous value for $\omega/g \geq 5$ at normal incidence, and within 5 percent of the rigorous value for $\omega/g \geq 20$ for angles of incidence up to about 45°.

1986

Herzfeld, K. F., "Reflection of Sound," Phys. Rev., 53, 899-906, 1938.

The losses in the reflection of sound on solids are investigated. The heat conduction of the solid disturbs the temperature distribution in the gas and sets up a temperature wave. That the pressure in the gas near the wall is no longer in phase with the density results in a heating of the gas on the wall. The effect amounts to a few percent for a million cycles. The scattering of the molecules on the wall, the scattering of the sound waves by uneven places, and the effect of absorption are also investigated. They become important only at higher frequencies.

1987

Hickling, R., "Frequency Dependence of Echoes from Bodies of Different Shapes," J. Acoust. Soc. Am., 30, 137-139, 1958.

The echo returned by a body is known to be frequency dependent if the incident sound has wavelengths greater than or comparable with the over-all dimensions of the body. This paper presents the results of calculations which determine the echoes from the end-on aspect of a rigid prolate spheroid of fineness ratio 5/3, and from the beam-on aspect of an infinite circular cylinder, the incident sound consisting of plane monochromatic waves. These are compared with similar known results for a sphere. For these examples it is shown that the frequency dependence of the echo varies significantly with the shape of the body which returns the echo. It is suggested that bats use such properties in determining the form of their surroundings.

1988

Howes, W. L., "Ground Reflection of Jet Noise," Rept. No. TN-4260, Natl. Advisory Comm. Aeron., Washington, D. C., 56 pp., 1958.
AD-156 898.

The effect of a reflecting plane is determined from theory and experiment. From the theoretical characteristics of far-field acoustic decay a correction-to-free-field procedure is developed for data obtained in the presence of a plane. Measurements of jet noise indicated the practical significance of reflections. Several theoretical predictions were confirmed from experimental decay curves and corrected spectra.

1989

Ingard, U., "Influence of Fluid Motion Past a Plane Boundary on Sound Reflection, Absorption, and Transmission," J. Acoust. Soc. Am., 31, 1035-1036, 1959.
AD-226 926.

The effect of fluid motion past a plane boundary on the reflection and absorption of sound is equivalent to an increase of the normal acoustic impedance of the boundary by a factor $(1 + M \sin \theta)$, where θ is the angle of incidence of the sound wave, and M is the Mach number of the flow velocity component in the incidence-reflection plane of the wave. Similarly, the acoustic energy flux perpendicular to the boundary and the flow is shown to be increased by the same factor. Reflection and transmission coefficients of a thin solid interface between a fluid in motion and one at rest are given. Furthermore, some comments on the problem of transmission in ducts are given. For propagation between two plane parallel boundaries with the same acoustic admittance, for sufficiently small values of the admittance, the sound pressure attenuation constant of the fundamental mode is modified approximately by the factors $(1 + M)^{-2}$ and $(1 - M)^{-2}$ for downstream and upstream propagation, where M is the flow Mach number.

1990

Ingard, U., "On the Reflection of Sound from a Grating," J. Acoust. Soc. Am., 33, 812-813, 1961.

The reflection of sound from a grating is discussed in the case when the slit-width of the grating is small compared to half a wavelength of the incident sound. Then only the specular reflection will be present. The corresponding reflection coefficient is determined as a function of the angle of incidence of the sound and the results are applied to study the influence of a floor grating on the acoustic performance of an anechoic room.

1991

Ingard, U., "On the Reflection of a Spherical Sound Wave from an Infinite Plane," J. Acoust. Soc. Am., 23, 329-335, 1951.

Treats the reflection of a spherical sound wave from a wall with the boundary conditions expressed in terms of a normal impedance independent of the angle of incidence. It is shown that the integral for the reflected wave can be evaluated exactly in closed form under certain conditions. The solution given for an arbitrary normal impedance involves a slight approximation of the integral. The reflected wave is brought into such a form that it can be considered as originating from an "image source" having a certain amplitude and phase. Graphs for determining this amplitude and phase are given in terms of a "numerical distance," which depends on the normal impedance and the position of the field point. Pressure distributions around point sources for different wall impedances are shown. The limitations in simulating plane wave conditions at a boundary and the corresponding effect on free-field methods of measuring acoustic impedance are discussed.

1992

Ingard, U., and G. L. Lamb, Jr., "Effect of a Reflecting Plane on the Power Output of Sound Sources," J. Acoust. Soc. Am., 29, 743-744, 1957.

The presence of a reflecting plane boundary will affect the power output of a sound source located above it. This effect may be expressed as a "power amplification factor," which was calculated for a number of elementary sound sources (monopole, dipole and longitudinal quadrupole) as a function of the distance between the plane and the source. Special attention was given to the evaluation of the source-height corresponding to minimum power output, and to the ratio between the maximum and minimum power radiated.

1993

Kastner, S., "The Reflection and Transmission of a Plane Sound Wave Incident at any Angle on a Layer-System Viscoelastic Medium, II" (in German), Ann. Physik, 19, 102-115, 1956.

Materials may be classified acoustically into two groups: those in which compression and shear waves appear (Group A) and and those in which compression and shear waves can be propagated (Group B). The reflection and transmission of plane waves through a layered system of viscoelastic material of Group A was discussed in Part I; in this part, the propagation of waves through a layered system composed of four different arrangements of Group A and Group B materials is considered theoretically.

1994

Kastner, S., "The Reflection and Transmission of a Plane Sound Wave Incident at any Angle on a Layered Viscoelastic Medium" (in German), Ann. Physik, 18, 190-219, 1956.

The propagation of a sound wave through an infinite viscoelastic medium is discussed theoretically. The treatment is then extended, using a matrix notation, to a system of n parallel plane layers of viscoelastic material; from the chain matrix of the system, expressions are derived for the reflected and transmitted waves as a function of the incident wave.

1995

Kawamura, R., and H. Salto, "Reflection of Shock Waves, I, Pseudo-Stationary Case," J. Phys. Soc. Japan, 11, 584-592, 1956.

Results of theoretical and experimental investigations on shock reflection at a fixed wall are reported. In the region of regular reflection, theory and experiment are found to agree well, except that experimental points extend slightly beyond the theoretical limit. A theoretical investigation of the flow characteristics is made on Mach reflection cases with the conclusion that singularity would appear at the triple point, and hence the reflected shock angle would not coincide with the theoretical one when the flow is subsonic behind the reflected shock. This theoretical prediction is fully confirmed by the results of shock-angle measurement in schlieren pictures obtained by the experiment.

In case of a strong incident shock, the angle of the reflected shock decreases discontinuously at the transition from regular to Mach reflection, as expected from the theory. In case of a weak incident shock, on the other hand, its change is continuous, which stands against the ordinary three-shock theory. It is found in the experiment that the boundary between these two cases takes place approximately at $\xi = 0.42$, where ξ is the pressure ratio across the incident shock. This agrees well with the theoretically predicted value, $\xi = 0.433$, above which the Mach reflection with a singularity at the triple point would appear. It corresponds to the condition of the stationary Mach reflection.

Also in this paper are comparisons of theory and experiment on the condition at which the flow behind the incident shock is just sonic relative to the triple point and on the angle of the Mach stem. A shock tube was used throughout.

1996

Keller, J. B., "Reflection and Transmission of Sound by a Moving Medium," J. Acoust. Soc. Am., 27, 1044-1047, 1955.

The reflection and transmission of sound by a moving medium are investigated theoretically and the reflection and transmission coefficients are determined. These coefficients are found to depend only upon that component of the velocity of the medium which lies in the plane of incidence. The reflection coefficient increases with the velocity of the moving medium until a velocity is reached at which total reflection occurs. Total reflection persists until a still higher velocity is reached, above which the reflection coefficient decreases as the velocity increases.

1997

Kinber, B. E., "Solution of Inverse Problem Geometric Acoustics," Soviet Phys. Acoust., English Transl., 1, 235-239, 1957.

The problem is considered of two reflecting or two refracting surfaces, by means of which a given field can be transformed into another given field. The full set of differential equations for the problem is obtained. A solution is worked out assuming the correctness of the laws of geometrical acoustics (or optics).

1998

Kontorovich, V. M., "Reflection and Refraction of Sound by Shock Waves," Soviet Phys. Acoust. English Transl., 5, 320-330, 1960.

This paper considers the reflection and refraction of small perturbations, mainly sound, at surfaces of discontinuity in a liquid or gas in general. At the discontinutiy it is assumed that the Rankine-Hugoniot conditions are satisfied. The coefficients of reflection and transmission of sound are determined and the reflection and refraction laws are given in simple geometric form. The author cites data which can be obtained by means of the acoustic "localization" of discontinuities.

1999

Kontorovich, V. M., "Reflection and Refraction of Sound by a Shock Wave," Soviet Phys. JETP, English Transl., 6, 1180-1181, 1958.

Theoretical note giving general expressions which, for oblique incidence, are more accurate than those given by Brillouin and, for normal incidence and an ideal gas, reduce to those previously obtained. (Acustica, 5, 149-63 (1955) (In French)).

2000

Kosachevskii, L. Ya., "The Reflection of Sound Waves from Stratified Two-Component Media," Appl. Math. Mech., 25, 1608-1617, 1961.

This paper is concerned with the solution of the problem of the propagation of plane sound waves in a two-component medium with a stratified structure, on the basis of Biot's equations. General expressions for the reflection and transmission coefficients are obtained for an arbitrary number of strata. The particular case of a single stratum is studied in greater detail. The two-component medium is further treated as a porous medium with an elastic skeleton (matrix) and pores that are filled with a viscous compressible fluid.

2001

LaCasce, E. O., Jr., "Some Notes on the Reflection of Sound from a Rigid Corrugated Surface," J. Acoust. Soc. Am., 33, 1772-1777, 1961.

The Rayleigh solution for reflection from a corrugated surface, and some possible modifications, are examined. For small slopes these methods produce similar analytical expressions and almost identical numerical results. When the first nonradiating term is included in the computations, the magnitude of the scattered amplitudes is essentially the same, but an estimate of the phase-change as a function of frequency is provided. For larger slopes, differences appear in the analytical form as well as in the numerical results. The Rayleigh expression has advantages above cutoff, while a new approach seems better before and just after cutoff.

2002

LaCasce, E. O., Jr., B. D. McCombe, and R. L. Thomas, "Measurements of Sound Reflection from a Rigid Corrugated Surface," J. Acoust. Soc. Am., 33, 1768-1771, 1961.

An examination of the scattering process in the vicinity of cutoff is made using rigid surfaces with sinusoidal corrugations which have a maximum slope near one. Measurements of the specular amplitude for several angles of incidence are presented with small increments in frequency. The ratio of the pressure amplitude at the peaks and troughs of the corrugations as a function of frequency is also observed for several angles of incidence.

2003

Lapin, A. D., "Reflection of Normal Modes at the Closed End of a Waveguide," Soviet Phys. Acoust., English Transl., 8, 145-147, 1962.

The author considers the two-dimensional problem of normal modes reflected from the end of a waveguide closed off by a rigid or compliant wall, oriented at a 45° angle with respect to the waveguide axis. By examination of the specular reflection in the plane of the end wall, this problem is found to be equivalent to that of sound propagation in two identical waveguides joined end-to-end at right angles. This problem is solved by "knitting" the fields at the boundaries of the regions in which the eigenfunctions are known. For the normal-mode amplitudes of the reflected field an infinite set of algebraic equations is obtained, which is solved by numerical reduction for several ratios of waveguide width to acoustic wavelength. The results are used to solve the problem of plane wave scattering on a sawtooth surface.

2004

Levine, H., "On the Theory of Sound Reflection in an Open-Ended Cylindrical Tube," Tech. Memo. No. 32, Acoustics Res. Lab., Harvard Univ., Cambridge, Mass., 53 pp., 1953.
AD-18 357.
Also in J. Acoust. Soc. Am., 26, 200-212, 1954.

A study was made of plane-sound-wave propagation within a cylindrical tube having an arbitrary cross section and extending indefinitely from an open end. The reflection coefficient and the end correction (which characterizes the reflection coefficient at wavelengths that are large compared to the transverse tube dimensions) comprise a boundary-value formulation of the wave-propagation problem. The solution involves integral equations which in general cannot be evaluated exactly. Practical techniques including stationary or variational principles were employed to determine approximately the physical quantities. Another technique was based on the initial modification of an integral equation to utilize the possibility of an explicit and rigorous solution. Approximate forms of the reflection coefficient and end-correction were obtained that yielded exact results for a tube of circular cross section. A brief comparison is included of the different formulations with reference to the circular tube.

2005

Lysanov, Iu. P., "Theory of the Scattering of Waves at Periodically Uneven Surfaces," Soviet Phys. Acoust., English Transl., 4, 1-10, 1958.

Reviews theories of wave scattering from uneven surfaces (applicable to reflection of sound waves from earth or ocean surface, radio wave reflection, submarine acoustic propagation, etc.). Discussed in particular are the methods of: (1) Rayleigh, (2) small disturbances, (3) L. M. Brekhovskikh, (4) integral equations, (5) V. Twersky, and (6) L. N. Deriugin. The literature references include Russian (25) and other (54) papers on radio- and acoustic-wave scattering.

2006

Mandl, P., "Reflection of a Plane Acoustic Shock by a Surface of Revolution," Aeron. Rept. No. LR-289, Natl. Aeronautical Establishment, Canada, 1961.
AD-248 520.

The influence of a structure on the pressure field and form of a passing shock wave, and that of the shock wave on the structure, are of considerable practical and theoretical interest. Existing two-dimensional theory is extended to the case of bodies of revolution. Although the resulting series solutions for the general case are rather unwieldy, they permit certain conclusions about the transient loading on a structure as a function of the principal curvatures of its boundaries. When the solutions are applied to the particular case of a spherical reflector, they are considerably simplified, and permit the transient loading and the blast impulse at various positions on the boundary to be calculated for various forms of incident front. The solutions converge well near the stagnation point but are less satisfactory near the shadow boundary. The results compare well with previous two-dimensional calculations. Certain extensions of the theoretical approach are suggested.

2007

Meecham, W. C., "Fourier Transform Method for the Treatment of the Problem of the Reflection of Radiation from Irregular Surfaces," J. Acoust. Soc. Am., 28, 370-377, 1956.
AD-79 305.

A method is presented which can be used for the calculation of the distribution of energy reflected from irregular surfaces. The formulation is useful for the first-boundary value problem and can be used in either two- or three-dimensional problems with any given incident field. The solution is reduced to quadrature with negligible error when the average square of the slope of the reflecting surface is small and when the wavelength of the incident radiation is not small compared with the displacement of the surface from its average value. A numerical example, the sinusoidal surface, is worked and is compared with experiment and with a method due to Rayleigh. It is found that the Fourier transform method is preferable to previous methods, noteably those that can be classified as physical optics (such as Rayleigh's), since the error in the transform method is of second order in the surface slope whereas the error in previous methods is of first order in the same quantity.

2008

Metz, A., "Refraction and Total Reflection of Waves in Media in Motion," Compt. Rend. Acad. Sci. (Paris), 250, 3591-3592, 1960.

The theory of the refraction and reflection of a plane acoustic wave when passing from one medium to another in which the wave velocity is different is discussed for the case in which there is relative motion between the two media.

2009

Metz, A., "The Total Reflection of Waves in Moving Media," Compt. Rend. Acad. Sci. (Paris), 250, 3796-3804, 1960.

Previous papers have shown that sound waves or ultrasonic waves propagated in media undergo refraction and total reflection not only when they pass from one medium to another where the speed of propagation is different, but also when the media are moving relative to one another. General formulae relating to these phenomena were given previously and the present paper derives a more exact formula relating to the propagation of waves under such conditions. Formulae derived in previous papers are used without detailed explanation.

2010

Miles, J. W., "Dispersive Reflection at the Interface Between Ideal and Viscous Media," J. Acoust. Soc. Am., 26, 1015-1018, 1954.

The effects of viscosity and heat conduction (in the reflecting medium) in producing dispersive reflection of a plane wave at the plane interface separating two media are investigated. If the reflecting medium is treated as a condensed fluid, heat conduction is found to have no effect, while in first approximation, viscosity is found to produce no change in amplitude but rather a phase shift proportional to frequency (and therefore no phase distortion) at angles of incidence above critical and to produce no phase shift but amplitude distortion at angles below critical. This amplitude distortion is found to be important only in the neighborhood of a sharp wave front.

2011

Miles, J. W., "On Nonspecular Reflection at a Rough Surface," J. Acoust. Soc. Am., 26, 191-199, 1954.

The reflection of a plane wave at a rough interface separating two fluid media is examined in the approximation of "small roughness," so that second-order terms in the magnitude of the roughness may be neglected. Exact solutions are obtained when the roughness is harmonic, while asymptotic results are obtained for arbitrary distributions. The analysis deals principally with an incident wave that is harmonic in time, but the problem of the reflection of a pulse from a perfectly reflecting, sinusoidal boundary is solved. It is found that such a boundary acts as a band-pass filter of the nonspecular components of the reflected wave. Outside of this pass band the reflection is not only specular but distortionless. Rather less generality is possible when the boundary is not perfectly reflecting, but the pass band is found to be independent of the properties of the reflecting medium.

2012

Miles, J. W., "On the Reflection of Sound at an Interface of Relative Motion," J. Acoust. Soc. Am., 29, 226-228, 1957.

The reflection of a plane wave of sound at an interface between two perfect fluids is considered. Previous analyses of Rudnick, Keller, Franken and Ingard are found in error as a result of improper boundary conditions. It is found that, in addition to the possibility of total reflection in some range of angles of incidence at all finite, relative speeds, there exists the possibility of a reflection coefficient exceeding unity for sufficiently high, supersonic speeds; in particular, resonance may occur at one or more angles of incidence.

The question of the stability of the vortex sheet separating the two fluids also is discussed.

2013

Neubauer, W. G., "Theoretical Analysis of Monostatic Reflection in the Far Field of Rigid, Finite Objects," Rept. No. 5467, Naval Res. Lab., Washington, D. C., 22 pp., 1960.
AD-241 100.

The solution to the approximate integral form of the reflection in the "far field" was developed as well as a graphical, or numerical, method for the case of a rigid, finite plane rotated about an edge and for a wedge shape. The reflection may be conveniently presented in diagrams in the complex plane. Extension of the method was made to the case for the reflection amplitude at any orientation of a reflector. Physically measurable quantities are required in the evaluation of this sum. Although the evaluation is not exact, rapid, or inclusive of all reflection mechanisms, it does make possible the derivation of the reflection from shapes not analytically describable by a means other than the methods that give the reflection in terms of the radii of curvature of the reflecting surface.

2014

Noble, W. J., "On the Focusing Effect of Reflection and Refraction in a Velocity Gradient," J. Acoust. Soc. Am., 27, 888-891, 1955.

The divergence factor, which is important in the reflection of waves from a convex spherical surface, is shown to have its counterpart in plane reflection and refraction in the presence of a velocity gradient. Within a small angle approximation, a linear velocity gradient gives the ordinary spherical spreading of a pencil of rays; any discontinuity of gradient causes a divergence or convergence of the pencil. Analytical expressions and tables of typical values are calculated for four different cases.

2015

Oberhettinger, F., "On the Diffraction and Reflection of Waves and Pulses by Wedges and Corners," Tech. Summary Rept. No. 15, Mathematics Research Center, Univ. of Wisconsin, Madison, 48 pp., 1957.
AD-156 733.

Various problems are considered which arise in the theory of the excitation of a perfectly reflecting wedge or corner by a plane, cylindrical, or spherical wave field. The incident cylindrical wave is represented by a (acoustic or electromagnetic) line source parallel to the edge. The spherical wave is emitted by an acoustic point source or by a Hertz dipole with its axis parallel to the edge. The case of an incident plane wave field is obtained as the limiting case (for large distance of the source from the edge) of the cylindrical or spherical wave excitation. Various representations for the time harmonic solution of the problems are given. A straightforward method is applied, based on the representation of the incident field in the form of a Kontorovich-Lebedev transform. The results obtained and the relations to geometric optics are discussed. An asymptotic expansion is given for the far field excited by the incidence of a plane wave on a wedge. Also given are the expressions for the energy radiated from a Hertz dipole in the presence of a perfectly reflecting wedge or corner (antenna and corner reflector), and the pulse or transient solutions corresponding to the time harmonic problems.

2016

Olson, W., J. Patterson, and J. Williams, "The Effect of Atmospheric Pressure on the Reflected Impulse from Air Blast Waves," BRL Memo. Rept. No. 1241, Ballistic Research Laboratories, Aberdeen Proving Ground, Baltimore, 25 pp. 1960.
AD-234 998.

Reports measurements of reflected impulses in air blast waves generated by explosive spheres (up to one pound in weight) detonated under reduced ambient pressures simulating altitudes up to 100,000 ft. (8 mm of mercury). Analysis reveals that the data may be scaled according to Sachs' law.

2017

Ooura, H., "Reflection of Sound at Snow Surface" (in Japanese), Tokyo, 12, 273-275, 1950.

The reflections of sound at the snow surface were observed with the method of standing wave. If the amplitude of the incident wave is a, and that of the reflected wave is b, then the maximum amplitude of standing wave is a + b, and the minimum is a - b. These values were measured with the carbon microphone and the Brown tube. From these values the rate of absorption, $A = (a^2 - b^2)/a^2$, was calculated. The results, in tables, show that: (1) the rate of absorption A is very large; (2) the smaller the density, the larger the absorption; (3) for settled snow, the higher the frequency of sound, the larger the absorption; and (4) for settled snow, when the snow was warmed and wetted, the absorption increased.

2018

Pack, D. C., "The Reflection and Transmission of Shock Waves, I. The Reflection of a Detonation Wave at a Boundary," Phil. Mag., 2, 182-188, 1957.

It is shown that for a shock wave advancing through any physically real barotropic medium the nature of the reflected wave is uniquely determined by the relative shock impedance of the medium through which the incident wave passes and the medium upon which it falls. A simple criterion is found for determining the nature of the reflection of a detonation wave at the end of a block of explosive. Particular attention is paid to the examples of an explosive in contact with a gas, water or solid surface. Certain approximations, which may be useful when there is a reflected shock wave, are discussed.

2019

Pack, D. C., "The Reflection and Transmission of Shock Waves, II. The Effect of Shock Waves on an Elastic Target of Finite Thickness," Phil. Mag., 2, 189-195, 1957.

An examination is made of the variation with time of the pressure and velocity in an elastic target of finite thickness subject to the impact of a shock wave. The cycle of reflections and transmissions at the boundaries of the target is described in detail.

2020

Parker, J. G., "Reflection of Plane Sound Waves from an Irregular Surface," J. Acoust. Soc. Am., 28, 672-680, 1956.

A plane sound wave is assumed to be incident upon an irregular pressure release surface $z = \xi(x, y)$. The solution for a reflected field is regarded as a superposition of plane waves having an amplitude spectrum $A(k_1, k_2)$. Next, the Fourier transform $G(x, y)$ of $A(k_1, k_2)$ is introduced and subjected to the boundary condition on ξ. This leads to an integral equation for $G(x, y)$ that cannot be readily solved. However, if one causes $G(x, y)$ to depend exponentially on a function $u(x, y)$, then a differential equation may be derived from this integral equation, the solution of which gives an approximate form of $u(x, y)$; the degree of approximation involved depends on the smallness of ξ. This method is applied to the problem of sound scattering from a one-dimensional, sinusoidally corrugated surface, and the results are compared with experimental measurements of LaCasce and Tamarkin and also with the results of a Rayleigh theory. This comparison shows the predictions of the theory presented here to be as good as the Rayleigh theory in all cases and closer in the majority of cases.

2021

Parker, J. G., "Reflection of Plane Sound Waves from a Rough Surface," Naval Res. Lab., Washington, D. C., 29 pp., 1954. AD-54 126.

A theoretical study is made of the reflection of plane sound waves from a stationary pressure release surface which is almost planar, but which exhibits a definite roughness. A general solution for the velocity potential which describes the reflected field is given by a Fourier integral representation, but the direct application of the boundary conditions to this solution to determine the wave-amplitude coefficients is impracticable. The boundary condition transformed from the surface $z = \xi(x, y)$ to the plane $z = 0$ results in a phase factor $\exp i[u(x, y)]$, where u is obtained as the solution of a differential equation which involves ξ. In the case of sound reflection from a sinusoidally corrugated surface, the solution for u depends only on ξ for angles of incidence near normal. For angles near grazing, $\partial\xi/\partial x$ is of consequence; the points on the surface for which $\partial\xi/\partial x > 0$ are most effective in scattering sound.

An energy equation for the reflected sound is derived that relates the average intensity incident on a unit area of reflecting surface to an integration of the average intensities of the waves scattered from the unit area. A consideration of isotropic and unidirectional surface roughness shows that, for the former, the Fourier-Bessel transform of the autocorrelation function of $\exp i[u(x, y)]$ is important, while for the latter case, the one-dimensional correlation in the direction of the surface roughness is of significance.

2022

Parker, J. G., "Reflection of Plane Sound Waves from a Sinusoidal Surface," J. Acoust. Soc. Am., 29, 377-380, 1957.

The problem of calculating the specular component of the sound field reflected from a sinusoidal pressure release surface is discussed. The incident field is assumed to be plane and directed normally to the surface. Basically, the problem consists of obtaining the solution to a nonlinear differential equation derived in an earlier paper. This was done numerically and the results compared with existing experimental data on sound reflection from two differently formed surfaces. In one case agreement between calculated and measured values is quite good, while in the second case there is considerable discrepancy. A possible explanation of this discrepancy is given.

2023

Paterson, S., "The Reflection of a Plane Shock Wave at a Gaseous Interface," Proc. Phys. Soc. (London), 61, 119-121, 1948.

A plane shock wave falls normally on the interface between two ideal gases of molecular weights M, m and constant ratios τ, γ of specific heats. As a rule, the character of the reflected wave then depends only on the ratio $\tau M/\gamma m$. In exceptional cases, however, the type of reflection may change at a critical value of the incident intensity. An example of this is given.

2024

Ribner, H. S., "Reflection, Transmission, and Amplification of Sound by a Moving Medium," J. Acoust. Soc. Am., 29, 435-441, 1957.

The reflection and transmission process is analyzed for plane sound waves originating in air at rest and impinging obliquely on a plane interface with a moving stream. Use of a moving reference frame provides transformation to an equivalent aerodynamic problem of flows past a wavy wall—the rippled interface. The angles of incidence, reflection, and refraction are identified with the Mach angles. The angular relations and the amplitude relations (coefficients of reflection and transmission) are evaluated in closed form. In a graph, three zones can be distinguished in the plane of angle of incidence vs. Mach number of the moving medium: ordinary reflection and transmission, total reflection, and amplified reflection and transmission. Included are three loci of infinite reflection, i.e., self-excited waves. The energy balance is examined, and the source of amplification is concluded to be the energy of the moving stream. In appendices the results are generalized (1) for the case of two moving media and (2) for differing density and speed of sound in the two media.

2025

Robinson, A., "Wave Reflexion near a Wall," Proc. Cambridge Phil. Soc., 47, 528-544, 1951.

The field of flow due to a shock wave or expansion wave undergoes a considerable modification in the neighborhood of a rigid wall. It has been suggested that the resulting propagation of the disturbance upstream is largely due to the fact that the main flow in the boundary layer is subsonic. Simple models were produced by Howarth, and by Tsien and Finston, to test this suggestion, assuming the coexistence of layers of uniform supersonic and subsonic mainstream velocities. The analysis developed in the present paper is designed to cope with any arbitrary continuous velocity profile that varies from zero at the wall to a constant supersonic velocity in the mainstream. Numerical examples are calculated, and it is concluded that a simple inviscid theory is incapable of giving an adequate theoretical account of the phenomenon. The analysis includes a detailed discussion of the process of continuous wave reflection in a supersonic shear layer.

2026

Rose, M. E., "The Specular Reflection of Plane Wave Pulses in Media of Continuously Variable Refractive Properties," Phys. Rev., 63, 111-120, 1943.

The problem is treated by the wave theory. For the case in which the velocity of propagation and the radiation impedance vary sufficiently slowly that multiple reflection may be neglected, the reflection coefficient is obtained for monochromatic waves incident on a set of n plane-parallel plates. The result is used to obtain the reflection coefficient for a plane-wave pulse of arbitrary shape and duration. The reflected wave train consists of a series of pulses of the same form as the incident pulse, with the amplitude reduced by the value of the Fresnel reflection coefficient. Periodicity of the coefficient is unnecessary.

The results for the n-plate problem are generalized for monochromatic waves and pulses for the case of stratified media having reflective properties that vary continuously in any manner. The case of rectangular pulse is analyzed and application is made to the reflection in sea water and in the atmosphere.

2027

Schoch, A., "Reflection, Refraction and Diffraction of Sound," Trans. by F. J. Berry, Ministry of Supply, Armament Research Establishment, 77 pp., 1953.
AD-116 801.

The present state of theory and experiment on the reflection, refraction, and diffraction of sound is very thoroughly presented in this book-length paper. After a brief introduction, the work begins with a comprehensive review of fundamentals including the dynamics of sound waves in homogeneous media, Huygens' Principle, boundary conditions, and uniqueness of solutions. The various situations involving reflection and refraction are then treated, including plane waves at a plane interface, free boundary layer waves along a plane interface, nonplanar waves at a plane interface, plates, and laminated media. Finally, diffraction is treated as phenomena resulting from the presence of curved boundaries. The diffracting properties of cylindrical, spherical, and more complex obstacle shapes are investigated. An extensive bibliography containing 144 references is included.

2028

Shao-sung, F., "Reflection of Finite Amplitude Waves," Soviet Phys. Acoust. English Transl., 6, 488-490, 1961.

The paper considers the problem of reflection of a finite amplitude wave in the case when it impinges on the wall at an angle of $\pi/4$. The results, obtained by the method of successive approximations correct to the second approximation inclusive, reveal the following: (1) appearance of a wave of twice the frequency, the amplitude of which increases with distance; this wave is reflected according to linear acoustic laws; (2) the appearance of a wave with a frequency 2ω, with no increase in amplitude and having circular symmetry.

2029

Smith, W. R., "Mutual Reflection of Two Shock Waves of Arbitrary Strengths," Phys. Fluids, 2, 533-541, 1959.

Experiments were performed in air on the mutual reflection of a pair of weak shock waves of strength $\xi = 0.915$. The strengths of the shock waves were measured interferometrically. The regular reflection data agreed with the weak-shock regular reflection solution for the flow, and terminated at the extreme angle α_e; Mach reflection was found for larger angles.

Four sets of experiments were performed in air with pairs of mutually reflecting shock waves of unequal strengths. The strengths of these shock waves were also measured interferometrically. The regular data agreed with the weak-shock regular reflection solution for the flow. Mach reflection was found to occur for angles larger than the extreme angle. The experiments failed to resolve any of the difficulties concerned with Mach reflection.

2030

Twersky, V., "Certain Transmission and Reflection Theorems," Res. Rept. No. EM-54, Inst. Math Sci., Univ. of New York, 1953.
AD-18 647.

The well-known relation between the total energy cross-section of a scatterer and its forward scattered amplitude is extended to obtain an approximate transmission coefficient for a uniform planar distribution of parallel cylinders. An analogous reflection theorem for an arbitrary cylindrical boss on a perfectly reflecting plane is then derived; here the total cross-section of the boss is related to the scattering amplitude in the specular direction of reflection of the plane. This is extended to obtain an approximate reflection coefficient for a uniform distribution of cylindrical bosses on a plane.

2031

Twersky, V., "On the Non-Specular Reflection of Plane Waves of Sound," J. Acoust. Soc. Am., 22, 539-546, 1950.

Scattered reflection by various rigid, nonabsorbent, nonporous surfaces composed of either semicylindrical or hemispherical bosses (protuberances) on an infinite plane is analyzed. Exact solutions for the problem of the single boss and a plane wave at an arbitrary angle of incidence are derived through consideration of a cylinder or sphere and two simultaneously incident "image waves." Finite patterned distributions of such bosses are then treated and the far-field solution obtained, subject to the restriction that the secondary excitations of the various bosses be neglected.

2032

Twersky, V., "On the Nonspecular Reflection of Sound from Planes with Absorbent Bosses," J. Acoust. Soc. Am., 23, 336-338, 1951.

The nonspecular reflection of plane waves of sound from certain surfaces composed of absorbent bosses (semicylinders or hemispheres of arbitrary impedance) on an infinite plane of ∞ or 0 impedance is considered. Exact solutions are obtained for the problem of the single boss and then extended, subject to the single-scattering hypothesis, to obtain far-field solutions for certain planar distributions of bosses that have small radii compared with the wavelength.

The results are compared with those obtained previously for non-absorbent bosses, and it is shown that the effects of the finite impedance are most pronounced in the simple source terms of the scattered components and may lead to either a decrease or an increase in the radiation reflected at the specular angle. Another effect of the finite impedance (for the small finite distributions) is to shift the critical value of the angle of incidence for which the reflection at the specular angle consists only of the specular component—below this value the reflection at the specular angle is minimal, and above it, maximal. For the infinite uniform random distributions it is found that the effect of the bosses is essentially but to change the impedance of the plane—these effective impedances being functions of the angle of incidence and of the parameters and distribution of the bosses. The effect of the finite impedance of the bosses is most pronounced for these distributions, yielding terms much larger than those previously retained for the nonabsorbent bosses.

The results for the analogous distributions of cylinders and spheres are also given.

2033

Twersky, V., "On Scattering and Reflection of Sound by Rough Surfaces," J. Acoust. Soc. Am., 29, 209-225, 1957.

Random distributions of arbitrary identical protuberances on free or rigid base are considered, and the approximate reflection coefficients

$$R = \left|\frac{1 + Z}{1 - Z}\right|^2$$

and differential scattering cross-sections per unit area

$$\sigma(\vec{s}, \vec{k}_i) = \frac{\rho}{k^2}\left|\frac{f(\vec{s}, \vec{k}_i)}{1 - Z}\right|^2$$

are derived. Here

$$Z = \frac{\pi\rho f(k_o, k_i)}{k^2 \vec{n} \cdot \vec{k}_o} k$$

where $f(\vec{s}, \vec{k}_i)$ is the scattering amplitude of an isolated protuberance, $\vec{k}_i$, $\vec{k}_o$, and $\vec{s}$ are the directions of incidence, specular reflection (with respect to the base plane), and observation; $\vec{n}$ is the normal of the base; ρ is the average number of scatterers in unit area; and $k = 2\pi/\lambda$. (For a two dimensional "striated" surface Z is divided by π/k, and σ by $\pi/2k$). If the horizon angle β approaches zero (i.e., near grazing incidence), then the reflection coefficients approach unity minus terms of the order β, while the back scattering vanishes like β^4, β^2 for a free, rigid base.

Explicit forms are given for arbitrary hemispheres and circular semicylinders, and for the limiting cases of free and rigid surfaces with scatterer radii very small and very large compared to wavelength. The analysis is based on a Green's function formulation of the problem of a single configuration; R and σ follow from an approximation of the ensemble averaged energy flux which takes account of multiple coherent scattering. (The transmission problem of a "random screen" is treated simultaneously).

An elementary derivation is also given, and extensions to distributions of nonidentical scatterers are made.

2034

von Schmidt, O., and A. Kling, "Acoustical Refraction and Total Reflection" (in German), Physik Z., 41, 407-409, 1940.

The main objective of this study was to obtain evidence about the influence continuous change in speed or in acoustical density exerts upon the wave fronts of compressional waves. The Schlieren method of photography was applied to projectiles fired obliquely upward from a rifle. The angle of elevation was so chosen as to cause the upper branch of the bow wave to be horizontal and to move vertically upward. The trajectories of the elongated bullets passed through the cylindrical columns of hot air rising above either one candle flame or two candle flames in succession. It was found that bow waves occur for the continuous transition from one speed of wave propagation to another, that secondary bow waves exist, that when plane waves experience total reflection at the hot air the waves are damped across the right section of the beam. This fact is interpreted as the physical cause of total reflection.

2035

Walther, K., "Model Experiments with Acoustic van Atta Reflectors," J. Acoust. Soc. Am., 34, 665-674, 1962.

This article presents the same information as the report covered by the following entry.

2036

Walther, K., "Research on Sound Reflecting and Scattering Systems," Final Tech. Rept. No. 1972, Bendix Corp., Detroit, Mich., 26 pp., 1961.
AD-266 450.

A van Atta reflector consists of an array of radiators that are interconnected by transmission paths in such a way that the energy of an incident wave is reradiated back into the direction of arrival. The van Atta acoustic array consists of 36 conical horns (aperture 1 1/2 in.) arranged on a 9 x 9-sq-in. flat surface. The horns are interconnected by plastic tubing with reinforced walls.

Model experiments on backscattering from acoustic van Atta reflectors are reported. Airborne sound waves in the frequency range between 2.5 and 9.0 kc were used in these measurements and the reflector shows a uniform backscattering over a wider range of angular orientation than that of the conventional corner reflector in the frequency range between 2.5 and 6.0 kc. For higher frequencies the angular coverage of the van Atta reflector under test is limited by the directivity of the horns.

Some tests on an assembly of two van Atta reflectors, mounted at an angle of 60° with respect to each other, are reported. They show a more uniform angular response as compared to a cluster of corner reflectors in the frequency range from 2.5 to 5.0 kc.

2037

Zeldovich, J. B., and K. P. Staniukovich, "On the Reflection of a Plane Detonation Wave," Compt. Rend. Acad. Sci. URSS, 55, 587-590, 1947.

The mathematical theory of the reflection at an absolutely unyielding wall enables expressions to be derived for the explosion pressure, the velocity of sound in the products, and the impulse, on the standard theory of shock absorption. Assuming that pv^3 is constant not only along the isentropic but also along the Hugoniot adiabatic line, expressions are derived for the same three physical "constants."

2038

Zharkovskii, A. G., and O. M. Todes, "Reflection of Waves from an Isotropic Inhomogeneous Layer" (in Russian), Zh. Eksperim. i Teor. Fiz., 31, 815-818. 1956.

An approximate method for calculating the reflection coefficient of a plane electromagnetic wave from an isotropic inhomogeneous layer is given for a single space coordinate. The methods also can be used in acoustics.

Reflection-see also Parabolic Reflectors; Reverberation; Echo Ranging; Wave Propagation, Standing Waves
See Also—12, 25, 26, 284, 318, 368, 478, 530, 729, 739, 750, 757, 864, 873, 874, 875, 876, 877, 880, 883, 884, 885, 897, 902, 928, 930, 1145, 1385, 1460, 1754, 1794, 1932, 2039, 2048, 2052, 2063, 2078, 2106, 2107, 2108, 2137, 2149, 2244, 2990, 3026, 3329, 3348, 3349, 3463, 3475, 3555, 3565, 3579, 3602, 3615, 3622, 3639, 3672, 3683, 3697, 3730, 3772, 3777, 3791, 3825, 3854, 3917, 4060, 4075, 4181, 4210, 4312

REFRACTION

2039

Ablow, C. M., "Wave Refraction at an Interface," Quant. Appl. Math., 18, 1, 15-29, 1960.

A plane wave in one of two perfect gases moves toward the parallel plane interface between the gases. The wave is either continuous or headed by a shock front weak enough that entropy changes may be neglected. Using Riemann's solution for the appropriate hyperbolic partial differential equation, four equations are derived giving the details of the reflected and refracted wave motions. The equations are of first-order integro-differential or implicit functional form, depending on the boundary conditions, and must be solved simultaneously for four functions of a single independent variable. The equations are suitable for numerical step-by-step solution.

2040

Bergmann, P. G., "The Wave Equation in a Medium with Variable Index of Refraction," J. Acoust. Soc. Am., 17, 329-333, 1945.

The paper deals theoretically with the effects of density gradients in the atmosphere or in large bodies of water on the propagation of sound waves. It is found that the gradient of hydrostatic pressure in water is comparable in effect with a temperature gradient of $0.1^{\circ}F/100$ feet. This is negligible if the temperature gradient appreciably exceeds that value. Similar considerations can be applied to the case of sound in air. It is concluded that gravity terms can be disregarded except in certain extreme cases, e.g., at very low frequencies.

2041

Brekhovskikh, L. M., "Waves in Stratified Media" (in Russian), Izd. Akad. Nauk SSSR, Moscow, 502 pp., 1957.

This general but detailed text on wave motions of all types in stratified media treats radio and light (electromagnetic) waves in liquids and gases at great length; reflection and refraction of spherical waves and propagation in stratified media in detail; and sound waves in particular. Sound waves in liquids and gases are treated on a theoretical and empirical basis with numerous nomograms and schematic diagrams (pp. 325-359 and 445-458). The special case of acoustical propagation in a three-layer medium is treated on pp. 343-347 and group velocities on pp. 349-350. Focusing of sound waves is discussed on pages 455-458. Much of the work is based on the author's own research in underwater propagation (1954-56).

2042

Brillouin, J., "Reflection and Refraction of Acoustic Waves by a Shock Wave" (in French), Acustica, 5, 149-163, 1955.

Investigates the reflection and refraction of acoustic waves incident upon the fluid regions on each side of a shock wave. Reflection occurs in the region of excess pressure, refraction in the region of reduced pressure. The characteristics of these waves are calculated for a plane, progressive, uniform incident wave. In the refracted case, the refracted acoustic wave can, according to the incidence, be plane, progressive and uniform or take the form of an onde d'accompagnement which remains attached to the front of the shock while sliding parallel to it. In each case geometric constructions allow the kinematic characteristics of the reflected or refracted acoustic waves to be determined. Dynamic relationships show that the amplitude of the reflected wave is always less than, but that of the refracted wave in certain cases greater than, the amplitude of the incident wave.

2043

Brillouin, J., "Reflection and Refraction of Acoustic Waves by a Shock Wave," Natl. Advisory Comm. Aeron., 42 pp., 1957. AD-134 968.

This paper treats the problem of reflection and refraction of sound waves by a plane, uniform shock wave separating two regions, in both of which the fluid pressure and temperature are originally in equilibrium. Calculations are made of conditions that prevail in the two regions after the equilibrium in either one or the other region has been upset by incidence of a plane, uniform acoustic wave. Dynamic relationships show that the amplitude of reflected waves is always less than that of the incident wave, but the amplitude of refracted waves may, in certain cases, be greater than that of the incident wave.

2044

Cox, E. F., "Sound Propagation in Air," in Handbuch der Physik (Encyclopedia of Physics), 48, 455-478, 1957.

This paper begins with a review of the basic laws of propagation of sound energy in air and explains why weak sound waves propagate with negligible distortion, while high amplitude sound waves distort and form shock fronts as they propagate. Expressions for shock wave velocity are given.

Meteorological factors affecting the speed and direction of sound rays are described, and the laws of sound ray refraction and reflection are reviewed. Absorption and dispersion of sound in real atmospheres are described. Formulas and graphs are given for determining attenuation with distance. Propagation of sound to great distances is treated in detail. Refraction in the troposphere and the formation of sound ducts at tropopause heights are described and documented. An excellent bibliography is included.

2045

Crary, A. P., "Investigation; of Stratosphere Compressional Wave Velocities by Studies of Refracted Waves from Explosive Sources — Part III: Alaska, January 1948, Latitude 65° North," AMC, Cambridge Research Labs., Mass., 17 pp., 1949. AD-73 073.

An investigation was made to determine the stratospheric compressional wave velocities in a high-latitude region; eleven tests were conducted in the Fairbanks, Alaska, area. Explosive charges were fired at the surface and a study was made of the stratosphere-refracted returns at locations 100 to 400 km away. Eight positive tests resulted, five recorded east of the source and three west. The apparent velocities ranged from surface velocity, about 320 to 400 meters per second. The average velocity of the returns was considerably greater in the easterly direction than in the westerly. The differences are thought to result from high westerly winds, reaching a maximum of 60 meters per second at 50-km altitude and probably decreasing sharply at 70 km. The north-south wind components are probably negligible.

2046

Crary, A. P., "Investigation of Stratosphere Compressional Wave Velocities by Studies of Refracted Waves from Explosive Sources — Part IV: Canal Zone, Latitude 9° North — July and August 1948." Geophys. Res. Rept., AMC, Cambridge Research Labs., Mass., 17 pp., 1949. AD-74 463.

Stratospheric compressional wave velocities were investigated near the Panama Canal Zone by studies of refracted waves from explosive sources. Bombs were dropped from an airplane at distances 100 to 400 km from a ground receiving station and the stratosphere-refracted waves received from the explosions were used to obtain information regarding the compressional wave velocities and winds in the stratosphere up to altitudes of 50 to 60 km.

Methods of operation and computations used are described, together with the results of each test. Eight tests resulted in a fairly good separation of stratospheric compressional wave velocities into temperature and wind effects. Averages of tests conducted in various regions areplotted, showing the variation of wave velocity with altitude. Variations of temperature, wind velocity, and azimuth with altitude are also shown.

2047

Franken, P. A., and U. Ingard, "Sound Propagation into a Moving Medium," J. Acoust. Soc. Am., 28, 126-127, 1956.

In the study of transmission of sound into a moving medium, if flow speeds larger than twice that of sound are allowed, the analysis indicates at least formally the existence of two critical angles between which total reflection occurs. A discussion of the corresponding behavior of the angle of refraction and the reflection coefficient is presented.

2048

Friedrichs, L. O., and J. B. Keller, "Geometrical Acoustics, II. Diffraction, Reflection, and Refraction of a Weak Spherical or Cylindrical Shock at a Plane Interface," J. Appl. Phys., 26, 961-967, 1955.
See also: Keller, J. Appl. Phys., 25, 938-947, 1954.

The method of Part I is applied to the reflection and refraction of a weak spherical or cylindrical shock wave at a plane interface and by a plane slab. The method is also extended to apply to the diffracted wave that appears in these problems whenever total reflection occurs. From the results are also obtained the leading terms in the asymptotic expansions for high frequency of the fields produced by periodic point or line sources over a plane interface. These terms, which apply to electromagnetic as well as acoustic fields, exactly agree with results previously obtained by much more complicated methods.

2049

Groves, G. V., "Geometrical Theory of Sound Propagation in the Atmosphere," J. Atmospheric Terrest. Phys., 7, 113-127, 1955.

Deals with the geometry of sound waves and rays propagated in a moving inhomogeneous medium, with particular reference to the atmosphere. The theory developed is, essentially, a generalization of that in geometrical optics for the propagation of light in an inhomogeneous isotropic medium to the case where the medium is in motion. Differential equations defining the wavefront and rays of a sound propagation in an inhomogeneous moving medium are derived, and then transformed by expressing the unit normal of the wavefront in terms of certain trace velocities.

With the equations in this form, an integral is immediately obtainable for sound propagated in the atmosphere by assuming that the velocity of sound and the wind-velocity vector are functions of height only. From this solution the law of refraction, the condition for total reflection of a sound ray, and the equations for the wavefront at any time are found. By way of example, the theory is applied to a simple velocity of sound vs. height relationship, and expressions are obtained for the range and time at which the abnormal propagation from a ground-level source returns to earth. Numerical results calculated from these formulae are found to be in accord with observations that have been made on this phenomenon.

2050

Gvozdena, L. G., "The Refraction of Detonation Waves Incident on the Boundary Between Two Gas Mixtures," Soviet Phys. Tech. Phys., English Transl., 6, 527-533, 1961.

Discusses one of the phenomena characteristic of detonation waves—the refraction of such a wave when it passes from one explosive mixture to another. By using a high-speed cinecamera, photographs were obtained of the phenomenon that takes place when a detonation wave moving through a medium capable of reaction passes through a boundary dividing this medium from an explosive or inert medium.

2051

Ingard, U., "Acoustics," in E. U. Condon, and H. Odishaw, eds., Handbook of Physics, McGraw-Hill, New York, 113-133, 1958.

This concise presentation of acoustic theory and applications discusses the general equations of sound propagation, sound sources and their fields, propagation in the atmosphere and in tubes, absorption of sound, scattering, detection of sound, architectural acoustics, and ultrasonics. The section on atmospheric sound propagation develops the equations pertaining to ray acoustics (phase velocity, group velocity, shadow zones), intensity in the shadow zone, scattering by turbulence, and ground absorption.

2052

Johnson, W. R., "The Interaction of Plane and Cylindrical Sound Waves with a Stationary Shock Wave," Rept. No. 2539-8-T, Doctoral Thesis, Eng. Res. Inst., Univ. of Mich., Ann Arbor, 133 pp., 1957.
AD-146 197.

This investigation theoretically treats the problem of the interaction of plane and cylindrical sound waves with a stationary shock wave. The linearized Euler differential equations and the corresponding linearized shock conditions serve as the fundamental laws for this study. Plane-wave solutions to the differential equations are found, and the analogues of Snell's laws of reflection and refraction are determined, together with the "Fresnel" formulae. Integral solutions to the differential equations corresponding to incident cylindrical waves are then found from the plane-wave solutions by a method devised by H. Weyl (Ann. Physik, 60, 481, 1919). These integrals are investigated to determine the reflected and refracted field of a line source. Generalizations of the theory for moving shocks and point sources are set up but not investigated in detail.

2053

Kinber, B. E., "Solution of Inverse Problem Geometric Acoustics," Soviet Phys. Acoust., English Transl., 1, 235-239, 1957.

The problem is considered of two reflecting or two refracting surfaces, by means of which a given field can be transformed into another given field. The full set of differential equations for the problem is obtained. A solution is worked out assuming the correctness of the laws of geometrical acoustics (or optics).

2054

Kock, W. E., and F. K. Harvey, "Refracting Sound Waves," J. Acoust. Soc. Am., 21, 471-481, 1949.

Structures which refract and focus sound waves are described. They are similar in principle to certain recently developed electromagnetic wave lenses in that they consist of arrays of obstacles which are small compared to the wavelength. These obstacles increase the effective density of the medium and thus effect a reduced propagation velocity of sound waves passing through the array. This reduced velocity is synonymous with refractive power so that lenses and prisms can be designed. When the obstacles $\approx \lambda/2$ in size, the refractive index varies with wavelength, and prisms then cause a dispersion of the waves (sound spectrum analyzer). Path length delay type lenses for focusing sound waves are also described. A diverging lens is discussed which produces a more uniform angular distribution of high frequencies from a loudspeaker.

2055

Kontorovich, V. M., "Reflection and Refraction of Sound by Shock Waves," Soviet Phys. Acoust. English Transl., 5, 320-330, 1960.

This paper considers the reflection and refraction of small perturbations, mainly sound, at surfaces of discontinuity in a liquid or gas in general. At the discontinutiy it is assumed that the Rankine-Hugoniot conditions are satisfied. The coefficients of reflection and transmission of sound are determined and the reflection and refraction laws are given in simple geometric form. The author cites data which can be obtained by means of the acoustic "localization" of discontinuities.

2056

Kontorovich, V. M., "Reflection and Refraction of Sound by a Shock Wave," Soviet Phys. JETP, English Transl., 6, 1180-1181, 1958.

Theoretical note giving general expressions which, for oblique incidence, are more accurate than those given by Brillouin and, for normal incidence and an ideal gas, reduce to those previously obtained. (Acustica, 5, 149-63 (1955) (In French)).

2057

Masterov, E. P., "Waveguide Propagation of Sound in Layered Inhomogeneous Media," Soviet Phys. Acoust. English Transl. (New York), 5, 339-343, 1960.

The waveguide propagation of sound in a medium of refractive index (n) is discussed; n^2 obeys a bi-exponential law

$$n^2(z) = p^2 + (1 - p^2 + q)e^{-az} - qe^{-2az}$$

where p, q and a are parameters that determine the distribution of the refractive index.

2058

Metz, A., "The Deflection of Waves by the Motion of the Propagating Media" (in French), Compt. Rend., 248, 1615-1617, 1959.
See also : Compt. rend., 245, 827-829, 1957.

The deflection of waves at the interface between two media, one of which moves with velocity v relative to the other, is given by cosec i - cosec r = v/c, where c is the propagation velocity, supposedly the same in the two media. This result is used to criticize Datzeffs' modified hypothesis of ether drift.

2059

Metz, A., "Refraction and Total Reflection of Waves in Media in Motion," Compt. Rend. Acad. Sci. (Paris), 250, 3591-3592, 1960.

The theory of the refraction and reflection of a plane acoustic wave when passing from one medium to another in which the wave velocity is different is discussed for the case in which there is relative motion between the two media.

2060

Metz, A., "The Total Reflection of Waves in Moving Media," Compt. Rend. Acad. Sci. (Paris), 250, 3796-3804, 1960.

Previous papers have shown that sound waves or ultrasonic waves propagated in media undergo refraction and total reflection not only when they pass from one medium to another where the speed of propagation is different, but also when the media are moving relative to one another. General formulae relating to these phenomena were given previously and the present paper derives a more exact formula relating to the propagation of waves under such conditions. Formulae derived in previous papers are used without detailed explanation.

2061

Milne, E. A., "Sound Waves in the Atmosphere," Phil. Mag., 42, 96-114, 1921.

This paper deals with the kinematics of the propagation of sound waves through a medium (such as the atmosphere) in which the velocity of the medium and the velocity of sound in the medium vary from point to point. The subject is taken up in connection with the location of aircraft by sound. Sections take up: equations of propagation; the general refraction formula for stratified media; application to a point source in the atmosphere; total reflection and the range of audibility; cases of limited audibility, etc.

2062

Noble, W. J., "On the Focusing Effect of Reflection and Refraction in a Velocity Gradient," J. Acoust. Soc. Am., 27, 888-891, 1955.

The divergence factor, which is important in the reflection of waves from a convex spherical surface, is shown to have its counterpart in plane reflection and refraction in the presence of a velocity gradient. Within a small angle approximation, a linear velocity gradient gives the ordinary spherical spreading of a pencil of rays; any discontinuity of gradient causes a divergence or convergence of the pencil. Analytical expressions and tables of typical values are calculated for four different cases.

2063

Penney, W. G., and H. H. Pike, "Shock Waves and the Propagation of Finite Pulses in Fluids," Repts Progr. Phys., 13, 46-82, 1950.

This paper is a review of theoretical work, much of it unpublished and contained in several Ministry of Home Security reports. Shockwave relationships are considered, and the refraction, reflection, and diffraction of plane shock waves are discussed.

2064

Polachek, H., and R. J. Seeger, "On Shock-Wave Phenomena; Refraction of Shock Waves at a Gaseous Interface," Phys. Rev., 84, 922-928, 1951.

Treats the problem of the refraction of a shock wave at a gaseous interface. The governing equations are formulated and analyzed. Continuous families of solutions are obtained numerically for a number of gas combinations at varying angles of incidence on a plane interface between ideal gases (characterized by a certain range of parameters). It is believed that these solutions, which represent a three-wave configuration at the interface with a reflected shock wave or with a reflected rarefaction wave, are physically real inasmuch as they tie in with the two known limiting solutions of an infinitesimal shock at any angle of incidence and of any finite shock at normal incidence.

Two of the significant features of the present solutions are: (1) regular refraction (three-wave configuration at the interface) does not occur at glancing incidence and (2) in the region of regular refraction there is no total reflection of finite shock waves.

2065

Rachele, H., "Sound Propagation Through a Windy Atmosphere," Tech. Rept. No. 109, Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 11 pp., 1961.
AD-266 240

Snell's equations, and variations thereof, for the refraction of sound in a temperature-stratified medium are derived from a ballistic standpoint. The equations are then transformed for ray-tracing through a windy atmosphere.

2066

Reynolds, O., "On the Refraction of Sound in the Atmosphere," Phil. Trans. Roy. Soc. London, 166, 315, 1876.

This paper is remarkable for its time (1876). It is one of the earliest attempts at correlating wind and temperature gradients with the apparent refraction of sound rays in the atmosphere. The author writes in narrative style and uses no formal mathematical treatment. The presentation of subjective data from carefully controlled tests on land and sea, however, substantiates the conclusions drawn.

2067

Rudnick, I., "Propagation of Sound in the Open Air," in C. M. Harris, ed, "Handbook of Noise Control," McGraw-Hill, New York, Chap. 3, 17 pp., 1957.

Chapter 3 decribes the propagation of sound in air and the various meteorological factors and boundary conditions that influence otherwise normal propagation. The effect of wind and temperature gradients, of fog and water vapor, and of reflecting and absorbing obstacles and boundaries are concisely treated. Mathematical expressions, graphs, and tabular data for determining divergence, diffraction, refraction, reflection, scattering, and attenuation with distance are presented. Anomalous propagation and shadow zones are investigated and explained in terms of sound-ray equations. In general, the chapter presents the basic results of work done by Kneser, Knudsen, Knotzel, Delsasso, Ingard, Nyborg, and Rudnick.

2068

Sandmann, B., "Contributions to Propagation of Sound, in Particular to Sound Diffraction and Anomalous Propagation of Sound" (in German, English Summary), Gerlands Beit. Geophys., 28, 241-278, 1930.

The conditions which cause diffraction of sound in the free atmosphere are discussed. Meteorological conditions are treated at length in conjunction with sound propagation. Sections discuss: sound refraction in the air; dependence of sound intensity on meteorological conditions; refraction in relation to a zone of silence; favorable conditions for sound refraction at great heights in the atmosphere; further confirmation of the assumption of sound refractions as cause of anomalous propagation.

2069

Sandmann, B., "Observational Results on the Influence of the Acoustic Refraction Layer on the Propagation of Sound" (in German), Z. Geophys., 10, 200-215, 1934.

Detailed, well-illustrated investigation.

2070

Schoch, A., "Reflection, Refraction and Diffraction of Sound," Trans. by F. J. Berry, Ministry of Supply, Armament Research Establishment, 77 pp., 1953.
AD-116 801.

The present state of theory and experiment on the reflection, refraction, and diffraction of sound is very thoroughly presented in this book-length paper. After a brief introduction, the work begins with a comprehensive review of fundamentals including the dynamics of sound waves in homogeneous media, Huygens' Principle, boundary conditions, and uniqueness of solutions. The various situations involving reflection and refraction are then treated, including plane waves at a plane interface, free boundary layer waves along a plane interface, nonplanar waves at a plane interface, plates, and laminated media. Finally, diffraction is treated as phenomena resulting from the presence of curved boundaries. The diffracting properties of cylindrical, spherical, and more complex obstacle shapes are investigated. An extensive bibliography containing 144 references is included.

2071

Stocker, P. M., "Shock Refraction in a Stratified Medium," Rept. No. B 31/58, Armament Research and Development Establishment, Great Britain, 17 pp., 1958.
AD-209 975.

If an initially plane shock enters a region of uniform pressure in which the sound speed varies in a direction perpendicular to the direction of propagation, the shock will be refracted and pressure gradients will arise behind the shock. The shock shape and the flow field behind the shock are found in the case where the density jump through the shock is large compared with the density variations ahead of it.

2072

Taylor, L., "The Oblique Shock-Compression Wave Intersection in Shock Refraction," Tech. Rept. No. 531-1, Penn. State Univ., College of Chem. and Phys., Univ. Park, 77 pp., 1954-1957.
AD-209 801.

The one-dimensional interaction of a shock wave overtaking a compressional wave traveling in the same direction was treated theoretically. Interferograms of a special case of shock-wave refraction at grazing incidence along the interface of two gases were obtained, in which the intersection of the retransmitted compressional wave and the slow incident shock approximates the theoretical situation. Interferograms were also shown for a similar configuration in which there is an incident shock presented to the "slow" gas layer only. This resulted in a diffracted fast gas signal and consequently a weaker retransmitted wave. Qualitative and quantitative comparisons were made between theory and experiment where possible; they were found to agree well.

2073

Tolstoy, I., "Modes, Rays, and Travel Times," J. Geophys. Res., 64, 815-821, 1960.

Relationships between the normal-mode and the ray-optical interpretations of seismic and acoustic measurements are discussed, and applications to the theory and practice of refraction techniques are given. The validity of the ray theory is sometimes open to question; that is, the results of travel-time and intercept measurements may be subjected to overinterpretation in terms of rays. Several questions of principle are examined in this connection. It is emphasized that the idea of mode cannot be brought into direct correspondence with the rays and travel-times of the optical, approximate approach, and efforts to interpret mode behavior in terms of rays can lead to paradoxical conclusions. This can be understood in terms of the plane-wave, asymptotic nature of such concepts as phase and group velocity.

2074

van Everdingen, E., "The Propagation of Sound in the Atmosphere," Proc. Acad. Sci. Amsterdam, 18, 933-960, 1915.

This paper, of historical interest, was written in 1915, and reviews the various theoretical and experimental approaches of that day on the anomalous propagation of sound in air. The theory of refraction of sound waves due to wind and temperature gradients is presented. Lack of temperature and wind data at high altitudes prevented accurate use of this theory in 1915. Other theories (now defunct), postulating a change in composition of the atmosphere with altitude, are reviewed. One of these predicted the existence of a gas, "geocoronium," five times lighter than hydrogen. Copious data on acoustic observations of various large explosions and volcanic eruptions is given in narrative and graphic form to demonstrate the existence of shadow zones and secondary areas of audibility.

2075

von Schmidt, O., and A. Kling, "Acoustical Refraction and Total Reflection" (in German), Physik Z., 41, 407-409, 1940.

The main objective of this study was to obtain evidence about the influence continuous change in speed or in acoustical density exerts upon the wave fronts of compressional waves. The Schlieren method of photography was applied to projectiles fired obliquely upward from a rifle. The angle of elevation was so chosen as to cause the upper branch of the bow wave to be horizontal and to move vertically upward. The trajectories of the elongated bullets passed through the cylindrical columns of hot air rising above either one candle flame or two candle flames in succession. It was found that bow waves occur for the continuous transition from one speed of wave propagation to another, that secondary bow waves exist, that when plane waves experience total reflection at the hot air the waves are damped across the right section of the beam. This fact is interpreted as the physical cause of total reflection.

2076

Wiechert, E., "Remarks on the Abnormal Propagation of Sound in the Air, Part I" (in German), Nachr. Ges. Wiss. Gottingen, Math.-Physik. Kl., 49-69, 1925.

REFRACTION

Discusses refraction and differences in speed of sound waves in layers of stratosphere and gives an explanation of abnormal audibility zones depending on actual layers of the stratosphere and wind conditions. Temperature is considered important in view of the new Lindemann-Dobson theory of warm upper-air conditions.

2077

Wiechert, E., "Remarks on the Abnormal Propagation of Sound in the Air, Part II," Nachr. Ges. Wiss. Gottingen, Math.-Physik. Kl., 93-103; "Part III," Ibid., 201-211, 1926.

See preceding abstract.

2078

Wing, G. M., "Mathematical Aspects of the Problem of Acoustic Waves in a Plane Stratified Medium," Quart. Appl. Math., 19, 309-319, 1962.

The paper is concerned with the problem of acoustic waves in layered media. In particular, the specific problem of a point source of acoustic radiation of a single frequency situated above a perfectly reflecting plane surface is considered, the source being in a medium of constant density and sound speed. A plane interface above the source and parallel to the reflector separates this medium from another infinite medium of constant properties. The pressure distribution at any point in the media is solved in the paper by the introduction of a mathematical device that avoids ambiguities in the solution.

Refraction
See also — 388, 432, 434, 435, 437, 445, 452, 453, 461, 480, 485, 487, 488, 539, 588, 763, 1185, 1390, 1391, 1399, 1402, 1403, 1418, 1419, 1420, 1421, 1423, 1437, 1442, 1447, 1458, 1459, 1475, 1491, 1493, 1505, 1529, 1534, 1538, 1565, 1566, 1569, 1791, 1897, 1919, 1922, 1938, 1942, 1945, 1947, 2026, 2206, 2339, 2364, 2413, 2463, 3270, 3348, 3349, 3364, 3365, 3366, 3367, 3370, 3396, 3397, 3400, 3401, 3403, 3586, 3682, 3712, 3721, 3791, 3961, 4181, 4312, 4455.

REVERBERATION

2079

Balachandran, C. G., "Random Sound Field in Reverberation Chambers," J. Acoust. Soc. Am., 31, 1319-1321, 1959.

A series of experiments were performed to compare the efficiency of different diffusing devices in producing a completely random sound field in a reverberation chamber, and the effectiveness of some of the methods for judging whether a sound field is completely random. An additional experiment was performed to compare two types of test signals — warble tone and the same nominal band width of random noise. Results of these measurements indicate the general superiority of the rotating vane over other diffusing devices and superiority of random noise over warble tone in producing a smooth decay curve. One of the significant conclusions is that, even when the diffusion is reasonably adequate, the measured absorption coefficient of a standard sample appears to vary with the chamber absorption especially at the high frequencies.

2080

Botsford, J. H., R. N. Lane, and R. B. Watson, "A Reverberation Chamber with Polycylindrical Walls," J. Acoust. Soc. Am., 24, 742-744, 1952.

A reinforced concrete reverberation chamber has been constructed with diffusing cylinders of random size cast in the ceiling and walls. Loss of energy in the empty chamber is low because the rigid, heavily enameled walls have a low absorption coefficient, and the loss of attenuation in the air is moderate for such a small volume. Materials are tested in the frequency range from 250 cps to 12 kc, using half-octave noise bands.

2081

Cho, A. C. F., and R. B. Watson, "Pulse Technique Applied to Acoustical Testing," J. Acoust. Soc. Am., 31, 1322-1326, 1959.

The lack of validity of the diffusion assumption makes it desirable to search for means of assessing the acoustical properties of a room other than a criterion based solely upon reverberation time. A pulse technique is devised to study transient sound in a room. An electroacoustic system was constructed for generating sound pulses in a room and for receiving and recording the pulses after transmission to various points in the room.

Acoustical testing also included the determination of the absorption coefficient of a wall and the tracing of a soundpath in a room. A pulse statistical analysis was made to give the r.m.s. deviations of the pulse transient response from the exponential steady-state decay based on the known reverberation time. It is concluded that for the lecture room tested a r.m.s. deviation less than 0.50 represents good acoustical conditions for speech.

2082

Chrisler, V. L., and C. E. Miller, "Factors Which Affect the Measurement of Sound Absorption," Bur. Standards J. Research, 9, 175-185, 1932.

It has been found that air has an appreciable absorption for sound at frequencies as low as 512 ~. This absorption varies with the temperature, the moisture content and the barometric pressure. Curves are given showing such changes in absorption in the reverberation room at the Bureau of Standards. Attention is called to the fact that when a highly absorbent sample is placed in a very reverberant room the decay curve may not be logarithmic.

2083

Cook, R. K., et al., "Measurement of Correlation Coefficients in Reverberant Sound Fields," J. Acoust. Soc. Am., 27, 1072-1077, 1955.

Reverberation chambers used for acoustical measurements should have completely random sound fields. We denote by R the cross-correlation coefficient for the sound pressures at two points a distance r apart.

$$R = \left\langle p_1 p_2 \right\rangle \mathrm{Av} \Big/ \left(\left\langle p_1^{\,2} \right\rangle \mathrm{Av} \left\langle p_2^{\,2} \right\rangle \mathrm{Av} \right)^{1/2}$$

where p_1 is the sound pressure at one point, p_2 that at the other e, and the angular brackets denote long time averages. In a random sound field, R = (sin kr)/kr, where k = 2/(the wavelength of the sound). An instrument for measuring and recording R as a function of time is described. A feature of this instrument is the use of a recorder's servomechanism to measure the ratio of two d-c voltages. The results of correlation measurements in reverberant sound fields are given.

2084

Domsch, G. H., "Tables for Technical Acoustics," Arch. Tech. Messen, T21-T22, 1937.

Four useful tables giving formulae relating to speed of propagation of sound in solids, liquids and gases, to sound intensity, to reverberation and similar topics in architectural acoustics, and to resonators. Each constant is defined algebraically, and separate columns are given to show the units in the cgs system, the value for air at 20°C and 760 mm Hg, together with general comments including the values for other media, and the methods of measurements or small diagrams.

2085

Fiala, W. T., and J. K. Hilliard, "High-Intensity Sound Reverberation Chamber and Loudspeaker Noise Generator, J. Acoust. Soc. Am., 31, 269-272, 1959.

A high-intensity sound test chamber capable of producing 145 db and having a working area of 6 × 3 × 1 1/2 ft is described. The chamber uses the principle of reverberant sound to test electronic packages used in aircraft and missiles. Double wall construction and use of Aquaplas for panel damping provides the necessary sound insulation. Complete instrumentation and the loudspeaker generator will be described.

2086

Furrer, W., and A. Lauber, "The Accuracy of Reverberation Time Measurements with Warble Tones and White Noise," J. Acoust. Soc. Am., 25, 90-91, 1953.

It is shown that in reverberation-time measurements, warble tones give greater accuracy at the lower frequencies, and white noise at the middle and higher frequencies. This behavior is within a wide range independent of room volume.

2087

Horiuchi, I., "The Absorption of Sound in Humid Air at Low Audio Frequencies," Tech. Rept. No. 6, Columbia Univ., New York, 48 pp., 1957.
AD-140 786.

The reverberation technique of Kudsen has been applied to the measurement of the absorption of sound in air over the frequencies 300 to 1100 cps with mole ratio concentrations of water vapor ranging from zero to 0.1. Pressures from 20 cm Hg to atmospheric, and temperatures from 0°C to 55°C were employed in the study. With the use of a 66-inch spherical resonator and dry nitrogen gas as reference, following the method of Delsasso and Leonard, it has been possible to observe the anomalous absorption of humid air down to 300 cps. Pertinent graphs, theory, and a detailed description of the experimental apparatus are presented.

2088

Kantarges, G. T., "Some Measurements of Noise Transmission and Stress Response of a 0.020-Inch Duralumin Panel in the Presence of Air Flow," Nat'l. Aeron. Space Admin., Washington, D. C., 25 pp., 1960.
AD-241 931.

Noise transmission measurements were made for a 0.020-inch panel with and without air flow on its surface. Tests were conducted with both an absorbent and reverberant chamber behind the panel. Panel stresses for some of these tests were also determined. Noise spectra obtained inside the absorbent chamber with flow attached and flow not attached to the panel appeared to contain several peaks corresponding in frequency to panel vibration modes. These peaks were notably absent when the chamber was reverberant. These noise reduction through the test panel measured with the aid of an absorbent chamber for the flow-not-attached case is in general agreement with values predicted by the theoretical weight law but indicate rather less noise reduction at the high frequencies. The main stress responses of the panel without air flow occurred at its fundamental vibration mode. In the presence of air flow the main response occurs in a vibration mode having a node line perpendicular to the direction of air flow.

2089

Kushner, S. S., and N. E. Barnett, "Reverberation-Room Anechoic Chamber Transmission-Measurement Technique," WADC Tech. Rept. No. 59-130, Acoust. Lab., Inst. Sci. Tech., Univ. of Mich., Ann Arbor, 1959.
AD-229 870.

A preliminary investigation was undertaken to characterize several parameters involved in a reverberant source room—anechoic termination method for measuring acoustic transmission. This method appears potentially capable of evaluating the acoustic transmission in great detail of samples possessing widely divergent physical characteristics. Exploratory experimentation included examination of reverberation-room diffusion, termination diffraction and directionality, effects of sample mass on transmission, and transmission of various stiff-panel configurations.

2090

Kuttruff, H., "Remarks on the Concept of the 'Mean Free Path' in Room Acoustics," Acustica, 11, 366-367, 1961.

Remarks on the work "Influence of scattering surfaces and reverberation-room dimensions on measured sound absorption coefficients" by Kath and Kuhl. In this paper the concept of the "mean-free path" (Weglange) of a sound ray in a closed room plays an important role, its value being given as 4 V/S (V being the volume and S the wall-surface area of the room).

2091

Lebedeva, I. V., "Investigation of the Moscow State University Acoustics-Department Reverberation Chamber," Soviet Phys. Acoust., English Transl., 6, 326-334, 1961.

The properties of the reverberation chamber were studied in considerable detail. Characteristics were obtained for the transmission of sound and uniformity of the field, and the correlation coefficient between acoustic pressures at two points was recorded. The reverberation time in the empty chamber at a frequency of 160 cps attained a value of 19 sec and dropped to 2.9 sec at a frequency of 5000 cps. The paper describes the necessary conditions for a diffuse field, which satisfies the requirements for measuring the statistical sound-absorption coefficient.

2092

Lebedeva, I. V., "Reverberation Chamber Techniques in the Measurement of Acoustic Absorption Coefficient," Soviet Phys. Acoust., English Transl., 8, 258-262, 1963.

An investigation of the sound absorption coefficient of the porous material "Silane" was conducted in line with the program of the International Standards Organization (ISO). The relationship between the measured sound absorption coefficient and the degree of diffuseness of the field, and the relationship between the sound absorption coefficient and the variation in the area presented by the specimen, were investigated. It is demonstrated that inadequate field diffuseness leads to absorption coefficient values which are too low at intermediate and high frequencies, from 300 cps up. Recommendations for achieving a proper degree of field diffuseness in a specific reverberation chamber are given.

2093

London, A., "The Determination of Reverberant Sound Absorption Coefficients from Acoustic Impedance Measurements," J. Acoust. Soc. Am., 22, 263-269, 1950.

A method is described for utilizing normal absorption coefficient or acoustic impedance measurements to predict reverberant sound absorption coefficients. The average of coefficients for the six standard frequencies determined from acoustic impedance measurements agrees closely with the average reverberant coefficient for cases where the material may be said to obey the normal impedance assumption. The normal absorption coefficients of some 26 different acoustic materials were measured at 512 cps. By using the method given in the paper, the predicted reverberant coefficient deviated from the measured reverberant coefficient by 0.05 or less for 18 materials; in only 3 cases were the deviations greater than 0.10. The method should be particularly applicable to the problem of acceptance testing of installed acoustic materials.

In the theoretical development, best agreement with experiment was obtained by introducing a new kind of reverberant statistics, which associates with each wave packet in a random field a scalar quantity equal to the square of the absolute value of the sound pressure in each packet, instead of the customary energy flow treatment. Also, it was found necessary to carry out the analysis by using a concept of equivalent real impedance to replace the usual complex impedance.

2094

Maa, D.-Y., "Fluctuation Phenomena in Room Acoustics," J. Acoust. Soc. Am., 18, 134-139, 1946.

Two types of fluctuational phenomena are discussed theoretically, utilizing the concept of normal modes of aerial vibration in the room. The fluctuation noise due to the random motion of air molecules is found to be a property of air alone, and independent of the room. On the other hand, the fluctuation during reverberation depends on both the room dimensions and its reverberation characteristics. Practical formulae for the magnitudes of the fluctuations are presented that agree well with previous experimental data. The ability of the blind to estimate room size with surprising accuracy is explained, and further investigations of the problem of room "liveness" as it relates to fluctuational phenomena as well as to its effect on the acoustical design of a room are suggested.

2095

Mariner, T., "Critique of the Reverberant Room Method of Measuring Air-Borne Sound Transmission Loss," J. Acoust. Soc. Am., 33, 1131-1139, 1961.

Some obscure but important philosophical difficulties with the standard method of measuring transmission loss by the reverberant room method have led to reexamination of the basic concepts. An equation is derived relating transmission loss to the "total loss area" H_2 of the receiving room. H_2 is found to be measurable within a negligibly small uncertainty by using familiar sound-decay techniques, providing that T_2/T_1, the ratio of "natural" reverberation times of the receiving and source rooms, is properly adjusted. It is shown that the equations commonly used in the existing standard method require knowledge of A_2, the total absorption of the receiving room, implicitly excluding transmission through the panel. A_2 is generally not measurable without prior knowledge of the transmission loss of the test panel. These and other considerations result in the proposal of a new procedure.

2096

McAuliffe, D. R., "Design and Performance of a New Reverberation Room at Armour Research Foundation, Chicago, Illinois," J. Acoust. Soc. Am., 29, 1270-1273, 1957.

In 1957 the ARF acoustics section moved into new quarters. In these new facilities a reverberation room was built for use in their research. The room has a volume of approximately 3000 cu ft and a reverberation time of about 5 sec. The four walls and the ceiling of the room have been splayed. Measurements indicate that the room has a relatively uniform reverberation time with respect to frequency. Data are presented to show the ambient noise level, the steady-state sound-energy distribution, and the reverberation time as a function of frequency and location within the room.

2097

Meyer, E., "Experiments on CM Waves in Analogy with Acoustic Techniques Made in Gottingen," J. Acoust. Soc. Am., 30, 624-632, 1958.

In the past four years a series of experiments has been carried out which serve to demonstrate the success of analogies between acoustical systems and electromagnetic wave systems in the microwave frequency region. Measuring techniques in the two disciplines are compared, with particular emphasis on the use of reverberation chambers. Analogous directive microphones and electromagnetic devices have been constructed. The design and performance of both nonresonant and resonant absorbing structures is discussed at length.

2098

Morch, K. A., "Measurement of Total Acoustic Power of Sources of Sound in a Reverberation Chamber," Ph. 8 (No. 286/1960), Acta polytech. Scand., 25 pp., 1960.

The report summarizes the theory of the reverberant sound field, and gives an account of the reverberation chamber investigations at the laboratory. The reverberation chamber is to be used for measurement of the total acoustic power of sources of sound. Investigations were carried out at frequencies between 2 and 15 kcs.

2099

Morse, P. M., and R. H. Bolt, "Sound Waves in Rooms," Revs. Mod. Phys., 16, 69-150, 1944.

This is a critical discourse and survey on the present position of room acoustics. It begins with Sabine's pioneer work, gives an account of progress, and points out where further research is required. It discusses the general principles of wave acoustics and shows how they clarify and supplement the geometrical results of earlier workers. It examines the importance of the reverberation time T, background noise, loudness of source, and shape of room, as they affect the recognizability of speech. The value of T given by Knudsen includes the absorptive effect of the air, for above 4000 cps this absorption may be several times the total absorption at the boundaries of the room. Methods of measuring room acoustics reveal the inadequacies of the geometrical theory. The general aspects of wave acoustics studied are the nature of the reaction between the sound wave and the walls of the room and the natures of the steady-state and transient response to a source of sound. The first of these involves a knowledge of the acoustic impedance of the surface; in the second and third the reverberant sound has the characteristic frequencies of the normal modes of vibration of the room and not necessarily the frequency of the source. In a simple rectangular room, a number of different decay rates exist; thus the decay curve cannot be a straight line, and rooms having smooth, regularly-shaped walls show the greatest divergence of decay rates for different standing waves. In general, wave acoustics will have to be used for small regularly shaped rooms, and geometrical acoustics will be sufficient for the analysis of most large auditoriums. The report ends with a very full bibliography.

2100

Rettinger, M., "Note on Reverberation Chambers," J. Audio Eng. Soc., 5, 108, 1957.

The design of reverberation rooms is discussed, including the absorptivity of building components, the high frequency limits, and the effect of relative humidity.

2101

Rettinger, M., "Selected Problems in Architectural Acoustic," Proc. I. R. E., 31, 18-22, 1943.

This paper deals with the absorption of hf sound in air, the change of hf reverberation with the relative humidity of the air and the average surface absorptivity required to provide constant reverberation time for frequencies > 1 kcs. Also noted is that the energy reduction of hf sound with change in reverberation and the air attenuation of hf sound interference are pictured as a function of the distance between source of sound and the point of observation.

2102

Richards, R. L., "New Airborne Sound Transmission Loss Measuring Facility at Riverbank," J. Acoust. Soc. Am., 30, 999-1004, 1958.

Reports on a then-new facility for measurtng sound transmission loss which, in 1958, had been in use for more than a year at Riverbank Acoustic Laboratories. Describes the two reverberation rooms, installation of the test panel, instrumentation, and measurement technique. The several checks made for measurement accuracy and repeatability are discussed. Test results are given, comparing an old method of test with the new, and results are also given for a folding door measured at four testing laboratories in the United States and Canada.

2103

Schroeder, M. R., "Measurement of Sound Diffusion in Reverberation Chambers," J. Acoust. Soc. Am., 31, 1407-1414, 1959.

This paper describes a variety of methods for the measurement of the diffusion of sound fields in reverberation chambers. Diffusion is defined on the basis of the angular distribution of sound energy flux, in accordance with the definition that has found its visual expression in the "sound hedgehog" of Meyer and Thiele. The theoretical foundations of the methods proposed here are: normal mode expansion, the sampling theorem (both in time and two-dimensional space), and either Fourier or correlation analysis. The quantities to be measured are sound pressures and, in some cases, sound pressure gradients at a number of sampling points on the measuring wall. Results of these measurements are suitably transformed to give the sound energy fluxes for all possible angles of incidence. The accuracy of measurement is determined by the Q (frequency times reverberation time) of the chamber and is typically of the order of 1°. This extraordinary directivity is achieved without substantial perturbation of the sound field. Methods applicable to both single frequencies and finite frequency bands are described.

2104

Slavik, J. B., and J. Tichy, "An Evaluation of the Sound Absorption Coefficients Measured by the Standing-Wave Method and by the Reverberation Method," (in Czech), Slaboproudy Obzor, 18, 545-548, 1957.

Previously reported experimental results (Tichy, Slaboproudy Obzor, 17, 197-202, 1956; Faiman, ibid., 322-324; and Kolmer, ibid., 500-507) are quoted and compared, together with some supplementary data. Great discrepancies are found between the values obtained by the two methods. It is therefore thought necessary to employ both types of measurement until the value of the reverberation method is definitely established.

2105

Venzke, G., and P. Dammig, "Measurement of Diffuseness in Reverberation Chambers with Absorbing Material," J. Acoust. Soc. Am., 33, 1687-1689, 1961.

The angular distribution of sound traveling in a reverberation chamber in which a certain amount of absorbing material had been installed was measured during the decay phase of sound. Two methods were used: the first with a directional sound source and a nondirectional microphone, the second with a nondirectional source and a directional microphone developed in the PTB. In the latter case, the differences of angular distribution of sound impinging on the absorbing sample could be shown for two different states of diffuseness accomplished in the reverberation chamber by installing different numbers of diffusing elements in the room. The angular distributions were investigated at frequencies of 1.2 and 4 kc.

2106

Walther, K., "The Upper Limits for the Reverberation Time of Reverberation Chambers for Acoustic and Electromagnetic Waves," J. Acoust. Soc. Am., 33, 127-136, 1961.

The upper limits for the reverberation time and Q factor of acoustic reverberation chambers with perfectly rigid, smooth walls are determined. The reflection factor for a rigid wall of arbitrary thermal conductivity is determined from a consideration of the viscosity and heat-conductivity boundary layer. The cases of isothermal and adiabatic boundary conditions are discussed. At very low frequencies the boundary absorption and at very high frequencies the volume absorption are the important factors in determining the losses.

The analogous problem of the electric reverberation chamber is compared with the acoustic case. For some conditions the electric and acoustic equations are identical in form, if the electric skin depth is replaced by the thickness of the acoustic viscosity boundary layer. At comparable wavelengths and room sizes the electric Q factors are approximately a factor of 50 higher than the acoustic upper-limiting values.

2107

Waterhouse, R. V., "Interference Patterns in Reverberant Sound Fields," J. Acoust. Soc. Am., 27, 247-258, 1955.

In a reverberant sound field, where at all points equal mean energy flows in all directions, the sound energy is distributed into interference patterns at the reflecting boundaries. Thus the mean energy density is not uniform at all points in the field. For a perfectly reflecting plane surface that is large compared with the wavelength, the interference pattern can be expressed as a mean-squared sound pressure varying as $(1 + \sin 2kx/2kx)$ where x is the distance from the surface and k is the wave number. Corresponding expressions are derived for the mean-squared particle velocity and the mean energy density. The energy level at the surface is found to be 2.2 db higher than at points further away where the interference patterns are negligible.

Similar expressions are derived for the interference patterns formed by two and three reflectors at right angles, as at the edges and corners of a room. The largest departure from uniformity occurs in a corner where the mean squared pressure is 9 db higher than at remote points. The effects of such interference patterns on transmission loss and reverberation room measurements are discussed briefly. The patterns are not much affected by the frequency band widths habitually used in room acoustics. Experimental confirmation of the theory is given.

2108

Waterhouse, R. V., "Output of a Sound Source in a Reverberation Chamber and Other Reflecting Environments," J. Acoust. Soc. Am., 30, 4-13, 1958.

It is important to know the output of a source as a function of position in a reverberation chamber. Expressions are given for the sound power output of simple monopole and dipole sources as functions of source position in various reflecting environments. They are obtained by the use of images and a general formula, from Rayleigh, for the output of a number of simple sources. The cases of dipole source near a reflecting plane and a simple source near a reflecting edge and corner are treated, and the effect of the bandwidth of the source is considered. The results apply when the reflectors enclose the source, as in a reverberation chamber, unless the distance in wavelengths between parallel walls is small and the absorption in the enclosure is low. Some experimental data are given, and the reverberation chamber method of measuring the power output of sources is discussed. In the general case of an extended source emitting nonspherical waves near reflecting surfaces, it may be more convenient to find the variation of power output with position by experiment than by calculation.

2109

Waterhouse, R. V., and R. D. Berendt, "A Reverberation Chamber Study of the Sound Power Output of Subsonic Air Jets," Rept. No. 4912, National Bureau of Standards, Washington, D. C., 1956.
AD-156 979.
See Also: J. Acoust. Soc. Am., 30, 114-121, 1958.

The reverberation chamber technique was used to determine the sound spectra and acoustic power radiated by air jets over a range of subsonic velocities. Different air jets were used with round and square velocity profiles; nozzles of circular cross section, and nozzles with sawtooth and corrugated ends were also used. Of these nozzles only the latter type gave a significant (9 db) reduction in sound-power output for a given thrust.

A study was made of the limitations of the reverberation chamber technique caused by the absorption in the chamber. When this absorption became considerable, the measurement of sound levels in a circle around the sound source revealed a directional pattern, and the assumption of uniform energy distribution in the chamber became invalid. This situation was noticeable at frequencies above 5 kc in the National Bureau of Standards chamber, owing to air absorption.

2110

Wells, R. J., and F. M. Wiener, "On the Determination of the Acoustic Power of a Source of Sound in Semi-Reverberant Spaces," Noise Control, 7, 21, 1961.

After briefly discussing the determination of acoustic power levels in reverberation chambers and anechoic rooms, the authors show that it is possible to determine acoustic power levels of small sources in ordinary (semi-reverberant) spaces with engineering accuracy. There is reason to believe that these results can frequently be extended to large sources as well.

Reverberation
See also—1, 9, 33, 92, 107, 108, 111, 329, 349, 529, 599, 666, 879, 992, 1040, 1573, 1638, 1862, 2265, 2383, 2527.

ROCKET-GRENADE EXPERIMENT

2111

Bandeen, W. R., "The Recording of Acoustic Waves From High-Altitude Explosions in the Rocket-Grenade Experiment and Certain Other Related Topics," Tech. Rept. No. 2056, Army Signal Res. and Development Lab., Fort Monmouth, N. J., 72 pp., 1959.
AD-231 943.

Discusses the instrumentation and operation of the sound-ranging installation for the rocket-grenade experiment at Fort Churchill. Applies Schrodinger's equation for the transmissivity of sound in the atmosphere to empirical data, illustrating the upper altitude limit of the experiment, and discusses a modified method of correcting for the test's finite-amplitude-propagation effect. Analyzes the specific problem of measuring arrival angles of sound waves. Examines the effect of the re-entry ballistic wave on grenade-sound arrivals, and presents a method for determining the times of such obscured arrivals, and also of weak sound arrivals.

2112

Bandeen, W. R., R. M. Griffith, et al., "Measurement of Temperatures, Densities, Pressures and Winds over Fort Churchill, Canada, by Means of the Rocket Grenade Experiment," Tech. Rept. No. 2076, Army Signal Res. and Development Lab., Fort Monmouth, N. J., 38 pp., 1959.
AD-288 466.

Ten successful Aerobee rocket firings carrying the Signal Corps-University of Michigan rocket-grenade experiment were conducted at Fort Churchill, Manitoba, Canada (59^{o}N). One hundred and fifty-three values of temperatures and winds between 25 and 94 km were measured in summer and winter, both during the day and at night, using the improved tracking and sound-ranging techniques required to make the grenade experiment an all-weather experiment. New facts about the arctic upper atmosphere were revealed. Temperatures in winter are unexpectedly high above 60 km with a second temperature maximum occurring between 70 to 80 km. Summer temperatures as low as 165^{o}K at 80 km were recorded. The temperature maximum lies at about 50 km and in summer is greater than in White Sands, while in winter these temperatures are lower. Densities and pressures were also calculated from these data. The winds show a pattern similar to that in the middle latitudes: strong and westerly in winter, weaker and easterly in summer.

2113

Bartman, F. L., and L. M. Jones, "Atmospheric Phenomena at High Altitudes," Final Rept. No. 2387-59-F, Coll. of Eng., Univ. of Mich., Ann Arbor, 7 pp., 1960.
AD-241 361.

Summarizes the tasks and the reports of results achieved in a five-year program that used rockets to measure atmospheric phenomena at high altitudes.

2114

Bartman, F. L., L. M. Jones, J. Otterman, et al., "Rocket-Grenade Experiment for Upper Atmosphere Temperature and Winds," Proj. No. 2387, Eng. Res. Inst., Univ. of Michigan, Ann Arbor, 1955-1960.

This series of Quarterly Progress Reports and Technical Reports covers the experimental and theoretical results of efforts to adapt the rocket-grenade experiment for use in the Arctic during the IGY. The rocket-grenade system provides an all-weather method for calculating upper atmosphere winds and temperatures from acoustic data. Various methods for computing these temperatures and winds are presented in complete detail. The effects of finite-amplitude acoustic propagation resulting from the use of high-explosive grenades are investigated. Rocket tracking, by the DOVAP method, is described, as are various methods for determining the positions of exploding grenades with respect to the rocket. Sound ranging gear for measuring the arrival times, elevation angles and azimuths of acoustic wavefronts is also described. Abstracts for six technical reports listed in this series are printed separately under appropriate authors and titles.

Qtly. Prog. Rept. 1, May-July 1955	AD-95 280	2387-4-P
Qtly. Prog. Rept. 2, August-October 1955	AD-95 279	2387-6-P
Qtly. Prog. Rept. 3, November-January 1956	AD-95 278	2387-10-P
Qtly. Prog. Rept. 4, February-April 1956	AD-118 569	2387-13-P
Qtly. Prog. Rept. 5, May-July 1956	AD-133 348	2387-17-P
Qtly. Prog. Rept. 6, August-October 1956	AD-133 347	2387-19-P
Qtly. Prog. Rept. 7, November-January 1957	AD-133 346	2387-22-P
Qtly. Prog. Rept. 8, February-April 1957	AD-146 638	2387-25-P
Qtly. Prog. Rept. 9, May-July 1957	AD-148 199	2387-27-P
Qtly. Prog. Rept.10, August-October 1957	AD-151 912	2387-32-P
Qtly. Prog. Rept.11, November-January 1958	AD-162 058	2387-36-P
Qtly. Prog. Rept.12, February-April 1958	AD-208 805	2387-39-P
Qtly. Prog. Rept.13, May-July 1958	AD-208 604	2387-45-P
Qtly. Prog. Rept.14, August-October 1958	AD-213 452	2387-47-P
Qtly. Prog. Rept.15, November-January 1959	AD-218 341	2387-51-P

Tech. Rept. 2387-34-T (1958)	AD-162 059
Tech. Rept. 2387-40-T (1958)	AD-201 454
Tech. Rept. 2387-42-T (1958)	AD-203 897
Tech. Rept. 2387-50-T (1959)	AD-215 303
Tech. Rept. 2387-57-T (1960)	AD-236 213
Tech. Rept. 2387-58-T (1960)	AD-241 362
Final Rept. 2387-59-F (1960)	AD-241 361

2115

Ference, M., W. G. Stroud, J. R. Walsh, and A. G. Weisner, "Measurements of Temperature at Elevations of 30 to 80 Kilometers by the Rocket Grenade Method," J. Meteorol., 13, 5-12, 1956. AD-104 510.

The temperatues in the atmospheric region between 30 and 80 km have been determined from measurements of the sound velocity in nearly vertical propagation. The sound sources were grenades consecutively ejected from Aerobee rockets. The method of analysing the data to obtain accurate temperatures is described, and the results are presented.

The temperature data are in good agreement with balloon data near 30 km and show a maximum of about 268°K at 48 km. The probable errors are less than 3%. There are no clear-cut seasonal effects at the latitude of the firings, 32° N, although a number of marked temperature irregularities was noted in individual firings.

2116

Groves, G. V., "Effect of Experimental Errors on Determination of Wind Velocity, Speed of Sound and Atmospheric Pressure in the Rocket-Grenade Experiment," J. Atmospheric Terrest. Phys., 9, 237-261, 1956.

Expressions are obtained for systematic and random errors in the grenade-experiment determination of wind velocity, speed of sound, and atmospheric pressure, arising from systematic and random errors in the various quantities measured; viz., the coordinates and time of explosion of each grenade and the coordinates of each microphone and the times of arrival of the sound waves.

The theory is first developed for a general distribution of microphones on the ground and of grenade bursts in the air. The results obtained are applied to the special case of four microphones, comprising a central microphone and three symmetrically placed microphones, with grenades bursting vertically above the central microphone. Under certain simplifying assumptions, expressions are obtained to show how the errors in the final determinations are related to the measurement errors, and also to the nature of the atmospheric structure under investigation.

Values are calculated for the errors that would arise in wind velocity, speed of sound, and pressure under certain typical conditions.

2117

Groves, G. V., "A Rigorous Method of Analyzing Data of the Rocket-Grenade Experiment," J. Atmospheric Terrest. Phys., 9, 349-351, 1956.

A set of three equations developed in an earlier paper (Groves, J. Atmospheric and Terrest. Phys., 8, 24-38, 1956) express in integral form the horizontal components of wind velocity and the speed of sound at any desired height up to 90 km in terms of quantities that can be measured at and from the ground. These measurable quantities are the x, y, z coordinates in space of at least two exploding grenades, the x and y components of the velocity of the sound as it passes a detection point 0 on the ground at the origin of the coordinate system, and finally, t, the travel times of the sounds from grenades to point 0. Either graphical or numerical differentiation of the integral equations then yields the desired components of wind velocity and speed of sound. With these quantities determined, the air temperature at the corresponding altitude may be calculated. With three grenades a rough linear variation of wind and temperature with height may be determined, while with four or more, an increasingly accurate variation with height may be determined.

2118

Groves, G. V., "Theory of the Rocket-Grenade Method of Determining Upper-Atmospheric Properties by Sound Propagation," J. Atmospheric Terrest. Phys., 8, 189-203, 1956.

Considers the problem of determining the wind field and velocity of sound as functions of height in the upper atmosphere by means of sound propagation from grenades exploded at these heights. Observations made are taken to be the location and time of each explosion, and the times of arrival of each resulting soundwave at a number of microphones at known points on the ground. The distribution of microphones is taken to be quite general, within a region of the earth's surface over which horizontal variations in the wind and sonic velocities can be neglected. Differences in the heights of the microphones, which would arise from topographical features and the curvature of the earth, are taken into account. The wavefront from each explosion is taken to be propagated at a known Mach number at any time, so that account can be taken of the departure of the Mach number from unity along any ray.

The nature of the problem requires the solution to proceed by successive approximation in terms of the variations in the wind components and speed of sound. The theory is developed as far as the second-order solution, and this is thought to be adequate for practical needs. It is shown that four microphones are, in general, sufficient for the determination of the three components of the wind-velocity and the speed of sound. By using more than four microphones, a least-squares determination is possible, and this allows a check to be made on the consistency of the observations and the adequacy of the theory. Finally, it is shown how atmospheric pressure, density, and temperature can be deduced from these determinations, assuming the composition of the atmosphere to be known.

2119

Harrington, J. B., Jr., "Acoustical Probing of the Upper Atmosphere," Univ. of Mich., 5500 East Engineering, Ann Arbor, 40 pp., 1959.

This paper presents a comprehensive review of historical and current techniques and investigations for accurately determining the propagation characteristics of sound in the atmosphere. Anomolous propagation and the application of Snell's Law of refraction for calculating sound-ray paths are discussed. Gutenberg's approach to measuring upper winds and temperatures using sound rays is described, followed by an account of Richardson's and Kennedy's "Study of Meteorological and Terrain Factors Which Affect Sound Ranging" and "Determination of Atmospheric Winds and Temperatures in the 30 to 60 Kilometer Region by Acoustic Means." The rocket-grenade experiment for determining upper-level wind and temperature profiles is explained as conducted by the Signal Corps and as modified by Groves. A bibliography of more than eighty reports and journal articles on the subject of propagating sound in air is included.

2120

Holzer, R. E., "The Rocket Program in Universities of the United Kingdom," Tech. Rept. ONRL-30-60, 9 pp., 1960. AD-239 258L.

The principal upper atmospheric research projects utilizing rocket measurements are described as activities at University College, London; Imperial College, London; Birmingham University; Queens College, Belfast; and the University of Wales. The principal experiment involving acoustics is that at University College, London, where grenade ejection and field microphone pickups are used for evaluating meteorological data.

2121

Hudson, G. E., et al., "A Study of High-Altitude Wind Research, Part I. Methods and Bibliography," Rept. No. 30, Smyth Research Associates, San Diego, Calif., 99 pp., 1957.

The rocket-grenade experiment is described on page 44.

2122

Machine Design, "Multiple-Explosive Rockets will Measure the North Wind, Spot Checks Under way in Three Spots," Mach. Design, 29, 27-28, 1957.

Refers, briefly, to experiments by Army scientists with Aerobee-Hi rockets, which it is expected will lead to more accurate predictions of cold weather.

2123

Maeda, K., H. Matsumoto, Y. Takeya, and T. Okumoto, "Measurement of Atmospheric Temperature and Wind Velocity by Kappa Rockets," Rep. Ionosphere Space Res. Japan, 14, 385-404, 1960.

Measurements were made in the region ranging from the height readily attainable by radiosonde up to about 60 km. The grenade-explosion method was used. The process of deducing the height distributions of temperature and wind velocity by sound propagation analysis is given. Results are given for Dec., 1958, and March, 1959.

2124

Newell, H. E., Jr., "Rocket Data on Atmospheric Pressure, Temperature, Density and Winds," Ann. Geophys., 11, 115-144, 1955.

A comprehensive review of all of the important results obtained by rocket observations of pressure, density, temperature and wind since 1945 at White Sands and other places by the U. S. Navy Signal Corps and Air Force. Rockets are illustrated and curves presented showing latest estimates of structure and behavior of these elements to 220 km in some cases. Data over the equator and at high latitudes are compared with those over New Mexico. Discussion includes: heating by ozone, measurement of pressure by X-rays, rocket grenade experiments (speed of sound), the falling-sphere experiment, the shock wave-angle experiment, and USAF-University of Michigan data obtained from impact pressure at the nose of an Aerobee. Not enough data exists to settle problems of diurnal vs. seasonal and geographical variations.

2125

Nordberg, W., "Acoustic Phenomena Observed on Rocket-Borne High Altitude Explosions," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 233-244, 1961.
AD-408 716.

A series of high-explosive charges, ranging from one to four pounds in weight, have been exploded from aboard Aerobee and Nike-Cajun rockets at altitudes between 30 and 90 km. Although the main purpose of these experiments was to study temperatures and winds in the upper atmosphere, a number of interesting phenomena pertinent to the propagation of shock and sound waves in a highly rarified and inhomogeneous atmosphere were observed. The propagation of the shock in the immediate vicinity of the explosion was observed by the modulation that the shock wave produced on a ground-to-missile-to-ground doppler radio link. Preliminary results show that the theory developed by H. L. Brode for shock propagation in higher density atmospheres applies well to these upper-air explosions. Qualitative analysis of the intensities of the ground arrivals at the microphone array on the ground indicate that there are large variations of sound amplitudes with temperature gradients in the vicinity of the explosions. For a complete explanation of these variations a treatment more complex than simple refraction focusing and exponential attenuation with altitude will have to be employed.

2126

Nordberg, W., "A Method of Analysis for the Rocket-Grenade Experiment," Tech. Memo. M-1856, Army Signal Engineering Labs., Fort Monmouth, N. J., 37 pp., 1957.
AD-143 218.

The method of analysis for the rocket-grenade experiment is reviewed. An analytical method is derived to obtain temperature and wind data from sound explosions between 30 and 80 km altitude. Errors stemming from both random measuring errors in the initial parameters and systematic sources in the method are investigated. It is concluded that average temperatures and winds in layers of several kilometer thickness between two successive explosions may generally be determined within ±2.5°K and ±5 m/sec, respectively.

2127

Nordberg, W., "Upper Atmosphere Rocket Soundings on the Island of Guam (IGY Project 10.18)," Tech. Rept. 2078, Army Signal Research and Development Lab., Fort Monmouth, N. J., 142 pp., 1959.
AD-228 443.

The performance of the rocket-grenade experiment on Guam during November, 1958, is reviewed. Nine rockets (six Nike-Cajuns and three Aerobee 75's) were launched successfully. A total of 43 data points, each representing one value for temperature, wind speed, and direction, were obtained. The measurements were spread over the period between local sunset and sunrise and cover an altitude range from about 30 to 80 km. Radiosonde data for heights below 30 km are available.

2128

Otterman, J., "A Simplified Method for Computing Upper-Atmosphere Temperature and Winds in the Rocket-Grenade Experiment," Rept. No. 2387-40-T, Eng. Res. Inst., Univ. of Mich., 40 pp., 1958.
AD-201 454.

Presents a new approach to the problem of the computation of winds and temperatures in the layers between explosions from the recorded data on propagation of the explosion waves. The effects of temperature and winds are taken into account simultaneously. The method is simple, both from the conceptual point of view and from the point of view of programming for a solution on a digital computer. As in the currently used method, zero vertical winds are assumed.

2129

Stroud, W. G., "Meteorological Rocket Soundings in the Arctic," Trans. Am. Geophys. Union, 39, 789-794, 1958.

Various techniques used by the US in IGY meteorological rocket soundings in the Arctic program are made available in this report. Temperature, pressure, density, and winds have been measured by these new devices. Experiments on the freely-falling sphere, rocket-grenade, gage, aerodynamic, and other methods of determining the dynamic processes of the upper atmosphere are discussed. The results achieved are compared with USSR ventures along similar lines.

2130

Stroud, W. G., "The Reduction of Data from the Rocket-Grenade Experiment," Tech. Memo. M-1570, Evans Signal Lab., Signal Corps Engineering Labs., Belmar, N. J., 35 pp., 1954.
AD-34 406.

A summary is presented of the firing of 16 Aerobee rockets at White Sands Proving Ground to measure the temperatures and winds in the region of the atmosphere between 30 to 80 km. Basic data were obtained by measuring the speed of sound in the atmospheric layers defined by the explosions of grenades successively ejected from the rocket along various points in its upward trajectory. An account of the method of analysis of the rocket-grenade experiment is given which covers step-by-step, equation-by-equation, the procedures for deducing the temperatures and winds from the basic field data. A complete set of data tabulation sheets is appended.

ROCKET-GRENADE EXPERIMENT

2131

Stroud, W. G., et al, "Temperatures and Winds in the Arctic as Obtained by the Rocket Grenade Experiment," IGY Rocket Rept. Ser. 1, 58-79, 1958.

Description of the grenade experiment, with the results of ten rocket firings at Fort Churchill, November 1956-January 1958.

2132

Stroud, W. G., E. A. Terhune, J. H. Venner, J. R. Walsh, and S. Weiland, "Instrumentation of the Rocket-Grenade Experiment for Measuring Atmospheric Temperatures and Winds," Rev. Sci. Instr., 26, 427-432, 1955.

Analyzes results of 92 grenade explosions from 15 Aerobee rocket firings from March 3, 1950, to September 4, 1953, at White Sands, N. M., to determine efficiency of this method of determining upper air temperatures and winds. From four to eight grenades are exploded on each flight at specified heights (which can be determined to ±1 to 6 ft at 100,000 ft by photographic methods) The formulas $C = kT^{1/2}$ and $V = C + W$ are used, where C is the velocity of sound due to elasticity, k is a constant, T is absolute temperature, V is the velocity of propagation of sound wave, and W is the wind velocity. Timing to 0.1 millisecond is necessary, and the sound detectors are arranged so they are nearly vertically beneath each grenade when it is exploded. The temperatures and wind can be determined for each successive layer (between grenade firings).

The text includes a summary of the fifteen firings; illustrations of equipment and of some of the records; and descriptions of methods, rockets, rocket instrumentation, grenade structure, flash detectors, telemetering system, safety features, sound ranging equipment, and positions of grenade explosions (with ground temperatures).

2133

Stroud, W. G., W. Nordberg, and J. R. Walsh, "Atmospheric Temperatures and Winds Between 30 and 80 KM," J. Geophys. Res., 61, 45-56, 1956.
AD-104 268.

The method and analysis of the rocket-grenade experiment are briefly described. The 59 values of temperatures and of wind speeds and directions between 30 and 80 km obtained during 12 Aerobee rocket firings are summarized. The mean temperature distribution has a maximum of about 270°K at 50 km, with a lapse rate of about 2.5°/km above the peak. The winds are strong and from the west during the winter months (October through February); less strong and from the east during the summer months (April through August); and are comparatively weak and predominantly from the north during the fall (September). The maximum wind speed measured was a value of 104 meters/sec at 55 km during a winter firing.

The average probable error for the temperature data is ±5°C; the average errors in wind speed and direction are ±10 meters/sec and ±18°, respectively.

2134

Walsh, J. R., G. J. Day, et al., "Description of the Instrumentation and Procedures for the Velocity of Sound (Grenade) Experiment," Eng. Rept. E-1140, Evans Signal Lab., Signal Corps Eng. Labs., Belmar, N. J., 1954.
AD-46 513.

Describes the technique of firing grenades from Aerobee rockets and determining the velocity and the angle at which sound propagating from the grenades arrives at acoustic detectors on the ground. Sound ranging equipment was employed for the system of detectors and the location of grenade explosions was determined by photographing the flashes with fixed plate cameras. Describes and evaluates performance of all equipment used in the experiment.

2135

Weisner, A. G., "Measurements of Winds at Elevations of 30 to 80 Kilometers by the Rocket-Grenade Experiment," J. Meteorol., 13, 30-39, 1956.
AD-104 501.

Thirty-two values of wind velocity between 30 and 80 kilometers have been obtained from six Aerobee rocket flights made at night at White Sands Proving Ground, N. Mex. (32° N) between July, 1950, and November, 1951. The average wind velocity in a horizontal layer at a particular altitude was determined from the effect of the wind on a sound wave traveling downward through the layer. The sources of the sound waves were grenades. The travel times of the sound waves to a point of ground almost directly underneath the grenades and the arrival angles of the waves at the ground are the data required for the calculations. The wind directions were found to be easterly in summer and westerly in autumn and winter. The maximum wind speeds were at about 55 km, the largest measured speed having been 104 meters per second.

Rocket-Grenade Experiment
See also--445, 570, 1451, 1453, 1520, 1523, 1524, 2291, 3648, 3649, 3914, 4051.

SCATTERING

2136

Ankerman, P. W., and R. A. Rubega, "Bistatic Scattering from Totally Reflecting Flat Plates," J. Acoust. Soc. Am., 32, 478-481, 1960.

This paper deals with an investigation of the characteristics of the scattering of sound from a flat plate, five wavelengths long. The scatter patterns were calculated, based on the simplifying assumption of total reflection and experimentally checked by echo-ranging in air. Agreement was found to be reasonably good, although some interesting deviations in the side-lobe structure were observed. Patterns calculated and experimentally obtained include bistatic backscatter patterns as well as the scatter patterns for a given incident wave.

2137

Barantsev, R. G., "Plane Wave Scattering by a Double Periodic Surface of Arbitrary Shape," Soviet Phys. Acoust. English Transl., 7, 123-126, 1961.

The stationary problem of a plane wave reflected from an arbitrary double periodic surface $z = \ell(x, y)$ is considered. The Laplace transform of z from ℓ to $+\infty$ leads to the representation of the scattered field for all $z \geq \ell(x, y)$. For $z > h = \max\{\ell(x, y)\}$ this field is represented by a Rayleigh series, the coefficient of which, as functionals of the unknown function $q(x, y)$, must be defined by a given infinite sequence of other functionals of the same function q. The expansion of q in a series with respect to any complete set of functions leads to an infinite algebraic set for the coefficients of this series. The structure of the matrix of the set enables one to draw a parallel between the approximate methods of solving this set and the actual problem in its original position, and to choose the proper initial approximation in solving the set by the method of iterations.

2138

Bellin, J. L. S., and R. T. Beyer, "Experimental Investigation of an End-Fire Array," J. Acoust. Soc. Am., 34, 1051-1054, 1962.

Experiments are reported on the measurement of the scattered pressure from two finite-amplitude, collinear sound beams. The measurements were carried out at a carrier frequency of 13.5 Mc in water and 350 kc in air. The slope of the half-pressure angle vs. difference frequency curve agrees well with that predicted by Westervelt, although the radiation pattern measured experimentally was in each case more directive than predicted by the theory.

2139

Bellin, J. L. S., and R. T. Beyer, "Scattering of Sound by Sound," J. Acoust. Soc. Am., 32, 339-341, 1960.

An attempt was made to determine the presence of scattering resulting from the nonlinear interaction of two finite-amplitude sources, operating in water. Experiments were performed with two beams crossed at right angles and also in the nonperpendicular case. A detector crystal, tuned to the summation frequency (13.4 Mc) of the two sources (7.4 Mc and 6.0 Mc), and pivoted about a point above the interaction region, was used to investigate the scattered field. The results, applicable to sound in air as well as sound in water, indicated no scattered sound above the noise level of the detection system. The lack of scattered sound is in agreement with the theoretical considerations of Westervelt, but is contrary to the predictions of Ingard and Pridmore-Brown.

2140

Dean, L. W., III, "Interactions Between Sound Waves," J. Acoust. Soc. Am., 34, 1039-1044, 1962.

Exact solutions for the interaction between two concentric cylindrical waves and between two concentric spherical waves are presented. The scattered-pressure amplitude in the far field is shown to be constant in the cylindrical case and to be proportional to $r^{-1} \ell hr$ in the spherical case, where r is the distance to the source of primary waves.

A near-field solution is derived for the scattered waves generated when two sharply defined, plane-wave beams of square cross section intersect at right angles. A comparison is made of the theory with recent experiments in which beams of circular cross section were used. It is concluded that if the scattered waves do exist, their amplitudes are at least 40 db below those that are predicted by this theory.

When a hard object is placed in the region of intersection, scattered waves are observed. This effect can be explained by the fact that with the addition of the hard object (a cylinder) the primary waves have components of the same symmetry. These components are the waves scattered from the primary beams by the object. Evidence is presented to show that these components, having the same symmetry, interact strongly in the volume surrounding the object.

2141

Einspruch, N. G., and C. A. Barlow, "Scattering of a Compressional Wave by a Prolate Spheriod," Quart. Appl. Math., 19, 253-258, 1961.

Solves the problem of the scattering of a plane acoustic wave by a soft prolate spheroidal obstacle embedded in a fluid medium. An exact solution is given as well as approximate solutions valid in the long and short wavelength limits. A solution is also presented for the problem of the scattering of a compressional wave by a small prolate spheroidal obstacle of arbitrary acoustic properties. In each case, an expression for the total scattering cross section is derived.

2142

Emertron, Inc., "Scattering of Electromagnetic Waves by Ultrasonic Beams," Final Rept. No. 3, Silver Spring, Md., 112 pp., 1962.
AD-274 810.

Factors affecting the scattering of radio waves by sonic beams are discussed from the point of view of existing theory. A review of sonic sources is presented along with the detailed characteristics of the sonic generators investigated during the course of field experimentation. The millimeter wave communications equipment used as the electromagnetic source is also briefly described. Field experiments performed over an open range of 154 feet yielded no positive results in indicating that scattering of radio waves can be effected by means of sonic energy. These results cannot be considered absolutely definitive in the light of limitations imposed on the experiment by both sonic and radio equipment.

2143

Emertron, Inc., "Scattering of Electromagnetic Waves by Ultrasonic Beams," Quart. Prog. Rept. No. 2, Silver Spring, Md., 103 pp., 1962.
AD-274 809.

The results of laboratory investigations on sonic generators are reviewed. Field experiments to determine the feasibility of scattering electromagnetic waves by means of ultrasonic beams are described, along with a brief presentation of the characteristics of the radio communications equipment used in the evaluation program. The field experiments were conducted over an open range of 154 feet. No positive results were obtained. In view of the limitations imposed on the experiment by both the sonic and the radio equipment, these results cannot be considered absolutely definitive.

2144

Eyges, L. J., "Proposal for Improving Tropospheric Propagation," Lincoln Lab., Mass. Inst. of Tech., Lexington, 6 pp., 1957.
AD-137 717.

Sound waves are proposed to produce index variations that will cause scattered waves in a uniform isotropic medium. The sound wave is explained as constituting a crude Brass layer of reflecting planes. With feasible amounts of power, the index variations appear to be less than those usually produced naturally by winds and turbulence in the atmosphere, but a wavelength can be chosen so that reflections add more or less coherently and thus compensate for this. The idea is discussed fully and estimates are given of the index variations made by reasonable amounts of sound power.

The possible difficulties and limitations of the technique are pointed out. These include the fact that because of the many estimates, any errors in the same direction would multiply to provide a completely wrong result. The variations proposed are often small compared with the natural variations that exist, and the question exists as to whether the atmosphere is generally sufficiently inhomogeneous that the regular periodic variations produced by a sound wave would be lost in the irregular atmosphere. The power that is scattered from the sound wave will probably be radiated in a very narrow beam that can be distorted by winds or other factors.

2145

Felsen, L. B., "Plane Wave Scattering by Small-Angle Cones," Rept. No. R-362-54, Microwave Research Inst., Polytechnic Inst. of Brooklyn, N. Y., 24 pp., 1954.
AD-31 750.

Rigorous expressions are developed for the scattering of acoustic (and electromagnetic) waves by the tip of a perfectly rigid (or perfectly conducting) semi-infinite cone. For plane-wave incidence on or off the cone axis, the expressions are valid for observation points lying in a region that excludes the rays reflected from the sides of the cone according to the laws of geometrical optics. Approximate closed-form results are obtained for cones with small apex angle for the acoustical plane-wave scattering, and for electromagnetic scattering of incident waves whose electric vector is directed perpendicularly to the cone axis.

2146

Ford, G. W., and W. Meecham, "Scattering of Sound by Isotropic Turbulence of Large Reynolds Number," J. Acoust. Soc. Am., 32, 1668-1672, 1960.
AD-244 259.

Lighthill has given an expression for the intensity of acoustical radiation scattered from turbulent fluids. He finds that such scattered energy is proportional to the square of the Mach number of the turbulence and is also proportional to the value of the turbulence-spectrum function at wave number equal to the magnitude of the change in the wave vector during the scattering. If it is supposed that the turbulent region has a Reynolds number sufficiently large to give rise to an inertial subrange, one can use similarity principles to obtain information concerning the spectrum of the scattered radiation. This is accomplished by the use of a Lagrangian-type space-time velocity correlation in order to properly treat convective effects of the macro-eddies.

The result is that the position of the maximum of the scattered-power spectrum is shifted from the incident frequency by an amount determined by the Doppler shift due to the mean flow. The half-width of the spectrum is proportional to the turbulence Mach number. The maximum of the spectrum is also proportional to the turbulence Mach number and to $(\omega_0)^{-2/3}$, where ω_0 is the angular frequency of the incident wave.

2147

Gerjuoy, E., and D. S. Saxon, "Variational Principles for the Acoustic Field," Phys. Rev., 94, 1445-1458, 1954.

Variational principles are presented for the scattering amplitude in the general acoustical scattering problem, and for the phase shifts of spherically symmetrical scatterers. Integral equations for the acoustic field are also given, and the properties of the scattering matrix are developed.. The entire formulation remains valid in the presence of discontinuities of density and/or velocity in the medium.

2148

Grace, J. C., "Reflection from a Statistical Array of Scatterers," J. Acoust. Soc. Am., 26, 103, 1954.

The average energy spectrum of the reflection from an array of randomly located point scatterers has been calculated. It is shown that this spectrum is proportional to the square of the sum of the individual scatterer amplitudes for wavelengths that are large compared to the extent of the array, and that it is proportional to the sum of squares of the individual amplitudes for wavelengths that are small compared to the array extent.

2149

Hart, R. W., "Sound Scattering of a Plane Wave from a Nonabsorbing Sphere," J. Acoust. Soc. Am., 23, 323-328, 1951.

Sound-scattering from a sphere of arbitrary size is treated theoretically when the acoustical properties of the sphere are similar to those of the surrounding medium. Closed-form analytic expressions are found for the reflectivity and the total cross section. These expressions become exact only in the limit as the ratio of the densities and ratio of the speeds approach unity, but it is shown that for ratios as large as 5/4 and probably as large as 3/2 the approximate reflectivity and total cross section compare favorably with results of exact calculation. Calculations of reflectivity and total cross section, which would require weeks if made from the exact solution of the wave equation, may be completed in a few hours using the approximate closed-form expressions.

2150

Heins, A. E., and R. C. MacCamy, "On the Scattering of Waves by a Disk," Tech. Rept. No. 29, Carnegie Inst. of Tech., Pittsburgh, Pa., 19 pp., 1959.
AD-225 546.

Analyzes the scattering of sound waves by a circular disk of so-called soft material. The appropriate boundary-value problem is the determination of a function $U(r, \theta, z)$ satisfying the equation,

$$U_{rr} + \frac{1}{r} U_r + \frac{1}{r^2} U_{\theta\theta} + U_{zz} + k^2 U = 0$$

with the condition $U(r, \theta, 0) = 0$ for $r < 1$. In addition $U(r, \theta, z)$ is to be made up of an incident field $U^o(r, \theta, z)$, which is prescribed, and a term $U^s(r, \theta, z)$, satisfying a radiation condition at infinity. An alternative method is to formulate the problem as an integral equation.

The method of solution is outlined and some simple calculations are presented for the case in which $U_0(r, \theta, z)$ represents a plane wave of arbitrary angle of incidence. An approximate formula is included for the scattering cross section, as a function of the angle of incidence, when the wave number k is small.

2151

Horiuchi, I., "Effects of Atmospheric Turbulence on the Propagation of Sound," Tech. Rept. No. 3, Acoustics Lab., Columbia Univ., N. Y., 12 pp., 1954.
AD-28 518.

Data-analysis of the characteristics of atmospheric turbulence was used as a basis for arriving at representative figures of expected sound scattering. Micrometeorological data pertaining to the study of sound propagation in open air were reviewed, and the pertinent data and expressions derived in previous work were used in calculations of the expected sound scattering. Discussions of atmospheric turbulence include isotropic turbulence, thermal and terrain effects of the ground, anisotropy of eddy velocities, and eddy sizes.

2152

Ingard, U., and D. C. Pridmore-Brown, "Scattering of Sound by Sound," J. Acoust. Soc. Am., 28, 367-369, 1956.

Reports calculations and measurements of the summation and difference frequency components that are scattered from the interaction region of two sound beams in air that intersect each other at right angles.

2153

Ingard, U., S. Oleson, and M. Mintz, "Measurements of Sound Attenuation in the Atmosphere," Final Rept., Res. Lab. Electron., Mass. Inst. Tech., Cambridge, 52 pp., 1961.
AD-248 636.

An attempt is made to measure acoustic scatter attenuation produced by atmospheric turbulence. Laboratory experiments on scattering of sound by turbulence are described; in particular, a new experimental technique involving pulse-height analysis of scattered sound.

2154

Junger, M. C., "The Concept of Radiation Scattering and Its Application to Reinforced Cylindrical Shells," J. Acoust. Soc. Am., 25, 899-903, 1953.

This paper presents an approach that permits the analysis of elastic scatterers embodying complicated structural characteristics. Such problems cannot be investigated by means of the methods previously applied to the study of the scattering action of simple elastic bodies.

The scattered wave pressure produced by elastic scatterers may be expressed as the sum of two terms, one representing "rigid body scattering," i.e., the scattering that would exist if the scatterer were rigid and immobile, the other representing "radiation scattering," which is associated with the sound radiated by the scatterer vibrating under the effect of the incident wave pressure. These two terms are derived here for three important cases.

The problem is now reduced to one in elasticity, specifically to the problem of solving the equations of motion for the elastic system's forced response. The scattering pattern can then be computed. This procedure is applied to a scatterer in the form of a cylindrical shell reinforced with regularly spaced septa.

2155

Kallistratova, M. A., "Experimental Investigation of Sound Scattering in a Turbulent Atmosphere," Dokl. Akad. Nauk SSSR, 125, 69-72, 1959.

A preliminary account of experiments carried out in the autumn of 1958 at the Tsimlyansk station of the Institute for Atmospheric Physics of the Academy of Sciences, U.S.S.R.

At the ends of a 40-meter base line, a transmitter and a receiving microphone were set up. The polar diagrams showed a (half-strength signal-angle)/2 of 1.5°. A theory of the scattering is worked out that agrees with the experimental results for angles of 25-30. The possibility is discussed of investigating the structure of atmospheric turbulences over a range of dimensions near to the internal dimensions of the turbulence.

2156

Kallistratova, M. A., "Procedure for Investigating Sound Scattering in the Atmosphere," Soviet Phys. Acoust. English Transl., 5, 512-514, 1961.

An 11-kcs pulse technique made it possible to isolate the required scattered signal from the direct and reflected ones. The construction, operation and performance of plane electrostatic transducers with good transfer characteristics—both as radiators and as microphones—are discussed.

2157

Kallistratova, M. A., and V. I. Tatarskii, "Accounting for Wind Turbulence in the Calculation of Sound Scattering in the Atmosphere," Soviet Phys. Acoust. English Transl., 6, 503-505, 1961.

Gives a mathematical derivation for the scattering of sound waves by turbulent fluctuations. Expressions are derived for the effective-scattering cross section per unit volume; the acoustical pressure of the scattered field, involving the effects of the vertical component of the wind field; and temperature fluctuations. Verification by actual measurements is shown.

2158

Karal, F. C., "A Study of the Scattering of Sound Waves in Fluids, I. Scattering of a Plane Wave by a Spherical Bubble," Tech. Rept. No. 2, Magnolia Petroleum Co., Dallas, Texas, 28 pp., 1953.
AD-14 874.

An analysis was made of the scattering of a plane wave by a spherical bubble immersed in a homogeneous, perfect fluid of infinite extent. An expression was obtained for the average sound intensity of the scattered wave in close proximity to the bubble. The cases of long wavelengths and of small bubble radii were given special consideration. Numerical results are presented in polar-diagram form for several values of r/a and $2\pi a/\lambda$, where r is the distance from the bubble center, a is the bubble radius, and λ is the wavelength.

An expression for the average total intensity of the entire sound field was compared with the average sound intensity of a plane wave traveling in an infinite, homogeneous fluid with no bubble present. The influence of the bubble on the average total sound intensity is negligible for small values of $2\pi a/\lambda$ and $r/a >> 10$. For small values of r/a, the presence of a bubble considerably alters the magnitude of the average total sound intensity from that of a plane wave. Polar diagrams of the ratio of the average total sound intensity to the average intensity of the incident plane wave are presented for several values of r/a.

2159

Kleinman, R. E., R. D. Low, and F. B. Sleator, "Studies in Non-Linear Modeling-IV: Far Field Scattering by Simple Shapes at Low Frequencies," Final Rept. No. 4405-1-F, Radiation Lab., Univ. of Michigan, Ann Arbor, 34 pp., 1962.
AD-274 528.

The effort on the problem of scattering by complicated shapes is part of a long range program, the ultimate goal of which is the theoretical determination, to any desired degree of accuracy, of the electromagnetic (and acoustic) scattering properties of an arbitrarily shaped target. Though this goal may never be fully attained, considerable activity, both in the Radiation Laboratory and in the field in general, has produced a variety of approximate techniques as well as exact solutions, thus considerably enlarging the class of shapes whose scattering properties can be said to be known. One concern has been refining techniques applicable for low frequencies (wavelength large with respect to scatterer) to extend their range of validity. This effort has met with considerable success.

2160

Kraichnan, R. H., "On the Scattering of Sound in a Turbulent Medium," Tech. Rept. No. 1, Acoustics Lab., Columbia Univ., N. Y., 24 pp., 1953.
AD-9918.

The scattering of a sound wave in a medium undergoing shear flow confined to a finite region is investigated under the assumption that the total velocity field is everywhere small compared to the velocity of sound. Formulas are obtained for the angular and frequency distributions of the scattered wave in terms of the four-dimensional Fourier transform of the shear velocity field. Under typical conditions, the cross-sections for the scattering of a plane wave of frequency ω by a shear flow of given scale and spatial structure are approximately of the form $\omega^4 M^2$, where M is a characteristic Mach number of the flow. The coupling between the shear and longitudinal velocity fields has a tensor character such that the scattering vanishes at 180° and at 90°.

The spectrum of the scattered sound wave is very sharp in the forward direction and becomes broader at larger scattering angles. Explicit compressions for the cross sections are obtained for the case of scattering from a region of isotropic turbulence. When the frequencies of importance in the turbulence are small compared to the frequency of the incident sound wave, the average differential scattering cross section can be expressed directly in terms of the energy-spectrum of the turbulence.

2161

Kraichnan, R. H., "The Scattering of Sound in a Turbulent Medium," J. Acoust. Soc. Am., 25, 1096-1104, 1953.

Journal article based on preceding entry.

2162

LaCasce, E. O., Jr., "Some Notes on the Reflection of Sound from a Rigid Corrugated Surface," J. Acoust. Soc. Am., 33, 1772-1777, 1961.

The Rayleigh solution for reflection from a corrugated surface, and some possible modifications, are examined. For small slopes these methods produce similar analytical expressions and almost identical numerical results. When the first nonradiating term is included in the computations, the magnitude of the scattered amplitudes is essentially the same, but an estimate of the phase-change as a function of frequency is provided. For larger slopes, differences appear in the analytical form as well as in the numerical results. The Rayleigh expression has advantages above cutoff, while a new approach seems better before and just after cutoff.

2163

LaCasce, E. O., Jr., B. D. McCombe, and R. L. Thomas, "Measurements of Sound Reflection from a Rigid Corrugated Surface," J. Acoust. Soc. Am., 33, 1768-1771, 1961.

An examination of the scattering process in the vicinity of cutoff is made using rigid surfaces with sinusoidal corrugations which have a maximum slope near one. Measurements of the specular amplitude for several angles of incidence are presented with small increments in frequency. The ratio of the pressure amplitude at the peaks and troughs of the corrugations as a function of frequency is also observed for several angles of incidence.

2164

Lauvstad, V., and S. Tjtta, "Problem of Sound Scattered by Sound," J. Acoust. Soc. Am., 34, 1045-1050, 1962.

The sound generated by the nonlinear interaction of two sound beams of high intensity, arranged to cross each other perpendicularly, is computed to the first order of interaction. Several of the assumptions and specializations in previous treatments of this problem, whose effects on the result it is hard to estimate, are avoided. The interaction is supposed to take place in the Fraunhofer zone of both beams.

Some results are valid. For instance, the Doppler angles computed and measured by Ingard and Pridmore-Brown are found without any strict specializations of the primary beams and the interaction region.

Estimates of the amplitudes of the generated pressure, governing rather wide ranges of frequencies of the primary beams, seem to agree with the previous apparently strongly differing results. This correspondence is brought forward by an amplitude factor, depending on the frequencies of the primary beams.

In the high-frequency limit, the destructive interference among the quadropoles, which cause the generated sound, dominates the results and gives an over-all zero value of the generated pressure, in accordance with Westervelt's treatment.

2165

Lighthill, M. J., "On the Energy Scattered from the Interaction of Turbulence with Sound or Shock Waves," Rept. No. 15, 432, Aeronautical Research Council, Great Britain, 22 pp., 1952. AD-20 290.

See abstract 914.

2166

Lighthill, M. J., "On the Energy Scattered from the Interaction of Turbulence with Sound or Shock Waves," Proc. Cambridge Phil. Soc., 49, 531-551, 1953.
Journal article based on preceding entry.

The energy scattered when a sound wave passes through turbulent fluid flow is studied by means of the author's general theory of sound generated aerodynamically. The energy scattered per unit time from unit volume of turbulence is estimated as

$$(8\pi^2 L_1/\Lambda^2)\cdot I\cdot\left(\overline{v'^2_1}/a^2\right)$$

where I is the intensity and Λ the wavelength of the incident sound, and $\overline{v'^2_1}$ is the mean square velocity and L_1 the macro-scale of the turbulence in the direction of the incident sound. This formula does not assume any particular kind of turbulence, but does assume that Λ/L_1 is less than about 1. For isotropic and homogeneous turbulence, the energy scattered and its directional distribution are obtained for arbitrary values of Λ/L_1. It is predicted that components of the turbulence with wave-number k will scatter sound of wave-number K at an angle $2 \sin^{-1}$ (k/2K). The statistics of multiple successive scatterings is considered, and it is predicted that sound of wavelength less than the micro-scale of the turbulence will become uniform (i.e., quite random) in its directional distribution in a distance approximately $\lambda a^2/\overline{v'^2_1}$. The theory is extended to the case of an incident acoustic pulse. However, this extended theory cannot be applied directly to the case of a shock wave, for which it would predict infinite scattered energy. This is due to the perfect resonance between successive rays emitted forwards which would occur if the shock wave were propagated at the speed of sound. By taking into account the true speed of the shock wave (subsonic relative to the fluid behind it), the theory is improved to give a finite value, 0.8s times the kinetic energy of the turbulence traversed by a weak shock of strength s, for the total energy scattered. However, the greater part of this energy catches up with the shock wave and probably is mostly reabsorbed by it, and only the remainder is freely scattered behind the shock wave as sound. The energy thus freely scattered when turbulence is convected through the stationary shock-wave pattern in a supersonic jet may form an important part of the sound field of the jet.

2167

Lysanov, Iu. P., "On the Scattering of a Sound by a Non-Uniform Surface," Soviet Phys. (Aerons.), 4, 45-49, 1958.

A method is given for solving the infinite system of algebraic equations derived in an earlier paper (Ibid., 1, 60-72, 1957), for the purpose of determining the complex amplitudes of waves that are scattered by a plane nonuniform surface with a periodically varying acoustic admittance; the case for normal incidence of a plane acoustic wave is treated. The method is applicable to arbitrary deviations of the acoustic admittance from its average value on the surface, and permits computation of the amplitudes of scattered waves to an arbitrary accuracy. It is demonstrated that for this purpose it is sufficient to solve a system of n equations whose number is determined by the parameters of the nonuniform surface, the wavelength of the sound, and the specified accuracy to which the amplitudes of the scattered waves must be evaluated.

2168

Lysanov, Iu. P., "Scattering of Sound from Plane Inhomogeneous Surfaces with Periodically Varying Acoustic Admittance," Soviet Phys. Acoust., English Transl., 1, 60-72, 1957.

Proposes a method for calculating the scattering of sound from a plane inhomogeneous surface characterized by a normal impedance or acoustic admittance that is independent of the angle of incidence of the sound wave. The solution is given in the form of a series, the r-th term of which can be obtained from a recurrence formula.

2169

Lysanov, Iu. P., "Theory of the Scattering of Waves at Periodically Uneven Surfaces," Soviet Phys. Acoust., English Transl., 4, 1-10, 1958.

Reviews theories of wave scattering from uneven surfaces (applicable to reflection of sound waves from earth or ocean surface, radio wave reflection, submarine acoustic propagation, etc.). Discussed in particular are the methods of: (1) Rayleigh, (2) small disturbances, (3) L. M. Brekhovskikh, (4) integral equations, (5) V. Twersky, and (6) L. N. Deriugin. The literature references include Russian (25) and other (54) papers on radio- and acoustic-wave scattering.

2170

Michurin, V. K., and L. A. Chernov, "Scattering of Sound in Dispersion Systems" (in Russian), Zhur. Tekh. Fiz., 21, 920-926, 1951.

The coefficient of sound scattering is calculated for sound wave propagating in heavy suspensions (e.g., fog) and in emulsions (e.g., 10% benzene in water).

2171

Miles, J. W., "On Radiation and Scattering from Small Cylinders," J. Acoust. Soc. Am., 25, 1087-1089, 1953.

Rayleigh's original work on scattering and radiation of harmonic disturbances by small cylinders is extended to transient disturbances. The analysis is closely related to Ward's treatment of the aerodynamics of slender bodies in supersonic flow.

2172

Mintz, M. D., "Sound Scattering from Turbulence," S. M. Thesis, Mass. Inst. Tech., Cambridge, 1959.

An explanation and clarification of the experimental problems encountered in investigations of sound scattering from turbulence is presented, after which a brief synopsis of Lighthill's scattering theory of sound and turbulence is given.

The experimental approach is divided into three phases: the design and construction of suitable transducers; investigation of sound attenuation in air in the absence of turbulence; and investigation of the scattering of sound by turbulence. A preliminary investigation of this third phase employing the relatively untried technique of pulse-height analysis is conducted for scattering of a sharp beam of 100-kc sound. Complete details of the experimental circuitry and technique are presented, and the resulting pulse-height spectra for scattering angles between -2.5^{o} and 15^{o} are presented and discussed. The broadening of the beam due to interaction with the turbulence is displayed in curves relating sound field pressure and laboratory angle to the incident beam. A brief list of suggestions for further investigation of this problem and possible application of the technique of pulse-height analysis to other statistical acoustics problems is presented in the concluding section.

A feasibility report for application of acoustical interferometric measurements is included in the appendix.

2173

Mittenthal, L., "Fluctuations of Scattered Noise," J. Acoust. Soc. Am., 30, 876-877, 1958.

The coefficient of variation of scattered sound is shown to be a decreasing function of the number of frequency components. The limit is found and the distribution of the rms value of scattered, narrowband random noise is shown to be a Dirac delta function.

2174

Mokhtar, M., and M. Shehata, "Scattering of Ultrasonic Waves in Gases," J. Acoust. Soc. Am., 22, 16-19, 1950.

Ultrasonic beams of frequencies in the range of 80 to 1000 kcs emerge from a rectangular slit of known adjustable width into air, O, or CO_2. The disposition of the field in front of the slit is studied with the aid of a hot-wire anemometer, which gives the angle of divergence of the beam and the intensity distribution across the main and the diffracted beams. The results obtained indicate that the laws of diffraction are valid so long as the gas is far removed from its anomalous dispersion region. CO_2 in the range between 100 and 200 kcs shows a high degree of scattering, with the result that the emergent beam loses its definition completely and becomes very diffused.

2175

Monin, A. S., "Characteristics of the Scattering of Sound in a Turbulent Atmosphere," Soviet Phys. Acoust. English Transl., 7, 370-373, 1962.

Proceeding from the complete set of equations for the acoustics of a moving inhomogeneous medium, an expression is derived for the effective cross section of sound scattering by turbulent inhomogeneities of the atmosphere; the expression is valid, correct to components whose relative smallness is of the order of the square of the Mach number for turbulent motion. This expression shows specifically that right-angle scattering does not occur, and back scattering happens as the result of turbulent temperature irregularities but not of velocity irregularities.

2176

Muller, E. A., "Some Experimental and Theoretical Refults Relating to the Production of Noise by Turbulence and the Scattering of Sound by Turbulence of Single Vortices," (2nd Symposium Naval Hydrodynamics, Washington, D. C., 1958) Washington: U. S. Government Printing Office, 1960.

A technological discussion of the matters described in the title. The problem of sound scattering by a single-line vortex is discussed in some detail, and polar diagrams of the scattered intensity are given. Some experimental results of sound intensity produced by turbulence, and on sound scattering by turbulence, are also given.

2177

Muller, E. A., and K. R. Matschat, "The Scattering of Sound by a Single Vortex and by Turbulence," Rept. No. AFOSR TN-59-337, Max-Planck-Institut für Stroemungsforschung, Germany, 50 pp., 1959.
AD-213 658.

As an elementary model for the scattering of sound by turbulence, the scattering of a plane sound wave as it passes through a single vortex of finite radius is investigated. The angular intensity distribution and the total power of the scattered sound are explicitly calculated in terms of the circulation and the radius of the vortex, the wave length of the incident sound wave, and the inclination angle between the direction of propagation of the incident wave and the axis or the vortex. The results of the single-vortex theory are applied to scattering by turbulence. The turbulent flow is represented by statistically distributed vortices. Isotropic and extreme nonisotropic turbulence are considered. The total scattering power turns out to be proportional to the 5th or 2nd power of the frequency of the incident sound wave, depending on whether the frequency is low or high.

2178

Obukhov, A. M., "Scattering of Waves and Microstructure of Turbulence in the Atmosphere," J. Geophys. Res., 64, 2180-2187, 1960.

A brief survey of the theory of the scattering of waves by turbulent inhomogeneities. Discusses experiments in the study of sound scattering by turbulence in the surface layer of the atmosphere. These experiments were carried out to obtain some information on the turbulent spectrum; their results are compared with the data of meteorological measurements in the surface layer.

Discusses application of scattered radio waves to the study of ionospheric turbulence.

2179

Papadopoulos, M., "Diffraction by a Refracting Wedge," Tech. Summary Rept. No. 297, Mathematics Research Center, Univ. of Wisconsin, Madison, 45 pp., 1962.
AD-275 795.

The refraction and scattering of acoustic plane waves following their arrival at the tip of a refracting wedge are examined. The scattered field contains not only plane waves reflected from the plane walls of the prisms but also the field diffracted at the sharp edge. It is not necessary to discuss the dominant refraction effects in any detail because they are so well known. The diffraction properties, however, are unknown. To understand these it is necessary to consider the mathematical difficulty of defining a normal derivative on the inside of an acute-angled wedge close to the vertex. It may be that the uniform use of the interaction conditions across the refracting surfaces at all distances from the vertex leads to no solution, and that the only well-set problem of this type may be one where the wedge has a rounded tip (as when the wedge is of hyperbolic section) with large curvature.

2180

Pekeris, C. L., "Note on the Scattering of Radiation in an Inhomogeneous Medium," Phys. Rev., 71, 268-269; erratum, 457, 1947.

An expression is derived for the scattering of a plane sound wave when it passes through a medium in which the velocity of sound fluctuates slightly and irregularly about a mean value.

2181

Tellmien, W., "Research on Investigation of the Interaction of Sound and Turbulence," Max-Planck Institute, Germany, 1957.
AD-154 138.

The scattering of sound by turbulence in the atmosphere was investigated both theoretically and experimentally, and the results of one year's work are presented in this report. The elementary process of scattering by one turbulent eddy is treated theoretically. Fields of flow are then postulated, in which the vortices are placed statistically according to an arbitrary distribution function that controls direction of axes, size, and circulation of the vortices. The choice of distribution function permits treatment of isotropic as well as nonisotropic turbulence.

The section of the report on experimentation describes the mechanical and electronic apparatus that was developed for controlling and measuring the degree of turbulence, the average size of the eddies, and the velocity profile of the mean flow. Preliminary measurements were made throughout the audio range and up to frequencies of about 200 K cps.

2182

Pridmore-Brown, D. C., and U. Ingard, "Tentative Method for Calculation of the Sound Field About a Source over Ground Considering Diffraction and Scattering into Shadow Zones," NACA TN 3779, Mass. Inst. of Tech., Cambridge, 1956.

A semiempirical method is given for the calculation of the sound field about a source over ground considering the effects of vertical temperature and wind gradients as well as scattering of sound by turbulence into shadow zones. The diffracted field in a wind-created shadow zone is analyzed theoretically in the two-dimensional case and is shown to be similar to the results obtained for a temperature-created shadow field as given in NACA TN 3494. The frequency and wind-velocity dependence of the scattered field into the shadow zone is estimated from Lighthill's theory, and on the basis of these two field contributions a semi-empirical formula is constructed for the total field which contains two adjustable parameters. From this expression a set of charts has been prepared showing equal sound-pressure contours at 10 feet above ground for various source heights, wind velocities, and frequencies.

The two adjustable parameters in the formula were obtained from measurements using a relatively small source height (10 feet). The parameters should actually be a function of height determined by the wind and temperature profiles. However, in these preliminary calculations the parameters have been kept constant, and the fields, particularly for large source heights, must be considered as preliminary estimates to be corrected when more information is available.

2183

Richter, A., and W. Cannon, "Low-Level Wind Measurement," Quart. Rept. No. 3, Ford Instrument Co., Div. of Sperry Rand Corp., Long Island City, N. Y., 32 pp., 1961.
AD-257 418L.

The nonlinearity of air as a medium for the propagation of high-intensity sound (SPL on the order of 0.1 atmosphere) is investigated. Emphasis is placed on the cross-modulation between two sound waves in a nonlinear medium, and on the resulting sum and difference frequencies produced. Experiments on the scattering of sound by sound are described. Each experiment employs a sonic beam as a target. A strong pulse of sound then propagates from a source that has been placed at a right angle to the beam. The experiments involve measuring the percentage of scatter in the return pulse reflected by the beam. Return times are measured for both fundamental frequency scatter and for difference frequency scatter. Application of the above principles to sonic anemometry is presented.

2184

Schilling, H. K., M. P. Givens, W. L. Nyborg, W. A. Pielemeier, and H. A. Thorpe, "Ultrasonic Propagation in Open Air," J. Acoust. Soc. Am., 19, 222-234, 1947.

Data and conclusions of practical interest in regard to ultrasonic signalling are presented. Fundamental ultrasonic phenomena of propagation are investigated, and their causes isolated through correlations with simultaneously observed micrometeorological phenomena. Results are presented with two viewpoints: propagation in a nonscattering atmosphere, and propagation in a scattering medium; it was found that sometimes the open air is a scattering, as well as an absorbing, medium. Values of absorption coefficients are presented for frequencies up to 30 kc.

2185

Schmidt, D. W., "Experimental Investigations on the Scattering of Sound by Turbulence," Tech. Rept. No. AFOSR-1666, Max-Planck-Institut für Stroemungsforschung, Germany, 60 pp., 1961.
AD-266 564.

Experimental investigations of the scattering of sound by turbulence were performed in a wind tunnel. Turbulence was produced by grids of parallel circular rods (with diameters of 0.1 to 1.0 cm and grid meshlengths of 0.5 to 2.5 cm); the sound frequencies covered a range of 100 to 500 kcs. Disturbances of the measurements due to reflections of sound waves at the tunnel walls were avoided by the application of short sound pulses. The dependence of the damping of the sound waves on the sound frequency, the Mach number of the turbulence, the length of the sound path in the turbulent flow, and a predominant direction of the turbulent eddies were measured. Theoretical predications were confirmed and partly extended.

In the range of the parameters that is of interest for practical use, the most important results are the proportionality of the damping to the square of the sound frequency and to the square of the turbulent Mach number. Based on the measurements and the theoretical considerations, a formula is derived which is applicable to the damping of sound by turbulent scattering in the atmosphere.

2186

Schmidt, D. W., "Experiments Relating to the Interaction of Sound and Turbulence," Max-Planck-Institut für Stroemungsfurschung, Germany, 19 pp., 1960.
AD-236 341.

Experimental results about the scattering of sound by a turbulent flow are given. The dependence of the scattering on the frequency of sound and on the direction of the scattering vortices were investigated. Equipment is described that facilitates the use of hot wires for the measuring of turbulence. Design characteristics of an apparatus are given, by which hot-wire probes can be rewired precisely and quickly.

2187

Sharples, A., "An Approximate Method in High-Frequency Scattering," Proc. Cambridge Phil. Soc., Great Britain, 58, 662-670, 1962.

The diffraction of high-frequency plane sound wave by a circular cylinder is investigated when the boundary condition on the cylinder is expressed by means of an equation of the form $\partial\phi/\partial n + kZ\phi = 0$. The special feature of this investigation is that an extended form of the Kirchhoff-Fresnel theory of diffraction is used to find an integral representation for the scattering coefficient. In order to avoid the complicated analysis that would be necessary to evaluate the integrals concerned, the more natural geometrical acoustics approach is used to find the first correction term in the scattering coefficient. Numerical results are given for large and small values of the impedance Z.

2188

Shaw, R. P., and M. B. Friedman, "Diffraction of Pulses by Arbitrary Two Dimensional Free Surfaces," Tech. Rept. No. 29, Columbia Univ., N. Y., 20 pp., 1961.
AD-272 751.

Studies the analysis of obstacles composed of free surfaces (surfaces of constant potential and pressure) corresponding to Dirichlet conditions. The field variable of interest is the spatial derivative of the potential, i.e., the velocity. As in the rigid problem, the effect of the discontinuity in the velocity at the wave front can be separated from the remaining surface effects and integrated directly. The remaining integrals are again approximated by assuming the surface velocity to have an averaged value over specified intervals in space and time. The integrations may then be replaced by summations which, because of the time-retarded effect, lead to successive, nonsimultaneous algebraic equations for the unknown surface velocities.

The free surface configuration for which results are obtained is that formed by a box-shaped obstacle composed of free surfaces and bisected by an infinite plane free surface; the asymptotic velocity field in the media is independent of time. The solution can be obtained from the case of the infinite media by the image principle, i.e., by an appropriate superposition of compression and expansion pulses of equal magnitude.

2189

Skeib, G., "On the Propagation of Sound in Atmospheric Turbulence" (in German), Z. Meteorol., 9, 225-234, 1955.

Measurements of the scatter of sound waves of 100 c to 4 kc from a loudspeaker were made at Lindenberg, with micrometeorological observations for comparison. Absorption and scattering are discussed theoretically and the instrumental set-up is described. At a height of 30 m and distance 150 m, with wind > 5 m/s, damping was 13 db, increasing with frequency, and decreasing to half at 3 m/s. At 5 m height and 50 m distance results were similar but the wind effect less.

2190

Skudrzyk, E., "Scattering in an Inhomogeneous Medium," J. Acoust. Soc. Am., 29, 50-60, 1957.

The standard mathematical procedure formally describes scattering by the superposition of a scattered pressure on the unscattered sound field. At low frequencies, because of the irregular distribution of the inhomogeneities, the phases of the scattered waves are at random, and scattering is an interference phenomenon. As the frequency increases, scattering becomes highly collimated in the forward direction and the phase differences decrease to zero. At this point, ray theory starts to apply. The scattered pressure, then, essentially describes only a phase change caused by the different sound velocities and the focusing and defocusing by the lens action of the patches. The medium in the neighborhood of the receiver can be shown to contribute only by focusing; the medium farther away, only by interference fluctuations. Focusing leads to normally distributed amplitude fluctuations, however, passes from normal to Rayleigh with increasing values of range.

2191

Spence, R. D., and S. Granger, "The Scattering of Sound from a Prolate Spheroid," J. Acoust. Soc. Am., 23, 701-706, 1951.

This paper presents the results of calculations of the scattering of a plane sound wave from a prolate spheroid. Scattering patterns are given for the major axis equal to λ/π, $2\lambda/\pi$, $3\lambda/\pi$, for the ratio of axes equal to 0.10, 0.20, 0.29, 0.37, and for the angle of incidence measured from the major axis equal to 0^o, 30^o, 60^o, 90^o.

2192

Tatarskii, V. I., "Theory of the Propagation of Sound Waves in a Turbulent Stream" (in Russian), Zh. Eksperim. i Teor. Fiz., 25, 74-80, 1953.

Examines in detail the problem of the scattering of sound waves for the case of isotropic turbulence in an incompressible liquid. Investigates the general form of the scattering indicatrix and develops for it an expression based on the formula $R_{rr}(\rho) = \bar{u}^2 \exp(-\rho\ell)/3$, where $\bar{u}^2$ is the mean square value of the pulsation velocity of the stream, ρ = one of the spherical coordinates of the point, and ℓ = the correlation scale characteristic of the average pulsation size. The analysis of this phenomenon, based on the scattering theory, yields the mean square fluctuations of the phase and amplitude of sound at large distances from the source.

2193

Tellmien, W., "Research on Investigation of the Interaction of Sound and Turbulence," Rept. AFOSR TN-58-236, Max-Planck-Inst., Germany, 34 pp., 1958.
AD-154 138.

Investigation was made of the elementary process of the scattering of sound by a vortex and of the dependence of the scattering properties on the characteristic parameters of the problem. Consideration is given to superposition of the effects of elementary scattering in a field of flow in which the vortices are statistically distributed due to an arbitrarily given distribution function controlling direction of the axis, and the size and circulation of the vortices. This case represents the turbulent motion. Because the distribution function can be chosen arbitrarily one can treat, for instance, isotropic as well as nonisotropic turbulence.

2194

Twersky, V., "Multiple Scattering of Radiation by an Arbitrary Configuration of Parallel Cylinders," J. Acoust. Soc. Am., 24, 42-46, 1952.

A formal solution in terms of cylindrical wave functions is obtained for the scattering of a plane acoustic or electro-magnetic wave by an arbitrary configuration of parallel cylinders; it takes into account all possible contributions to the excitation of a particular cylinder from the radiation scattered by the remaining cylinders. The solution, satisfying any of the usual prescribed boundary conditions simultaneously at the surface of each cylinder, is expressed as the incident wave plus a sum of various orders of scattering.

The first order of scattering (the usual, single scattering approximation) results from the excitation of each cylinder by only the plane wave or primary excitation. The second order results from the excitation of each cylinder by the first order of scattering from the remaining cylinders, and so on to an infinite order of scattering. The first order therefore consists of waves scattered by one cylinder; the second order of waves scattered by two cylinders, etc. The scattering coefficients of the m-th order of scattering are expressed recursively in terms of the previous orders, and finally as sums of products of m scattering coefficients of the single cylinder and Hankel and trigonometric functions, depending on the geometry of the configuration.

2195

Twersky, V., "Multiple Scattering of Radiation; Part I, Arbitrary Configuration of Parallel Cylinders, Planar Configurations, Two Cylinders," Res. Rept. No. EM-34, Washington Square College, Univ. of New York, 68 pp., 1951.
ATI-119 353.

A formal solution in terms of cylindrical wave functions is obtained for the scattering of a plane wave by an arbitrary configuration of parallel cylinders; it takes into account all contributions to the excitation of a particular cylinder from the radiation scattered by the remaining cylinders. The wavelengths and values of the parameters for which the effects of multiple scattering are maximal, or indicate the greatest departure from single scattering theory, are determined; the effects being most pronounced when either all orders of scattering are in phase, and reinforce to yield an increase of the intensity over that predicted by elementary theory, or when successive orders are completely out of phase and partially annul to yield a decrease.

2196

Twersky, V., "Multiple Scattering of Waves by Planar Random Distributions of Parallel Cylinders and Bosses," Res. Rept. No. EM-58, Inst. of Math. Sci., Univ. of New York, 56 pp., 1953.
AD-23 564.

The two-dimensional problem of multiple scattering of a plane wave by a planar random distribution of parallel cylinders is considered. A formal solution ψ for the wave scattered by a single configuration is obtained, and the ψ and $|\psi|^2$ are averaged over an ensemble of configurations specified by the probability distribution function for pairs of cylinders. The treatment is sufficiently general to include both the limiting cases of either a periodic or a uniform distribution. Closed-form approximations for the averages are derived and used to obtain the average energy flux, and to discuss certain energy theorems. The results are then applied to the scattered reflection of electromagnetic or acoustic waves from striated surfaces composed of cylindrical bosses on a perfectly reflecting plane.

It is shown that whereas the single-scattered wave may become infinite as grazing incidence is approached, the multiple-scattered wave approaches the negative of the incident wave; thus the results are reduced to those for a dielectric plane near grazing incidence. The maximum effects of multiple scattering are discussed, and practical expressions for the reflection coefficients and differential scattering cross sections are obtained.

2197

Twersky, V., "Multiple Scattering of Waves by a Volume Distribution of Parallel Cylinders," Res. Rept. No. EM-59, Inst. of Math. Sci., Univ. of New York, 16 pp., 1953.

Consideration is given to the multiple scattering of a plane electromagnetic or acoustic wave by a uniform distribution of cylinders lying parallel to the z-axis in the range 0 x d, - y ∫ ∞. A closed-form representation is derived for the average wave function, and a heuristic procedure is used to obtain the incoherent scattering. The results agree with the principle that the energy removed from a unit area of the incident wave front by reflection and transmission is equal to the total energy scattered by the elements, illuminated by a unit area of the wave front.

2198

Twersky, V., "On Scattering and Reflection of Sound by Rough Surfaces," J. Acoust. Soc. Am., 29, 209-225, 1957.

Random distributions of arbitrary identical protuberances on free or rigid base are considered, and the approximate reflection coefficients

$$R = \left|\frac{1 + Z}{1 - Z}\right|^2$$

and differential scattering cross-sections per unit area

$$\sigma(\vec{s}, \vec{k}_i) = \frac{\rho}{k^2}\left|\frac{f(\vec{s}, \vec{k}_i)}{1 - Z}\right|^2$$

are derived. Here

$$Z = \frac{\pi\rho f(k_o, k_i)}{k^2\vec{n}\cdot\vec{k}_o} k$$

where $f(\vec{s}, \vec{k}_i)$ is the scattering amplitude of an isolated protuberance, $\vec{k}_i$, $\vec{k}_o$, and $\vec{s}$ are the directions of incidence, specular reflection (with respect to the base plane), and observation; $\vec{n}$ is the normal of the base; ρ is the average number of scatterers in unit area; and $k = 2\pi/\lambda$. (For a two dimensional "striated" surface Z is divided by π/k, and σ by $\pi/2k$). If the horizon angle β approaches zero (i.e., near grazing incidence), then the reflection coefficients approach unity minus terms of the order β, while the back scattering vanishes like β^4, β^2 for a free, rigid base.

Explicit forms are given for arbitrary hemispheres and circular semicylinders, and for the limiting cases of free and rigid surfaces with scatterer radii very small and very large compared to wavelength. The analysis is based on a Green's function formulation of the problem of a single configuration; R and σ follow from an approximation of the ensemble averaged energy flux which takes account of multiple coherent scattering. (The transmission problem of a "random screen" is treated simultaneously).

An elementary derivation is also given, and extensions to distributions of nonidentical scatterers are made.

2199

Waterman, P. C., and R. Truell, "Multiple Scattering of Waves," Brown Univ., 1957.
AD-146 492.

Governing equations are obtained for the problem of multiple scattering of waves in a homogeneous isotropic medium containing a statistical array of scattering regions. The equations are applicable to sound waves in solids, liquids, and gases, electromagnetic waves, and stationary quantum-mechanical problems. From these equations the macroscopic properties of the "scattering medium" may be obtained in terms of the scattering properties of a single scatterer. Questions of energy and measurement are discussed, and several examples are considered. An extension of the theory to the elastic problem with node conversion is included.

2200

Waterman, P. C., and R. Truell, "Multiple Scattering of Waves," J. Math. Phys., 2, 512-537, 1961.

Multiple scattering effects due to a random array of obstacles are considered. Employing a "configurational averaging" procedure, a criterion is obtained for the validity of approximate integral equations describing the various field quantities of interest. The extinction theorem is obtained and shown to give rise to the forward-amplitude theorem of multiple scattering. In the limit of vanishing correlations in position, the complex propagation constant of the scattering medium is obtained. Under appropriate restrictions, this expression is shown to include both the square-root law of isotropic scatterers and the additive rule for cross sections valid for sufficiently low densities of anisotropic obstacles. Some specific examples from acoustics and electromagnetic theory then indicate that at least in the simplest cases the results remain valid for physically allowable densities of obstacles.

2201

Westervelt, P. J., "Scattering of Sound by Sound," Brown Univ., Providence. R. I., 5 pp., 1956.
AD-138 758.

Owing to the inherent nonlinearity of the equations of motions for a perfect fluid, two or more sound waves passing through a common region generally will interact with one another and give rise to scattered waves. In this paper, a source function is obtained for the lowest order scattering process, which is quadratic in the primary-field variables. This function is rewritten in a form that demonstrates that no scattered waves exist outside the region of interaction of two sound beams intersecting each other at right angles. Furthermore, it is demonstrated that no such scattered waves exist when the two beams intersect at the angle

$$\theta = -\cos^{-1}\left[1/2\rho_0 c_0^{-2}\left(\frac{d^2\rho}{dp^2}\right)\rho = \rho_0\right],$$

where ρ, c, and p stand for the density, sound velocity and pressure, respectively, and the subscript 0 means ambient values of these quantities.

The interfering effect of pseudo-sound, induced by radiational pressure, is suggested as an explanation for the results of Ingard and Pridmore-Brown, who have reported recently what they believe to be scattered waves from the interaction region of two sound beams intersecting each other at right angles.

2202

Westervelt, P. J., "Scattering of Sound by Sound," J. Acoust. Soc. Am., 29, 199-203, 1957.

Journal article based on preceding article.

2203

Westervelt, P. J., "Scattering of Sound by Sound," J. Acoust. Soc. Am., 29, 934-935, 1957.

Earlier studies of the mutual nonlinear interaction of two plane waves of sound are extended to encompass the arbitrary directions of travel of one wave with respect to the other; an exact solution to the first-order scattering process is obtained.

Scattering
See also—225, 299, 429, 459, 460, 461, 478, 479, 480, 554, 581, 590, 747, 748, 749, 755, 761, 766, 771, 775, 776, 790, 818, 883, 884, 885, 1141, 1383, 1465, 1897, 1900, 1902, 1903, 1909, 1919, 1932, 1980, 1983, 1984, 2003, 2007, 2020, 2021, 2030, 2031, 2032, 2035, 2036, 2220, 2585, 2844, 2846, 2876, 2880, 2893, 2907, 3099, 3399, 3586, 3688, 3722, 3777, 3785, 3829, 3990

SHADOW ZONES

2204

Acoustics Lab., Mass. Inst. of Tech., "Quarterly Progress Reports," Cambridge, 1950-1957.

This is a seven-year series of quarterly progress reports on government-sponsored research contracts with the Acoustics Laboratory of MIT. A wide variety of problems in acoustics was investigated. Among a host of miscellaneous items, all issues contain one or more brief reports on research related to the propagation of sound in air. Typical subject headings are: atmospheric acoustics; scattering of sound from a vortex; short range propagation in the atmosphere; propagation of sound waves of finite amplitude; absorption of sound in gases; scattering of sound from turbulence; sound field from a random noise source above ground; wind-created shadow formation over ground; instrumentation for field measurements of sound propagation; scattering of sound by sound; acoustic behavior in moving media; diffraction and scattering into the shadow zone; outdoor sound propagation measurements; the effect of a ground layer with a temperature inversion on the field within an acoustic shadow zone; and, computation of the sound field over an absorbing surface. The following is a complete list of MIT Acoustic Laboratory Quarterly Reports with corresponding DDC Document numbers where applicable.

July-September 1950
October-December 1950
January-March 1951
April-June 1951
July-September 1951
October-December 1951
January-March 1952
April-June 1952
July-September 1952
October-December 1952, AD-7 815
January-March 1953, AD-14 656
April-June 1953, AD-16 881
July-September 1953, AD-22 517
October-December 1953, AD-25 861
January-March 1954, AD-35 322
April-June 1954, AD-44 511
July-September 1954, AD-49 532
October-December 1954, AD-54 507
January-March 1955, AD-61 541
April-June 1955, AD-70 101
July-September 1955, AD-76 096
October-December 1955, AD-85 884
January-March 1956, AD-102 751
April-June 1956, AD-107 074
July-September 1956, AD-110 161
October-December 1956, AD-117 032
January-March 1957, AD-117 117
April-June 1957, AD-133 735
July-September 1957, AD-133 794

2205

Arabadzhi, V. I., "On Extinction of Sounds in the Atmosphere" (in Russian), Izv. Akad. Nauk SSSR, Ser. Geograf. i Geofiz., 12, 162-164, 1949.

Consideration of the extinction of sound by temperature variations in the lower layers of the atmosphere.

2206

Barkhatov, A. N., and I. Shmelev, "Experimental Investigations into the Waveguide Propagation of Sound in Laminar-Inhomogeneous Media," Soviet Phys. Acoust., EnglishTransl., 5, 414-418, 1960.

A procedure for the laboratory simulation of a waveguide in laminar-inhomogeneous media is presented. The results of an experimental investigation of the sound field in media in which the axis of the waveguide lies both on the surface of the inhomogeneous fluid and below it are cited. The fields in the region of the first geometric shadow and in the region of the first caustic are studied in detail. In the latter case a comparison is made between the experimental data and theory.

2207

Baron, P., "Propagation of Sound in the Atmosphere and Audibility of Warning Signals in the Presence of Ambient Noise" (in French), Ann. Telecommun., 9, 258-274, 1954.

In an introductory section the author reviews the various factors which affect the long distance propagation of sound in the atmosphere: attenuation (influenced by water vapor content), winds, and temperature gradients. A description follows of experiments carried out in "les vals d'Yonne." Sirens were used as sound sources at different heights above the ground, and wind and temperature gradients were recorded and correlated with the observed signal strengths received. Variations of signal strength were recorded at different distances from the source and at various times of the year. The effects of noise and wind on the audibility of the received signals were studied.

2208

Bolt, Beranek, and Newman, Inc., "Investigation of the Transmission of Sound Through Fog over Water," Final Rept. on Phase 2, Investigation of Acoustic Signalling over Water in Fog, Cambridge, Mass., 1960.
AD-236 659

The physics of sound propagation along the surface of the earth is discussed with particular attention to the conditions existing where sound is propagated for long distances over ocean waters in fog. The results of an extensive measurement program of sound transmission over water are presented, together with the results of measurements of the relevant micrometeorological parameters and a description of the instrumentation and experimental techniques used. The experimental data are analyzed in the light of available theory with a view of applying the results in generalized form to an improved design procedure for audible fog signals. Among the more important conclusions resulting from the analysis and evaluation of the field studies presented in this report are as follows.

(1) The propagation of audible sound over ocean waters in fog is governed by the same micrometeorological parameters which determine the propagation of audible sound over land. (2) The presence of wind and temperature gradients just above the surface of the ocean causes the sound to be refracted from the normal

2209

Burkhard, M., H. Karplus, and H. Sabine, "Sound Propagation near the Earth's Surface as Influenced by Weather Conditions," WADC TR 57-353, Armour Research Foundation, Chicago, 1961.
AD-254 670.

The effects of weather on the propagation of sound from an elevated source to the ground were studied. Measurements include weather conditions in Arizona and propagation angles down to 2 degrees elevation above the horizon. Attenuations were correlated with absolute humidity, temperature, temperature gradient, wind velocity, and wind direction. For source elevations of 5 degrees and higher and source altitudes above a few hundred feet, only temperature and absolute humidity have a significant effect on attenuation. For source elevations of less than 5 degrees large attenuations occur in the presence of strong wind and temperature gradients. These are due to upwind refraction of sound and the resulting creation of shadow zones on the ground.

2210

Dneprovskaya, I. A., V. K. Iofe, and F. I. Levitas, "On the Attenuation of Sound as It Propagates Through the Atmosphere," Soviet Phys. Acoust., English Transl., 8, 235-239, 1963.

The attenuation of sound as it propagates through the atmosphere was studied in the 200- to 2000-cps range, both in the presence and in the absence of acoustic shadowing. Measurements were performed at distances from 1.5-5 km in 12 steps (in the Leningrad region). Measurement of the sound level at the acoustic source was conducted with the aid of an objective noise meter and, at the receiving point, with the aid of a subjective noise meter.

The results of the measurements demonstrated the seasonal dependence of the excess attenuation of sound (with molecular attenuation subtracted), as well as the dependence on time of day, nature of the terrain over which the sound propagated, distance, and frequency. No relation was found between attenuation and wind direction or wind velocity. The averaged absolute value of the excess attenuation varies, depending again on the conditions of propagation, from 2-12 db/km for frequency 300 cps and from 5-23 db/km for frequencies ranging from 1800-2000 cps. Acoustic shadowing was observed on an average in 30% of the total number of observations. The averaged absolute magnitude of the excess attenuation in the presence of acoustic shadowing lies within the range from 20 db/km at 300-cps frequency to 50 db/km at 1800-cps frequency.

2211

Eyring, C. F., "Jungle Acoustics," Rept. No. 4699, Office of Scientific Research and Development, NDRC Div. 17, Washington, D. C., 80 pp., 1945.
ATI-62654.

This study of jungle acoustics and micrometeorology is one of the most comprehensive and useful documents available for anyone concerned with the transmission of sound at the earth's surface in tropical climates. The study was conducted during the wet season in Panama and includes propagation measurements over hard, bare surfaces, short and tall grasslands, and through a variety of tropical forests. Terrain loss coefficients and their variations with acoustic frequency and environment were determined from measurements. Ambient jungle noise levels in the audible and ultrasonic ranges were measured. Acoustical and meteorological measurements were taken concurrently in order to demonstrate their inter-relationships. Refraction and shadow zone formation, as caused by combined wind and temperature effects, were investigated and found to be significant in open, sunny areas, but not significant under a jungle canopy. The report clearly shows the typical variations to be expected throughout the day and night for each acoustic and meteorological parameter investigated. The various instruments that were developed for acoustic detection and measurement are described in detail. Calibration procedures are also described.

2212

Hayhurst, J. D., "The Attenuation of Sound Propagated Over the Ground," Acustica, 3, 227-232, 1953.

Theoretical calculations by Knudsen, supported by the results of laboratory experiments, have established the attenuation of sound in still air. Little work has hitherto been done out-of-doors because of the difficulty in allowing for the effect of wind on the attenuation. In the course of an aircraft-noise-abatement investigation made recently by the Ministry of Civil Aviation, the effect of wind on the propagation of sound over a dry concerte runway has been explored up to a distance of about half a mile from a source of sound. It was found that the only significant parameter was the component of wind in the direction of propagation, and the values that emerged showed that wind effects cannot be neglected in any acoustic work made out-of-doors. By interpolation the attenuations corresponding to a zero wind component in the direction of propagation were derived and were found to be substantially greater than those previously determined for still air. The attenuations were, however, statistically independent of the absolute wind speed. Repetition of the investigation over grassed areas produced no reliable results.

2213

Hubbard, B. R., "Influence of Atmospheric Conditions upon the Audibility of Sound Signals," J. Acoust. Soc. Am., 3, 111-125, 1931.

Summarizes the causes of the irregularity noticed in the audibility of fog signals. The observations and theories of various writers are quoted and the results of the test of fog-horns at Boston, carried out in Sept., 1930, are given. Striking instances are given of the unreliability of loudness observations for ascertaining distance; e.g., a fog signal that is audible for eight miles under favorable conditions may be just audible under other atmospheric conditions at a mile or less. The effect of "silent zones," due to the bending of the sound waves when temperature decreases normally upwards, is considered.

There are now few phenomena of fog signalling that cannot be explained in accord with generally recognized principles. The atmosphere is seldom homogeneous and aberrations in audibility may be due to any or all of three causes—wind, temperature, and humidity. The work of all investigators points to the first of these causes as the most important in causing inefficiency. The observed effects are illustrated by diagrams and tables summarizing the results obtained.

2214

Ingard, U., "Acoustics," in E. U. Condon, and H. Odishaw, eds., Handbook of Physics, McGraw-Hill, New York, 113-133, 1958.

This concise presentation of acoustic theory and applications discusses the general equations of sound propagation, sound sources and their fields, propagation in the atmosphere and in tubes, absorption of sound, scattering, detection of sound, architectural acoustics, and ultrasonics. The section on atmospheric sound propagation develops the equations pertaining to ray acoustics (phase velocity, group velocity, shadow zones), intensity in the shadow zone, scattering by turbulence, and ground absorption.

2215

Ingard, U., "Field Studies of Sound Propagation over Ground," Acoustics Lab., Mass. Inst. Tech., Cambridge, 1954.

The results of two sets of field studies of sound propagation over ground are presented. One study utilized pure tones, the levels of which were measured at various distances and different wind velocities. For the second study an airplane propeller served as the source with octave band levels measured over various ground covers, at different wind velocities and at several distances. The importance of wind is shown by the shadow formation obtained. Fluctuation of sound level was shown to increase with distance and frequency. For propagation over the ground, the effect of turbulence scatter was found to be small.

2216

Ingard, U., "The Physics of Outdoor Sound," Proc. Fourth Ann. National Noise Abatement Symp., 4, 11-25, 1953.

The effects of wind and temperature gradients, wind fluctuations, turbulence scattering, and absorption due to humidity are described and explained in this clearly written paper. The formation of shadow zones and the dependence of attenuation upon frequency in the shadow zone is discussed. Illustrative data for each of the meteorological parameters affecting the propagation of sound in a natural atmosphere are presented.

2217

Ingard, U., "A Review of the Influence of Meteorological Conditions on Sound Propagation," J. Acoust. Soc. Am., 25, 405-411, 1953.

The study of the different atmospheric effect indicates that in short-range sound propagation the attenuation by irregularities in the wind structure (gustiness) often is of major importance in comparison with humidity, fog, and rain, and ordinary temperature and wind refraction. However, the ground attenuation can be just as important as the gustiness, particularly when the sound source and the receiver are sufficiently close to the ground. The effect on the attenuation of the height of the source and the receiver off the ground is presented as a function of frequency for a typical ground impedance. The attenuation curve exhibits a maximum which in most cases lies at a frequency between 200-500 cps.

2218

Milne, E. A., "Sound Waves in the Atmosphere," Phil. Mag., 42, 96-114, 1921.

This paper deals with the kinematics of the propagation of sound waves through a medium (such as the atmosphere) in which the velocity of the medium and the velocity of sound in the medium vary from point to point. The subject is taken up in connection with the location of aircraft by sound. Sections take up: equations of propagation; the general refraction formula for stratified media; application to a point source in the atmosphere; total reflection and the range of audibility; cases of limited audibility, etc.

2219

Moies, P. C., "Strong Sound Signals, Effect of the Wind," Tech. Notes No. FRL TN 31, Feltman Res. Labs., Picatinny Arsenal, Dover, N. J., 5 pp., 1961. AD-253 793.

The range of audibility does not depend on wind velocity as such but on the rate at which the speed increases with height. The effect of a height gradient in wind velocity is to produce curved rays. Equations are given for calculating the radius of curvature from the speed and relative direction of the sound and the gradients in the temperature and velocity of the wind. Sound heard downwind is intensified; that heard upwind is weakened.

2220

Pekeris, C. L., "Theory of Propagation of Sound in a Half-Space of Variable Sound Velocity Under Conditions of Formation of a Shadow Zone," J. Acoust. Soc. Am., 18, 295-315, 1946.

In the case of sound emanating from a source some distance below the surface of a medium in which sound velocity decreases with depth, there is a shadow zone into which no rays penetrate. This paper consists of a theoretical study of the diffracted radiation penetrating into the shadow zone. The intensity falls off essentially exponentially with distance from the shadow boundary, but there exists for each point a frequency of optimum penetration. Travel times for the disturbance are calculated, and the method for computing the pressure-time curve for pulses is indicated. Constant and depth-varying velocity gradients are treated.

2221

Pridmore-Brown, D. C., "Sound Propagation in a Temperature- and Wind-Stratified Medium," J. Acoust. Soc. Am., 34, 438-443, 1962.

The general linearized equations governing the propagation of sound in a dissipationless temperature- and wind-stratified medium are derived. A formal integral expression is given for the field of a point-source located in such a medium, when it is bounded by an absorbing plane under conditions which lead to the formation of a shadow zone. This integral yields the following approximate (high-frequency) expression for the decay rate within the shadow

$$|p| = (B/r) \exp [-(n/c)f^{1/2}(-c' - U' \cos \phi)^{2/3}r]$$

Here p is the acoustic pressure, r is radial distance from the source, B is independent of r, f is frequency in cps, c is sound speed, c' and U' are sound- and wind-speed gradients at the ground surface, ϕ is the angle between the wind direction and the direction of sound propagation, and n is equal to 5.93 for a pressure-release boundary and to 2.58 for a hard boundary.

2222

Pridmore-Brown, D. C., and U. Ingard, "Sound Propagation into the Shadow Zone in a Temperature-Stratified Atmosphere Above a Plane Boundary," J. Acoust. Soc. Am., 27, 36-42, 1955.

The sound field in the "shadow zone" (diffraction region) formed over a plane boundary in an atmosphere with a constant vertical temperature gradient is analyzed both theoretically and experimentally. The boundary condition at the plane is given by a normal acoustic impedance independent of the angle of incidence. As in the corresponding problem of underwater sound, where the boundary is a pressure release surface, it is found that the major portion of the sound pressure in the shadow zone decays exponentially with distance at a rate proportional to the one-third power of frequency and to the two-thirds power of temperature gradient.

The effect of boundary impedance enters mainly through its resistive component. The rate of sound decay for a pressure release boundary (zero impedance) is found to be 2.3 times that for a rigid boundary (infinite impedance). Sound pressure in the shadow zone was measured in a laboratory chamber in which a large temperature gradient was created. Measurements were made for both hard and absorbing boundaries, and the results were found to be essentially in agreement with theory.

2223

Pridemore-Brown, D. C., and U. Ingard, "Sound Propagation into the Shadow Zone in a Temperature-Stratified Atmosphere Above a Plane Boundary," NACA TN 3494, Mass. Inst. of Tech., 1955.

In this report, geometrical ray acoustics are employed to derive the ray paths and the intensity distribution about a sound source located in a uniformly stratified medium. A comparison of the relative effect of the stratification on the intensity from a directive source and from a spherical source is made.

Also presented is a theoretical analysis of the sound field in the "shadow zone" (diffraction region) formed over an absorbing-plane boundary in a temperature-stratified atmosphere. The analysis holds for both two and three dimensions. The boundary condition at the plane is given by a normal acoustic impedance independent of the angle of incidence. As in the corresponding problem of underwater sound, where the boundary is a pressure-release surface, it is found that the major portion of the sound intensity in the shadow region decays exponentially with distance at a rate proportional to the one-third power of frequency and to the two-thirds power of temperature gradient. The effect of ground impedance enters mainly through its resistive component. The rate of sound decay for a pressure-release boundary (zero impedance) is found to be 2.3 times that for a reflecting boundary (infinite impedance).

Finally, the results of measurements of the sound distribution in a two-dimensional laboratory chamber in which a large temperature gradient was created are reported. Measurements were made at various frequencies for both reflecting and absorbing boundaries, and the results are found to agree well with theory.

2224

Pridmore-Brown, D. C., and U. Ingard, "Tentative Method for Calculation of the Sound Field About a Source over Ground Considering Diffraction and Scattering into Shadow Zones," NACA TN 3779, Mass. Inst. of Tech., Cambridge, 1956.

A semiempirical method is given for the calculation of the sound field about a source over ground considering the effects of vertical temperature and wind gradients as well as scattering of sound by turbulence into shadow zones. The diffracted field in a wind-created shadow zone is analyzed theoretically in the two-dimensional case and is shown to be similar to the results obtained for a temperature-created shadow field as given in NACA TN 3494. The frequency and wind-velocity dependence of the scattered field into the shadow zone is estimated from Lighthill's theory, and on the basis of these two field contributions a semi-empirical formula is constructed for the total field which contains two adjustable parameters. From this expression a set of charts has been prepared showing equal sound-pressure contours at 10 feet above ground for various source heights, wind velocities, and frequencies.

The two adjustable parameters in the formula were obtained from measurements using a relatively small source height (10 feet). The parameters should actually be a function of height determined by the wind and temperature profiles. However, in these preliminary calculations the parameters have been kept constant, and the fields, particularly for large source heights, must be considered as preliminary estimates to be corrected when more information is available.

2225

Sieg, H. "On Sound Transmission in the Open Air and Its Dependence on Weather Conditions," Halstead Exploiting Center, Brit. Intelligence Objective Sub-Committee, London, 1940. AD-55 755.

Meteorological factors affecting sound transmission in the open air are discussed. Normal sound transmission is mainly disturbed by the influence of temperature and wind, which attenuate sound on its progress through the air. Wind has a far greater effect on transmission than temperature, except in approximately calm weather. "Fine" weather, in an acoustic sense, was found to be nearly calm weather with sky overcast, as well as fog and drizzle; whereas weather was "bad" if the wind velocity was high, with consequent squalliness, especially when the wind blew against the direction of sound transmission. Molecular absorption and height of the transmitter above ground were found to be more conductive to transmission of higher frequencies than to lower frequencies.

2226

Wiener, F. M., "On the Propagation of Audible Sound over Water in Fog," Rept. No. 6-1-2, Coast Guard, Washington, D. C., 14 pp., 1960.
AD-242 087.

Field experiments which consisted of sound transmission measurements over water under a variety of atmospheric conditions, including fog, and of extensive micrometeorological measurements taken, for the most part, simultaneously with the acoustic measurements. The micrometeorological data were obtained to describe, as completely as possible, the properties of the lowest layers of the atmosphere above the ocean through which the acoustical signal was propagated. Representative samples are given of the sound attenuation characteristics obtained in the field. The instrumentation is briefly described, and is followed by a brief analysis of the results. This is preceded by a short discussion of the physics of sound propagation through the lower atmosphere in the light of available theory.

2227

Wiener, F. M., "Sound Propagation over Ocean Waters in Fog," J. Acoust. Soc. Am., 33, 1200-1205, 1961.

Audible fog signals are extensively used as aids to marine navigation during periods of low visibility. Performance, however, has frequently been inadequate. To obtain a better understanding of the physics of sound propagation over water in fog, a series of field experiments was carried out off the coast of Maine. Signals in the frequency range between about 200 and 2000 cps were employed to measure sound attenuation for distances up to a few miles. Simultaneous micrometeorological measurements were performed to describe the relevant properties of the lowest layers of the atmosphere through which the sound was propagated. This paper describes briefly the measurement techniques used and presents typical samples of the results obtained. Downwind, the average excess attenuation over and above inverse square law can be accounted for principally by molecular absorption. Upwind, large values of excess attenuation were found due to shadow zone formation. This constitutes a severe limitation of the useful range of audible fog signals. Fog itself contributes little to the average excess attenuation.

2228

Wiener, F. M., and D. N. Keast, "Experimental Study of the Propagation of Sound over Ground," J. Acoust. Soc. Am., 31, 724-733, 1959.

The attenuation of sound propagated out-of-doors is conveniently separated into attenuation due to spherical divergence and excess attenuation due to atmospheric and terrain effects. This excess attenuation is principally caused by sound absorption in the air, the refractive effects of temperature and wind gradients, turbulence, and terrain and ground cover. To investigate these effects, the propagation of sound over open, level ground, through dense evergreen forests, and between hilltops was studied experimentally in the frequency range between about 300 and 5000 cps. Extensive micrometeorological instrumentation was utilized to measure and record the relevant micrometeorological parameters simultaneously with the acoustic data for a wide variety of weather conditions. Data on the attenuation of the mean sound pressure level as well as on the fluctuations about the mean were obtained and correlated with the state of the atmosphere. Over open, level terrain, the excess attenuation upwind was found to exceed that for downwind propagation by as much as 25-30 db for source and receiver heights of 12 and 5 feet, respectively. Temperature and wind gradients near the ground-air interface largely account for this difference. In hilltop-to-hilltop propagation, wind direction is of secondary importance and in dense woods absorption and scattering control. Empirical functions were derived for the purpose of estimating the mean excess attenuation as a function of frequency and distance, for a given set of micrometeorological conditions. These charts were found useful in many practical problems involving the propagation of sound over open level ground.

Shadow Zones
See also — 83, 87, 88, 89, 431, 434, 441, 452, 478, 524, 525, 527, 569, 1086, 1122, 1513, 1516, 1548, 1565, 1690, 1872, 3291.

SIGNALING

2229

Arnold, J. S., and A. Picker, "The Modification of a Warning Siren to a Modulated Airstream Loudspeaker," Final Tech. Rept., Stanford Res. Inst., Menlo Park, Calif., 83 pp., 1961. AD-272 937.

The feasibility of modifying a warning siren to add speech capability was demonstrated by adding a modulated airstream loudspeaker to the siren. The siren's air supply and control circuit were used by the loudspeaker, with appropriate auxiliary equipment and minor modifications of the existing siren. Using a recorded-speech input, an average sound pressure level of 117 db was achieved on the horn axis at a distance of 100 ft. At a distance of 675 ft (limited by terrain) observers reported that the sound was loud, clear, and intelligible. Extrapolation of the data indicates that speech is intelligible within a maximum range between one and two miles, depending on ambient noise and other conditions.

2230

Blaise, P., "General Report on the Range of Sound Signals," Rept. No. General-3, Coast Guard, Washington, D. C., 36 pp., 1960.
AD-242 002

Questionnaires concerning fog signals were submitted to the Sixth International Technical Conference on Lighthouses and Other Aids to Navigation. Replies to the inquiries, concerned with the problem of determining the range of sound signals, are analyzed individually.

2231

Bolt, Beranek, and Newman, Inc., "Investigation of Acoustic Signalling over Water in Fog," Final Rept. on Phase 1, Evaluation of Present U. S. Coast Guard Design Procedure for Fog Signals, Cambridge, Mass., 14 pp., 1960.
AD-236 583.

The present USCG design procedure for fog signals represents considerable progress over previous methods. It is based on the concept of the average audible range and uses a fixed loudness level as the criterion for detection. Sound sources are specified in terms of the on-axis free-field sound pressure level at a distance of 25 feet. The transmission path is described by means of a curve of average sound transmission loss obtained many years ago. The following areas of improvement and refinement are suggested: (1) description of the sound source in terms of acoustic power output and directivity; (2) description of the transmission path by means of sound attenuation functions which take into account, in addition to frequency and distance, such parameters as source and receiver heights, wind direction and speed, and temperature and wind gradients, on a statistical basis; (3) description of the process of signal detection and location by the listener in terms of a detection criterion of minimum s/n, taking account of background noise levels and spectra, signal frequency and duration, and other relevant factors.

2232

Bolt, Beranek, and Newman, Inc., "Investigation of the Transmission of Sound Through Fog over Water," Final Rept. on Phase 2, Investigation of Acoustic Signalling over Water in Fog, Cambridge, Mass., 1960.
AD-236 659

The physics of sound propagation along the surface of the earth is discussed with particular attention to the conditions existing where sound is propagated for long distances over ocean waters in fog. The results of an extensive measurement program of sound transmission over water are presented, together with the results of measurements of the relevant micrometeorological parameters and a description of the instrumentation and experimental techniques used. The experimental data are analyzed in the light of available theory with a view of applying the results in generalized form to an improved design procedure for audible fog signals. Among the more important conclusions resulting from the analysis and evaluation of the field studies presented in this report are as follows.

(1) The propagation of audible sound over ocean waters in fog is governed by the same micrometeorological parameters which

determine the propagation of audible sound over land. (2) The presence of wind and temperature gradients just above the surface of the ocean causes the sound to be refracted from the normal

2233

Coast Guard, "The Average Audible Range of Sound Signals," Civil Eng. Rept. No. CG-250-29, Washington, D. C., 1958. AD-225 675.

The three-fold purpose of the report is: (1) to describe a new method for determining the average audible range of a sound signal under average conditions of fog; (2) to indicate how the results of this method may be used in the Coast Guard; and (3) to publish the average audible ranges of those fog signals for which acoustical measurements have been made.

The reliable range for sound signals (the distance at which the sound can always be heard) seldom exceeds one-quarter mile, and reliable ranges of over one-half mile are believed to be unachievable. The average audible range is that distance at which the sound will be heard roughly 50% of the time; that is, the maximum range at which the signal is usable under favorable conditions of sound propagation.

A method was developed for the determination of the average audible range both for signals of the electric oscillator type, and for those that have a complex frequency structure, such as the diaphone. The methods by which the results of this procedure may be used in the Coast Guard are discussed, and actual results are included for those fog signals for which adequate acoustical measurements are available.

2234

Coast Guard, "Proceedings of the Sixth International Technical Conference on Lighthouses and Other Aids to Navigation, September 25-October 7, 1960," Washington, D. C., 245 pp., 1960. AD-277 064.

Descriptors: Conferences-Lighthouses, Lighthouses, Navigational lights, Symposia-Navigational lights, Indexes, Light homing, Lighting equipment, Navigation, Coast Guard, Signal lights, Fog signals, Power supplies, Electronic equipment, Auditory signals, Ships.

2235

Delsasso, L. P., "The Attenuation of Sound in the Atmosphere," Dept. of Phys., Univ. of Calif., Los Angeles, 37 pp., 1953. AD-89 256.

The attenuation of sound at sea level pressures and normal temperatures is extended to pressures and temperatures which may be encountered in acoustical signalling and tracking problems. Measurements were made both in the laboratory and in the field. In the laboratory results are reported for the frequency range 1000 to 6000 cps for a temperature range of from 2° to $35^{\circ}C$ and for pressures from 76 to 26 cm of Hg. In the field, measurements have been obtained at an altitude of 10,000 feet for representative variations of meteorological conditions. Limits for the possible absorption coefficients to be met with in practice have been extablished. Progress is reported on the development of instruments to measure more accurately the details of the meteorological conditions excountered, particularly with reference to the accurate description of natural fogs. Instrumentation for measuring the attenuation of sound under laboratory conditions and the attenuation of sound propagating outdoors is described and illustrated.

2236

Fischer, F. A., "Distribution of Sound from Sources in the Neighborhood of Plane Reflectors," Elek. Nackr.-Tech., 10, 19-24, 1933.

When sound is emitted from a point source near a reflecting surface, the effect at a distance is that of an acoustical doublet composed of the source and its image. Polar diagrams are drawn to show the sound distribution for typical cases when (a) there is no phase change, and (b) the reversal of phase occurs at the reflecting surface. In case (a) a maximum of intensity always occurs in the plane of the reflector, and other maxima and minima occur in directions inclined to this plane. In case (b) a minimum is always found in the plane of the reflector, and provided the source is not more than a quarter wavelength from the reflector, nowhere else. On increasing this distance other maxima and minima appear. If, instead of a single source, a series of equidistant sources on a normal to the surface is used, in case (a) the maximum in the plane of the reflector becomes relatively much greater; similarly the first maximum in (b), which is in a direction inclined to the surface, is more pronounced. Formulae are given in each instance for the acoustical energy of the system; and the application of the results to signalling on land and below the surface of water is discussed.

2237

Hilliard, J. K., and W. T. Fiala, "Electro-Pneumatic Air Modulator for Fog Signals," Rept. No. 6-2-1, United States Coast Guard, Washington, D. C., 11 pp., 1960. AD-242 094.

A highly directional electro-pheumatic, air-modulated loudspeaker was designed. It is capable of radiating speech or any type of warning signal in the 100-c to 1000-c range. Tests were conducted to delineate the directional qualities of the sound generator, both in absolute terms and in practical navigation. In these tests, 200-c and 400-c warbled tones, plus a voice signal, were compared with a standard diaphone fog signal.

The electro-pneumatic equipment used for the tests included a single unit consisting of four air-modulated loudspeakers driving an exponential horn six ft. in length, with a mouth cross-section of four sq. ft. Voice signals were generated by two air-modulated loudspeakers mounted on an Altec-Lansing 1003 multicell horn with a cutoff of 200 c.

A shadow zone was established in the upwind direction which fully substantiated the effect of sound over water as described by Francis M. Weiner (AD-242 087).

2238

Hirai, S., "Decrease of a Sound Signal on the Sea," Rept. No. 6-1-1, Sixth International Technical Conference on Lighthouses and Other Aids to Navigation, U. S. Coast Guard, Washington, D. C., 10 pp., 1960. AD-242 086.

Sound signals were projected over the water of Tokyo Bay, Japan, to acoustic receiving equipment located 1200 meters from the source. The transmitted frequency was varied in 50-cycle steps from 100-3000 cps. An assumed inverse-square spreading loss was subtracted from the near-field response of the source. Signal levels actually received at 1200 meters were then subtracted from the preceding result to show atmospheric attenuation-vs-frequency. This was found to increase at a rate of about 10 db/octave for frequencies from 100-1500 cps and at a progressively slower rate from 1500-3000 cps.

2239

Hirai, S., "The Rated Range of a Sound Fog Signal," Rept. No. 6-1-6, Coast Guard, Washington, D. C., 10 pp., 1960. AD-242 091.

The paper, "Defining and Calculating the Rated Range of a Sound Signal" by M. R. Ginoechis, is considered. It was presented to the 5th International Conference on Lighthouses and Other Aids to Navigation. Experiments and observations were conducted on (1) the intensity and stress of a sound signal defined as the sound loudness level at its origin and as measured at 10-m distance directly from the mouth of the horn; (2) the question of whether the value of the atmospheric transmission coefficient, T, used correspondingly to the wavelength, should be regarded as proper (AD-242 086); (3) the question of whether it is proper to consider a decrease in sound to be proportional to the distance to the minus squared; and (4) the accuracy of using the value 70 db as the minimum audible sound among the noises. Results indicated that a distance of 10 m is too near to measure the intensity of the source of sound and that in the case where a larger distance cannot be had because of a topographical situation, a compensating value should be added to the value or the value should be made smaller. Noises from diesel and reciprocal engines were measured on different kinds of vessels for stress and loudness level. For the diesel engines, the average noise values were 100, 76, 97, and 85 phons for the engine room, pilot house, and bridge end at 18% and 6% wind velocity, respectively. In the case of the reciprocal engine, the noise values were 80, 67, and 75 to 85 phons in the engine room, pilot house, and bridge end, respectively. The value of minimum audible sound will be about 70 phons.

2240

Hubbard, B. R., "Influence of Atmospheric Conditions upon the Audibility of Sound Signals," J. Acoust. Soc. Am., 3, 111-125, 1931.

Summarizes the causes of the irregularity noticed in the audibility of fog signals. The observations and theories of various writers are quoted and the results of the test of fog-horns at Boston, carried out in Sept., 1930, are given. Striking instances are given of the unreliability of loudness observations for ascertaining distance; e.g., a fog signal that is audible for eight miles under favorable conditions may be just audible under other atmospheric conditions at a mile or less. The effect of "silent zones," due to the bending of the sound waves when temperature decreases normally upwards, is considered.

There are now few phenomena of fog signalling that cannot be explained in accord with generally recognized principles. The atmosphere is seldom homogeneous and aberrations in audibility may be due to any or all of three causes—wind, temperature, and humidity. The work of all investigators points to the first of these causes as the most important in causing inefficiency. The observed effects are illustrated by diagrams and tables summarizing the results obtained.

2241

Levy, S. E., and R. W. Carlisle, "Generation of Intense Audio Sound Fields Utilizing Arrays of Multiple-Driver Horns," J. Acoust. Soc. Am., 33, 936-940, 1961.

There are several major applications for intense audio sound fields: the outdoor propagation of speech and of warning signals, and the sonic fatigue testing of missile and aircraft components. In these applications, several factors combined make it necessary to limit the portion of the frequency spectrum covered by any one loudspeaker unit. In order to provide adequate power capacity, selection is required between the alternatives of (a) using a large number of identical drivers, (b) using a plurality of drivers each especially designed for a selected portion of the frequency range, and (c) using combinations of these arrangements. In an array currently being used for sonic-fatigue testing, a plurality of large open-cone loudspeakers is used for low frequencies, and a plurality of horns is used for middle and high frequencies. Each horn is driven by several drivers. The driver voice coil and diaphragm proportions have been optimized to withstand fatigue stresses under the thermal conditions encountered. The driver is rated at 50 w input for programme material. Horn assemblies are available having throat arrays for mounting 6, 12, or 24 drivers. Various applications are illustrated.

2242

Moies, P. C., "Influence of Wind on Propagation of Loud Sounds," Bull. soc. belge electriciens, 53, 237-240, 1937.

Deals with the propagation of sounds from high-power loudspeakers such as might be used for giving warning signals over a wide area. In calm air the frequency range 1500-2500 is propagated best, a range of about 1500 meters being obtained from a 60-W output. The acoustic efficiency of an ordinary loudspeaker is given as about 0.03%. The results for the influence of wind are given in the form of an empirical formula involving the velocity gradient (with height above the ground) of the wind.

2243

Perrigo, W. R., "Air-to-Ground Loudspeaker Equipment," Tech. Rept. No. 59-625, Communication and Navigation Lab., Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, 9 pp., 1959. AD-227 278.

Describes design, development, and testing of air-to-ground loudspeaker equipment and systems for application in psychological warfare. Presents the development of droppable and fixed airborne loudspeaker systems designed to meet USAF operational requirements, outlined in applicable military characteristics dated 21 Nov 1951. Describes application of the resultant equipment in support of psychological missions of the Strategic and Tactical Air Commands.

It was concluded that the droppable loudspeaker system AN/ANH-4(XA-2 and XA-3) and public address set AN/AIC-11(XA-2) met basic USAF requirements, could be used effectively in psychological warfare, and had potential application in other types of USAF missions.

2244

Pierce, G. W., and A. Noyes, Jr., "Transmission of Sound over Reflecting Surfaces," J. Acoust. Soc. Am., 9, 193-204, 1937.

The paper presents an experimental and theoretical discussion of acoustic signalling between a sending station and a receiving station near a plane reflecting surface, and is applicable to foghorn and submarine signalling. The experiments were made with a small-scale apparatus employing supersonic waves of a frequency of 67.5 kcs. It is shown that at grazing incidence the direct and reflected waves cancel, or partially cancel, as predicted by theory. The cancellation for propagation in air near a water surface, or near another surface of high sound velocity and high density, is found to be restricted to angles very near to grazing incidence.

On the other hand, theory predicts cancellation for much larger departures from grazing incidence if the reflecting surface has high density but low velocity; experimental curves for transmission over beach sand and certain other substances resemble such theoretical results very closely. Acoustic mirages caused by temperature gradients were studied experimentally, and their effects are shown to be of striking importance in modifying the above results.

2245

Schilling, H. K., M. P. Givens, W. L. Nyborg, W. A. Pielemeier, and H. A. Thorpe, "Ultrasonic Propagation in Open Air," J. Acoust. Soc. Am., 19, 222-234, 1947.

Data and conclusions of practical interest in regard to ultrasonic signalling are presented. Fundamental ultrasonic phenomena of propagation are investigated, and their causes isolated through correlations with simultaneously observed micrometeorological phenomena. Results are presented with two viewpoints: propagation in a nonscattering atmosphere, and propagation in a scattering medium; it was found that sometimes the open air is a scattering, as well as an absorbing, medium. Values of absorption coefficients are presented for frequencies up to 30 kc.

2246

Sher, M., "Loudhailer Evaluation for Airborne Use, Phase I," Rept. No. 1606, Central Experimental and Proving Establishment (Canada), 26 pp., 1961.
AD-272 056.

The CMA-402 Canadian Marconi loudhailer was evaluated for use in an airborne public address system to be employed in search, rescue, and survival operations. Order-of-magnitude of ranges was measured by taking readings on a sound level meter at intervals of 100 ft. or more from the loudhailer assembly with a fixed input. Polar patterns were determined with the sound level meter in a fixed position, and the loudhailer assembly rotated through fixed angles on a rotatable table. Distortion and frequency response were measured with a distortion analyzer and power meter.

2247

Webster, J. C., R. G. Klumpp, and A. L. Witchey, "Evaluation of a Modulated Air-Flow Loudspeaker," J. Acoust. Soc. Am., 31, 795-799, 1959.

As part of an overall evaluation of the USNEL Flight Deck Communications System, an RCA modulated-airflow loudspeaker (air speaker) was tried out as an alarm-signalling transducer on the flight deck of an aircraft carrier. Tests with 200-cps to 6000-cps noise showed that the air speaker produced 130 db SPL at optimum points on the deck, as compared to 110 db for the present system. Speech intelligibility and alarm detection tests showed the air speaker to be usable with jet aircraft at idle (30%) power while the present loudspeakers could not be heard. Neither loudspeaker system was adequate with jets at full power.

2248

Wiener, F. M., "Sound Propagation over Ocean Waters in Fog," J. Acoust. Soc. Am., 33, 1200-1205, 1961.

Audible fog signals are extensively used as aids to marine navigation during periods of low visibility. Performance, however, has frequently been inadequate. To obtain a better understanding of the physics of sound propagation over water in fog, a series of field experiments was carried out off the coast of Maine. Signals in the frequency range between about 200 and 2000 cps were employed to measure sound attenuation for distances up to a few miles. Simultaneous micrometeorological measurements were performed to describe the relevant properties of the lowest layers of the atmosphere through which the sound was propagated. This paper describes briefly the measurement techniques used and presents typical samples of the results obtained. Downwind, the average excess attenuation over and above inverse square law can be accounted for principally by molecular absorption. Upwind, large values of excess attenuation were found due to shadow zone formation. This constitutes a severe limitation of the useful range of audible fog signals. Fog itself contributes little to the average excess attenuation.

Signaling
See also—83, 88, 89, 108, 111, 432, 485, 488, 567, 668, 965, 1029, 1086, 1121, 1291, 1549, 1665, 1863, 1864, 1866, 1867, 2718.

SOUND IN AIR, GENERAL, UNCLASSIFIED

2249

Acoustics Lab., Mass. Inst. of Tech., "Quarterly Progress Reports," Cambridge, 1950-1957.

This is a seven-year series of quarterly progress reports on government-sponsored research contracts with the Acoustics Laboratory of MIT. A wide variety of problems in acoustics was investigated. Among a host of miscellaneous items, all issues contain one or more brief reports on research related to the propagation of sound in air. Typical subject headings are: atmospheric acoustics; scattering of sound from a vortex; short range propagation in the atmosphere; propagation of sound waves of finite amplitude; absorption of sound in gases; scattering of sound from turbulence; sound field from a random noise source above ground; wind-created shadow formation over ground; instrumentation for field measurements of sound propagation; scattering of sound by sound; acoustic behavior in moving media; diffraction and scattering into the shadow zone; outdoor sound propagation measurements; the effect of a ground layer with a temperature inversion on the field within an acoustic shadow zone; and, computation of the sound field over an absorbing surface. The following is a complete list of MIT Acoustic Laboratory Quarterly Reports with corresponding DDC Document numbers where applicable.

July-September 1950
October-December 1950
January-March 1951
April-June 1951
July-September 1951
October-December 1951
January-March 1952
April-June 1952
July-September 1952
October-December 1952, AD-7 815
January-March 1953, AD-14 656
April-June 1953, AD-16 881
July-September 1953, AD-22 517
October-December 1953, AD-25 861
January-March 1954, AD-35 322
April-June 1954, AD-44 511
July-September 1954, AD-49 532
October-December 1954, AD-54 507
January-March 1955, AD-61 541
April-June 1955, AD-70 101
July-September 1955, AD-76 096
October-December 1955, AD-85 884
January-March 1956, AD-102 751
April-June 1956, AD-107 074
July-September 1956, AD-110 161
October-December 1956, AD-117 032
January-March 1957, AD-117 117
April-June 1957, AD-133 735
July-September 1957, AD-133 794

2250

Army Signal Missile Support Agency, "Proceedings of the Symposium on Atmospheric Acoustic Propagation," Headquarters, USA SMSA, Missile Meteorology Div., 1, 268 pp, 1961.
AD-408 716.

This document comprises twenty-five technical papers on various aspects of the propagation of sound in air. It features the results of recent research. These deal with high-altitude acoustic detection from balloons, the sound duct at high altitudes, very-long-range detection of low-frequency sound, atmospheric absorption of sound, sound ray theory, shock wave propagation, sound ranging, and the inter-relationships of meteorological parameters with sound propagation. Some of the papers emphasize theory, others emphasize measurements and experimental results, and some describe special instrumentation. Anyone interested in military applications of sound propagation in the atmosphere will find this document especially useful. Most of the papers include extensive bibliographies.

2251

Catlin, J. B., and R. J. McGrattan, "Sound Radiation from a Cylindrical Shell, David Taylor Model Basin Model Study," Final Rept. No. U413-61-210, Electric Boat Div., General Dynamics Corp., 28 pp., 1961.
AD-267 030.

Describes an analytic and experimental investigation of the mechanical and acoustical behavior of a 1/7-scale submarine-like model hull section in air and water environments. A relatively new analytic approach, the point-mass technique, is utilized to determine the dynamic behavior of the model and the resulting acoustical fields. Experimental results are discussed and compared with the theoretical results.

2252

Chertock, G., "General Reciprocity Relation," J. Acoust. Soc. Am., 34, 989, 1962.

A reciprocity relation is derived between the radiation field of a surface vibrating in an arbitrary mode with arbitrary time dependence, and the generalized force exerted on the surface in the same mode by an external source with the same time dependence.

2253

Domsch, G. H., "Tables for Technical Acoustics," Arch. Tech. Messen, T21-T22, 1937.

Four useful tables giving formulae relating to speed of propagation of sound in solids, liquids and gases, to sound intensity, to reverberation and similar topics in architectural acoustics, and to resonators. Each constant is defined algebraically, and separate columns are given to show the units in the cgs system, the value for air at 20°C and 760 mm Hg, together with general comments including the values for other media, and the methods of measurements or small diagrams.

2254

Eyring, C. F., "Jungle Acoustics," J. Acoust. Soc. Am., 18, 257-270, 1946.

The study of jungle acoustics was carried out during the wet season in Panama. Measurements permit the following conclusions to be drawn. Within a jungle the temperature and wind velocity gradients are so small that the sound refraction they produce may be neglected for all practical purposes. Humidity increases the transmission loss at high frequencies and field measurements of the loss agree with laboratory values reported by others. Terrain loss, measured in db, between any two specified distances from the sound source is defined as the transmission loss between these points less that caused by the geometrical divergence of the sound beam. Terrain loss in the jungle was found to increase linearly with distance. The terrain loss coefficients, in db per foot, were measured for various types of jungle and were found to be a function of frequency and of the density of the terrain, the density of terrain being measured by the difficulty of penetration and the distance that a foreign object may be seen. The level of the ambient noise in the wet-season jungle is very low, especially for the quiet periods between animal calls. At night the low frequencies decrease as the light breezes cease and the high frequencies increase as the insects begin their nocturnal chorus. A jungle is a difficult place in which to judge the direction of a sound—a probable error of 20° is to be expected. The error is found to be smallest when the sound comes from a direction near the axis passing through the two ears, and in the range studied the error decreases as the sound source moves farther away. Reverberation and scattering cause part of the error of judgment, but an improved technique of listening which may increase the observer's accuracy is suggested.

2255

Eyring, C. F., "Jungle Acoustics," Rept. No. 4699, Office of Scientific Research and Development, NDRC Div. 17, Washington, D. C., 80 pp., 1945.
ATI-62654.

This study of jungle acoustics and micrometeorology is one of the most comprehensive and useful documents available for anyone concerned with the transmission of sound at the earth's surface in tropical climates. The study was conducted during the wet season in Panama and includes propagation measurements over hard, bare surfaces, short and tall grasslands, and through a variety of tropical forests. Terrain loss coefficients and their variations with acoustic frequency and environment were determined from measurements. Ambient jungle noise levels in the audible and ultrasonic ranges were measured. Acoustical and meteorological measurements were taken concurrently in order to demonstrate their inter-relationships. Refraction and shadow zone formation, as caused by combined wind and temperature effects, were investigated and found to be significant in open, sunny areas, but not significant under a jungle canopy. The report clearly shows the typical variations to be expected throughout the day and night for each acoustic and meteorological parameter investigated. The various instruments that were developed for acoustic detection and measurement are described in detail. Calibration procedures are also described.

2256

Gosewinkel, M., and F. Spandock, "Electric-Acoustic Sound-Pressure Measurements in Practice" (in German), Arch. Tech. Messen, 153-155, 1940.

From measurements of sound pressure the other quantities of the sound field may be computed if the type of wave is known. The sound-pressure meter usually consists of a condenser microphone, an amplifier and an indicating instrument. Calibrating curves, different for pressure-chamber or open-field measurements, are required. General disturbances, the influence of the arrangement in space, and the accuracy of measurements, are discussed. With regard to errors due to the sound field an accuracy of 10-20% is sufficient for practical purposes. A bibliography of 37 publications is given.

2257

Gutenberg, B., "Sound Propagation in the Atmosphere," in T. F. Malone, ed., Compendium Meteorol. Am. Meteorol. Soc., Boston, 366-375, 1951.

This is a detailed study of the theory of sound waves in gases, the equations for velocity of sound in quiet and in moving air, and the energy of sound waves in the atmosphere. Microbarographs and their limitations are discussed. Observations and records from microbarographs of sound propagation through the troposphere and the stratosphere, and abnormal audibility zones are also treated. Numerous illustrations show types of records, areas of abnormal audibility from explosions (Germany, 1925, and Vergiate, Italy, November, 1920), and travel time curves. Cross sections showing typical paths of sound waves, and temperature and sound velocity profiles from V-2 flights and other sound propagation data are included.

2258

Gutin, L., "Acoustics of the Atmosphere" (in German), Physik. Z. Sowjetunion, 8, 71-80, 1935.

Stresses the need for more consideration of sound curves and damping in the study of sound propagation, de-emphasizing the geometrical aspects.

2259

Harrington, J. B., Jr., "Acoustical Probing of the Upper Atmosphere," Univ. of Mich., 5500 East Engineering, Ann Arbor, 40 pp., 1959.

This paper presents a comprehensive review of historical and current techniques and investigations for accurately determining the propagation characteristics of sound in the atmosphere. Anomolous propagation and the application of Snell's Law of refraction for calculating sound-ray paths are discussed. Gutenberg's approach to measuring upper winds and temperatures using sound rays is described, followed by an account of Richardson's and Kennedy's "Study of Meteorological and Terrain Factors Which Affect Sound Ranging" and "Determination of Atmospheric Winds and Temperatures in the 30 to 60 Kilometer Region by Acoustic Means." The rocket-grenade experiment for determining upper-level wind and temperature profiles is explained as conducted by the Signal Corps and as modified by Groves. A bibliography of more than eighty reports and journal articles on the subject of propagating sound in air is included.

2260

Hazel, H., "Beat Notes, Combination Tones and Side-Bands," Phil. Mag., 19, 103-114, 1935.

Following a brief discussion of the Helmholtz-Koenig controversy and the more recent side-band controversy, an account is given of experimental work bearing on these questions. It is shown that there is a difference between beat tones and differential tones. Beat tones, produced by simple addition of frequencies, elicit no response in detecting devices tuned to their frequency. Combinational tones or sidebands have objective existence if peak response in a linear periodic circuit is used as the criterion of existence. These derived frequencies are produced by modulation, which is the multiplication of one periodic disturbance by another. Modulation can be secured either in linear or nonlinear circuits. Sound waves do not appreciably modulate one another in air and their sources do not give appreciable modulation even when mechanically coupled.

The Helmholtz-Koenig combinational tone controversy was due to misunderstanding of the conditions for modulation and to failure of the experimenters to make the receiving devices independent of the ear. The sideband controversy was based on vague definitions of physical existence and upon the illegitimate use of nonlinear elements in detecting apparatus.

2262

Krasil'nikov, V. A., "The All-Union Acoustics Conference," Soviet Phys. Acoust., English Transl., 4, 106-107, 1958.

The All-Union Acoustics Conference, organized by the Academy of Sciences of the USSR and by Moscow University, was held on 24-29 June 1957 in Moscow. About 150 papers on the following subjects were presented: propagation of sound in non-homogeneous media, production and diffraction of sound, waves of finite amplitude, physics of the ultrasound, musical acoustics, physiological acoustics and speech.

2261

Ingerslev, F., and A. K. Nielsen, "Sound Pressure, Hearing Intensity and Frequency Analysis of Airborne Sound" (in Danish), Ingeniørvidenskab. Skrifter, 2, 26-34, 1947.

Air pressure variations occurring when a car passes close to (50 cm) a column were measured by a crystal microphone coupled through an amplifier to a cathode-ray oscillograph. With a car speed of 100 km/hr an excess pressure of 50 kg occurs when the front of the car meets the front of the column, followed by a pressure deficit of 100 kg at approximately the middle position, then a renewed rise, gradually vanishing.

Routine measurements of pressure and hearing intensity and frequency analysis are carried out by combined motor and band-filter (1/3 octave) and a wave analyzer, which are described. Examples of analysis of some organ-pipe tones and of noise in a canteen are given.

2263

Lobachevskii, M. I., "A Little-Known Article on Acoustics (The Origin and Propagation of Sound in the Air)," discovered by I. M. Bronstein, Soviet Phys. Acoust., English Transl., 2, 338-341, 1956.

Lobachevskii's first published article (according to Bronstein) is this popular essay on the propagation of sound in air, which appeared in the journal "Kazan Bulletin" in 1823. It is an essentially nonmathematical treatment, very clearly written, and still very timely in most respects.

2264

Mawardi, O. K., "On the Generalization of the Concept of Impedance in Acoustics," J. Acoust. Soc. Am., 23, 571-576, 1951.

The conventional definitions of acoustical impedances, so useful in the investigations of the properties of idealized systems with lumped parameters, fail when applied indiscriminately to systems with distributed constants. In general, the present definitions are valid only when the specific impedance is constant on a wave front. By extending the notion of vector fields to specific impedances, the previous restriction is removed and the scope of application is considerably increased. A definition for the acoustic impedance, based on energy concepts, is also proposed.

2265

Medwin, H., "Acoustics in West Germany, Part I," Tech. Rept. ONRL 82-61, Office of Naval Research, London, 14 pp., 1961. AD-266 988.

This report is concerned with work in three fields: underwater acoustics, air acoustics and turbulence, and auditorium acoustics. Under the first heading it covers the development of low-frequency absorbers for use in water, underwater transducers, wall acceleration during turbulent flow, and cavitation studies; under the second, the use of sound to inhibit turbulence, the absorption of single shocks by porous materials, and the interaction of sound and turbulence.

Covers work done at Gottingen, Braunschweig, and Heidelberg.

2266

Medwin, H., "Acoustics in West Germany, Part II," Tech. Rept. ONRL 33-62, Office of Naval Research, London, 13 pp., 1962. AD-276 517.

Activity in the study of acoustics in Western Germany is surveyed. Particular attention is given to the institutes at West Berlin and Aachen.

2267

Meyer, E., "Experiments on CM Waves in Analogy with Acoustic Techniques Made in Gottingen," J. Acoust. Soc. Am., 30, 624-632, 1958.

In the past four years a series of experiments has been carried out which serve to demonstrate the success of analogies between acoustical systems and electromagnetic wave systems in the microwave frequency region. Measuring techniques in the two disciplines are compared, with particular emphasis on the use of reverberation chambers. Analogous directive microphones and electromagnetic devices have been constructed. The design and performance of both nonresonant and resonant absorbing structures is discussed at length.

2268

Pennsylvania State University, "Atmospheric Physics and Sound," Final Rept., Dept. of Physics, Acoustics Lab., University Park, 288 pp., 1950.

This voluminous report contains a detailed account of the instrumentation developed, methods used, and results achieved at Pennsylvania State University in a five-year study aimed at investigating the production and propagation of sound, both sonic and ultrasonic, in the lower atmosphere, through the ground, and in other media. Chapter 7 "Micrometeorology and Atmospheric Acoustics," is a summary of results of temperature and wind velocity measurements (mostly with hot wire thermometers and aneomometers) made up to 50 feet from the ground in conjunction with sound intensity measurements. A definite correlation is found between sound signal fluctuations and inhomogeneities of temperature, but not of wind. Likewise no effect of snow cover on sound propagation was noted.

2269

Piccard, A., "Audition of a Concert, of Distant Sounds, and the Scintillation of Stars" (in French), Helv. Phys. Acta, 16, 425-427, 1943.

Cites various examples of sound interference in concert halls and churches in which, using one ear, surfaces of silence may be detected, as well as changes in the quality of the sound heard. The variation in the loudness of the hum of a one-engined aeroplane high overhead or of a distant churchbell at night is due to inhomogeneities in the air which cause changes in the speed and direction of the sound waves. Interference of light waves in their passage through the air is the cause of the twinkling of the stars.

2270

Richards, W. T., "Acoustical Behavior of a Gas with Several Independent Internal Energy States," J. Chem. Phys., 1, 863-879, 1933.

The method founded by Einstein for the description of the acoustical behavior of a dissociating gas has been extended to cover a nondissociating gas in which five groups of internal energy states have different relaxation times. Since the resulting expressions are unwieldy, approximations based on them, which permit the rough description of experiments, have been given. The study of the variation in the velocity of sound with frequency demonstrates differences in the relaxation times of the various states. The variation in the velocity of sound with pressure shows additional effects from three-body collisions or from radiation from optically active states. It has been suggested that the temperature coefficient of the kinetic relaxation time be treated by introducing an empirical quantity that may be called "the activation energy of collision." By this means a rough kinetic analysis of the probability of transition is possible. In gaseous mixtures, the relative spatial and energetic effectiveness of various types of collisions in exciting internal energy may be compared.

2271

Skogen, N., "Movement of Air Past Obstacles in a Sound-Field, Studied by Means of Smoke Particles, Parts I-III," Kgl. Norske Videnskab. Selskabs Forh., 24, 60-71, 1951.

The movement of air around various obstacles in a sound field is made visible by means of smoke particles, employing a method used by E. N. da C. Andrade [Proc. Roy. Soc. (London), 134, 445, 1932]. In Part I, the motion of the air around a thin rectangular plate is observed. Two kinds of circulation were found, depending on the position of the plate; (a) when the plate is parallel to the direction of the sound, the motion of the air at the plate surface is parallel to this direction, and (b) when the plate is normal to the direction of the sound, the motion of air at the plate surface is also normal to the sound.

Part II deals with the more complex motion in the neighborhood of a circular hole in a screen, normal to the direction of sound. It shows that the various types of circulation which may occur may be reduced to the two types described in Part I.

Part III describes the motion of air that occurs around a cylinder—an "inner" and an "outer" circulation system being observed.

2272

Soviet Phys. Acoust., English Transl., "Soviet Acoustics over the Last 40 Years," 3, 321-339, 1957.

Gives an historical account covering architectural acoustics, electroacoustics, musical acoustics, ultrasonics, propagation of sound and the acoustics of nonhomogeneous and moving media, physiological acoustics and noise.

2273

van Everdingen, E., "The Propagation of Sound in the Atmosphere," Proc. Acad. Sci. Amsterdam, 18, 933-960, 1915.

This paper, of historical interest, was written in 1915, and reviews the various theoretical and experimental approaches of that day on the anomalous propagation of sound in air. The theory of refraction of sound waves due to wind and temperature gradients is presented. Lack of temperature and wind data at high altitudes prevented accurate use of this theory in 1915. Other theories (now defunct), postulating a change in composition of the atmosphere with altitude, are reviewed. One of these predicted the existence of a gas, "geocoronium," five times lighter than hydrogen. Copious data on acoustic observations of various large explosions and volcanic eruptions is given in narrative and graphic form to demonstrate the existence of shadow zones and secondary areas of audibility.

2274

West, G. D., "Circulations Occurring in Acoustic Phenomena," Proc. Phys. Soc. (London) B, 64, 483-487, 1951.

An investigation was made, using smoke particles, of the movements of the air in the neighborhood of a vibrating reed. At very low frequencies, the paths of the particles exhibit a pattern which, at first sight, resembles the lines of hydrodynamic flow. A more careful examination at sufficiently high magnification shows, however, that the particles do not move along the hydrodynamic lines but trace out small ellipses. In addition, a mass circulation of the particles is superimposed on the above motion. At low frequencies this circulation is feeble, but with increasing frequency it strengthens and soon becomes the salient feature. Eventually yet another circulation is superimposed.

It is shown how this work connects with that of other observers, and emphasis is placed on the common occurrence in acoustic phenomena of circulatory motion in association with vibratory motion.

2275

Wood, W. W., and J. G. Kirkwood, "Hydrodynamics of a Reacting and Relaxing Fluid," J. Appl. Phys., 28, 395-388, 1957.

Reports formulation of general equations governing the hydrodynamic behavior of an ideal compressible fluid in which chemical reactions and internal relaxations proceed. For one-dimensional flow the equations are transformed to characteristic form, in which the "frozen" or high-frequency sound velocity plays a role analogous to the unambiguous sound velocity in the nonreactive case.

2276

Woolf, W. L., "Acoustical Tables for Air and Sea Water," J. Acoust. Soc. Am., 15, 83-86, 1943.

The tables contain the fixed relationships, for a sound wave in a nonchanging medium, among sound pressure, intensity level. particle velocity, and the product of particle displacement and frequency, in air and sea water, under the condition that $\rho \times c$ (density $\times$ velocity) is 40 cgs for air and 150,500 for sea water. Equations connecting the quantities and reference values are added.

2277

Young, W. H., "Tactical Use of Shock Waves from Aircraft," Rept. No. DR 1808, Bureau of Aeronautics, Navy Dept., Washington, D. C., 11 pp., 1958.
AD-204 249

Considers the possible tactical use of shock waves produced by supersonic aircraft. The effects upon light structures, camouflage, and helicopters on the ground and in the air were examined in particular. A graph is presented that indicates the estimated overpressures produced by an aircraft as a function of the distance from its flight path. Shown on this chart are the estimated minimum overpressures required to damage the items of interest. More test work is necessary to evaluate the probable effectiveness of shock wave attacks. It appears that some damage to light structures is probable, but damage to aircraft is improbable.

Assuming that damage can be produced which is equal or slightly superior to that estimated, there is the question whether it is sufficient to be economically feasible. The airplane must be flown within a few hundred feet of its target to be effective. The shock wave attack may prove useful against secondary targets and targets of opportunity after using "live" ammunition against a primary target. Although difficult to evaluate, the harassment of personnel by low-flying supersonic aircraft should be considerable.

2278

Zhivlyuk, Yu. N., and S. L. Mandel'shtan, "The Temperature of Lightning and Force of Thunder," Soviet Phys. JETP, English Transl., 13, 338-340, 1961.

The temperature in the lightning channel was measured by a spectroscopic method with the help of the N II and O II lines, and a value T = 20,000^0 was obtained. This value agrees well with the results of a calculation based on the hydrodynamic theory of development of the spark channel. The hydrodynamic model was further used to calculate the force of the thunder, i.e., the pressure on the front of the shock wave. Excess pressures are obtained which in a number of cases may lead to destruction of objects located a few meters from the lightning.

SOUND RANGING

2279

Army Artillery Board, "Evaluation of British Recorder, Sound Ranging (Long and Short Base) NR. 5, MK 1," Proj. No. FA 3257, Fort Sill, Okla., 11 pp., 1958.
AD-207 987.

Evaluates the British recorder, sound ranging (long and short base) Nr 5, Mk 1, on a comparative basis with the United States' Sound Ranging Set GR-8. The Nr 5, Mk 1 set is superior to the GR-8 with respect to (1) number of recording channels, (2) design of stylus assemblies, (3) adjustable trace intensity, (4) ease of maintenance, (5) timing circuits, and (6) modular design concepts. The Nr 5, Mk 1 is comparable to the GR-8 with respect to ease of installation and accuracy. The two recorders are comparable and functionally interchangeable.

2280

Bandeen, W. R., "The Recording of Acoustic Waves From High-Altitude Explosions in the Rocket-Grenade Experiment and Certain Other Related Topics," Tech. Rept. No. 2056, Army Signal Res. and Development Lab., Fort Monmouth, N. J., 72 pp., 1959.
AD-231 943.

Discusses the instrumentation and operation of the sound-ranging installation for the rocket-grenade experiment at Fort Churchill. Applies Schrodinger's equation for the transmissivity of sound in the atmosphere to empirical data, illustrating the upper altitude limit of the experiment, and discusses a modified method of correcting for the test's finite-amplitude-propagation effect. Analyzes the specific problem of measuring arrival angles of sound waves. Examines the effect of the re-entry ballistic wave on grenade-sound arrivals, and presents a method for determining the times of such obscured arrivals, and also of weak sound arrivals.

2281

Carrell, R. M. and R. Richter, "A Modern Acoustic Missile Launch Locator, the AN/TNS-5," J. Audio Eng. Soc., 9, 208-214, 1961.

Describes design of the azimuth ranging equipment, the Short Range Missile Launch Locator, AN/TNS-5, which determines the azimuth of acoustic signals arriving at a microphone array and permits a fix on a mortar, artillery, or missile site to be obtained by triangulation of the azimuth indications from a number of stations.

(See Erikson, W., and Richter, R., for listing of complete series of progress reports.)

2282

Crary, A. P., "Stratosphere Winds and Temperatures in Low Latitudes from Acoustical Propagation Studies," J. Meteorol., 9, 93-109, 1952.

Tests of sound-ranging methods near Hawaii, the Canal Zone, Bermuda and Florida are described, and velocity-height curves up to 40-60 km (100-120 km near Florida) are presented. Most probable temperatures and winds are deduced. The results confirm earlier studies, showing light winds over continental areas in low latitudes in winter, and low temperatures and high winds over oceanic areas. The sources of error in this experimental method are discussed.

2283

Diamond, M., and A. B. Gray, "Accuracy of Missile Sound Ranging," Tech. Rept. No. 110, Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 14 pp., 1961.
AD-264 856.

This report presents a technique for determining the impact point of missiles by the detection of the shock wave generated during a missiles descent. It includes the instrumentation and computations involved and an error analysis.

2284

Erikson, W., and R. Richter, "Short Range Missile Launch Locator AN/TNS-5() and Sound Ranging Set AN/TNS-4()," Quart. Progr. Rept. No. 2, RCA Defense Electronic Products, Camden, N. J., 62 pp., 1958.
AD-219 010.

Breadboard models of several portions of the AN/TNS-5 were constructed and are described. These include a perforated aluminum tape-storage bin and a transistorized oscilloscope using a three-inch electrostatically deflected cathode ray tube.

Reports on evaluation of samples of magnetic tape with test patterns printed on the Mylar base, using the Diazo process; on the derivation of requirements for the magnetic playback heads and their associated amplifiers, with a one-mcs ultra stable crystal-controlled oscillator, using a proportional controlled oven, selected as a frequency standard; on the testing of several loudspeakers used as microphones; and on a method devised for simulating the alignment of gun signals to determine the effect of microphone phase shift. (See under above authors for listing of complete series of progress reports.)

2285

Erikson, W., and R. Richter, "Short Range Missile Launch Locator AN/TNS-5() and Sound Ranging Set AN/TNS-4()," RCA Defense Electronic Products, Camden, N. J., 1958-1959.

Qtly. Prog. Rept. 1, 15 April-15 July 1958	AD-216 058
Qtly. Prog. Rept. 2, 15 July-15 October 1958	AD-219 010
Qtly. Prog. Rept. 3, 15 October 1958-15 January 1959	AD-227 815
Qtly. Prog. Rept. 4, 15 January-15 April 1959	AD-225 129
Qtly. Prog. Rept. 5, 15 April-15 July 1959	AD-225 976
Qtly. Prog. Rept. 6, 15 July-15 October 1959	AD-230 424

The design, development, and laboratory testing and evaluation of a Sound Ranging Set AN/TNS-4() and a Short Range Missile Launch Locator AN/TNS-5() are described in this series of quarterly progress reports. The purpose of the equipment is to locate rapidly, by electroacoustical means, the source of enemy weapons fire. The sound ranging set consists of three azimuth measuring stations, each employing a four-microphone array plus associated tape recorder, electronic and data-processing components. The missile-launch locator consists of five azimuth measuring stations each equipped as above. (Abstracts for individual reports in this series appear under appropriate authors.)

2286

Federici, M., "The Telemetric Characteristics of a Passive Receiving Apparatus for Measuring the Distance of a Sound Source" (in Italian), Ric. Sci., 30, 2009-2020, 1960.

This paper theoretically investigates the possibility of finding the range of a sound source by means of a linear array of microphones whose outputs are fed to a central amplifier. Because of the phase differences, the amplifier output will depend on the range, and the range can be estimated by the addition of artificial delay lines. The output variation is similar to that obtained when the arrangement is used for direction finding.

2287

Fisher, E. E., R. P. Lee, and H. Rachele, "Meteorological Effects on an Acoustic Wave Within a Sound Ranging Array," Tech. Rept. No. MM-435, Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 20 pp., 1962.
AD-275 415.

Equations are derived for determining the direction cosines of a plane or spherical wave front by assuming the arrival time at each microphone in an array to be an independent observation and requiring a minimum sum of the squares of the corrections to the individual recordings. In addition, the effects on the direction cosines and/ or the time-arrival errors resulting from considering sound-speed variations (profile) with height are also considered. In particular, five examples were considered for different profiles, none of which were extreme, and resulted in direction-angle errors as large as two degrees and apparent time errors on the order of .04 second.

2288

Frick, R. H., "Proposed Method of Sound Ranging Eliminating Meterological Corrections," Duke Univ., Durham, N. C., 1945.
ATI-63 428

Describes a new method of sound ranging which requires no corrections for the effects of wind, temperature, or curvature of the wavefront. This method may also be used in measurement of effective meteorological conditions and of their effects on the shape of the wavefront. The new method requires the use of a two-dimensional array and six or more microphones. By determining the time of arrival of the sound wave at each of these microphones with respect to an arbitrary time zero, it is possible to compute directly the position of the sound source with respect to a known position in the target area.

It is recommended that, for either the study of meteorological conditions or for sound locations, eight microphones be used rather than the minimum of six, since the precision will be increased by the large number of microphones. A detailed mathematical analysis of the two-dimensional array is given.

2289

Gandin, L. S., "Application of Theory of Observations from Three Points to the Problem of Acoustical Artillery Reconnaissance" (in Russian), USSR Glavnoe Upravlenie Gidrometeorologicheskoi Sluzhby, Trudy Nauchmoissledovatel'skikh Uchrezhdenii, Ser. 1, Meteorologiia, 25-33, 1946.

The conditions for more effective construction of nonalignment triangles are analyzed, and the dependence of the accuracy on distance, on length of base, and on other factors are discussed.

2290

Golden, A., "Evaluation of Meteorological Corrections for Sound Ranging," Proc. of the Symposium on Atmospheric Acoustics Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 149-161, 1961.
AD-408 716.

A method for the computation of meteorological corrections is evaluated. The results of a comparison between this method and the standard method of meteorological corrections employed by the U. S. Army artillery are presented. The comparison is made on a ray-by-ray basis.

In the first case tested (consisting of a weighted average of 12 readings), three out of the five rays to the target were more improved by the use of this method than by the artillery method. In the second case tested (also a weighted average of 12 readings), all rays were more improved by this method than by the standard method.

2291

Groves, G. V., "Determination of Impact Point of a Vertically-Falling Body by Acoustical Observations," J. Atmospheric Terrest. Phys., 11, 284-288, 1957.

Concerns estimating the point-of-fall of instrumentation used in upper-atmosphere experiments with rockets.

2292

Groves, G. V., "Trajectory Determination of a Supersonic Body by Acoustical Observations," J. Atmospheric Terrest. Phys., 12, 17-25., 1958.

A theory is developed for deriving the trajectory of a body moving at supersonic speeds through the atmosphere from observations on the times of arrival of its shock wave at a number of microphones at known points on the ground, wind and temperature effects being taken into account. It is shown that with 3n + 4 microphones, the position, velocity, acceleration, etc., up to the nth derivative of the spatial coordinates of the body with respect to time can be found at some determined instant of time. Hence, with seven microphones, the position and velocity of the body at a certain instant of time can be found, although four microphones are seen to be adequate for a more approximate determination of these quantities. Particular consideration is given to the method of solution in the seven-microphone case.

2293

Herrenden-Harker, G. F., "Acoustic Phenomena Associated with the Firing of a Gun," Am. J. Phys., 13, 351-362, 1945.

Existing published work is extended in a theoretical treatment covering modern high-speed projectiles, with an application to sound-ranging.

2294

Howard, W. H., "Remote Recording System for Sonic Observation of Trajectory and Impact of Missiles," Army White Sands Signal Agency, White Sands Proving Ground, N. Mex., 18 pp., 1957.
AD-135 449.

The remote recording system of sonic observation of the trajectory and impact of missiles (SOTIM) requires interception of the acoustic front which is generated by a missile in flight. Data is collected by recording the individual outputs of microphones arrayed in clusters. These clusters, separated by distances varying from twenty to one hundred miles, require associated recording equipment, communications equipment, and shelter. A new system of operations for the SOTIM has been designed which offers considerable logistic, equipment, and equipment-maintenance advantages, and which requires fewer personnel. The development and present status of this new operational system are discussed in this report.

2295

Kennedy, W. B., et al., "Study of Meteorological and Terrain Factors Which Affect Sound Ranging," Denver Research Inst., Univ. of Denver, Colo., 1954-1957.

Qrtrly. Prog. Rept. 1, March-May 1954, AD-38 446
" " " 2, June-August 1954, AD-43 297
" " " 3, September-November 1954, AD-54 480
" " " 4, December 1954-February 1955, AD-61 530
" " " 5, March-May 1955, AD-70 078
" " " 6, June-August 1955, AD-74 855
" " " 7, September-November 1955, AD-95 798
" " " 8, December 1955-February 1956, AD-95 799
Final Report, March 1954-April 1956, AD-139 326
Qrtrly. Prog. Rept. 1, May-July 1956, AD-140 087
" " " 2, August-October 1956, AD-140 088
" " " 3, November 1956-January 1957, AD-140 090
Interim Prog. Rept., February-August 1957, AD-160 696

This series of reports covers four years of intensive theoretical and applied research and development on sound-ranging as influenced by meteorological and terrain factors. The general problem of increasing the accuracy of sound-ranging by means of corrections based on meteorological and topographical conditions is discussed. Equations are presented for applying wind and temperature corrections to reduce error in observed sound-source azimuths. Problems encountered in setting up the field operation to provide data for a study of meteorological and terrain corrections for the whole sound path are analyzed. Proposed methods for time measurement of sound arrivals, temperature measurement, control of field operations, and power distribution are presented in detail.

The firing-recording arrays are described. The results and the methods of reducing data are given. Special investigations include: an analysis of the problem of acoustic ray-tracing in the atmosphere; determinations of the sonic data obtainable with various geometries of detecting arrays; an analysis for determining the velocity of sound; studies of errors generated within the Short-Range Whole-Path Firing-Recording Array by elevation differences, angular errors in placing the sensing microphones, and errors due to the assumption that the wave front is plane; a study determining the effect of oscillogram-reading errors on calculated sound-wave-arrival azimuths; a discussion of methods of removing data from oscillograms; and tests to determine the calibration requirements of the T-23 microphones. Other discussions include microphone-wind-shield development, the surveying program, and the general field operational problem.

The application of a drift correction to the primary sound-ranging information provided results superior to those obtained by standard artillery methods. For these calculations, data were used from an array of 14 microphones arranged in an isosceles-trapezoidal configuration. The arrival azimuth obtained by using this configuration is more representative of the direction of arrival of the acoustic wave front than that obtained by standard methods. The corrections which were applied for the refraction of the wave front along its path do not appear to be greatly significant from a study of the small sample presented.

2296

Kuhlenkamp, A., "Acoustical Location for Shooting at Invisible Aircraft," Ver. Deut. Ing. Z., 85, 393-400, 1941.

Reasons for the inferiority of sound locating to optical methods are given. The principles of sound locating are discussed, and a mechanism for computing the delay is described. The principle of the cotangent method is explained. Equipment developed in France and Austria is described and illustrated.

2297

Lukes, G. D., "Sound Ranging for Artillery," SCL Eng. Rept. No. S-6, Fort Monmouth, N. J., Vol. 1, 1940.

This is a report dealing with the effect of meteorological conditions on the propagation of sound through the atmosphere, and the development of a technique for sound-ranging whereby existent meteorological conditions can be quantitatively evaluated in terms of their net effect on sound propagation from source to microphone position. It is the intent of the report to formulate a theory of sound-propagation from basic analytical considerations, adequate for any meteorological situation, and the theory is so presented that it may readily be applied to military sound-ranging on artillery.

2298

Lukes, G. D., "Sound Ranging for Artillery," SCL Eng. Rept. No. 753, Fort Monmouth, N. J., Vol. 2, 1942.

A technique for sound-ranging is developed for the determination of position of a sound-source by evaluating extant meteorological factors and their effect on sound-ray propagation. Among the facets developed are:

1. The practical application of the theoretical principles given in Vol. 1 to the problem of artillery spotting.

2. Presentation of pertinent data in chart form.
3. Design of mechanical aids to computation in the field.
4. A field procedural technique for evaluation of meteorological factors.
5. An illustration of the technique using representative data.
6. A summation of valid applications for the ranging system.

2299

Melkas, A., "The Influence of Temperature and Wind on Propagation of Sound in the Air" (in German), Geophysica (Helsinki), 3, 207-219, 1948.

The correction for direction, used in determining the position of aircraft by means of an acoustical sound detector, is based upon ground temperature. In order to secure greater exactness the temperature and wind conditions of the total sound path must be known. The author analyzes mathematically the influence of the temperature gradient alone upon the rate of sound propagation in still air and the combined effect of temperature and horizontal wind movement. Equations are derived for calculating the angles of elevation for the two conditions.

2300

Morley, F., and H. A. Robinson, "Range-Finding," Proc. Natl. Acad. Sci., U. S., 16, 74-77, 1930.

A note on the theory of the location of an object, such as a sound or other vibration of known velocity at three, four or five different stations in a plane or on a sphere.

2301

Newell, H. E., Jr., "Upper Atmosphere Research Report, VIII. Prediction and Location of Rocket Impacts at White Sands Proving Ground," Rept. No. 3485, U. S. Naval Res. Lab., Washington, D. C., 18 pp., 1949.

This report discusses the problems of rocket-impact prediction and location as they apply to range safety and to recovery of research records. An approximate method for predicting the impact points of all types of rockets is considered, and a sound-ranging method for locating the impacts of small missiles is outlined, together with results.

2302

Payne, R., "Acoustic Orientation of Prey by the Barn Owl," Tech. Rept. No. 1, Tyto Alba, Div. of Engineering and Applied Physics, Harvard Univ., Cambridge, Mass., 67 pp., 1961.
AD-271 031.

Barn owls (Tyto alba) can locate prey in total darkness using hearing alone, with an accuracy of about one degree in both the vertical and horizontal planes. Differences between the behavior of barn owls flying at prey in complete darkness (analyzed from films taken under infrared illumination) and their behavior in the light are correlated with the problems they must face in acoustical orientation. Experiments with owls trained to strike a concealed loudspeaker show that they depend on frequencies of sound above 9,000 cps. At such frequencies, regions of high and low sensitivity are directed along different paths for the two ears. These are correlated with the assymmetry of the barn owl's external ears. Movements of a flap of skin in front of the ear opening change the over-all pattern of sensitivity by redirecting the regions of maximum and minimum sensitivity. A theory is presented to explain how a barn owl might localize the position of a sound-source by moving its head until the intensity of all frequencies comprising a complex sound is maximal in both ears. When it hears this maximum frequency spectrum, with both ears, it will automatically be facing the sound.

2303

Puth, J. W., "Investigation of Stratosphere Compressional Wave Velocities by Studies of Refracted Waves from Explosive Sources," Final Rept., Geophys. Inst., Univ. of Alaska, College, Alaska, 4 pp., 1951.
AD 4 412

In order to investigate the temperature and winds at 30-60 km altitudes, a study of compressional wave velocities was undertaken by firing a series of five two-hundred-pound charges per month for a year and recording the signal received by a five-microphone array utilizing T21-C condenser microphones and a GR-8 sound-ranging recorder.

The conclusions indicate little significant seasonal variation in winds. Azimuth shifts were small, providing little opportunity for resolving a coherent picture of winds aloft. In general, the magnitude of the winds was less than expected. No firm conclusions concerning stratospheric temperature could be obtained.

2304

Rothwell, P., "Calculation of Sound Rays in the Atmosphere," J. Acoust. Soc. Am., 12, 205-221, 1947.

Highly theoretical work in which methods of tracking sound rays for acoustical location of aircraft are described, with a view to their possible application to other meteorological investigations by acoustical methods. Tables have been constructed for meteorological investigations of the upper atmosphere, covering the range of temperature from ground to stratosphere, the range of angles of descent, and time factors, with respect to equations. The procedure for calculating rays by the use of tables of range and time factors is outlined, and examples are given.

2305

Schriever, W., "Sound Ranging in a Medium Having an Unknown Constant Phase Velocity," Geophys., 17, 915-923, 1952.

A method for the sound-ranging of explosions is described, in which the direction-angle of the explosion is given in terms of the ratio of the differences in the arrival times at two pairs of microphones, geophones, or hydrophones. It is unnecessary to know either the phase-velocity in the intervening medium or the absolute values of the time differences. However, the paths and the phase-velocities must be such that the time differences are the same as they would be for a wave-front traveling from explosion to the microphones at some constant velocity. A rapid graphical method for determining the location of the explosion is described. The precision of the determination is discussed. Applications of the method to the scoring of bomb hits on bombing practice areas are suggested. The effect of the motion of the medium is considered.

2306

Schumaker, R. L., and A. Bustos, "Ballistic Versus Spherical Fronts Originating from Supersonic Missiles," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 69-76b, 1961.
AD-408 716.

In SOTIM analysis a shock front is generally associated with the ballistic front generated by a supersonic missile. The fronts are then related to the speed of the missile from a relationship between the angle of elevation of the sound source and the line of the missile's trajectory. Occasionally events occur, such as explosions within the missile, which cannot be related to the speed of the missile. A method that permits identification of such nonconical waves by normal SOTIM techniques, and without the use of harmonic analysis equipment, is outlined. Also provided are data from which analyses are made of various events that appear to substantiate the theory and method.

2307

Swingle, D. M., "Atmospheric and Geometric Considerations in Sound Location Data Processing," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 162-167, 1961.
AD-408 716.

Several ways of processing data obtainable by two-dimensional square microphone arrays are examined, and the optimum formulation is selected given specified random errors. The role of atmospheric turbulence in base-line length selection is discussed in the light of recent progress in this country and the USSR.

2308

Swingle, D. M., "Theory for Meteorological Correction to Artillery Sound Ranging Data," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 141-148, 1961.
AD-408 716.

Reports derivation of a theory for making meteorological corrections to artillery sound-ranging data. It is based on an analysis of the basic characteristics of atmospheric information available to artillery units. Based on a critique of the method derived, approaches toward further improvements to the overall system are suggested.

2309

Swingle, D., and A. Golden, "Meteorological Corrections For Sound Ranging," Tech. Rept. 2106, Army Signal Re-Search and Development Lab., Fort Monmouth, N. J., 63 pp., 1961.
AD-251 614.

A method for the computation of the meteorological corrections for sound ranging is presented, along with the results of an application of the standard method for meteorlogical corrections as employed by the Artillery. The comparison is made on a ray-by-ray basis. In the first case (consisting of a weighted average of 12 readings), three out of the five rays to the target were more improved by the use of this method than by the Artillery method; and in the second case (also a weighted average of 12 readings), all rays were more improved by this method than by the Artillery method.

2310

Webb, W. L., and A. L. McPike, "Sound Ranging Technique for Determining the Trajectory of Supersonic Missiles," Progr. Rept. Nos. 1 and 2, White Sands Signal Corps Agency, White Sands Proving Ground, N. Mex., 6 pp. and 23 pp., 1955.

These two reports are part of a series, the rest of which is classified. These reports describe the application of the Signal Corps GR-8 sound ranging system to the Sonic Observation of the Trajectory and Impact of Missiles (SOTIM). It was found that missiles traveling at supersonic speeds generate shock fronts which are easily observed over wide areas around the missile's trajectory. Analysis of the acoustic signals determined the location and speed of missiles at certain points along their trajectories. Furthermore, this data has been utilized to describe the manner in which pressure waves propagate over long distances through the earth's atmosphere.

Sound Ranging
See Also——467, 522, 539, 562, 570, 638, 662, 674, 682, 687, 691, 698, 1015, 1108, 1149, 1150, 1152, 1160, 1164, 1167, 1177, 1178, 1179, 1180, 1181, 1184, 1406, 1435, 1436, 1437, 1438, 1439, 1440, 1441, 1444, 1449, 1450, 1451, 1457, 1471, 1475, 1565, 2045, 2046, 2061, 2113, 2118, 2120, 2121, 2124, 2125, 2131, 2133, 2601, 3254, 3758, 3914

SOUND SOURCES, AIRCRAFT

2311

Bies, D. A., J. H. Caffrey, and O. B. Wilson, Jr., "A Study of Internal Acoustic Absorbers as a Technique for Turbojet Engine Noise Reduction," Final Rept. No. 94, Vol. 1, Soundrive Engine Co., Los Angeles, Calif., 192 pp., 1957.
AD-150 553.

A comprehensive investigation was begun of several configurations of a modified J34 WE-42 turbojet engine designed for sound suppression. Twenty-two configurations of mild engine changes involving acoustic suppression means were tested, and some of these showed a reduction in particular frequency bands. The sound radiated from a particular configuration was not reduced by more than 1 db. Three tests were made with an untreated engine to establish a standard for comparing the efficacy of the various acoustic absorbers under investigation. Two configurations involving acoustic treatment to the diffuser cone which were not effective in reducing the radiated sound did improve the engine thrust by about 5%. The validity of internal noise measurements was questionable. Possibly less than half of the noise radiated from the turbojet had its origin with the engine.

2312

Bies, D. A., J. H. Caffrey, and O. B. Wilson, Jr., "A Study of Internal Acoustic Absorbers as a Technique for Turbojet Engine Noise Reduction," Final Rept. No. 94, Vol. 2, Soundrive Engine Co., Los Angeles, Calif., 166 pp., 1957
AD-150 554.

Data sheets are presented for the 22 configurations of the modified J34 WE-42 turbojet engine and 3 untreated engines.

2313

Bolt, Beranek, and Newman, Inc., "Free-Field Noise Measurements on Carrier-Based Jet Aircraft NATO, Patuxent River, Maryland," Rept. No. 282, 74 pp., 1955.
AD-78 060.

Free-field noise measurements were made on an AJ-2, an F2H-3, an F9F-6, and an F7U-1 for several engine operating conditions. Data obtained are presented in the form of directivity patterns, frequency spectra plots, and tabulated values of acoustic power.

The frequency spectrum of jet noise varies with angle and operating condition. The angular dependence of the frequency spectra can be reduced to a consideration of two angular areas, the regions between 0^{o} and 120^{o} and between 130^{o} and 150^{o}. For each of the aircraft, the frequency spectrum in each of the angular ranges is relatively constant as a function of angle, and the typical spectrum shape in each range differs from that in the other. The spectrum shape is relatively constant in relation to frequency in the region between 130^{o} and 150^{o}, and most of the peak sound-pressure levels occur in this region.

A design procedure for estimating the noise field characteristics of carrier-based planes was developed. The procedure is based primarily on data from planes without afterburners (AJ-2, F9F-6, and the F2H-3). By means of the procedure, it is possible to estimate the acoustic power level, the frequency spectra, and the directivity pattern of the noise field from a knowledge of the jet-engine operating conditions.

2314

Bolt, Beranek, and Newman, Inc., "Handbook of Acoustic Noise Control, Vol. I. Physical Acoustics, Supplement 1," Suppl. 1 to WADC Tech. Rept. No. 52-204, Vol. 1, 308 pp., 1955. AD-66,250.

Contents (additions and revisions to Volume I):

Propeller noise.
Noise from aircraft reciprocating engines.
Total external noise from aircraft with reciprocating engines.
Noise generating mechanisms in axial flow compressors.
Ventilating fans and ventilating systems.
Insulation of airborne sound by rigid partitions.
Insulation of impact sound.
Transmission of sound through cylindrical shells.
Specification of sound absorptive properties.
Lined ducts.
The resonator as a free-field sound absorber.
Acoustical shielding by structures.

2315

Bolt, Beranek, and Newman, Inc., "Handbook of Acoustic Noise Control," WADC Tech. Rept. No. 52-204, Wright-Patterson Air Force Base, Ohio, 1, 397 pp., 1952 AD-12,015.

An over-all view is presented of the acoustic noise-control problem. The following noise source characteristics and methods of noise control are discussed: specification of a noise source, aircraft propellers and reciprocating engines, aircraft jet and rocket engines, fluid flow devices, industrial machine noise, physical characteristics of miscellaneous environmental noise, general noise-control panning, noise-control requirements, control of structure-borne noise, control of airborne noise, rooms and special enclosures, and evaluation of sound-control installations.

Chapter 12 describes methods for reducing the propagation of noise through air, indoors and outdoors. Lined ducts, parallel baffles, mufflers, resonators, resonant linings, isolating walls and combined treatments are considered. In covering the subject, the propagation of sound in the atmosphere and the effects of temperature, pressure, wind and ground impedance on propagation are described. The presentation is essentially non-mathematical. Most of the data and design criteria appear in the form of charts, graphs, and tables.

2316

Bolt, R. H., "The Aircraft Noise Problem," J. Acoust. Soc. Am., 25, 363-366, 1953.

Aircraft noise presents a system problem which to date has been attacked mainly at the level of individual components. The system includes: (a) aircraft as noise sources; (b) atmosphere and terrain as influences on sound propagation; (c) people, under several classes and conditions, as responders to noise; (d) physical components for controlling noise; (e) operating procedures for reducing noise exposure in communities; (f) public relations; (g) aviation planning policies and economics; (h) organizations concerned with characteristics and consequences of aircraft noise.

The nature of these components is reviewed in a general way, with emphasis on their inherent interrelations. This discussion provides a framework for unifying the several subjects included in an aircraft noise symposium.

2317

Callaway, V. E., "Terminal Operations of 707," Noise Control, 5, 42, 1959.

Summarizes, from test measurements, data on noise, blast, and temperature conditions incident to operations at terminals of the Boeing 707 jet transport.

2318

Clark, W. E., "Noise from Aircraft Operations," Final Rept. No. ASD TR 61-611, Bolt, Beranek, and Newman, Inc., Cambridge, Mass., 124 pp., 1961. AD-278-625.

Summarizes knowledge of aircraft ground and flight operations in the vicinity of air bases, noise-source characteristics of military aircraft, and propagation of sound from aircraft to observers near or on air bases. Data from earlier Air Force studies, together with new data, have been summarized and incorporated into aircraft noise prediction procedures and descriptions of operations characteristics. The report provides an integrated presentation of available information, techniques, and factors to be considered in determination of noise from aircraft operations that is intermediate in complexity between a simplified "handbook" and detailed source material.

2319

Clark, W. E., A. C. Pietrasanta, and W. J. Galloway, "Noise Produced by Aircraft During Ground Run-up Operations," Bolt, Beranek and Newman, Cambridge, Mass., 142 pp., 1957. AD-130 763.

Measurements of the noise field around six turbojet aircraft (T33-A, F89-D, F84-G, B-57, F84-F and F86-D) and one propeller aircraft (C-124) during ground run-up operations are reported. Sound pressure levels in octave bands of frequency have been obtained for different operating conditions of the aircraft engines, at distances ranging from 100 to 1600 ft. These data are analyzed and the results reported in terms of acoustic power level, directivity, and noise spectra. An empirical procedure is described for making engineering estimates of the characteristics of the noise field produced during ground run-up operations of jet aircraft.

2320

Cox, R. J., H. J. Parry, and J. Clough, "A Study of the Characteristics of Modern Engine Noise and the Response Characteristics of Structures," Rept. No. WADD TR 60-220, Lockheed Aircraft Corp., Burbank, Calif., 154 pp., 1961. AD-272 210.

Jet engine noise and the response of structures to that noise were studied. The near-sound-field characteristics of a jet engine operating on the ground at both military and afterburner thrust were measured. Sound pressure levels were obtained in the near field and within the jet wake, as were pressure levels and cross-correlation coefficients. The latter two were obtained at two locations in the noise field for the free field, a rigid boundary, and a flexible boundary. Several panels, representative of typical airframe structure, were subjected to this jet engine noise. Structural response in terms of strain and accelerations was measured and analyzed. These panels were also subjected to discrete frequency excitation to determine basic response parameters. An analytical method for predicting the response of complex structures in an actual jet noise environment was developed. Predicted and measured responses were compared.

2321

Doelling, N., K. S. Pearsons, and others, "Acoustical Evaluation of a B-58 Run-Up Pen at Convair-Fort Worth," WADC Tech. Note No. 57-389, Bolt, Beranek, and Newman, Inc., Cambridge, Mass., 57 pp., 1958. AD-142 160.

This report describes the acoustical evaluation of the B-58 run-up pen at CONVAIR-Fort Worth. Data are presented which show that the noise reduction in forward quadrants is of the order of 20 or 30 db, while in the aft quadrants it is about 0 db. This pen provides hearing protection to personnel located in adjacent pens.

The noise characteristics of the B-58 are also presented.

2322

Dyer, I., P. A. Franken, and E. E. Ungar, "Noise Environments of Flight Vehicles," Noise Control, 6, 31, 1960.

Article presents estimates of the external noise environments of air- and space-craft based on information currently available. Engine noise, oscillating shocks, surface pressure fluctuations, and wake noise appear most significant. Many more measurements are needed.

2323

Emmitt, M., "Fundamental Study of Jet Noise Generation and Suppression, Volume II. Bibliography," WADD TR 61-21, Rept. for Feb.-Dec. 1960, Armour Research Foundation, Chicago, 67 pp., 1961. AD-264 682 and AD-264 919.

The bibliography is divided into two parts. The first part (AD-264 919) consists of unannotated references chosen from the 1150 documents which were evaluated during the program, and which are considered to be significant contributions to the basic subject categories mentioned above. These references are arranged chronologically by year and within each year alphabetically according to author. The second part consists of annotated references which were essential to the theoretical discussions to be found in Volume I. They are arranged alphabetically according to author. The name or names of the scientific personnel who selected each reference follows each annotation.

2324

Fakan, J. C., and H. R. Mull, "Effect of Forward Velocity on Sound-Pressure Level in the Near Noise Field of a Moving Jet," Tech. Note No. D-61, NASA, 16 pp., 1959. AD-227 291.

An in-flight investigation of the near-field noise along the boundary of an aircraft-mounted jet engine was conducted over a flight Mach number range of 0.35 to 0.70 at altitudes of 10,000, 20,000, and 30,000 feet, at two and three nozzle-exit diameters downstream of the jet exit. The sound-pressure levels were found to be constant over the full Mach number range. The results of the experiment tend to substantiate predictions of the Mach number effect on jet noise production.

2325

Franken, P. A., and E. M. Kerwin, Jr., "Methods of Flight Vehicle Noise Prediction," WADC Tech. Rept. No. 58-343, Bolt, Beranek, and Newman, Cambridge, Mass., 1958. AD-205 776.

Presents detailed engineering procedures for estimating sound-pressure levels on or within a flight vehicle. The report is oriented for use by the aircraft engineer in making preliminary estimates of noise levels on or in a vehicle while the vehicle is still in the design stage. The procedures are expressed in terms of general parameters (such as mechanical power, typical dimensions, forward speed) which may be obtained to a satisfactory degree of accuracy long before flight testing.

The first step is the estimation of noise levels exterior to the vehicle. Next, the basic noise-transmitting properties of panel structures are studied. The effects of coincidences, resonances, damping, etc., are included. Finally, the particular vehicle geometry of interest is considered. The source and transmission properties already determined can then be combined, with appropriate geometrical corrections for the character of the receiving space, to yield the desired estimates of interior noise levels.

Several examples are worked out in detail to illustrate the application of the report procedures to typical vehicle configurations.

2326

Gordon, B. J., "A Review of Work in Jet Engine Noise Control at the General Electric Company," Noise Control 7, 14, 1961.

This paper summarizes the research and development work of the General Electric Company in the field of jet-engine noise control. Noise data are presented for various stages in the development of engine-noise suppressors, and the turbojet engine and the new G.E. turbofan engine are compared.

2327

Hazard, D. M., "Aircraft Engine Noise Control as Viewed by the Engine Manufacturer," J. Acoust. Soc. Am., 25, 412-416, 1953.

In developing and testing engines, the manufacturer has a continuing problem with noise control. Efforts to meet the problem have undergone a manifold growth in scope because of the rapid increase in types and size of military power plants.

This paper presents a review of the overall control procedure, including typical noise sources, control objectives, recent techniques used in the control and attenuation of aircraft power-plant noise, problems associated with the design of noise-control provisions, and limitations in the existing methods. Includes data on reciprocating, turbojet, turboprop, and ram-jet power plants, along with a description of installations used for controlling the noise in both ducted exhaust systems and propeller-type test cells. The discussion cites cost, space, and high tolerance as the major design problems.

The areas needing continued endeavor are outlined for the engine manufacturer, the acoustical consultant, and the manufacturer of noise-control equipment.

2328

Hoover, R. M., and L. N. Miller, "Noise Characteristics of Some Jet Ground Operations," Noise Control, 5, 28, 1959.

Presents results of noise measurements of various ground operations of two-engine Caravelle and four-engine, suppressed, Comet 4 jet airliners. Data include directional characteristics and spectra for static operation at idle, taxi, climb-out, and take-off powers and spectra at side of runway during take-off.

2329

Hubbard, H. H., and D. J. Maglieri, "An Investigation of Some Phenomena Relating to Aural Detection of Airplanes," Tech. Note 4337, NASA, Washington, D. C., 49 pp., 1958. AD-205 675.

Conventional noise-level measurements consisting of broad- and narrow-band frequency analyses were made for static ground tests of an unmodified and modified single-engine airplane. Also, listening data with the aid of ground observers were obtained in flight during cruise as well as for take-offs, landings, and power-off glides. The test results indicate that the external noise-level characteristics of the airplane, the propagation phenomena relating to the conditions of the problem, and the ambient or background noise conditions at the location are all significant factors in aural detection by ground observers.

2330

Hubbard, H. H., and D. J. Maglieri, "Noise Characteristics of Helicopter Rotors at Tip Speeds Up to 900 Feet Per Second," J. Acoust. Soc. Am., 32, 1105-1107, 1960.

Evidence is presented which suggests that the noise of full-scale helicopter rotors results mainly from conditions of unsteady flow. Measurements of the sound-pressure levels and spectra are presented for test conditions where gear train, engine, and other propulsion system noises are minimized. These data cover a range of tip speeds from 100 ft/sec to 900 ft/sec for various rotor disk loadings. Results indicate that both tip speed and disk loading have an important influence on the noise radiated from the rotor. During stall, the sound pressure levels increased at all frequencies, but particularly at the high end of the spectrum. As a matter of special interest, a highly-peaked wave form due to possible Doppler effects was noted to be associated with high-tip speed operation.

2331

Hubbard, H. H., and D. J. Maglieri, "Noise Considerations in the Design and Operations of the Supersonic Transport," Noise Control, 7, 4, 1961.

The main sources of noise from the supersonic transport are the power plants, the aerodynamic boundary layers, and the shock waves. This article discusses the state of knowledge about each of these, and the manner in which noise considerations may affect the design and operation of this type aircraft.

2332

Jordan, G. H., N. J. McLeod, and L. D. Guy, "Structural Dynamic Experiences of the X-15 Airplane," NASA Tech. Note No. D-1158, Washington, D. C., 14 pp., 1962.
AD-273 566.

The structural dynamic problems anticipated during the design of the X-15 airplane are reviewed briefly, and the actual flight experiences with the airplane are described. The noise environment, acoustic fatigue problems, and panel-flutter experiences are discussed. Where these problems lead to structural modifications, the modifications are described.

2333

Kamps, E. C., "Statistical Evaluation of Near-Field Sound Pressures Generated by the Exhaust of a High-Performance Jet Engine," J. Acoust. Soc. Am., 31, 65-67, 1959.

The operation of modern, high-performance turbojet engines creates an environment that promoted rapid structural fatigue in many areas in jet aircraft. To facilitate the simulation of a valid test environment and, therefore, enable fatigue-resistant structures to be readily developed, the characteristics of the near-field sound pressures created by the jet stream must be established. This study is concerned with the establishment of the level and the rate of occurrence of peak pressures in relation to the commonly measured rms level. A method is presented which enables the determination of these qualities from rms sound pressures generated by the jet exhaust of a General Electric CJ805 turbojet engine. Noted conclusions: (1) occurrence of peak pressures does not follow a Rayleigh Distribution; (2) peak pressure distribution is not altered by the physical position related to the jet stream nor does it appear to be a function of frequency; (3) a maximum of ratio of peak to rms pressure is shown to exceed four, but a physical limit is not established.

2334

Kamrass, M., and K. D. Swartzel, "Evaluation of the Noise Field Around Jet-Powered Aircraft," Noise Control, 1, 30, 1955.

Following a review of the factors which affect the ground-level noise from aircraft in flight, a technique is discussed which permits the prediction of ground noise levels, and which indicates flight patterns that will permit minimum noise levels for those areas requiring that such annoyance be held to a minimum.

2335

Koenig, R. J., "Noise Control for Convair 880 and 600 Jets," Noise Control, 5, 23, 1959.

Discusses measures for controlling outdoor noise of these airliners. Data include power levels, directional characteristics, and spectra. The 880 uses GE CJ-805-3 engines and an eight-lobed suppressor nozzle with centerbody and ejector. The 600 uses GE CJ-805-21 engines of aft-fan type, which have markedly different spectrum.

2336

Kryter, K. D., and K. S. Pearsons, "Judgment Tests of the Sound from Piston, Turbojet, and Turbofan Aircraft," Sound, 1, 24-31, 1962.

The authors discuss the results of recent subjective tests on the perceived noisiness of five different aircraft, including piston-engine, turbojet, and turbofan types. The judgments of several subjects are compared with different ways of expressing quantitatively the relative noisiness of the aircraft.

2337

Kurbjun, M. C., "Noise Survey Under Static Conditions of a Turbine-Driven Transonic Propeller with an Advance Ratio of 4.0," Memo No. 4-18-59L, NASA, Washington, D. C., 14 pp., 1959.
AD-215 388.

Overall sound-pressure levels and frequency spectra of the noise emitted from a three-blade, 6.85-foot-diameter propeller have been measured. The results are compared with similar results obtained from a supersonic propeller having an advance ratio of 2.2 and from a modified supersonic propeller having an advance ratio of 3.2. The effects of power changes on the noise levels and spectra are also shown.

2338

Lilley, G. M., R. Westley, A. H. Yates, and J. R. Busing, "The Supersonic Bang," Nature, 171, 994-996, 1953.

The double (occasionally triple) bang heard when an airplane passes through the sound barrier is explained by consideration of movements of bow and tail waves relative to the plane at different Mach numbers.

2339

Lina, L. J., and D. J. Maglierei, "Ground Measurements of Airplane Shock-Wave Noise at Mach Numbers to 2.0 and at Altitudes to 60,000 Feet," NASA Tech. Note No. D-235, Washington, D. C., 25 pp., 1960.
AD-233 657.

Measurements of sonic-boom intensities were made for flights at altitudes to 60,000 ft and Mach numbers to 2.0. The measurements were made on the ground near the flight tracks. Effects of altitude, flight-path angle, Mach number, and atmospheric refraction at the cutoff Mach number were investigated. The effects of airplane size and weight were determined by a comparison of measurements made from one flight of a supersonic bomber with data for the supersonic fighter that was used for most of the tests.

2340

Lyster, H. N. C., "A Review of Theoretical and Experimental Information Relating to the Sonic Boom," Aero. Rept. No. LR-313, Natl. Aeronautical Establishment, Canada, 1961.

Sonic boom theory (originated by Whitham) was reviewed and comparisons were made with experimental data. Cutoff Mach number (below which no shock wave reached the ground) has been shown to be primarily a function of altitude and climb-path angle. Variations of boom intensity with Mach number and with altitude were examined. The volume effect appears to predominate for altitudes below the tropopause. Proper estimation of the total intensity when the lift effect is appreciable awaits additional data from large supersonic aircraft. Conversely, designing an aircraft for minimum boom intensity when volume and all-up-weight are fixed remains a complex problem for which only general rules may be given.

2341

MacPherson, P. A., D. B. Thrasher, and O. Logan, "A Survey of Noise at RCAF Station Cold Lake and RCAF Station Uplands," Rept. No. 228-1, Defence Research Medical Labs., Canada, 21 pp., 1958.
AD-158 849.

Results of the noise survey indicate that the overall noise levels generated by aircraft during take-off conditions are influenced mainly by ground absorption out to distances of approximately 1000 feet from the aircraft. Beyond this distance the overall noise levels are influenced primarily by temperature conditions. The overall noise levels generated by aircraft under take-off conditions may be predicted. The noise produced by aircraft at RCAF Station Cold Lake and RCAF Station Uplands may result in the deterioration of hearing of exposed personnel. In addition voice communications may be disrupted in areas near where aircraft are being maintained, taxied or taking-off.

2342

Maglieri, D. J., and D. L. Lansing, "Sonic Booms from Air-Craft in Maneuvers," Sound, 2, 39, 1963.

Ground-pressure measurements are presented for fighter aircraft in various maneuvers involving accelerations along the track and perpendicular to it. Complex wave patterns, and so-called "superbooms," in which pressure buildups occur, are presented for some representative cases. Results obtained from an array of ground measuring stations are correlated with tracking and weather information and with theory. Computed ground-pressure patterns show good agreement with measurements for some specific maneuvers.

2343

Maglieri, D. J., and H. H. Hubbard, "Ground Measurements of the Shock-Wave Noise from Supersonic Bomber Airplanes in the Altitude Range from 30,000 to 50,000 Feet," Tech. Rept. No. D-880, NASA, Washington, D. C., 24 pp., 1961.
AD-260 635.

Shock-wave ground-pressure measurements have been made for supersonic bomber airplanes in the Mach number range between 1.24 and 1.52, for altitudes between 30,000 and 50,000 feet, and for a gross-weight range between 83,000 and 120,000 pounds. The measured overpressures were generally higher than would be predicted by theory, which accounts only for volume effects. There is thus a suggestion that lift effects on sonic-boom intensity may be significant for this type of airplane within the altitude range of the present tests.

2344

Maglieri, D. J., H. H. Hubbard, and D. L. Lansing, "Ground Measurements of the Shock-Wave Noise from Airplanes in Level Flight at Mach Numbers to 1.4 and at Altitudes to 45,000 Feet," Rept. No. NASA TN-D-48, NASA, Washington, D. C., 38 pp., 1959.
AD-225 816.

Time histories of noise pressures near ground level were measured during flight tests of fighter-type airplanes over fairly flat, partly wooded terrain for M = 1.13 to 1.4 and at altitudes from 25,000 to 45,000 ft. Atmospheric soundings and radar-tracking studies were made for correlation with the measured noise data. The measured and calculated values of the pressure rise across the shock wave were generally in good agreement. There is a tendency for the theory to over-estimate the pressure at locations remote from the track and to underestimate the pressures for conditions of high tailwind at altitude. The measured values of ground-reflection factor averaged about 1.8 for the surfaces tested as compared to a theoretical value of 2.0. Two booms were measured in all cases. The observers also generally reported two booms; but in some cases, only one boom was reported. The shock-wave noise associated with some of the flight tests was judged to be objectionable by ground observers, and in one case the cracking of a plate-glass store window was correlated in time with the passage of the airplane at an altitude of 25,000 ft.

2345

Maglieri, D. J., and H. W. Carlson, "The Shock-Wave Noise Problem of Supersonic Aircraft in Steady Flight," NASA Memo. No. 3-4-59L, Washington, D. C., 15 pp., 1959.
AD-214 070.

Presents an insight into the nature of the shock-wave noise problem, the significant variables involved, and the manner in which airplane operation may be affected. Flight-test data are compared with the available theory. An attempt is made to correlate the subjective reactions of observers and some physical phenomena associated with the pressure amplitudes during full-scale flight.

2346

Miller, L. N., and L. L. Beranek, "Comparison of the Take-Off Noise Characteristics of the Caravelle Jet Airliner and of Conventional Propeller-Driven Airliners," J. Acoust. Soc. Am., 29, 1169-1179, 1957.

Based upon earlier published information concerning the factors that influence neighborhood response to noise exposure, it is assumed that there are three principal characteristics of noise which must be considered in comparing community response to jet take-offs with that to propeller aircraft take-offs. These three noise factors are: (1) relative noise levels; (2) duration of noise; and (3) frequency distribution of noise.

This paper is devoted to a comparison of the noise produced by the French jet aircraft, the Caravelle, with that produced by conventional propeller-driven airliners in terms of these three factors. Noise-level measurements were made under the take-off path at various distances from the beginning of the runway. The conclusion is drawn that the comparative noise levels of the Caravelle, when considered in terms of probable response of listeners to the spectrum distribution of the noise, are approximately equal to those of large propeller aircraft for similar climb rates when heard out-of-doors. Second, the Caravelle noise levels, based on relative listener response, are somewhat lower than those of propeller aircraft when heard indoors or when the Caravelle is permitted to take off under steep climb conditions. Third, the Caravelle noise persists for longer time intervals than does propeller aircraft noise by a factor of between 1.5 and 3.5, depending upon the distance from the runway.

2347

Miller, L. N. and L. L. Beranek, "Survey of the Take-Off Noise Characteristics of the Caravelle Jet Airliner and of Conventional Propeller-Driven Airplanes," Noise Control, 3, 42, 1956.

Following noise tests, the French Caravelle Airliner was granted permission to land at New York International Airport at Idlewild on May 3, 1957, and to make a series of demonstration flights. The noise tests performed and the methods used for evaluating them are described in this article.

2348

Obata, J., and Y. Yosida, "Sounds Emitted by Aircraft," Rept. No. 59, Aeron. Res. Inst., Tokyo Imp. Univ., 185 pp., 1930.
See Also: Proc. Phys. Math. Soc. Japan, 12, 80-92, 1930.

Describes the electrical methods used for recording the sounds emitted by various types of aircraft. These included a bomber, a chaser, a reconnaissance machine and a small dirigible. Straight-line flights and vertical turns were made. The sounds are generally very complex in nature, overtones being predominant in most cases. At short distances the exhaust sound predominates, while at longer distances the propeller provides the greater part of the sound, the fundamental and second harmonic being predominant. Different aeroplanes equipped with the same kind of engine gave different records. The pitch of the fundamental depends far more on the number of cylinders per bank than on the total number of cylinders in the engine.

A large number of the records obtained are reproduced in the paper.

2349

O'Bryan, T. C., and J. B. Hammack, "Flight Performance of a Transonic Turbine-Driven Propeller Designed for Minimum Noise," NASA Memo. 4-19-59L , Natl. Aeron. Space Admin., Washington, D. C., 22 pp., 1959.
AD-216 733.

Presents results of a flight investigation to determine the aerodynamic characteristics of a transonic-type propeller. This propeller was designed for an advance ratio of 4.0 at a forward Mach number of 0.82 in an effort to limit the noise production. The measured efficiency of the propeller was 68% at the design Mach number of 0.82. This value is to be compared with the as-much-as-15% greater efficiency of a propeller designed with the same Mach number but an optimum advance ratio of about 3.0. This penalty in efficiency must be considered in light of the resulting noise reduction. The noise under static and take-off conditions was measured to be 117.5 decibels, which represents a noise reduction of about five decibels, (at 1400 horsepower) compared with the advance-ratio-three design.

2350

Pietrasanta, A. C., "Jet Noise Problem in Aircraft Carrier Islands," J. Acoust. Soc. Am., 28, 427-433, 1956.

Noise during jet aircraft launching operations seriously interferes with communications in important island spaces aboard aircraft carriers. Measurements of sound-pressure levels made in these spaces during normal jet operations at sea are reported. It was found that these levels could be estimated from a knowledge of jet-engine operating conditions (A. A. Pietrasanta, J. Acoust. Soc. Am., 28, 434, 1956) and the physical properties of the structures involved. The problem of selecting criteria for speech communication is discussed. Noise-reduction requirements for island spaces, based on estimated noise levels of present and future jet aircraft, are presented.

2351

Pietrasanta, A. C., "Noise Measurements Around Some Jet Aircraft," J. Acoust. Soc. Am., 28, 434-442, 1956.

The noise fields around several jet aircraft have been measured for various engine operating conditions. Directivity patterns as a function of octave bands of frequency are presented. Acoustic power levels have been computed and found to agree with a previously published correlation of power level with engine operating conditions (D. K. Mawardi and I. Dyer, J. Acoust. Soc. Am., 25, 389, 1953). Analysis of these data has led to the development of a procedure for estimating the characteristics of the noise fields around non-afterburner jet aircraft operating at military power.

2352

Regier, A. A., and H. H. Hubbard, "Status of Research on Propeller Noise and its Reduction," J. Acoust. Soc. Am., 25, 395-404, 1953.

Reviews the basic concepts concerning the generation of propeller noise generation, and gives equations for calculating the noise field both near and far from the propeller. Noise from nonsteady airloads on the blades and differences in noise from the approaching and retreating blades are discussed. Effects of tip speed, number of blades, blade thickness, and blade width are considered, and it is shown that reducing the tip speed and increasing the number of blades are probably the most effective means of reducing the efficiency of noise generation and alleviating the noise problem.

Noise characteristics of such special propellers as the supersonic, dual rotating, tandem, and shrouded types are also presented. Studies of propeller weights show that substantial noise reduction on transport propellers would result in a considerable weight penalty. For the propeller-driven aircraft in the 400 to 500 mph speed range, the slower-turning, quieter propeller is likely to have better propulsive efficiency than the noisier high-speed propeller. Hence, in this speed range, the weight penalty of the quiet propeller may be offset by its higher propulsive efficiency.

2353

Seltz, R. H., "Aircraft Noise Emission, Survey of A3J-1 Airplane," Interim Rept. No. 6, Naval Air Test Center, Patuxent River, Md., 1961.
AD-264 593.

The Service Test Division conducted a survey of the ground-noise profile of the A3J-1 airplane. Measurements were made with both the airplane engines operating at military thrust and at maximum thrust with full afterburner augmentation (MAX A/ B). The maximum overall noise level measured during military thrust operation was 152 db; the maximum overall noise level measured during MAX A/ B operations was 156 db. However, at the point where previous experience has indicated that the noise level would be approximately four db higher, no measurements were made because of the danger to personnel from the heat and blast. Data are presented in tabular and graphic form.

2354

Seltz, R. H., "Aircraft Noise Emission, Survey of A4D-2 Airplane," Interim Rept. No. 4, Naval Air Test Center, Patuxent River, Md., 12 pp., 1959.
AD-220 300.

A survey of the ground-noise profile of the A4D-2 airplane was conducted by the Service Test Division. Measurements were made with the engine operating at military power. The maximum overall noise level encountered during these tests was 150 db. Data are presented in tabular and graphic form.

2355

Veneklasen, P. S., "Noise Control for Ground Operation of the F-89 Airplane," J. Acoust. Soc. Am., 25, 417-422, 1953.

Describes a noise-control project that includes a muffler for the ground testing of the F-89 airplane, which is powered by two turbojet engines. Topics discussed include the prediction of performance, acoustical design, correlation of acoustical and thermodynamic requirements, general construction, acoustical tests during construction, surveying the noise around the exposed airplane, and surveying noise in the neighborhood of the completed installation. This noise suppressor is comparatively simple and inexpensive, requires no water cooling even for afterburner operation, and has proved adequate in terms of neighborhood relief and the protection of operating personnel.

2356

von Gierke, H. E., "Physical Characteristics of Aircraft Noise Sources," J. Acoust. Soc. Am., 25, 367-378, 1953.

Available basic characteristics of different aircraft noise sources under the condition of zero forward speed are summarized. Total acoustic power, acoustic mechanical efficiency, directivity and frequency characteristics are given for the rotation and vortex noise of propellers, for the exhaust noise of reciprocating engines, and for different types of jet engines. The physical mechanisms underlying the different noise sources are discussed and the influence of changes in the parameters, such as tip speed or pitch of the propeller, and diameter or velocity of the gas jet, are shown. In cases where measurements on the actual propulsion systems are incomplete, the basic physical conclusions are drawn from experiments on model airscrews and small air jets. The changes in the characteristics of the noise generators during flight are discussed briefly.

2357

von Gierke, H. E., H. O. Parrack, W. J. Gannon, and R. G. Hansen, "The Noise Field of a Turbo-Jet Engine," J. Acoust. Soc. Am., 24, 169-174, 1952.

The noise fields generated by a standard turbo-jet aircraft engine have been measured for three different power settings. Measurements were made at points on circles around the engine having radii of 25 and 50 feet. For the distance of 50 feet, the directional characteristic is presented for the over-all sound pressure and for the noise in the different octave bands, starting at 37.5 cps. From these measurements the total acoustic power radiated from the engine is calculated to be approximately 69 kw at full engine power. The distribution of this power over the different frequency bands and space angles is shown. The highest total energy per cycle and the highest sound levels are found at frequencies near 100 cps for the higher power settings of the engine. Above that frequency range the total energy per cycle drops approximately as the reciprocal of the square of the frequency.

The data should help us understand qualitatively the jet engine as a sound source and are therefore discussed in that respect. On the other hand, the data have practical significance with respect to the design of test facilities for adequate protection of personnel. They are equally important with respect to problems of noise control on an airport.

2358

Withington, H. W., "Silencing the Jet Aircraft," Noise Control 2, 46, 1956.

The Boeing 707 Jet Transport incorporates an engine sound-suppression device which substantially reduces the external jet noise. Technical progress has been achieved which makes possible airplanes capable of operating from present airport facilities with no more noise for the surrounding areas than is produced by propeller-driven transport aircraft. This noise reduction has been achieved with only a minor degradation of airplane performance.

2359

Wolfe, M. O. W., "Near Field Jet Noise," AGARD Rept. No. 112, Royal Aircraft Establishment, Great Britain, 43 pp., 1957. AD-154 857.

This paper deals with the subject of jet-engine noise in relation to its effects on aircraft structures. Near-field noise measurements are described for a range of jet-shear velocities on two representative turbo-jet engines, one of them operating with an afterburner. Contours of equal noise pressure in the horizontal plane containing the axis of the jet are presented for a range of shear velocity for overall noise pressure and for noise pressures in 1/3-octave frequency bands in the noise spectra. In the velocity range 790 to 1800 feet per second, 400 cps is the dominant frequency. At most velocities the noise pressures at this frequency are about ten decibels less than the corresponding overall noise pressures. The increase in noise level due to reheat is not as great as would have been predicted from a consideration of the noise-level trends at much lower values of velocity without reheat.

Sound Sources, Aircraft
See Also——329, 352, 433, 437, 440, 480, 489, 498, 510, 517, 1232, 1377, 1513, 1585, 1587, 1604, 1612, 1622, 1624, 1626, 1628, 1652, 1657, 1659, 1662, 1715, 1722, 1731, 1746, 1747, 1988, 2277, 2817, 3929, 3945, 3961, 3962, 3964, 4079

SOUND SOURCES, EXPLOSIVE

2360

auf Kampe, H. J., "Results of Acoustic Measurement at Helogoland" (in German), Meteorol. Rundschau, 5, 99-105, 1952.

On April 18, 1947, 6000 tons of explosive were set off at Helgoland; normal and anomalous waves recorded at German stations are charted up to a distance of 440 km. Results are discussed in the light of upper winds and temperatures and the weather situation, and the paths of anomalous waves plotted, with some alternative solutions. Above tropopause at 10 km a rise of temperature is determined, to a value of nearly 50°C at 50 km.

2361

Bolt, Beranek, and Newman, Inc., "Characteristics of Noise Produced by Several Contemporary Army Weapons," Rept. No. 630, Cambridge, Mass., 31 pp., 1959. AD-212 420.

Measurements were made of the noises associated with the firing of an M-1 rifle, 30- and 50-cal. machine guns, a 76-mm gun, a 90-mm gun and a 105-mm howitzer. The noises are described in terms of the maximum instantaneous peak value, the duration, the rise time, and the frequency spectrum. The distributions of these parameters in and around the several weapons are also reported. Recommendations are made concerning efficient data recording techniques.

2362

Boyer, D. W., "An Experimental Study of the Explosion Generated by a Pressurized Sphere," J. Fluid Mech., 9, 401-429, 1960.

An experimental investigation of the explosions of two-inch diameter glass spheres under high internal pressure has been made. The spheres were initially filled with air or helium at 400 and 326 psi., respectively, and were exploded in air at atmospheric pressure. Experiments on the simulation of high-altitude explosions are also described. Schlieren and spark shadowgraph records of explosion phenomena, and pressure records of the reflection of the spherical shock wave at various radii, are presented.

An account of some initial experiments on the implosion of five-inch-diameter glass spheres is given. The results were not very satisfactory because of the failure of the spheres to shatter in a desirable manner while under an external pressure of 65 psi.

Numerical solutions to the air and helium-sphere explosions are described, and the experimental wave phenomena are shown to agree well quantitatively with the theoretical predictions, in that they exhibit all the main features that were predicted and are modified only be the physical limitations of the glass diaphragm. In practice, a formation process is associated with the spherical shock waves, resulting in initial shock velocities that are lower than the theoretical values.

2363

Collignon, M., "Explosions at a Great Distance," Compt. Rend., 187, 357-359, 1928.

Continuation of a study of the properties of explosive sounds made in the open air. The audible harmonics observed arise from "infra-sounds" caused by explosions at distances greater than 120 km. Numerous observations have been made at a large number of stations with specific acoustical conditions in their surroundings, and the reduced observations (method not detailed) are shown in tabular form. Errata, ibid., 452.

2364

Davison, C., "The Sound of a Great Explosion," Quart. Revs. (London), 452, 51-60, 1917.

The first recognition of abnormal behavior of sound waves was in 1901, when noise from guns at Queen Victoria's funeral in London was heard at long distances but not near London. The first explanation of zone of silence attributed to an upward refraction of sound waves through the troposphere, followed by downward bending of the waves by increasing wind velocity at higher altitudes. A figure shows areas of sound.

2365

Davison, C., "The Sound-Waves and Other Air-Waves of the East London Explosion of January 19, 1917," Proc. Roy. Soc., Edinburgh, 38, 115-129, 1918.

A highly detailed report on the areas of audibility and zones of silence associated with an enormous explosion that occurred in East London, England. The report is in narrative style, essentially nontechnical, and presents the results from 725 queries made in 533 places to distances of as much as 150 miles from London. The nature of the sound in various locations and some of its side effects are described. Correlation of the silent zones and areas of audibility with wind and temperature profiles is only casual due to insufficient meteorological data.

2366

Donn, W. L., and M. Ewing, "Atmospheric Waves from Nuclear Explosions, II. The Soviet Test of 30 October 1961," J. Atmos. Sci., 19, 264-273, 1962.

Atmospheric waves from the Soviet nuclear test of 30 October 1961 are described for nine stations having wide global distribution. The records are characterized by waves which begin with the highest amplitudes and which show normal dispersion. These appear to be superimposed on a lower amplitude, long period train of waves which shows inverse dispersion. As shown on dispersion curves of group velocity against period, a maximum of group velocity is indicated by the Airy phase formed through the merging of the two dispersive trains. A more prolonged train of waves of nearly uniform period is attributed to higher modes. The direct waves from the epicentre to the stations give dispersion curves that indicate significant variation in atmospheric structure along different azimuths and probably along different segments of the same azimuth. The curves for waves which have travelled more than once around the earth represent better sampling of world-wide atmospheric conditions and give better agreement with preliminary theoretical models. The average speed of the first arrivals is 324 m/sec, comparing well with the maximum obtained for the Krakatoa eruption.

2367

Dubois, E., "Researches on the Waves from an Explosive Source," (in French), Mem. Artillerie Franc., 21, 369-393, 1947.

By means of a piezoelectric quartz crystal, the forces due to the instantaneous pressure on an obstacle from the waves derived from an explosure source were investigated. The pressure curve consisted of an excess pressure, followed by a depression and again by a weaker excess pressure. The mechanical action that should result on the obstacle has been determined. In addition, it is shown that, in the case of flat sources, there is a concentration of the emitted energy around the normal to the plane of the source.

2368

Esclangon, E., "Acoustics of Guns and Projectiles," Dept. of Physics, Univ. of Calif., Los Angeles, 1941.

This book is primarily concerned with ballistic acoustics but, considering its introduction in 1925, is also a source of surprisingly accurate and complete information on physical acoustics. It is divided into two sections. The first is concerned with the geometrical acoustics of guns and projectiles and covers in detail muzzle waves, ballistic waves, and hissings. The second is concerned with physical acoustics. Both sonic and subsonic acoustics are discussed, as are physiological acoustics, atmospheric reflection and refraction, zones of silence, and sound ranging.

2369

Furrer, W., "Acoustics of Detonations and Gunblast" (in German), Schweiz. Arch. Angew. Wis. Tech., 12, 213-219, 1946.

The characteristics of such explosions are discussed and it is shown that the impulse can be calculated from the weight of explosive used. Experimental curves are shown indicating the variation in maximum pressure with distance and with weight of charge. The variation of wave velocity with distance from the muzzle is shown graphically. Very close to the muzzle the velocity is as high as 2000 meters per second, falling rapidly to 340 meters per second at a distance of one meter. Reference is made to the energy in the explosion wave and to the frequency spectrum of explosions. The oscillographic recording apparatus is described.

2370

Galloway, W. J., B. G. Watters, and J. J. Baruch, "An Explosive Noise Source," J. Acoust. Soc. Am., 27, 220-223, 1955.

A ten-gauge blank shotgun shell, exploded in a small cannon, has been used as an impulse source in performing a variety of acoustical measurements. The source has a peak power of the order of 10,000 watts with good reproducibility. The frequency spectrum simulates that of a typical turbojet engine. Instrumentation has been developed to permit simple and rapid analyses of measurements made with this source. Typical applications are described, and results obtained with the impulse source are compared to results obtained with continuous sources.

2371

Heap, J. C., "Bibliography on Various Topics Pertaining to Blast Effects," ANL-5792, Argonne Nat'l. Lab., Lemont, Ill., 23 pp., 1957.
AD-144 450

Contents:
Prevailing containment
Atomic explosions
Blast effects
Explosions
Explosives
Pressure vessels
Shelters
Shock waves
Structures
Submarine intermediate reactor-containers
Tanks

2372

Herrenden-Harker, G. F., "Acoustic Phenomena Associated with the Firing of a Gun," Am. J. Phys., 13, 351-362, 1945.

Existing published work is extended in a theoretical treatment covering modern high-speed projectiles, with an application to sound-ranging.

2373

Hull, G. F., Jr., R. T. Jenkins, et al., "Analysis and Oscillograms of Sounds from Field Artillery and Machine Guns," Rept. No. 4594, National Defense Research Committee, Office of Scientific Research & Development, Vol. 1, 180 pp., Vol. 2, 93 pp., 1945.
ATI-14972.

Volume one describes the equipment, methods of measurement, analysis procedures and spectrum analyses for a detailed study of sounds from field artillery and machine guns. The bulk of the data are of muzzle waves, but there are also data for the sounds of projectiles in flight (ballistic waves) and for shell explosions. In general, the spectrum analyses show maximum acoustic energies at frequencies roughly equal to the reciprocal of the time required for the first compression-rarefaction cycle of the muzzle wave associated with each weapon type.

Volume two is an atlas of oscillograms showing the waveforms and instantaneous acoustic amplitudes of muzzle waves, ballistic waves, and shell explosions as recorded for various weapons and at various distances from the sources of sound. For machine guns, sounds were recorded at ranges of 33, 112, 428, and 648 yards. For large caliber weapons, recordings were made at various ranges from 115 to 14200 yards to show the effects of terrain and atmosphere on sound propagating from firing artillery.

2374

Jones, R. V., "Sub-Acoustic Waves from Large Explosions," Nature, 193, 229-232, 1962.

The Krakatoa volcanic explosion, the great Siberian meteor, and the large Russian nuclear explosion at Novaya Zemlya are compared, and microbarographic records of the latter two are shown. Both direct and antipodal pressure waves are evident. The author calculates that the Krakatoa explosion was by far the largest of the three, and that the great Siberian meteor and the Russian nuclear explosion were each roughly equivalent to 30 megatons of TNT. He concludes that the meteor must have weighed about 30,000 tons.

2375

Klein, E., "Air Shock Wave Velocities over Water," J. Acoust. Soc. Am., 21, 109-115, 1949.

A procedure was devised for determining the air blast pressures of the A-bomb at Bikini. In such a disturbance the air particles move with large and finite amplitudes; hence the propagated waves do not obey the ordinary laws of acoustics. By measuring the ratio of the air shock wave velocity to normal acoustic velocity, an indication may be obtained as to the peak pressure of the explosion. Blast waves in water, on the other hand, follow substantially the familiar acoustic laws and are propagated at a well-known velocity. Measurements of transit times made at identical positions for the air and for the water blast waves immediately yielded the desired air blast velocity in terms of the known velocity of sound in water. This procedure eliminated the need for simultaneous measurement of the continually shifting distances between buoys which carried observational equipment. However, careful positioning of the buoys was necessary in order to avoid their destruction and yet record the maximum possible air blast. These positions were calculated on the basis of an equivalent explosion from 20,000 tons of TNT. Since the measurements had to be made automatically and without human observers, special timing and recording systems were provided. All requirements for gathering the data were successfully met in the assembly of apparatus described herein.

2376

Lawrence, R. W., "Mechanism of Detonation in Explosives," Geophysics, 9, 1-18, 1944.

Results of photographic work on the detonation of high explosives are presented and discussed, relative to hydrodynamic theory. Methods for determining strength and detonation velocity are described. The photographs illustrate the nature of detonation waves in explosives and of shock waves in air. The duration of the detonation waves in nitro-glycerin and blasting gelatin is $< 10^{-6}$ sec. and the duration of the shock waves in air is of the same order. The high temperature of shock waves predicted by theory is confirmed.

Photographs are included showing the propagation of detonation from one cartridge of blasting gelatin to another across air gaps and water gaps. In the latter case, no visible shock wave is produced in the water and the highly luminous after-burning is eliminated. Calculations indicate that pressures in the detonation wave may run to 140,000 atm and temperatures to 4,300°C. The shape of the detonation wavefront in a high-velocity explosive is planar, whereas in low-velocity explosives it is convex.

2377

Miller, D. C., "Sound Waves; Their Shape and Speed," Macmillan, New York, 164 pp., 1937.

This description of the phonodeik (an apparatus for photographic recording of sound waves) and its application includes a report on experiments made at Sandy Hook (1918-1919) on acoustical phenomena associated with the firing of large guns (pp. 91-155). Some results are presented in graphical and tabular form on: (1) pressure effects in the air near large guns during firing; (2) wave forms of the sounds; (3) propagation of sound waves from the muzzle of a gun and (4) normal velocity of sound in free air.

2378

National Defense Research Committee, "Summary Technical Report of Division 17; Compasses, Odographs, Combat Acoustics, and Sonic Deception," Office of Scientific Research & Development, Washington, D. C., 2, 117-130, 1946.
ATI-30810.

Oscillographs of the sounds from rifles, machine guns, mortars, and howitzers are shown as sampled at ranges of 1500 feet and 2900 yards. Simulations of these sounds by use of small charges of nitrostarch, Primacord, dynamite, etc., are shown. The general effect of increasing range is atmospheric absorption of the high-frequency content of each sound plus an increase in signal duration.

2379

Partlo, F. L., and J. H. Service, "Instantaneous Speeds in Air of Explosion Reports at Short Distances from the Source," Physics, 6, 1-5, 1935.

In the first series of measurements the source was one No. 6 blasting cap, while in the second series 1 lb of 50% nitroglycerin stick dynamite was used as source. A telephone carbon-button microphone was the receiver and was held fixed in location while shots were fired successively at 5, 8, 12.5, 25, 35, 50, 100 and 600-meter distances. A two-element string oscillograph was used for timing, one element recording the instant of firing, the other element recording the arrival of the wave at the microphone. The work was done at a time of no perceptible wind; air temperatures were measured carefully; no humidity measurements were made. Travel times could be read reliably to 10^{-4} sec, and distance measurements were at least correspondingly good. Instantaneous speeds were obtained by plotting time computed minus time observed against distance, and measuring slopes of the resulting curve. Since this work was incidental to seismic prospecting, the observations were not quite as numerous as those of von Angerer and Ladenburg. However, the results are similar, showing abnormally high speeds near the source. Also, the use of instantaneous speeds appears to show abnormally low speeds a little farther from the source, perhaps masked in the work of von Angerer and Ladenburg due to their use of average speeds instead of instantaneous speeds.

2380

Savitt, J., and R. H. F. Stresau, "Velocity Attenuation of Explosive-Produced Air Shocks," J. Appl. Phys., 25, 89-91, 1954.

Describes a method for measuring the velocities of explosively produced air shocks using an electrical ionization probing system. The results of such measurements indicate that under varying conditions of confinement of explosive and air shock, the reciprocal of the air shock velocity varies linearly with the distance to the charge surface.

2381

Suffield Experimental Station (Canada), "Scientific Observations on the Explosion of a 20 Ton TNT Charge, Volume One. General Information and Measurements," Rept. No. 203, Vol. 1, 76 pp., 1961.
AD-272 040.

A 20-ton block-built hemisphere of TNT was detonated on the ground, and air blast and ground shock measurements were taken. Teams from UK and USA laboratories were associated in the observations. One project of interest to the three countries was the establishment of a lane, radial from the charge, to provide a common ground in which each contributed piezo gauges and recording systems for comparisons of the readings obtained among the systems. The details of the construction and detonation of the charge, the range observations and procedures during the trial, the surface meteorological observations, and the air and ground scientific observations other than the shock overpressure measurements, are presented.

2382

Taylor, G., "The Formation of a Blast Wave by a Very Intense Explosion, I. Theoretical Discussion," Proc. Roy. Soc. (London) A, 201, 159-174; "II. The Atomic Explosion of 1945," Ibid., 175-186, 1950.

Theoretical problems connected with the energy dissipation from an intensive explosion are treated in detail in Part I. The energy, form, and time of decay of the blast wave; similarity to sound wave propagation; heat energy remaining in the air after its return to atmospheric pressure; and comparison with blasts from high explosives, are determined mathematically and expressed in tables and graphs.

In Part II, the theoretical results are checked against measurements made from photographs of the 1945 atomic explosion in New Mexico, and calculations made for total energy, shock wave, rate of rise of hot air, etc.

2383

Watters, B. G., "The (Sound of a Bursting) Red Balloon," Sound, 2, 8, 1963.

This article shows that the larger sizes of children's rubber balloons, well-inflated, provide convenient and useful impulsive sound sources for reverberation time measurements in room acoustics.

2384

Weston, V., "The Pressure Pulse Produced by a Large Explosion in the Atmosphere," Radiation Lab., Univ. of Mich., Ann Arbor, 17 pp., 1961.
AD-263 023.
See Also: Can. J. Phys., 39, 933-1009.

The pressure pulse produced by a large explosion in the atmosphere is investigated. The explosion is represented in terms of the excess pressure and normal velocity on a closed surface, outside of which the hydrodynamical equations are linearized. The pulse is represented in terms of a Fourier transform of the associated harmonic frequency problem for which a ring-source Green's function is obtained in terms of an expansion of the discrete modes. It is shown that the excess pressure may be represented in terms of an integral (containing the Green's function) over the surface surrounding the source. The gravity-wave portion of the pressure pulse at the ground is computed for various altitudes, and for three models of the atmosphere. In calculating the head of the pulse, a new asymptotic technique is introduced that gives very good results for intermediate and long ranges.

2385

Wood, W. W., and J. G. Kirkwood, "Diameter Effect In Condensed Explosives, The Relation Between Velocity and Radius of Curvature of the Detonation Wave," J. Chem. Phys., 22, 1920-1924, 1954.

The limiting slope of the detonation velocity-wave front curvature locus for small velocity deficits is obtained under an assumption concerning the "reaction zone length" as related to the charge diameter and the radius of curvature of the wavefront. The model is an extension to two dimensions of von Neumann's classical theory of the plane wave detonation.

Sound Sources, Explosive
See Also——515, 550, 564, 844, 924, 1112, 1181, 1336, 1372, 1414, 1416, 1422, 1435, 1436, 1437, 1438, 1439, 1442, 1443, 1447, 1484, 1520, 1555, 1802, 2045, 2046, 2125, 2515, 2980, 3028, 3038, 3223, 3230, 3231, 3232, 3236, 3248, 3249, 3254, 3258, 3264, 3274, 3275, 3276, 3277, 3279, 3287, 3298, 3307, 3308, 3312, 3344, 3347, 3358, 3367, 3370, 3417, 3445, 3446, 3447, 3448, 3449, 3467, 3468, 3469, 3483, 3506, 3507, 3531, 3532, 3533, 3534, 3535, 3649, 4125, 4271, 4424

SOUND SOURCES, FOG HORNS

2386

Blaise, P., "General Report on the Range of Sound Signals," Rept. No. General-3, Coast Guard, Washington, D. C., 36 pp., 1960.
AD-242 002

Questionnaires concerning fog signals were submitted to the Sixth International Technical Conference on Lighthouses and Other Aids to Navigation. Replies to the inquiries, concerned with the problem of determining the range of sound signals, are analyzed individually.

2387

Bolt, Beranek, and Newman, Inc., "Investigation of Acoustic Signalling over Water in Fog," Final Rept. on Phase 1, Evaluation of Present U. S. Coast Guard Design Procedure for Fog Signals, Cambridge, Mass., 14 pp., 1960.
AD-236 583.

The present USCG design procedure for fog signals represents considerable progress over previous methods. It is based on the concept of the average audible range and uses a fixed loudness level as the criterion for detection. Sound sources are specified in terms of the on-axis free-field sound pressure level at a distance of 25 feet. The transmission path is described by means of a curve of average sound transmission loss obtained many years ago. The following areas of improvement and refinement are suggested: (1) description of the sound source in terms of acoustic power output and directivity; (2) description of the transmission path by means of sound attenuation functions which take into account, in addition to frequency and distance, such parameters as source and receiver heights, wind direction and speed, and temperature and wind gradients, on a statistical basis; (3) description of the process of signal detection and location by the listener in terms of a detection criterion of minimum s/n, taking account of background noise levels and spectra, signal frequency and duration, and other relevant factors.

2388

Bolt, Beranek, and Newman, Inc., "Investigation of the Transmission of Sound Through Fog over Water," Final Rept. on Phase 2, Investigation of Acoustic Signalling over Water in Fog, Cambridge, Mass., 1960.
AD-236 659

The physics of sound propagation along the surface of the earth is discussed with particular attention to the conditions existing where sound is propagated for long distances over ocean waters in fog. The results of an extensive measurement program of sound transmission over water are presented, together with the results of measurements of the relevant micrometeorological parameters and a description of the instrumentation and experimental techniques used. The experimental data are analyzed in the light of available theory with a view of applying the results in generalized form to an improved design procedure for audible fog signals. Among the more important conclusions resulting from the analysis and evaluation of the field studies presented in this report are as follows.

(1) The propagation of audible sound over ocean waters in fog is governed by the same micrometeorological parameters which determine the propagation of audible sound over land. (2) The presence of wind and temperature gradients just above the surface of the ocean causes the sound to be refracted from the normal

2389

Coast Guard, "The Average Audible Range of Sound Signals," Civil Eng. Rept. No. CG-250-29, Washington, D. C., 1958.
AD-225 675.

The three-fold purpose of the report is: (1) to describe a new method for determining the average audible range of a sound signal under average conditions of fog; (2) to indicate how the results of this method may be used in the Coast Guard; and (3) to publish the average audible ranges of those fog signals for which acoustical measurements have been made.

The reliable range for sound signals (the distance at which the sound can always be heard) seldom exceeds one-quarter mile, and reliable ranges of over one-half mile are believed to be unachievable. The average audible range is that distance at which the sound will be heard roughly 50% of the time; that is, the maximum range at which the signal is usable under favorable conditions of sound propagation.

A method was developed for the determination of the average audible range both for signals of the electric oscillator type, and for those that have a complex frequency structure, such as the diaphone. The methods by which the results of this procedure may be used in the Coast Guard are discussed, and actual results are included for those fog signals for which adequate acoustical measurements are available.

2390

Coast Guard, "Proceedings of the Sixth International Technical Conference on Lighthouses and Other Aids to Navigation, September 25-October 7, 1960," Washington, D. C., 245 pp., 1960.
AD-277 064.

Descriptors: Conferences-Lighthouses, Lighthouses, Navigational lights, Symposia-Navigational lights, Indexes, Light homing, Lighting equipment, Navigation, Coast Guard, Signal lights, Fog signals, Power supplies, Electronic equipment, Auditory signals, Ships.

2391

(U. S.) Coast Guard Testing and Development Division, "Catenoidal Horn for Electric Air Oscillator," Field Testing and Development Unit, U. S. Coast Guard Yard, Curtis Bay, Baltimore, Md., 57 pp., 1959.
AD-225 803.

A set of catenoidal horns was designed, manufactured, installed and tested as a replacement for the conical horns on a Coast Guard Type 1954 Electric Air Oscillator. The design method and calculations are presented in this report together with a detailed description of the testing and evaluation of the catenoidal horn in comparison to the original conical horn. The report also contains pictures of the test facilities employed and circuit diagrams for the eletrical analog of the acoustic system involved. The catenoidal horn was found to be more efficient though less directive than the conical horn. The on-axis sound intensity available with the catenoidal horn was found to be more than double that obtainable from the same air oscillator loaded by the conical horn.

2392

Hilliard, J. K., and W. T. Fiala, "Electro-Pneumatic Air Modulator for Fog Signals," Rept. No. 6-2-1, United States Coast Guard, Washington, D. C., 11 pp., 1960.
AD-242 094.

A highly directional electro-pheumatic, air-modulated loudspeaker was designed. It is capable of radiating speech or any type of warning signal in the 100-c to 1000-c range. Tests were conducted to delineate the directional qualities of the sound generator, both in absolute terms and in practical navigation. In these tests, 200-c and 400-c warbled tones, plus a voice signal, were compared with a standard diaphone fog signal.

The electro-pneumatic equipment used for the tests included a single unit consisting of four air-modulated loudspeakers driving an exponential horn six ft. in length, with a mouth crosssection of four sq. ft. Voice signals were generated by two airmodulated loudspeakers mounted on an Altec-Lansing 1003 multicell horn with a cutoff of 200 c.

A shadow zone was established in the upwind direction which fully substantiated the effect of sound over water as described by Francis M. Weiner (AD-242 087).

2393

Hirai, S., "The Rated Range of a Sound Fog Signal," Rept. No. 6-1-6, Coast Guard, Washington, D. C., 10 pp., 1960.
AD-242 091.

The paper, "Defining and Calculating the Rated Range of a Sound Signal" by M. R. Ginoechis, is considered. It was presented to the 5th International Conference on Lighthouses and Other Aids to Navigation. Experiments and observations were conducted on (1) the intensity and stress of a sound signal defined as the sound loudness level at its origin and as measured at 10-m distance directly from the mouth of the horn; (2) the question of whether the value of the atmospheric transmission coefficient, T, used correspondingly to the wavelength, should be regarded as proper (AD-242 086); (3) the question of whether it is proper to consider a decrease in sound to be proportional to the distance to the minus squared; and (4) the accuracy of using the value 70 db as the minimum audible sound among the noises. Results indicated that a distance of 10 m is too near to measure the intensity of the source of sound and that in the case where a larger distance cannot be had because of a topographical situation, a compensating value should be added to the value or the value should be made smaller. Noises from diesel and reciprocal engines were measured on different kinds of vessels for stress and loudness level. For the diesel engines, the average noise values were 100, 76, 97, and 85 phons for the engine room, pilot house, and bridge end at 18% and 6% wind velocity, respectively. In the case of the reciprocal engine, the noise values were 80, 67, and 75 to 85 phons in the engine room, pilot house, and bridge end, respectively. The value of minimum audible sound will be about 70 phons.

2394

Hubbard, B. R., "Influence of Atmospheric Conditions upon the Audibility of Sound Signals," J. Acoust. Soc. Am., 3, 111-125, 1931.

Summarizes the causes of the irregularity noticed in the audibility of fog signals. The observations and theories of various writers are quoted and the results of the test of fog-horns at Boston, carried out in Sept., 1930, are given. Striking instances are given of the unreliability of loudness observations for ascertaining distance; e.g., a fog signal that is audible for eight miles under favorable conditions may be just audible under other atmospheric conditions at a mile or less. The effect of "silent zones," due to the bending of the sound waves when temperature decreases normally upwards, is considered.

There are now few phenomena of fog signalling that cannot be explained in accord with generally recognized principles. The atmosphere is seldom homogeneous and aberrations in audibility may be due to any or all of three causes—wind, temperature, and humidity. The work of all investigators points to the first of these causes as the most important in causing inefficiency. The observed effects are illustrated by diagrams and tables summarizing the results obtained.

2395

Levy, S. E., and R. W. Carlisle, "Generation of Intense Audio Sound Fields Utilizing Arrays of Multiple-Driver Horns," J. Acoust. Soc. Am., 33, 936-940, 1961.

There are several major applications for intense audio sound fields: the outdoor propagation of speech and of warning signals, and the sonic fatigue testing of missile and aircraft components. In these applications, several factors combined make it necessary to limit the portion of the frequency spectrum covered by any one loudspeaker unit. In order to provide adequate power capacity, selection is required between the alternatives of (a) using a large number of identical drivers, (b) using a plurality of drivers each especially designed for a selected portion of the frequency range, and (c) using combinations of these arrangements. In an array currently being used for sonic-fatigue testing, a plurality of large open-cone loudspeakers is used for low frequencies, and a plurality of horns is used for middle and high frequencies. Each horn is driven by several drivers. The driver voice coil and diaphragm proportions have been optimized to withstand fatigue stresses under the thermal conditions encountered. The driver is rated at 50 w input for programme material. Horn assemblies are available having throat arrays for mounting 6, 12, or 24 drivers. Various applications are illustrated.

2396

Pierce, G. W., and A. Noyes, Jr., "Transmission of Sound over Reflecting Surfaces," J. Acoust. Soc. Am., 9, 193-204, 1937.

The paper presents an experimental and theoretical discussion of acoustic signalling between a sending station and a receiving station near a plane reflecting surface, and is applicable to foghorn and submarine signalling. The experiments were made with a small-scale apparatus employing supersonic waves of a frequency of 67.5 kcs. It is shown that at grazing incidence the direct and reflected waves cancel, or partially cancel, as predicted by theory. The cancellation for propagation in air near a water surface, or near another surface of high sound velocity and high density, is found to be restricted to angles very near to grazing incidence.

On the other hand, theory predicts cancellation for much larger departures from grazing incidence if the reflecting surface has high density but low velocity; experimental curves for transmission over beach sand and certain other substances resemble such theoretical results very closely. Acoustic mirages caused by temperature gradients were studied experimentally, and their effects are shown to be of striking importance in modifying the above results.

2397

Thiessen, G. J., "Improved Type B Fog Horn System Using Exponential and Catenoidal Horns," J. Acoust. Soc. Am., 28, 356-362, 1956.

The use of a high impedance acoustical load for the type B diaphone is capable of raising the efficiency of the fog horn system to values of 10% to 16% for normal operating pressures. The high impedance is provided by a resonant exponential or catenoidal horn. To provide the high degree of frequency stability required by high Q resonant loads the mechanical impedance of the diaphone is reduced to permit it to lock in with the horn frequency. The reduction of the mechanical impedance is achieved by reducing the mass of the piston through the use of aluminum and reducing and stabilizing the frictional forces by using a central shaft for supporting the piston instead of allowing it to float in the liner. The resulting frequency stability is such that the efficiency under field conditions equals that obtained in the laboratory. An incidental benefit arises from the fact that the horns are smaller and made of aluminum, reducing the weight by a factor of six.

2398

Thiessen, G. J., "Performance of a Type B Fog Horn," J. Acoust. Soc. Am., 28, 281-285, 1956.

Measurements on a type B fog horn indicate that the nominal frequency of 180 cps is far from any resonance peak in the resistance ratio of the horn. Efficiencies of much less than one percent are therefore commonly encountered. Actual diaphone frequencies in the field range between 180 and 245 cps. The frequency stability with pressure is poor, and large deviations from symmetrical piston movement occur. It can generally be stated that a fog horn that grunts is not operating efficiently.

2399

Vyal'tsev, V. V., and V. G. Khorguani, "A Powerful Low Frequency Acoustic Siren," Soviet Phys. Acoust., English Transl., 7, 299-300, 1962.

This short article describes some of the constructional details of a low-frequency, horn-loaded acoustic siren. The siren consists of a cylindrical chamber and rotor-shaft assembly. Four rectangular exhaust openings are coupled to a catenoidal horn 4.2 meters long and having a mouth area of 8.2 square meters. The siren operates by passing compressed air through the rotating element. The working frequency range is 60 to 300 cps.

Sound Sources, Fog Horns
See Also—83, 111, 432, 485, 487, 711, 968, 1121, 1665

SOUND SOURCES, JETS, ORIFICES, PIPES, ROCKETS, WHISTLES, ETC.

2400

Anderson, A. B. C., "A Circular-Orifice Number Describing Dependency of Primary Pfiefenton Frequency on Differential Pressure, Gas Density, and Orifice Geometry," J. Acoust. Soc. Am., 25, 626-631, 1953.

A nondimensional number $[\Delta p\ (\rho)^{1/2}]/ft$ for primary Pfiefentüne relating the dependence of differential pressure Δp across an orifice to density of gas ρ, thickness t of orifice-plate terminating pipe, and frequency f of primary Pfiefentune is obtained by dimensional analysis. Correlation of experimental data presented on the basis of this number indicates that it is relatively constant in numerical value over studied range of variation in the parameters, pipe length, orifice diameter, differential pressure across orifice, and Pfeifenton frequency.

2401

Anderson, A. B. C., "A Jet-Tone Orifice Number for Orifices of Small Thickness-Diameter Ratio," J. Acoust. Soc. Am., 26, 21-25, 1954.

The dependence of a jet-tone orifice number $tf/(\Delta p/\rho)^{1/2}$ on Reynolds number $[\rho\ t\ (\Delta p/\rho)^{1/2}]/\mu$ is shown for thin sharp-edged circular orifices whose thickness and diameter both vary from approximately 1/8 to 3/8 in, where t is thickness of orifice plate; f, frequency; Δp, pressure difference across orifice; ρ density; and μ, viscosity of gas. Each jet-tone, in general, is composed of harmonics (fundamental and overtones) as well as subharmonics (tones whose frequencies are less than the fundamental). The subharmonics are relatively unsteady in amplitude compared to the harmonics and may at times have a greater amplitude. The jet-tones at low Reynolds numbers appear relatively free of noise background. In general, as Reynolds number is increased to high values the noise background at first engulfs the subharmonics, then the harmonics. The fundamental is the last to remain, finally disappearing in the noise background.

2402

Anderson, A. B. C., "Metastable Jet-Tone States of Jets from Sharp-Edged, Circular, Pipe-Like Orifices," J. Acoust. Soc Am., 27, 13-21, 1955.

Characteristics of spectra from relatively thick orifices differ from those from relatively thin. In many cases within a given range of Reynolds numbers, the jet may exist in any one of several reproducible jet-tone states (metastable states) characteristic of the orifice. The dependence of the component frequencies of the jet-tone spectra (expressed in terms of the orifice number $fd/(\Delta p/\rho)^{1/2}$) on Reynolds number $[\rho d(\Delta p/\rho)^{1/2}]/\mu$ is shown, where d is diameter of orifice; Δp, pressure difference across orifice; ρ, density; and μ, viscosity of gas. The orifice numbers of the components of the jet-tone spectra generally tend to fall on a single array of equally spaced orifice-number levels. Jet-tones from the same orifice plate, characteristic of both thin and thick orifice plates, are found to coexist over a small transitional range of orifice thickness-diameter ratios. If the orifice number of the head of the most probable spectral mode for a given ratio is noted, the same will be found again for the head of the most probable mode at approximate orifice thickness $t \pm nd$, where n is a small integer.

2403

Anderson, A. B. C., "Structure and Velocity of the Periodic Vortex-Ring Flow Pattern of a Primary Pfeifenton (Pipe Tone) Jet," J. Acoust. Soc. Am., 27, 1048-1053, 1955.

Visualization of the vortex-flow pattern in typical primary Pfeifenton jets was made by means of shadowgraph techniques to show the formal transition of the vortex pattern as it moves downstream in the jet, as well as the dependence of the downstream translational vortex velocity and the geometry of the pattern on the Reynolds number of the jet.

Results of experiment are compared with available theory. These studies were carried out with carbon dioxide jets discharging into the atmosphere. The flow channel geometry consisted of a pipe 7/8 in. in diameter, 12.013 in. long, and open at one end; it was inserted into a large stilling tank and terminated at the other end by an orifice plate containing a sharp-edged circular orifice, 0.250 in. in diameter and 0.093 in. thick.

SOUND SOURCES, JETS, ORIFICES, PIPES, ROCKETS, WHISTLES, ETC.

2404

Anderson, A. B. C., "Vortex-Ring Structure-Transition in a Jet Emitting Discrete Acoustic Frequencies," J. Acoust. Soc. Am., 28, 914-921, 1956.

Visualization of the vortex flow pattern in typical jets emitting jet tones was made by means of shadowgraph techniques to show the nature of the ever-present process of vortex coalescence in the jet and how this determines the values of the eigenton sound frequencies radiated by the jet. These frequencies are superimposed on the noise background radiated by the jet. The dependence of (a) vortex shedding frequency from the orfice, (b) jet-tone frequencies, and (c) translational velocity of the vortices on Reynolds number (Re) are shown.

These studies were carried out with carbon dioxide jets discharging into the atmosphere. The flow channel geometry consisted of an orifice plate containing a sharp-edged, circular orifice, 0.250 in. in diameter and 0.093 in. thick, attached to a large stilling tank partly filled with sound-absorbing material to eliminate any effects of cavity resonance on the jet. The studies were carried out over the range from Re zero to Re 7000, where $Re = vpt/\mu$ and v is mean velocity of discharge of jet; p, gas density; t, orifice plate thickness, and μ, gas viscosity.

2405

Bawtree, E., "How the Fluepipe Speaks, I," Organ, Great Britain, 41, 101-105, 1961.

The "aeroplastic reed" theory of Helmholtz and Hermann Smith and the "edge-tone" theory attributed to Wachsmuth (1904) are shown to be untenable. The two components in the pipe, windstream and air column, and their wave motions, are discussed. "Coupling at resonance" between the two components is shown not to occur. A reappraisal is found necessary.

2406

Bawtree, E., "How the Fluepipe Speaks, II," Organ, Great Britain, 41, 123-127, 1962.

Oscillations in the air column and in the windstream are discussed. Coupling between them is shown to be an effect due to the windstream's situation between the body of air within the pipe and its extension (end-correction) through the mouth into ambient atmosphere. Carriere's discovery of vortices in the mouth space is noted and their relationship to the air-column oscillation shown.

2407

Bawtree, E., "How the Fluepipe Speaks, III," Organ, Great Britain, 41, 183-187, 1962.

Carriere's drawings of configurations at the mouth of a fluepipe are shown to have been wrongly identified as vortices and as examples of edge-tone action. They are analyzed in detail and a fresh interpretation worked out consistent with Carriere's description of them as spirals. Properties of the dual system of windstream and air column are described.

2408

Bawtree, E., "How the Fluepipe Speaks, IV," Organ, Great Britain, 42, 11-15, 1962.

A fresh "modus operandi" for the production of root frequencies in the pipe is worked out. It embodies separate functions for vortices and for spirals in the production of tone. Mouth tone is the aggregation of both. Division of the mouth area into three operational zones is depicted. The relationship of voicing operations to the physical phenomena described is briefly estimated.

2409

Bonavia-Hunt, N., "Flue Pipes," Organ, Great Britain, 42, 55, 1962.

It is contended that the "cyclones" of Carriere are identical to the "spirals" of Bawtree. The demonstration of the vortex system and its application to the organ fluepipe are reviewed, and it is suggested that Bawtree has in fact added nothing to the work of Carriere in this matter.

2410

Brun, E., and R. M. G. Boucher, "Research on the Acoustic Air-Jet Generator: A New Development," J. Acoust. Soc., 29, 573-583, 1957.

The structure and operation of the Hartmann air-jet ultrasonic generator has been reviewed critically, and modifications are described that substantially increase the efficiency and available power output of the original device. Experimental results are presented in confirmation of the theoretical analysis.

An important part of the development has been the employment of a secondary resonator and projecting exponential horn. A novel design using a large number of whistles in a single horn (Multiwhistle R. B.) is described. This unit has a wide frequency and power range, and has been employed in France for agglomeration of aerosols, ultrasonic drying, fog dispersal, and other interesting applications.

2411

Callaghan, E. E., and W. D. Coles, "Far Noise Field of Air Jets and Jet Engines," Rept. No. 1329, Natl. Advisory Comm. Aeron., Washington, D. C., 18 pp., 1957. AD-158 944.

The effect of nozzle-exit shape was studied using a small (four-in. diam.) air jet. Circular, square, rectangular, and elliptical convergent-divergent and plug nozzles were investigated. At low jet-pressure ratios (less than 2.2) the effect of nozzle shape on the sound field was negligible. At high ratios all the nozzles exhibited discrete-frequency noises associated with shock formations in the jet. The convergent-divergent nozzle showed an elimination of such noises at its design pressure ratio. The acoustic power radiated by the engines and air jet was correlated by the Lighthill parameter. The free-field spectral distribution of the sound power agreed well for both engine and air jet.

2412

Canac, F., and M. Merle, "Oscillations and Sound Emission of a Jet of Compressed Air Studied with an Ultra-Rapid Electronic Camera," Compt. Rend., 250, 1795-1797, 1960.

Jets issuing from nozzles of various shapes and dimensions have been shown to oscillate with a definite frequency that decreases with increasing gas pressure. The pattern of sound waves recorded by a schlieren system has the same frequency as the motion of the jet.

2413

Cheng, Sin-I., "On the Aerodynamic Noise of a Jet," Tech. Rept. No. 148, General Applied Science Labs., Westbury, N. Y., 56 pp., 1960.
AD-233 164.

A new model is advanced for analyzing the broad-spectrum noise of a turbulent jet. The shear layer bounding the turbulent jet is assumed to play an important role in modifying the quadrupole sound radiation from the interior. To the sound-emitting small-scale turbulent eddies (with frequencies much larger than those large-scale ones responsible for the intermittent phenomena near the edge of a turbulent jet), the shear layer is laminar and is of an irregular contour, as if the large-scale turbulent motions were frozen. The linearized analysis is then applied to the laminar shear layer to relate the acoustic oscillations across it. The concept of geometrical acoustics is generalized to represent the passage of an acoustic ray through a laminar shear layer.

Acoustic rays may be traced across the shear layer as transmission and refraction but may also be stopped or be apparently generated from the laminar layer. This generation is visualized as the schematic representation, within the framework of geometrical acoustics, of the action of the Reynolds stress in transferring energy from the shearing mean flow to the acoustic waves. In relating the quadrupole strength across the shear layer, those acoustic waves that become stationary with respect to the local mean flow somewhere in the interior of the shear layer, are significantly modified by the viscous action through the critical layer. The shear layer, therefore, serves as a selective amplifier of the acoustic waves passing through it.

2414

Chobotov, V., and A. Powell, "On the Prediction of Acoustic Environments from Rockets," Rept. No. GM TR 190, Thompson Ramo Wooldridge, Inc., Los Angeles, 26 pp., 1957.
AD-217 248

Presents a procedure for estimating the far-field acoustical environment generated by rocket engines. Although the problem of estimating far-field noise is complicated by a number of factors, including a scarcity of reliable data, it is believed that the procedure described will predict the over-all sound pressure level to within ±5 db.

Outlines a procedure for estimating the frequency spectrum of the sound pressure. Various factors, such as meteorological conditions, that affect sound-pressure levels at large distances are briefly discussed.

2415

Cole, J. N., and C. E. Thomas, "Far Field Noise and Vibration Levels Produced During the Saturn SA-1 Launch," Preliminary Rept. No. ASD TR 61-607, Aerospace Medical Div., Wright Air Development Div., Wright-Patterson Air Force Base, Ohio, 22 pp., 1961.
AD-273 666.

Acoustic measurements were made of the sound pressure level-time functions which were produced at six locations on Cape Canaveral Missile Test Annex and at four locations in the surrounding communities during the Saturn SA-1 launch on 27 October 1961. The frequency range of measured data was from the 4.7-to-9.4-cps octave band to the 4800-to-9600-cps octave band. Distances from the launch site to the noise vibration data were measured in three locations at the Tel-2 telemetry site. The frequency range of measured data was from the 4.5-to-9-cps octave band to the 1125-to-2250-cps octave band. The distance from the launch site was 5200 feet. Only the basic sound pressure level-time environments and vibration level-time environments as a function of frequency octave bands are presented in this report.

2416

Cole, J. N., H. E. von Gierke, et al., "Noise Radiation from Fourteen Types of Rockets in the 1000 to 130,000 Pounds Thrust Range," WADC Tech. Rept. No. 57-354, Aero Medical Lab., Wright Air Development Center, Wright-Patterson AFB, Ohio, 64 pp., 1957.
AD-130 794.

Detailed noise characteristics were measured on fourteen types of rockets, with both solid and liquid propellants, in the thrust range from 1000 to 130,000 lb. Near-field and far-field levels on static-fired and vertical-launched rockets were measured under essentially free-field conditions. Measurements and data reduction methods are described. Final results are given as near-field sound pressure spectra, far-field directivities, acoustic power spectra and pressure-time histories. This noise environment is studied as a function of several nozzle configurations and as a function of flame front action in the jet stream. Generalization and correlation of the data result in a formula for the overall acoustic power level output of rockets, OA PWL 78 + 13.5 $\log_{10} W_m$ db re 10^{-13} watts, where W_m is the rocket jet stream mechanical power in watts. Also given is an approximate generalized power spectrum dependent upon nozzle diameter and jet flow characteristics. These correlations result in procedures for predicting far field noise environments produced by static-fired or launched rockets.

2417

Cole, J. N., and R. G. Powell, "Estimated Noise Produced by Large Space Vehicles as Related to Establishing Tentative Safe Distances to Adjacent Launch Pads and the Community," MRL Memo. No. M-2, 6570th Aerospace Medical Research Labs., Aerospace Medical Div., Wright-Patterson Air Force Base, Ohio, 15 pp., 1962.
AD-276 204.

Sound-pressure environments are presented for 19 sizes of rocket propulsion vehicles covering the pound-thrust range between 1 × 10 to the 6th power and 2.2 × 10 to the 7th power. These environments are specified in simplified form, using overall sound-pressure level as a measure, are given as a function of distance from the launch site for each of the 19 different rocket sizes. Two criteria are assumed and expressed in terms of OASPL: (1) one criterion for maximum levels tolerable by the community; and (2) a criterion for maximum levels tolerable by space vehicle or missile systems (based on Atlas/Titan type) on adjacent pads.

Caution is given that the use of OASPL's as a measure of environment or criteria is only valid on the assumption that pertinent frequency dependencies have been included in the analysis, as they are for the units considered herein. Comparison of estimated levels to assumed criteria resulted in tentative launch-hazard radii for siting of each system. The range of uncertainty in these estimates is also indicated.

2418

Cox, R. J., H. J. Parry, and J. Clough, "A Study of the Characteristics of Modern Engine Noise and the Response Characteristics of Structures," Rept. No. WADD TR 60-220, Lockheed Aircraft Corp., Burbank, Calif., 154 pp., 1961.
AD-272 210.

Jet engine noise and the response of structures to that noise were studied. The near-sound-field characteristics of a jet engine operating on the ground at both military and afterburner thrust were measured. Sound pressure levels were obtained in the near field and within the jet wake, as were pressure levels and cross-correlation coefficients. The latter two were obtained at two locations in the noise field for the free field, a rigid boundary, and a flexible boundary. Several panels, representative of typical airframe structure, were subjected to this jet engine noise. Structural response in terms of strain and accelerations was measured and analyzed. These panels were also subjected to discrete frequency excitation to determine basic response parameters. An analytical method for predicting the response of complex structures in an actual jet noise environment was developed. Predicted and measured responses were compared.

2419

Dyer, I., "Distribution of Sound Sources in a Jet Stream," J. Acoust. Soc. Am., 31, 1016-1022, 1959.

It is shown that the axial distribution of sound sources in a turbulent jet stream can be found simply in terms of the spectrum of the total radiated power and the frequency of the sources as a function of location along the jet axis. With the use of existing data on the sound-power spectrum and recently reported but preliminary data on the frequency dependence of the most probable source location, an approximate axial distribution is derived. The derived distribution agrees with calculations by Sanders (Gen. Eng. Lab. Rep. No. 57 Gt222, General Electric Company, 1957) based on turbulence measurements, and with calculations by Ribner based on Lighthill's theory [see J. Acoust. Soc. Am., 30, 876, 1958; Proc. Roy Soc. (London) A, 222, 1-32, 1954].

2420

Emmitt, M., "Fundamental Study of Jet Noise Generation and Suppression, Volume II. Bibliography," WADD TR 61-21, Rept. for Feb.-Dec. 1960, Armour Research Foundation, Chicago, 67 pp., 1961.
AD-264 682 and AD-264 919.

The bibliography is divided into two parts. The first part (AD-264 919) consists of unannotated references chosen from the 1150 documents which were evaluated during the program, and which are considered to be significant contributions to the basic subject categories mentioned above. These references are arranged chronologically by year and within each year alphabetically according to author. The second part consists of annotated references which were essential to the theoretical discussions to be found in Volume I. They are arranged alphabetically according to author. The name or names of the scientific personnel who selected each reference follows each annotation.

2421

Fakan, J. C., and H. R. Mull, "Effect of Forward Velocity on Sound-Pressure Level in the Near Noise Field of a Moving Jet," Tech. Note No. D-61, NASA, 16 pp., 1959.
AD-227 291.

An in-flight investigation of the near-field noise along the boundary of an aircraft-mounted jet engine was conducted over a flight Mach number range of 0.35 to 0.70 at altitudes of 10,000, 20,000, and 30,000 feet, at two and three nozzle-exit diameters downstream of the jet exit. The sound-pressure levels were found to be constant over the full Mach number range. The results of the experiment tend to substantiate predictions of the Mach number effect on jet noise production.

2422

Franken, P., "Generation of Sound in Cavities by Flow Rate Changes," J. Acoust. Soc. Am., 33, 1193-1195, 1961.

Sound generated by mass or heat-flow changes in a cylindrical cavity is considered. The special case of a high-pressure-ratio orifice is studied. Experimental results agree well with values predicted from a scaling equation.

2423

Franklin, R. E., and J. H. Foxwell, "Pressure Fluctuations Near a Cold, Small-Scale Air Jet (Measurement of Space Correlations)," Rept. No. 20182, Aeronautical Research Council, Great Britain, 9 pp., 1958.
AD-209 851.

Gives details of experimental observations on a two-inch model jet. These observations consist of velocity distributions, root mean square pressure fluctuations in the field round the jet, and space correlations of the fluctuating pressures in limited regions near the jet. The main interest lies in the space correlations that were observed by using fine-bore probe microphones and associated correlation equipment.

2424

Gavreau, V., "Pneumatic Generators of Intense Ultra-Sound," Acustica, 8, 121-130, 1960.

Toroidal whistles derived from the police whistle are described. Their operation at low pressure is discussed: oscillation of the air jet produced by the emitted sound, conditions to obtain high efficiency (30%) and pure sinusoidal tone without harmonics; and at high pressure; oscillations produced by the air jet returning to strike at its base, edge sound superposed on the other components of the emitted complex sound. The equation of whistles and the calculation of their theoretical efficiency are given. A contradiction between the theory of horns and the experimental results is no cutoff frequency. Annular exponential horns for emission of plane waves are calculated. Advantages and disadvantages of whistles and of ultrasonic sirens are given, and applications are described.

2425

Gerranrd, J. H., "An Investigation of the Noise Produced by a Subsonic Air Jet," Rept. No. 17724, Aeronautical Research Council, Great Britain, 19 pp., 1955.
AD-200 869.

To investigate the theoretical prediction of Lighthill on aerodynamic sound, measurements were made of the sound field of a one-inch air jet issuing from a long pipe. The measurements were made over a wide frequency band (30 to 10,000 cps) and in 1/3 octave bands in this frequency range. The mean Mach number at the pipe orifice was varied from 0.3 to 1.0. The dependence of the apparent position of the noise sources on frequency and jet speed was investigated. The dependence of the noise intensity upon jet speed is examined in terms of the power law relation: $\overline{P^2}$ a M^n. The spectrum of the acoustic power output of the jet derived by integration of the measured noise intensity is found to be extremely flat. The acoustic efficiency of the jet is found to be very small: $10^{-4}M^{4.2}$ in the frequency band from 30 to 10,000 cps. The observed noise field is well represented, qualitatively, by the Lighthill theory.

2426

Hardy, H. C., "Standard Mechanical Noise Sources," Noise Control, 5, 22, 1959.

Two types of mechanical noise sources are described, a fan and an air jet. Their use as standards for evaluating sound-power output of other noisy devices is discussed in full.

2427

Hill, R. S., and C. Armstrong, "Aerodynamic Sound in Tube Banks," Proc. Phys. Soc., Great Britain, 79, 225-227, 1962.

Brief reference is made to experiments on two-dimensional air flow through tube banks having regular geometrical arrangements. At certain well defined velocities through the bank, intense acoustic noise is produced. With the arrangements described, it is shown that the frequencies of these sounds cannot be predicted either by vortex shedding (Lighthill) or in terms of the Strouhal number. It is concluded that the units to be considered for producing the sound are the velocity of the air-flow and space between two consecutive rows of tubes. This conclusion is further supported by the observed absence of sound in a "single-row" experiment.

2428

Hubbard, H. H., and L. W. Lassiter, "Experimental Studies of Jet Noise," J. Acoust. Soc. Am., 25, 381-384, 1953.

The mixing region of a jet is observed to be a complex noise generator. The noise produced is highly directional and is affected by various geometric and flow parameters as well as by conditions in the settling chamber upstream of the nozzle. Noise measurements for a family of circular-model air jets, ranging in diameter from 3/4 to 12 inches, are consistent with available data for a turbojet engine.

The intensity of the fluctuating pressure field near the jet is greatest at an axial distance of approximately two diameters downstream from the nozzle exit, and generally decreases with increasing distance. The frequency spectrums recorded near the jet boundary are usually peaked, the peak frequencies being higher near the jet exit than at points farther downstream. These noise frequencies generally increase with increasing jet fluid velocity and decrease with increasing jet size. Hot-wire surveys of turbulence (axial velocity fluctuation) in the jet stream indicated spectra which were very similar in quality to the noise spectrum recorded outside the jet boundary and at the same axial stations.

2429

Ingard, U., and G. C. Maling, "Noise Generated by Two Interacting Air Jets," J. Acoust. Soc. Am., 31, 1031-1033, 1959.

It has been observed that the excess noise generated as a result of the interaction or mixing of two small air jets is considerably greater than the noise produced by the individual jets. The interaction noise produced by jets that lie in the same plane has been measured for jet intersection angles between 0 and 180°. Similar measurements have been made as a function of jet separation by using two jets that intersect at a 90° angle but do not lie in the same plane.

2430

Kamps, E. C., "Statistical Evaluation of Near-Field Sound Pressures Generated by the Exhaust of a High-Performance Jet Engine," J. Acoust. Soc. Am., 31, 65-67, 1959.

The operation of modern, high-performance turbojet engines creates an environment that promoted rapid structural fatigue in many areas in jet aircraft. To facilitate the simulation of a valid test environment and, therefore, enable fatigue-resistant structures to be readily developed, the characteristics of the near-field sound pressures created by the jet stream must be established. This study is concerned with the establishment of the level and the rate of occurrence of peak pressures in relation to the commonly measured rms level. A method is presented which enables the determination of these qualities from rms sound pressures generated by the jet exhaust of a General Electric CJ805 turbojet engine. Noted conclusions: (1) occurrence of peak pressures does not follow a Rayleigh Distribution; (2) peak pressure distribution is not altered by the physical position related to the jet stream nor does it appear to be a function of frequency; (3) a maximum of ratio of peak to rms pressure is shown to exceed four, but a physical limit is not established.

2431

Kling, R., and J. Crabol, "The Production of Ultrasonic Waves by Gas Jets" (in French), Compt. Rend., 229, 1209-1211, 1949.

Hartmann's modification of the Galton whistle may be further modified to produce ultrasonic vibrations in air. In Hartmann's siren, an air jet is directed at a hole in a rigid diaphragm that forms a resonant cavity, and then impinges on a flexible membrane. By this means, an air pressure of 1.2 kg/cm^2 gives a frequency of 34 kcs with a jet orifice of 1.5 mm diameter. When the resonance cavity is replaced by an arrangement in which the air jet impinges directly on the center of a rigid plane disc, a jet orifice of 0.8 mm diameter, placed 2 mm from the disc gives a frequency of 220 kcs when an air pressure of 4.1 kg/cm^2 is used. A Hartmann siren operated at this pressure, and fitted with an orifice and resonator of 0.7 mm diameter, will not give frequencies > 126 kcs.

2432

Kling, R., and O. Guillou, "On Certain Characteristics of Ultrasonic Emission from High-Speed Gaseous Jets" (in French), Compt. Rend., 230, 1736-1738, 1950.

Ultrasonic waves (frequencies 50-400 kcs) are observed when a high-speed jet emerges from an orifice into the atmosphere. The wavelength discontinuously varies with the distance of a plane obstacle from the orifice, as in the case of sound waves produced by slower jets. It is concluded that the production of ultrasonic waves is closely associated with the formation of vortices.

2433

Kramer, H. P., "Note on the Emission of Noise by Supersonic Jets," J. Acoust. Soc. Am., 27, 789-790, 1955.

The sound produced in a supersonic jet issues predominantly at an acute angle θ to the direction of gas flow. This is reminiscent of the Cherenkov effect, in which a charged particle passing through a medium at a speed v greater than the local speed c of propagation of electromagnetic waves, radiates light in a direction $\sec^{-1} v/c$.

The author has applied this method to the acoustical problem and shows that it is essentially equivalent to Lighthill's method (Proc. Roy. Soc. (London) A, 211, 565-87, 1952) since it consists in replacing his quadrupole source distribution in the interior of the jet by the surface pressure distribution.

2434

Kurkin, V. P., "Sound Generated by a Gas Jet Siren," Soviet Phys. Acoust., English Transl., 7, 357-358, 1962.

Describes a static gas-jet siren with movable reflector, which enables the radiator to be adjusted to the radiation maximum. The siren is a set of Hartmann gas-jet radiators joined to form a nozzle, through which gas is forced at a supersonic speed; resonators are placed in the gas jet. The nozzle and resonators are distributed radially about the throat of an annular, exponential horn.

An investigation and analysis of the mechanism for sound generation in gas-jet radiators made it possible to establish the essential laws of behavior necessary for the design of static gas-jet sirens.

2435

Lassiter, L. W., and H. H. Hubbard, "Some Results of Experiments Relating to the Generation of Noise in Jets," J. Acoust. Soc. Am., 27, 431-437, 1955.

Presents some sample experimental results relating to the nature and sources of noise in jets. Previous work is extended to include more detailed information about the jet structure. In this regard noise data are compared for jets having somewhat different turbulence profiles. High-temperature jets are noted to have different radiational patterns and to be more efficient noise radiators than are low-temperature jets. Noise data for the high-temperature supersonic jet of a rocket engine are included for comparison with those of subsonic jets. Some experiments have shown the noise levels at the low frequencies can be markedly reduced by the use of grids in the jet stream.

2436

Lee, R., "Free Field Measurements of Sound Radiated by Subsonic Air Jets," Rept. 868, David Taylor Model Basin, Washington, D. C., 15 pp., 1953.
AD-23 417.

Measurements are reported of the sound radiated by small air jets at subsonic velocities. The measurements were made in a free acoustic field to obtain the directional pattern of the radiation in half-octave frequency bands covering the 38- to 13,600-c range. Results indicated that the directivity patterns of the sound depend on the frequency. The sound pressure spectrum at any point in the noise field is dependent upon the jet velocity and azimuth angle; the entire spectrum shifts towards higher frequencies with increase in velocity and azimuth angle. Somewhat smaller values of total acoustic power than previously reported were indicated. Comparison of the present results with those obtained by other workers showed general agrrement with respect to the directional characteristics of the radiated jet noise. Certain differences were attributed to the effect of the length-diameter ratio of the nozzle.

2437

Lilley, G. M., "On the Noise from Air Jets, " Rept. No. ARC 20, 376, Aeron, Res. Council, Great Britian, 1958.
AD-206 360.

Reviews the current position of research into aerodynamic noise. The contents include: (1) Lighthill's theory of aerodynamic noise; (2) Structure of various regions of a turbulent subsonic jet; (3) Sound generated in various regions of a turbulent subsonic jet; (4) Noise emitted by a supersonic jet; (5) Experimental work on noise of subsonic air jets; and (6) Methods of noise reduction.

2438

Marsh, A. H., "Noise Measurements Around a Subsonic Air Jet Impinging on a Plane, Rigid Surface," J. Acoust. Soc. Am., 33, 1066, 1961.

Measurements are presented of the noise produced by a 1.5-in. diameter air jet, with an exit Mach number of 0.66, impinging perpendicularly on a plane, rigid plate. The overall sound power output increased rapidly, as the nozzle-to-plate separation distance was decreased. The overall sound power generated, when the plate was two diam. from the nozzle, was ten db greater than that produced with the plate removed. For a two-diam. plate separation the overall sound-pressure levels (SPL's) (measured at a radius of 24 nozzle diameters from the center of the jet exit in the horizontal plane through the jet centerline) were 15 to 18 db greater than those produced at corresponding positions with the plate removed, while for a 20-diam. separation, the increase varied between two and seven db. The spectrum of the noise changed as the separation distance was increased as follows: (a) the peak frequency decreased, (b) the pronounced peak changed to a broad one, and (c) the magnitude of the peak decreased.

2439

Mayes, W. H., "Some Near- and Far-Field Noise Measurements for Rocket Engines Operating at Different Nozzle Pressure Ratios," J. Acoust. Soc. Am., 31, 1013-1015, 1959.

Measurements of near- and far-field noise pressures are presented for a 1650-lb-thrust engine and for 6000-7500-lb-thrust engines for which the nozzle exit pressure was changed systematically in order to study the effects on the noise level and spectra. Near-field surveys indicated that the highest noise pressure occurred at about 20 exit diameters distance downstream of the nozzle, near the transition from supersonic to subsonic flow. At a radial distance of three exit diameters, the noise pressure levels varied from about 145 db just upstream of the nozzle to about 170 db downstream of the nozzle, and no consistent trends were noted as a function of nozzle-exit pressure. In general, the spectra at points downstream of the nozzle contained considerably more low-frequency noise than those measured upstream of the nozzle. It was noted that the maximum far-field noise was radiated in the downstream direction at angles of 30^{o} to 45^{o} from the jet axis. The acoustical power radiated from all nozzles averaged about 0.5% of the mechanical power of the exhaust stream, the least noise being radiated by the nozzle having an exit pressure less than atmospheric.

2440

Merle, M., "On the Frequency of Sound Waves Emitted by a High Speed Jet of Air," (in French), Compt. rend., 243, 490-493, 1956.

Jets of revolution (4, 6, 8 and 14 mm diameter) operated at pressures of the order 7 kg/cm^2 emit sound waves in which the distribution of frequency appears in five successive stages of unequal stability. These different domains are attributable to the periodic structure of the jet. If, however, the jet is bidimensional (issuing from a more or less flattened-slit orifice) this discontinuity of frequency does not exist. When square jets (in the form of a truncated pyramid) are used, two stages have been observed, the frequency of the square jet being higher than that of the corresponding bidimensional (slit) jet.

2441

Merle, M., "Sound Waves Emitted by an Air Jet" (in French), Compt. rend., 240, 2055-2057, 1955.

A supersonic jet emits sound waves that can be made visible by an optical method— striatons using a heterodyned neon lamp as a source of illumination. The stroboscopic illumination of the lamp made it possible to observe the spectral distribution of sound at different frequencies. These were as follows: (1) a spherical emission of sound propagated in a direction opposite to that of the jet and centered at the orifice of the jet; a second emission of sound of the same frequency is propagated in the same direction as the jet and visibly centered on the fourth or fifth striation, where the jet ceases to possess a periodic aspect and becomes turbulent; (2) an emission normal to the jet of frequency double that in (1), but feebler and narrower; (3) four directed beams of frequency the same as in (2), two directed forwards and two backwards, relative to the direction of the jet.

2442

Michelson, I., "Theory of Vortex Whistle," J. Acoust. Soc. Am., 27, 930-931, 1955.

The characteristic feature of Vonnegut's vortex whistle is the proportionality of pitch to rate of flow (B. Vonnegut, J. Acoust. Soc. Am., 26, 18, 1954), in contrast to more common types of whistle, in which geometry determines the pitch. A formula for the performance of vortex whistles was proposed by its discoverer on the basis of tests; this article confirms the formula, on the basis of elementary physical considerations that show that high velocity and multi-dimensionality of the jet are essential.

2443

Modlin, Jr., C. T., and P. M. Edge, Jr., "Model Studies of Jet Noise Generation," Sound, 36 pp., July-August, 1962.

Describes some studies relating to means of increasing the noise generated by jets to enhance their use as laboratory noise sources in research and environmental testing. A series of special nozzles having two-inch exit diameter and incorporating several types of upstream bands were investigated over a range of temperatures up to 700°F. Over-all sound-pressure levels and one-third octave-band spectra were measured in the near and far noise fields. Compared with conventional converging nozzles, those incorporating upstream bands result in increases of up to 15 decibels in the overall sound-pressure levels in the near field. Some further increases are obtained as a result of increasing the air temperature. Significant changes in the spectra are also noted and described.

2444

Monson, H., and R. Binder, "Intensities Produced by Jet-Type Ultrasonic Vibrators," J. Acoust. Soc. Am., 25, 1007-1009, 1953.

Intensity and frequency measurements were made with different jet-type generators. High values of intensity were reached at certain nozzle inlet pressures, certain cup positions, and with certain proportions of the generator.

2445

Moretti, G., and S. Slutsky, "The Noise Field of a Subsonic Jet," Tech. Rept. No. 150, Gen. Appl. Sci. Labs., Inc., N. Y., 165 pp., 1960.
AD-236 386.

The acoustical far field of a singularity is investigated under several different conditions of the medium. The simple cases of a source in an infinite wind, as observed at a fixed or a moving point, are analyzed to permit comparison with physical systems of practical interest, e.g., analysis of jet-engine fly-by noise. Misunderstanding of the Lighthill Mach number dependence was clarified by means of this analysis. The far field of a singularity imbedded in a jet is determined as a function of jet velocity and temperature distribution, with special emphasis on the case of uniform distribution in the jet.

Comparison of experimental results is made and fair agreement noted. Factors involved in failure to obtain complete agreement are discussed.

2446

Mull, H. R., Effect of Jet Structure on Noise Generation by Supersonic Nozzles," J. Acoust. Soc. Am., 31, 147-149, 1959.

In this study the near-noise field of a supersonic jet (Mach 2.87), exhausting into quiescent air, is analyzed with respect to the aerodynamic structure of the jet. The noise field is shown to shift away from the jet exit with the most intense sound near the end of the supersonic portion of the exhaust structure. Downstream of this point, the jet radiates noise in the same manner as a subsonic jet.

2447

Nyborg, W. L., "Self-Maintained Oscillations of the Jet in a Jet-Edge System, I.," J. Acoust. Soc. Am., 26, 174-182, 1954.

A theory is presented for the self-maintained transverse oscillations that arise in a low-velocity jet as it plays upon an obstacle, thus generating edge tones. It is assumed that transverse forces act on each particle of the jet as it travels toward an obstacle, and that this force is due to "sources" of hydrodynamic origin localized near the obstacle. The law of motion is set up in the form of an integral equation involving unknown functions for the force field. It is shown that a number of important properties of jet-edge systems and of the edge tones they produce can be deduced from the equation, even for highly simplifying trial assumptions about the unknown functions.

2448

Nyborg, W. L., C. L. Woodbridge, and H. K. Schilling, "Characteristics of Jet-Edge-Resonator Whistles," J. Acoust. Soc. Am., 25, 138-146, 1953.

A jet-edge-resonator (JER) whistle consists essentially of a jet-edge (JE) system, such as may itself produce edge tones, and a resonator. Sound fields generated by such sources are described, as well as dependence of various aspects of these fields on airflow and whistle dimensions. Empirical findings are interpreted in terms of independently determined properties of JE systems and of resonators. A method is described for adjustment of a given whistle to maximum or near-maximum output for a given frequency; typical output data so obtained are presented for each of several models. Approximate values are also given for the modulation coefficient M for various circumstances. This quantity is an index of effectiveness with which steady flow into a whistle is converted into a sinusoidally varying flow out of its mouth.

2449

Nyborg, W. L., M. D. Burkhard, and H. K. Schilling, "Acoustical Characteristics of Jet-Edge and Jet-Edge-Resonator Systems," J. Acoust. Soc. Am., 24, 293-304, 1952.

A jet-edge (JE) system is an arrangement whereby a thin blade of fluid impinges on an edge, and thus, under appropriate circumstances, gives rise to tones called edge tones. Experimental results are presented for such JE systems as might be employed in jet-edge-resonator type whistles. Operating ranges of parameters are mapped out for various possible stages of self-oscillation. Edge-tone fields are described as functions of parameters, particular emphasis being given to magnitudes and distributions-in-space of first-stage edge-tone sound fields. Examination is also made of sound fields generated by a JE system coupled to a resonator; a characteristic interaction pattern is described.

2450

Oleson, S. K., and U. Ingard, "Acoustic Characteristics of Model Pulsed Jets," J. Acoust. Soc., Am., 29, 1145-1146, 1957.

A note of general interest regarding some of the acoustical properties of model jet engines that have been found to be satisfactory sound sources for certain purposes in connection with studies of sound propagation in the atmosphere.

2451

Powell, A., "Concerning the Noise of Turbulent Jets," J. Acoust. Soc. Am., 32, 1609-1612, 1960.

The suggestion that the noise generators of turbulent jets undergo convection effects which are limited in such a way as to follow a similarity behavior leads directly to a resolution of Lighthill's paradox, namely, the problem of accounting for the noise power's depending upon the eighth power of the jet velocity simultaneously with the gross directional bias. This hypothesis is shown to be at least plausible to a first approximation because the general velocity field of the jet has typical dimensions comparable to a fraction of a wavelength; an important corollary is the expectation of appreciable refraction effects. Aspects relevant to the higher-frequency directional peaks being less -pronounced and located further from the jet axis, and of the slow frequency rise, and briefly discussed.

2452

Powell, A., "Experimental Comparison Between Noise From Unheated Subsonic Air Jets Having 4:1 Elliptic and Circular Orifices," J. Acoust. Soc. Am., 30, 642-643, 1958.

This note describes a short series of experiments investigating the nature and magnitude of the differences in the noise field from subsonic cold-air jets having circular and elliptic orifices. An anticipated increase in the noise level occurs in directions normal to the major axis, but other changes having more obscure origins are also revealed.

2453

Powell, A., "The Noise of Choked Jets," J. Acoust. Soc. Am., 25, 385-389, 1953.

The noise of a jet changes character after the pressure ratio exceeds the critical value appropriate to sonic exit velocity, the general roar being dominated by a loud "whistling" or "screeching." Schlieren photographs show that sound waves of ultrasonic frequency are caused by the transition of the initially laminary boundary layer to turbulence and also be interaction of this turbulence and the shock waves of the flow. Larger disturbances have also been noted, involving both the jet stream and some of the air external to the jet, and these also give rise to sound waves that have been photographed: it is these that are held responsible for the audible effects. A two-dimensional study has shown the latter phenomenon to be enhanced, and it is shown how the system of disturbances is self-maintained by virtue of sound waves creating initially small disturbances at the jet exit. The directionality of the soundfield has been predicted and found to agree with experiment, and the dimensions of the motion are compatible with the suggested mechanism. The relation to edgetones is pointed out, and the mechanism indicated; a photograph of this phenomenon is shown. Finally, mention is made of how the characteristic noise of jets working above the critical pressure might be reduced, the suggested methods having been found successful in practice.

2454

Powell, A., "On the Edgetone," J. Acoust. Soc. Am., 33, 395-409, 1961.

The feedback mechanism of classical low-speed edgetones, in which the action at the edge is interpreted as an acoustical source, is developed in detail. A theoretical development indicating that the acoustical field is primarily due to the dipole associated with the fluctuating fluid force on the edge has been verified. It is the hydrodynamic field of the dipole that disturbs the jet, whose instability characteristics are shown to depend acutely on the Reynolds and Strouhal numbers, and the orifice-edge distance. The gain criterion is developed in detail; it is shown how the eigenfrequencies (which can form no algebraic sequence) arise; the lower limit to the orifice-edge distance is discussed, yielding an estimate of the "linear" instability of the stream.

The amplitude of the established edgetone depends on the nonlinear behavior of large-amplitude stream disturbances and the corresponding upper limit to the edge force proves to agree satisfactorily with measurements, thus yielding acceptable expressions for the sound pressure. Multiple tones and the circumstances of the hysteretic frequency jumps are discussed. The basic action depends only on Reynolds number for geometrically similar systems, while the sound power also depends on the cube of the Mach number.

2455

Powell, A., "On the Effect of Missile Motion on Rocket Noise," J. Acoust. Soc. Am., 30, 1048, 1958.

On the assumption that turbulent mixing accounts for the major part of rocket noise, it is tentatively suggested that the rocket noise intensity at a given point on a missile varies as

$$\left[\frac{M_j - M_m}{M_j}\right]^3 (1 - M_m)^2$$

where M_j is the highly supersonic Mach number of the jet efflux relative to the exit, and M_m is the subsonic Mach number of the missile, both referred to the speed of sound in the external air. The frequency characteristics are little affected.

2456

Powell, A., "Similarity and Turbulent Jet Noise," J. Acoust. Soc. Am., 31, 812-813, 1959.

In a recent letter, Dr. Ribner noted how the assumption of simple similarity in a turbulent jet gives certain indications about the distribution of noise-generation intensity along its length. An independent analysis produced the same results, and also considered the spectral shape implied by that assumption. The latter analysis is given very briefly.

2457

Powell, A., "Theory and Experiment in Aerodynamic Noise, with a Critique of Research on Jet Flows in Their Relationship to Sound," 2nd Sympos. on Naval Hydrodynamics, 1958, U. S. Govt. Print. Office, Washington, D. C., 27 pp. 1960.

A survey of recent theoretical and experimental work on sound generation by unsteady flows where boundary effects are not important. After some comments on the basic theory, the author describes phenomena associated with discrete tones—the sensitive flame, edge tones and the sound from a choked jet. Experiments on sound generated by a turbulent jet are reviewed, and it is concluded that the technological demands on the subject considerably exceed the present understanding of it.

2458

Powell, A., "Vortex Action in Edgetones," J. Acoust. Soc. Am., 34, 163-166, 1962.

The elements essential to a new vortex theory of edgetones are described with the aid of a simple flow model valid for small edges. It is shown how both the feedback to the orifice and the sound radiation may be directly attributed to the velocity field of the vortex cast off from the edge, together with the sympathetic circulation about it. An upper limit to the intensity of the edgetone when the edge is very small is discussed; it depends on the size of the edge. It is shown how the small edge used by Lenihan and Richardson is quite adequate in size to support the flow pattern implied by the feedback explanations of the mechanism of edgetones. The theory is shown to be equivalent to the so-called acoustical one, in which the action at the edge is represented by a dipole whose strength is associated with the fluctuating force sustained by the edge.

While the rift between these two approaches to the theory of edgetones may be considered closed, it is to be noted that each may continue to have its special attractions with respect to specific requirements.

2459

Putnam, A. A., and W. R. Dennis, "Organ-Pipe Oscillations in a Burner with Deep Ports," J. Acoust. Soc. Am., 28, 260-269, 1956.

Presents data on acoustic-oscillations produced by a burner that uses a hexagonal bank of hypodermic tubes as deep ports. Most of the tests were made with ethane as the fuel, but some tests were run with methane and propane, for comparison. Both the diameter and length of the combustion chamber were varied. It was found that the combustion chamber could be considered as a driver that forced the slugs of gas in the ports to oscillate. Burning the incremental pulses of combustible mixture periodically issuing from the ports furnished energy to drive the oscillations when the pulses burned in phase with the oscillating component of the pressure in the chamber. The phasing depended on a time-lag factor that was a function of the velocity of the gases through a space, similar to dark space, between the burner ports and the mean burning points, and the width of the space itself.

The oscillations not only ceased when there was a failure to satisfy the timing criterion, but also ceased upon approach to either rich or lean blowoff limits of the conventional type. This premature cessation apparently results from the flame's burning from fewer ports as the limits are approached, less driving energy being available.

2460

Putnam, A. A., and W. R. Dennis, "Survey of Organ-Pipe Oscillations in Combustion Systems," J. Acoust. Soc. Am., 28, 246-259, 1956.

Fifty-three references from the open literature dealing with organ-pipe combustion oscillations are reviewed; these oscillations were generated by the flame, or by the combustion process, in various types of combustion systems. The many systems discussed range from simple singing-flame burners to industrial furnaces and high-duty rockets. The combustion systems are classified, for purposes of discussion, according to the basic arrangement of the components of the unit. These classes are burners with singing diffusion flames, flash tubes, gauze-tone burners, rocket-shaped burners, burners utilizing secondary air, and ram-jet type burners. The acoustical behavior of each system is described, and possible driving mechanisms for producing the observed oscillations are indicated. Some general remarks are made, based on the survey, concerning the mathematical formulation of the mechanism, to explain the oscillations in particular cases.

2461

Regier, A. A., W. H. Mayes, and P. M. Edge, Jr., "Noise Problems Associated with Launching Large Space Vehicles," Sound, 1, 7, 1962.

Engine-noise data for current large launch vehicles have been reviewed, and extrapolations have been made for future vehicles of the multimillion-pound thrust class. The results indicate that the latter vehicles will generate high sound-pressure levels at large distances from the launch site, and the noise spectra will probably peak in the sub-audible frequency range. With regard to the effects of intense low-frequency noise, reference is made to experience in the operation of a large blow-down wind tunnel and in laboratory studies of building components. A ground-building damage criterion is proposed and a brief description is given of a proposed low-frequency-noise environmental test facility.

2462

Riabouchinsky, D., "Theory of Gaseous Jets," Compt. Rend., 202, 889-891, 1936.

By making a number of simplifying assumptions, a mathematical analysis is obtained that gives the pressure and velocity distributions in a gaseous jet. An undulatory movement of the gas is indicated.

2463

Ribner, H. S., "Aerodynamic Sound from Fluid Dilatations," Rept. No. 86, Inst. of Aerophys., Univ. of Toronto, 101 pp., 1962.
AD-291 534L.

An alternative to the quadrupole theory of flow noise is given in terms of simple sources. In this view the volume of a fluid element fluctuates inversely as the local pressure: part of this dilatation generates sound and another part propagates the sound. The local pressure consists of a quasi-incompressible "pseudosound" plus the sound field (relatively weak in low-speed flows). The effective part of the dilatations appears in a virtual acoustic source strength $\sim\partial^2 p^{(0)}/\partial t^2$.

These sources are individually nondirectional. Jointly they yield a directional pattern for the sound from a turbulent jet. Some basic directionality may be provided by a statistical sorting of the dilatations. Convection tends to beam the sound into a broad downstream lobe. Finally, refraction of the sound away from the jet axis yields a heart-shaped pattern. The sorting and convection can be accounted for in the statistics (the correlation) of the dilatation pattern. The refraction is treated via a convected-wave equation. Several of these features are illustrated by examples.

2464

Ribner, H. S., "Energy Flux from an Acoustic Source Contained in a Moving Fluid Element and its Relation to Jet Noise," J. Acoust. Soc. Am., 32, 1159-1160, 1960.

It is found that a high-frequency source (or multipole) imbedded in a moving patch of fluid emits a constant acoustic power independent of the motion. (The directivity is, however, altered). This holds when the wavelength $\lambda << $ radius R' of the entire region of flow. At the other extreme, $\lambda >> 2\pi R'$, it appears that the acoustic power is enhanced by the motion, somewhat (but not exactly) as the emission of a source is enhanced by motion through fluid at rest. A typical wavelength of a radiating eddy in a jet lies between the two extremes and a limited convective enhancement of the power is inferred. The amount should be less than that predicted by Lighthill or the much more conservative values suggested by the work of Ribner; it could conceivably lie within experimental error, justifying the nonconvective law, power $\int U^8$, found by measurement.

2465

Ribner, H. S., "New Theory of Jet-Noise Generation, Directionality, and Spectra," J. Acoust. Soc. Am., 31, 245-246, 1959.

A theory of jet noise is developed from the observation that in low-speed turbulence Lighthill's quadrupoles combine to behave like simple sources $\sim\partial^2 p^{(0)}/\partial t^2$, where $p^{(0)}$ is the "incompressible" local pressure in the turbulence. An integral for the far-field intensity involves the space-time pressure covariance R within the turbulence. Choice of R in a worked example shows how pronounced directionality results from pattern "convection" (modified by fluctuation) in conjunction with the time retardation. Further directionality is accounted for in terms of a Green's function (discussed qualitatively but not worked out) for a point source at rest in the mean shear flow, describing the lateral refraction and diffraction.

SOUND SOURCES, JETS, ORIFICES, PIPES, ROCKETS, WHISTLES, ETC.

2466

Ribner, H. S., "On the Strength Distribution of Noise Sources Along a Jet," Rept. No. 51, Inst. of Aerophys., Univ. of Toronto (Canada), 26 pp., 1958.
AD-154 264.
See Also: J. Acoust. Soc. Am., 30, 876, 1958.

The spatial distribution of noise sources along a jet is investigated by application of Lighthill's theory to regions of "similar" profiles. The analysis refers to the noise power emitted by a "slice" of jet (section between two adjacent planes normal to the axis) as a function of distance x of the slice from the nozzle. It is found that this power is essentially constant with x in the initial mixing region (x^0 law), then further downstream (say 8 or 10 diameters from the nozzle) it falls off extremely fast (x^{-7} law or faster) in the fully developed jet. Because of this striking attenuation of strength with distance, it is concluded that the mixing region produces the bulk of the noise and must dominate in muffler behavior; conversely, the "fat" part of the jet must contribute much less to the total noise power than is commonly supposed.

Powell's experiments on the effects of nozzle velocity profile on total noise power are interpreted qualitatively. The behavior of multiple-nozzle or corrugated mufflers, both as to overall quieting and frequency-shifting, is also interpreted in the light of the results. The possibility emerges that such mufflers may be improved, without serious loss of thrust, by the addition of a sound-attenuating shroud.

2467

Rollin, V., "Effect of Multiple-Nozzle Geometry on Jet-Noise Generation," NASA Tech. Note No. D-770, Natl. Aeron. Space Admin., Washington, D. C., 17 pp., 1961.
AD-262 410.

An experimental investigation was conducted in order to determine the effect of changes in the geometry of multijet nozzles on noise generation. Jet-pressure ratios of 1.67 and 2.33 were investigated for three-, five-, and seven-nozzle configurations with nozzle widths of 0.5, 0.75, 1.0, and 1.5 inches. Test results showed that minimum power ratios were obtained with spacing ratios of 2.0 and 1.5 at subsonic and supersonic pressure ratios, respectively. Changing the geometrical configuration of multiple nozzles to one with a minimum power ratio produces significant reductions in the intensity of power-spectrum levels at the low- and mid-frequency portions of the spectral distribution curve. Full-scale test results agree well with the established curves.

2468

Slutsky, S., "Acoustic Field of a Cylindrical Jet Due to a Distribution of Random Sources or Quadrupoles," Tech. Rept. No. 281, Gen. Appl. Sci. Labs., Inc., Westbury, New York, 58 pp., 1962.
AD-267 032.

Describes the far field of a random distribution of sources and quadrupoles arising in an axisymmetric field of steady flow. This field is treated as one of a single harmonic oscillator. The random source distribution is described in terms of a spatial and temporal correlation function. Expressions are obtained for the mean square intensity and power spectral density of the acoustic noise field. The effect of eddy convection is not included. It is found that the assumtion of a source mechanism results in a far-field distribution which resembles those experimentally available, whereas the lateral quadrupole mechanism fails in this respect.

2469

Slutsky, S., and J. Tamagno, "Sound Field Distribution About a Jet," Tech. Rept. No. 259, Gen. Appl. Sci. Labs., Inc., Hempstead, New York, 66 pp., 1961.
AD-271 007.

A mathematical model to study the acoustic field generated by a subsonic jet in air at rest was applied to: (1) evaluation of the near-field sound intensity radiated by a source in a jet; (2) effectiveness of shielding around a jet, and its influence on sound-field directionality; and (3) the effect on the far field of nonuniformity in the jet velocity and temperature profiles.

2470

Smith, M. G., "The Behavior of an Axially Symmetric Sonic Jet near to the Sonic Line," Memo. No. (B) 70/57, Armament Research and Development Establishment, Great Britain, 15 pp., 1957.
AD-162 596.

The behavior near the sonic plane of an axially symmetric sonic jet of gas, emerging into a region of lower pressure, is studied. The form of the singularity at the sonic plane is found, and expansions in series near to the plane are found for the variables of state. The expansion for the natural logarithm of the density is compared with the corresponding solution in two dimensions. It is found that there are very important differences between the two solutions.

2471

Sperry, W. C., "Fundamental Study of Jet Noise Generation and Suppression," Rept. No. WADD TR 61-21, Armour Res. Foundation, Chicago, Vol. 1, 182 pp., 1961.
AD-264 919.

The fundamental aspects of jet-noise generation and suppression are examined and evaluated. Initially, the basic equations of acoustics and fluid dynamics are considered with respect to the usual simplifying assumptions; the non-linear characteristics that lead to increased generality are emphasized. The Lighthill theory of subsonic jet-stream noise and theories of supersonic jet-stream noise are studied and extended. The sound field surrounding a jet is analytically represented, yielding a solution that provides some insight into noise-generating mechanisms. Finally, the report includes a general review and analysis of experimental studies by others concerning jet-noise generation and suppresion.

Vol. I contains the technical details and Vol. II is a bibliography.

2472

Sperry, W. C., R. Kamo, and A. Peter, "Experimental and Theoretical Studies of Jet Noise Phenomena," Final Rept. No. ASD TDR 62-303, Armour Res. Foundation, Chicago, 163 pp., 1962.
AD 282 273.

Over-all sound pressure levels were measured in an anechoic room for noise generated by cold air flow through more than twenty different nozzle configurations, including converging, converging-diverging, slot, and annular types (the latter with and without center-core flow). The results are examined in terms of over-all acoustic power and directivity versus mass flow, and compared with various eighth-power relations. The acoustic performance of most nozzles was similar in the subsonic region. However, certain annular-type nozzles exhibited a marked superiority in the supersonic region.

Theoretical discussions are presented concerning the generation of sound and the relationship between various turbulence and statistical theories. A modified mixing-length theory is developed, showing its applicability to the generation of turbulence as well as its influence on the general equation for the forcing function. Temperature effects are included. Empirical data are given pertaining to the correlation of jet noise from circular and annular nozzles.

2473

Springer, H. S. and R. O. Olsen, "Launch Noise Distribution of Nike-Zeus Missiles," Special Rept. No. 53, Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 17 pp., 1961.
AD-261 505.

Maximum sound pressure levels averaging 115 decibels, with extreme values of 90 and 128 decibels, were measured about one mile behind the Nike-Zeus Missile Launcher for the variety of meteorological conditions occurring during four monthly tests. Additional small samples of data taken both near the launcher and two miles distant suggest a 20-decibel decline in peak noise level per mile. The decay of the noise level following peak was between two and three decibels per second for the first ten seconds. A frequency analysis of the sound level measured at launch indicates that frequencies below 125 cps are predominant. Under most meteorological conditions, the sound pressure levels at one mile behind the launcher would not be great enough to cause any structural damage or personnel injury. The levels would be above 90 decibels, however, which approach the level at which complaints of annoyance become frequent.

2474

Sutherland, L. C., and W. V. Morgan, "Use of Model Jets for Studying Acoustic Fields Near Jet and Rocket Engines," Noise Control, 6, 6, 1960.

Scale-model jets have been used to study the noise field to be expected around full-size jet or rocket engines. Sufficient experimental comparisons between relatively simple model and full-size jets have been made to validate the approach for more complicated configurations. The comparisons show good correlation of both magnitude and spatial distribution for the model jets.

2475

Sutton, R. M., "Demonstration of Beat Note and Other Phenomena," Science, 81, 255-256, 1935.

Two whistles are made from 6 cm lengths of brass tube 4 mm in internal diameter, threaded internally by a 10-32 tap. A V-shaped mouth is cut at the middle of the tube, and a piece of 10-32 screw, flattened on one side to make a narrow air passage, is fixed in the upper end to direct the air against the lip, and a movable 10-32 screw in the lower part controls the pitch. The whistles give a loud fundamental with an approximate range from 2500 to 5000. The whistles are connected to a T-piece, and may be adjusted to sound in unison, or to produce a beat note that rises in pitch as one of the whistles is lowered from unison. The effect of temperature is obtained by holding a lighted match under one whistle. By using coal gas to blow one whistle, the effect of gas density on pitch may be demonstrated, the two whistles being first tuned in air. The Doppler effect may also be shown. With smaller whistles at higher frequencies the beat note disappears when either whistle sounds beyond the upper limit of audibility.

2476

Thomas, N., "On the Production of Sound by Jets," J. Acoust. Soc. Am., 27, 446-448, 1955.

Gives an analysis of sound production by vortices in air jets. Specifically, the flow of air through sharp-edged orifices is considered, and it is shown how Anderson's results on the excitation of jet-tones under these conditions may be explained. The analysis also covers excitation of resonant cavities by the jet, a phenomenon giving rise to pipe-tones.

2477

Veneklasen, P. S., "Noise Characteristics of Pulse-Jet Engines," J. Acoust. Soc. Am., 25, 378-380, 1953.

Data obtained as part of a noise control program are presented to show the magnitude, spectral characteristics, directional properties, and variation with operating conditions of the noise produced by two sizes of pulse-jet engines.

2478

Vonnegut, B., "A Vortex Whistle," J. Acoust. Soc. Am., 26, 18-20, 1954.

Simple whistles have been constructed that produce sound by the escape of a vortex from the open end of a tube. The whistle operates equally well on either air or water.

When the frequency that is produced by the passage of either air or water is plotted against the volume rate of fluid flow, it is found that the frequency depends almost linearly on the rate of flow, and that the number of cycles produced by the flow of a unit volume of air is nearly the same as that produced by the flow of a unit volume of water. Measurements have been made relating the frequency of the sound produced to different pressures of air applied to the whistle.

2479

Waterhouse, R. V., and R. D. Berendt, "A Reverberation Chamber Study of the Sound Power Output of Subsonic Air Jets," Rept. No. 4912, National Bureau of Standards, Washington, D. C., 1956.
AD-156 979.
See Also: J. Acoust. Soc. Am., 30, 114-121, 1958.

The reverberation chamber technique was used to determine the sound spectra and acoustic power radiated by air jets over a range of subsonic velocities. Different air jets were used with round and square velocity profiles; nozzles of circular cross section, and nozzles with sawtooth and corrugated ends were also used. Of these nozzles only the latter type gave a significant (9 db) reduction in sound-power output for a given thrust.

A study was made of the limitations of the reverberation chamber technique caused by the absorption in the chamber. When this absorption became considerable, the measurement of sound levels in a circle around the sound source revealed a directional pattern, and the assumption of uniform energy distribution in the chamber became invalid. This situation was noticeable at frequencies above 5 kc in the National Bureau of Standards chamber, owing to air absorption.

2480

Wells, R. J., and B. E. Crocker, "Sound Radiation Patterns of Gas Turbine Exhaust Stacks," J. Acoust. Soc. Am., 25, 44-437, 1953.

Patterns of wide-band noise radiation from gas turbine exhaust stacks have been calculated, assuming negligibly low gas velocities and temperatures. Both the shape of the stack and the band width of the analyzing equipment are considered. Theoretical results are compared with data measured on models and on a proto-type exhaust system.

2481

Westley, R., and G. M. Lilley, "An Investigation of the Noise Field from a Small Jet and Methods for its Reduction—and Errata," Rept. No. 53, College of Aeronautics, Cranfield, England, 56 pp., 1952.
ATI-153 224.

Sound measurements are reported which were made on the noise from the jet of a one-inch diameter convergent nozzle at atmospheric temperature and at speeds above and below choking. The noise level and spectrum were investigated in both near and distant fields. Results agree in some measure with the predictions of the Lighthill theory, that the elementary sound radiator is an acoustic quadrupole. The agreement is more marked if attention is confined to the higher frequencies. Simple empirical formulae are derived which give the overall sound intensity and frequency spectrum in terms of the position relative to the jet, the stagnation pressure excess over the atmospheric pressure, and the frequency. Tests on various noise-reduction devices are discussed, which indicate promising lines of investigation. Maximum reduction in total noise level was about 10 db.

SOUND SOURCES, JETS, ORIFICES, PIPES, ROCKETS, WHISTLES, ETC.

2482

Williams, J. E. F., "Measuring Turbulence with a View to Estimating the Noise Field," Rept. No. 20381, Aeron. Res. Council, Great Britain, 11 pp., 1959. AD-207 235.

Suggests an experimental procedure that is designed to measure, by hot-wire techniques, the distribution of acoustical sources in an air jet. The noise producing parameters are discussed along with the capabilities of present experimental equipment, and it is suggested that the proposed experimental program is at present the only one within the scope of equipment available. A stationary reference frame is used, and it is shown that although the theory based on this system is not as revealing as Lighthill's analysis of moving axes, it is nevertheless the only one available for experimental purposes.

2483

Wolfe, M. O. W., "Near Field Jet Noise," AGARD Rept. No. 112, Royal Aircraft Establishment, Great Britain, 43 pp., 1957. AD-154 857.

This paper deals with the subject of jet-engine noise in relation to its effects on aircraft structures. Near-field noise measurements are described for a range of jet-shear velocities on two representative turbo-jet engines, one of them operating with an afterburner. Contours of equal noise pressure in the horizontal plane containing the axis of the jet are presented for a range of shear velocity for overall noise pressure and for noise pressures in 1/3-octave frequency bands in the noise spectra. In the velocity range 790 to 1800 feet per second, 400 cps is the dominant frequency. At most velocities the noise pressures at this frequency are about ten decibels less than the corresponding overall noise pressures. The increase in noise level due to reheat is not as great as would have been predicted from a consideration of the noise-level trends at much lower values of velocity without reheat.

2484

Yoshihara, H., "Rocket Exhaust into a Hypervelocity Stream, Far Field Analysis," Rept. No. ERR-AN-128, General Dynamics Astronautics, San Diego, Calif., 13 pp., 1962. AD-272 813.

The far field of a rocket jet exhausting into a surrounding medium moving at hypervelocity is analyzed; the compressible turbulent Navier-Stokes equations simplified by the boundary-layer approximations are used.

Sound Sources, Jets, Orifices, Pipes, Rockets, Whistles, etc.
See Also—18, 36, 351, 353, 541, 709, 781, 940, 960, 972, 986, 1303, 1375, 1584, 1585, 1587, 1590, 1624, 1661, 1662, 1695, 1698, 1710, 1725, 1740, 1745, 1749, 1988, 2539, 2597, 2821, 3564, 3639, 3752, 3784, 3916, 3990, 4079

SOUND SOURCES, NATURAL

2485

Astapovich, I. S., "The Power of the Sound Detonations of the Choulak-Kurgan Bolide," Byul. Turkin, FAN SSSR, 77-80, 1946.
Translation No. F-TS-8844/III, Air Technical Intelligence Center, Wright-Patterson Air Force Base, Dayton, Ohio, 7 pp.
AD-111 033.

The acoustical field produced by a meteorite's entry into the atmosphere is theoretically devolved. Mathematical evidence for the production of a shock wave followed by a decay similar to a thunder peal is shown. Detailed evidence of the Chalak-Kurgan bolide's entry and acoustical field is documented.

2486

Beals, C. S., "Audibility of the Aurora and Its Appearance at Low Atmospheric Levels," J. Roy. Meteorolog. Soc., 59, 71-78, 1933.

The author reviews former reports of these phenomena and analyzes reports he has received from reliable observers in Canada. Two types of sounds, corresponding to swishing and crackling, are distinguished, and the infrequency of the reports is attributed to the phenomenon's being rare and having local variations of audibility, while the acuteness of hearing varies among observers. The sounds are attributed to a form of brush discharge. The existence of low level aurorae is confirmed by trained scientific observers who have seen them against a recognized background.

2487

Benioff, H., M. Ewing, and F. Press, "Notes on Sound Waves in the Atmosphere Generated by a Small Earthquake," Proc. Natl. Acad. Sci. U.S., 37, 600-603, 1951. AD-4456.

Sound waves from the Imperial Valley earthquake of 24 Jan. 1951 are interpreted as the result of coupling between the atmosphere and Rayleigh waves crossing the valley. An order-of-magnitude calculation, based on the theory of air-coupled Rayleigh waves, satisfactorily explains the duration, travel time, period, and path of the sounds.

2488

Cave, C. J. P., "The Barisal Guns," Weather, 5, 149; comments by W. Hayes and J. Wadsworth, Ibid., 293; further comments by M. W. Chiplonkar and G. C. Wooldridge, Ibid., 425, 1950.

Correspondence initiated by C. J. P. Cave about unexplained booming noises in hot, still weather, known in the Ganges delta as "Barisal guns," and in Australia as "Hanley's guns."

Chiplonkar attributes the phenomena to subterranean noises transmitted through the stratosphere.

2489

Chrzanowski, P., G. Greene, K. T. Lemmon, and J. M. Young, "Traveling Pressure Waves Associated with Geomagnetic Activity," J. Geophys. Res., 66, 3727-3733, 1961.

Travelling atmospheric pressure waves with periods from 20 to 80 sec and pressure amplitude from about 1 to 8 d/cm^2 were recorded at a microphone station at Washington, D. C., during intervals of high geomagnetic activity. Trains of these waves can be expected at Washington, from a quadrant approximately centered on north whenever the magnetic index K_p rises to a value above 5. Their horizontal phase velocity across the station is usually higher than the local speed of sound. During two "red" aurorae, clearly visible at Washington, and at lower latitudes, the 20- to 80-second-period waves were accompanied by longer period, higher pressure, and much slower-travelling pressure disturbances. Observational data on the wave systems are presented and discussed.

2490

Chrzanowski, P., J. M. Young, G. Green, and K. T. Lemmon, "Infrasonic Pressure Waves Associated with Magnetic Storms," J. Phys. Soc. Japan, 17, Supplement A-II, 9-13, 1962.

Cosmic Ray and Earth Storm Conference, Kyoto, 1961, IL joint sessions. Pressure waves with predominant periods between 20 and 80 seconds and amplitudes up to 8 d/cm^2 were recorded with a quadrilateral microphone array near Washington, D.C., during intervals of high magnetic activity. These waves have a trace velocity along the earth's surface higher than the local speed of sound and show diurnal-directional properties consistent with a source on the night side of the earth. A high degree of association with large values of the planetary magnetic index K_p is established.

2491

Cook, R. K., "Strange Sounds in the Atmosphere, I," Sound 1, 12-16, 1962.

This is the first of two papers dealing with infrasound in the atmosphere, i.e., sound waves of such low frequency (below about 15 cps) that they cannot be heard. Such sounds are generated by a variety of physical phenomena, including tornadoes, volcanic eruptions, earthquakes, and magnetic storms. This paper describes certain aspects of the propagation of such waves and instruments that have been set up by the National Bureau of Standards to detect them.

2492

Cook, R. K., and J. M. Young, "Strange Sounds in the Atmosphere, Part II," Sound, 1, 25-33, 1962.

Sources of infrasonic energy propagating in the earth's atmosphere are discussed. Topics taken into consideration are microbaroms, microseisms, and the possible sources of each. Sources discussed include gravity waves, earthquake waves, magnetic waves, and tornadic storms. Several figures showing correlation of acoustical signals from various sources are included.

2493

Daniels, F. B., "Acoustical Energy Generated by the Ocean Waves," J. Acoust. Soc. Am., 24, 83, 1952.

An estimate of the order of magnitude of the acoustical energy generated by ocean waves indicates that this energy is large enough to cause an appreciable heating effect at ionospheric levels, where most of it is absorbed. Using data obtained from surface measurements of the pressure amplitude, it is found that relative density changes of the order of 1% occur at ionospheric levels, and the suggestion is made that the "twinkling" of cosmic sources of radio waves is a result of this phenomenon.

2494

Daniels, F. B., "The Mechanism of Generation of Infrasound by the Ocean Waves," J. Acoust. Soc.Am., 25, 796, 1953.

A detailed explanation is given of a mechanism by means of which the ocean waves may generate sound waves.

2495

Doroshenko, F. D., "Thunder Peal" (in Russian), Meteorol. i Gidrol., 32, 1956.

An attempt is made to explain more adequately the rolling of thunder following the first peal. Reflection of the sound from the clouds cannot explain why the rolls may be louder than the initial thunder clap. The author suggests that since the length of the lightning stroke may range from several hundred meters to several kilometers, it is natural that the sound from the various parts of the stroke cannot reach the observer at the same time. This may explain the fact that the sound of thunder is a multiple sound.

2496

Drummond, A. J., "Sound Waves and Seismology," Weather, 1, 214, 1948.

A brief reference to the October, 1946, meeting of the Geophysical Section of the Royal Astronomical Society; the discussion then concerned the investigation into the explosion at Burto-on-Trent.

2497

Fesenkov, V. G., "The Conditions of Falling of Sikhotealin Meteorite" (in Russian), Astron. Zh., 15, 190-200, 1948.

Reports of the meteor that fell in Siberia, February 12, 1947. Appearance, composition, accompanying rain of iron, speed of flight, angle of flight, explosion, and sound waves and effects are discussed. No tabulated data. A comparison is made with the Tungus meteorite of 1908 (the Great Siberian Meteor).

2498

Fleagle, R. G., "The Audibility of Thunder," J. Acoust. Soc. Am., 21, 411-412, 1949.

The relatively short range of audibility of thunder is explained by use of the observed vertical distributions of temperature and wind velocity in the neighborhood of thunderstorms.

2499

Frings, M., and H. Frings, "Sound Production and Sound Reception by Insects: A Bibliography," Penn. State Univ. Press, University Park, 108 pp., 1960.

This is a compilation of 1752 titles arranged alphabetically by author's name, covering references to insect sounds and hearing from Aristotle to the present, with complete listings through 1957. Particularly valuable are the authors' indications of the nature and subject matter of each reference. After naming the family or order of insects studied, they classify the subject as to sound production or sound reception, approach (morphological, physiological, or behavioral), type of receptor employed, method of study (casual observations, field observations, or experimental results), and whether or not analysis of the sound was performed. Unfortunately, the index incorporates very little of this arduously collected information. The reader interested in a specific topic, is confined either to the taxonomic index, which lists all references by family, or to the partial index based on the distinction between sound production and sound reception. The authors will keep this bibliography up to date with periodic revisions.

2500

Griffin, D. R., "Measurements of the Ultrasonic Cries of Bats," J. Acoust. Soc. Am., 22, 247-255, 1950.

The ultrasonic sounds emitted by bats have been analyzed with a system sensitive to frequencies from 1 to 150 kc. These sounds, used by the bats to detect obstacles by means of their echoes, consist of pulses about two msec long. Most of the measurements were made with the common little brown bat, Myotis 1. lucifugus; with this spécies the sound pressure at 40 to 55 kc, measured 5 to 10 cm from the animal's mouth, averaged 60 dynes/cm^2 (109 db on the conventional scale of sound pressure levels). The highest recorded intensity was 173 dynes/cm^2 (119 db). The frequency of the ultrasonic sound falls during each pulse by about one octave; the average frequency at the peak amplitude was 47.8 kc, while the average at the beginning of the pulse was 77.9 kc, and at the end 39.1 kc. Low frequency waves (about 10 kc) accompany the pulse, but their amplitude is a very small fraction (1/100 to 1/1000 or less) of the peak sound pressure at ultrasonic frequencies. The envelope form is variable; the emission is directional with most of the energy concentrated into the forward direction; and the pulses are commonly repeated at rates of 20 to 30 per second.

2501

Hart, J. C., "Ambient Acoustic Noise at High Altitudes," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 195-212, 1961.
AD-408 716.

Half-octave-band spectra of high-altitude ambient acoustic noise as sampled from more than 60 balloon flights at high altitude have been examined to empirically determine the dependence of both (1) the relative frequency content of the ambient noise and (2) the overall ambient noise level upon (a) the presence of local meteorological disturbances such as thunderstorms, (b) the sound velocity profile with respect to altitude, and (c) the wind structure as a function of altitude.

Man-made acoustics signals, such as those from aircraft, have intentionally been excluded from this study in so far as these signals are strong enough to be identified. The data are believed to be meaningful between 0.1 and about eight cycles per second. Overall levels have been observed within this frequency band as low as approximately 43 db re .0002 d/cm^2 (0.03 d/cm^2); levels in the 0.25-to-8.0-cps band have been observed as low as 35 db (0.01 d/cm^2).

This work was begun with the support of Melpar, Incorporated, Applied Science Division, and completed with the support of Bay State Electronics Corporation.

2502

Hartridge, H., "Acoustic Control in the Flight of Bats," Nature, 156, 490-494, 1945.

Bats undoubtedly emit sounds of more than one frequency, and it is stated that four different kinds of sound are produced: (1) a buzz, observable only at close quarters: (2) the signaling tone of about 7000 cps, usually having a duration of about 1/4 sec; (3) the supersonic tone, which is usually in the range 40-50 kcs — This sound can be emitted at rest and in flight; it may be emitted in single pulses of about 0.01 sec, or in a number of such pulses; at rest the number may be 5-10 per sec, but in flight it increases to 20-30 per sec — (4) a click. Physical characteristics connected with the production of these sounds and with the hearing of bats are discussed, and a brief comparison is made with radar. In the latter the wavelength goes down to 1 cm and in the bat it is about 0.7 cm. The bat has the further advantage of stereophonic reception to aid in the location of obstacles.

2503

Lighthill, M. J., "Aerodynamic Noise of Turbulence as a Source of Sound," Aeronaut. Res. Council, Fluid Motion Sub-Committee, London, England, 298, 26 pp., 1950.
ATI-164 845.

A study is made of aerodynamic noise or turbulence as a source of sound, using the equations of gas dynamics and ideas from acoustics and turbulence theory. Specifically analyzed is the noise radiated into a quiescent atmosphere by a subsonic turbulent flow that has a steady mean flow. It is shown that the flow constitutes a volume distribution of instantaneous sources of sound, whence some simple interferences are drawn. But these sources largely cancel one another as far as the radiation of acoustic energy is concerned, in essentially the same way as would the oscillations of a deformable solid sphere without any change of volume or motion of the centroid. This theory is discussed in detail.

2504

Mache, H., "Causes of Rolling Thunder" (in German), SB Osterr. Akad. Wiss. Mat.-nat. Kl. Abt. II (Austria), 169, 27-34, 1960.

Earlier views regarding rolling thunder, such as echoes from clouds of water or ice particles, air masses of different temperatures or reflection from mountains, were examined and found to be faulty. The theory of the step-by-step building up of a discharge path from cloud to earth, or from cloud to cloud is described as the basis of a discharge. The main noise of thunder arises from expansion of the air that is heated when a spark flows along the discharge path, and the return of the air to the partial vacum that is created. With the irregular branching of the track and the different diameters at different points, the noise acquires an irregular intensity, with time intervals developing and the rolling of thunder resulting.

2505

Meecham, W. C., "Theory of Acoustic Propagation at High Altitudes," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 177-181, 1961.
AD-408 716.

Discusses the theory of pressure-fluctuation backgrounds at high altitudes, as observed by freely floating balloon systems. Examines the various possible sources of such backgrounds, and proposes a theoretically predicted level and power spectrum. The pressure levels of local hydrodynamic (incompressible) phenomena and the time characteristics of such effects are considered in particular. Propagated acoustic backgrounds are considered and correlation methods for separating these effects from local hydrodynamic phenomena are reviewed; the characteristics of such backgrounds, if generated by turbulence, are treated with particular emphasis on the sound power-spectrum. Emphasis is placed upon the predicted difference in spectra, from two theories (those of Kraichnan on the one hand and of Meecham and Ford on the other).

These theoretical remarks are examined in the light of actual measurements taken at high altitudes, and tentative conclusions are drawn.

2506

Mukherjee, S. M., "Landslides and Sounds Due to Earthquakes in Relation to the Upper Atmosphere," Indian J. Meteorol. Geophys., 3, 240-257, 1952.

A general discussion of the abnormal propagation of sound by earthquakes, with special reference to the earthquake of Aug. 15, 1950. A comprehensive survey of acoustical observations of this earthquake and some important previous ones is added. Travel times of abnormal sounds are computed, and their connection with the thermal structure of the upper stratosphere is briefly described.

2507

Remillard, W. J., "The Acoustics of Thunder," Tech. Memo. No. 44, Acoust. Res. Lab., Harvard Univ., Cambridge, Mass., 145 pp., 1961.
AD-253 115.

A survey was made of the extensive literature on lightning and the meteorological conditions that exist during thunderstorms. Particular emphasis was placed on phenomena that might affect the generation, development, and propagation of thunder. It was then possible to formulate mathematical models of a lightning stroke and of the lower atmosphere; these models are consistent with the phenomena, and account for long duration (or roll) of thunder. The periods between the sudden, sharp, loud sounds (or claps) of thunder, which are predicted by these models, are shown to agree well with observational data.

Theoretical analysis predicts the existence of an invariant characteristic of the frequency spectra of thunder. A method was developed for obtaining such spectra, then a typical frequency spectra was deduced from the theoretical sound radiated by the model source, and the invariant characteristic (the product of the observation distance and the dominant frequency) was calculated. This value agrees well with the corresponding quantity taken from measurements of actual thunder.

2508

Richardson, E. G., "Sound and the Weather, Part I," Weather, 2, 169-173, 1947; "Part II," Ibid., 205-210, 1947; Comment by P. Rothwell and reply by E. G. Richardson, Ibid., 3, 1948.

Some of the results of British research. Considers noises caused by meteorological agencies and the propagation of sound, both normal and abnormal.

2509

Roberson, R. E., "Random Noise in an Attenuating Fluid Medium," J. Acoust. Soc. Am., 23, 353-358, 1951.

It is assumed that acoustical background noise is caused by a distribution of random "white" noise sources whose physical mechanism is unspecified. A law expressing the amplitude-distance attenuation characteristic of the medium is also assumed. Several distributions of noise sources are considered: uniform volume distributions, uniform surface dipole distribution, and two mixed cases. The noise drop-off at a point below the surface is found for each case. For an infinite volume of noise sources, this drop-off is 6 db/octave at all frequencies. It is shown how this simple model can be generalized to other attenuation laws and other spatial and amplitude distributions of noise sources.

2510

Saby, J. S., and H. A. Thorpe, "Ultrasonic Ambient Noise in Tropical Jungles," J. Acoust. Soc. Am., 18, 271-273, 1946.

A description of equipment, experimental procedure, and data obtained on field trips into the jungles of Panama. The acoustic intensity level of ambient, jungle background noise was monitored and measured for 24-hour periods. Data is reported on an intensity-per-cycle basis (db above 10^{-16} watts per cm^2) for the frequency range of 8-25 kc, and on a broad band basis for the two regions 0-10 kc and 15-25 kc. The band from 0-10 kc varies in intensity from about 50 to 60 db with a slight broad peak at nightfall. The region from 15-25 kc is at a much lower average intensity level, but with a peak rising to 45 to 55 db at nightfall. Observations and analysis of data indicate that most of the ultrasonic noise was made by insects.

2511

Spandock, F., "Noise of the Wind and the Carry of Sound in the Free Atmosphere" (in German), Z. Angew. Phys. 3, 228-231, 1951.

It is considered that wind noise arises from turbulence and has a falling-off spectrum for both low and high frequencies. From measurements of screening of wind noise and of its influence on the amplitude, the distribution of sound in consequence of the sheltering effect has been calculated. On the basis of the fact that the frequency change of wind noise and the excitation of waves in the ear are similar, the possibility is discussed that the ear adapts itself to the conditions in the free atmosphere.

2512

Suzuki, S., "Aeolian Tones in a Forest and Flowing Cloudlets over a Hill," Weather, 13, 20-25, 1938.

The notes heard when the wind blows through a pine forest are caused by the shedding of vortices with a certain frequency that depends on the wind speed. These sounds are called "matsukaze" in Japan. Examples of similar vortices in lees of hills or bullrushes are cited (Karman vortex streets). The same effects are produced by a rod in running water or a coin or plate sinking in water. Periods observed in these instances are checked against Reynolds number, Stroubal number, etc. The lee clouds showing the Stroubal effect are not the same as those due to standing waves, as they are moving with the stream.

2513

Tillotson, E., "Microseisms and Atmospheric Oscillations," Nature, 160, 321-322, 1947.

A short review is given of investigations into the nature and origin of microseisms. They appear always to originate in areas of low barometric pressure at sea, and since 1943 storms in the Caribbean Sea have been tracked by seismographical observations made simultaneously from three stations (Florida, Cuba, and Puerto Rico).

2514

Voznesenskii, A. V., "Falling of a Meteorite on June 30, 1908 in the Upper Part of Khatanga Basin" (in Russian), Mirovedenie, 14, 25-38, 1925.

The fall of this meteorite was recorded by Magnetic-Meteorological Observatory, Irkutsk, as a light earthquake. From these data, the place of fall was estimated to be in the upper part of Khatange River region, 893 km from Irkutsk. Earth tremblings were noted at other points in radius 800 km, and powerful air waves were observed over a radius of 900 km. Sounds of the explosion were heard at a distance of 1350 km. From evaluating various records, the size of the meteorite and the speed of its fall are estimated.

2515

Wegener, A., "The Detonated Meteor of April 3, 1916, 3 1/2 Hours After Noon in Kurhessen" (in German), Gesellschaft zur Beforderung der gesammten Naturwissenschaften, Marburg, 14, 1-83, 1917.

Reports detailed observations made of the incident at various points, including physical phenomena, the trail, etc., and the sound. Zones of silence observed after this occurrence between Narburg and Cassel. Two earlier instances cited, supporting the hypothesis of the occurrence of an outer zone of audibility.

2516

Wescott, J. W., "Acoustic Background at High Altitudes," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 182-194, 1961.
AD-408 716.

The power spectrum of acoustic background noise at altitudes of 60,000 feet has been determined with balloon-borne acoustic detectors, a data link and recording system, and spectrum analyzers. Background levels are surprisingly high with acoustic pressures of 0.2 d/cm^2 persisting at frequencies below 5 cps. The acoustic energy spectrum falls off as the second power of frequency.

Flights have been made with double detectors, one hanging on a long cord below the other. Cross-correlation of the resulting data indicates that a significant portion of it propagates from lower altitudes. The most probable sources of this acoustic energy are turbulent eddies caused by wind shear.

In addition to background noise some specific signals have been detected. Analyzed samples are presented. Some observed Doppler effects suggest a possible method for measuring the absorption of sound in air at low frequencies.

2517

Whipple, F. J. W., "The Detonating Meteor of October 2, 1926," Meteorol. Mag., 61, 253-258, 1926.

Presents details of the occurrence with the idea of investigating upper air temperatures. Some not-completely-satisfactory evidence of audibility in an outer zone is shown.

2518

Whipple, F. J. W., "The Detonating Meteor of September 6, 1926; An Instance of an Outer Zone of Audibility," Monthly Notices Roy. Astron. Soc, Geophys. Supplement, 2, 89-96, 1928.

Offers evidence of an outer zone of audibility in the case of this detonating meteor. Observations are analyzed to derive information with regard to the velocity of sound in the upper atmosphere. No final conclusions are drawn, but the observations for areas in which there were audible detonations are valuable. Figures show hypothetical sound rays from sources 32 and 40 km above ground. Zones of silence and of normal and abnormal audibility are discussed, and further evidence is provided for the existence of high temperatures in a certain region of the upper atmosphere.

2519

Whipple, F. J. W., "The Great Siberian Meteor and the Waves, Seismic and Aerial, Which it Produced," Quart. J. Roy. Meteorol. Soc., 56, 287-304, 1930.

Six microbarograms show pressure oscillations at British stations, June 30, 1908, the day of the fall of the Great Meteor north of Kansk, Siberia. Brief descriptive accounts at the time are translated from the Russian. The investigation made in 1921 by the geologist, Kulik, is noted, as are accounts from local sources on the meteor's appearance. The pressure and sound waves are reported to have broken windows, sucked up clods of earth, felled trees, etc. Seismological records are given for Irkutsk, Tashkent, Tiflis, and Jena, and reports of the shock as it was felt in surrounding regions. The microbarograms made in England are analyzed as to time and the speed of travel of the wave. The rate of travel of the air waves is discussed; equations are given for calculations of the energy of the air waves.

2520

Zamorskii, A. D., "Thunder During a Clear Sky" (in Russian), Meteorol. i Gidrol., 37-38, 1955.

In connection with a distant thunderstorm, a deafening thunder without any peals or lightning was heard in Leningrad on July 12, 1954, at 20 hours (Moscow time) on a sunny day with the clear sky near the zenith. A detailed description is given of the clouds before, during, and after the occurrence of this phenomenon. The distance of possible lightning was estimated at 500 m, but the height of rain clouds in part of the sky was approximately 5 km. Simultaneous weather observations at the Leningrad weather station are given. An analysis of the cloud front and rain conditions leads to the conclusion that the thunder was of distant origin.

2521

Zhivlyuk, Yu. N., and S. L. Mandel'shtan, "The Temperature of Lightning and Force of Thunder," Soviet Phys. JETP, English Transl., 13, 338-340, 1961.

The temperature in the lightning channel was measured by a spectroscopic method with the help of the N II and O II lines, and a value T = 20,000^o was obtained. This value agrees well with the results of a calculation based on the hydrodynamic theory of development of the spark channel. The hydrodynamic model was further used to calculate the force of the thunder, i.e., the pressure on the front of the shock wave. Excess pressures are obtained which in a number of cases may lead to destruction of objects located a few meters from the lightning.

Sound Sources, Natural
See Also——452, 453, 515, 844, 906, 924, 1715, 1750, 1760, 1764, 1806, 2074, 2374, 2868, 2886, 2898, 2918, 3095, 3245, 3270, 3274, 3279, 3293, 3295, 3300, 3307, 3323, 4425

SOUND SOURCES, SIRENS

2522

Allen, C. H., and B. G. Watters, "Siren Design for Producing Controlled Wave Forms at High Intensities," J. Acoust. Soc. Am., 31, 177-185, 1959.

On the assumption of the additivity of steady and acoustic flow characteristics, an equation was developed for the time variation of a siren port area required to produce a sinusoidal wave. If low efficiencies can be tolerated the port opening may be kept small and the operating pressure made large compared with the acoustic pressure; then the equation reveals the well-known fact that the proper port-area variation is nearly sinusoidal. For high efficiencies the operating pressure must be made to approach the peak acoustic pressure and the port-area variation must depart widely from a sinusoid if a sinusoidal pressure wave is to be generated.

A siren was designed and built to verify the assumptions. The output signal was found to be sinusoidal at the designed operating pressure, and to depart from sinusoidal as expected at operating pressures either higher or lower. Efficiency at the designed pressure was between 35 and 45%, which is between 70 and 90% of the theoretically maximal efficiency for a sinusoidal sound generator, of the siren type, using a dissipative valving mechanism.

The derived equation might be used to determine the port-area variation of a siren for generating a chosen nonsinusoidal wave form by substituting, within limits, the expression for the desired wave in place of the sine function.

2523

Allen, C. H. and B. G. Watters, "Siren Design for Producing Controlled Wave Form with Amplitude Modulation," J. Acoust. Soc. Am., 31, 463-469, 1959.

A siren has been developed that permits the generation of a sound-pressure wave with harmonics more than 15 db below the fundamental over a broad frequency range and over a range of power output exceeding 40 db. The large dynamic range was obtained by the use of a shutter that changes the maximum open area of the siren ports and simultaneously alters the time variation of area so that the output signal remains substantially sinusoidal at any shutter position. The shutter can be operated rapidly to provide a means for programed amplitude-modulation of the output signal with a minimum of harmonic distortion.

2524

Arnold, J. S., and A. Picker, "The Modification of a Warning Siren to a Modulated Airstream Loudspeaker," Final Tech. Rept., Stanford Res. Inst., Menlo Park, Calif., 83 pp., 1961. AD-272 937.

The feasibility of modifying a warning siren to add speech capability was demonstrated by adding a modulated airstream loudspeaker to the siren. The siren's air supply and control circuit were used by the loudspeaker, with appropriate auxiliary equipment and minor modifications of the existing siren. Using a recorded-speech input, an average sound pressure level of 117 db was achieved on the horn axis at a distance of 100 ft. At a distance of 675 ft (limited by terrain) observers reported that the sound was loud, clear, and intelligible. Extrapolation of the data indicates that speech is intelligible within a maximum range between one and two miles, depending on ambient noise and other conditions.

2525

Bolt, Beranek, and Newman, Inc., "Wide Band Sound Source for WADD Sonic Facility," Summary Analysis Rept. WADD TR 61-109, Cambridge, Mass., 66 pp., 1961. AD-266 342.

The following were concluded regarding a wide-band sound source: (a) The gas-fuel-powered wide-band acoustic generator is feasible and probably practical in the 100 kw (net) power range. There is no apparent reason why much higher power ratings could not be considered. (b) The optimum acoustic efficiency is obtained with tandem-type devices operating at high inlet charge density, low fuel energy, and low compression ratio so as to avoid excessive exhaust temperatures. The air-spring device is much less efficient but can use high-energy fuels and high compression ratios. (c) The exhaust temperatures can be lowered by injection of secondary air at low (close-to-atmospheric) pressure. (d) The discussion was based on acetylene, but butane, coke-gas or methane would probably be satisfactory. There appears to be no advantage in the use of hydrogen, which was disqualified because of its detonation characteristics.

2526

Cole, J. N., R. G. Powell, H. L. Oestreicher, and H. E. von Gierke, "Acoustic Siren for Generating Wide-Band Noise," J. Acoust. Soc. Am., Bio-Acoustics Branch, Aerospace Medical Res. Labs., Wright-Patterson Air Force Base, Ohio, 35, 173-191, 1963.

Principle, theory, and an experimental development program for a new type of siren, capable of generating wide-band noise, are discussed with special emphasis on its application to the economic and realistic simulation of high-intensity jet and rocket-noise environments. In contrast to conventional sirens with a single rotor, this wide-band noise siren uses a series of overlapping, slotted rotors rotating at different speeds to produce the modulation of an air flow through a nozzle. Mathematically, the sound field generated by this siren can best be approximated by an "almost periodic" function; that is, a function whose spectrum is a line spectrum but with infinitely many lines in each interval of frequency. A series for the power spectrum can be derived and used to guide the design. For most practical purposes, the resulting acoustic field radiated by the siren represents random noise. Data on acoustic power, spectrum, efficiency of noise generation, and fine structure of the noise for various experimental siren types are presented. The potential value of this principle for large-scale installations (sonic fatigue and missile-component testing and bio-acoustic applications) is evaluated.

2527

Durand, F. L., "High Intensity Pure Tone Sound Generator Capabilities During Anechoic and Reverberant Operation," AMLR Memo. No. M-17, Biomedical Lab., Aerospace Medical Div., Wright-Patterson AFB, Ohio, 50 pp., 1962. AD-289 675.

A high intensity siren was constructed. Although this sound source was designed to cover the frequency range from 10 c to 200 kc, this evaluation was made to establish its capabilities within the audio-frequency range. In the anechoic chamber, the maximum SPL was recorded at 2.5 ft. from the tip of the cone, and at frequencies above 2500 c, levels of 160 to 165 db were recorded. The decrease in level beyond that point closely followed the "inverse square law," i.e., 6 db drop per doubling of distance. It was found that significant side lobes were present in the wave front at the lower frequencies, but at higher frequencies, the directivity pattern was reduced to a single, centrally located lobe. The siren power output was determined to be approximately 300 watts at a rotor pressure of 3 psig except for the region near 2600 c where the power output is reduced by about half. An average sound pressure level of 140 db was achieved in a reverberation chamber (approximately 4000 cubic feet volume) for the frequency range from 1 to 10 kc.

2528

Kamperman, G. W., "Design of the High Intensity Noise Test Facility," Tech. Rept. No. 58-367, Bolt, Beranek, and Newman, Inc., Cambridge, Mass., 99 pp., 1958. AD-202 561.

The facility described is for performing research and development on the prevention of noise-induced fatigue damage on electronic equipment and structures. The facility has been designed primarily for progressive wave testing at high sound intensities. A special high intensity sound source has been developed for this facility. This sound source will cover the frequency range from 50 to 10,000 cps with a maximum acoustic power output of 22,000 w. The sound source will be programmed to produce pure tones or narrow bands of noise having a controlled peak-to-rms ratio.

2529

Kamperman, G. W., C. H. Allen, et al., "Performance of Intense Acoustic Facility for Flight Vehicle and Electronic Research," Bolt, Beranek, and Newman, Inc., Cambridge, Mass. Rept. for May-Oct. 1959 on Aeroelasticity, Vibration and Noise, and Thermionics and Solid State Electronic Technology, 40 pp., 1960. AD-236 365.

A unique sonic failure research facility was constructed for testing flight vehicle structures and electronic systems in the presence of high intensity sound. The siren sound source will produce pure tones or narrow bands of noise throughout the frequency range from 50 to 10,000 c with controlled amplitude modulation from 0 to 50 c. The maximum acoustic power output is 22,000 w to produce a sound pressure level of approximately 174 db in the 1-ft-square progressive-wave test section. The performance of the facility is discussed.

2530

Kling, R., and J. Crabol, "The Production of Ultrasonic Waves by Gas Jets" (in French), Compt. Rend., 229, 1209-1211, 1949.

Hartmann's modification of the Galton whistle may be further modified to produce ultrasonic vibrations in air. In Hartmann's siren, an air jet is directed at a hole in a rigid diaphragm that forms a resonant cavity, and then impinges on a flexible membrane. By this means, an air pressure of 1.2 kg/cm^2 gives a frequency of 34 kcs with a jet orifice of

1.5 mm diameter. When the resonance cavity is replaced by an arrangement in which the air jet impinges directly on the center of a rigid plane disc, a jet orifice of 0.8 mm diameter, placed 2 mm from the disc gives a frequency of 220 kcs when an air pressure of 4.1 kg/ cm^2 is used. A Hartmann siren operated at this pressure, and fitted with an orifice and resonator of 0.7 mm diameter, will not give frequencies > 126 kcs.

2531

Kling, R., and O. Guillou, "On Certain Characteristics of Ultrasonic Emission from High-Speed Gaseous Jets" (in French), Compt. Rend., 230, 1736-1738, 1950.

Ultrasonic waves (frequencies 50-400 kcs) are observed when a high-speed jet emerges from an orifice into the atmosphere. The wavelength discontinuously varies with the distance of a plane obstacle from the orifice, as in the case of sound waves produced by slower jets. It is concluded that the production of ultrasonic waves is closely associated with the formation of vortices.

2532

Kurkin, V. P., "Sound Generated by a Gas Jet Siren," Soviet Phys. Acoust., English Transl., 7, 357-358, 1962.

Describes a static gas-jet siren with movable reflector, which enables the radiator to be adjusted to the radiation maximum. The siren is a set of Hartmann gas-jet radiators joined to form a nozzle, through which gas is forced at a supersonic speed; resonators are placed in the gas jet. The nozzle and resonators are distributed radially about the throat of an annular, exponential horn.

An investigation and analysis of the mechanism for sound generation in gas-jet radiators made it possible to establish the essential laws of behavior necessary for the design of static gas-jet sirens.

2533

Pimonow, L., "A High Power Ultrasonic Siren" (in French), Ann, Telecommun., 6, 23-26, 1951.

Discusses the utility and practical applications of detection and production of ultrasound—e.g., the high-frequency sound spectra of airplanes and the agricultural application of powerful ultrasound in the war against insects. Describes a motor-driven siren, with a rotor disk having a peripheral speed of 132 meters per second (a second model, under construction, runs at 270 meters per second). The number of teeth on the rotor is 110, and the number of revolutions is 250/sec, whence the ultrasonic frequency of 27.5 kcs can be attained. It is stated that the acoustic power radiated is about 2 kw.

2534

Soundrive Engine Co., "High Amplitude Sound Abatement Research Program," Final Rept., Los Angeles, Calif., 27 pp., 1953. AD-13 144.

A sound source (siren) was developed which is capable of delivering continuous acoustic power into a 10-in.-diameter tube at acoustic levels up to 100 kw, provided the tube temperature does not exceed 170°F. An accurate and reliable condenser microphone system was developed for continuous use in the acoustic field with pressure swings approaching 1 atm. Theories were developed for the attenuation of high-amplitude plane waves; however, the predicted attenuation rates were higher than those obtained experimentally. Preliminary measurements of water-spray influence on attenuation rates indicated no significant attenuation effect due to water spray and no clear evidence of frequency dependance. Measurements of the shunting impedance presented by a Helmholtz rêsonator placed in the 10-in.-tube wall indicated that, for an approximate 56-c low-amplitude frequency, the combination of the resonator and the downstream portion of the tube appeared resistive when the sound frequency matched the low-amplitude resonator frequency. An analysis of the standing-wave structure at this frequency for six particle-velocity amplitudes established that the impedance was given by $R = 1/2\rho_0 \frac{U_0}{S}$, where ρ_0 is the equilibrium density of air, U is the particle velocity amplitude, and S is the cross-sectional area of the neck of the resonator.

2535

Tsedilin, S. A., and V. M. Tsetlin, "A Siren for the Acoustic Coagulation of Aerosols," Soviet Phys. Acoust., English Transl., 7, 60-66, 1961.

Presents the design specifications and the gas, dynamic, and acoustical characteristics of a siren developed, assembled and tested at the State Institute of Nonferrous Metals. An investigation of the acoustical field generated by the siren in a coagulation column 610 mm in diameter showed that the acoustical energy flux reaches 3240 W at a frequency of 3.9 kcs and a distance of 3.1 meters, with a mass flow of air equal to 451 normal $meters^3$ per hour and a pressure of 699 mm Hg. The generator in question makes it possible to generate an acoustical field over the range of frequencies and sound intensity levels necessary for the acoustical coagulation of aerosols.

2536

Vyal'tsev, V. V., and V. G. Khorguani, "A Powerful Low Frequency Acoustic Siren," Soviet Phys. Acoust., English Transl., 7, 299-300, 1962.

This short article describes some of the constructional details of a low-frequency, horn-loaded acoustic siren. The siren consists of a cylindrical chamber and rotor-shaft assembly. Four rectangular exhaust openings are coupled to a catenoidal horn 4.2 meters long and having a mouth area of 8.2 square meters. The siren operates by passing compressed air through the rotating element. The working frequency range is 60 to 300 cps.

Sound Sources, Sirens
See Also—34, 331, 347, 361, 432, 965, 2725, 3801

SOUND SOURCES, ULTRASONIC

2537

Brun, E., and R. M. G. Boucher, "Research on the Acoustic Air-Jet Generator: A New Development," J. Acoust. Soc., 29, 573-583, 1957.

The structure and operation of the Hartmann air-jet ultrasonic generator has been reviewed critically, and modifications are described that substantially increase the efficiency and available power output of the original device. Experimental results are presented in confirmation of the theoretical analysis.

An important part of the development has been the employment of a secondary resonator and projecting exponential horn. A novel design using a large number of whistles in a single horn (Multiwhistle R. B.) is described. This unit has a wide frequency and power range, and has been employed in France for agglomeration of aerosols, ultrasonic drying, fog dispersal, and other interesting applications.

2538

Dolinski, S., "Production and Observation of High Frequencies by Combination of Several Low Frequencies" (in French), Compt. Rend., 229, 812-814, 1949.

After discussing the subjective and objective aspects of the formation of sum and difference tones due to the vibration of two reeds of a harmonium, the author extends the principle to the summations of any number "n" of vibrators—the summation including all possible combinations of + and - signs. Consideration is given to the application of the principle to the production of high-frequency sounds by combining several low frequencies, by a system of multiple sirens, and by a system of vibrating bars or tuning forks. Analogous observations are also made with electromagnetic waves.

2539

Ehret, L., and H. Hahnemann, "A New Sonic and Ultrasonic Generator to Produce High Intensities in Gases," Z. Tech. Phys., 23, 245-267, 1942.

Describes in detail a new generator that utilizes a resonator mounted between a membrane and a compressed-air nozzle. Intensities of the order of 1 W/cm^2, free from air flow, could be obtained.

2540

Emertron, Inc., "Scattering of Electromagnetic Waves by Ultrasonic Beams," Final Rept. No. 3, Silver Spring, Md., 112 pp., 1962.
AD-274 810.

Factors affecting the scattering of radio waves by sonic beams are discussed from the point of view of existing theory. A review of sonic sources is presented along with the detailed characteristics of the sonic generators investigated during the course of field experimentation. The millimeter wave communications equipment used as the electromagnetic source is also briefly described. Field experiments performed over an open range of 154 feet yielded no positive results in indicating that scattering of radio waves can be effected by means of sonic energy. These results cannot be considered absolutely definitive in the light of limitations imposed on the experiment by both sonic and radio equipment.

2541

Emertron, Inc., "Scattering of Electromagnetic Waves by Ultrasonic Beams," Quart. Prog. Rept. No. 2, Silver Spring, Md., 103 pp., 1962.
AD-274 809.

The results of laboratory investigations on sonic generators are reviewed. Field experiments to determine the feasibility of scattering electromagnetic waves by means of ultrasonic beams are described, along with a brief presentation of the characteristics of the radio communications equipment used in the evaluation program. The field experiments were conducted over an open range of 154 feet. No positive results were obtained. In view of the limitations imposed on the experiment by both the sonic and the radio equipment, these results cannot be considered absolutely definitive.

2542

Gavreau, V., "Pneumatic Generators of Intense Ultra-Sound," Acustica, 8, 121-130, 1960.

Toroidal whistles derived from the police whistle are described. Their operation at low pressure is discussed: oscillation of the air jet produced by the emitted sound, conditions to obtain high efficiency (30%) and pure sinusoidal tone without harmonics; and at high pressure; oscillations produced by the air jet returning to strike at its base, edge sound superposed on the other components of the emitted complex sound. The equation of whistles and the calculation of their theoretical efficiency are given. A contradiction between the theory of horns and the experimental results is no cutoff frequency. Annular exponential horns for emission of plane waves are calculated. Advantages and disadvantages of whistles and of ultrasonic sirens are given, and applications are described.

2543

Griffin, D. R., "Measurements of the Ultrasonic Cries of Bats," J. Acoust. Soc. Am., 22, 247-255, 1950.

The ultrasonic sounds emitted by bats have been analyzed with a system sensitive to frequencies from 1 to 150 kc. These sounds, used by the bats to detect obstacles by means of their echoes, consist of pulses about two msec long. Most of the measurements were made with the common little brown bat, Myotis 1. lucifugus; with this species the sound pressure at 40 to 55 kc, measured 5 to 10 cm from the animal's mouth, averaged 60 dynes/cm^2 (109 db on the conventional scale of sound pressure levels). The highest recorded intensity was 173 dynes/cm^2 (119 db). The frequency of the ultrasonic sound falls during each pulse by about one octave; the average frequency at the peak amplitude was 47.8 kc, while the average at the beginning of the pulse was 77.9 kc, and at the end 39.1 kc. Low frequency waves (about 10 kc) accompany the pulse, but their amplitude is a very small fraction (1/100 to 1/1000 or less) of the peak sound pressure at ultrasonic frequencies. The envelope form is variable; the emission is directional with most of the energy concentrated into the forward direction; and the pulses are commonly repeated at rates of 20 to 30 per second.

2544

Griffin, D. R., and H. Hartridge, "Supersonic Cries of Bats," Nature, 158, 46-48, 135, 1946.

Oscillograph studies have revealed no sign of any low-frequency component, audible to humans, in the bat's cry, so that the audible sounds mentioned by Hartridge are most likely transient components caused by the impulsive nature of the cry, which was found to be only 1-2 msec in duration, with a relatively rapid cut-off. There usually is a fall of frequency of nearly an octave during the pulse. Evidence is presented to show that the cry is not emitted through the nostrils, but that the nasal cavity may play a part in determining the envelope shape of the cry.

Hartridge raises several criticisms to Griffin's interpretations.

2545

Hartridge, H., "Acoustic Control in the Flight of Bats," Nature, 156, 490-494, 1945.

Bats undoubtedly emit sounds of more than one frequency, and it is stated that four different kinds of sound are produced: (1) a buzz, observable only at close quarters; (2) the signaling tone of about 7000 cps, usually having a duration of about 1/4 sec; (3) the supersonic tone, which is usually in the range 40-50 kcs — This sound can be emitted at rest and in flight; it may be emitted in single pulses of about 0.01 sec, or in a number of such pulses; at rest the number may be 5-10 per sec, but in flight it increases to 20-30 per sec — (4) a click. Physical characteristics connected with the production of these sounds and with the hearing of bats are discussed, and a brief comparison is made with radar. In the latter the wavelength goes down to 1 cm and in the bat it is about 0.7 cm. The bat has the further advantage of stereophonic reception to aid in the location of obstacles.

2546

Kling, R., and J. Crabol, "The Production of Ultrasonic Waves by Gas Jets" (in French), Compt. Rend., 229, 1209-1211, 1949.

Hartmann's modification of the Galton whistle may be further modified to produce ultrasonic vibrations in air. In Hartmann's siren, an air jet is directed at a hole in a rigid diaphragm that forms a resonant cavity, and then impinges on a flexible membrane. By this means, an air pressure of 1.2 kg/cm^2 gives a frequency of 34 kcs with a jet orifice of 1.5 mm diameter. When the resonance cavity is replaced by an arrangement in which the air jet impinges directly on the center of a rigid plane disc, a jet orifice of 0.8 mm diameter, placed 2 mm from the disc gives a frequency of 220 kcs when an air pressure of 4.1 kg/ cm^2 is used. A Hartmann siren operated at this pressure, and fitted with an orifice and resonator of 0.7 mm diameter, will not give frequencies > 126 kcs.

2547

Kling, R., and O. Guillou, "On Certain Characteristics of Ultrasonic Emission from High-Speed Gaseous Jets" (in French), Compt. Rend., 230, 1736-1738, 1950.

Ultrasonic waves (frequencies 50-400 kcs) are observed when a high-speed jet emerges from an orifice into the atmosphere. The wavelength discontinuously varies with the distance of a plane obstacle from the orifice, as in the case of sound waves produced by slower jets. It is concluded that the production of ultrasonic waves is closely associated with the formation of vortices.

2548

Leslie, F. M., "The Relative Output from Magnetostriction Ultrasonic Generators," J. Acoust. Soc. Am., 22, 418-421, 1950.

First, the author develops an approximate theoretical treatment of the output from the simplest type of ultrasonic generator in the form of a laminated bar. The dumbbell generator is shown to be very similar to the simple bar type, and the previously obtained relations are then employed for determining the relative output in terms of its face and neck dimensions.

2549

Monson, H., and R. Binder, "Intensities Produced by Jet-Type Ultrasonic Vibrators," J. Acoust. Soc. Am., 25, 1007-1009, 1953.

Intensity and frequency measurements were made with different jet-type generators. High values of intensity were reached at certain nozzle inlet pressures, certain cup positions, and with certain proportions of the generator.

2550

Pimonow, L., "A High Power Ultrasonic Siren" (in French), Ann, Telecommun., 6, 23-26, 1951.

Discusses the utility and practical applications of detection and production of ultrasound—e.g., the high-frequency sound spectra of airplanes and the agricultural application of powerful ultrasound in the war against insects. Describes a motor-driven siren, with a rotor disk having a peripheral speed of 132 meters per second (a second model, under construction, runs at 270 meters per second). The number of teeth on the rotor is 110, and the number of revolutions is 250/sec, whence the ultrasonic frequency of 27.5 kcs can be attained. It is stated that the acoustic power radiated is about 2 kw.

2551

Powell, A., "The Noise of Choked Jets," J. Acoust. Soc. Am., 25, 385-389, 1953.

The noise of a jet changes character after the pressure ratio exceeds the critical value appropriate to sonic exit velocity, the general roar being dominated by a loud "whistling" or "screeching." Schlieren photographs show that sound waves of ultrasonic frequency are caused by the transition of the initially laminary boundary layer to turbulence and also be interaction of this turbulence and the shock waves of the flow. Larger disturbances have also been noted, involving both the jet stream and some of the air external to the jet, and these also give rise to sound waves that have been photographed: it is these that are held responsible for the audible effects. A two-dimensional study has shown the latter phenomenon to be enhanced, and it is shown how the system of disturbances is self-maintained by virtue of sound waves creating initially small disturbances at the jet exit. The directionality of the soundfield has been predicted and found to agree with experiment, and the dimensions of the motion are compatible with the suggested mechanism. The relation to edgetones is pointed out, and the mechanism indicated; a photograph of this phenomenon is shown. Finally, mention is made of how the characteristic noise of jets working above the critical pressure might be reduced, the suggested methods having been found successful in practice.

2552

Saby, J. S., and H. A. Thorpe, "Ultrasonic Ambient Noise in Tropical Jungles," J. Acoust. Soc. Am., 18, 271-273, 1946.

A description of equipment, experimental procedure, and data obtained on field trips into the jungles of Panama. The acoustic intensity level of ambient, jungle background noise was monitored and measured for 24-hour periods. Data is reported on an intensity-per-cycle basis (db above 10^{-16} watts per cm^2) for the frequency range of 8-25 kc, and on a broad band basis for the two regions 0-10 kc and 15-25 kc. The band from 0-10 kc varies in intensity from about 50 to 60 db with a slight broad peak at nightfall. The region from 15-25 kc is at a much lower average intensity level, but with a peak rising to 45 to 55 db at nightfall. Observations and analysis of data indicate that most of the ultrasonic noise was made by insects.

2553

Trommler, H., "Ultrasonic Transmitter for Use in Laboratories and Industry" (in German), Carl Zeiss Jena Nachricht (Germany), 9, 93-105, 1961.

After briefly illustrating the various techniques for producing ultrasonic waves, describes and presents the relevant data for several ultrasonic transmitters of 400 kcs and 800 kcs. With reference to a large ultrasonic vessel, discusses the forces produced in the ultrasound field and their effects in liquids.

2554

Willard, G. W., "Focusing Ultrasonic Radiators," J. Acoust. Soc. Am., 21, 360, 1949.

Piezoelectric ultrasonic radiators made in the form of a thin spherical shell radiate spherical sound waves which come to a focus at the center of curvature of the shell, thus enabling the production of much greater ultrasonic intensity in a small locality removed from the radiator than it is possible to obtain directly at the surface of a radiator. It is here shown by ultrasonic light-diffraction pictures of the radiated soundfield that the sharpness of focus is limited by wave diffraction in the manner well known in astronomical telescopes and may be calculated by optical diffraction formulas. By the same means the radiation efficiency of different areas of the curved surface is explored and the results compared with theory. The variation of efficiency is, of course, due to the variation of the effective elastic and piezoelectric constants of the differently oriented areas.

Calculations are made of the radiation efficiency of a quartz radiator, and it is shown that a greatly improved focusing spherical radiator may be obtained by varying the thickness of the radiator to compensate for the varying frequency constant. Further, cylindrical radiators whose focusing is superior may be obtained by special orientation or by shaping thickness, or by both.

Sound Sources, Ultrasonic—see also Transducers, Ultrasonic
See Also—515, 535, 590, 882, 890, 960, 1061, 1266, 2527, 2790, 2798, 2821, 2972

SOUND SOURCES, UNCLASSIFIED

2555

Baron, P., and J. Prunieras, "Results Obtained with a Group of Sound Sources," Rept. No. 6-1-8, U. S. Coast Guard, Washington, D. C., 8 pp., 1960.
AD-242 093.

By using n identical vibrators set on a vertical line at intervals of half a wave length and operating in phase, it was possible to obtain a substantial strengthening of the sound in the median horizontal plane; by comparison with a single vibrator with an acoustical power n times greater than that of each vibrator, the resulting level increase was 10 log n. In fact, it is the pressures that are added, in phase, and not the intensities. However, it is not evident that this result, obtained close to the source, will also obtain at a distance, owing to the irregularity of sound propagation in the atmosphere. It may also be expected that, in practice, the equality of power of the vibrators and above all, the phase control, will not be achieved by reason of the very principle of operation of the vibrator, the diaphragm of which is tuned to the excitor frequency (in particular, there is a significant phase variation when it is slightly out of time). An experimental test was conducted on a facility in operation. It was found that the efficiency of the group remains the same at long range. The results obtained in the test are less favorable than expected theoretically, because one of the vibrators is so weak that it contributes nothing to the group, and another is relatively strong.

2556

Bolt, Beranek, and Newman, Inc., "Wide Band Sound Source for WADD Sonic Facility," Summary Analysis Rept. WADD TR 61-109, Cambridge, Mass., 66 pp., 1961.
AD-266 342.

The following were concluded regarding a wide-band sound source: (a) The gas-fuel-powered wide-band acoustic generator is feasible and probably practical in the 100 kw (net) power range. There is no apparent reason why much higher power ratings could not be considered. (b) The optimum acoustic efficiency is obtained with tandem-type devices operating at high inlet charge density, low fuel energy, and low compression ratio so as to avoid excessive exhaust temperatures. The air-spring device is much less efficient but can use high-energy fuels and high compression ratios. (c) The exhaust temperatures can be lowered by injection of secondary air at low (close-to-atmospheric) pressure. (d) The discussion was based on acetylene, but butane, coke-gas or methane would probably be satisfactory. There appears to be no advantage in the use of hydrogen, which was disqualified because of its detonation characteristics.

2557

Bordoni, P. G., "Approximate Methods for Studying Sound-Sources" (in Italian), Pontif. Acad. Sci., Acta, 8, 61, 1944.
See Also: Ric. Sci. Ricostruz., 15, 147-148, 1945.

The field radiated from a sphere is determined for velocity varying from point to point, in amplitude and phase, and in the case of specified pressure, as boundary conditions. On the basis of the results, more complicated boundary conditions can be dealt with by such approximate methods as screened loudspeakers.

2558

Bordoni, P. G., "The Conical Sound Source," J. Acoust. Soc. Am., 17, 123-126, 1945.

An asymptotic expansion has been derived that allows the plotting of directional and response curves for a vibrating cone in an infinite baffle. The results are compared with those pertaining to a flat disc of the same radius.

2559

Brigham, G. A., and M. F. Borg, "An Approximate Solution to the Acoustic Radiation of a Finite Cylinder," J. Acoust. Soc. Am., 32, 971-981, 1960.

Utilizing the assumption of an omnidirectional point source and varying degrees of acoustical transparency associated with a finite cylindrical shell that has rigid end caps, the authors have derived two separate approaches to the problem of far-field sound radiation emanating from a normal mode of vibration. In addition, a third approach is obtained by expanding the expressions of Laird and Cohen and applying them to a shell-band source on an infinite cylinder. Several different environments are considered for each approach, and for one of these environments, the results are compared to the experiment.

The comparison of these theories indicates that for acoustical wavelengths considerably greater than structural wavelengths and dimensions, the assumption of omnidirectional point sources and acoustical transparency is reasonable even though the source is curved and unbaffled. At higher frequencies the pressure levels and directivity in the far field are approximately independent of the transparency or opaqueness of the source, thus indicating that an equivalent transparent cylinder of infinitesimal spherical sources could give, at most, only three- or four-db cancellation effects when a single-mode excitation basis is assumed.

2560

Brown, W. N., Jr., "Theory of Conical Sound Radiators," J. Acoust. Soc. Am., 13, 20-22, 1941.

An expression is derived for the sound pressure resulting from the vibration of a conical sound radiator, and the sound field is compared with that generated by a plane piston.

2561

Burgess, R. E., "Line Source with Progressive Phase Shift," Can. J. Phys., 34, 149-150, 1956.

The integral representation obtained by Thiessen (Can. J. Phys., 33, 618-621, 1955) in evaluating the energy radiated from an acoustical line source with progressive phase shift can be expressed in a form containing tabulated functions. This simplifies calculations and enables asymptotic approximations to be made readily when $R = 1/\lambda$ is large. Some discrepancies in Thiessen's curves near $\alpha = 2$ are noted.

2562

Burgtorf, W., "A Sound Source for the Production of Short Duration Pulses," Akust. Beih. (Acoustica), 325-328, 1960.

Describes an apparatus that produces short and reproducible sound pulses by purely mechanical means. It acts as a point source of high energy.

2563

Carriere, Z., "Sound Diagrams of a Tuning Fork," Cahiers Phys., France, 16, 165-172, 1962.

The various sound sources that depend on impact are discussed, and then the measurement of local air speeds round the tuning fork by a Pitot tube is described, and diagrams showing the variation of these speeds are given. Measurements of the sound pressure round the tuning fork have also been made and the technique used is described in some detail. Sound pressure diagrams for the tuning fork used are given.

2564

Carter, A. H., and A. O. Williams, Jr., "A New Expansion for the Velocity Potential of a Piston Source," J. Acoust. Soc. Am., 23, 179-184, 1951.

The Rayleigh surface integral, giving the velocity potential for a plane-piston source surrounded by an infinite rigid flange, reduces to a line integral when the coordinates are suitably chosen. As shown by Schoch, for points within the geometrical cylinder whose base is formed by the piston surface, the line integral is expressible as a plane-wave term plus a "perturbation" integral. For external points, a different integral results. In the present work, these two complementary expressions are evaluated for a circular piston, as series of half-integral order Hankel functions in kz and polynomials in x/a; k is the propagation constant, a the piston radius, z the axial and x the radial coordinate of a field point. The resulting rigorous equation (valid for points not on the piston surface) converges for any value of ka, provided $z > a$. For large values of kz, where asymptotic formulas apply, the expression assumes a particularly simple form. Sample calculations have been made for $ka = 10$, $z = 10a$, $ka = 50$, and $z = 50a$. Also, an approximate expansion has been derived, which may be more useful than the rigorous result in paraxial regions.

2565

Catlin, J. B., and R. J. McGrattan, "Sound Radiation from a Cylindrical Shell, David Taylor Model Basin Model Study," Final Rept. No. U413-61-210, Electric Boat Div., General Dynamics Corp., 28 pp., 1961.
AD-267 030.

Describes an analytic and experimental investigation of the mechanical and acoustical behavior of a 1/7-scale submarine-like model hull section in air and water environments. A relatively new analytic approach, the point-mass technique, is utilized to determine the dynamic behavior of the model and the resulting acoustical fields. Experimental results are discussed and compared with the theoretical results.

2566

Dolinski, S., "Production and Observation of High Frequencies by Combination of Several Low Frequencies" (in French), Compt. Rend., 229, 812-814, 1949.

After discussing the subjective and objective aspects of the formation of sum and difference tones due to the vibration of two reeds of a harmonium, the author extends the principle to the summations of any number "n" of vibrators—the summation including all possible combinations of + and - signs. Consideration is given to the application of the principle to the production of high-frequency sounds by combining several low frequencies, by a system of multiple sirens, and by a system of vibrating bars or tuning forks. Analogous observations are also made with electromagnetic waves.

2567

Embleton, T. F. W., and G. J. Thiessen, "Efficiency of Circular Sources and Circular Arrays of Point Sources with Linear Phase Variation," J. Acoust. Soc. Am., 34, 788-795, 1962.

The intensity and power radiated from circular ring sources and circular arrays of point sources are derived from first principles. The shape of the radiation patterns and efficiency of power output are studied as a function of phase changes between different parts of the source and of the ratio of the over-all source dimensions to the wavelength of the sound field. These expressions are applicable to the reduction of noise from such sources as centrifugal and axial blowers and aircraft propellers. The relationship between the mathematical phase parameter and such mechanical quantities as the number of blades is described. As in the case of the linear source the radiated power drops if the phase parameter exceeds a certain critical value. However, the drop in the power for the circular source is greater than that for the line source. For the circular source alone the anomaly exists wherein the power—at most ratios of the source diameter to sound wavelength greater than about 0.6—is greater for a source "dephased" by a small amount than for one having all elements radiating in phase.

2568

Embleton, T. F. W., and G. J. Thiessen, "Efficiency of a Linear Array of Point Sources with Periodic Phase Variation," J. Acoust. Soc. Am., 30, 1124-1127, 1958.

The radiation efficiency of a uniform linear array of point sources with periodic-phase variation is evaluated. Two different types of interference are found, depending on whether the characteristic length of the phase variation is greater or less than the wavelength of the sound radiated. In its application to suction roll silencing in paper mills it is found to be less effective than a linear continuous-phase variation.

2569

Etkin, B., G. K. Korbacher, and others, "Acoustic Radiation from a Stationary Cylinder in a Fluid Stream (Aeolian Tones)," J. Acoust. Soc. Am., 29, 30-36, 1957.

The equation for the radiated sound associated with body forces in a fluid is applied to the flow past a circular cylinder. The sound field is found to be related to the oscillating lift and drag forces that act on the cylinder. Quantitative predictions are made of the directionality and intensity of the field. Some experiments were conducted both inside and outside a wind tunnel. Overall sound pressure levels and sound spectra were measured with various cylinders mounted in the test section. There is a qualitative agreement between the theory and the experimental results.

2570

Felson, L. B., "Radiation of Sound from a Vibrating Wedge," Rept. No. R-613-57, Microwave Research Inst., Polytechnic Inst. of Brooklyn, N. Y., 15 pp., 1957.
AD-155 314.

Utilizing a Green's function procedure, an exact solution for the sound pressure radiated by a vibrating wedge is obtained and cast into alternative forms convenient for computation for large and small values of $k\rho$, where k is the wave-number in the medium and the distance from the wedge apex. This investigation was prompted by a recent article by G. D. Malyuzinec who has solved this problem by an alternative, but somewhat more cumbersome technique proceeding from the general Sommerfield integral representation of solutions in wedge-shaped regions.

For the quasi-optic case $k\rho >> 1$, this report also contains expressions valid in geometric-optical transition regions, which were not explored in the above mentioned reference. The results are also directly applicable to the electromagnetic problem of radiation from magnetic currents distributed over the face of a perfectly conducting wedge.

2571

Fischer, F. A., "Ideal Forms of Electro-Acoustic Transducers and the Properties of Circuits Constructed from Them," Acustica, 6, 421-424, 1960.

The ideal forms of the four types of electroacoustic transducer are discussed. The properties of the electric quadripole that results from the mechanical coupling of two ideal transducers of similar and opposite classes are investigated.

2572

Franken, P., "Generation of Sound in Cavities by Flow Rate Changes," J. Acoust. Soc. Am., 33, 1193-1195, 1961.

Sound generated by mass or heat-flow changes in a cylindrical cavity is considered. The special case of a high-pressure-ratio orifice is studied. Experimental results agree well with values predicted from a scaling equation.

2573

Freedman, A., "Sound Field of a Rectangular Piston," J. Acoust. Soc. Am., 32, 197-209, 1960.

The amplitude and phase of the pressure in the field of a rectangular piston, assumed to be vibrating within an infinite, rigid baffle, are examined theoretically for ranges down to the order of the piston length. Various laws of behavior for this field, both on and away from the acoustical axis, are deduced. An indication is given of the errors introduced by the approximations used. Such experimental evidence as is available supports the theory. Simple means are provided for constructing curves of axial pressure amplitude and phase for any ratio of length and breadth of the radiating surface, and a method is suggested for predicting the long-range axial pressure of a rectangular piston from measurements taken well within the latter's Fresnel region.

The near fields of a rectangular and of a circular piston are compared. That of the rectangular piston produces the more useful approximation to a plane wave.

2574

Hanish, S., "The Mechanical Self Resistance and the Mechanical Mutual Resistance of an Unbaffled Rigid Disk (ka 1) Radiating Sound from a Single Face into an Acoustic Medium," Rept. No. 5538, Naval Research Lab., Washington, D. C., 52 pp., 1960.
AD-246 588.

The acoustic radiation properties of an unbaffled, rigid, oscillating disk are reviewed in the light of Gutin's theory of superposition and Bouwkamp's analysis. Two such unbaffled, rigid pistons are placed in juxtaposition in a plane and are driven with equal velocity amplitude. Formulas for the radiational characteristic and mechanical resistance to radiation of the pair as a function of separation distance are derived. From these formulas the mechanical self-resistance coefficient and the mechanical mutual resistance coefficient for separation distance are deduced. Tables of self and mutual resistance to radiation for an unbaffled, rigid disk are computed and printed in the appendix.

2575

Hardy, H. C., "Standard Mechanical Noise Sources," Noise Control, 5, 22, 1959.

Two types of mechanical noise sources are described, a fan and an air jet. Their use as standards for evaluating sound-power output of other noisy devices is discussed in full.

2576

Horton, C. W., and A. E. Sobey, Jr., "Studies on the Near Fields of Monopole and Dipole Acoustic Sources," J. Acoust. Soc. Am., 30, 12, 1088-1099, 1958.

It is shown that when an observer is not farther than one wavelength from an acoustic source, he can determine the distance to the source from measurements of the pressure and of the particle velocity of the medium. The expressions are developed using integrals of the power so that they are relatively insensitive to the pulse shape. Exact expressions are obtainable only in the case of a monopole source. However, a ratio R_2 is introduced that shows a monotonic dependence on distance in the near field; it is surprisingly insensitive to the nature of the source and to the shape of the wave. Experimental measurements are carried out for a dipole source. Agreement between the theory and the experiment is only moderate because of the difficulty in making sufficiently accurate acoustical measurements.

2577

Howes, F. S., and R. R. Real, "Noise Origin, Power, and Spectra of Ducted Centrifugal Fans," J. Acoust. Soc. Am., 30, 714-720, 1958.

Forward and backward curved blade centrifugal fans as noise sources were subjected to an extensive study, measurements being made in a duct with an acoustic termination. The data obtained support the following conclusions:
(1) The noise output from each homologous series of fans can be defined by one V-shaped specific noise power vs log-speed curve, with the minimum close to the maximum static efficiency.
(2) Fan outlet noise power at maximum fan efficiency approximates 10^{-5} times the input fan power.
(3) The noise origin is primarily blade- and air-flow boundary turbulence.

2578

Ingard, U., and D. Pridmore-Brown, "Sound Radiation from the Acoustic Boundary Layer," J. Acoust. Soc. Am., 28, 128-129, 1956.

Presents the calculation of the sound radiated from a finite rectangular plate in an infinite wall oscillating in shear motion. The order of magnitude of the intensity of this sound field is compared with that produced when the plane oscillates with the same amplitude in a direction normal to its surface.

2579

Junger, M. C., "The Physical Interpretation of the Expression for an Outgoing Wave in Cylindrical Coordinates," J. Acoust. Soc. Am., 25, 40-47, 1953.

The sound field generated by a vibrating cylinder of infinite length, whose dynamic configuration is periodic in ϕ and z, is expressed in terms of acoustical impedance ratios. It is noted that symmetrical modes of vibration are suppressed at certain frequencies because the corresponding reactive impedance is infinite, and that all z-dependent modes become nonradiating below certain cut-off frequencies, the corresponding impedance being purely reactive. Graphs are presented for the impedance ratios corresponding to certain modes.

For modes independent of z, the sound field is in the form of concentric cylindrical waves. For z-dependent modes, as the length of the plane wave increases from zero to a certain critical cut-off value, the sound field changes from a set of concentric cylindrical waves to two sets of conical waves of decreasing vertex angle; at and beyond the cut-off point, the conical waves have degenerated into a set of plane standing waves normal to the z axis. Simultaneously, the sound field has ceased being periodic in the radial direction.

Practical applications of these phenomena are suggested.

2580

Kozina, O. G., and G. I. Makarov, "Transient Processes in the Acoustic Fields of Special Piston Membranes," Soviet Phys. Acoust., English transl., 8, 49-52, 1962.

The paper discusses transient processes in the acoustic fields generated by piston-type membranes with circular, square, and triangular shapes.

2581

Kozina, O. G., G. I. Makarov, and N. N. Shaposhnikov, "Transient Processes in the Acoustic Fields Generated by a Vibrating Spherical Segment," Soviet Phys. Acoust., English Transl., 8, 53-57, 1962.

The problem considered here is a perfectly stiff sphere with membranes in the form of spherical segments on its surface. It is assumed that prior to the time t = 0 the surrounding medium and membranes are at rest and that at + = 0 the segments are set into motion according to a specified law. The transition processes involved are examined for three cases: a) one radiating segment on the surface of the sphere; b) two symmetrically situated radiating segments on the surface of the sphere, both moving in phase; c) two symmetrically situated radiating segments on the surface of the sphere, both moving in counterphase.

2582

Laird, D. T., and H. Cohen, "Directionality Patterns for Acoustic Radiation from a Source on a Rigid Cylinder," J. Acoust. Soc. Am., 24, 46-49, 1952.

The directionality patterns produced by an acoustic source located on a rigid cylinder of infinite length have been investigated for the case in which the source strength may be represented as a separable funtion of azimuth angle and axial dimension. It is observed that the pattern in a plane orthogonal to the axis of the cylinder is independent of the axial distribution of the source, and is, in fact, identical with the pattern given by Morse for a source of infinite axial extent. For the particular case in which the ratio of circumference to wavelength is 14, patterns in this plane have been computed numerically using an IBM Card-Programmed Calculator. Patterns in a plane containing the axis of the cylinder have also been investigated.

2583

Lessells and Associates, Inc., "Acoustic Emission Under Applied Stress," Prog. Rept. No. 8, Boston, Mass., 7 pp., 1960. AD-235 448.

Tests were continued on the zinc and aluminum single crystals. Strain was successfully recorded simultaneously with the occurrence of the acoustic emission and load data. The stress-strain behavior data is processed in relation to the acoustic emission. The strain information is connected with the deformation mechanics taking place within the specimen. The strain recording has the capacity to show erratic or discontinuous behavior, variation in the rate and in the degree of strain, and relative amounts of elastic and plastic strain. These peculiarities are expected to show correlation with the behavior of the acoustic emission if the mechanisms are essentially at the same level of resolution, but in any case will provide insight into this area.

2584

Lindsay, R. B., "High-Frequency Sound Radiation from a Diaphragm," Phys. Rev., 32, 515-519, 1928.

By a hydrodynamical-acoustical method a calculation is made of the intensity of the high-frequency sound radiation from a circular piston-like oscillator at a distance from the oscillator greater than 2a, where a is the radius. It is shown that there is no parallel "beam" of sound of cross-sectional area equal to the area of the oscillator, but that nevertheless most of the sound energy is contained in a cone of solid angle $\pi(0.45\ \lambda/a)^2$ steradians, where λ is the wavelength of the radiation. Solution of the problem for points at great relative distance from the source then yields a result analogous to that obtained for the Fraunhofer diffraction of light through a circular aperture. The corresponding formula is $\pi(0.61\ \lambda/a)^2$. Comparison is made between the two methods and they are shown to be essentially the same, the difference in the formulae being solely due to difference in interpretation.

2585

Lyamshev, L. M., "Aeolian Tones," Soviet Phys. Acoust., English Transl., 8, 66-71, 1962.

The effect of rod or string vibrations in a fluid stream on the generation of sound (aeolian tones) is theoretically investigated in the linear approximation. It is found that when the material densities of the rod and surrounding medium have almost the same value, and when the propagation velocity of bending modes along the rod, or of transverse modes in a string, is greater than the velocity of sound in the medium, the rod or string vibrations will contribute heavily to the radiation of sound. When an elastic object executing small vibrations is present in the fluid stream, as in the case of a perfectly rigid and immovable body of similar proportions, the intensity of the sound generated will vary in proportion to the sixth power of the flow velocity.

To calculate the spectal intensity it is enough to know the solution to the problem involving scattering of a spherical (plane) sound wave by a body situated in a fluid stream, along with the correlation function for the pressure fluctuations acting on the rod in the direction of flow. It is shown that the resultant expression for the radiational intensity, applied to the special case of a stationary rod, can be used to arrive at the well-known Blokhintsev-Yudin equation.

2586

Lyamshev, L. M., "Sound Radiation from Elastic Shells Excited by Turbulent Aerodynamic Flow," Soviet Phys. Acoust., English Transl., 7, 44-49, 1961.

Gives an approximate calculation for the field generated by infrasonic turbulent flow outside or inside thin elastic shells in the flow itself. It is shown that the calculation reduces to solving the auxiliary diffraction problem and defining the velocity or pressure-fluctuation correlation tensor in the flow and on the surface of the shell. When the auxiliary solution and corresponding correlation function are known it is only necessary to calculate the square. The mean square pressure fluctuation in the acoustic field radiated by a moving thin plate oscillating under the action of pressure fluctuations in the boundary layer is calculated approximately.

2587

Lyon, R. H., "Sound Radiation from a Beam Attached to a Plate," J. Acoust. Soc. Am., 34, 1265-1268, 1962.

Presents a computation of the sound power radiated by acoustically slow waved scattered by a beam. An acoustical radiation resistance per unit length of beam is computed, based on the radiated power and the mean square transverse-plate velocity in the absence of the beam. For a diffuse reverberant vibrational field and supported, clamped, or edge-supported lines, explicit expressions for the radiation resistance are obtained. The reduction of radiation coupling due to beam vibration is also computed.

2588

Mangulis, V., "On the Radiation of Sound from a Piston in a Nonrigid Baffle," J. Acoust. Soc. Am., 35, 115-116, 1963.

The pressure in the far field and the radiation-resistance of a piston in an infinite-plane baffle are derived when the baffle is almost rigid and the piston dimensions are either very large or very small as compared to a wavelength.

2589

Miles, J. W., "Transient Loading of a Baffled Strip," J. Acoust. Soc. Am., 25, 204-205, 1953.

The force-time history required to produce a unit step in the velocity of a two-dimensional plate mounted in an infinite baffle is determined and applied to more general velocity variations by Duhamel superposition.

2590

Nimura, T., and Y. Watanabe, "Effect of a Finite Circular Baffle Board on Acoustic Radiation," J. Acoust. Soc. Am., 25, 76-80, 1953.

The effect of a finite circular baffle board on acoustic radiation was computed by the use of the oblate spheroidal wave function developed by Kotani and by Boukamp. The directivity, power radiation, and radiation impedance of the vibrating disk with a concentric, circular baffle board are shown, together with a design diagram for a circular baffle board.

2591

Oberst, H., "Method for Generating Extremely Strong Stationary Sound Waves in Air" (in German), Akust. Zh., 5, 27-38, 1940.

A method is described for producing by resonance an acoustic pressure of about 0.1 atm. with purely sinusoidal shape of the pressure/time curve at the antinode formed at the closed end of a thin pipe connected to a pipe of larger diameter. The theory of the system and its experimental examination are discussed, and some hints for its application are given.

2592

Pachner, J., "On the Acoustical Radiation of an Emitter Vibrating Freely or in a Wall of Finite Dimensions," J. Acoust. Soc. Am., 23, 198-208, 1951.

An acoustical radiation field excited by an emitter vibrating freely or in a wall of finite dimensions is considered as superposed by two fields. The first of these is that one where the same emitter is vibrating in an infinite wall and the second is that which (a) causes the resultant field in the free part of the plane going through the wall to vanish, and (b) has a normal derivative that vanishes on the surface of the emitter and of the wall. While the first field may be considered as known from other papers, the second is computed from an integro-differential equation that follows from Rayleigh's formula.

The equations expressing the velocity potential distribution and those deduced from it are written in an abstract form by means of the Dirac bra-vectors, ket vectors, and linear operators represented by the corresponding matrices. This method of solving the given special diffraction problem of a scalar wave may be used for any mode of vibrations of the emitter and for any shape of the wall, but the computation becomes far easier if the wall is circular. It may be applied also for any wavelength of the radiated sound, but the functions expressing the dependence on the azimuthal angle and containing the Legendre associated functions of the first kind converge faster, the longer the wavelength in comparison with the dimensions of the wall.

Numerical calculations are not given. They will be adequate for the difficulty of the problem, i.e., very tedious; but they can be done, especially with the help of calculating machines.

2593

Pachner, "On the Acoustical Radiation of an Emitter Vibrating in an Infinite Wall," J. Acoust. Soc. Am., 23, 185-198, 1951.

The velocity potential distribution of a circular emitter vibrating in an infinite wall is calculated by the King method for the points immediately before the wall. The study shows the close connection between the Rayleigh formula and the King method for calculating velocity potential. The equation for the space distribution of the velocity potential expanded in spherical wave functions is transcribed into an abstract form by means of the Dirac bra-vector, the ket-vector, and the linear operator, represented by the corresponding matrices. The space distribution of the velocity potential is then computed from the known values in the plane immediately before the emitter by the well-known method of undetermined coefficients, written in its matrix form. Thereafter the space distribution of the velocity potential is determined by another, new method due to H. Stenzel. In both methods explicit expressions are given for the case of a vibrating rigid disk, membrane, and plate.

2594

Plumblee, H. E., J. S. Gibson, and L. W. Lassiter, "A Theoretical and Experimental Investigation of the Acoustic Response of Cavities in an Aerodynamic Flow," Final Rept. No. WADD TR 61-75, Lockheed Aircraft Corp., Marietta, Ga., 152 pp., 1962.
AD-277 803.

The theory is developed for the resonant frequencies and pressure amplifications of a rectangular cavity of arbitrary dimensions in a flow field. An intermediate step involves the derivation of radiation impedance for a cavity at all Mach numbers, using the concepts of retarded potential theory. Experimental results are given for small cavities tested in the subsonic regime and for cavities up to 8 in. in length at supersonic Mach numbers from 1.75 to 5.0. Comparisons are drawn between theoretical and experimental frequency and amplitude responses, indicating that the theory developed defines the problem very well.

2595

Powell, A., and A. Shulman, "Effect of Wire Resonance on Aeolian Tones," J. Acoust. Soc. Am., 34, 1146-1147, 1962.

It was found that the oscillatory flow that generates aeolian tones when a wire is exposed to a steady wind may adjust itself to the resonant frequency of the wire, if it is flexible, over a speed range of up to 10% or so in the experiments reported. The tone is then very steady and relatively strong. On each side of this range are regions where the frequency is unsteady; they lie between the resonant and the fixed-wire aeolian tone.

2596

Regier, A. A., and H. H. Hubbard, "Status of Research on Propeller Noise and its Reduction," J. Acoust. Soc. Am., 25, 395-404, 1953.

Reviews the basic concepts concerning the generation of propeller noise generation, and gives equations for calculating the noise field both near and far from the propeller. Noise from nonsteady airloads on the blades and differences in noise from the approaching and retreating blades are discussed. Effects of tip speed, number of blades, blade thickness, and blade width are considered, and it is shown that reducing the tip speed and increasing the number of blades are probably the most effective means of reducing the efficiency of noise generation and alleviating the noise problem.

Noise characteristics of such special propellers as the supersonic, dual rotating, tandem, and shrouded types are also presented. Studies of propeller weights show that substantial noise reduction on transport propellers would result in a considerable weight penalty. For the propeller-driven aircraft in the 400 to 500 mph speed range, the slower-turning, quieter propeller is likely to have better propulsive efficiency than the noisier high-speed propeller. Hence, in this speed range, the weight penalty of the quiet propeller may be offset by its higher propulsive efficiency.

2597

Roginskii, O. G., "Oscillatory Combustion," Soviet Phys. Acoust., English Transl., 7, 107-122, 1961.

Auto-oscillations that occur as a reaction between a flame and the combustible gas are surveyed thoroughly under the following headings: sensitive flames; sound acting on flames; oscillatory propagation of flames; oscillatory combustion in flows; and oscillatory combustion in engineering.

2598

Rosen, M. W., "Noises of Two Spur-Gear Transmissions," Noise Control, 7, 11, 1961.

Two conventional but precision-quality planetary-gear trains have been driven to 20,000 and 27,500-rpm speeds, with as much as 70 hp. Details of the noise measurements and a law of gear noises are given in this paper.

2599

Roux, M., "Production of Acoustic Waves as a Result of RF Breakdown of Gases and Experimental Study," Tech. Rept. No. 3, Elec. Eng. Res. Lab., Univ. of Illinois, Urbana, 170 pp., 1962.
AD-286 359.

The delayed propagation of longitudinal waves in the afterglow of a weakly ionized plasma created by a 1 μsec, high power, rf pulse at a frequency of 3000 mcs was investigated. The results show that the waves are excited during the breakdown of the gas and exhibit two different geometries. These waves can be located in space and time, by means of a photomultiplier or a separate microwave system, from the perturbation they introduce in the light radiated by the plasma or in the density of the electrons. The results show that only the type of the gas and the temperature of the electrons have a decisive influence on the propagational velocity of these waves.

By using a mixture of gases, in which the nature of the ions can be changed as a result of charge transfer, or by selectively heating the electron gas, the propagational velocity of the detected waves could be altered or controlled. In the mixture experiment, the results are in quantitative agreement and in the heating experiment in qualitative agreement with the theoretically predicted propagational velocity of a pseudo-sound wave. From these two types of experiments, which independently act on a different parameter controlling the wave velocity, it appears reasonable to conclude that the wave detected is a pseudo-sound wave.

2600

Rzhevkin, S. N., "Sound Radiators with Travelling Waves" (in Russian), Univ. of. Vestn. Mosk., 9, 3-17, 1954.

Examines the velocity potential of a sound wave excited by a rotating body, and the radiational field is discussed. This is done for a sphere, with ridges along certain meridians, and for a cylindrical radiator. The similarity between the latter and a plane-surface wave-radiator using a periodic surface structure is discussed. Some experimental results are given.

2601

Schofield, B. H., "Acoustic Emission Under Applied Stress," Lessells and Associates, Inc., Boston, Mass., Prog. Rept. No. 4, 7 p., 1959.
AD-215 047.

A considerable number of tests were conducted to develop the dual transducer technique. A method for determining the location of the source of emission is extremely important in evaluating the behavior of the emission. By measuring the delay in time between signals observed on a dual-beam oscilloscope, the approximate location of the source of emission can be determined.

2602

Schultz, T. J., "Effect of Altitude on Output of Sound Sources," Noise Control, 5, 17, 1959.

Curves are presented to show the variation with altitude of the acoustical output of several types of sound source. Theoretical justification of the curves is given.

2603

Skudrzyk, E., "Sound Radiation of a System with a Finite or an Infinite Number of Resonances," J. Acoust. Soc. Am., 30, 1152-1158, 1958.

The sound field generated by a composite vibrator consists of a wattless near field that decreases very rapidly with distance and an energy-carrying radiational field. For radiators more than half a wavelength apart, the sound fields are spatially incoherent. The radiational field of a complex sound generator can therefore be computed by adding up the energy contributions of its various radiating elements. The radiating elements can be grouped as vibrators that are small in comparison to the wavelengths, vibrators without nodal lines that are large in comparison to the wavelengths, and vibrators with a nodal-line pattern.

2604

Strasberg, M., "Radiation from Unbaffled Bodies of Arbitrary Shape at Low Frequencies," J. Acoust. Soc. Am., 34, 520-521, 1962.

A simple relation is discussed for calculating the sound pressure in the distant radiational field of an unbaffled body of arbitrary shape vibrating in an arbitrary pattern. Comparison with more exact calculations for spheroids indicates that the relation is limited to low frequencies, where the wavelength is at least ten times the major dimension of the body.

2605

Strittmater, R., L. Watermeier, and S. Pfaff, "Virtual Specific Acoustic Admittance Measurements of Burning Solid Propellant Surfaces by a Resonant Tube Technique," Memo. Rept. No. 1412, Ballistic Research Labs., Aberdeen Proving Ground, Md., 21 pp., 1962.
AD-284 554.

A resonance tube technique was used to measure the virtual specific acoustical admittance at the surface of a burning solid propellant. The admittance determined by experiments is directly related to the propellant amplificational function. Only the real part of the complex admittance is presented because of its importance in determining the acoustical power-generating capacity of a burning propellant. A cast double-base propellant, ARP, was investigated. Results are given in the frequency range from 3500 to 13,500 cps and in the mean chamber pressure range from 310 to 1030 psi. The theory that forms the basis for the analysis of data is given together with approximate working equations.

2606

Thiessen, G. J., and T. F. W. Embleton, "Efficiency of a Linear Array of Point Sources with Linear Phase Variation," J. Acoust. Soc. Am., 30, 449-452, 1958.

The radiation efficiency of a linear array of point sources with linear phase variation is solved by using different approximations for different ranges of the phase parameter. The results are compared with experimental results on small models and also on full-scale suction rolls in paper mills with different drilling patterns. The experiments agree quite closely with theory and indicate that a noise reduction of 15 to 30 db can be obtained by the choice of a substitute drilling pattern that can easily be drilled by multiple spindle machines. Design charts for choosing and evaluating drilling patterns are given.

2607

Waller, M. D., "Solid CO_2 as an Exciter of Vibrations," Nature, 148, 185-187, 1941.

The conditions necessary for the production and maintenance of loud tones by means of solid CO_2 are set forth. Tubes, rings, and other metal objects are suitable. The atmosphere must be dry or the object gently warmed. The pressure on the object should be very light and the area of contact small. The range of frequencies most easily excited is about 1000 to 4000 and depends on the mean free path of the CO_2 molecule but little on the size, shape, mass or material acted upon. The similarity to the action of a Trevelyan rocker is pointed out. Series of Chladni figures have been produced, and attention is drawn to several practical applications of the method.

2608

Watson, R. B., "Radiation Loading of a Piston Source in a Finite Circular Baffle," J. Acoust. Soc. Am., 24, 225-228, 1952.

Experimental data are exhibited for the radiation loading of a piston source enclosed in a circular finite baffle of dimensions to the order of the wavelength. A partial explanation of the data is given in terms of the directly radiated wave from the piston source, the diffracted wave arising at the edge of the baffle, and the wave arising from vibration of the baffle. The effect of flexural vibration of the piston source is shown to increase the radiation loading appreciably. Examination of the theoretical attempts to evaluate the radiation loading shows the lack of suitable expressions for calculation.

2609

Watters, B. G., "The (Sound of a Bursting) Red Balloon," Sound, 2, 8, 1963.

This article shows that the larger sizes of children's rubber balloons, well-inflated, provide convenient and useful impulsive sound sources for reverberation time measurements in room acoustics.

2610

Weyers, P. F. R., "Vibration and Near-Field Sound of Thin-Walled Cylinders Caused by Internal Turbulent Flow," NASA, Washington, D. C., 58 pp., 1960.
AD-237 717.

Noise produced by turbulent flow adjacent to the flexible wall was investigated. Measurements were taken of the spectrum and intensity of the pressure field outside thin-walled Mylar cylinders containing turbulent pipe flow. The resulting spectra could be interpreted in relation to the elastic properties of the cylinders and the character of the turbulent fluctuations inside the flow. The eigen frequencies of the cylinders would be identified, and similarity parameters for the spectra were established. The effect of cylinder-wall thickness on the spectrum and intensity of the pressure fluctuations was investigated. It was found that the intensity of the external pressure field scaled with the fifth power of the velocity at the center of the pipe.

For one particular case the spectrum and intensity of the pressure fluctuations exerted by the turbulent flow on the wall were measured. The intensity of the pressure fluctuations at the wall scaled with the fourth power of the velocity, as expected. The ratio of the root-mean-square wall pressure to the dynamic pressure was found to be independent of the Mach number and equal to a constant (0.0078). Similarity laws for the spectra of the wall-pressure fluctuations were also confirmed.

2611

Zahradnicek, J., and F. Kozumplik, "Strouhal's Relation Between Wind Speed and Pitch of the Sound Produced by Friction—A General Law of Physics" (in Czech), Cas. Pest. Mat. Fis., 75, 97-102, 1950.

There is a complete analogy between the phenomena of the Barkhausen-Kurz oscillations in electron tubes, the Zacek oscillations of magnetrons (Z. Hochfrequenztech., 32, 172, 1928), and those investigated by Sahanek in a diode designed for the purpose. Strouhal found in 1878 a relation ND = ku when studying the friction sounds excited by wind in taut wires (N frequency, D diameter of the wire, u wind speed). It is shown that this relation is a general law of physics that is valid for liquid and gas particles hitting an obstacle, as well as for electrons in a triode with a positive grid, in a magnetron or in a diode with an external cathode, the internal anode of which is in the form of a wire.

Sound Sources, Unclassified
See Also——329, 355, 398, 409, 410, 489, 515, 918, 926, 973, 986, 1304, 1365, 1374, 1377, 1663, 1671, 1706, 1708, 1709, 1715, 1756, 1771, 1992, 2464, 2710, 2821, 2913, 3569, 3671, 3787, 3961, 4313, 4344

SPECIFIC HEAT

2612

Bouchard, J., "On the Determination of the Ratio of Specific Heats of Gases by an Electro-Acoustic Method" (in French), Compt. Rend., 226, 1434-1436, 1948.

A modified electroacoustic method for determining the ratio of specific heats γ from the velocity of sound in a gas is described, resonance in the tube being detected not by ear or microphone but by its reaction on the telephone diaphragm emitting the sound. The impedance of the circuit including the interrupter is a minimum at maximum resonance. A cathode-ray oscillograph gives the waveform and precise frequency and ensures absence of harmonics in determining the half-wavelength. The method is also applicable to free air. Values of γ for air of 1.395 in a 4.5 cm tube and 1.403 in free air were obtained, but the method is of most value in studying variations of γ, by using a closed tube to avoid leakage, determining resonance values for various frequencies, and comparing them with values for a known gas.

2613

Eggers, A. J., Jr., "One-Dimensional Flow of an Imperfect Diatomic Gas," Tech. Note No. 959, Aeron. Natl. Advisory Comm., 11 pp., 1950.

Berthelot's equation is used to describe the equilibrium states of the gas. Only the temperature-dependent part of the specific heats needs to be considered. For aerodynamic applications, the number of translational and rotational degrees of freedom is constant, and only the temperature variation of the vibrational heat capacity need be considered. This is done through the Einstein function, involving the characteristic temperature θ. One-dimensional isentropic flow equations and shock relations are then obtained.

2614

Eucken, A., and R. Becker, "Excitation of Intramolecular Vibrations in Gases and Gas Mixtures by Collisions, Based on Measurements of Sound Dispersion," Z. Physik, Chem., B, 27, 219-262, 1934.

The paper is in two parts. The first part describes an apparatus for measuring ultrasonic wavelengths, based on the principle of the acoustic interferometer described by Pierce. The apparatus can also be used in investigating chemically active gases within a temperature range of several hundred degrees. Certain difficulties dealt are those which arise when frequencies of the order of 50 kcs are used. The method of calculation is described by which the values of C_p/C_v at zero pressure for the pure components of a gaseous mixture are determined from the speed of sound in the mixture at a given pressure. In the second part, results are given for the speed of sound and the value of C_p/C_v for Cl_2 and CO_2 for frequencies 58, 145, and 292 kcs. It is deduced that the number of collisions required to withdraw a quantum of energy from the pure gases CO_2 and Cl_2 is 51,000 and 34,000, respectively, at room temperature. Under certain conditions these numbers may be greatly reduced. The effect of temperature is such that a rise from -32° to +145° causes a sevenfold increase in pure Cl_2, a fourfold one in CO_2, and a fivefold one in Cl_2 containing CO. A formula was derived theoretically and was found to agree with experiment, according to which the number of impacts required for the release of one quantum is proportional to $1/T^n$ where n is a number depending on two molecular factors.

2615

Hafele, W., "Analytical Treatment of Powerful, Plane, Non-Stationary Shock Waves," (in German), Z. Naturforsch., 10a, 1005-1015, 1955.

The work of von Weizsacker, Hain, and von Hoerner relating to shock waves, and based on the work of Taylor and Guderley (Luftfahrt-Forsch., 19, 302, 1942) is extended. It is shown that with the passage of time shock waves having different initial distributions tend increasingly towards a homologous solution. Such plane solutions are studied by means of Guderley's method; a single such solution is derived and discussed for ratios (ρ) of specific heats respectively equal to 1.1, 1.4, 1.66 and 2.8; a simple, explicit, analytical solution for the case $\rho = 1$ is derived. This solution is characterized by a markedly linear velocity distribution, while for the other values of ρ the velocity distribution is approximately linear. The approximation, in the course of time, of the nonhomologous types of shock waves to the homologous types is discussed.

2616

Hochstim, A. R., "Gas Properties Behind Shocks at Hypersonic Velocities, II. Introduction to General Thermodynamics of a Real Gas," Rept. No. ZPh-003, Convair, San Diego, Calif., 50 pp., 1957.

Basic thermodynamical relations are derived as a function of compressibility and internal energy. Derived is a list of formulas for velocity of sound, specific heats and reversible adiabatic (isentropic) properties for a real or ideal hot gas in complete equilibrium (which may include dissociation or ionization, or both). It is shown how these general expressions reduce to formulas for cold, ideal gas. Many of the derived quantities are going to be used in computation of various properties of air in equilibrium from 2,000 to 15,000°K.

2617

Hochstim, A. R., and R. J. Arave, "Gas Properties Behind Shocks at Hypersonic Velocities, III. Various Thermodynamical Properties of Air," Rept. No. ZPh-004, Convair, San Diego, Calif., 135 pp., 1957.
AD 152 728

Various equilibrium properties of argon-free air from 2000°K to 15,000°K are computed and tabulated. There are 31 temperatures and 37 densities between $10^{1.6}$ and $10^{-5.6}$ times the sea level density. Calculations are based on a numerical differentiation method. The tables included the velocity of sound, specific heats, various γ's—functions for isentropic (reversible adiabatic) processes and partial derivatives of internal energy and compressibility with respect to density at constant temperature, and with respect to temperature at constant density. It is found that the specific heats have maxima corresponding to the points where compressibility $Z = \frac{Pv}{RT}$ as a function of temperature and density has maximum values of derivatives (at $Z \sim 1.11$, $Z \sim 1.65$ and $Z \sim 3.15$). Specific heats have minima at points corresponding to complete dissociation of oxygen ($Z \sim 1.21$), oxygen and nitrogen ($Z \sim 2.0$) and at points corresponding to completely (singly) ionized oxygen and nitrogen ($Z \sim 4.0$).

It is shown that in isentropic processes the γ's to be used are neither the ratio of specific heats nor enthalpy over internal energy. Three γ's, one for P - p, one for T - P and one for the P - T relation are introduced and tabulated. An extensive appendix on numerical differentiation accompanies this report.

2618

Hubbard, J. C., and A. H. Hodge, "Ratio of Specific Heats of Air, N_2, and CO_2 as a Function of Pressure by the Ultrasonic Method," J. Chem. Phys., 5, 978-979, 1937.

Hodge has made measurements of ultrasonic velocities at 27°C and pressures from one to 100 atm in air and N_2, and at one to 60 atm in CO_2. The results for air and N_2 combined with the respective compressibility data of Holborn and Otto for air at 27°C give values of γ between 1.406 at one atm and 1.580 at

100 atm, and for N_2, 1.403 at one atm to 1.564 at 100 atm. The acoustic velocities in CO_2 combined with the compressibility data of Amagat, give for γ at 27°C values from 1.304 at one atm to 3.524 at 60 atm. These and the other results between these limits are in excellent general agreement with the few findings available for comparison.

2619

Jatkar, S. K. K., "Supersonic Velocity in Air, Steam, CO_2 and CS_2," J. Indian Inst. Sci., 22A, 93-110, 1939.

The results of the present investigation are summarized in the following table:

	V		C_p	
	m/sec	γ	obs	cal
Steam (134°)	496.3	1.3295	8.26	8.26
CO_2 (25°)	269.6	1.3028	8.74	8.68
CO_2 (97.1°)	299.7	1.2899	8.94	8.93
CO_2 (97.1°)	220.1	1.2350	11.2	11.6

2620

Keesom, W. H., A. van Itterbeek, and J. A. vanLammeren, "Velocity of Sound in Oxygen Gas," Commun, 216d, Communs, Phys. Lab., Univ. Leiden, 996-1003, 1931.

By a method previously described the velocity of sound in oxygen gas is determined at 0°C and at temperatures between 164.63°K to 77.48°K, and at pressures between 0.1 and 1.0 atm. From the results c_p and c_v and their ratio c_p/c_v are determined. By extrapolation, the value of this ratio at zero pressure is obtained at various temperatures, and is found to be always slightly greater than 1.400. Whether or not this small deviation indicates a departure from classical dynamics cannot, however, be decided at present. If W is the velocity of sound, p the pressure, N, P, Q functions of temperature only, then $W^2 = N(1 + Pp + Qp^2)$. Values of N, P and Q are tabulated. The variation of W with pressure is not so great as in the case of hydrogen. From N is deduced a formula for the temperature variation of the second virial coefficient.

2621

Keesom, W. H., and J. A. van Lammeren, "Velocity of Sound in Nitrogen Gas," Commun. No. 221c, Communs. Kamerlingh Onnes Lab., Univ. Leiden, Proc. 35, 727-736, 1932.

The velocity of sound in nitrogen gas has been measured in the temperature-range extending from 0°C down to liquid nitrogen temperatures, in dependence on the pressure. Four resonators were used to get an idea of the validity of the formula of Kirchhoff-Helmholtz; the results were good. A curve $B = f(1/T)$ (B being the second virial coefficient) has been calculated, holding from 150° down to 80°K. Also, the ratio c_p/c_v and the specific heats c_p and c_v were calculated.

2622

King, F. E., and J. R. Partington, "Velocity of Sound in Air, O_2 and CO_2 at High Temperatures, Temperature Coefficients of Molecular Heat," Phil. Mag., 9, 1020-1026, 1930.

The method and apparatus used for measurements of the velocity of sound in air, O_2 and CO_2 were similar to those previously employed, but the temperatures were higher (900° to 1200°C) except for air, for which measurements up to 1300°C have been given. Tables are given for the velocity of sound in each gas and for the molecular heats of CO_2 and O_2. In all three cases, the velocity increases with temperature. As regards the molecular heats for CO_2 and O_2, both gases show a gradual rise with temperature of C_v and C_p, but the ratio C_p/C_v decreases with increasing temperature.

2623

Kneser, H. O., "Sound Absorption, Specific Heat and Period of Adjustment of the Electron Spin in NO" (in German), Ann. Physik, 39, 261-272, 1941.

The half-value widths and the frequencies of the resonance points of a cylindrical resonator are measured in NO with the aid of the condenser microphone; from these results the absorption and the velocity of sound are determined, the latter relative to air. Between 300 and 3000 cps the sound absorption is too small to be measured. From the velcoity a value is obtained for the sp ht, which is very close to that calculated from spectroscopic data. From both it follows that at these sound frequencies a delay in establishing thermic equilibrium is not observable, and that especially the distribution of the molecules on the two levels of the split ground state occurs in less than 10^{-6} sec. The probability of reversal of the electron spin in a gas-kinetic collision is thus > 1:6500.

2624

Nomoto, O., "Phenomenological Theory of the Molecular Absorption and Dispersion of Sound in Fluids and the Relation Between the Relaxation Time of the Internal Energy and the Relaxation Time of the Internal Specific Heat," J. Phys. Soc. Japan, 12, 85-99, 1957.

Molecular absorption and dispersion formulae applicable to both liquids and gases have been derived in a phenomenological manner. It is pointed out that the relaxation time of the molecular internal energy γ must be distinguished from the relaxation time of the internal specific heat β, and the relation between these two quantities is discussed in detail. The relaxation time γ has the advantage of making the dispersion formula simpler and directly comparable with the dispersion formulae in other cases, such as the relaxation of shear viscosity. The relaxation time β on the other hand, is more closely related to the collision excitation probability of the molecules than γ.

2625

Quigley, T. H., "An Experimental Determination of the Velocity of Sound in Dry CO_2 -Free Air and Methane at Temperatures Below the Ice Point," Phys. Rev., 67, 298-303, 1945.

The fixed-path acoustic interferometer was used. Acoustic resonance in a limited column of gas, coupled to a driven X-cut quartz crystal whose fundamental frequency is about 600 kcs, is produced by temperature variation. The procedure is such that differences in temperature readings, when the temperature is rising and when it is falling, are reduced to an amount in keeping with the other errors of measurement. No molecular acoustic dispersion has been observed, so that the results are made available with special reference to their value for computations of specific heats. The results are given, within experimental error, by the following formulae.
For air,

$$v^2 = 3.8762 \times 10^2 T + 806 + 1.8043 \times 10^5 T^{-1} - 2.0364 \times 10^7 T^{-2} + 3.007 \times 10^{-2} T^2$$

And for methane,

$$v^2 = 6.6176 \times 10^2 T + 1.0016 \times 10^6 T^{-1} - 1.3846 \times 10^8 T^{-2}$$

2626

Rechel, F., "Kirchhoff Constant and its Variation with Temperature," Ann. Physik, 10, 1-14, 1931.

A previous investigation of the constant for air is extended to other gases. Modifications of the experimental method are described, and results are given for air, CO_2 and NH_3, the values being reduced to those for a uniform frequency of 1600. All the graphs of γ against temperature show a rise from about 0^oC, rapid at first, but tailing off to a slow uniform increase of γ with rise of temperature from about 150^oC upwards. In this respect all the graphs are more or less parallel to, but higher than, the theoretical curves for γ.

2627

Smith, D. H., and H. J. Wintle, "The Propagation of Sound in Relaxing Gases in Tubes at Low Frequencies," J. Fluid Mech., 9, 29-38, 1960.

The frequency dependence of the velocity and the attenuation of sound waves in a gas which undergoes vibrational relaxation have been investigated theoretically. At low audible frequencies the attenuations due to viscosity, thermal conduction, and relaxation in the gas add linearly, while the velocity is the relaxation velocity diminished by the Helmholtz-Kirchhoff factor. The relations have been confirmed experimentally, and the free gas velocities of sound at zero frequency, one atm. pressure and 30^oC, found for carbon dioxide, air and oxygen, are 270.57 ± 0.04 m/sec^{-1}, 349.18 ± 0.02 m/sec^{-1}, and 331.33 ± 0.03 m/sec^{-1}, respectively. The corresponding specific heats are $C_p/R = 4.537 \pm 0.008$ for carbon dioxide and $C_p/R = 3.547 \pm 0.003$ for oxygen.

2628

Smith, P. W., Jr., "Computation of the Velocity of Sound in Gases," Tech. Memo. No. 29, Acoust. Res. Lab., Harvard Univ., 28 pp., 1952.
AD-10 247

Summarizes a method for the precise computation of the velocity of sound in a real gas and of its variations with experimental conditions. Two problems are discussed, the inclusion of the effects of departures of the equation of state from the perfect gas law, and the computation of specific heats from spectroscopic data. The method is applied to air, and data are presented for the computation of the velocity in air under pressures between 720 and 820 mm Hg and temperatures between 0^o and 30^oC. These results are summarized in the form of correction factors for the reduction to standard conditions of velocities measured at various frequencies and in this range of pressure and temperature.

2629

Spakovskij, V., "Velocity of Propagation of Sound in Carbon Dioxide near the Critical State," Compt. Rend., 3, 31-34, 1934.

The velocity of propagation of sound in CO_2 gas at temperatures of 15, 20, 30, 31.5, 35, 40, and 50^oC and at various pressures from 1 to 85 atmospheres, was measured. The values of the ratio of the thermal capacities at constant pressure and constant volume were calculated, and the causes of the small increase in the molecular thermal capacity at constant volume resulting from the pressure are discussed.

2630

Tucker, W. S., "The Determination of Velocity of Sound by the Employment of closed Resonators and the Hot-Wire Microphone," Phil. Mag., 34, 217-235, 1943.

A resonator consisting of two cavities connected by a narrow neck is employed. Sound is introduced by a telephone diaphragm forming the boundary of one enclosure, and temperature and response of the resonator to sound are indicated by the change in electrical resistance of a hot wire in the neck of the resonator. Frequency-response curves are obtained from which the true resonance-frequency maximum is obtained. Theoretical support is given to the existence of a linear relationship between velocity and resonance frequency for different gases. Determinations of velocity of sound for air saturated with water vapor were made and data obtained for calculation of γ. From this the velocity of sound in water vapor at 0^oC was deduced. Results were also obtained for the velocity of sound in ether and acetone vapors by a similar process.

2631

van Itterbeek, A., and J. Zink, "Measurements on the Velocity of Sound in Oxygen Gas Under High Pressure," Appl. Sci. Res. A, 7, 375-385, 1958.

Using the acoustical interferometer for high pressures described in an earlier publication, the velocity of sound in oxygen gas between one and 70 atm was measured as a function of pressure at different temperatures. From the experimental data the change of the ratio of the specific heats and the specific heats themselves, as a function of pressure at the different temperatures, were calculated.

2632

van Itterbeek, A., W. de Rop, and G. Forrez, "Measurements on the Velocity of Sound in Nitrogen Under High Pressure," Appl. Sci. Res. A, 6, 421-432, 1957.

Using an acoustical interferometer for high pressures, the velocity of sound was measured in nitrogen gas between one and 75 atm as a function of pressure and at different temperatures. The experimental data are compared with direct measurements on the equation of state of nitrogen gas. From the experimental results for the velocity, the change of the ratio of the specific heats and the specific heats themselves were calculated as a function of pressure, and at different temperatures.

2633

Vrkijan, V., "The Velocity of Sound in Gaseous Mixtures," Periodicum Math. Phys. Astron. (Yugoslavia), 2, 299-301, 1960.

Purports to show that a formula already published for the velocity of sound in mixtures of ideal monatomic gases holds for other gases provided their molecules have similar degrees of freedom. The specific heats of the individual gases are calculated in terms of the gas constants and, if both gases have the same number of degrees of freedom, they cancel, and the equation for the velocity of sound in the gaseous mixture then becomes identical with that for a mixture of monatomic gases. The equation only applies over the temperature range in which the specific heats are approximately constant.

2634

Wittliff, C. E., and J. T. Curtis, "Normal Shock Wave Parameters in Equilibrium Air," Rept. No. CAL-111, Cornell Aeron. Lab., Inc., Buffalo, N. Y., 94 pp., 1961.
AD-270 202.

Gives tables and graphs of normal shock wave parameters for equilibrium air. The composition of the air behind the shock is also tabulated. The results cover the range of velocities from 2000 to 26,000 fps in increments of 1000 fps and altitudes from sea level to 300,000 ft at 10,000-ft intervals. The 1959 ARDC model atmosphere was used to specify ambient conditions ahead of the shock. An effective specific heat ratio was tabulated that permits solution of oblique shock waves.

Specific Heat
See Also—58, 59, 66, 160, 262, 281, 299, 813, 932, 990, 1805, 1856, 2023, 2985, 3008, 3064, 3111, 3112, 3135, 3181, 3468, 3493, 3619, 3824, 3825, 4037, 4125, 4131, 4160, 4183, 4186, 4196, 4197, 4209, 4213, 4241, 4248, 4263, 4264, 4287

TERRAIN EFFECTS

2635

Arabadzhi, V. I., "Acoustical Characteristics of the Air Layer near the Ground" (in Russian), Uch. Zap., Leningr. Gos. Ped. Inst., 7, 87-91, 1957.

Investigations of sound propagation in the ground layer of the atmosphere over various natural surfaces are described. The measurements were made over a straight road, a flat grass field, a water surface, and a depression, with a microphone joined to an amplifier output by a millivoltmeter. Sound reflection from a dense grass cover, from a surface of cut grass, and from bushes and leaves was recorded at frequencies of 0.2-4.0 kcs. The effect of atmospheric temperature inhomogeneities upon sound attenuation was investigated by means of laboratory apparatus, which is described in detail. In these laboratory experiments attenuation coefficients between 10^{-5} and 10^{-4} cm^{-1} were obtained, which is in fair agreement with investigations made in the free atmosphere.

2636

Bolt, Beranek, and Newman, Inc., "Investigation of Acoustic Signalling over Water in Fog," Final Rept. on Phase 1, Evaluation of Present U. S. Coast Guard Design Procedure for Fog Signals, Cambridge, Mass., 14 pp., 1960.
AD-236 583.

The present USCG design procedure for fog signals represents considerable progress over previous methods. It is based on the concept of the average audible range and uses a fixed loudness level as the criterion for detection. Sound sources are specified in terms of the on-axis free-field sound pressure level at a distance of 25 feet. The transmission path is described by means of a curve of average sound transmission loss obtained many years ago. The following areas of improvement and refinement are suggested: (1) description of the sound source in terms of acoustic power output and directivity; (2) description of the transmission path by means of sound attenuation functions which take into account, in addition to frequency and distance, such parameters as source and receiver heights, wind direction and speed, and temperature and wind gradients, on a statistical basis; (3) description of the process of signal detection and location by the listener in terms of a detection criterion of minimum s/n, taking account of background noise levels and spectra, signal frequency and duration, and other relevant factors.

2637

Bolt, Beranek, and Newman, Inc., "Investigation of the Transmission of Sound Through Fog over Water," Final Rept. on Phase 2, Investigation of Acoustic Signalling over Water in Fog, Cambridge, Mass., 1960.
AD-236 659

The physics of sound propagation along the surface of the earth is discussed with particular attention to the conditions existing where sound is propagated for long distances over ocean waters in fog. The results of an extensive measurement program of sound transmission over water are presented, together with the results of measurements of the relevant micrometeorological parameters and a description of the instrumentation and experimental techniques used. The experimental data are analyzed in the light of available theory with a view of applying the results in generalized form to an improved design procedure for audible fog signals. Among the more important conclusions resulting from the analysis and evaluation of the field studies presented in this report are as follows.

(1) The propagation of audible sound over ocean waters in fog is governed by the same micrometeorological parameters which determine the propagation of audible sound over land. (2) The presence of wind and temperature gradients just above the surface of the ocean causes the sound to be refracted from the normal straight-line path. As a consequence the useful range of a fog signal may be severely limited upwind from the signal. (3) The sound attenuation caused by fog itself is generally too small to be of engineering importance for typical fogs encountered along the Eastern Seaboard.

2638

Cook, J. C., "Further Investigations of Geophysical Mine-Detection Methods," Final Tech. Rept., 31 May 57, Southwest Research Inst, San Antiono, Tex., 1957.
AD-202 546.

Activity under this contract has been devoted to perfecting three mine-detection methods: air-to-ground-coupled acoustic methods, surface-temperature methods including those employing the normal thermal radiation from the ground, and a low-frequency electro-magnetic method sensitive to resistivity variations of the soil. The work has included the discovery of new phenomena, efforts to improve the experimental apparatus, and the collection of basic data concerning the physical effects utilized. A successful acoustic air-to-ground-to-air system was developed. However, the previously developed air-to-ground system is superior and is recommended as a basis for practical mine detectors. Efforts to improve acoustic coupling to the earth have not significantly bettered the techniques already in use. The thermal investigations have demonstrated the existence in sand and loam of clear surface-temperature anomalies over large buried mines in the afternoon, which arise from the diurnal cycle of insolation. These anomalies can be detected with suitable radiometers, but there are serious interfering effects. The electromagnetic resistivity method is very sensitive, successful and promising, except for the "tilt effect" which prevents free manipulation of the search head. Two promising approaches for eliminating the tilt effect have been partially investigated.

2639

Dneprovskaya, I. A., V. K. Iofe, and F. I. Levitas, "On the Attenuation of Sound as It Propagates Through the Atmosphere," Soviet Phys. Acoust., English Transl., 8, 235-239, 1963.

The attenuation of sound as it propagates through the atmosphere was studied in the 200- to 2000-cps range, both in the presence and in the absence of acoustic shadowing. Measurements were performed at distances from 1.5-5 km in 12 steps (in the Leningrad region). Measurement of the sound level at the acoustic source was conducted with the aid of an objective noise meter and, at the receiving point, with the aid of a subjective noise meter.

The results of the measurements demonstrated the seasonal dependence of the excess attenuation of sound (with molecular attenuation subtracted), as well as the dependence on time of day, nature of the terrain over which the sound propagated, distance, and frequency. No relation was found between attenuation and wind direction or wind velocity. The averaged absolute value of the excess attenuation varies, depending again on the conditions of propagation, from 2-12 db/km for frequency 300 cps and from 5-23 db/km for frequencies ranging from 1800-2000 cps. Acoustic shadowing was observed on an average in 30% of the total number of observations. The averaged absolute magnitude of the excess attenuation in the presence of acoustic shadowing lies within the range from 20 db/km at 300-cps frequency to 50 db/km at 1800-cps frequency.

2640

Eisner, F., and K. Kruger, "Reflecting Power of the Earth's Surface for Sound Waves Incident Normally," Hochfrequenztech. u. ElektAkust., 42, 64-67, 1933.

Sound waves of a frequency of 2900 cps were sent out from a whistle on board an airship and were received at the other side of the gondola by a microphone tuned to the whistle. The received sound was amplified by a three-valve apparatus and the intensity recorded by an impulse-measuring instrument. The reflecting power of water being taken as unity, that of thin ice is 1.07, of meadow land 0.49, and of pine woods from 0.21 for young trees to 0.45 for full-grown trees. With the varying nature of country, the height above the ground for a given intensity of echo varies as the square root of the reflection coefficient.

2641

Embleton, T. F.W., and G. J. Thiessen, "Train Noises and Use of Adjacent Land," Sound, 1, 10-16, 1962.

This article describes the effect of train noises on the industrial and residential uses of the land adjacent to the railroad right-of-way. Sound pressure levels are given for a variety of train noises as a function of distance from the tracks and the environment (cuts, barriers of various sorts, etc.). Track noise may be reduced to acceptable levels for an urban residential area at a distance to 300 feet from the right-of-way and engine noise at a corresponding distance of 500 feet, if a cut of suitable depth is employed.

2642

Eyring, C. F., "Jungle Acoustics," J. Acoust. Soc. Am., 18, 257-270, 1946.

The study of jungle acoustics was carried out during the wet season in Panama. Measurements permit the following conclusions to be drawn. Within a jungle the temperature and wind velocity gradients are so small that the sound refraction they produce may be neglected for all practical purposes. Humidity increases the transmission loss at high frequencies and field measurements of the loss agree with laboratory values reported by others. Terrain loss, measured in db, between any two specified distances from the sound source is defined as the transmission loss between these points less that caused by the geometrical divergence of the sound beam. Terrain loss in the jungle was found to increase linearly with distance. The terrain loss coefficients, in db per foot, were measured for various types of jungle and were found to be a function of frequency and of the density of the terrain, the density of terrain being measured by the difficulty of penetration and the distance that a foreign object may be seen. The level of the ambient noise in the wet-season jungle is very low, especially for the quiet periods between animal calls. At night the low frequencies decrease as the light breezes cease and the high frequencies increase as the insects begin their nocturnal chorus. A jungle is a difficult place in which to judge the direction of a sound—a probable error of 20° is to be expected. The error is found to be smallest when the sound comes from a direction near the axis passing through the two ears, and in the range studied the error decreases as the sound source moves farther away. Reverberation and scattering cause part of the error of judgment, but an improved technique of listening which may increase the observer's accuracy is suggested.

2643

Eyring, C. F., "Jungle Acoustics," Rept. No. 4699, Office of Scientific Research and Development, NDRC Div. 17, Washington, D. C., 80 pp., 1945.
ATI-62654.

This study of jungle acoustics and micrometeorology is one of the most comprehensive and useful documents available for anyone concerned with the transmission of sound at the earth's surface in tropical climates. The study was conducted during the wet season in Panama and includes propagation measurements over hard, bare surfaces, short and tall grasslands, and through a variety of tropical forests. Terrain loss coefficients and their variations with acoustic frequency and environment were determined from measurements. Ambient jungle noise levels in the audible and ultrasonic ranges were measured. Acoustical and meteorological measurements were taken concurrently in order to demonstrate their inter-relationships. Refraction and shadow zone formation, as caused by combined wind and temperature effects, were investigated and found to be significant in open, sunny areas, but not significant under a jungle canopy. The report clearly shows the typical variations to be expected throughout the day and night for each acoustic and meteorological parameter investigated. The various instruments that were developed for acoustic detection and measurement are described in detail. Calibration procedures are also described.

2644

Franken, P. A., "The Field of a Random Noise Source Above an Infinite Plane," Acoust. Lab., Mass. Inst. Tech., Cambridge, 1955.

This report on the field of a random noise source above an infinite plane represents one phase of a general program of research in atmospheric acoustics initiated in May 1953 under NACA sponsorship at the Acoustics Laboratory of MIT.

The sound field from a random noise source above ground as measured by a receiver with a finite band width is studied theoretically. For simplicity, only the far field has been considered. The special case of the perfectly reflecting plane is discussed, and nondimensional curves are given of sound pressure level versus distance for two different receiver band widths. The analysis is then extended to a plane of arbitrary impedance, and pressure level-versus-distance curves are given for typical field operating conditions. The sound field consists of two major regions. In the first, the sound pressure level fluctuates about an average curve sloping approximately 6 db per doubling of distance. Later, beyond a certain distance from the source, the level decreases monotonically 12 db per doubling of distance. The fluctuations depend on the band width of the receiver and on the ground impedance. With, for example, an octave band of 1000 to 2000 cycles and the receiver 10 feet above a ground of normal impedance ρc, the maximum pressure level fluctuation is about 2 db and occurs around 300 feet from the source, and the transition between the 6-db slope region and the 12-db slope region occurs around 700 feet from the source.

2645

Givens, M. P., W. L. Nyborg, and H. K. Schilling, "Theory of the Propagation of Sound in Scattering and Absorbing Media," J. Acoust. Soc. Am., 18, 284-295, 1946.

The theory predicts that curves of physical transmission loss against distance should be convex upward if the sound is detected by means of a directional microphone directed toward the source, and concave upward if perpendicular to a line from the source. The theory also predicts the directionality of sound in the medium and is applied to transmission through forests and through open air containing inhomogeneities.

2646

Hayhurst, J. D., "The Attenuation of Sound Propagated Over the Ground," Acustica, 3, 227-232, 1953.

Theoretical calculations by Knudsen, supported by the results of laboratory experiments, have established the attenuation of sound in still air. Little work has hitherto been done out-of-doors because of the difficulty in allowing for the effect of wind on the attenuation. In the course of an aircraft-noise-abatement investigation made recently by the Ministry of Civil Aviation, the effect of wind on the propagation of sound over a dry concerte runway has been explored up to a distance of about half a mile from a source of sound. It was found that the only significant parameter was the component of wind in the direction of propagation, and the values that emerged showed that wind effects cannot be neglected in any acoustic work made out-of-doors. By interpolation the attenuations corresponding to a zero wind component in the direction of propagation were derived and were found to be substantially greater than those previously determined for still air. The attenuations were, however, statistically independent of the absolute wind speed. Repetition of the investigation over grassed areas produced no reliable results.

2647

Ingard, U., "Field Studies of Sound Propagation over Ground," Acoustics Lab., Mass. Inst. Tech., Cambridge, 1954.

The results of two sets of field studies of sound propagation over ground are presented. One study utilized pure tones, the levels of which were measured at various distances and different wind velocities. For the second study an airplane propeller served as the source with octave band levels measured over various ground covers, at different wind velocities and at several distances. The importance of wind is shown by the shadow formation obtained. Fluctuation of sound level was shown to increase with distance and frequency. For propagation over the ground, the effect of turbulence scatter was found to be small.

2648

Ingard, U., "A Review of the Influence of Meteorological Conditions on Sound Propagation," J. Acoust. Soc. Am., 25, 405-411, 1953.

The study of the different atmospheric effect indicates that in short-range sound propagation the attenuation by irregularities in the wind structure (gustiness) often is of major importance in comparison with humidity, fog, and rain, and ordinary temperature and wind refraction. However, the ground attenuation can be just as important as the gustiness, particularly when the sound source and the receiver are sufficiently close to the ground. The effect on the attenuation of the height of the source and the receiver off the ground is presented as a function of frequency for a typical ground impedance. The attenuation curve exhibits a maximum which in most cases lies at a frequency between 200-500 cps.

2649

Ingram, L. F., "Air Blast Phenomena in an Arctic Climate," Office of the Chief, Army Research, Research and Development, Washington, D. C. (Paper presented at the 1962 Army Science Conference, 20-22 June 1962, at the U. S. Military Academy, West Point, N. Y.), 9 pp., 1962. AD-286 639.

In 1960, 4- and 32-lb TNT spheres were fired at scaled burst heights over natural and processed snow on the Greenland Ice Cap at Camp Fistclench, where the snow cover is 100 ft deep. Air-blast pressure-time measurements were made at the surface to obtain height-of-burst information and at several elevations above the surface to determine Mach-triple-point loci. Surface pressure measurements were made at reduced horizontal distances. Pressure data were obtained for the range 2- to 100-psi peak overpressure. Results show that considerable energy is absorbed by snow, snow cannot be regarded as an ideal reflecting medium, and the Mach stem formation over snow is not essentially different from that over a rigid boundary.

2650

Kaye, G. W. C., and E. J. Evans, "Sound-Absorbing Properties of Common Outdoor Materials," Proc. Phys. Soc. (London), 52, 371-379, 1940.

The sound absorption coefficients of pure sounds of frequencies from 125 to 4000 cps have been measured at random incidence for specimens of some commonly occurring outdoor materials, such as gravel, turf, sand, ashes, railway-track ballast, and snow. They mostly share the common characteristic of increased absorption with rising pitch. Some of the materials (e.g., loose gravel, soil and ashes) are highly absorbent; snow is remarkably so, while other (e.g., compressed gravel and wet sand) are indifferent absorbents. Some practical aspects are discussed, as is the influence of nearly grazing incidence, such as often obtains with outdoor sounds, in raising the degree of absorption.

2651

Kennedy, W. B., et al., "Study of Meteorological and Terrain Factors Which Affect Sound Ranging," Denver Research Inst., Univ. of Denver, Colo., 1954-1957.

Qrtrly. Prog. Rept. 1, March-May 1954, AD-38 446
" " " 2, June-August 1954, AD-43 297
" " " 3, September-November 1954, AD-54 480
" " " 4, December 1954-February 1955, AD-61 530
" " " 5, March-May 1955, AD-70 078
" " " 6, June-August 1955, AD-74 855
" " " 7, September-November 1955, AD-95 798
" " " 8, December 1955-February 1956, AD-95 799
Final Report, March 1954-April 1956, AD-139 326
Qrtrly. Prog. Rept. 1, May-July 1956, AD-140 087
" " " 2, August-October 1956, AD-140 088
" " " 3, November 1956-January 1957, AD-140 090
Interim Prog. Rept., February-August 1957, AD-160 696

This series of reports covers four years of intensive theoretical and applied research and development on sound-ranging as influenced by meteorological and terrain factors. The general problem of increasing the accuracy of sound-ranging by means of corrections based on meteorological and topographical conditions is discussed. Equations are presented for applying wind and temperature corrections to reduce error in observed sound-source azimuths. Problems encountered in setting up the field operation to provide data for a study of meteorological and terrain corrections for the whole sound path are analyzed. Proposed methods for time measurement of sound arrivals, temperature measurement, control of field operations, and power distribution are presented in detail.

The firing-recording arrays are described. The results and the methods of reducing data are given. Special investigations include: an analysis of the problem of acoustic ray-tracing in the atmosphere; determinations of the sonic data obtainable with various geometries of detecting arrays; an analysis for determining the velocity of sound; studies of errors generated within the Short-Range Whole-Path Firing-Recording Array by elevation differences, angular errors in placing the sensing microphones, and errors due to the assumption that the wave front is plane; a study determining the effect of oscillogram-reading errors on calculated sound-wave-arrival azimuths; a discussion of methods of removing data from oscillograms; and tests to determine the calibration requirements of the T-23 microphones. Other discussions include microphone-wind-shield development, the surveying program, and the general field operational problem.

The application of a drift correction to the primary sound-ranging information provided results superior to those obtained by standard artillery methods. For these calculations, data were used from an array of 14 microphones arranged in an isosceles-trapezoidal configuration. The arrival azimuth obtained by using this configuration is more representative of the direction of arrival of the acoustic wave front than that obtained by standard methods. The corrections which were applied for the refraction of the wave front along its path do not appear to be greatly significant from a study of the small sample presented.

2652

MacPherson, P. A., D. B. Thrasher, and O. Logan, "A Survey of Noise at RCAF Station Cold Lake and RCAF Station Uplands," Rept. No. 228-1, Defence Research Medical Labs., Canada, 21 pp., 1958.
AD-158 849.

Results of the noise survey indicate that the overall noise levels generated by aircraft during take-off conditions are influenced mainly by ground absorption out to distances of approximately 1000 feet from the aircraft. Beyond this distance the overall noise levels are influenced primarily by temperature conditions. The overall noise levels generated by aircraft under take-off conditions may be predicted. The noise produced by aircraft at RCAF Station Cold Lake and RCAF Station Uplands may result in the deterioration of hearing of exposed personnel. In addition voice communications may be disrupted in areas near where aircraft are being maintained, taxied or taking-off.

2653

Nyborg, W. L., and D. Mintzer, "Review of Sound Propagation in the Lower Atmosphere," WADC TR-54-602, Brown Univ., Providence, R. I., 1955.
AD-67 880.

Available information on sound propagation through the lower atmosphere is critically reviewed. The application is to the prediction of sound fields due to aircraft (in flight or on the ground), especially at distances up to a few miles from the aircraft sound sources. Treatment of the prediction problem requires consideration of a number of topics including absorption processes in the air, boundary effects caused by the earth, and refraction of sound due to spatial variations in air temperature and wind. Although a fair amount of information is now available on these topics, a considerable amount of research remains to be done before practical solutions will be available. Numerous charts and nomograms (for determining absorption losses) and a bibliography containing 92 references are included.

2654

Oleson, S. K., "Instrumentation for Field Measurements of Noise Propagation over Ground," Acoustics Lab., Mass. Inst. Tech., Cambridge, Mass., 1956.

Describes an improved method of experimental procedure for studies of sound propagation over varied terrain. The improvements described deal mainly with simultaneous recording of meteoroligical and acoustical data, thus minimizing experimental errors resulting from constantly changing meteorological conditions.

2655

Ooura, H., "Reflection of Sound at Snow Surface" (in Japanese), Tokyo, 12, 273-275, 1950.

The reflections of sound at the snow surface were observed with the method of standing wave. If the amplitude of the incident wave is a, and that of the reflected wave is b, then the maximum amplitude of standing wave is a + b, and the minimum is a - b. These values were measured with the carbon microphone and the Browntube. From these values the rate of absorption, $A = (a^2 - b^2)/a^2$, was calculated. The results, in tables, show that: (1) the rate of absorption A is very large; (2) the smaller the density, the larger the absorption; (3) for settled snow, the higher the frequency of sound, the larger the absorption; and (4) for settled snow, when the snow was warmed and wetted, the absorption increased.

2656

Ooura, H., "A Study on the Optical and the Acoustical Properties of the Snow Cover," International Union of Geodesy and Geophysics, Assoc. of Sci. Hydrology, Rome, 1954 (Transactions), 4, 71-81, 1956.

The snow cover does not always show perfectly diffused reflection (type E) for the incidence of light. There are the diffused specular reflection (type C) and another reflection (type A) such that the nearer 90^o the angle of reflection, the higher the brightness of the snow cover becomes. By quantitative treatment, it was found that in reflection type E, the reflection from the deep places plays the main role while types C and A are due to the reflection from the shallow places whose depth is not more than ten times the size of the snow grain. The degree of polarization of reflected light for the incidence of the linearly polarized light increases with the angle of reflection and is nearly equal to the percentage of light reflected only at the boundary surface of the snow cover. The albedoes are in the range from 40 to 90 %. The extinction coefficients in snow are in the range from 0.4 to 1.2/cm.

The relation between these values and the number of snow grains in unit volume was investigated. It was found that the sound wave propagates mainly in air among the snow grains with velocities about 180-300 m/sec. Velocity increases with the temperature and the grain snow surface is about 10-40% of the incident.

2657

Pierce, G. W., and A. Noyes, Jr., "Transmission of Sound over Reflecting Surfaces," J. Acoust. Soc. Am., 9, 193-204, 1937.

The paper presents an experimental and theoretical discussion of acoustic signalling between a sending station and a receiving station near a plane reflecting surface, and is applicable to foghorn and submarine signalling. The experiments were made with a small-scale apparatus employing supersonic waves of a frequency of 67.5 kcs. It is shown that at grazing incidence the direct and reflected waves cancel, or partially cancel, as predicted by theory. The cancellation for propagation in air near a water surface, or near another surface of high sound velocity and high density, is found to be restricted to angles very near to grazing incidence.

On the other hand, theory predicts cancellation for much larger departures from grazing incidence if the reflecting surface has high density but low velocity; experimental curves for transmission over beach sand and certain other substances resemble such theoretical results very closely. Acoustic mirages caused by temperature gradients were studied experimentally, and their effects are shown to be of striking importance in modifying the above results.

2658

Pridmore-Brown, D. C., and U. Ingard, "Sound Propagation into the Shadow Zone in a Temperature-Stratified Atmosphere Above a Plane Boundary," J. Acoust. Soc. Am., 27, 36-42, 1955.

The sound field in the "shadow zone" (diffraction region) formed over a plane boundary in an atmosphere with a constant vertical temperature gradient is analyzed both theoretically and experimentally. The boundary condition at the plane is given by a normal acoustic impedance independent of the angle of incidence. As in the corresponding problem of underwater sound, where the boundary is a pressure release surface, it is found that the major portion of the sound pressure in the shadow zone decays exponentially with distance at a rate proportional to the one-third power of frequency and to the two-thirds power of temperature gradient.

The effect of boundary impedance enters mainly through its resistive component. The rate of sound decay for a pressure release boundary (zero impedance) is found to be 2.3 times that for a rigid boundary (infinite impedance). Sound pressure in the shadow zone was measured in a laboratory chamber in which a large temperature gradient was created. Measurements were made for both hard and absorbing boundaries, and the results were found to be essentially in agreement with theory.

2659

Pridemore-Brown, D. C., and U. Ingard, "Sound Propagation into the Shadow Zone in a Temperature-Stratified Atmosphere Above a Plane Boundary," NACA TN 3494, Mass. Inst. of Tech., 1955.

In this report, geometrical ray acoustics are employed to derive the ray paths and the intensity distribution about a sound source located in a uniformly stratified medium. A comparison of the relative effect of the stratification on the intensity from a directive source and from a spherical source is made.

Also presented is a theoretical analysis of the sound field in the "shadow zone" (diffraction region) formed over an absorbing-plane boundary in a temperature-stratified atmosphere. The analysis holds for both two and three dimensions. The boundary condition at the plane is given by a normal acoustic impedance independent of the angle of incidence. As in the corresponding problem of underwater sound, where the boundary is a pressure-release surface, it is found that the major portion of the sound intensity in the shadow region decays exponentially with distance at a rate proportional to the one-third power of frequency and to the two-thirds power of temperature gradient. The effect of ground impedance enters mainly through its resistive component. The rate of sound decay for a pressure-release boundary (zero impedance) is found to be 2.3 times that for a reflecting boundary (infinite impedance).

Finally, the results of measurements of the sound distribution in a two-dimensional laboratory chamber in which a large temperature gradient was created are reported. Measurements were made at various frequencies for both reflecting and absorbing boundaries, and the results are found to agree well with theory.

2660

Prout, J. H., "Some Measurements of the Absorption Coefficients of Soil Using the Impedance Tube Technique," Rept. No. 2900-257-S, Inst. Sci. Tech., The Univ. of Michigan, Ann Arbor, 1961. AD-261 359.

In any field tests which involve horizontal propagation of sound, it is desirable to know how much is absorbed by the ground. Since the sound-absorption properties of the ground are affected by many factors, it is usually necessary to estimate this effect. This paper describes an experiment for measuring the absorption coefficient of the soil by means of an impedance tube. Controlled laboratory tests are described which measured the effect of moisture content and particle size on the absorption coefficient. Effects of grass on the absorption coefficient are also noted.

2661

Rudnick, I., "Propagation of Sound in the Open Air," in C. M. Harris, ed, "Handbook of Noise Control," McGraw-Hill, New York, Chap. 3, 17 pp., 1957.

Chapter 3 decribes the propagation of sound in air and the various meteorological factors and boundary conditions that influence otherwise normal propagation. The effect of wind and temperature gradients, of fog and water vapor, and of reflecting and absorbing obstacles and boundaries are concisely treated. Mathematical expressions, graphs, and tabular data for determining divergence, diffraction, refraction, reflection, scattering, and attenuation with distance are presented. Anomalous propagation and shadow zones are investigated and explained in terms of sound-ray equations. In general, the chapter presents the basic results of work done by Kneser, Knudsen, Knotzel, Delsasso, Ingard, Nyborg, and Rudnick.

2662

Syono, S., "Anomalous Propagation of Sound at a Short Distance," Geophys. Mag. (Tokyo), 9, 175-194, 1935.

In a former paper the author explained by an approximate method some anomalous sound wave propagation phenomena described by J. Kolzer. The present paper, which is almost entirely mathematical, is concerned with making the treatment more rigorous by taking into account the effects of wind and absorption of the earth's surface.

2663

Wallace, N. R., and A. B. Willoughby, "Effects of Topography on Dynamic Pressure," Rept. No. 170-7, Broadview Res. Corp., Burlingame, California, 195 pp., 1961. AD-272 596.

Describes an experimental study of the effect of idealized topography on the dynamic pressure of a spherically expanding air shock. Model-scale techniques were used in which small charges of desensitized cyclonite were exploded in reduced ambient pressure to increase the effective weight of the charge through Sachs's scaling. Model topographies studied were symmetrical, 2-dimensional ridges and valleys. Slope angles of 15 and 30 degrees and shock strengths of 2, 4, and 8 were examined. Measurements of stagnation, side-on, and dynamic pressure were made on the front and back slopes and in the flat region behind each modeled topography.

2664

Watson, R. B., "On the Propagation of Sound over Snow," J. Acoust. Soc. Am., 20, 846-848, 1948.

Many qualitative observations have been made on the quieting effect of newly fallen snow, which must depend on its acoustical properties. The physical constants for snow vary over a considerable range, and data for calculating its acoustic constants are meagre. The calculated absorption coefficient ranges uniformly from 0.25 at 100 cps to 0.75 at 2000 cps. Calculations are made of the sound level at an observer's position due to sound transmitted over a layer of snow. Because of the appreciable absorption, the sound level is found to be considerably reduced at distances as small as 500 feet from the source.

2665

Wiener, F. M., and D. N. Keast, "Experimental Study of the Propagation of Sound over Ground," J. Acoust. Soc. Am., 31, 724-733, 1959.

The attenuation of sound propagated out-of-doors is conveniently separated into attenuation due to spherical divergence and excess attenuation due to atmospheric and terrain effects. This excess attenuation is principally caused by sound absorption in the air, the refractive effects of temperature and wind gradients, turbulence, and terrain and ground cover. To investigate these effects, the propagation of sound over open, level ground, through dense evergreen forests, and between hilltops was studied experimentally in the frequency range between about 300 and 5000 cps. Extensive micrometeorological instrumentation was utilized to measure and record the relevant micrometeorological parameters simultaneously with the acoustic data for a wide variety of weather conditions. Data on the attenuation of the mean sound pressure level as well as on the fluctuations about the mean were obtained and correlated with the state of the atmosphere. Over open, level terrain, the excess attenuation upwind was found to exceed that for downwind propagation by as much as 25-30 db for source and receiver heights of 12 and 5 feet, respectively. Temperature and wind gradients near the ground-air interface largely account for this difference. In hilltop-to-hilltop propagation, wind direction is of secondary importance and in dense woods absorption and scattering control. Empirical functions were derived for the purpose of estimating the mean excess attenuation as a function of frequency and distance, for a given set of micro-meteorological conditions. These charts were found useful in many practical problems involving the propagation of sound over open level ground.

Terrain Effects—see also Absorption, Boundary Layer & Surface; Attenuation; Atmospheric Wave Propagation, Boundary Effects
See Also—83, 429, 432, 433, 437, 442, 457, 458, 460, 465, 482, 485, 486, 487, 529, 554, 562, 765, 986, 1086, 1291, 1354, 1475, 1552, 1580, 1751, 1863, 1864, 1866, 1867, 1988, 2118, 2151, 2213, 2233, 2810, 2837, 3101, 3463

TRANSDUCERS, HOT WIRE DEVICES

2666

Baker, S., "An Acoustic Intensity Meter," J. Acoust. Soc. Am., 27, 269-273, 1955.

Describes a device for measuring the intensity of an acoustic wave at a point. The instrument employs a crystal microphone as a pressure transducer, a directional hot-wire anemometer as a velocity transducer, and an electronic multiplier and integrator. It will directly measure the intensity of any pressure or velocity wave form without assuming any relationship between pressure and velocity.

Reports several types of measurements performed, indicating present capabilities of the instrument.

2667

Bartman, F. L., V. C. Liu, and E. J. Schaefer, "An Aerodynamic Method of Measuring the Ambient Temperature of Air at High Altitudes," Eng. Res. Inst., Univ. of Mich., Ann Arbor, 64 pp., 1950.
ATI-83, 051.

Describes an aerodynamic method of measuring ambient air temperatures at high altitudes by determination of the shape of the shock cone attached to the nose cone of a missile capable of high supersonic speeds. A trial of this method on V-2 guided missiles, yielded data which are analyzed on the basis of first-order conical shock wave theory. Pirani gauge signals were obtained up to 230,000 ft, indicating that the method may be applicable up to this altitude. Temperatures calculated for altitudes up to 183,000 ft agree fairly well with previously known information about temperatures at high altitudes. The experimental errors are shown to be negligibly small. The possible existence of large systematic errors and plans for investigating them are discussed together with the use of this method for the measurement of winds at high altitudes.

2668

Betchov, R., "Spectral Analysis of Turbulence" (in French), Proc. Koninkl. Ned. Akad. Wetenschap., 51, 1063-1072, 1948.

Describes a device that uses a hot-wire anemometer and thermocouple for electronically measuring the velocity fluctuations in a turbulent aerodynamic flow. The electrical signals are applied to the grid of a thermionic valve through a low-pass filter with a very large time constant, thus assuring a strictly linear recording. The theory and layout of the circuit are outlined and test results given.

2669

Fand, R. M., and J. Kaye, "A Hot-Wire Method for Visualizing Intense Stationary Sound Waves," WADC Tech. Note No. 59-74, Heat Transfer Lab., Mass. Inst. of Tech., Cambridge, 6 pp., 1959.
AD-214 148.
See Also: J. Acoust. Soc. Am., 31, 810-811.

A simple method was developed for visualizing intense stationary sound waves, using a thin, electrically heated wire stretched in the direction of sound propagation. The nodes and antinodes of the sound waves appear as a series of alternate incandescent and dark areas on the wire. Photographs of the hot wire indicate the presence of hitherto unreported thermo-acoustic phenomena.

2670

Gowan, E. H., "Low-Frequency Sound Waves and the Upper Atmosphere," Nature, 124, 452-454, 1929.

Describes instruments for the mechanical registration of sound waves, such as the hot-wire ammeter and the undograph. There are several indications to show that the rate of transmission of low-frequency waves is greater at a level of about 40 km than on the ground. The supposition that above 30 km the temperature of the atmosphere increases again with height until it reaches, or even surpasses, ground temperature, is sufficient to account for the abnormal zone of audibility. The velocity of 340 m/sec at 40 km indicates a temperature of about 15°C there. Such high temperatures in the upper atmosphere were first indicated by a study of meteors, and it has recently been shown that the absorption of solar energy in the ozone layer (center of gravity about 45-50 km) is responsible for their maintenance.

2671

Hayashi, T., "Periodic Variation of Temperature Caused by Sound Waves," Electrotech. J., 3, 103-106, 1939.

Two experimental arrangements are described, one for the purpose of indicating the temperature variations due to the adiabatic changes in sound waves sent along a tube by a loudspeaker. The equipment contains a twelve-couple thermopile, the output of which is passed through amplifiers, attenuator and band-pass filter to a valve voltmeter. In the second set a hot wire is in contact with the sound. The hot wire registers the temperature changes which occur at the antinode of the stationary wave. The amplifying and other equipment is similar to that used in the first experiment.

2672

Jones, J. I. P., "The Measurement of Turbulence near the Ground," Porton Tech. Paper No. 786, Chemical Defence Experimental Establishment, Great Britain, 1961.
AD-265 939.

An instrument for measuring vertical and horizontal (lateral) gustiness over frequencies up to 70 cycles is described. Its output voltage is proportional to the angle of the wind over a range of 1-1/2 radians vertically and 6 radians horizontally. This voltage is passed to bandpass filter circuits which automatically provide the major part of the power spectrum of vertical gustiness, and of horizontal gustiness above a frequency of 3.6 cycles per hour. A squaring/multiplying circuit is also described and is used to test the method of power measurement. Form factors for turbulence under widely varying conditions are found to be remarkably consistent and indicate a frequency distribution with more peaks than are normal. Use of the equipment in the field is described, and examples of vertical and horizonal spectra at 16 meters are presented.

2673

Matta, K., and M. Mokhtar, "The Velocity of Sound in Vapors," J. Acoust. Soc. Am., 16, 120-122, 1944.

A form of Kundt's tube is employed in which a hot wire records the amplitude in the stationary-wave system. It is calibrated by the use of dry air and of oxygen. The results agree with those determined by other methods.

2674

Muller, H., and E. Waetzmann, "Absolute Velocity Measurements with Hot Wires in Stationary Sound Waves," Z. Physik, 62, 167-179, 1930.

The constant cooling effect that a hot wire experiences through the air vibrations in a sound wave were again investigated according to the method of Goldbaum and Waetzmann. The discrepancy between the results obtained by the above-named workers and other observers was stated and discussed. Absolute measurements were made of the periodic cooling effect, and it was established that for the absolute measurement in sound waves of both the constant and periodic cooling effects on a heated wire, this can only be done successfully by taking special precautionary measures and for certain thicknesses of the wire. Full experimental and theoretical details are given.

2675

Pennsylvania State University, "Atmospheric Physics and Sound," Final Rept., Dept. of Physics, Acoustics Lab., University Park, 288 pp., 1950.

This voluminous report contains a detailed account of the instrumentation developed, methods used, and results achieved at Pennsylvania State University in a five-year study aimed at investigating the production and propagation of sound, both sonic and ultrasonic, in the lower atmosphere, through the ground, and in other media. Chapter 7 "Micrometeorology and Atmospheric Acoustics," is a summary of results of temperature and wind velocity measurements (mostly with hot wire thermometers and aneomometers) made up to 50 feet from the ground in conjunction with sound intensity measurements. A definite correlation is found between sound signal fluctuations and inhomogeneities of temperature, but not of wind. Likewise no effect of snow cover on sound propagation was noted.

2676

Railston, W., and E. G. Richardson, "Effect of Pressure on Supersonic Dispersion in Gases,"Proc. Phys. Soc. (London), 47, 533-542, 1935.

Measurements of wavelengths by interferometer and hot-wire methods, and of absorption by hot-wire methods alone, have been made for supersonic radiation at frequencies between 40 and 2000 kcs in CO_2, N_2O and SO_2 at various pressures up to 2 atm. For the hot-wire method, a circuit which gives a linear relation between amplitude or particle velocity and response at constant frequency is described. The velocity-measurements in the two former gases may be reduced to a common curve by plotting them against the parameter (f/p). Although the observed velocity rise in the region where this parameter lies between 100 and 1000 is in accordance with the relaxation-time theory, the decrease in velocity at lower and higher values is not. In SO_2 the rise of velocity is in the neighborhood of 4000. The absorption in all three gases rises sharply at pressures below 400 mm of mercury.

2677

Rice, C. B., "Upper Atmosphere Research Program," Wentworth Inst., Boston, Mass., 14 pp., 1949.
ATI-66 500.

Summarizes the upper-atmosphere research program at The University of Michigan. Atmospheric pressure and temperature measurements were made between the altitudes of 40 and 110 km in three rocket flights. Instrumentation was developed to cover pressure and temperature measurements for all altitudes from the ground to rocket ceiling. Ambient pressure data were obtained by means of the Pirani pressure gage and the ionization gage.

The Pirani gage functions best below 70 km altitude, over a range of 10^1 to 10^{-2} mm Hg. The ionization gage functions well in the pressure range 10^{-2} to 10^{-6} mm Hg or lower. Curves are plotted, showing complete pressure vs. altitude, complete temperature vs. altitude, and velocity of sound vs. altitude data.

2678

Richardson, E. G., "Absorption and Velocity of Sound in Vapors," Rev. Modern Phys., 27, 15-25, 1955.

A review of the work on this subject during the past fifteen years. The paper deals with the theory of interferometers of the Pierce, double-crystal, capillary tube, and hot-wire types. Discusses results of measurements at varying pressures in air, rare gases, triatomic molecules, and polyatomic molecules (organic vapors). Examines effects of temperature and of vapor mixtures.

Observations of velocity and absorption near the critical state for CO_2 as functions of pressure and frequency are dealt with in a later section of the paper, where there are also derivations of thermodynamical relationships that lead to expressions for the propagation of shock waves in vapors.

Concluded with a useful list of 100 references to current literature.

2679

Richardson, E. G., "Supersonic Dispersion in Gases," Proc. Roy. Soc. (London) A, 146, 56-71, 1934.

The propagation through various gases of supersonic radiation emitted by piezoelectrically maintained quartz crystals is examined experimentally. New methods involving the change of resistance of an electrically heated wire exposed to the radiation are developed, enabling the wavelength and amplitude of the gaseous vibration to be measured. The method of calibrating the apparatus is also described, and the results are compared with those obtained by older methods. The anomalous dispersion and absorption shown by certain gases is critically examined, and suggestions put forward to account for it. Evidence is adduced to show that some of the radiation "absorbed" is scattered by the gas.

2680

Schmidt, D. W., "Experiments Relating to the Interaction of Sound and Turbulence," Max-Planck-Institut für Stroemungsfurschung, Germany, 19 pp., 1960.
AD-236 341.

Experimental results about the scattering of sound by a turbulent flow are given. The dependence of the scattering on the frequency of sound and on the direction of the scattering vortices were investigated. Equipment is described that facilitates the use of hot wires for the measuring of turbulence. Design characteristics of an apparatus are given, by which hot-wire probes can be rewired precisely and quickly.

2681

Tucker, W. S., "The Determination of Velocity of Sound by the Employment of closed Resonators and the Hot-Wire Microphone," Phil. Mag., 34, 217-235, 1943.

A resonator consisting of two cavities connected by a narrow neck is employed. Sound is introduced by a telephone diaphragm forming the boundary of one enclosure, and temperature and response of the resonator to sound are indicated by the change in electrical resistance of a hot wire in the neck of the resonator. Frequency-response curves are obtained from which the true resonance-frequency maximum is obtained. Theoretical support is given to the existence of a linear relationship between velocity and resonance frequency for different gases. Determinations of velocity of sound for air saturated with water vapor were made and data obtained for calculation of γ. From this the velocity of sound in water vapor at 0^oC was deduced. Results were also obtained for the velocity of sound in ether and acetone vapors by a similar process.

2682

Williams, J. E. F., "Measuring Turbulence with a View to Estimating the Noise Field," Rept. No. 20381, Aeron. Res. Council, Great Britain, 11 pp., 1959.
AD-207 235.

Suggests an experimental procedure that is designed to measure, by hot-wire techniques, the distribution of acoustical sources in an air jet. The noise producing parameters are discussed along with the capabilities of present experimental equipment, and it is suggested that the proposed experimental program is at present the only one within the scope of equipment available. A stationary reference frame is used, and it is shown that although the theory based on this system is not as revealing as Lighthill's analysis of moving axes, it is nevertheless the only one available for experimental purposes.

Transducers, Hot-Wire
See Also—1451, 1682, 2174, 2826, 2837, 2838, 2849, 2856, 2857

TRANSDUCERS, LOUDSPEAKERS

2683

Ackerman, E., A. Anthony, and F. Oda, "Corona-Type Loudspeaker for Animal Studies," J. Acoust. Soc. Am., 33, 1708-1712, 1961.

By use of a high-power, corona-type loudspeaker we have been able to demonstrate behavioral and endocrine responses of laboratory rodents to measured high sound-pressure levels at the frequencies at which their hearing is most sensitive, namely, 10 to 40 kc. The corona-type loudspeaker behaves in the fashion predicted by the theoretical analysis reviewed in this paper. It is limited by extremely low efficiency (2.5%) and high production of ozone. At high frequencies it is limited by the volume of the corona, and at low frequencies by the failure of the quasi-adiabatic condition within the corona. Despite these limitations its performance has not been equaled by other types of loudspeakers; it is a unique tool for studying the responses of laboratory rodents to sound fields.

2684

Arnold, J. S., and A. Picker, "The Modification of a Warning Siren to a Modulated Airstream Loudspeaker," Final Tech. Rept., Stanford Res. Inst., Menlo Park, Calif., 83 pp., 1961. AD-272 937.

The feasibility of modifying a warning siren to add speech capability was demonstrated by adding a modulated airstream loudspeaker to the siren. The siren's air supply and control circuit were used by the loudspeaker, with appropriate auxiliary equipment and minor modifications of the existing siren. Using a recorded-speech input, an average sound pressure level of 117 db was achieved on the horn axis at a distance of 100 ft. At a distance of 675 ft (limited by terrain) observers reported that the sound was loud, clear, and intelligible. Extrapolation of the data indicates that speech is intelligible within a maximum range between one and two miles, depending on ambient noise and other conditions.

2685

Beranek, L. L., "Loudspeakers and Microphones," J. Acoust. Soc. Am., 26, 618-629, 1954.

This paper covers the development of loudspeakers and microphones and gives many illustrations of commercially available units dating from 1915 to the present time.

2686

Bobb, L., R. B. Goldman, and R. W. Roop, "Design and Performance of a High-Frequency Electrostatic Speaker," J. Acoust. Soc. Am., 27, 1128-1133, 1955.

An electrostatic speaker has been developed that provides a high quality of high-frequency reproduction not available with electromagnetic tweeters. The diaphragm consists of a thin plastic film bearing an evaporated metallic layer. The membrane is stretched around a semicylindrical perforated electrode on which ridges are embossed to provide clearance. The response varies less than -2 db in the frequency range between 8 and 16 kc. The azimuthal distribution pattern is excellent, owing to the cylindrical geometry, and is essentially independent of frequency in the same range. The second harmonic distortion inherent in this type of speaker is maintained at low value.

An indication of the quality of high-frequency reproduction is provided by oscillograms of the response to tone-burst signals. The speaker is in quantity production and has been incorporated in several models of home instruments.

2687

Caldwell, J., Jr., and F. C. Fischer, "Design and Development of a Droppable Loudspeaker," Cook Electric Co., Skokie, Ill., 1953-1955.

This series of reports covers the design, development and testing of a high-power speaker-amplifier system capable of being dropped by parachute from high-speed aircraft to radiate intelligible speech to areas on the ground during descent. The complete system is dropped in a bomb-like container which holds brake and final parachutes, a tape playback unit, amplifiers, power supply, horn driver, horn, and deployment control devices. The reports describe in detail the engineering progress, construction and testing that led to the completed system.

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	8 - 1 June - 1 July 54	AD-48,264
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	19 - 1 May - 1 June 55	AD-76,333
	20 - 1 June - 1 July 55	AD-76,331
	21 - 1 July - 1 Aug 55	AD-76,334

2688

Carlisle, R. W., "Conditions for Wide-Angle Radiation from Conical Sound Radiators," J. Acoust. Soc. Am., 15, 44-49, 1943.

The loudspeaker cone is approximated to an array of pairs of point sources, and conditions of wide-angle radiation depend on the selection of the cone angle, the number and depth of the corrugations, and the weight and stiffness of the cone material.

2689

Cunningham, W. J., "The Growth of Subharmonic Oscillations," J. Acoust. Soc. Am., 23, 418-422, 1951.

Subharmonic oscillations at one-half the frequency of excitation may appear in certain types of oscillating systems, among which is the direct-radiator loudspeaker. These oscillations occur at very nearly the resonant frequency of the system when the parameters of the system are made to vary at twice this frequency. The rate of growth of the subharmonic depends upon the amount of vibration of the parameters relative to the dissipation in the system. If the dissipation is small, the rate of growth may be large. In the loudspeaker, conditions are such that the rate of growth is usually small for typical conditions of operation.

2690

De Boer, E., "Acoustic Interaction in Vented Loudspeaker Enclosures," J. Acoust. Soc. Am., 31, 246-247, 1959.

In the design of vented loudspeaker enclosures the acoustic interaction between the two radiating openings is usually left out of the discussion. This letter will show how a simple, yet adequate, representation of this interaction can be obtained. The ideas presented here are not new, but in view of its implications, the method deserves some further discussion.

2691

Densberger, P. J., "Development of a New Flight-Deck Loudspeaker for U. S. Navy Aircraft Carriers," J. Audio Eng. Soc., 4, 138-144, 1956.

A new flight-deck loudspeaker for use in a highly noisy environment was developed, with the following factors as design criteria: (1) Size, weight, number, and configuration of loudspeaker components consistent with ruggedness requirements for shipboard use; (2) the audio-input power required and the manner of distribution of this power to the loudspeaker system; (3) the length of cable runs and the number required; (4) size of the flight deck; (5) a method of installation without jeopardy to flight operations; (6) ease of servicing and reliability.

2692

Eggers, F., "Measurement of Amplitude and Phase Distribution on Conical Loudspeaker Diaphragms," Acoustica, 7, 21-28, 1960.

A continuous record was made of amplitude and phase over the whole conical diaphragm of a loudspeaker. Whereas the motion at low frequencies is of the piston type, at moderate frequencies, azimuthal variations, and at higher frequencies, radial variations, become apparent. With warble tones or noise bands, a ring zone of maximum amplitude appears on the membrane, which moves towards the center as the frequency goes up. The piston type vibration is more important for radiation at low and middle frequencies, the azimuthal flexural waves superposed thereon having little effect.

2693

Ewaskio, C. A., and K. M. Osman, "Electroacoustic Phase Shift in Loudspeakers," J. Acoust. Soc. Am., 22, 444-448, 1950.

Direct measurements of envelope delay have been obtained for a series of commercial and experimental loudspeakers. The modulation phase shift method of Nyquist and Brand has been adapted for direct indication of envelope delay by utilizing an electronic phase meter. A continuous record of the delay is obtained by an automatic level recorder suitably connected to the phase meter. Pressure-amplitude curves measured under the same conditions provide date for a preliminary attempt to interpret the correlation between delay and pressure responses.

2694

Fagen, E. A., "A Figure of Merit for Horn Loudspeaker Drivers," J. Audio Eng. Soc., 10, 302-305, 1962.

The figure of merit (F) for horn loudspeaker drivers is derived. By imposing several restrictions, F may be obtained by simple laboratory tests.

2695

Fiala, W. T., "Recent Cone Speaker Developments," J. Audio Eng. Soc., 7, 110-114, 1959.

This paper discusses the factors governing the low-frequency response and distortion of cone speakers. Laboratory techniques for the evaluation of cone compliances are described. A cone speaker design using a new linear compliance is discussed in detail, and acoustic measurements on this speaker are presented.

2696

Gayford, M. L., "Acoustical Techniques and Transducers," Macdonald and Evans, Ltd., London, England, 372 pp.

This book presents the state of the art and a survey of recent developments in the field of applied acoustics as related to sound reproduction.

The book is introduced by a brief general discussion of physical phenomena encountered in acoustical and mechanical systems and analogies between electrical, mechanical, and acoustical systems. The treatment is advanced enough for the specialist but not enough to discourage the reader who has very little specific training in acoustics.

The major portion of the book is devoted to a survey of recent developments in loudspeakers, microphones, and disk recording and reproducing equipment. The discussions on vibration-measurement equipment and the acoustics of studios and listening rooms are somewhat shorter. For example, the section on microphones covers 30% of the book.

The discussion of each topic is concluded with references to books and journals. The references are well chosen and practically all the references relate to articles or books published in the last decade.

2697

Hilliard, J. K., and W. T. Fiala, "Electro-Pneumatic Air Modulator for Fog Signals," Rept. No. 6-2-1, United States Coast Guard, Washington, D. C., 11 pp., 1960. AD-242 094.

A highly directional electro-pheumatic, air-modulated loudspeaker was designed. It is capable of radiating speech or any type of warning signal in the 100-c to 1000-c range. Tests were conducted to delineate the directional qualities of the sound generator, both in absolute terms and in practical navigation. In these tests, 200-c and 400-c warbled tones, plus a voice signal, were compared with a standard diaphone fog signal.

The electro-pneumatic equipment used for the tests included a single unit consisting of four air-modulated loudspeakers driving an exponential horn six ft. in length, with a mouth cross-section of four sq. ft. Voice signals were generated by two air-modulated loudspeakers mounted on an Altec-Lansing 1003 multicell horn with a cutoff of 200 c.

A shadow zone was established in the upwind direction which fully substantiated the effect of sound over water as described by Francis M. Weiner (AD-242 087).

2698

Hoodwin, L. S., "The Compound Diffraction Projector," J. Audio Eng. Soc., 2, 40-44, 1954.

A new horn-type loudspeaker has been developed to provide improved reproduction in public address and multiple-channel loudspeaker installations. The name of this unit is the compound diffraction projector (CDP). Although the qualities desirable in a public address loudspeaker depend on the specific application of the loudspeaker, general requirements may be obtained by considering average applications and the demands those applications make on the five measurements of loudspeaker performance: efficiency, frequency response, polar distribution, distortion, and power handling capacity. These measurements are presented for the CDP.

2699

Janszen, A. A., "An Electrostatic Loudspeaker Development," J. Audio Eng. Soc., 3, 87-90, 1955.

The idea of bringing electromechanical forces of transduction to bear directly on the transmitting medium spurred many pre-high-fidelity experimenters to extensive attempts to harness the electrostatic mechanism of transduction to the design of loudspeakers. Early attempts were not notably successful, either in this country or abroad. The advent of new materials and techniques and the growing awareness of, and demand for, fidelity in the reproduction of recorded music and other program material have provided both the incentive and the means for a renewal of effort. One of the results of this effort is the Janszen electrostatic loudspeaker, which is designed for use with two-way systems. High efficiency is obtained over a wide frequency range, which extends from below 1000 cps to above 20 kcs. The membrane used in its building-block elements is so light that, over most of its frequency range, it functions as an imaginary boundary in the air. The axial pressure response, therefore, is extremely smooth. The unit operates from the 8-ohm or 16-ohm output of any amplifier, and contains its own bias supply. Maximum power output is 0.5 acoustic watt.

2700

Kalusche, H., "A Loudspeaker Arrangement with Unilateral Directivity," (in German), Z. Angew. Phys., 2, 411-415, 1950.

By combining a first-order transmitter with an acoustic transit-time element, a heart-shaped diagram of radiation can be obtained. Curves are given showing the radiation characteristics of a linear arrangement of six such combinations for frequencies of 100, 200, 500, 1000, 3000, and 10,000 cps, and for both the horizontal and the vertical plane. Less than 10% of the sound energy is radiated backwards.

2701

Kantrowitz, P., "Distortion Measurements of High-Frequency Loudspeakers," J. Audio Eng. Soc., 10, 310-317, 1962.

Reports investigation of the relative importance of linearity and distortion in high-frequency loudspeakers. Hemispherical direct radiators, conical direct radiators, a ribbon horn, dynamic horns, a single-ended and a push-pull electrostatic speaker were evaluated for frequency response, nonlinear distortion and directionality.

Quadratic and cubic nonlinear distortion terms were found to be present in high-frequency loudspeakers. The maximum cubic CCIF nonlinear distortion in horns was greater than that found for the direct radiator and push-pull electrostatic types. Smoothness of response, directional characteristics, and extent of frequency range were generally more significant than distortion in the classification of the "listenability" of the high-frequency loudspeaker. Subjective listening tests, however, indicated that total CCIF nonlinear distortion above approximately 3% is objectionable.

It was found that in a complete speaker system, the capabilities of a superior high-frequency loudspeaker may be severely limited or altered due to the selection of an improper cross-over network or the use of inferior middle- and low-range speaker units.

2702

Klein, S., "Strong Demodulation in Air of Two Ultrasounds of Different Frequencies" (in French), Ann. Telecommun., 9, 21-23, 1954.

Two ultrasonic sound sources are situated 10 cm apart and facing each other. The frequency of audible sound is exactly the difference betwen the two ultrasonic frequencies. The intervening space is analyzed and it is shown that the audible sound arises at the nodes and antinodes of pressure of the ultrasonic stationary wave system. To obtain reproduction of music and speech two systems are indicated, one utilizing frequency and amplitude modulation, and the other, only frequency modulation. Circuit diagrams are given.

2703

Levy, S. E., and R. W. Carlisle, "Generation of Intense Audio Sound Fields Utilizing Arrays of Multiple-Driver Horns," J. Acoust. Soc. Am., 33, 936-940, 1961.

There are several major applications for intense audio sound fields: the outdoor propagation of speech and of warning signals, and the sonic fatigue testing of missile and aircraft components. In these applications, several factors combined make it necessary to limit the portion of the frequency spectrum covered by any one loudspeaker unit. In order to provide adequate power capacity, selection is required between the alternatives of (a) using a large number of identical drivers, (b) using a plurality of drivers each especially designed for a selected portion of the frequency range, and (c) using combinations of these arrangements. In an array currently being used for sonic-fatigue testing, a plurality of large open-cone loudspeakers is used for low frequencies, and a plurality of horns is used for middle and high frequencies. Each horn is driven by several drivers. The driver voice coil and diaphragm proportions have been optimized to withstand fatigue stresses under the thermal conditions encountered. The driver is rated at 50 w input for programme material. Horn assemblies are available having throat arrays for mounting 6, 12, or 24 drivers. Various applications are illustrated.

2704

Lindenberg, T., "The Isophase Loudspeaker," J. Audio Eng. Soc., 4, 56-59, 1956.

The author describes a push-pull electrostatic loudspeaker, featuring large diaphragm area, which makes possible low-velocity sound propagation per unit area.

2705

Lyon, R. H., "On the Low-Frequency Radiation Load of a Bass-Reflex Speaker," J. Acoust. Soc. Am., 29, 654, 1957.

By drawing the equivalent circuit of a port-cone combination of a bass-reflex system near the fundamental resonance, the radiation load can be derived. The effect is one of coupling between the "mass plugs" of the radiators, and the mutual inductance varies inversely with the spacing between the port and the cone.

2706

Madella, G. B., "The Acoustic Coupling Between the Diaphragms of Two Coaxial Loudspeaker Units" (in Italian), Alta Frequenza, 19, 267-276, 1950.

An equivalent circuit is derived for a pair of loudspeakers, and it is shown that the acoustical coupling between them may have a considerable effect on their combined performance. Curves given show typical values of the various parameters.

2707

Malme, C. I., "A Wide-Range Electrostatic Loudspeaker," J. Audio Eng. Soc., 7, 47-54, 1959.

A newly designed wide-range electrostatic loudspeaker incorporates: push-pull operation with a light, 20-inch diameter, peripherally-supported diaphragm; a high-resistivity coating on the diaphragm surfaces to give constant-charge operation without the use of an external series resistor; a bias voltage of 16 kv applied through a corona-ring around the edge of the diaphragm; a high-output-voltage audio amplifier to provide a driving signal of 4.5 kilovolts rms; large diaphragm excursion to allow adequate low-frequency reproduction; and electrical segmentation of the diaphragm to give broad directivity patterns at all frequencies.

The experimental electrostatic loudspeaker is capable of a frequency response essentially flat within 8 db from 16 cps to 16,000 cps. Total harmonic distortion at 16 cps is 6%. The figures quoted are for a sound pressure level of 80 db (re 2×10^{-4} bar) measured at a distance of 6 ft on the loudspeaker axis in an anechoic chamber.

2708

Mawardi, O. K., "A Physical Approach to the Generalized Loudspeaker Problem," J. Acoust. Soc. Am., 26, 1-14, 1954.

Most analyses of loudspeaker performances are based primarily on the consideration of details of the electromechanical coupling. This approach has proved too inadequate to handle loudspeaker-radiation problems. An attempt has been made to set up a general expression relating the free-field sound pressure at a remote point to the electrical signal applied to the loudspeaker terminals. This relation, in the form of an integral equation, is solved exactly for a loudspeaker of circular shape. By means of the solution of the integral equation it appears possible to apply to this problem methods analogous to circuit-analysis techniques, which represent the transfer function of the system in terms of its characteristic points in the complex-frequency plane.

2709

Meixner, J., and U. Fritze, "The Sound Field in the Vicinity of a Free Vibrating Piston Diaphragm" (in German), Z. Angew. Phys., 1, 535-542, 1949.

The sound distribution has been calculated for various ratios of piston diameter to wavelength, and compared with the sound field due to the same piston source operating in an infinite rigid wall (according to Stenzel). Sound fields of this nature are plotted for the cases ka = 4, 6 and 10. Reference is made to theoretical work of Rayleigh, Stenzel, and McLachlan.

2710

Miles, J. W., "Transient Loading of a Baffled Piston," J. Acoust. Soc. Am., 25, 200-203, 1953.

The force-time history required to produce a step in the velocity of a circular piston mounted in an infinite baffle is determined with the aid of the Laplace transform. Working from this result, the inverse problem of the velocity response to a step force is calculated approximately. These two results suffice to treat arbitrary distributions of applied force or velocity by Duhamel superposition. The application of the results to a loudspeaker model shows that a system designed for critical damping on the steady-state approximation for the air loading will actually be slightly overdamped in its initial motion, but that the characteristic time during which the design assumption is inadequate is of the order of 10^{-3} seconds.

2711

Oda, F., "Corona Type Loudspeaker," WADC Tech. Rept. No. 58-368, Pennsylvania State Univ., University Park, 64 pp., 1958. AD-155 782.

Presents development of a HF (1-50 kc), high power (1.3 kw) speaker needed in biological research. It includes a theoretical discussion of corona sound generation (thermal) and the reasons for upper (corona size) and lower (corona cooling rate) frequency limitations. Eleven speaker designs were tested. A 60-w and a 1.3-kw speaker system are described.

2712

Oliveros, E. V., "Amplifier-Loudspeaker Equipment Designed for Non-Tactical Applications," Material Lab., New York Naval Shipyard, Brooklyn, 1957. AD-156 655.

Performance specifications were developed for amplifier loudspeaker equipment for use in protected areas aboard ships or in naval installations ashore. Prototypical equipment constructed to demonstrate the feasibility of the specifications met the requirements in all but two minor respects. The maximum permissible power comsumption was exceeded by 0.4 db. The amplifier was capable of delivering undistorted power of more than six watts with a response well within the desired limits. Amplifier-loudspeaker equipment submitted by two manufacturers did not meet the performance and design requirements of the proposed specification.

2713

Olson, H. F., "Acoustical Engineering," D. Van Nostrand, New York, 725 pp., 1957.

This is a new edition of H. F. Olson's book, formerly titled Elements of Acoustical Engineering. It retains the organization of the earlier work, but adds two chapters: Chapter 13, "Complete Sound Reproducing Systems," and Chapter 14, "Means for the Communication of Information."

In addition, the text has been thoroughly brought up to data, recording the developments of the last few years. New and often large sections appear in all chapters. For example, Chapter 5 contains added material on the pulsating cylinder and vibrating strip; Chapter 6, on the theory of the electrostatic loudspeaker; Chapter 7, on the throttled air flow speaker and on the ionophone loudspeaker; Chapter 8, on the theory of the electronic microphone; and Chapter 9, on magnetic tape sound recording and reproducing systems. In the revision of Chapter 10 advantage has been taken of the considerable number of new and revised standards on acoustical measurements published by the American Standards Association since 1945.

2714

Olson, H. F., "Loudspeakers," Proc. Inst. Radio Engrs., 50, 730-737, 1962.

A loudspeaker is an electroacoustic transducer intended to radiate acoustical power into the air, the acoustical waveform being essentially equivalent to that of the electrical input. Electrodynamic, electromagnetic and electrostatic driving systems have been used for loudspeakers operating in air. However, during the past two decades the electrodynamic has overwhelmingly predominated in all applications for loudspeakers operating in air. The almost universal use of the direct-radiator dynamic loudspeaker in radio receivers, phonographs, magnetic-tape reproducers, television receivers, announcing and intercommunicating systems is due to the simplicity of construction, small space requirements, and the relatively uniform response-frequency characteristics. For small-scale applications, the low efficiency of the direct-radiator loudspeaker is not a handicap. However, for large-scale high-power sound applications, the high-efficiency horn loudspeaker is particularly suitable because the amplifier requirements are reduced by an order of magnitude. For the future, the promising developments in loudspeakers appear to be in the field of motion control.

2715

Perrigo, W. R., "Air-to-Ground Loudspeaker Equipment," Tech. Rept. No. 59-625, Communication and Navigation Lab., Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, 9 pp., 1959.
AD-227 278.

Describes design, development, and testing of air-to-ground loudspeaker equipment and systems for application in psychological warfare. Presents the development of droppable and fixed airborne loudspeaker systems designed to meet USAF operational requirements, outlined in applicable military characteristics dated 21 Nov 1951. Describes application of the resultant equipment in support of psychological missions of the Strategic and Tactical Air Commands.

It was concluded that the droppable loudspeaker system AN/ANH-4(XA-2 and XA-3) and public address set AN/AIC-11(XA-2) met basic USAF requirements, could be used effectively in psychological warfare, and had potential application in other types of USAF missions.

2716

Pohls, M., "Measurements on Loudspeakers," (in German), Arch. Tech. Messen (Germany), 310, 243-244, 1961.

Consideration is given to electrical and acoustical measurements of loudspeakers. The electrical measurements to which reference is made are effective resistance, fundamental resonance, and limit of power output (over long periods of continuous use). The acoustical measurements relate to the output of sound as a function of frequency from 0 to 15 kcs, directional characteristics (dbs-angle), and frequency characteristics as a function of angle.

2717

Rettinger, M. "Practical Electroacoustics," Chemical Publishing Co., N. Y., 1956.

Mr. Rettinger has compiled a pocket-sized volume on present-day electroacoustic devices and techniques. Throughout eight chapters and a short appendix, he presents several hundred typical handbook figures and formulas in a conversational manner.

The initial chapter deals with microphone types and characteristics, emphasizing placement and directivity. There is also an enlightening discussion on the use of the effective microphone output level in dbm. Following this is a chapter on direct radiator and horn loudspeakers. In addition to some fundamental theory on electromechanical transducer mechanisms, the fine points of enclosures and horns are treated at some length. These chapters, plus one on circuits involving crossover networks, mixers, and attenuators, provide the necessary background for a section on public address systems.

2718

Salmon, V., and J. C. Burgess, "Development of a Modulated Air Stream Loudspeaker," Stanford Inst., Calif., 1953-1955.

This is a series of quarterly progress reports concerned with the theoretical, experimental and developmental work required to produce a high-output loudspeaker with low distortion and wide frequency response. The objective is to produce optimal design parameters for a modulated air-stream method of generating high-intensity acoustical waves in air at efficiencies far in excess of those obtainable with moving-coil driving units. The problem of inherent nonlinearity of air as an acoustical medium is considered, and horn and modulator designs are optimized to provide good efficiency at reasonably low distortion. A sound pressure level of 121 db at 30 feet on axis was obtained with a developmental model driven by 10 watts of audio input power and 1-1/2 shaft HP for the air compressor.

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January-March 1955	AD-62 846
April-June 1955	AD-70 393
July-September 1955	AD-77 057

2719

Shirley, G., "The Corona Wind Loudspeaker.," J. Audio Eng. Soc., 5, 23-31, 1957.

The discovery in England of a method for controlling the wind produced by a corona discharge provides the basis for a new loudspeaker design having no moving parts and offering other potential advantages over conventional speakers. The inventor of the Corona Wind Loudspeaker is Dr. David M. Tombs.

The author first describes the construction of a corona triode in which a ring mounted coaxially about one electrode and given suitable potentials is found to control the discharge and hence the magnitude of the wind. Characteristic curves indicating triode-like behavior for various electrode spacings are presented.

By applying an af voltage to the ring, a sound source results. An early experimental model of such a loudspeaker is described and illustrated, together with its observed frequency response. Comparisons with the Ionophone and the electrostatic loudspeaker are made; they indicate its potential superiority in wide-range reproduction. The author discusses the acoustical and electrical problems that arise in the construction of a practical loudspeaker, and concludes with details of the research and development program necessary for its commercial realization.

2720

Stroh, W. R., "Phase Shift in Electroacoustic Transducers," Tech. Memo No. 42, Acoustics Research Lab., Harvard Univ., Cambridge, Mass., 31 pp., 1958.
AD-160 120.

Defines a complex transfer function that relates the sound pressure at a point on the principal axis of an electroacoustical transducer to the electrical input of the transducer. The argument of this function is composed of a phase function representing phase shift in the transducer, plus a shift proportional to frequency representing travel-time phase shift; the shift in the transducer itself can be measured directly. Typical phase functions for moving-coil and electrostatic loudspeakers are shown and discussed. The effect of transducer phase distortion on correlation functions is discussed, as is the use of the phase measurement in phasing a multiple transducer system.

2721

Tappan, P. W., "Loudspeaker Enclosure Walls," J. Audio Eng. Soc., 10, 224-231, 1962.

While it is traditional to use thick enclosure walls for loudspeakers, thick or heavy walls are not always necessary for high quality. Acoustical requirements, typical wall behavior, and the effects on system performance of various wall properties are discussed.

2722

Villchur, E., "A Method of Testing Loudspeakers with Random Noise Input," J. Audio Eng. Soc., 10, 306-309, 1962.

A method of obtaining a comparative relation between a given speaker and a standard is demonstrated.

2723

Webster, J. C., R. G. Klumpp, and A. L. Witchey, "Evaluation of a Modulated Air-Flow Loudspeaker," J. Acoust. Soc. Am., 31, 795-799, 1959.

As part of an overall evaluation of the USNEL Flight Deck Communications System, an RCA modulated-airflow loudspeaker (air speaker) was tried out as an alarm-signalling transducer on the flight deck of an aircraft carrier. Tests with 200-cps to 6000-cps noise showed that the air speaker produced 130 db SPL at optimum points on the deck, as compared to 110 db for the present system. Speech intelligibility and alarm detection tests showed the air speaker to be usable with jet aircraft at idle (30%) power while the present loudspeakers could not be heard. Neither loudspeaker system was adequate with jets at full power.

2724

Werner, R. E., "Effect of a Negative Impedance Source on Loudspeaker Performance," J. Acoust. Soc. Am., 29, 335-341, 1957.

A direct-radiator, moving-coil loudspeaker driven by an amplifier whose output impedance approaches the negative of the blocked voice-coil impedance can be made to exhibit extended low-frequency response with reduced distortion. The effect of the system is in some ways analogous to a manifold increase in loudspeaker efficiency. In a typical case, neutralization of 70% of the blocked voice-coil impedance completely damps the cone resonance, as well as substantially reducing the nonlinear distortion below resonance. When the amplifier is compensated for the falling resistance to radiation at low frequencies, uniform output can be obtained to any arbitrary low frequency, limited only by the ultimate power-handling capability of the amplifier and speaker. In this system, no additional amplifier power is required at frequencies down to the speaker resonance; additional power is required below that point.

Transducers, Loudspeakers

See Also—61, 103, 113, 331, 335, 482, 515, 553, 594, 612, 613, 619, 759, 873, 915, 965, 971, 973, 1012, 1015, 1017, 1026, 1057, 1086, 1250, 1291, 1294, 1315, 1321, 1325, 1331, 1581, 1830, 1851, 1862, 1864, 1866, 1873, 1877, 2156, 2302, 2557, 2558, 2560, 2564, 2573, 2574, 2588, 2589, 2590, 2592, 2593, 2848, 3647, 4035

TRANSDUCERS, MICROPHONES

2725

Ackerman, E., and W. Holak, "Ceramic Probe Microphones," WADC Tech. Rept. No. 53-77, Penn. State College, State College, Penn., 21 pp., 1953.
AD-12 966.

The limitations of these microphones were studied to determine the best form of probe to use for an electrokinetic hydrophone. The sensitive element of the microphones studied is a 1/16-in. long, 1/16-in. diam. hollow cylinder of barium titanate. The Spencer-Allen (S-A), modified version of the complex Pennsylvania State College probe, was constructed, as well as a simpler type, the Holak-Ackerman (H-A) microphone. The S-A has a flat response to 100 kc and is sufficiently small to cause negligible interference in a complicated sound field. A comparative study made to determine the amount of pickup along the tubing of each microphone showed that the S-A was the better insulated.

Calibrations using a 640 AA microphone as a source were made from 6 to 100 kc. The sensitivity of the tube to the sound field depended on the length of 1/16-in. diam metal tubing left exposed. The H-A microphones gave a flat response, within the limits of experimental error, ±1 db, when calibrated against an S-A microphone in the siren field. Since the H-A probe has a small effect on the sound field, it can be left in the field as a monitor during experiments. To study the details of weaker lobes in the siren field, an S-A probe microphone is desirable. These probes are also used as hydrophones in liquid volumes. The response in air differed little from that in water.

2726

Badmaieff, A., and E. S. Seeley, "Development of a Large Area Microphone," Quart. Prog. Rept. No. 1, Altec Lansing Corp., Anaheim, Calif., 17 pp., 1961.
AD-270 158.

Work was initiated on a large-area microphone system. The microphone is to have an active area of approximately 570 sq ft. It is to be broken up into 96 individual microphone modules, each 2 × 3 ft. in area. Each module is to be a microphone in itself, complete for individual operation. The module is a condenser-type microphone consisting of back and side enclosure, dielectric, guard circuit, back-plate electrode, and diaphragm electrode.

Details and techniques of construction were established by tests of samples of the backplate-dielectric-guardplate assembly. An experimental module was then built for use in preliminary measurements. Facilities were designed and constructed for testing the modules, consisting of a large piston-phone driven by special cone-type speakers, and an infrasonic power amplifier to drive the speakers. The preliminary measurements established the gain requirement for meeting the sensitivity specifications, and indicated the need for special provisions in the electronic circuits to meet the objectives of S/N.

2727

Bauch, F. W. O., "New High-Grade Condenser Microphones," J. Audio Eng. Soc., 1, 232-240, 1953.

The principles of condenser microphones are discussed in detail, including the Bramunuhl and Weber principle. Various Neumann-type microphones and associated power supplies are described, including a new pressure unit.

2728

Bauer, B. B., "A Century of Microphones," Proc. I. R. E., 50, 719-729, 1962.

Innumerable transducers have been tried, but five are pre-eminent: carbon, condenser, piezoelectric, moving conductor, moving armature. Important microphone improvements during the late twenties and the thirties came about as a result of application of equivalent circuit analysis to acoustical structures. The principle of pressure microphones, pressure-gradient microphones, combination microphones and phase-shift microphones are described. Each of these has found an important niche in modern microphone applications.

A small number of important applications require super-directional microphones. Here, three approaches are used: reflectors, refractors, and diffractors; line microphones; higher-order combination microphones. In the future, improvements in design of directional microphones will continue; wireless microphones are bound to increase in popularity. New methods of transduction based upon solid-state technology appear to be imminent. Unconventional methods of sound pickup may find wide use in space communication.

2729

Bauer, B. B., "Microphones for Sound Level Meters," J. Acoust. Soc. Am., 29, 1333-1334, 1957.

Microphones for sound-level meters comprise a combination of conflicting requirements. High sensitivity is important to minimize noise problems, and it is obtainable with a large microphone. Frequency-response and equal reception of sounds from all directions are also important. This calls for a microphone of small size. Good low-frequency response and freedom from electromagnetic induction points to the use of capacitor or piezoelectric transducers, preferably the latter, because they do not require a costly preamplifier. The piezoelectric and capacitor microphones are usually not as free from the effects of heat and humidity as are the magnetic types. The magnetics, on the other hand, have a poor low-frequency response, and are subject to electromagnetic pickup. A piezoelectric microphone is the most frequent choice.

2730

Bauer, B. B., "A Miniature Microphone for Transistorized Amplifiers," J. Acoust. Soc. Am., 25, 867-869, 1953.

A new magnetic microphone has been developed for use in hearing aids and other kinds of communication equipment that require a small, light, medium-impedance microphone. The new microphone has a diameter of 1 inch and a thickness of 3/8 inch, and it weighs 10 grams. The sensitivity is high enough to override the relatively high noise level of transistors in the frequency range most useful for voice transmission.

2731

Beaverson, W. A., and A. M. Wiggins, "A Second-Order Gradient Noise Canceling Microphone Using a Single Diaphragm," J. Acoust. Soc. Am., 22, 592-601, 1950.

A close talking, noise-canceling microphone has been developed that responds to the second order of the pressure gradient and that has only one diaphragm. Since there are four sound pressures involved in a second-order gradient microphone, it has been deemed necessary in the past to have four surfaces for the four pressures to act upon. This microphone has sound entrances to the two surfaces of a single diaphragm, spaced and oriented in such a manner as to produce the second-order effect, thereby increasing the signal-to-noise ratio over that obtained in a first-order gradient microphone.

Mathematical analyses are made of the microphone first as a purely theoretical microphone with infinitesimal spacing of the sound entrances, then as a microphone with dimensions between sound entrances that are practical for use in a microphone of this type.

2732

Benson, R. W., "The Calibration and Use of Probe-Tube Microphones," J. Acoust. Soc. Am., 25, 128-134, 1953.

A study was undertaken to obtain the free-field and the coupler calibrations of several probe-tube microphones with tubes of different sizes and to determine those characteristics of a probe tube which are necessary for accurate measurements in both a free field and in closed couplers. For accurate measurements with a probe-tube microphone, precautionary measures must be taken. The probe tube must be sealed to the frame of the microphone in order to prevent an acoustic leak. Such a leak causes a reduction in the output of the probe-tube microphone at the lower frequencies. A probe tube with a high input impedance should be used for making measurements in a closed coupler. A high input impedance is necessary if the pressure in the coupler is to remain the same as before the insertion of the probe tube. If measurements are to be made with the accuracy of measurements made with a standard laboratory microphone, there is a significant difference between the pressure and the free-field calibrations of probe-tube microphones.

2733

Beranek, L. L., "Loudspeakers and Microphones," J. Acoust. Soc. Am., 26, 618-629, 1954.

This paper covers the development of loudspeakers and microphones and gives many illustrations of commercially available units dating from 1915 to the present time.

2734

Black, R. D., "Ear-Insert Microphone," J. Acoust. Soc. Am., 29, 260-264, 1957.

It has been observed by several different technical groups that an acoustic transducer placed at the ear can be used as a microphone to pick up the voice of the wearer. This paper presents the results of an investigation to determine the various factors that make possible the use of a microphone in the ear.

The investigation, using a laboratory model dynamic ear-insert microphone and a protective headset, determined the relative importance of the two principal paths that conduct sound pressure from the mouth to the outer ear canal, the air path around the head, and the path through the head. The voice spectrum in the outer ear canal, contributed by the path through the head, was also obtained.

It appears that the ear-insert microphone could compete with a conventional microphone in front of the lips only in an application where it is difficult to use the conventional microphone because of its size or its interference with other equipment. The investigation forms a basis for further study to determine whether the ear-insert microphone has a future as a practical communications device.

2735

Bohn, J. L., "Study of Atmospheric Temperature and Meteoric Content by Ultrasonic Techniques and Development of Special Microphones," Final Rept., Res. Inst., Temple Univ., Philadelphia, 9 pp., 1953.
AD 38 283.

Describes the microphones used in making measurements of high-intensity radiation; they are considered superior to previous ones because they are smaller and have a better reflecting diaphragm — the diaphragms are clamped so that they can expand under prolonged heat absorption. Presents complete drawings of the assembly, including the Teflon carriage, which fits into the glass envelope; mounting parts made of Teflon reduce sound transmission, withstand a fairly high temperature for the baking-out process, and have the advantage of low vapor pressure.

Reports an improvement in the transmitter made by loosely coupling the oscillator to a two-tube class C amplifier, which in turn was coupled to the antenna.

Includes a complete schematic of a six-channel magnetic recorder. Four of the channels derive their inputs from the same source; sections of one signal at various amplitude levels may be recorded, permitting the full dynamic range of the recording medium to be utilized. The remaining two channels are conventional in that each gives a record of the signal from an independent unit.

Discusses the use of FM with the condenser microphones.

2736

Bolt, Beranek, and Newman, Inc., "Probe Microphones for Measurements in Ventilating Systems," Rept. No. 242, 39 pp., 1954.
AD-38 055.

A probe microphone system for the measurement of fluctuating pressures in shipboard ventilating systems has been developed under Contract NObs 62094. This system is primarily intended for measurements made within a moving airstream, for example, within a ventilating duct, and measurements at the inside wall of the ventilating duct. The elements that go to make up the probe-microphone assembly are a sintered-metal end piece, a probe tube of adjustable length, and a spiral acoustical termination containing a condenser microphone. When measurements are to be made within a moving airstream, the sintered-metal end is housed within a windscreen to reduce wind-generated noise. The microphone assembly can be used interchangeably with either a-c-operated or battery-operated electronic analysis equipment.

The use of a complete battery-operated system, which is supplied under the contract, is described in detail. Sufficient information is given on the assembly, adjustment, operation, calibrations, corrections, and limitations of the equipment to enable one to make effective use of the measuring system. In addition to a simple measurement example, there are presented some general remarks on the measurement of fluctuating pressures in moving media and a short bibliography on ventilating noise measurement and allied subjects.

2737

Burd, A. N., "Symposium on Calibration of Microphones and Hydrophones, London, January 1962," J. Sci. Instr., 39, 185-187, 1962.

A report of a symposium held by the Acoustics Group of The Institute of Physics and the Physical Society on 17 January 1962.

2738

Burns, F. P., "Piezoresistive Semiconductor Microphone," J. Acoust. Soc. Am., 29, 248-253, 1957.

A microphone using the piezoresistive effect of n-type germanium has been designed and constructed with a cantilever-beam arrangement. Frequency-response curves were taken in a sound field of 10 microbars with the microphone in a bridge type circuit and biased with 9 and 18 milliamperes.

The microphone produces 10^{-11} watts in the flat, low-frequency range, and peaks to 10^{-9} watts at a resonance of 2570 cps, and with a total bias of 18 ma in a bridge-type circuit. Other designs of transducers and different types of semiconductor material are discussed. The performance of a germanium-rod microphone is compared with a standard carbon-button transmitter.

2739

Carrell, R. M., "A Method for the Quantitative Measurement of Wind-Noise Sensitivity in Microphones," J. Audio Eng. Soc., 3, 102-105, 1955.

A spring-hinge pendulum may be used to carry a microphone noiselessly through the still air of an anechoic chamber. The noise generated by the flow of air past the microphone is easily measured and analyzed. Velocities of the order of 15-20 mph are obtainable with the pendulum, whose period is about 3 sec.

The output of the microphone may be recorded with a high-speed recorder. With the addition of a variable bandpass filter at the input to the recorder, a noise spectroanalysis may be accomplished. Wind-noise spectra of an RCA 77D in three-directional characteristic settings are presented and commented upon.

2740

Chalupnik, J., E. Rule, and F. Suellentrop, "Pressure Response of Condenser Microphones at Low Ambient Pressures," J. Acoust. Soc. Am., 33, 177-178, 1961.

The frequency response characteristics of condenser microphones at low ambient pressures are of interest when such microphones are used to make measurements on high-altitude rockets and capsules. Pressure response curves at a number of ambient pressures in the range 10^6 d/cm^2 (atmospheric pressure at sea level) to 1.7×10^4 d/cm^2 (atmospheric pressure at 90,000 ft alt) have been obtained for two commonly used condenser microphones (Western Electric 640AA, Bruel and Kjaer type 4111). Features of the response curves are discussed from a qualitative point of view.

2741

Cox, W. F., "Test Setup for Microphone Calibration," J. Acoust. Soc. Am., 32, 508-509, 1960.

This article describes a unique instrument setup for the calibration of a microphone by the comparison method. Conventional instrumentation for calibration by comparison with the Western Electric #640 or other standard uses two VTVM's to measure outputs. A phase meter or Lissajou pattern may also be used for phase relations. Complete definition of the output of the unknown requires measurement of distortion, however, as well as phase and amplitude. In the method of this article one automated display gives "quick look" data on distortion, phase, and amplitude.

2742

Daniels, F. B., "Noise-Reducing Line Microphone for Frequencies Below 1 CPS," J. Acoust. Soc. Am., 31, 529-531, 1959.

Describes a novel line microphone that utilizes a distributed input primarily for the purpose of improving signal-to-wind-noise ratio. The input to the transducer takes place through a tapered pipe that is coupled to the atmosphere by means of acoustical resistances uniformly spaced along the length of the pipe. The relationship between the resistances of the openings and the longitudinal variation in the characteristic impedance of the pipe is so adjusted as to make the system nonreflecting. Microphones of this type have been constructed for use in the frequency range below 1 cps for the purpose of studying atmospheric pressure oscillations in this range. A prototype, 1980 ft long with 100 openings, which gives an improvement in the signal-to-noise ratio of as much as 20 db under severe wind conditions, is described.

2743

Eliason, M. C., "A Condenser Microphone for Quantitative Determinations of Ballistic Shock-Wave Intensities," J. Audio Eng. Soc., I, 208-212, 1953.

Presents the design and construction features, testing and operating characteristics of the D-42 Microphone, originally developed for use with an acoustic firing error indicator. Briefly, this equipment consists of two microphones which are mounted at opposite ends of a plastic sphere in a towed sleeve target, and which modulate tiny FM transmitters in response to ballistic shock waves. Two receivers near the gunner actuate indicators that show this distance and inform the gunner whether he is leading or lagging a target.

2744

Embleton, T. F. W., and I. R. Dagg, "Accurate Coupler Pressure Calibration of Condenser Microphones at Middle Frequencies," J. Acoust. Soc. Am., 32, 320-326, 1960.

The technique whereby the reciprocity theorem is applied to the determination of the pressure sensitivities of microphones has been modified to improve the reliability and accuracy of the measurements. Sensitivities are measured in terms of the volume of a cavity, the capacity of a fixed condenser, and the variable setting of an accurate potentiometer. Six different pairs of measurements are made instead of three, which is the minimum possible number: this enables a check to be made on the internal consistency of each calibration. The accuracy of the measured sensitivities is estimated to be 0.05 db on an absolute scale and 0.03 db relative to each other. This technique has been employed to measure the properties of several condenser microphones of each of three well-known types over periods ranging from five months to two years. Results are given for their temperature and pressure coefficients, effective volumes due to nonrigidity of their diaphragms, and drift with the passing of time.

2745

Embleton, T. F. W., and I. R. Dagg, "Statistical Detection of Errors in Microphone Calibrations," J. Acoust. Soc. Am., 35, 108-112, 1963.

Microphone sensitivities obtained by reciprocity calibration depend on the measurements of several quantities (e.g., volume of a coupler, electrical capacitance). Errors in the best values of these parameters are systematic and undetectable unless an alternate method of calibration is used. A number of microphones of various types have been measured by both reciprocity and pistonphone methods, and the individual pairs of sensitivities are studied statistically to determine the probable existence and amount of the following classes of errors: (a) those related to constants of the pistonphone or

2746

Gayford, M. L., "Acoustical Techniques and Transducers," Macdonald and Evans, Ltd., London, England, 372 pp.

This book presents the state of the art and a survey of recent developments in the field of applied acoustics as related to sound reproduction.

The book is introduced by a brief general discussion of physical phenomena encountered in acoustical and mechanical systems and analogies between electrical, mechanical, and acoustical systems. The treatment is advanced enough for the specialist but not enough to discourage the reader who has very little specific training in acoustics.

The major portion of the book is devoted to a survey of recent developments in loudspeakers, microphones, and disk recording and reproducing equipment. The discussions on vibration-measurement equipment and the acoustics of studios and listening rooms are somewhat shorter. For example, the section on microphones covers 30% of the book.

The discussion of each topic is concluded with references to books and journals. The references are well chosen and practically all the references relate to articles or books published in the last decade.

2747

Goff, K. W., and D. M. A. Mercer, "Probe Microphone Analysis and Testing at High Temperatures and High Intensities," J. Acoust. Soc. Am., 27, 1133-1141, 1955.

A probe microphone has been developed suitable for measuring sound fields within such structures as altitude wind tunnels and jet engine test cells. This paper describes the methods of testing and analyzing the instrument. The microphone consists of a 3/8-inch inside diameter probe tube with a porous metal tip, a condenser microphone, and a spiral resistive termination. It operates at sound-pressure levels up to 170 db with 2% distortion, at ambient pressures down to 0.2 atmosphere, and with probe tip temperatures up to 900°F. The normal incidence response is flat within ±3 db from 10 to 10,000 cps.

An electrical analog of the acoustical system is given as a basis for explaining and predicting the performance of the microphone under varying ambient conditions. It appears that the microphone can be used satisfactorily as a cavity terminated probe microphone for frequencies below the frequency at which the spiral termination ceases to be "anechoic." The required length of the spiral termination is then determined by the probe-tube length rather than the lowest frequency of interest.

Testing methods and apparatus are discussed, including a high-temperature flow resistant apparatus, a low-pressure test chamber, and a resonant tube device for developing sound pressures up to 175 db with low distortion.

2748

Gutenberg, B., "The Velocity of Sound-Waves from Gun-Fire in Southern California," Trans. Am. Geophys. Union, 156, 1938.

Description of a sensitive instrument for recording changes in air pressure. Sound waves recorded by this short period Benioff barograph shown.

2749

Hanel, R. A., "Thermoelectric Microphone for Modulated Ultrasonic Waves," J. Acoust. Soc. Am., 32, 1436-1442, 1960.

Conventional thermal microphones record the increase in temperature generated by the absorption of acoustical energy. The microphone described in this paper measures the periodic change of the temperature that is generated by an amplitude-modulated sound wave. This microphone is small, omnidirectional, free of drift, and extremely sensitive. Temperature variations in the order of 3×10^{-5}°C have been recorded by means of a narrow-band amplifier tuned to the modulation frequency. The temperature distribution in a thermocouple enclosed in a sound-absorbing material, and the optimum modulation frequency are calculated. A relaxation function is introduced to help interpret the results physically. Also, the electronic input circuit is discussed in detail.

2750

Harrington, H. E., "Research Directed Toward the Design, Development, and Construction of Meteoritic Microphone Detectors of Various Sensitivities for Use in Satellites," Sci. Rept. No. 1, Oklahoma State Univ. Research Foundation, Stillwater, 1960.
AD-233 737.

An electronic system designed for the express purpose of exploiting the data-gathering potential of a specific vehicle in obtaining information regarding the influx of micrometeor material was developed. An acoustic sensing technique is employed, whereby the particulate matter to be detected activates a supersonic microphone device. The resultant electrical signal is amplified to a suitable level, graded as to magnitude, and stored internally by electronic means for subsequent recording and/or telemetering to ground receiving stations by the system inherently available within the chosen vehicle. A brief historical background of the development of the technique is presented, together with details of the specific system evolved for this application. Various design features which are peculiar to this application are presented and discussed. The prototypical equipment which resulted from the development program was subjected to a testing program to verify its suitability for the anticipated use, and several sets are currently under construction.

2751

Hilliard, J. K., and W. T. Fiala, "Condenser Microphones for Measurement of High Sound Pressures," J. Acoust. Soc. Am., 29, 254-260, 1957.

A series of small condenser microphones with accessory equipment has been developed for the measurement of high sound-pressure levels. The paper derives expressions leading to the evaluation of the nonlinear distortion of the microphone, describes the construction of the several elements of the microphone system, and presents performance data. Four interchangeable microphones, all employing clamped glass-plate diaphragms, provide linear measurements over a pressure range of 1 to 10 d/cm^2. The microphones are 0.6 in. in diameter and their low directivity is shown by polar response patterns. A cathode follower tube is housed in a printed circuit base on top of which the microphone is mounted. Maximum output is 30 v rms. The equipment can be used over a wide range of temperature and barometric pressure and is sufficiently rugged to withstand severe overload and rough handling.

2752

Houdek, J. F., Jr., "A Stable Laboratory Standard Condenser Microphone," J. Audio Eng. Soc., 2, 234-238, 1954.

A laboratory-standard microphone must provide dependable calibration stability, satisfactory performance, and reliability. The rugged construction of the Kellogg microphone and a spring-loaded rear electrode assembly are intended to maintain constant diaphragm tension for improved stability. Appropriate modifications of the acoustic controls provide either a pressure-type or a free-field type of microphone. Each microphone has uniform characteristics and meets the ASA performance requirements for its type. Supporting performance data and other information relative to condenser microphones are presented.

2753

Izquierdo, M., "Problems in the Construction of Infrasonic Microphones," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 131-134, 1961.
AD-408 716.

This paper details the practical problems encountered in the production of infrasonic capacitor microphones. It covers both electronic and acoustical considerations and the steps taken to overcome these problems in prototype production.

2754

Kallistratova, M. A., "Procedure for Investigating Sound Scattering in the Atmosphere," Soviet Phys. Acoust. English Transl., 5, 512-514, 1961.

An 11-kcs pulse technique made it possible to isolate the required scattered signal from the direct and reflected ones. The construction, operation and performance of plane electrostatic transducers with good transfer characteristics—both as radiators and as microphones—are discussed.

2755

Kamperman, G. W., "Measurement of High Intensity Noise," Noise Control, 4, 22, 1958.

A thorough discussion of microphones usable for high-intensity measurement is given along with a discussion of planning an entire measuring system.

2756

Koidan, W., "Microphone Diaphragm Null Method for Sound Pressure Measurement," J. Acoust. Soc. Am., 32, 505-507, 1960.

A null technique is described for accurately measuring sound pressure with a condenser microphone while its diaphragm is held stationary. The method is particularly useful when it is desirable that the microphone present an infinite impedance to the medium and absorb no energy from the sound field. Sound pressure is determined by means of the electromechanical coupling constant, defined as $\phi = (p/e)_{u=0}$ where p is the sound pressure, e is the alternating voltage applied to the microphone terminals, and u is the volume velocity of the diaphragm. By using this definition, a concise derivation of an expression for ϕ in terms of measurable quantities is described. The value of ϕ for two Western Electric Company type 640AA condenser microphones was measured as constant with frequency to within ±0.25 db from 500 cps to 20 kc.

The effect of the finite acoustic impedance of a microphone on the magnitude of the incident sound pressure is calculated in terms of quantities obtained by driving the microphone electrically. The measurement of high sound pressure levels in resonant tubes is also discussed.

2757

Levine, L. M., and J. Hershkowitz, "Measurement of Noise Canceling Effectiveness of Microphones," J. Acoust. Soc. Am., 28, 973-976, 1956.

The noise-canceling effectiveness of a microphone is determined by measuring the random-noise discrimination as a function of frequency under conditions simulating actual usage, and then using this characteristic to compute the articulation index for an ideal system containing the microphone, when operating under specified noise and speech conditions. Results so obtained are shown to correlate with those of articulation tests for three microphones evaluated for three noise types at different noise levels.

2758

Levine, R. C., "DeForest's Diffraction Microphone—Optical Detection of Sound in Air," J. Acoust. Soc. Am., 33, 1625-1626, 1961.

A theoretical analysis of a microphone which optically detects the changes in air density or index of refraction due to sound waves (Lee DeForest, U. S. Patent, 1,726,289; 1924). A light ray penetrates a thermal gradient in the air, and predicted deflection of the ray is approximately 3×10^{-5} cm per microbar sound pressure for a 300°K temperature change in a centimeter of path length.

2759

Massa, F., "Comments on 'Pressure Response of Condenser Microphones at Low Ambient Pressures'," J. Acoust. Soc. Am., 33, 810, 1961.

The main point made is that in order to avoid variations in response that could cause serious errors in the measurement of sound pressure, it is necessary to use a measurement microphone in which the mechanical impedance is high and not subject to the influence of the air impedance associated with a vibrating system. It is suggested that an ADP microphone would be suitable at low ambient pressures.

2760

Matsuzawa, K., "Condenser Microphones with Plastic Diaphragms for Airborne Ultrasonics, II.," J. Phys. Soc. Japan, 15, 167-174, 1961.

A detailed study was made of the condenser microphones with backplates, called "group IA" in Pt I of the present paper. For each backplate, the surface roughness is studied by using profilograms, and the distribution function of the surface profile is obtained. Formulas for the resonance frequency, the electrostatic capacitance, and the low-frequency sensitivity are obtained theoretically, assuming a simple-model microphone with a backplate having a profile represented by the above distribution function. The formulas are found to agree fairly well with the experiments.

2761

McDonald, C., "Infrasonic Capacitor Microphone Systems," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 119-130, 1961. AD-408 716.

This paper summarized the characteristics, advantages, and disadvantages of various types of infrasonic capacitor microphone systems. The types of microphone systems considered are those employing the capacitor element as a polarized element, as a bridge-impedance element, and as an element of a tuned circuit. The characteristics of the microphone system discussed include sensitivity, practical frequency response limits, dynamic range, stability, and design considerations. Also included in the discussion is a comparison of the advantages and disadvantages of these microphone systems when they are used in conjunction with balloon-borne telemetry systems.

2762

Medill, J., "A Miniature Piezoelectric Microphone," J. Acoust. Soc. Am., 25, 864-866, 1953.

A new rochelle-salt microphone has been developed for use as a secondary standard in production testing, sound-level measurements, high-quality transmission of sound, and similar applications. The diameter of the new microphone (1 1/8 inch) is half the diameter of similar units in current use. Frequency response, directional characteristics, and moisture protection have been improved without a significant loss in sensitivity.

2763

Newitt, W., "Laboratory Standard Ceramic Microphones," J. Acoust. Soc. Am., 29, 1356-1365, 1957.

Microphones using barium-titanate disk ceramics in conjunction with a split-tube diaphragm have been designed and constructed. Frequency-response measurements were obtained by use of reciprocity techniques and by comparison with a known standard.

Sensitivities from -86 to -88 db referred to one volt per dyne per square centimeter, were obtained with a frequency response of plus or minus one db from 10 cycles to 30 kilocycles. The rugged construction and high stiffness of the microphone make it adaptable for use in high sound pressure, and for sound measurement in liquids.

The paper discusses theoretical relations pertinent to the development, describes the construction, and presents performance data of the microphone and associated electronic equipment.

2764

Niemoeller, A. F., "Reciprocity Calibration of Electro-Acoustic Transducers in the Time Domain," J. Acoust. Soc. Am., 33, 1712-1719, 1961.

A method of directly evaluating the impulse response of a reciprocal electroacoustic transducer is presented. The method is essentially the time-domain analog of the conventional (frequency-domain) reciprocity method. The transient response of a coupled pair of identical transducers is used to compute the impulse response of either of the pair. A numerical method of obtaining a solution is presented and is shown to be equivalent to the numerical solution of a real convolution integral equation. First, an approximate solution for one member of the pair of identical transducers is obtained. Then, a more precise solution is generated by minimizing the squared error between the actual response of the coupled pair and the one obtained by convolving the approximate impulse response with itself.

The method was tried on two pairs of condenser microphones, the microphones within each pair being very nearly identical. A pair of Western Electric 640-AA microphones were tested with the grids both on and off, and a pair of Bruel and Kjaer type 4131 microphones were tested with the grids on an off and with grids equivalent to those on the W. E. 640-AA both on and off.

Two unsatisfactory solutions resulted when W. E. 640-AA grids were used on the transducers. Three solutions were satisfactory, even though each contained a slight negative drift for large values of time. One solution contained no appreciable error in its entire time course.

2765

Pardue, D. R., and A. L. Hedrich, "Absolute Method for Sound Intensity Measurement," Rev. Sci. Instr., 27, 631-632, 1956.

Since sound propagation is an adiabatic process, a temperature fluctuation accompanies the sound wave in media for which the specific heat ratio is greater than unity. If the equation of state and the sound field are known, this temperature fluctuation may be related to the intensity of the sound wave.

Describes a thermometer capable of measuring fast, small-amplitude temperature variations. Its output is calculated for the case of plane, sinusoidal sound waves in an ideal gas. Its uses as a microphone and sound intensity meter are then considered.

2766

Peterson, A., "Sound Measurements at Very High Levels," I.R.E. Trans. Audio, AU-3, 71-76, 1955.

The behavior of a number of microphones at high sound levels is described. Some of the problems of making measurements at these levels are discussed.

2767

Peverley, R. W., "Vibration Problems with Microphones for Rocket-Engine Noise Measurements," Sound, 1, 21, 1962.

The vibration-response of crystal microphones in a missile-vibration environment has been examined. A very sensitive microphone was exposed to several vibration tests and the results were analyzed to predict the amount of vibration output and its effect on measured-noise data. This analysis revealed that at some discrete frequencies, vibration output of the microphone would exceed the acoustical output. Such peaks were not found, however, during examination of measured data. Comparison of vibration-response of other crystal microphones leads to the conclusion that crystal microphones can be used in high-vibration environments without degrading data quality.

2768

Rettinger, M. "Practical Electroacoustics," Chemical Publishing Co., N. Y., 1956.

Mr. Rettinger has compiled a pocket-sized volume on present-day electroacoustic devices and techniques. Throughout eight chapters and a short appendix, he presents several hundred typical handbook figures and formulas in a conversational manner.

The initial chapter deals with microphone types and characteristics, emphasizing placement and directivity. There is also an enlightening discussion on the use of the effective microphone output level in dbm. Following this is a chapter on direct radiator and horn loudspeakers. In addition to some fundamental theory on electromechanical transducer mechanisms, the fine points of enclosures and horns are treated at some length. These chapters, plus one on circuits involving crossover networks, mixers, and attenuators, provide the necessary background for a section on public address systems.

2769

Rogers, E. S., "Experimental Tunnel-Diode Electro-Mechanical Transducer Elements and Their Use in Tunnel-Diode Microphones," J. Acoust. Soc. Am., 34, 883-893, 1962.

A tunnel-diode transducer element is described in which stress is applied normal to the diode junction by a small probe. Static measurements on these elements have yielded strain-gauge factors as high as 7300. A number of experimental microphones have been built to evaluate the transducers; response-frequency characteristics and S/N ratios have been determined for several of them. The most sensitive microphone had a sensitivity of -31 dbm and a S/N of 45 db at resonance. These microphones have been operated both as variable resistance transducers and as modulated negative-resistance oscillator transducers.

An analytical description is given of these two basic circuit configurations. In their present form, tunnel-diode transducers are fragile; further effort will be required to produce a rugged, practical transducer element.

2770

Rouche, N., "Transducers and Their Equivalent Electric Circuits; Application to Microphones," Acustica, 6, 317-323, 1960.

It is shown that a system analogous to that set up by Fischer can be established on a general basis. All possible forms of the transducer equations compatible with the conservation of energy are examined from this standpoint.

2771

Rowehl, H. C., and R. C. Phillips, "H-182/PT Headset Microphone," Final Rept. No. 264-08, Telephonics Corp., Huntington, N. Y., 33 pp., 1962.
AD-284 389.

Reports the development of the H-182/PT Headset Microphone, which is intended for use with the Telephone Set TA-312/PT and Switchboard SB-22. If required, it may be worn with combat helmet M-1. Telephone or radio signals are continuously monitored. The microphone functions are switch-selected; push-to-talk telephone transmission, continuous telephone transmission, and push-to-talk radio transmission. The H-182/PT is a small unit designed to be stored in the top cover of Switchboard SB-22, or folded and carried in the pocket of a combat field jacket.

2772

Rule, E., F. Suellentrop, and T. Peris, "Vibration Sensitivity of Condenser Microphones," J. Acoust. Soc. Am., 32, 821-823, 1960.

The problem of operating condenser microphones in a vibration environment is considered, and it is pointed out that there is a precise relation between the vibration and pressure response for any given transducer. This relation is shown to be dependent on the mass per unit area of the microphone diaphragm, and graphs are given from which the suitability of a given microphone to perform its function in a vibration environment can be assessed. The results of measurements on a well-known type of condenser microphone are presented to support the theory, and the usefulness and disadvantages of vibration-isolating mounts and of systems using two transducers are discussed. A proposed design for a condenser microphone that will be insensitive to vibration is described.

2773

Schultz, T. J., "Air-Stiffness Controlled Condenser Microphone," J. Acoust. Soc. Am., 28, 337-342, 1956.

There has been developed a very small condenser microphone that exploits materials and methods of construction only recently made available by the post-war developments in plastics. These techniques have made possible a microphone with extremely regular voltage amplitude and phase responses as functions of frequency and with a reasonably high sensitivity. An analysis is given for the resonance frequencies of a circular membrane stretched over a closed cavity, with its center fixed over a small area.

2774

Seeley, E. S., and A. Badmaieff, "Development of a Large Area Microphone," Third Quart. Prog. Rept. No. 3, ALTEC Lansing Corp., 1962.
AD-276 701.

Microphone-diaphragm mounting problems were solved by employing a rigid module frame built from the extruded channel, and by developing an improved method for mounting the Mylar diaphragm, prestretched in two dimensions. The range of the attenuator was increased by adding five steps, to provide a total of 60 db. The field junction box circuits were redesigned to a reduced power output and an increased load impedance. The changes reduced the heat generation of the circuits by 70%, and resulted in a temperature rise of only 50°F. A complete microphone system, consisting of two modules, a field junction box, and a station rack completely implemented with cables and power equipment, was constructed.

2775

Seligson, A. L., "Free-Field Technique for Secondary Standard Calibration of Microphones," J. Audio Eng. Soc., 4, 110-115, 1956.

The acoustic environment required for the performance of free-field secondary standard microphone calibrations is examined. The technique includes automatic compensation for variations in sound output level versus frequency of the sound source. Size and orientation of the standard and object microphones and mounting are considered with a view toward minimizing disturbances in the sound field, and resulting calibration errors, arising from reflections at high frequencies. Maximum and minimum working distances from sound sources of various dimensions necessary to maintain plane-wave free-field conditions are given for a variety of microphone types. The accuracy limits of the calibration method are indicated.

2776

Soundrive Engine Co., "High Amplitude Sound Abatement Research Program," Final Rept., Los Angeles, Calif., 27 pp., 1953.
AD-13 144.

A sound source (siren) was developed which is capable of delivering continuous acoustic power into a 10-in.-diameter tube at acoustic levels up to 100 kw, provided the tube temperature does not exceed 170°F. An accurate and reliable condenser microphone system was developed for continuous use in the acoustic field with pressure swings approaching 1 atm. Theories were developed for the attenuation of high-amplitude plane waves; however, the predicted attenuation rates were higher than those obtained experimentally. Preliminary measurements of water-spray influence on attenuation rates indicated no significant attenuation effect due to water spray and no clear evidence of frequency dependance. Measurements of the shunting impedance presented by a Helmholtz resonator placed in the 10-in.-tube wall indicated that, for an approximate 56-c low-amplitude frequency, the combination of the resonator and the downstream portion of the tube appeared resistive when the sound frequency matched the low-amplitude resonator frequency. An analysis of the standing-wave structure at this frequency for six particle-velocity amplitudes established that the impedance was given by $R = 1/2\rho_0 \frac{U_0}{S}$, where ρ_0 is the equilibrium density of air, U is the particle velocity amplitude, and S is the cross-sectional area of the neck of the resonator.

2777

Terry, R. L., and R. B. Watson, "Pulse Technique for the Reciprocity Calibration of Microphones," J. Acoust. Soc. Am., 23, 684-685, 1951.

This paper describes a pulse technique which makes possible a free-field reciprocity calibration of a microphone indoors, without recourse to an anechoic chamber. The method is limited to frequencies above the middle audio range by consideration of the room size and pulse spectrum. An experimental calibration of a microphone is included, and waveforms are presented which demonstrate the validity of the method.

2778

Thurston, G. B., and R. L. Heiserman, "Calibration and Free Field Evaluation of a Pressure Gradient Microphone," Oklahoma State Univ. Res. Foundation, Stillwater, 19 pp., 1962.
AD-281 773.

The design, calibration procedure, and evaluation in a free field for a condenser-type pressure gradient microphone are described. Procedures were carried out for determining both magnitude and phase of the pressure gradient. The microphone responded to the differential action of the pressure at two closely spaced field points as communicated by two small probe tubes to either side of a sensing metal diaphragm. By means of a coupling chamber calibration procedure it was possible to obtain a sensitivity factor and an error factor which may be used both to describe the precision of the internal structure of the microphone and to correct for its imperfections. The free field studies analyzed the directional characteristics and resolution capabilities of the microphone. The radiation characteristics of a circular orifice in a plane baffle, as measured with the gradient microphone, are compared with those predicted by simple field theory with regard to the relationship between the pressure gradient magnitude and phase, and the pressure magnitude and phase.

2779

Weingartner, B., "Investigation of a Condenser Microphone with Cardioid Characteristic" (in German), Acoustica, 12, 158-165, 1962.

With the usual directional condenser microphones that employ phase-shifting circuits, deviations from the desired frequency-response curve and directivity pattern are observed at the lower and higher frequencies. These deviations are investigated in detail, and theoretical results are compared with experimental data obtained on a commercial condenser microphone. A simple way to improve the low-frequency response is indicated.

2780

Werner, R., "On Electrical Loading of Microphones," J. Audio Eng. Soc., 3, 194-197, 1955.

Electrical loading of microphones by preamplifier circuits heretofore has not been of great concern to the audio engineer. In the past, the input impedance of preamplifiers has been so much higher than the output impedance of microphones that the effect upon the performance of microphones has been indeed negligible.

The recent appearance of transistorized preamplifiers whose input impedance is sometimes quite low, and the growing use of high-sensitivity ribbon microphones, which have a highly frequency-variant output impedance, has stimulated new interest in this loading problem. A study of the Thevenin equivalent circuit of certain common types of broadcast microphones discloses that the input impedance of a preamplifier must be maintained at a value at least five times the nominal impedance of the microphones with which the preamplifier may be used—in order to avoid undesirable alteration of the microphone's frequency-response characteristic. This applies unless the preamplifier has been designed for a particular microphone.

2781

Wiggins, A. M., "Unidirectional Microphone Utilizing a Variable Distance Between the Front and Back of the Diaphragm," J. Acoust. Soc. Am., 26, 687-692, 1954.

A unidirectional pressure-gradient microphone is described; it utilizes a front-to-back distance that varies approximately inversely as the frequency. The varying front-to-back relationship is achieved by utilizing two sound entrances with frequency-discriminating parameters. One entrance is situated at a large distance from the front surface of the generating element, while the other entrance is placed directly behind the sound-responsive element. With this microphone, desirable characteristics can be obtained that would not be possible in the conventional cardioid type having a fixed front-to-back distance. The principle of its operation is described and compared with that of the conventional fixed-distance cardioid microphone.

2782

Zalivadnyi, B. S., "A Wideband Velocity Microphone," Soviet Phys. Acoust., English Transl., 7, 74-76, 1961.

The construction of a velocity microphone for measurements in a plane-wave (standing or traveling) field is described. The principle involved is the production of an ion cloud, which, on contact with the plane-wave forces, tends to oscillate with the same particle velocity as that of the particles in the medium.

Transducers, Microphones
See Also—15, 39, 61, 368, 397, 399, 401, 411, 420, 428, 515, 550, 553, 567, 594, 596, 599, 604, 605, 606, 608, 609, 612, 615, 656, 711, 759, 968, 1015, 1044, 1057, 1061, 1086, 1103, 1117, 1121, 1126, 1159, 1160, 1165, 1177, 1178, 1179, 1182, 1221, 1245, 1260, 1277, 1281, 1306, 1314, 1315, 1331, 1333, 1384, 1447, 1610, 1828, 2097, 2120, 2256, 2423, 2855, 3445, 3449, 3532, 3533, 4406

TRANSDUCERS, ULTRASONIC

2783

Ackerman, E., A. Anthony, and F. Oda, "Corona-Type Loudspeaker for Animal Studies," J. Acoust. Soc. Am., 33, 1708-1712, 1961.

By use of a high-power, corona-type loudspeaker we have been able to demonstrate behavioral and endocrine responses of laboratory rodents to measured high sound-pressure levels at the frequencies at which their hearing is most sensitive, namely, 10 to 40 kc. The corona-type loudspeaker behaves in the fashion predicted by the theoretical analysis reviewed in this paper. It is limited by extremely low efficiency (2.5%) and high production of ozone. At high frequencies it is limited by the volume of the corona, and at low frequencies by the failure of the quasi-adiabatic condition within the corona. Despite these limitations its performance has not been equaled by other types of loudspeakers; it is a unique tool for studying the responses of laboratory rodents to sound fields.

2784

Ackerman, E., and W. Holak, "Ceramic Probe Microphones," WADC Tech. Rept. No. 53-77, Penn. State College, State College, Penn., 21 pp., 1953.
AD-12 966.

The limitations of these microphones were studied to determine the best form of probe to use for an electrokinetic hydrophone. The sensitive element of the microphones studied is a 1/16-in. long, 1/16-in. diam. hollow cylinder of barium titanate. The Spencer-Allen (S-A), modified version of the complex Pennsylvania State College probe, was constructed, as well as a simpler type, the Holak-Ackerman (H-A) microphone. The S-A has a flat response to 100 kc and is sufficiently small to cause negligible interference in a complicated sound field. A comparative study made to determine the amount of pickup along the tubing of each microphone showed that the S-A was the better insulated.

Calibrations using a 640 AA microphone as a source were made from 6 to 100 kc. The sensitivity of the tube to the sound field depended on the length of 1/16-in. diam metal tubing left exposed. The H-A microphones gave a flat response, within the limits of experimental error, ±1 db, when calibrated against an S-A microphone in the siren field. Since the H-A probe has a small effect on the sound field, it can be left in the field as a monitor during experiments. To study the details of weaker lobes in the siren field, an S-A probe microphone is desirable. These probes are also used as hydrophones in liquid volumes. The response in air differed little from that in water.

2785

Baerwald, H. G., and D. A. Berlincourt, "Electro-Mechanical Response and Dielectric Loss of Prepolarized Barium Titanate Under Maintained Electric Bias, Part I," J. Acoust. Soc. Am., 25, 703-710, 1953.

In transducer applications of ferroelectric ceramics, it is standard practice to rely on retained polarization for the electromechanical response. This is practicable only for moderate driving amplitudes and sufficiently low temperature. At higher driving fields, dielectric losses increase inordinately and lead to eventual depolarization and loss of response. This can be remedied by application of a comparatively modest dc bias. The quantitative loss behavior of various ceramic bodies over extended ranges of temperature, field amplitude, and for various values of aiding bias, is investigated. Results are also presented on various other effects obtained with bias operation, such as increase of electromechanical coupling and shifts of thermodynamic transition points. Work on other associated phenomena—electrostriction, secular relaxation, etc.—will be reported in part II.

2786

Bohn, J. L., "Study of Atmospheric Temperature and Meteoric Content by Ultrasonic Techniques and Development of Special Microphones," Final Rept., Res. Inst., Temple Univ., Philadelphia, 9 pp., 1953.
AD 38 283.

Describes the microphones used in making measurements of high-intensity radiation; they are considered superior to previous ones because they are smaller and have a better reflecting diaphragm—the diaphragms are clamped so that they can expand under prolonged heat absorption. Presents complete drawings of the assembly, including the Teflon carriage, which fits into the glass envelope; mounting parts made of Teflon reduce sound transmission, withstand a fairly high temperature for the baking-out process, and have the advantage of low vapor pressure.

Reports an improvement in the transmitter made by loosely coupling the oscillator to a two-tube class C amplifier, which in turn was coupled to the antenna.

Includes a complete schematic of a six-channel magnetic recorder. Four of the channels derive their inputs from the same source; sections of one signal at various amplitude levels may be recorded, permitting the full dynamic range of the recording medium to be utilized. The remaining two channels are conventional in that each gives a record of the signal from an independent unit.

Discusses the use of FM with the condenser microphones.

2787

Brun, E., and R. M. G. Boucher, "Research on the Acoustic Air-Jet Generator: A New Development," J. Acoust. Soc., 29, 573-583, 1957.

The structure and operation of the Hartmann air-jet ultrasonic generator has been reviewed critically, and modifications are described that substantially increase the efficiency and available power output of the original device. Experimental results are presented in confirmation of the theoretical analysis.

An important part of the development has been the employment of a secondary resonator and projecting exponential horn. A novel design using a large number of whistles in a single horn (Multiwhistle R. B.) is described. This unit has a wide frequency and power range, and has been employed in France for agglomeration of aerosols, ultrasonic drying, fog dispersal, and other interesting applications.

2788

Ehret, L., and H. Hahnemann, "A New Sonic and Ultrasonic Generator to Produce High Intensities in Gases," Z. Tech. Phys., 23, 245-267, 1942.

Describes in detail a new generator that utilizes a resonator mounted between a membrane and a compressed-air nozzle. Intensities of the order of 1 W/cm^2, free from air flow, could be obtained.

2789

Gavreau, V., "Pneumatic Generators of Intense Ultra-Sound," Acustica, 8, 121-130, 1960.

Toroidal whistles derived from the police whistle are described. Their operation at low pressure is discussed: oscillation of the air jet produced by the emitted sound, conditions to obtain high efficiency (30%) and pure sinusoidal tone without harmonics; and at high pressure; oscillations produced by the air jet returning to strike at its base, edge sound superposed on the other components of the emitted complex sound. The equation of whistles and the calculation of their theoretical efficiency are given. A contradiction between the theory of horns and the experimental results is no cutoff frequency. Annular exponential horns for emission of plane waves are calculated. Advantages and disadvantages of whistles and of ultrasonic sirens are given, and applications are described.

2790

Gericke, O. R., "Point-Contact Transducers for Ultrasonic Testing," Tech. Rept. No. WAL TR143.5/1, Rept. on Research of Material for High Temperature Use, Watertown Arsenal Labs., Mass., 9 pp., 1962.
AD-276 965.

The feasibility of employing point-shaped ultrasonic transducers, which directly amplify the detected ultrasonic signal, was investigated. Two approaches were considered: one used a semi-conductor point with a depletion layer at the very tip produced by a bias voltage, the other employed the variation of contact resistance with contact pressure. The latter method was explored experimentally and found suitable for the detection of ultrasonic energy.

In addition, experiments are described in which high-frequency sparks were produced at the specimen surface to generate ultrasonic vibrations.

2791

Golyamina, I. P., "Magnetostrictive Ferrites as a Material for Electroacoustic Transducers," Soviet Phys. Acoust., English Transl., 6, 311-320, 1961.

The paper describes the mechanical, magnetic, and magnetostriction properties of four types of ferrite to be used in an electroacoustic transducer. It is shown that the magnetostriction parameters of these materials necessary for conversion are comparable in magnitude with the corresponding parameters of the magnetostrictive metals in current use. The dependence of the ferrite properties on the magnitude of the steady magnetic field and temperature is given.

2792

Gurbitch, A. S., "Acoustic Microanemometer for Investigating the Microstructure of Turbulence," Soviet Phys. Acoust. English Transl., 5, 375-377, 1960.

Acoustic manometers, as described in the literature, are not too suitable for pulse measurements, since they give a value for the velocity that is averaged over a large base of the order 100 cm. Reduction in the base is limited for the most part by the dimensions of the microphones and the radiators. In this microanemometer design cylindrical condenser transducers having a diameter of 2 mm and a working length of 5 mm are used for the microphones and radiators. A terpilene film with a thickness of 3.5 μ and an external metallic coating serves as the movable electrode. The sensitivity of the microphone is 0.07-0.1 mv/bar at frequencies of 75-100 kcs. The application of high-frequency miniature transducers has made it possible to shorten the base of the microanemometer to 2.5 cm.

2793

Hanel, R. A., "Thermoelectric Microphone for Modulated Ultrasonic Waves," J. Acoust. Soc. Am., 32, 1436-1442, 1960.

Conventional thermal microphones record the increase in temperature generated by the absorption of acoustical energy. The microphone described in this paper measures the periodic change of the temperature that is generated by an amplitude-modulated sound wave. This microphone is small, omnidirectional, free of drift, and extremely sensitive. Temperature variations in the order of 3×10^{-5}°C have been recorded by means of a narrow-band amplifier tuned to the modulation frequency. The temperature distribution in a thermocouple enclosed in a sound-absorbing material, and the optimum modulation frequency are calculated. A relaxation function is introduced to help interpret the results physically. Also, the electronic input circuit is discussed in detail.

2794

Jacobsen, E., "Sources of Sound in Piezoelectric Crystals," J. Acoust. Soc. Am., 32, 949-953, 1960.

The production of sound in piezoelectric crystals is examined from the viewpoint of the inhomogeneous wave equation. It is shown that sound is generated by a gradient in the piezoelectric stress and that consequently the free surfaces of a piezoelectric crystal are usually the most effective wave sources. The excitation of sound at microwave frequencies is also discussed and shown to be equivalent to the case of rf recitation at low frequencies.

2795

Kling, R., and J. Crabol, "The Production of Ultrasonic Waves by Gas Jets" (in French), Compt. Rend., 229, 1209-1211, 1949.

Hartmann's modification of the Galton whistle may be further modified to produce ultrasonic vibrations in air. In Hartmann's siren, an air jet is directed at a hole in a rigid diaphragm that forms a resonant cavity, and then impinges on a flexible membrane. By this means, an air pressure of 1.2 kg/cm^2 gives a frequency of 34 kcs with a jet orifice of 1.5 mm diameter. When the resonance cavity is replaced by an arrangement in which the air jet impinges directly on the center of a rigid plane disc, a jet orifice of 0.8 mm diameter, placed 2 mm from the disc gives a frequency of 220 kcs when an air pressure of 4.1 kg/ cm^2 is used. A Hartmann siren operated at this pressure, and fitted with an orifice and resonator of 0.7 mm diameter, will not give frequencies > 126 kcs.

2796

Kolb, J., "New Developments in the Physics and Applications of Ultrasound," Acta Phys. Austriaca, 13, 234-261, 1960.

The paper deals briefly with recent progress in ultrasound. Reference is made to magnetostrictive transducers—nickel, useful up to 100 kcs, aluminum-iron alloys up to about 300 kcs, metallic oxides (NiO, CoO, FeO and Fe_2O_3)—and piezoelectric transducers—various forms of ceramic vibrators (barium titanate, clevite, zirconates, etc.) for still higher frequencies. Methods of producing extremely high ultrasonic frequencies (0.1-1 kmcs) using quartz vibrators are mentioned, and methods of display and measurement are discussed. The implications of ultrasonics in physics are considered particularly with reference to the velocity and attenuation characteristics of materials as a function of frequency, and to ultrasonic research at very low temperatures. In conclusion, the paper has a section dealing with the technical applications of ultrasonics (e.g. ultrasonic cleaning, generation of large amplitude vibrations by means of a $BaTiO_3$ transducer on a brass cone, ultrasonic drilling tools, ultrasonic soldering irons, etc.). Also described is an ultrasonic vibrator for the measurement of magnetic flux and flux-gradient.

2797

Kopvillem, U. Kh., and V. D. Korepanov, "Generation of Hypersound During Para Magnetic Resonance Saturated in Crystals," Soviet Phys. Solid State, 3, 1464-1469, 1961.

A theoretical investigation is made of the nonequilibrium state of a spin system due to paramagnetic resonance saturation, during which hypersound may be self-generated in the crystal because of the alternating-field energy. Parameters are introduced that determine the conditions for the inverse piezomagnetic effect. On the basis of existing theories and experimental data on the acoustical magnetic resonance and changes produced by pressure in constants of the crystal field, an estimate is made of piezomagnetic constants of a number of crystals, including electron, nuclear, and mixed-spin systems.

At the present level of experimental techniques, hypersound can be generated by an interaction of the crystal lattice with electron spins, or nuclear spins in magnetic ions. Interference phenomena due to an indirect interaction of hypersound with an alternating magnetic field are discussed.

2798

Lane, A. L., "Design Techniques for a High Frequency Transducer with a Wide-Beam Searchlight Pattern," J. Acoust. Soc. Am., 25, 697-702, 1953.

It is frequently essential for a transducer to have a smooth, wide-beam directivity pattern with negligible side lobes. If, in addition, this transducer must operate in the fractional megacycle-frequency region, then such conventional designs as small plane radiators or curved surface mosaics are not satisfactory. As a result of an extensive investigation, it was found that a barium-titanate spherical shell sector, properly designed, will meet these difficult wide-pattern and high-frequency specifications.

This paper outlines some of the design considerations required to adapt a ceramic shell into a transducer with the desired performance. The problems discussed are shell size, included angle of the spherical shell, inside diameter-to-thickness ratio, and the uniformity of the thickness dimension. Various baffle techniques are also examined in detail. Shell arc lengths ranging from four to twenty wavelengths are considered as to their effects on the shape of the surface displacement distribution and on the pattern of directivity. Though this paper presents a solution to a specific transducer problem, the design techniques discussed are applicable to transducers having other frequency and pattern requirements.

2799

Leslie, F. M., "The Relative Output from Magnetostriction Ultrasonic Generators," J. Acoust. Soc. Am., 22, 418-421, 1950.

First, the author develops an approximate theoretical treatment of the output from the simplest type of ultrasonic generator in the form of a laminated bar. The dumbbell generator is shown to be very similar to the simple bar type, and the previously obtained relations are then employed for determining the relative output in terms of its face and neck dimensions.

2800

Lessells and Associates, Inc., "Acoustic Emission Under Applied Stress," Prog. Rept. No. 8, Boston, Mass., 7 pp., 1960. AD-235 448.

Tests were continued on the zinc and aluminum single crystals. Strain was successfully recorded simultaneously with the occurrence of the acoustic emission and load data. The stress-strain behavior data is processed in relation to the acoustic emission. The strain information is connected with the deformation mechanics taking place within the specimen. The strain recording has the capacity to show erratic or discontinuous behavior, variation in the rate and in the degree of strain, and relative amounts of elastic and plastic strain. These peculiarities are expected to show correlation with the behavior of the acoustic emission if the mechanisms are essentially at the same level of resolution, but in any case will provide insight into this area.

2801

Macpherson, P., and D. Thrasher, "High-Frequency Calibration of an ADP Crystal Microphone," J. Acoust. Soc. Am., 32, 1061-1064, 1960.

The free-field sensitivity of a microphone over the frequency range 10,000 to 100,000 cps is determined by the reciprocity technique, in which the transducers are oriented perpendicular to each other in order to minimize diffraction effects. This orientation introduces a complication when the wavelength of sound is comparable to or smaller than the diameter of the microphone face. On theoretical grounds it is established that the sensitivity of the microphone should fall to zero at a discrete set of frequencies. Experimental minimum responses in reasonable agreement with the theory were observed.

2802

Matsuzawa, K., "Condenser Microphones with Plastic Diaphragms for Airborne Ultrasonics, II.," J. Phys. Soc. Japan, 15, 167-174, 1961.

A detailed study was made of the condenser microphones with backplates, called "group IA" in Pt I of the present paper. For each backplate, the surface roughness is studied by using profilograms, and the distribution function of the surface profile is obtained. Formulas for the resonance frequency, the electrostatic capacitance, and the low-frequency sensitivity are obtained theoretically, assuming a simple-model microphone with a backplate having a profile represented by the above distribution function. The formulas are found to agree fairly well with the experiments.

2803

Monson, H., and R. Binder, "Intensities Produced by Jet-Type Ultrasonic Vibrators," J. Acoust. Soc. Am., 25, 1007-1009, 1953.

Intensity and frequency measurements were made with different jet-type generators. High values of intensity were reached at certain nozzle inlet pressures, certain cup positions, and with certain proportions of the generator.

2804

Morita, S., "Sonde Method of Measuring the Ultrasonic Field Intensity," J. Phys. Soc. Japan, 7, 214-219, 1952.

A new probe method of measuring the field intensity of ultrasonics was devised. The probe is made of a small ball (about 2 mm in diameter) of sound-absorbing material, in which a thermistor of much smaller dimensions is included in its center. From experimental results and theoretical considerations, two noteworthy facts are derived. They are "surface heat generation" (on the surface of any solid material heat is generated in an ultrasonic field) and the cooling effect of ultrasonic waves.

2805

Pimonow, L., "A High Power Ultrasonic Siren" (in French), Ann, Telecommun., 6, 23-26, 1951.

Discusses the utility and practical applications of detection and production of ultrasound—e.g., the high-frequency sound spectra of airplanes and the agricultural application of powerful ultrasound in the war against insects. Describes a motor-driven siren, with a rotor disk having a peripheral speed of 132 meters per second (a second model, under construction, runs at 270 meters per second). The number of teeth on the rotor is 110, and the number of revolutions is 250/sec, whence the ultrasonic frequency of 27.5 kcs can be attained. It is stated that the acoustic power radiated is about 2 kw.

2806

Trommler, H., "Ultrasonic Transmitter for Use in Laboratories and Industry" (in German), Carl Zeiss Jena Nachricht (Germany), 9, 93-105, 1961.

After briefly illustrating the various techniques for producing ultrasonic waves, describes and presents the relevant data for several ultrasonic transmitters of 400 kcs and 800 kcs. With reference to a large ultrasonic vessel, discusses the forces produced in the ultrasound field and their effects in liquids.

2807

Williams, A. O., Jr., "The Piston Source at High Frequencies," J. Acoust. Soc. Am., 23, 1-6, 1951.

For a circular plane piston of radius a, producing an ultrasonic beam with propagation constant k (or $2\pi/\lambda$), an expression is derived for the velocity potential or the acoustic pressure, averaged with respect to magnitude and phase over a "measurement circle" equal in area to the piston and centered in the beam. The expression should be highly accurate for $ka \geq 100$, at distances z from the source governed by $(z/a)^3 \geq ka$. It agrees well with results computed, in another way, by Huntington, Emslie, and Hughes. The assumption that relatively near the source there is a collimated beam of plane waves is shown to be not very accurate; the averaged pressure falls off monotonically over all distances considered. The velocity potential at the rim of the "measurement circle" is also computed, and compared with the plane-wave assumption.

2808

Ziemer, R. E., and R. F. Lambert, "Shock Wave Transducer Calibration," J. Acoust. Soc. Am., 34, 987-988, 1962.

The use of a shock-wave technique to obtain a frequency-response calibration of a small lead zirconate titanate transducer is described. The response curve is obtained through numerical Fourier transformation of the recorded response to a shock-wave excitation. Sources or error and agreement with other methods of calibration are discussed.

Transducers, Ultrasonic
See Also—118, 134, 284, 297, 470, 515, 535, 615, 711, 716, 717, 729, 960, 964, 975, 1061, 1143, 1266, 1267, 1277, 1278, 1392, 1404, 1821, 2142, 2143, 2244, 2432, 2453, 2763, 2821, 2855, 2944, 2972, 4385, 4397, 4401

TURBULENCE, MEASUREMENT

2809

Bull, M. K., and J. L. Willis, "Some Results of Experimental Investigations of the Surface Pressure Field Due to a Turbulent Boundary Layer," Rept. No. ASD TDR 62-425, Southampton Univ., Great Britain, 27 pp., 1962. AD-284 433.

Gives experimental results for the space-time correlations of the fluctuating pressure field of a turbulent boundary layer, and an empirical representation of the pressure field suitable for structural response calculations is put forward. Variation with Mach number of rms pressure as a function of skin friction is given for Mach numbers up to about 1.6. The probability distribution of the pressure fluctuations at a fixed point in the field closely approximates the Gaussian. The acoustic power output from a boundary layer on a large boundary surface is obtained. Spectra of boundary-layer noise in two jet aircraft are compared with the spectrum of the boundary-layer excitation.

2810

Businger, J. A., V. E. Suomi, and H. A. Panofsky, "Studies on the Structure of Turbulence," Rept. No. AFCRC TR-59-213, Univ. of Wisconsin, Madison, 1959. AD-210 492.

This report offers a generalization of the mixing-length concept; it also discusses the similarity and dissimilarity between turbulent transfer of heat and momentum near the earth's surface, the spectrum of vertical velocity, and sonic anemometer-thermometer observations at Hancock, 1957.

2811

Chabai, A. J., "Measurement of Wall Heat Transfer and Transition to Turbulence During Hot Gas and Rarefaction Flows in a Shock Tube," Tech. Rept. No. 12, Inst. of Res., Lehigh Univ., Bethlehem, Pa., 86 pp., 1958. AD-203 835.

A thin film resistance thermometer was developed for the study of transient boundary layer flows in the shock tube. Measurements of wall heat flux during laminar flow are presented and compared with theories for the hot gas, the cold gas, and the rarefaction regions of shock tube flows. The experimental results indicate an excellent agreement with the theories of hot gas flow, a general consistency with the theory of cold gas flow, but some unaccountable deviations from the theoretical expectations for rarefaction flows. A Reynolds number for the hot gas flow was proposed; the critical value of this number predicts the time at which the laminar flow is observed to become turbulent. Several Reynolds numbers for the rarefaction flow are proposed, but no correlation between these numbers and the measured transition times are found to exist. The instrument allows previously unexplored boundary layer phenomena to be investigated.

2812

Fage, A., and R. F. Sargent, "Shock-Wave and Boundary-Layer Phenomena near a Flat Surface," Proc. Roy. Soc. (London), A, 190, 1-20, 1947.

Shock-wave and turbulent boundary-layer phenomena near the smooth, flat, metal floor of a specially designed supersonic tunnel are studied from traverses made with pitot, static-pressure, and surface tubes, and from direct-shadow and Topler-striation photographs. Near-normal and oblique shock-wave systems, with or without a bifurcated foot, are considered.

2813

Franklin, R. E., and J. H. Foxwell, "Pressure Fluctuations Near a Cold, Small-Scale Air Jet (Measurement of Space Correlations)," Rept. No. 20182, Aeronautical Research Council, Great Britain, 9 pp., 1958.
AD-209 851.

Gives details of experimental observations on a two-inch model jet. These observations consist of velocity distributions, root mean square pressure fluctuations in the field round the jet, and space correlations of the fluctuating pressures in limited regions near the jet. The main interest lies in the space correlations that were observed by using fine-bore probe microphones and associated correlation equipment.

2814

Gerranrd, J. H., "An Investigation of the Noise Produced by a Subsonic Air Jet," Rept. No. 17724, Aeronautical Research Council, Great Britain, 19 pp., 1955.
AD-200 869.

To investigate the theoretical prediction of Lighthill on aerodynamic sound, measurements were made of the sound field of a one-inch air jet issuing from a long pipe. The measurements were made over a wide frequency band (30 to 10,000 cps) and in 1/3 octave bands in this frequency range. The mean Mach number at the pipe orifice was varied from 0.3 to 1.0. The dependence of the apparent position of the noise sources on frequency and jet speed was investigated. The dependence of the noise intensity upon jet speed is examined in terms of the power law relation: $\overline{P^2}$ a M^n. The spectrum of the acoustic power output of the jet derived by integration of the measured noise intensity is found to be extremely flat. The acoustic efficiency of the jet is found to be very small: $10^{-4}M^{4.2}$ in the frequency band from 30 to 10,000 cps. The observed noise field is well represented, qualitatively, by the Lighthill theory.

2815

Gerrard, J. H., "Measurements of the Sound from Circular Cylinders in an Air Stream," Proc. Phys. Soc. (London), B, 68, 453-456, 1955.

The frequency and intensity of the sound produced by flow past circular cylinders was investigated experimentally within the range of Reynolds numbers in which a periodic shedding of vortices occurs. The cylinders were placed in a wind tunnel or on a whirling device. The sound resulting from the production of a vortex street was found to possess a dipole field that consisted of a predominant fundamental frequency accompanied by harmonics. The investigation was confined to the examination of the intensity and frequency of the fundamental. When this frequency was expressed as a Strouhal number Nd/U agreement was obtained between the acoustic frequency and that found, by other workers, in the wake itself. The sound intensity was found to vary with Reynolds number similarly as the pressure coefficient at the rear of the cylinder.

2816

Gerrard, J. H., "Measurement of the Sound from Circular Cylinders in an Air Stream," Rept. No. 17725, Aeronautical Research Council, Great Britain, 8 pp., 1955.
AD-200 921.

Original report of the work covered by the preceding entry.

2817

Gibbs, H., "Micro-Meteorological Measurements by Means of Sound," Rept. No. SRA-154, Smyth Research Associates, San Diego, Calif., 76 pp., 1961.
AD-260 028.

This study deals with the investigation of the scale and spectra of the turbulent fluctuations over an extended range in the lower atmosphere by means of sound-propagation measurements. The measurements were carried out using single-engine, low-flying jet aircraft as the source of sound, and the reception at the ground was accomplished by acoustical transducers in horns that were pointed vertically. The analysis of the data was performed by studying several discrete frequencies in the range from 500 to 2000 cycles per second. It is concluded that the sound-propagation measurements are a feasible means of evaluating characteristics of atmospheric turbulence.

2818

Golitsyn, G. S., A. S. Gurvich, and V. I. Tatarskii, "Investigation of the Frequency Spectra of Amplitude and Phase Difference Fluctuations of Sound Waves in a Turbulent Atmosphere," Soviet Phys. Abstracts, October-December, 185-194, 1960.

The paper presents the results of an experimental investigation of the frequency spectra of amplitude and phase difference fluctuations for sound propagated in the layer of atmosphere near the surface of the earth. Comparison of the results of the measurements with theory (the latter based on Kolmogorov's turbulence scheme) shows that there is satisfactory agreement between the two.

2819

Gooderum, P. B., "An Experimental Study of the Turbulent Boundary Layer on a Shock-Tube Wall," Tech. Note TN 4243, Natl. Advisory Comm. Aeron., Washington, D. C., 63 pp., 1958.
AD-160 213.

Interferometric measurements were made of the density profiles of a turbulent boundary layer on the flat wall of a shock tube. The investigation included both subsonic and supersonic flow (Mach numbers of 0.50 and 1.77) with no pressure gradient and with heat transfer to a cold wall. Velocity profiles and average skin-friction coefficients were calculated. Effects on the velocity profile of surface roughness and flow length are examined.

2820

Hollyer, R. N., Jr., and R. E. Duff, "Growth of the Turbulent Region at the Leading Edge of Rectangular Obstacles in Shock Wave Diffraction—Project M720-4," Rept. 51-2, Engineering Research Inst., Univ. of Mich., Ann Arbor, 22 pp., 1951.
ATI-159 407.

This report presents the results of an investigation of the growth of the vortex or turbulent region at the leading edge of a rectangular block following the passage of a shock wave over the block. The primary purpose of the study is to determine the dependence of the growth upon the various parameters of the problem—namely, model height, shock strength, and flow velocity. The length of the block is assumed to be infinite. A representative sequence of schlieren photographs of the phenomenon under investigation is included.

2821

Ingard, U., and S. Labate, "Acoustic Circulation Effects and the Nonlinear Impedance of Orifices," J. Acoust. Soc. Am., 22, 211-218, 1950.

In his theory of streaming caused by sound waves, Eckart shows that time-independent streams necessarily follow as part of the solution of the complete wave equation, taking into account viscosity and second-order terms. His treatment is mainly valid for liquids and it proves that the driving force of the streams is proportional to frequency squared. The effect, therefore, is especially important in the ultrasonic region (crystal winds). However, he suggests that slow streams might also be carried in air at audio frequencies.

Studies of acoustical streaming phenomena around orifices have been made by the use of smoke particles in a 3-in diameter circular tube. These studies covered a range of orifices from thicknesses of 0.5 mm to 19 mm and diameters of 3.5 mm to 20 mm. The frequency lay between 150 to 1000 cps. Velocities in the orifice cover the range of 0 to 700 cm/sec.

Close studies of the flow patterns have disclosed that there exist four definite regions of flow as the particule velocity in the orifice is increased. These regions have been represented by "phase diagrams." Photographs of the various flow patterns in each region of the "phase diagram" have been taken for a number of orifices. Under each observed condition, the acoustic impedance of the orifice is determined by a conventional standing-wave measurement in the tube.

It is shown that the nonlinear properties of the acoustic impedance of an orifice is closely connected with the circular effects. Quantitative check in one of the circulation regions and a good qualitative overall agreement indicate that the nonlinear properties of the impedance is due to the interaction between the sound field and the circulatory effects.

2822

Ingard, U., S. Oleson, and M. Mintz, "Measurements of Sound Attenuation in the Atmosphere," Final Rept., Res. Lab. Electron., Mass. Inst. Tech., Cambridge, 52 pp., 1961.
AD-248 636.

An attempt is made to measure acoustic scatter attenuation produced by atmospheric turbulence. Laboratory experiments on scattering of sound by turbulence are described; in particular, a new experimental technique involving pulse-height analysis of scattered sound.

2823

Jones, J. I. P., "The Measurement of Turbulence near the Ground," Porton Tech. Paper No. 786, Chemical Defence Experimental Establishment, Great Britain, 1961.
AD-265 939.

An instrument for measuring vertical and horizontal (lateral) gustiness over frequencies up to 70 cycles is described. Its output voltage is proportional to the angle of the wind over a range of 1-1/2 radians vertically and 6 radians horizontally. This voltage is passed to bandpass filter circuits which automatically provide the major part of the power spectrum of vertical gustiness, and of horizontal gustiness above a frequency of 3.6 cycles per hour. A squaring/multiplying circuit is also described and is used to test the method of power measurement. Form factors for turbulence under widely varying conditions are found to be remarkably consistent and indicate a frequency distribution with more peaks than are normal. Use of the equipment in the field is described, and examples of vertical and horizonal spectra at 16 meters are presented.

2824

Kallistratova, M. A., "Experimental Investigation of Sound Scattering in a Turbulent Atmosphere," Dokl. Akad. Nauk SSSR, 125, 69-72, 1959.

A preliminary account of experiments carried out in the autumn of 1958 at the Tsimlyansk station of the Institute for Atmospheric Physics of the Academy of Sciences, U.S.S.R.

At the ends of a 40-meter base line, a transmitter and a receiving microphone were set up. The polar diagrams showed a (half-strength signal-angle)/2 of 1.5°. A theory of the scattering is worked out that agrees with the experimental results for angles of 25-30. The possibility is discussed of investigating the structure of atmospheric turbulences over a range of dimensions near to the internal dimensions of the turbulence.

2825

Kallistratova, M. A., "Procedure for Investigating Sound Scattering in the Atmosphere," Soviet Phys. Acoust. English Transl., 5, 512-514, 1961.

An 11-kcs pulse technique made it possible to isolate the required scattered signal from the direct and reflected ones. The construction, operation and performance of plane electrostatic transducers with good transfer characteristics—both as radiators and as microphones—are discussed.

2826

Laufer, J., "Aerodynamic Noise in Supersonic Wind Tunnels," Prog. Rept. No. 20-387, Jet Propulsion Lab., Calif. Inst. of Tech., Pasadena, 15 pp., 1959.
AD-218 786.

Hot-wire measurements in the free stream of a supersonic wind tunnel were made in the Mach-number range 1.6 to 5.0. It is shown that the mass-flow fluctuations increase very rapidly with increasing Mach number. If the fluctuation field is assumed to consist of sound waves—an assumption that is consistent with the measurements—the sound intensity is approximately proportional to M. Furthermore, the orientation of the field is found to be different from the Mach-line direction; it corresponds to a sound-source velocity of approximately one-half the free-stream velocity for the higher Mach numbers. It is suggested that the turbulent boundary layer along the nozzle and the tunnel walls is responsible for this sound field.

2827

Martin, W. A., "An Experimental Study of the Boundary Layer Behind a Moving Plane Shock Wave," UTIA Rept. No. 47, Inst. of Aerophysics, U. of Toronto (Canada), 1957.
AD-149 136.

The shock-tube boundary layer between the initial shock wave and the contact region was investigated by shadowgraph, schlieren, and interferogram photographs, and by thin-film thermometer measurements. The region was almost completely occupied by a turbulent boundary layer. An interferometer was used to determine the nature of this turbulent boundary layer for shock pressure ratios of 2.75 and 8. Comparison with theory was made of experimental density profiles, boundary layer thickness, calculated temperature and velocity profiles, displacement and momentum thicknesses, and local skin friction. The velocity profiles at higher Reynolds number and for a shock pressure ratio of 2.75 indicated better conformity with a 1/5 power law than with a theoretical 1/7-power law. All the experimental profiles conformed to a 1/5-power law at a shock pressure ratio of 8. The assumption that the wall temperature was constant was substantiated by measurements with a thin Au-film resistance thermometer.

2828

Mawardi, O. K., and I. Dyer, "On Noise of Aerodynamic Origin," J. Acoust. Soc. Am., 25, 389-395, 1953.

An attempt is made in this paper to classify noises of various aerodynamic origin by means of an efficiency of conversion from mechanical to acoustical energy, and also by means of representative spectra associated with corresponding characteristic frequencies. The classification has been tried successfully on measurements of wind tunnel noises, turbojet noises, and air jet noises.

2829

Mintz, M. D., "Sound Scattering from Turbulence," S. M. Thesis, Mass. Inst. Tech., Cambridge, 1959.

An explanation and clarification of the experimental problems encountered in investigations of sound scattering from turbulence is presented, after which a brief synopsis of Lighthill's scattering theory of sound and turbulence is given.

The experimental approach is divided into three phases: the design and construction of suitable transducers; investigation of sound attenuation in air in the absence of turbulence; and investigation of the scattering of sound by turbulence. A preliminary investigation of this third phase employing the relatively untried technique of pulse-height analysis is conducted for scattering of a sharp beam of 100-kc sound. Complete details of the experimental circuitry and technique are presented, and the resulting pulse-height spectra for scattering angles between -2.5^{o} and 15^{o} are presented and discussed. The broadening of the beam due to interaction with the turbulence is displayed in curves relating sound field pressure and laboratory angle to the incident beam. A brief list of suggestions for further investigation of this problem and possible application of the technique of pulse-height analysis to other statistical acoustics problems is presented in the concluding section.

A feasibility report for application of acoustical interferometric measurements is included in the appendix.

2830

Muller, E. A., "Some Experimental and Theoretical Refults Relating to the Production of Noise by Turbulence and the Scattering of Sound by Turbulence of Single Vortices," (2nd Symposium Naval Hydrodynamics, Washington, D. C., 1958) Washington: U. S. Government Printing Office, 1960.

A technological discussion of the matters described in the title. The problem of sound scattering by a single-line vortex is discussed in some detail, and polar diagrams of the scattered intensity are given. Some experimental results of sound intensity produced by turbulence, and on sound scattering by turbulence, are also given.

2831

Nelson, W. L., and C. M. Alaia, "Aerodynamic Noise and Drag Measurements on a High-Speed Magnetically Suspended Rotor," WADC Tech. Rept. No. 57-339, Acoust. Lab., Columbia Univ., New York, 52 pp., 1958.
AD-142 153.

Measurements were made of the drag torque, temperature rise, and aerodynamic noise produced at the surface of a high-speed, magnetically suspended cylindrical rotor as a function of the surface velocity at normal atmospheric pressure. The primary objective was the measurement of aerodynamic noise. Apparatus and instrumentation were developed for controlled measurement, within the laboratory, of the noise, drag and thermal effects encountered in high-speed atmospheric flight. Results of the study indicated this apparatus, with modifications, can be developed as a fruitful method for the study of boundary layer phenomena. For the measurement of aerodynamic noise, the apparatus should be improved by increases in rotor speed and by enlarging the enclosure to permit acoustic treatment for free-field conditions. In the measurement of drag, the essential frictionless support provided by the magnetic support system would yield accurate drag data, with variations of atmospheric conditions and surface treatment.

2832

Obukhov, A. M., "Scattering of Waves and Microstructure of Turbulence in the Atmosphere," J. Geophys. Res., 64, 2180-2187, 1960.

A brief survey of the theory of the scattering of waves by turbulent inhomogeneities. Discusses experiments in the study of sound scattering by turbulence in the surface layer of the atmosphere. These experiments were carried out to obtain some information on the turbulent spectrum; their results are compared with the data of meteorological measurements in the surface layer.

Discusses application of scattered radio waves to the study of ionospheric turbulence.

2833

Tellmien, W., "Research on Investigation of the Interaction of Sound and Turbulence," Max-Planck Institute, Germany, 1957.
AD-154 138.

The scattering of sound by turbulence in the atmosphere was investigated both theoretically and experimentally, and the results of one year's work are presented in this report. The elementary process of scattering by one turbulent eddy is treated theoretically. Fields of flow are then postulated, in which the vortices are placed statistically according to an arbitrary distribution function that controls direction of axes, size, and circulation of the vortices. The choice of distribution function permits treatment of isotropic as well as nonisotropic turbulence.

The section of the report on experimentation describes the mechanical and electronic apparatus that was developed for controlling and measuring the degree of turbulence, the average size of the eddies, and the velocity profile of the mean flow. Preliminary measurements were made throughout the audio range and up to frequencies of about 200 K cps.

2834

Powell, A., "Theory and Experiment in Aerodynamic Noise, with a Critique of Research on Jet Flows in Their Relationship to Sound," 2nd Sympos. on Naval Hydrodynamics, 1958, U. S. Govt. Print. Office, Washington, D. C., 27 pp. 1960.

A survey of recent theoretical and experimental work on sound generation by unsteady flows where boundary effects are not important. After some comments on the basic theory, the author describes phenomena associated with discrete tones—the sensitive flame, edge tones and the sound from a choked jet. Experiments on sound generated by a turbulent jet are reviewed, and it is concluded that the technological demands on the subject considerably exceed the present understanding of it.

2835

Pridmore-Brown, D. C., and U. Ingard, "Tentative Method for Calculation of the Sound Field About a Source over Ground Considering Diffraction and Scattering into Shadow Zones," NACA TN 3779, Mass. Inst. of Tech., Cambridge, 1956.

A semiempirical method is given for the calculation of the sound field about a source over ground considering the effects of vertical temperature and wind gradients as well as scattering of sound by turbulence into shadow zones. The diffracted field in a wind-created shadow zone is analyzed theoretically in the two-dimensional case and is shown to be similar to the results obtained for a temperature-created shadow field as given in NACA TN 3494. The frequency and wind-velocity dependence of the scattered field into the shadow zone is estimated from Lighthill's theory, and on the basis of these two field contributions a semi-empirical formula is constructed for the total field which contains two adjustable parameters. From this expression a set of charts has been prepared showing equal sound-pressure contours at 10 feet above ground for various source heights, wind velocities, and frequencies.

The two adjustable parameters in the formula were obtained from measurements using a relatively small source height (10 feet). The parameters should actually be a function of height determined by the wind and temperature profiles. However, in these preliminary calculations the parameters have been kept constant, and the fields, particularly for large source heights, must be considered as preliminary estimates to be corrected when more information is available.

2836

Rabinowicz, J., "Measurement of Turbulent Heat Transfer Rates on the AFT Portion and Blunt Base of a Hemisphere-Cylinder in the Shock Tube," Memo No. 41, Guggenheim Aeronautical Lab., Calif. Inst. of Tech., Pasadena, 24 pp., 1957. AD-149 977.

Turbulent heat-transfer rates were measured on the aft portion and on the blunt base of a hemisphere cylinder in the Galcit shock tube with a 2 7/8-in. square cross section over a range of shock M 3.25 to 5.1 and initial pressures between 3 and 17 cm Hg. The local Reynolds numbers on the cylindrical afterbody varied between 3.5×10^4 and 3.0×10^5/cm. A side support for the model was used in order to eliminate the disturbing effect of a rear sting support. The measured turbulent heat-transfer rates on the cylindrical portion agreed very well with previous flat plate measurements for small temperature differences, although the ratio of stagnation to surface enthalpy varied between 3 to 8. The measured heat-transfer rate on the base indicated that at the center of the base it is comparable to that on the surface just ahead of the base, while the rate falls off to 1/2 to 1/3 of this value towards the rim of the base. This unexpected distribution of heat-transfer rate over the base, and particularly the high value at the center, shows the necessity for a careful study of wake phenomena.

2837

Richardson, E. G., "The Fine Structure of Atmospheric Turbulence in Relation to the Propagation of Sound over the Ground," Proc. Roy. Soc. (London), 203, 149-164, 1950.

With the aid of hot-wire instruments, measurements have been made of the fluctuations of the wind in the lowest 50 feet of the atmosphere and, in particular, of the mean eddy diameter and of the ratio of vertical and cross-wind components in such fluctuations. It appears that the turbulent elements near the ground are smaller in size and more nearly isotropic in character than those higher up. Some correlation between the temperature and velocity fluctuations near the ground has been observed. Simultaneous measurements of the fluctuations in sound intensity at a distance from a steady source and of the intervening gustiness have been made in order to discuss the noise, on the one hand, and the intensity and scale of the prevailing turbulence on the other. The effect of the latter on the phase relationships between the signals picked up at two points is also demonstrated.

2838

Sato, H., "Experimental Investigation on the Transition of Laminar Separated Layer," J. Phys. Soc. Japan, 11, 702-709, 1956.

A transition from the laminar to the turbulent air flow for a layer separated from a surface was investigated in detail. The laminar-flow mean velocity distribution in the separated layer is similar to that in the laminar boundary layer and it agrees with Lin's calculation. In the transitional region, a hot-wire anemometer survey of velocity fluctuation revealed the existence of a sinusoidal wave, the frequency of which lies in the unstable zone predicted by the stability theory. Transitional regions determined by the layer thickness and by the fluctuation measurements agree well. A simple empirical relation was derived for the transitional distance.

2839

Sato, H., "Experimental Study of the Spectrum of Isotropic Turbulence, II," J. Phys. Soc. Japan, 7, 392-396, 1952.

In the isotropic turbulent field, energy spectrum was observed by an improved equipment. The measurements were made in a closed channel which was added to the exit cone of an open-type windtunnel. A voltage integrator was used to read the fluctuating output of lf components. A low-cut filter attached to the input terminal increased the accuracy at hf region.

Measured spectrum curves are nearly the same as previously reported. The decay of spectral components is more severe at high wave-number throughout the decay process. The energy transition is estimated from the measurements mentioned above; the wave-number of zero transition decreases as the turbulence decays. Finally the gradient of spectrum curve is determined by differentiating the spectrum with respect to windspeed. At medium wave-number region the power index is about -5/3. Three-dimensional spectrum is also obtained by this method.

2840

Schmidt, D. W., "Experimental Investigations on the Scattering of Sound by Turbulence," Tech. Rept. No. AFOSR-1666, Max-Planck-Institut für Stroemungsforschung, Germany, 60 pp., 1961. AD-266 564.

Experimental investigations of the scattering of sound by turbulence were performed in a wind tunnel. Turbulence was produced by grids of parallel circular rods (with diameters of 0.1 to 1.0 cm and grid meshlengths of 0.5 to 2.5 cm); the sound frequencies covered a range of 100 to 500 kcs. Disturbances of the measurements due to reflections of sound waves at the tunnel walls were avoided by the application of short sound pulses. The dependence of the damping of the sound waves on the sound frequency, the Mach number of the turbulence, the length of the sound path in the turbulent flow, and a predominant direction of the turbulent eddies were measured. Theoretical predications were confirmed and partly extended.

In the range of the parameters that is of interest for practical use, the most important results are the proportionality of the damping to the square of the sound frequency and to the square of the turbulent Mach number. Based on the measurements and the theoretical considerations, a formula is derived which is applicable to the damping of sound by turbulent scattering in the atmosphere.

2841

Schmidt, D. W., "Experiments Relating to the Interaction of Sound and Turbulence," Max-Planck-Institut für Stroemungsfurschung, Germany, 19 pp., 1960.
AD-236 341.

Experimental results about the scattering of sound by a turbulent flow are given. The dependence of the scattering on the frequency of sound and on the direction of the scattering vortices were investigated. Equipment is described that facilitates the use of hot wires for the measuring of turbulence. Design characteristics of an apparatus are given, by which hot-wire probes can be rewired precisely and quickly.

2842

Sperry, W. C., R. Kamo, and A. Peter, "Experimental and Theoretical Studies of Jet Noise Phenomena," Final Rept. No. ASD TDR 62-303, Armour Res. Foundation, Chicago, 163 pp., 1962.
AD 282 273.

Over-all sound pressure levels were measured in an anechoic room for noise generated by cold air flow through more than twenty different nozzle configurations, including converging, converging-diverging, slot, and annular types (the latter with and without center-core flow). The results are examined in terms of over-all acoustic power and directivity versus mass flow, and compared with various eighth-power relations. The acoustic performance of most nozzles was similar in the subsonic region. However, certain annular-type nozzles exhibited a marked superiority in the supersonic region.

Theoretical discussions are presented concerning the generation of sound and the relationship between various turbulence and statistical theories. A modified mixing-length theory is developed, showing its applicability to the generation of turbulence as well as its influence on the general equation for the forcing function. Temperature effects are included. Empirical data are given pertaining to the correlation of jet noise from circular and annular nozzles.

2843

Steward, R. M., Jr., R. E. Post, et al., "Sonic Anemometer Data Acquisition and Analysis System and Calculation of Eulerian Scale of Turbulence from Bivane Data," Iowa Engineering Experiment Station, Ames, AFCRL 62-465, Final Rept., 52 pp., 1962.
AD-284 964.

Describes methods used for measuring wind speed and short-period fluctuations in wind speed. The results are applied to an investigation of atmospheric turbulence. Includes descriptions of the sonic anemometer and of the other instruments used, and explains the methods employed to analyze data.

2844

Suchkov, B. A., "Fluctuations of Sound Amplitude in a Turbulent Medium," Soviet Phys. Acoust., English Transl., 4, 84-90, 1958.

Fluctuations of amplitude of a sound spreading in a layer of the atmosphere near the ground were measured. The root-mean-square value of fluctuations appears to vary linearly with distance. A comparison is made of the magnitude of fluctuations, obtained directly from acoustic measurements, with that calculated from the vertical gradient of temperature and wind velocity. An attempt is made, using the experimental material obtained above, to determine the transverse correlation functions of the acoustical field.

2845

Tack, D., M. Smith, and R. Lambert, "Wall Pressure Correlations in Turbulent Airflow," J. Acoust. Soc. Am., 33, 410-418, 1961.

The correlation properties of turbulent wall-pressure fluctuations are investigated experimentally with a view toward developing an adequate phenomenological model of the pressure correlation function for use in engineering calculations. It was found that neither mean eddy sizes nor mean eddy lifetimes, determined by averaging over broad frequency bands, contained sufficient information to accurately describe the high-frequency end of the turbulent power spectrum. Thus, such gross quantities are of somewhat limited utility in detailed analysis, for instance, in predicting response of multmodal mechanical systems driven by flowing turbulence. However, by measuring eddy sizes and lifetimes over narrow frequency bands it appears possible to construct mathematical models for the turbulent pressure correlations that are successful in predicting the turbulent-power spectrum over the frequency band of interest, which could include the entire spectrum. In addition, measurements of rms pressure and space-time correlations are presented that supplement the data obtained by W. W. Willmarth (NASA Memo. 3-17-59 W, 1959) for a somewhat higher Mach range.

2846

Tatarskii, V. I., "Fluctuations of Sound Phase in a Turbulent Medium" (in Russian), Izv. Akad Nauk SSSR, Ser. Geofiz., 252-258, 1953.

The fluctuations of the sound phases received by two microphones situated in a turbulent medium are examined. Analysis is carried out in limits of geometric acoustics. The mean square of the fluctuations of phase difference is calculated with variable relationship between the base and the distance covered by sound in a turbulent medium.

2847

Tverskoi, N. P., "Acoustical Characteristics of Atmospheric Turbulence" (in Russian), Glavnaia Geofizicheskaia Observatoriia, Trudy, 54-60, 1958.

The turbulence of the atmosphere can be studied by observing the propagation of sound waves within it. An indirect means of evaluating atmospheric turbulence is the use of the oscillation of the phase difference of a sound wave passing through an atmospheric layer. The equation for the missing coefficient is

$$K_A = \frac{\sqrt{\overline{\Delta\phi}^2}}{A\frac{\omega}{\bar{c}^2}\left(\frac{L}{\ell_k}\right)^{1/2}} = \bar{u}_1 \ell_k$$

[$\sqrt{\Delta\phi^2}$ = value of phase difference between the sound source and the sound wave, passing through mean characteristic distance (scale of correlation), L = distance covered by the sound wave in the region investigated, $\bar{c}$ = corresponding frequency and mean velocity of sound, $\bar{u}_p$ = mean pulsational velocity of sound].

An experimental design to determine these relationships is described and the results are presented in graphs. The mean square variability of the phase difference depends essentially upon the condition of the atmosphere, wind velocity, gradient wind, temperature, etc. The oscillation of the phase increased sharply with the wind velocity. The phase oscillation diminishes with increased height of wave propagation and of receiver placement.

Registration of pulsations of wind velocity for constant ω, $\bar{c}$, L and $\bar{\ell}$ provided data for determining $\bar{u}_p$ and ultimately A = a dimensionless magnitude which is equal to 5-6. The most characteristic values of turbulent structures occurring under different atmospheric conditions were determined by moving one sound receiver relatively to the other, which remains situated perpendicularly to the sound wave. The value $\bar{\ell}_k$ was found to be an adequate characteristic of the turbulence belonging to an atmospheric state. Further, the oscillation of the phase difference reflects the true turbulence of the atmosphere.

The turbulence coefficients computed by meteorological and acoustical means are compared and a close correlation is observed.

2848

Welkowitz, W., "Sound Fluctuations Caused by Turbulent Winds," Tech. Rept. No. 2, Columbia Univ., 1955.
AD-77 478.

In this report data is presented from measurements taken with a fairly simple experimental system consisting of a wind-speed instrument, a wind-direction instrument, some microphones at one location, and a loudspeaker located some distance away. Numerous measurements were taken at a few frequencies over the course of a month, and the results appear to indicate that despite the simplicity of the experimental system some useful quantitative data on the fluctuations of received sound caused by turbulent winds have been obtained.

2849

Werner, J. E., "Shockwave-Turbulence Interaction, Investigations in a Shock Tube," Rept. No. AFOSR TR 59-46, Inst. for Cooperative Res., Johns Hopkins Univ., Baltimore, Md., 134 pp., 1959.
AD-214 847.

Various aspects of the shock-turbulence interaction problem were investigated analytically and experimentally. The model of a cellular vortex field with a discrete front convected through a shock wave was studied theoretically. Expressions were derived for the unsteady pressure disturbance on the downstream face of the shock, and the displacement of the shock wave itself as the vortex field is carried through it by the mean flow. The interaction of a shock with a random-velocity fluctuation field was also considered. The relationship between pressure fluctuation and shock displacement was explored. In particular, the pressure-fluctuation level is found to depend on shock displacement, turbulence scale, and turbulence intensity. Techniques for measuring these three quantities in a shock tube are the subject of the experimental work. The constant temperature hot-wire anemometer was used to measure turbulence intensity, spectra and scale, while shock displacement measurements were made with the aid of shadowgraph pictures. A comparison was made between measured and theoretically derived shock displacement, and order-of-magnitude agreement is found.

2850

Wescott, J. W., "Acoustic Background at High Altitudes," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 182-194, 1961.
AD-408 716.

The power spectrum of acoustic background noise at altitudes of 60,000 feet has been determined with balloon-borne acoustic detectors, a data link and recording system, and spectrum analyzers. Background levels are surprisingly high with acoustic pressures of 0.2 d/cm^2 persisting at frequencies below 5 cps. The acoustic energy spectrum falls off as the second power of frequency.

Flights have been made with double detectors, one hanging on a long cord below the other. Cross-correlation of the resulting data indicates that a significant portion of it propagates from lower altitudes. The most probable sources of this acoustic energy are turbulent eddies caused by wind shear.

In addition to background noise some specific signals have been detected. Analyzed samples are presented. Some observed Doppler effects suggest a possible method for measuring the absorption of sound in air at low frequencies.

2851

Wescott, J. W., and S. S. Kushner, "Acoustic Background at the Earth's Surface," Final Rept. No. 3746-35-F, Acoust. and Seismics Lab., Inst. of Sci. and Tech., Univ. of Mich., 30 pp., 1963.
AD-405 837

Acoustic background noise at the earth's surface for frequencies from 0.2 to 100 cps was monitored outdoors with two low-frequency condenser microphones placed 1500 feet apart. The wind speed at each nicrophone was monitored with cup anemometers. Data were transmitted by microwave links to a central receiving station and recorded on magnetic tape. The acoustic data were preemphasized six db/octave before transmission to improve s/ n.

Oscillograms of the multichannel acoustic data show cross-correlations by visual inspection for the sounds radiated from upper-air turbulence and aircraft. Oscillograms of noise generated locally by surface winds show no apparent cross-correlation.

Details of instrumentation are presented. These include a block diagram of the detection, data-link, and recording system and circuit diagrams of components developed for it. A pistonphone calibrator with pushbutton frequencies from 0.125 to 30 cps is described and its use for amplitude and phase calibration of microphones is explained.

2852

Weyers, P. F. R., "Vibration and Near-Field Sound of Thin-Walled Cylinders Caused by Internal Turbulent Flow," NASA, Washington, D. C., 58 pp., 1960.
AD-237 717.

Noise produced by turbulent flow adjacent to the flexible wall was investigated. Measurements were taken of the spectrum and intensity of the pressure field outside thin-walled Mylar cylinders containing turbulent pipe flow. The resulting spectra could be interpreted in relation to the elastic properties of the cylinders and the character of the turbulent fluctuations inside the flow. The eigen frequencies of the cylinders would be identified, and similarity parameters for the spectra were established. The effect of cylinder-wall thickness on the spectrum and intensity of the pressure fluctuations was investigated. It was found that the intensity of the external pressure field scaled with the fifth power of the velocity at the center of the pipe.

For one particular case the spectrum and intensity of the pressure fluctuations exerted by the turbulent flow on the wall were measured. The intensity of the pressure fluctuations at the wall scaled with the fourth power of the velocity, as expected. The ratio of the root-mean-square wall pressure to the dynamic pressure was found to be independent of the Mach number and equal to a constant (0.0078). Similarity laws for the spectra of the wall-pressure fluctuations were also confirmed.

2853

Williams, D. J. M., "Measurements of the Surface Pressure Fluctuations in a Turbulent Boundary Layer in Air at Supersonic Speeds," A.A.S.U. Rept. 162, Univ. of Southampton, 1960.

The report describes experiments to measure the root-mean-square turbulent pressure fluctuations on the plane wall of a supersonic nozzle.

The root-mean-square pressure was found to decrease from .0069 × dynamic head at a Mach number of 1.2 and skin friction coefficient .0058, to .00475 × dynamic head at a Mach number of 1.54 and skin friction coefficient .0022.

The corresponding pseudo-sound levels were 143.5 db and 140.5 db (rel. .0002 d/cm^2) at a constant EAS of 873 ft./sec.

2854

Williams, J. E. F., "Measuring Turbulence with a View to Estimating the Noise Field," Rept. No. 20381, Aeron. Res. Council, Great Britain, 11 pp., 1959.
AD-207 235.

Suggests an experimental procedure that is designed to measure, by hot-wire techniques, the distribution of acoustical sources in an air jet. The noise producing parameters are discussed along with the capabilities of present experimental equipment, and it is suggested that the proposed experimental program is at present the only one within the scope of equipment available. A stationary reference frame is used, and it is shown that although the theory based on this system is not as revealing as Lighthill's analysis of moving axes, it is nevertheless the only one available for experimental purposes.

2855

Willmarth, W. W., "Wall Pressure Fluctuations in a Turbulent Boundary Layer," J. Acoust. Soc. Am., 28, 1048-1053, 1956.

When a turbulent boundary layer is produced by air flow past a solid surface, the turbulence in the boundary layer can generate a sound field in the free stream and will also induce fluctuating loads on the solid surface. If the surface is flexible, this motion will generate an additional sound field on both sides of the surface. In an initial investigation of the latter form of sound generation, suitable equipment has been developed to measure the fluctuating wall pressure in the turbulent boundary layer. The equipment includes a specially designed, low-noise-and-turbulence wind tunnel, and a small barium titanate transducer and preamplifier combination for frequencies up to 50 kcs. The transducer and preamplifier may be useful for other applications.

Using this equipment, some of the properties of the wall-pressure fluctuations in a turbulent boundary layer have been measured. It was found that the spectrum of the wall-pressure fluctuations extends to 50 kcs, and that the root-mean-square wall pressure was a constant portion (0.0035) of the free-steam dynamic pressure for $0.2 < M < 0.8$ and $1.5 \times 10^6 < Re < 20 \times 10^6$. A few typical spectra are given for different values of the Reynolds number and Mach number.

2856

Wilson, L. N., "Experimental Investigation of the Noise Generated by the Turbulent Flow Around a Rotating Cylinder," J. Acoust. Soc. Am., 32, 1203-1207, 1960.

The near- and far-field noise from the turbulent boundary layer developed on a rotating cylinder has been studied; both smooth and artificially roughened surfaces were employed. The cylinder walls were sufficiently thick to inhibit appreciable boundary-layer-excited vibration noise. The mean square pressure followed a U^4 law in the near field, and the total acoustic power radiated to the far field followed a higher-exponent law—approximately U^6.

The necessity to excise spurious peaks at harmonics of the cylinder speed from the measured far-field spectrum introduced inaccuracy in the computed power law, bringing some doubt to bear on the accuracy of the exponent. The U^6 law, unless it is a fortuitous average of laws of lower and higher power, suggests that the dominant radiators are of a dipole type. Drag calculations from hot-wire measurements allowed an estimate of the efficiency (acoustic power/mechanical power) of the far-field radiation, resulting in an efficiency of the order of 30 times that for the quadrupole radiation from a jet at a Mach number of 0.228. Even so, the measured noise power from the boundary layer over a rigid wall appears to be relatively small in any practical application to the noise in aircraft. This is in contradistinction to the noise radiated by boundary-layer-induced vibrations of a flexible wall or panel, which can exceed the former by some orders of magnitude.

2857

Wilson, L. N., "An Experimental Investigation of the Noise Generated by the Turbulent Flow Around a Rotating Cylinder," Rept. No. 57, Inst. of Aerophys., Univ. of Toronto (Canada), 27 pp., 1959.
AD-228 504.

The near- and far-field noise from the turbulent boundary layer developed on a rotating cylinder was studied; both smooth and artificially roughened surfaces were employed. The cylinder walls were sufficiently thick to inhibit appreciable boundary-layer-excited vibration noise. The mean square pressure followed a U^4 law in the near field, and approximated a U_o^6 law, as did the acoustic power, in the far field. Drag calculations from hot wire measurements allowed an estimate of the efficiency (acoustic power/mechanical power) of the far-field radiation, resulting in an efficiency about ten times that for the quadrupole radiation from a jet at a Mach number of .288. Even so, the measured noise power from the boundary layer over a rigid wall appears to be relatively small in any practical application to the noise in aircraft.

2858

Zverev, V. A., and I. K. Spiridonova, "Statistical Analysis of an Acoustic Field in the Atmosphere to Determine the Characteristics of Atmospheric Turbulence," Soviet Phys. Acoust., English Transl., 7, 346-351, 1962.

By measuring the correlation coefficient of an acoustic field in the atmosphere at scattered points, the inhomogeneity scale and mean-square-phase fluctuation were determined.

The measurements were performed by recording a signal at four points of the field simultaneously and processing the records. The processing included finding the mutual correlation functions of the field with a small averaging time, then subjecting them to spectral analysis with a large time constant. In the case of strong winds (of the order of 10-15 meters/sec) the inhomogeneity scales were of the order of 1.2-1.6 meters, the mean-square phase fluctuation of the order of 130-150^o. The measurements were performed in the interval from 4 to 7 kc.

Turbulence, Measurement
See Also—36, 337, 343, 352, 420, 429, 442, 459, 460, 482, 488,

TURBULENCE, MEASUREMENT

510, 641, 668, 883, 884, 887, 934, 951, 1035, 1086, 1252, 1301, 1352, 1434, 1545, 1557, 1587, 1682, 1695, 2265, 2429, 2435, 2440, 2441, 2452, 2453, 2512, 2902, 2928, 3392, 3545, 3765, 3832, 3833

TURBULENCE, THEORY

2859

Andres, J. M., and U. Ingard, "Acoustic Streaming at High Reynolds Numbers," J. Acoust. Soc. Am., 25, 928-932, 1953.

The apparent discrepancies between the observations of Andrade and Schlichting and those of Carriere, with regard to the direction of acoustic streaming near obstacles have been re-examined. It is pointed out that the geometry of the streaming is determined by the two dimensionless parameters $R = U_0 a / v$ and s/a, where R is the Reynolds number, U_0 the velocity amplitude of the incident wave, a the characteristic length of the obstacle (radius of cylinder), v the kinematic viscosity, and s the displacement amplitude of the incident sound wave. It is found that the Andrade-Schlichting observations correspond to large values of R(~1000), whereas the Carriere observations correspond to small values of R(~10). The present paper deals specifically with the theory for large R and extends the work of Schlichting to discuss the distortion of the flow pattern as a function of the sound intensity. The case corresponding to small Reynolds numbers is treated in an accompanying paper. The results obtained are found to agree with experiments.

2860

Andres, J. M., and U. Ingard, "Acoustic Streaming at Low Reynolds Numbers," J. Acoust. Soc. Am., 25, 932-938, 1953.

This paper is a continuation of an analysis of acoustic streaming begun in a previous paper where streaming at high Reynolds numbers (order of several hundred) was treated. The corresponding problem for low Reynolds numbers (order of ten) is now considered, and it is shown that the flow pattern obtained around a cylinder in a sound field is opposite to the one corresponding to high Reynolds numbers. The Reynolds number is defined as $R = U_0 a/v$, where U_0 is the particle velocity in the incident sound wave, a is the radius of the cylinder, and v is the kinematic viscosity. The two types of flow associated with different values of Reynolds numbers seem to correspond to the two types of circulations that have been experimentally observed and reported in the literature.

2861

Bazilevich, V. V., "Influence of Atmospheric Turbulence on the Audibility of Sounds in the Atmosphere" (in Russian), Trudy, Glavnaia Geofizichekaia Observatoriia, Leningrad, 50-53, 1958.

In this study of the effect of dynamic atmospheric turbulence upon the audibility of sounds in the atmosphere, the author assumes that turbulence is isotropic and uniform. The wave equation for a sound wave field in an isotropic medium is

$$\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2} - \frac{n^2 \partial^2}{c_0^2 \partial t^2}\right)\psi = 0$$

(where ψ is the state of point of the medium with coordinates; x, y, z, n, the index of refraction; and c_0, the velocity of the propagation of sound for selected initial conditions). In the case of plane waves this equation describes the propagation of an oscillatory process of the type

$$\psi = A\,(x,y,z)e^{i\omega\left(t - \frac{E}{c_0}\right)}.$$

The equation $\psi = Ae^{-\frac{\mu\omega x}{c_0}} e^{i\omega\left(t - \frac{E}{c_0}\right)}$ is derived; the magnitude $\mu\omega/c_0$ represents the coefficient of attenuation of the amplitude of sound with distance in an atmosphere that has given situation of dynamic turbulence. The equation

$$\mu = n_m \sqrt{\frac{3\,[(c - c_m)^2]_m}{c_m^2}}$$

is obtained (c is the instantaneous velocity of propagation of sound, and c_m is the average velocity of propagation for a given interval of time in a given place.

The coefficient of attenuation of sound intensity in the presence of dynamic atmospheric turbulence is given by

$$\alpha = \frac{4\pi}{\lambda_0}\,\theta\,\frac{\sigma(\mu)}{c_m} \quad \text{where } \theta = \sqrt{3\,A_m} \text{ (having any positive value),}$$

o(u) is the mean square value of the fluctuation of wind velocity, and $c_m = \sqrt{kRT}$. In the case of a simultaneous influence of thermal and dynamical atmospheric turbulence upon the propagation of sound in the atmosphere, the total coefficient of attenuation of sound is given by

$$\alpha = \alpha_t + \alpha_d = \frac{4\pi}{\lambda_0}\left(\eta\,\frac{\sigma(T)}{T_m} + \theta\,\frac{\sigma(u)}{c_m}\right)$$

2862

Bolgiano, R., Jr., "Turbulent Spectra in a Stably Stratified Atmosphere," J. Geophys. Res., 64, 2226-2229, 1960.

After noting the discrepancy between the predictions of turbulence theory and the empirical evidence from radio experiments, the author suggests that it may be the result of modification of the turbulent spectra by the effects of buoyancy in stably stratified layers. It is pointed out that in such situations kinetic energy of turbulence is converted, over a wide range of scales, to potential energy of the resulting density deviations; that this potential energy is subsequently destroyed by the action of further turbulent mixing and molecular diffusion; and, finally, that the primary effect is to reduce the viscous dissipation rate significantly below that which normally would be estimated on the basis of large-scale turbulent motions. Universal forms are predicted for the kinetic energy and density fluctuation spectra, and in the buoyancy subrange (the part of the equilibrium range that reflects the anisotropy induced by the density gradient) the energy spectrum is found to be proportional to $k^{-11/15}$, the density spectrum to $k^{-7/5}$.

2863

Businger, J. A., V. E. Suomi, and H. A. Panofsky, "Studies on the Structure of Turbulence," Rept. No. AFCRC TR-59-213, Univ. of Wisconsin, Madison, 1959.
AD-210 492.

This report offers a generalization of the mixing-length concept; it also discusses the similarity and dissimilarity between turbulent transfer of heat and momentum near the earth's surface, the spectrum of vertical velocity, and sonic anemometer-thermometer observations at Hancock, 1957.

2864

Chanaud, R. C., and A. Powell, "Experiments Concerning the Sound-Sensitive Jet," J. Acoust. Soc. Am., 34, 907-915, 1962.

An experimental study of laminar jets sensitive to sound was conducted both in air and in water at low Reynolds numbers, with the water jet permitting visual determination of a condition of neutral stability. Plotted on a Reynolds-Strouhal diagram, the neutral contours show the unstable region to be bounded at high Strouhal numbers and low Reynolds numbers. The boundary is dependent on disturbance amplitude, enclosing a somewhat larger region for larger disturbances. The lower Strouhal number boundary, if it exists, must be extremely close to the axis of the Reynolds number. The recent results of instability theory for pseudolaminar jets are qualitatively compared with the experimental results, on the basis of local parameters and making allowance for jet-spreading that otherwise is a major cause of disparity. However, even at low Reynolds numbers the velocity profiles determined in the air jet do not compare closely with the analytic ones for a slit jet, which have been used in recent theoretical studies of laminar-jet instability.

It appears that the embryo vortex, formed when the jet is disturbed, begins near the inflection point of the velocity profile and at a phase when the fluctuating velocity at the orifice is near maximum. Very long waves, which become quite unstable after an initially very small special rate of amplification, are considered as a possible cause of transition to turbulence in the jet.

2865

Chandrasekhar, S., "The Fluctuations of Density in Isotropic Turbulence," Proc. Roy. Soc. (London), A, 210, 18-25, 1951.

In this paper the fluctuations of density in a compressible fluid under conditions of homogeneous isotropic turbulence are considered. It is shown that from the equation of continuity alone an invariant can be derived. Thus, if $\omega(r, t) = \overline{\delta\rho\delta\rho'}$ denotes the correlation between the instantaneous fluctuations of the density from the mean, at two points separated by a distance r, then

$$\int_0^\infty r^2\omega(r, t)dr = \text{constant}$$

The meaning of this invariant is that the largest scales of the fluctuations of density are determined by the initial conditions of the problem and represent permanent features of the system.

An equation of motion for $\omega(r, t)$ is also derived; it relates the fluctuations in density with the fluctuations in velocity. If, as an approximation, we substitute in this equation of motion the expression for the fundamental correlation tensor $\overline{u_i u_j'}$ which is valid for an incompressible fluid, we obtain a simple equation connecting ω and the defining scaler, Q, of $\overline{u_i u_j'}$. When $\overline{u^2} \ll c^2$ (where c denotes the velocity of sound) the equation for ω is of the same form as that governing the propagation of spherical sound waves, except that the velocity of propagation is not c but $\sqrt{2}c$. More generally, it is found that when the term in Q is included, the equation for ω still admits periodic solutions of the form of spherical waves; but they are distorted for small values of r and are propagated with a velocity $(2c^2 + 2/3\overline{u^2})^{1/2}$. Also, under the same conditions we can picture $\omega(r, t)$ as a superposition of the fundamental periodic solutions.

2866

Chuang, F.-K., "On the Decay of Turbulence," Acta Sci. Sinica, 2, 187-200, 1953.

The macrostructure of turbulent flow is discussed as a supplement to Kolmogoroff's study of the microstructure, and it is shown how the viscous forces are important only in a limited number of regions in the fluid. The transfer of mass, heat, etc., are determined, largely by motion of the large eddies. Kolmogoroff's law of decay is extended, and it is shown that Lin's law of decay is a particular case of the one developed in the present paper.

An analysis, similar to that developed by Sedow, for the correlation coefficients is applied to the turbulent spectrum, and the transition of the law of decay from the initial to the final period is derived, together with the approximate transfer function, and it is shown that, near the final period of decay, the effect of the transfer terms is equivalent to an eddy viscosity.

2867

Corcos, G. M., "Resolution of Pressure in Turbulence," Div. of Aero. Sci., Univ. of Calif., Berkeley, J. Acoust. Soc. Am., 35, 192-199, 1963.

The finite size of a transducer-sensing element limits its space resolution of a pressure field associated with a local turbulent flow. Such pressure fields are translated at a speed comparable to the characteristic velocity of the flow. Consequently, a lack of resolution in space causes an apparent inability to resolve in time. This problem—an example of the mapping of a random function of several variables by a linear operator—is examined here. With the help of a formalism that has been previously discussed and of some recent experimental information about the spatial structure of turbulent pressure fields in boundary layers, the mapping or distortion of statistical quantities associated with the second-order moments of the pressure field is given. The attenuations of the frequency-spectral density and of the cross-spectral density are given explicitly in table form and in asymptotic form. The numerical results indicate that the attenuation caused by the finite size of transducers is generally more severe than previous computations had suggested, mainly because the lateral correlation of pressure is highly frequency-dependent, a typical turbulent pressure-wave component being inclined to the stream direction at roughly 45 degrees.

The results are applied to an evaluation of contemporary measurements of turbulent pressure fields in shear flows. It is shown that the transducer size used introduces large errors in these measurements; these errors lead to doubts even about the magnitude of the intensity of turbulent pressure fluctuations.

Asymptotic formulas are given for the attenuation of large transducers. They yield estimates of the degree to which a flush-mounted sonar receiver immersed in a boundary layer is able to reject the background noise provided by turbulent pressure fluctuations.

2868

Curle, N., "The Generation of Sound by Aerodynamic Means," Rept. No. 22114, Aeron. Res. Council, Great Britain, 12 pp., 1960.
AD-245 763.

A physical and mathematical discussion of aerodynamic noise generation is given. Included are a general theory of aerodynamic noise, amplification by shear, effect of isotropic turbulence, the effect of convection, and the application of the above theory to the consideration of noise from a turbulent jet.

2869

Curle, N., "The Origins of Aerodynamic Noise," Sci. Progr., Great Britain, 49, 440-446, 1961.

An attempt to reduce the theory of the generation of aerodynamic noise to the simplest possible terms. The discussion is essentially physical; the important mathematical results are stated without proof.

2870

Doak, P. E., "Acoustic Radiation from a Turbulent Fluid Containing Foreign Bodies," Proc. Roy. Soc. (London), A, 254, 129-145, 1960.

The problem of the acoustic radiation from a turbulent fluid containing foreign bodies of arbitrary shape and arbitrary composition is solved formally by the method of Green functions. Particular attention is given to the radiation from the surface of these bodies. A practical advantage of the method is that provided an appropriate Green function can be found, either exactly or approximately, then knowledge of the values on the surface of the fluctuations in only one scalar variable is needed to permit estimation of the radiation from the surface. This variable may be either the pressure or the normal density gradient. The pressure fluctuations at the surface, in particular, are relatively easy to measure. It is shown that if fluctuations in the fluid are locally isentropic the volume-source distribution of the pressure fluctuations is quadrupole.

A proof is given of the proposition that when arbitrary obstacles are immersed in a fluid, all dipole radiation must come from surface-source distributions on these obstacles. For rigid bodies these distributions represent physically the reaction by the obstacles to the stresses imposed upon them by the fluid. It is proved that if the density fluctuations or the normal density gradient fluctuations on these surfaces vanish, there is no dipole radiation. The same is true for pressure and pressure-gradient fluctuations within the limits of validity of the assumption of local isentropy.

A brief description is given, together with references to more detailed accounts, of some of the principal features of the behavior of Green functions, which may be useful in practical estimates of aerodynamic surface sound. As a representative example of acoustic radiation from a turbulent boundary layer, the total acoustic power radiated by a turbulent boundary layer on an infinite rigid plane is estimated, using the limited available experimental data on wall-pressure fluctuations. For low and moderate subsonic speeds the power radiated per unit wall area covered by the turbulent boundary layer is Kp a M, where M is the free stream Mach number, p is the density, and a the speed of sound in the undisturbed fluid, and the dimensionless parameter K is approximately a constant whose order of magnitude is ten.

2871

Ford, G. W., and W. Meecham, "Scattering of Sound by Isotropic Turbulence of Large Reynolds Number," J. Acoust. Soc. Am., 32, 1668-1672, 1960.
AD-244 259.

Lighthill has given an expression for the intensity of acoustical radiation scattered from turbulent fluids. He finds that such scattered energy is proportional to the square of the Mach number of the turbulence and is also proportional to the value of the turbulence-spectrum function at wave number equal to the magnitude of the change in the wave vector during the scattering. If it is supposed that the turbulent region has a Reynolds number sufficiently large to give rise to an inertial subrange, one can use similarity principles to obtain information concerning the spectrum of the scattered radiation. This is accomplished by the use of a Lagrangian-type space-time velocity correlation in order to properly treat convective effects of the macro-eddies.

The result is that the position of the maximum of the scattered-power spectrum is shifted from the incident frequency by an amount determined by the Doppler shift due to the mean flow. The half-width of the spectrum is proportional to the turbulence Mach number. The maximum of the spectrum is also proportional to the turbulence Mach number and to $(\omega_0)^{-2/3}$, where ω_0 is the angular frequency of the incident wave.

2872

Horiuchi, I., "Effects of Atmospheric Turbulence on the Propagation of Sound," Tech. Rept. No. 3, Acoustics Lab., Columbia Univ., N. Y., 12 pp., 1954.
AD-28 518.

Data-analysis of the characteristics of atmospheric turbulence was used as a basis for arriving at representative figures of expected sound scattering. Micrometeorological data pertaining to the study of sound propagation in open air were reviewed, and the pertinent data and expressions derived in previous work were used in calculations of the expected sound scattering. Discussions of atmospheric turbulence include isotropic turbulence, thermal and terrain effects of the ground, anisotropy of eddy velocities, and eddy sizes.

2873

Jorand, M., "Influence of Turbulence on the Attenuation of Sound in Free Air" (in French), Compt. Rend., 248, 1306-1308, 1959.

Classical theories fail to explain the observed sound attenuation. Better agreement is given by replacing the classical viscosity by an appropriate kinematic viscosity.

2874

Kallistratova, M. A., and V. I. Tatarskii, "Accounting for Wind Turbulence in the Calculation of Sound Scattering in the Atmosphere," Soviet Phys. Acoust. English Transl., 6, 503-505, 1961.

Gives a mathematical derivation for the scattering of sound waves by turbulent fluctuations. Expressions are derived for the effective-scattering cross section per unit volume; the acoustical pressure of the scattered field, involving the effects of the vertical component of the wind field; and temperature fluctuations. Verification by actual measurements is shown.

2875

Kao, S.-K., "Turbulent Transfer in the Boundary Layer of a Stratified Fluid," J. Meteorol., 16, 497-503, 1960.

An analysis is made of some characteristics of the steady turbulent transfer in the boundary layer of a stratified fluid. The effect of the heat flux on the variation of the mixing length and the flux Richardson number with height is determined. The velocity and temperature profiles are derived. It is found that for a constant free-stream velocity, an upward heat flux increases the frictional velocity, whereas a downward heat flux decreases it. The lower limiting value of the flux Richardson number is found to be -0.5 which, together with the upper limiting value, 0.5, obtained by Townsend (1958), gives the range of the flux Richardson number. Velocity profiles for the non-neutral conditions converge in the higher level towards the profile for the neutral condition, a characteristic that agrees with the classical velocity profiles observed by Thornthwaite and Kaser (1943).

2876

Kraichnan, R. H., "On the Propagation of Sound in a Turbulent Fluid," Tech. Rept. No. 4, Acoustics Lab., Columbia Univ., N. Y., 23 pp., 1954.
AD-28 517.

Eikonal and continuity equations are derived for a sound wave propagating through a fluid in which there is a shear motion of low Mach number and a turbulence scale that is large compared to the soundwave length. A comparison between the eikonal equation and the Hamilton-Jacobi equation for a charged particle in a magnetic field revealed that the acoustic-ray paths are identical with the trajectories of the particles provided the magnetic field is proportional to the vorticity. Expressions are obtained in terms of correlation products of the turbulent flow for the attenuation and fluctuation in intensity of a sound beam scattered in a turbulent flow. Expressions are also derived for the phase and intensity fluctuations associated with the propagation of sound through large-scale turbulence. The differential cross section for the scattering of sound by turbulence is developed in a form suited to the treatment of anisotropic turbulence. A simple anisotropic distribution involving symmetry about a preferred vorticity axis is discussed.

2877

Kraichnan, R. H., "Pressure Field Within Homogeneous Anisotropic Turbulence," J. Acoust. Soc. Am., 28, 64-72, 1956.

Integral expressions are derived for the mean-square fluctuation pressure, pressure correlation, and certain moments of the pressure correlation within general anisotropic, homogeneous turbulence. Application is made to idealized flow models exhibiting certain anisotropy characteristics similar to those observed in boundary-layer turbulence. Pressure fluctuations arising from the turbulence itself and from interaction of the turbulence with a mean flow exhibiting constant shear are compared with the isotropic case. It is found that, in contrast to the completely isotropic case, the anisotropic pressure correlation is negative for some difference-coordinate values, and exhibits a "tail" that falls off with distance x as x^{-3} at separations for which the velocity correlations have fallen essentially to zero. It is concluded that in general the principal normalized moments of the pressure correlation will tend to be less than the corresponding velocity correlation moments. For isotropic turbulence this implies that the pressure correlation must fall off with distance faster than does the velocity correlation. For the models of anisotropic turbulence treated, it is found that departure from isotropy results in lower mean-square pressure fluctuations for a given mean kinetic energy of turbulence.

2878

Kraichnan, R. H., "On the Scattering of Sound in a Turbulent Medium," Tech. Rept. No. 1, Acoustics Lab., Columbia Univ., N. Y., 24 pp., 1953.
AD-9918.

The scattering of a sound wave in a medium undergoing shear flow confined to a finite region is investigated under the assumption that the total velocity field is everywhere small compared to the velocity of sound. Formulas are obtained for the angular and frequency distributions of the scattered wave in terms of the four-dimensional Fourier transform of the shear velocity field. Under typical conditions, the cross-sections for the scattering of a plane wave of frequency ω by a shear flow of given scale and spatial structure are approximately of the form $\omega^4 M^2$, where M is a characteristic Mach number of the flow. The coupling between the shear and longitudinal velocity fields has a tensor character such that the scattering vanishes at 180° and at 90°.

The spectrum of the scattered sound wave is very sharp in the forward direction and becomes broader at larger scattering angles. Explicit compressions for the cross sections are obtained for the case of scattering from a region of isotropic turbulence. When the frequencies of importance in the turbulence are small compared to the frequency of the incident sound wave, the average differential scattering cross section can be expressed directly in terms of the energy-spectrum of the turbulence.

2879

Kraichnan, R. H., "The Scattering of Sound in a Turbulent Medium," J. Acoust. Soc. Am., 25, 1096-1104, 1953.

Journal article based on preceding entry.

2880

Krasil'nikov, V. A., "On the Propagation of Sound in a Turbulent Atmosphere," Compt. Rend., 47, 469-471, 1945.

On the basis of statistical theory of turbulence, an attempt is made to explain experimental results on fluctuations of the phase of sound waves in a turbulent atmosphere. Formulas based on Krasil'nikov (1945), Kolmogorov (1941), Obukhov (1941) and empirical data of Godecke (1935) and Findeisen (1936), show the dependence on the speed of the wind and on the 2/3 law of Kolmogorov.

2881

Krasil'nikov, V. A., and V. I. Tatarskii, "Dispersion of Sound in Turbulent Flow" (in Russian), Dokl. Akad. Nauk SSSR, 90, 159-162, 1953.
Translation available: U. S. Natl. Sci. Found., NSF-tr-121.

On the assumptions that (1) a turbulent flow can be described by the equations of motion of an incompressible viscous fluid, (2) in an incompressible fluid, the dispersions by temperature irregularities and velocity fluctuations, respectively, are independent, and (3) the fluctuations of the velocity of flow v are considerably smaller than the speed of sound c in the medium, it is shown that the wave equation of sound in the moving medium, neglecting acceleration, can be reduced to $\Delta\psi - \partial^2\psi/c^2\partial t^2 = 2v\partial^2\psi/c^2\partial x_i\partial t$, where ψ is the potential function of the sound field. This equation is solved by the method of successive approximations. Expressions are derived for the effective range of sound dispersion in the solid angle of $d\Omega$ per unit of distance travelled by the incident sound wave and for the dispersion coefficient. The coefficient of "backward dispersion" is constant at high frequencies. It is possible that the dispersion of sound by the acceleration field may afford a better explanation of the damping of infrasonic sound waves in the atmosphere than that afforded by the present theory of dispersion due to viscosity and thermal conductivity.

2882

Kulsrud, R. M., "Effect of Magnetic Fields on Generation of Noise by Isotropic Turbulence," Astrophys. J., 121, 461-480, 1955.

Lighthill's (1952) and Proudman's (1952) results on the generation of aerodynamic noise by isotropic turbulence are generalized to include magnetic effects. It is found that if there are only turbulent magnetic fields present, and no constant magnetic field, the magnetic turbulence generates sound very efficiently and considerably increases the generation of sound by kinetic turbulence. If there is a constant magnetic field, hydromagnetic waves are generated instead. For the modified sound mode of the hydromagnetic waves, a result similar to the case of no general field is obtained. No energy is generated into the Alfven and modified Alfven waves unless the energy density of the magnetic field is greater than the energy density of the kinetic turbulence. Expressions are found for the rate of noise generated per unit mass, and these results are applied to the problem of heating the chromosphere and the corona.

2883

Laufer, J., "Sound Radiation from a Turbulent Boundary Layer," Tech. Rept. No. 32-119, Jet Propulsion Lab., Calif. Inst. of Tech., Pasadena, 14 pp., 1961.
AD-266 301.

If the restriction of incompressibility in the turbulence problem is relaxed, the phenomenon of energy radiation in the form of sound from the turbulent zone arises. To calculate this radiated energy, new statistical quantities, such as time-space correlation tensors within the turbulent zone, have to be known, in addition to the conventional quantities. For the particular case of the turbulent boundary layer, indications are that the intensity of radiation becomes significant only in supersonic flows.

Under these conditions, the recent work of Phillips (J. Fluid. Mech. 9:1-28, 1960) is examined together with some experimental findings of the author. It is shown that the qualitative directionality as predicted by the theory are consistent with the measurements; however, even for flow with the highest Mach number, some of the assumptions of the asymptotic theory are not yet satisfied in the experiments. Finally, the question of turbulence damping due to radiation is discussed, with the result that in the Mach number range covered by the experiments, the energy lost from the boundary layer due to radiation is a small percentage of the work done by the wall shearing stresses.

2884

Lighthill, M. J., "Aerodynamic Noise of Turbulence as a Source of Sound," Aeronaut. Res. Council, Fluid Motion Sub-Committee, London, England, 298, 26 pp., 1950.
ATI-164 845.

A study is made of aerodynamic noise or turbulence as a source of sound, using the equations of gas dynamics and ideas from acoustics and turbulence theory. Specifically analyzed is the noise radiated into a quiescent atmosphere by a subsonic turbulent flow that has a steady mean flow. It is shown that the flow constitutes a volume distribution of instantaneous sources of sound, whence some simple interferences are drawn. But these sources largely cancel one another as far as the radiation of acoustic energy is concerned, in essentially the same way as would the oscillations of a deformable solid sphere without any change of volume or motion of the centroid. This theory is discussed in detail.

2885

Lighthill, M. J., "The Bakerian Lecture, 1961, Sound Generated Aerodynamically," Tech. Memo. No. DIR. 8., Royal Aircraft Establishment (Great Britain)., 47 pp., 1961.
AD-275 075.

The original theory of sound generated aerodynamically, that is, of sound radiation fields that are byproducts of airflows, has been extended and improved by Curle and Ffowes Williams (Proc. Roy. Soc. A216:412-422 and A231:505-514; and Univ. Southampton Aero. Astr. Rept. No. 109 and 155). It is explained in this lecture as simply as possible, and used as a framework for the discussion of our experimental knowledge on pulse-jet noise, hydrodynamic sound generation, Aeolian tones, propeller noise, boundary-layer noise and, especially, the noise of jets, both stationary and in flight. Improved knowledge of space-time correlations in turbulent flow is used to obtain new results on the noise radiated by turbulent boundary layers, as well as by jets at the higher Mach numbers. Supersonic bangs and the scattering of both sound and shock waves by turbulence are briefly touched upon. The lecture ends with a discussion of the methods used for the reduction of jet-aircraft noise.

2886

Lighthill, M. J., "On Sound Generated Aerodynamically, I. General Theory," Proc. Roy. Soc. (London), A. 211, 565-587, 1952.

A theory, based on the equations of motion of a gas, is initiated for the purpose of estimating the sound radiated from a fluid flow with rigid boundaries, which as a result of instability contains regular fluctuations or turbulence. The sound field is that which would be produced by a static distribution of acoustic quadrupoles whose instantaneous strength per unit volume is $\rho v_i v_j + p_{ij} - a_0^2 \rho \delta_{ij}$, where ρ is the density, v_i the velocity vector, p_{ij} the compressive stress tensor, and a_0 the velocity of sound outside the flow. This quadrupole strength density may be approximated in many cases as $\rho_0 v_i v_j$.

The radiation field is deduced by means of retarded potential solutions. In it, the intensity depends crucially on the frequency as well as on the strength of the quadrupoles, and as a result increases in proportion to a higher power, near the eighth, of a typical velocity U in the flow. Physically, the mechanism of conversion of energy from kinetic to acoustic is based on fluctuations in the flow of momentum across fixed surfaces, and it is explained how this accounts both for the relative inefficiency of the process and for the increase of efficiency with U. It is shown how the efficiency is also increased, particularly for the sound emitted forwards, in the case of fluctuations convected at a not-negligible Mach number.

2887

Lighthill, M. J., "On Sound Generated Aerodynamically, II. Turbulence as a Source of Sound," Proc. Roy. Soc. (London), A, 222, 1-32, 1954.

Journal article based on report covered by entry No. 638.

2888

Lighthill, M. J., "On Sound Generated Aerodynamically, II, Turbulence as a Source of Sound," Univ. of Manchester, England, 1953.

The theory of sound generated aerodynamically is extended by taking into account the statistical properties of turbulent airflows, from which the sound radiated (without the help of solid boundaries) is called aerodynamic noise. The theory is developed with special reference to the noise of jets, for which a detailed comparison with experiment is made (Chap. 7 for subsonic, Chap. 8 for supersonic jets).

The quadrupole distribution of Part I (Lighthill, 1952) is shown to behave (see Chap. 3) as if it were concentrated into independent-point quadrupoles, one in each "average eddy volume." The sound field of each of these is distorted, in favor of downstream emission, by the general downstream motion of the eddy, in accordance with the quadrupole convection theory of Part I. This explains, for jet noise, the marked preference for downstream emission, and its increase with jet velocity. For jet velocities considerably greater than the atmospheric speed of sound, the "Mach number of convection" M_c may exceed 1 in parts of the jet, and then the directional maximum for emission from these parts of the jet is at an angle of $\sec^{-1}(M_c)$ to the axis (Chap. 8).

Although turbulence without mean flow has an acoustic power output, which was calculated to a rough approximation from the expressions of Part I by Proudman (1952; see also Chap. 4 below), nevertheless, turbulence of given intensity can generate more sound in the presence of a large mean shear (Chap. 5). This sound has a directional maximum at 45° (or slightly less, due to the quadrupole convection effect) to the shear layer. These results follow from the fact that the most important term in the rate of change of momentum flux is the product of the pressure and the rate of strain. The higher-frequency sound from the heavily sheared mixing region close to the orifice of a jet is found to be of this character. But the lower-frequency sound from the fully turbulent core of the jet, further downstream, can be estimated satisfactorily (Sect. 7) from Proudman's results, which are here reinterpreted (Chap. 5) in terms of sound generated from combined fluctuations of pressure and rate of shear in the turbulence. The acoustic efficiency of the jet is of the order of magnitude $10^{-4}M^5$, where M is the orifice Mach number.

However, the good agreement of total acoustic power output with the dimensional considerations of Part I, is partly fortuitous. The quadrupole convection effect should produce an increase in the dependence of acoustic power on the jet velocity above the predicted U^8 law. Largely cancelling this, the experiments show that some other dependence on velocity is present, tending to reduce the intensity below the U^8 law at the stations where the convection effect would be absent. At these stations (at 90^o to the jet) proportionality to about $U^{6.5}$ is more common. A suggested explanation of this, compatible with the existing evidence, is that at higher Mach numbers there may be less turbulence (especially for larger values of nd/U, where n is frequency and d diameter), because as the turbulence builds in the mixing region it loses energy by sound radiation. This would explain also the slow rate at which supersonic mixing regions spread, and, indeed, is notincompatible with existing rough explanations of that phenomenon.

A consideration (Chap. 6) of whether the terms other than momentum flux in the quadrupole strength density might become important in heated jets indicates that they should hardly ever be dominant. Accordingly, the physical explanation (Part I) of aerodynamic sound generation still stands. It is re-emphasized, however, that whenever there is a fluctuating force between the fluid and a solid boundary, a dipole radiation will result which may be more efficient than the quadrupole radiation, at least at low Mach numbers.

2889

Lilley, G. M., "On the Noise from Air Jets," Rept. No. ARC 20, 376, Aeron, Res. Council, Great Britian, 1958. AD-206 360.

Reviews the current position of research into aerodynamic noise. The contents include: (1) Lighthill's theory of aerodynamic noise; (2) Structure of various regions of a turbulent subsonic jet; (3) Sound generated in various regions of a turbulent subsonic jet; (4) Noise emitted by a supersonic jet; (5) Experimental work on noise of subsonic air jets; and (6) Methods of noise reduction.

2890

Lyamshev, L. M., "The Acoustic Radiation of Turbulent Flow in the Presence of Elastic Boundaries," Soviet Phys. "Doklady",English Transl., 6, 341-343, 1961.

The equation derived by Lighthill is used as a basis for computing the radiation of sound by turbulent aerodynamic flow around streamlined elastic bodies (plates, rods, etc.) extended in the direction of flow. The solution shows that turbulent flow around elastic bodies in the stream produces superimposed fields of radiation from volume sources and fields from the surfaces of the bodies. The surface sources consist of fluctuations of pressure and viscous stress and fluctuations of speed at the surface of the bodies. Dimensional analysis leads to the conclusion that the field of the volume (quadrupole) sources is proportional to the eighth power of the ratio of the speed of flow to the speed of sound in the medium (M^8); the field of the surface (dipole) sources is proportional to M^6, and of simple sources to M^4. The results reported by Doak and Powell are found to be particular cases of the more general solution found here.

2891

Lyamshev, L. M., "Analysis of Acoustic Radiation from a Turbulent Aerodynamic Flow," Soviet Phys. Acoust., English Transl., 6, 472-476, 1961.

Starting from Lighthill's equation, a method is presented for calculating the acoustic radiation of a turbulent aerodynamic flow in free space and in the presence of elastic surfaces outside the flow. It is shown that if one knows the solution to the nonstatistical problem of diffraction of a spherical (or plane) sound wave by the said elastic surfaces, and the correlation function for pressure fluctuations in the flow, calculation of the spectral intensity of the radiation from the turbulent flow reduces to quadratics.

2892

Lyamshev, L. M., "Sound Radiation from Elastic Shells Excited by Turbulent Aerodynamic Flow," Soviet Phys. Acoust., English Transl., 7, 44-49, 1961.

Gives an approximate calculation for the field generated by infrasonic turbulent flow outside or inside thin elastic shells in the flow itself. It is shown that the calculation reduces to solving the auxiliary diffraction problem and defining the velocity or pressure-fluctuation correlation tensor in the flow and on the surface of the shell. When the auxiliary solution and corresponding correlation function are known it is only necessary to calculate the square. The mean square pressure fluctuation in the acoustic field radiated by a moving thin plate oscillating under the action of pressure fluctuations in the boundary layer is calculated approximately.

2893

Mawardi, O. K., "Aero-Thermoacoustics (The Generation of Sound by Turbulence and by Heat Processes)," Repts. Progr. in Phys., 19, 156-186, 1956.

An analysis of the general equations of the motion of a viscous compressible fluid leads to the identification of three modes (vorticity, compression and entropy modes) of energy associated with the fluid. Interaction between these modes gives rise to acoustical phenomena, of which some are of great interest to the study of aircraft noises. The first part of this report deals with acoustical effects resulting from the interaction of a vorticity and a compression mode. It considers in detail the generation of sound from turbulence as encountered in a jet and in a boundary layer, and the scattering of sound from turbulence.

In the remaining part, the interaction of the entropy mode with the compression mode is discussed. Special emphasis has been placed on the study of heat-maintained vibrations as encountered in Rijke's phenomenon and in flame-driven oscillations. The article concludes with a speculative discussion of acoustical phenomena in which the couplings between the three modes are equally important.

2894

Mawardi, O. K., "On the Spectrum of Noise from Turbulence," J. Acoust. Soc. Am., 27, 442-446, 1955.

Reports development of an approximate method for estimating the acoustical power-frequency spectrum of the sound generated fromisotropic turbulence. The method is based on a hypothetical model for the sound sources, originally produced by Lighthill, consisting of an assembly of quadrupoles extending over the region of turbulence.

2895

Mawardi, O. K., and I. Dyer, "On Noise of Aerodynamic Origin," J. Acoust. Soc. Am., 25, 389-395, 1953.

An attempt is made in this paper to classify noises of various aerodynamic origin by means of an efficiency of conversion from mechanical to acoustical energy, and also by means of representative spectra associated with corresponding characteristic frequencies. The classification has been tried successfully on measurements of wind tunnel noises, turbojet noises, and air jet noises.

2896

Meecham, W. C., "On Noise Produced by Boundary Layer Turbulence," J. Acoust. Soc. Am., 35, 116-117, 1963.

Discusses the question of possible sound produced by stresses at a rigid surface. It has been previously pointed out that these stresses won't produce sound; the error in the original analysis is shown to be a confusion between hydrodynamic pressure and sound-field pressure.

2897

Meecham, W. C., "Theory of Acoustic Propagation at High Altitudes," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 177-181, 1961.
AD-408 716.

Discusses the theory of pressure-fluctuation backgrounds at high altitudes, as observed by freely floating balloon systems. Examines the various possible sources of such backgrounds, and proposes a theoretically predicted level and power spectrum. The pressure levels of local hydrodynamic (incompressible) phenomena and the time characteristics of such effects are considered in particular. Propagated acoustic backgrounds are considered and correlation methods for separating these effects from local hydrodynamic phenomena are reviewed; the characteristics of such backgrounds, if generated by turbulence, are treated with particular emphasis on the sound power-spectrum. Emphasis is placed upon the predicted difference in spectra, from two theories (those of Kraichnan on the one hand and of Meecham and Ford on the other).

These theoretical remarks are examined in the light of actual measurements taken at high altitudes, and tentative conclusions are drawn.

2898

Meecham, W. C., and G. W. Ford, "Acoustic Radiation from Isotropic Turbulence," J. Acoust. Soc. Am., 30, 318-322, 1958.
AD-217 911.

For low Mach number turbulence, Lighthill has given a result that expresses the acoustic radiation of turbulent fluid in terms of a fourth-rank velocity correlation. Through the use of the Navier-Stokes equation, this relation can be put in terms of the space-time pressure correlation. For very large Reynolds number turbulence (in the inertial subrange where Kolmogoroff's similarity principles are valid) one can write this pressure correlation in terms of a function of a single variable. Since the space-time correlation of the pressure is needed one must take into account convective effects; this is done here by introducing a new Lagrangian type of correlation that is defined in such a way that, without difficulty, a similarity argument can be applied from the convective effects. Such convective effects then enter only through negligible Doppler shifts.

Using this similarity result and Lighthill's formulation, one obtains the acoustic self-noise power spectrum for the turbulence. The spectrum is proportional to $\omega^{-7/2}M^{21/2}$ for high frequencies ($\omega >> c_0 M/L$), where ω is the acoustic angular frequency, M is the turbulence Mach number, c_0 is the velocity of sound in the fluid, and L is the size of the large-scale turbulent eddies. The spectrum at the high-frequency end is universal; that is, it is independent of the details of the driving mechanism. Furthermore, the spectrum is proportional to $\omega^4 M^3$ at the low-frequency end, and depends on the large-scale eddies there.

The similarity hypothesis made here for the special Lagrangian type of space-time correlation is of interest in itself in turbulence theory. It is difficult to check this hypotheis directly; however, a measurement of the acoustic power spectrum offers an interesting indirect check on the hypothesis.

2899

Menkes, J., "On the Stability of a Shear Layer," Prog. Rept. No. 30-10, Jet Propulsion Lab., Calif. Inst. of Tech., Pasadena, 9 p., 1959.
AD-219 682.

Investigates the effects of density variation in the absence of gravity on a horizontal shear layer between two streams of uniform velocities. The density is assumed to decrease exponentially with height and the velocity is represented by $U(y) = \tanh y$. The method of small disturbances is employed to obtain a neutral boundary of stability. It is demonstrated that disturbances with a wave number that is larger than a characteristic length (i.e., the width of the transition layer) are attenuated. Qualitative agreement with experimental evidence is obtained.

2900

Mollo-Christensen, E., "Some Aspects of Free Shear-Layer Instability and Sound Emission," Fluid Dynamics Res. Lab., Mass. Inst. of Tech., Cambridge, 6 pp., 1960.
AD-240 658.

Examines the relative importance of instability fluctuations and turbulence as sources of noise in a jet. Some problems associated with the supersonic disturbances in a shear layer are also discussed. Results indicate that in supersonic free shear flow it appears necessary to consider three dimensional disturbances in an analysis of stability, as pointed out by Lin (The Theory of Hydrodynamic Stability, Cambridge Univ. Press, 1955). For supersonic disturbances it is necessary to take into account the presence of boundaries that are not in contact with the shear layer. Sound emission from instability fluctuations may be dominant under certain circumstances, and observation of emitted sound may provide information about the mechanisms of instability and transition.

2901

Monin, A. S., "On the Similarity of Turbulence in the Presence of a Mean Vertical Temperature Gradient," J. Geophys. Res., 64, 2196-2197, 1960.

The frequency spectrum of vertical turbulence components is considered in the case of a vertical temperature gradient. Similarity methods are employed, one to describe the ranges of energy and inertia, another (Kolmogoroff) to describe the ranges of inertia and dissipation. It is proposed that, since both theories hold in the inertial range, a relation can be determined between the two unknown universal functions involved.

2902

Monin, A. S., "The Structure of Atmospheric Turbulence," Teor. Veroyatnost. i Primenen., 3, 285-317, 1961.

This is an account of experimental and theoretical work on the structure of the turbulence in the earth's boundary layer. The layer is assumed to be in a condition of horizontal homogeneity, and to be transferring constant shear stress and constant flux of total heat. It is therefore specified by these quantities and the characteristic length

$$L = - \frac{\tau^{3/2}}{k(g/T_o)\ (Q/\rho\, c_p)}$$

Experimental measurements of mean velocity distributions agree well with the dimensional consequences of the specification for upward and downward heat fluxes. Also considered are the magnitudes of the turbulent velocity fluctuations and the balance between their production, transport and dissipation, and the temperature fluctuations and their balance. The correlations and spectra of the fluctuations within the Kolmogoroff range of similarity are described, and the theory of the space and time spectra in the inertial subrange is treated in some detail. A short summary is given of work relating to fluctuations in pressure, acceleration of particles, turbulent diffusion, and the production of waves.

2903

Muller, E. A., "Some Experimental and Theoretical Refults Relating to the Production of Noise by Turbulence and the Scattering of Sound by Turbulence of Single Vortices," (2nd Symposium Naval Hydrodynamics, Washington, D. C., 1958) Washington: U. S. Government Printing Office, 1960.

A technological discussion of the matters described in the title. The problem of sound scattering by a single-line vortex is discussed in some detail, and polar diagrams of the scattered intensity are given. Some experimental results of sound intensity produced by turbulence, and on sound scattering by turbulence, are also given.

2904

Muller, E. A., and K. R. Matschat, "The Scattering of Sound by a Single Vortex and by Turbulence," Rept. No. AFOSR TN-59-337, Max-Planck-Institut für Stroemungsforschung, Germany, 50 pp., 1959.
AD-213 658.
As an elementary model for the scattering of sound by turbulence, the scattering of a plane sound wave as it passes through a single vortex of finite radius is investigated. The angular intensity distribution and the total power of the scattered sound are explicitly calculated in terms of the circulation and the radius of the vortex, the wave length of the incident sound wave, and the inclination angle between the direction of propagation of the incident wave and the axis or the vortex. The results of the single-vortex theory are applied to scattering by turbulence. The turbulent flow is represented by statistically distributed vortices. Isotropic and extreme nonisotropic turbulence are considered. The total scattering power turns out to be proportional to the 5th or 2nd power of the frequency of the incident sound wave, depending on whether the frequency is low or high.

2905

Nature, "Flow Noise," 181, 388-389, 1958.

Report of a conference on aero- and hydrodynamic noise, organized by the Physical Society and the Institute of Physics, and held in Newcastle-upon-Tyne, 15-16 November 1957. Three papers were given on turbulence and its relation to noise, and seven essentially on discrete-frequency sound phenomena.

2906

Obukhov, A. M., "On Propagation of Sound Waves in Eddying Flow," Compt. Rend., 39, 46-48, 1943.

Differential equations are set up and solved for acoustical propagation in turbulent air under conditions of small change in sound velocity, and quasi-stationary flow. This is an extension of the work of Andreev (1934).

2907

Odintsov, M. G., and I. G. Shaposhnikov, "On the Influence of Large Scale Turbulence on the Propagation of Sound in a Turbulent Medium" (in Russian), J. Tech. Phys. (USSR), 19, 1001-1009, 1949.

Theoretical. The effect of turbulence on sound-propagation depends on its scale: for small-scale turbulence (small compared with the wavelength of the sound) the effect is one of scattering and dispersion, but large-scale eddies cause distortion of the acoustic wavefront, which leads to periodic fluctuations in the intensity of the signal at a distant receiver (acoustic fading). An investigation is made of phenomena of the second type; the influence of source-receiver distance, of wavelength, and of the mean velocity of the turbulent medium are examined. It is assumed that source-receiver distance is >> dimensions of the source, that compressibility of the medium is negligible, and that the mean velocity of the medium is << that of sound. The equations of propagation give series solutions for θ, the phase-angle of the soundwave, and for $L = \overline{\pi}^2/\rho c$, where $\overline{\pi}$ is the mean pressure energizing the receiver during a short period, ρ the density of the medium, and c the velocity of sound.

The first two terms in these series are evaluated, and hence the mean-square-fluctuation in sound intensity is obtained. If ΔL represents the deviation of L from its mean value over a long period, $(\Delta L)_{av}^2$ is $\propto r^3$, where r is the source-receiver distance. An expression for the dependence of $(\Delta L)_{av}^2$ upon the correlation function between turbulent velocity fluctuations and distance is also given, but the further step of deriving the dependence of $(\Delta L)_{av}^2$ upon wavelength and the bulk velocity of the medium is not carried out. This further step is omitted because of uncertainty as to the way in which the correlation function is related to these two factors.

2908

Pengelley, C. D., "Flow in a Viscous Vortex," J. Appl. Phys., 28, 86-92, 1957.

Equations have been derived for velocity, temperature, and pressure distribution in a two-dimensional compressible viscous vortex with a steady-state component of radial flow. Radial velocity has been assumed to be small compared with the tangential component, and heat transfer has been neglected. The equations are based upon the Navier-Stokes equation in its most general form, the first law of thermodynamics, and the gas laws. A reference radius has been defined where viscous stress is zero; from this, nondimensional forms have been set up and generalized charts prepared for ready visualization and numerical applications. Because of the classical concept of viscosity as used in the Navier-Stokes equation, results are strictly applicable to laminar flow only; a discussion is presented regarding possible application to turbulent flow.

2909

Phillips, O. M., "On the Generation of Sound by Supersonic Turbulent Shear Layers," J. Fluid Mech., 9, 1-28, 1960.

A theory is proposed to describe the generation of sound by turbulence at high Mach numbers. The problem is formulated most conveniently in terms of the fluctuating pressure, and a convected wave equation (2.8) is derived to describe the generation and propagation of the fluctuations in pressure.

The supersonic turbulent shear zone is examined in detail. It is found that, at supersonic speeds, sound is radiated as eddy Mach waves, and as the Mach number increases, this mechanism of generation becomes increasingly dominant. Attention is concentrated on the properties of the pressure fluctuations just outside the shear zone, where the interactions among the weak shock waves have had little effect. An asymptotic solution for large M is derived by a Green's function technique, and it is found that radiation with given frequency n and wave-number k can be associated with a corresponding critical layer within the shear zone.

It is found that $\overline{(p - p_0)^2}$ increases approximately as $M^{3/2}$ for M >> 1 contrasting with the M^8 variation found by Lighthill for M << 1. The acoustic efficiency thus varies as $M^{-3/2}$ for M >> 1, and as M^5 for M << 1, indicating a maximum acoustic efficiency for Mach numbers near one. The directional distribution of the radiation is discussed and the direction of maximum intensity is shown to move towards the perpendicular to the shear zone as M increases. The predictions of the theory are supported qualitatively by the few available experimental observations.

2910

Tellmien, W., "Research on Investigation of the Interaction of Sound and Turbulence," Max-Planck Institute, Germany, 1957.
AD-154 138.

The scattering of sound by turbulence in the atmosphere was investigated both theoretically and experimentally, and the results of one year's work are presented in this report. The elementary process of scattering by one turbulent eddy is treated theoretically. Fields of flow are then postulated, in which the vortices are placed statistically according to an arbitrary distribution function that controls direction of axes, size, and circulation of the vortices. The choice of distribution function permits treatment of isotropic as well as nonisotropic turbulence.

The section of the report on experimentation describes the mechanical and electronic apparatus that was developed for controlling and measuring the degree of turbulence, the average size of the eddies, and the velocity profile of the mean flow. Preliminary measurements were made throughout the audio range and up to frequencies of about 200 K cps.

2911

Powell, A., "Aerodynamic Noise and the Plane Boundary," J. Acoust. Soc. Am., 32, 982-990, 1960.
AD-248 036.

In an earlier paper entitled "Thoughts on Boundary Layer Noise" (Aeronautical Research Council Report 16727, 1954), it was pointed out that while the fluctuating pressures exerted upon a rigid boundary by a contiguous unsteady flow can be shown in a formal manner to generate sound as of a distribution of dipoles, it can be argued by means of the reflection principle that all such dipole effects cancel out if the boundary is plane; yet observations of aeolian tones adequately confirm the presence of effective dipole-like generators in that case. Here the image principle is developed in a rigorous manner, and the apparent paradox is resolved with the help of an extension of Lighthill's and Curle's analyses to include boundaries which are not wholly immersed in the noise-generating flow.

In particular, it is shown that the pressures exerted on a plane boundary are simply reflections of the quadrupole generators of the flow itself; thus the pressure dipoles account for an enhancement of the quadrupole power, in fact a quadrupling when the wavelength is relatively large, except that degeneration into octupoles occurs for those lateral quadrupoles of the type that would be associated with fluctuations across the shear of an adjacent boundary layer. Under these circumstances it should be possible to estimate the noise of a plane turbulent boundary layer with satisfactory accuracy from sufficient knowledge of the principal quadrupole source strength alone (provided that it is reasonable to neglect the contribution of the fluctuating shear stresses acting on the boundary).

2912

Powell, A., "Concerning the Noise of Turbulent Jets," J. Acoust. Soc. Am., 32, 1609-1612, 1960.

The suggestion that the noise generators of turbulent jets undergo convection effects which are limited in such a way as to follow a similarity behavior leads directly to a resolution of Lighthill's paradox, namely, the problem of accounting for the noise power's depending upon the eighth power of the jet velocity simultaneously with the gross directional bias. This hypothesis is shown to be at least plausible to a first approximation because the general velocity field of the jet has typical dimensions comparable to a fraction of a wavelength; an important corollary is the expectation of appreciable refraction effects. Aspects relevant to the higher-frequency directional peaks being less -pronounced and located further from the jet axis, and of the slow frequency rise, and briefly discussed.

2913

Powell, A., "On the Aerodynamic Noise of a Rigid Flat Plate Moving at Zero Incidence," J. Acoust. Soc. Am., 31, 1649-1653, 1959.

The aerodynamic noise resulting from the subsonic flow over a flat plate at zero incidence has three origins. Surface noise due to fluctuating surface pressure is postulated to vanish by the author's image argument, except near the edges of the plate, where it is more appropriately called edge noise. Of dipole nature, its acoustical power depends on the velocity raised to between the fourth and fifth power, and consequently is to be expected to be of prime importance at sufficiently low speeds. The contribution from fluctuating shear stresses is likely to be much smaller and so has been neglected. Quadrupole radiation takes place from the turbulence of the boundary layer, producing layer noise and also from the turbulent wake, producing wake noise. Together, the latter two are suggested to have a spectrum with a single peak, bounded by slopes like f^2 and $f^{-7/4}$. Their noise power depends on nearly the eighth power of velocity, so it is of increasing importance with speed. Analytical details rest on similarity concepts; the spectra in particular are subject to certain conditions. Also, the convection effects on the acoustical power and spectra are excluded on empirical grounds stemming from considerations of jet noise.

2914

Powell, A., "On Aerodynamic Sound from Dilatation and Momentum Fluctuations," J. Acoust. Soc. Am., 33, 1798-1799, 1961.

Physical reasoning suggests that aerodynamic sound from free flows may be attributed to local fluid dilatation coupled with local fluid accelerations, the former acting like a simple source field and the latter like a dipole field that reduces to a quadrupole field. A supporting mathematical development is given; it discloses the formal need of an additional surface integral. The rather poor convergence of the integrals is discussed, and comparison is made with theories that rest on the dilatational effect alone.

2915

Powell, A., "Similarity and Turbulent Jet Noise," J. Acoust. Soc. Am., 31, 812-813, 1959.

In a recent letter, Dr. Ribner noted how the assumption of simple similarity in a turbulent jet gives certain indications about the distribution of noise-generation intensity along its length. An independent analysis produced the same results, and also considered the spectral shape implied by that assumption. The latter analysis is given very briefly.

2916

Powell, A., "Three-Sound-Pressures Theorem, and its Application, in Aerodynamically Generated Sound," J. Acoust. Soc. Am., 34, 902-906, 1962.

A theorem is presented that is a direct consequence of Lighthill's theory of aerodynamic noise-generation when expressed in the equivalent point-source approximation. It states that the sum of the sound pressures at points located at equal distances on each of three mutually perpendicular axes, with the origin in the flow, is zero. This is based on the incompressible-flow approximation and applies to a free flow that is inviscid and unconvected. The next approximation is given also, the sum varying as the Mach number raised to the fourth power.

There is also an analogous form of the theorem for two-dimensional systems concerning the sum of the sound pressure on any two mutually perpendicular axes. The value of the theorem is demonstrated by showing how, for example, there can be, in general, no net longitudinal quadrupole strength for an inviscid noise-generating flow. This is illustrated by application to the sound radiators of a plane shear layer undergoing a two-dimensional disturbance.

2917

Powell, A., "Vortex Sound," Rept. No. 61-70, Univ. of Calif., Los Angeles, 43 pp., 1961.
AD-266 495.

Physical arguments are developed to show how aerodynamic sound is generated as a result of the movement of vortices, or of vorticity, in an unsteady fluid flow. In a very simple model the aeolian tone is attributed to the dipole-like flow caused by the stretching of vortex rings. There is no net stretching of vortex rings in a free flow, but each moving element of vorticity still causes a local dipole-like flow, so that equal and opposite elements act together to form quadrupoles. Mathematical developments follow. The simple aeolian tone model is shown to be valid for low Strouhal numbers, the genral result also incorporating the effect of the fluctuating Bernoulli pressure at the surface of the body. The free flow quadrupole model is shown to be exact, and also to agree with Lighthill's result. Using vorticity as a common basis, the compressible flow is compared to the corresponding incompressible one, the hydrodynamic field and the relationship to classical field theory being discussed.

2918

Proudman, I., "The Generation of Noise by Isotropic Turbulence," Proc. Roy. Soc. (London), A, 214, 119-132, 1952.

A finite region, with fixed boundaries, of an infinite expanse of compressible fluid is in turbulent motion. This motion generates noise and radiates it into the surrounding fluid. In this report, the acoustical properties of the system are studied in the special case in which the turbulent region consists of decaying isotropic turbulence. It is assumed that the Reynolds number of the turbulence is large, and that the Mach number is small. The noise appears to be generated mainly by those eddies of the turbulence whose contribution to the rate of dissipation of kinetic energy by viscosity is negligible.

It is shown that the intensity of sound at large distances from the turbulence is the same as that due to a volume distribution of simple acoustical sources occupying the turbulent region. In this analogy, the whole fluid is to be regarded as a stationary and uniform acoustical medium. The local value of the acoustical power output P per mass of turbulent fluid is given approximately by the formula

$$P = -\frac{3}{2}\,\alpha d\overline{u^2}/dt(\overline{u^2}/c^2)^{5/2}$$

where α is a numerical constant, $\overline{u^2}$ is the mean-square velocity fluctuation, t is the time, and c is the velocity of sound in the fluid. The constant α is expressed in terms of the well-known velocity correlation function f(r) by assuming the joint probability distribution of the turbulent velocities, and their first two time-derivatives at two points in space, to be Gaussian. The numerical value $\alpha \sim 38$ is then obtained by substituting the form of f(r) corresponding to Heisenberg's theoretical spectrum of isotropic turbulence. It is found that the effects of decay make only a small contribution to the value of α, and that the order of magnitude of α is not changed when widely differing forms of the function f(r) are used.

2919

RCA Defense Electronic Products, "Theoretical Study of Hydromagnetic Stability and Turbulence, Volume II. Investigations and Detailed Results," Ann. Tech. Rept. No. AFSWC TDR 62-12, Moorestown, N. J., Vol. 2, 1962.
AD-276 932.

Describes fourteen investigations of the smooth and perturbed motion of bomb-debris plasma expanding into an ionized atmosphere and magnetic-field background. An abstract of each investigation is provided.

2920

Riabouchinsky, D., "Fluid Motion at Velocities Approximating to that of Sound," Compt. Rend., 202, 1389-1391, 1936.

The method for analyzing fluid motion previously applied to a compressible fluid having local velocities exceeding that of sound is now extended to include the cases where this velocity is either definitely below that value, or is fluctuating above and below it. The necessary modifications to the principal equations are given, and conclusions are drawn as to the nature of the fluid motion.

2921

Ribner, H. S., "Aerodynamic Sound from Fluid Dilatations," Rept. No. 86, Inst. of Aerophys., Univ. of Toronto, 101 pp., 1962.
AD-291 534L.

An alternative to the quadrupole theory of flow noise is given in terms of simple sources. In this view the volume of a fluid element fluctuates inversely as the local pressure: part of this dilatation generates sound and another part propagates the sound. The local pressure consists of a quasi-incompressible "pseudosound" plus the sound field (relatively weak in low-speed flows). The effective part of the dilatations appears in a virtual acoustic source strength $\sim \partial^2 p^{(0)}/\partial t^2$.

These sources are individually nondirectional. Jointly they yield a directional pattern for the sound from a turbulent jet. Some basic directionality may be provided by a statistical sorting of the dilatations. Convection tends to beam the sound into a broad downstream lobe. Finally, refraction of the sound away from the jet axis yields a heart-shaped pattern. The sorting and convection can be accounted for in the statistics (the correlation) of the dilatation pattern. The refraction is treated via a convected-wave equation. Several of these features are illustrated by examples.

2922

Ribner, H. S., "Energy Flux from an Acoustic Source Contained in a Moving Fluid Element and its Relation to Jet Noise," J. Acoust. Soc. Am., 32, 1159-1160, 1960.

It is found that a high-frequency source (or multipole) imbedded in a moving patch of fluid emits a constant acoustic power independent of the motion. (The directivity is, however, altered). This holds when the wavelength $\lambda << $ radius R' of the entire region of flow. At the other extreme, $\lambda >> 2\pi R'$, it appears that the acoustic power is enhanced by the motion, somewhat (but not exactly) as the emission of a source is enhanced by motion through fluid at rest. A typical wavelength of a radiating eddy in a jet lies between the two extremes and a limited convective enhancement of the power is inferred. The amount should be less than that predicted by Lighthill or the much more conservative values suggested by the work of Ribner; it could conceivably lie within experimental error, justifying the nonconvective law, power $\int U^8$, found by measurement.

2923

Ribner, H. S., "New Theory of Jet-Noise Generation, Directionality, and Spectra," J. Acoust. Soc. Am., 31, 245-246, 1959.

A theory of jet noise is developed from the observation that in low-speed turbulence Lighthill's quadrupoles combine to behave like simple sources $\sim \partial^2 p^{(0)}/\partial t^2$, where $p^{(0)}$ is the "incompressible" local pressure in the turbulence. An integral for the far-field intensity involves the space-time pressure covariance R within the turbulence. Choice of R in a worked example shows how pronounced directionality results from pattern "convection" (modified by fluctuation) in conjunction with the time retardation. Further directionality is accounted for in terms of a Green's function (discussed qualitatively but not worked out) for a point source at rest in the mean shear flow, describing the lateral refraction and diffraction.

2924

Spandock, F., "Noise of the Wind and the Carry of Sound in the Free Atmosphere" (in German), Z. Angew. Phys. 3, 228-231, 1951.

It is considered that wind noise arises from turbulence and has a falling-off spectrum for both low and high frequencies. From measurements of screening of wind noise and of its influence on the amplitude, the distribution of sound in consequence of the sheltering effect has been calculated. On the basis of the fact that the frequency change of wind noise and the excitation of waves in the ear are similar, the possibility is discussed that the ear adapts itself to the conditions in the free atmosphere.

2925

Tatarskii, V. I., "Theory of the Propagation of Sound Waves in a Turbulent Stream" (in Russian), Zh. Eksperim. i Teor. Fiz., 25, 74-80, 1953.

Examines in detail the problem of the scattering of sound waves for the case of isotropic turbulence in an incompressible liquid. Investigates the general form of the scattering indicatrix and develops for it an expression based on the formula $R_{rr}(\rho) = \bar{u}^2 \exp(-\rho\ell)/3$, where $\bar{u}^2$ is the mean square value of the pulsation velocity of the stream, ρ = one of the spherical coordinates of the point, and ℓ = the correlation scale characteristic of the average pulsation size. The analysis of this phenomenon, based on the scattering theory, yields the mean square fluctuations of the phase and amplitude of sound at large distances from the source.

2926

Tellmien, W., "Research on Investigation of the Interaction of Sound and Turbulence," Rept. AFOSR TN-58-236, Max-Planck-Inst., Germany, 34 pp., 1958. AD-154 138.

Investigation was made of the elementary process of the scattering of sound by a vortex and of the dependence of the scattering properties on the characteristic parameters of the problem. Consideration is given to superposition of the effects of elementary scattering in a field of flow in which the vortices are statistically distributed due to an arbitrarily given distribution function controlling direction of the axis, and the size and circulation of the vortices. This case represents the turbulent motion. Because the distribution function can be chosen arbitrarily one can treat, for instance, isotropic as well as nonisotropic turbulence.

2927

Uberoi, M. S., "Eddy Turbulence and Random Sound in a Compressible Fluid," Proc. Cambridge Phil. Soc., 49, 731-734, 1953.

Moyal has shown that the field variables characterizing homogeneous and isotropic turbulence in a compressible fluid can be decomposed into two groups, one corresponding to fluctuating acoustical waves, or random sound, and the other to rotational fluctuation velocity or eddy turbulence. The proof is based on special representation of a random field in which random field variables (e.g., velocity) are represented by the expression $u_i(x) = \int \exp(ik \cdot x) dZ_i(k)$. It is now shown that it is not necessary to use this expression to get Moyal's result, and that any turbulence field can be decomposed into two uncorrelated parts, one corresponding to eddy turbulence, the other to random sound. The analysis is based upon the decomposition of any second-order tensor into divergence-free and vorticity-free components.

2928

Webb, W. L., "Acoustic Component of Turbulence," Tech. Rept. No. NM-456, Army Signal Missile Support Agency, White Sands, Missile Range, N. Mex., 15 pp., 1962. AD-281 703.

Discusses the intimate relationship between the local speed of sound of a flight environment and the lift and/or drag on a vehicle. The fact that this parameter will become increasingly significant as the speed increases is pointed out. In addition, it is noted that wind variations, the usual source of flight bumpiness, tend to become less effective as the speed increases. Examples of the sonic gradients which have thus far been observed in the high altitude regions of the earth's atmosphere are presented, and the circumstances under which such gradients would be most effective in perturbing a particular flight-path are described.

It is concluded that the variable vehicle loads imposed by atmospheric structure are composed of flow and thermodynamic components, and that both of these atmospheric parameters must be studied in the light of our expanding speed and spatial activities.

2929

Westervelt, P. J., "The Theory of Steady Rotational Flow Generated by a Sound Field," J. Acoust. Soc. Am., 25, 60-67, 1953.

Starting from the Navier-Stokes equations, a general equation governing the generation of vorticity R is obtained: $\nabla^2 R = \mu_o^{-1} \nabla \times \nabla \cdot \langle \rho_o uu \rangle$, wherein R is the time-independent vorticity in the Eulerian frame and $\langle \rho_o uu \rangle$ is the average value of Reynold's stress dyadic. The solution to this vorticity equation, when properly transformed to the particle coordinates, is shown to be divergence-free.

A specialization of the vorticity equation to the case of solenoidal first-order motion is shown to lead to the generating term employed by Rayleigh and by Schlichting; a specialization to the case of irrotational first-order motion is shown to lead to the generating term employed by Eckart. The sum of the two specialized driving terms does not equal the general term, indicating that the contributions to vorticity from rotational and compression effects are not independent of one another.

The theory is applied to find the streaming generated by a well-defined beam of sound giving results agreeing with Eckart and with Markham. However, when it is applied to a two-dimensional standing-wave problem, the configuration of the streaming velocity in the boundary layer is found to differ from the results obtained by Rayleigh.

Finally, the effect on streaming of a time-dependent viscosity coefficient is examined.

2930

Yoshihara, H., "Rocket Exhaust into a Hypervelocity Stream, Far Field Analysis," Rept. No. ERR-AN-128, General Dynamics Astronautics, San Diego, Calif., 13 pp., 1962.
AD-272 813.

The far field of a rocket jet exhausting into a surrounding medium moving at hypervelocity is analyzed; the compressible turbulent Navier-Stokes equations simplified by the boundary-layer approximations are used.

Turbulence, Theory
See Also——36, 41, 400, 420, 429, 470, 510, 527, 572, 765, 790, 913, 914, 1434, 1445, 1487, 1531, 1698, 1754, 1757, 1765, 1766, 1772, 1774, 1775, 1904, 2155, 2171, 2175, 2185, 2413, 2419, 2466, 2470, 2849, 3206, 3210, 3391, 3555, 3560, 3573, 3580, 3680, 3681, 3752, 3916, 3955, 4177, 4240

ULTRASONICS, GENERAL AND/OR UNCLASSIFIED

2931

Alexander, P., "Powerful Acoustic Waves," Research (London), 3, 68-73, 1950.

The present position of ultrasonics is summarized, and the piezoelectric and magnetostriction generators and the Pohlmann whistle are described. The chemical and physiochemical effects of ultrasonic vibrations are ascribed to cavitation or to the accelerations of particles in the sound field, and the results obtained so far are described.

2932

Bellin, J. L. S., and R. T. Beyer, "Experimental Investigation of an End-Fire Array," J. Acoust. Soc. Am., 34, 1051-1054, 1962.

Experiments are reported on the measurement of the scattered pressure from two finite-amplitude, collinear sound beams. The measurements were carried out at a carrier frequency of 13.5 Mc in water and 350 kc in air. The slope of the half-pressure angle vs. difference frequency curve agrees well with that predicted by Westervelt, although the radiation pattern measured experimentally was in each case more directive than predicted by the theory.

2933

Bertolini, A., "An Ultrasonic Receiver for Detecting Signals of Bats," Rept. No. 47G-0010, Lincoln Lab., Mass. Inst. of Tech., Lexington, Rev. 1, 16 pp., 1961.
AD-268 702.

A portable ultrasonic receiver was designed for detecting the signals of bats and other fauna which may emit ultrasonic sounds. The receiver has a passband extending from 15 to 200 kc, but bandwidth selection within this interval can be obtained with the use of plug-in filters. It has a small-signal voltage gain of 78 db preceding a rectifier which envelope-detects the ultrasonic signal. Following detection is 10 db of audio voltage gain. Additional gain is provided by a preamplifier inserted between the microphone and ultrasonic amplifier. All of the power is supplied by five 1.35-volt mercury cells but D-cell flashlight batteries may be used when necessary. The total weight of the unit is 5 pounds.

2934

Borisov, Yu. Ya., and L. O. Makarov, "Certain Records in Ultra-Acoustics," (Trans. No. MCL-1229 from "Ultrasonics in the Technology of the Present and Future," Moscow, 77-80, 1960) 4 pp., 1961
AD-264 498.

These are excerpts from the book "Ultrasonics in the Technology of the Present and Future." Several methods of obtaining high density focused ultrasonic energy are briefly discussed: shaped transducers, passive focusing devices, and a new method of irradiation.

2935

Borisov, Yu. Ya., and N. M. Gynkina, "On Acoustic Drying in a Standing Sound Wave," Soviet Phys. Acoust., English transl., 8, 95-96, 1962.

An investigation is carried out to determine the effect of sound intensity on the drying rate of porous capillary material.

2936

Bradfield, G., "Obstacle Detection Using Ultrasonic Waves in Air," Electron. Eng., 21, 464-468, 1949.

This paper describes the results which have been achieved with simple equipment for use as a safety-in-fog aid to road transport, or blind man's aid, to detect the proximity of on-coming traffic, up- or down-going steps, walls, windows, etc. Expressions are given for determining the optimum frequency for certain conditions (e.g., at 20 ft large objects require a frequency of 23 kcs, but clusters of tiny objects require 50 kcs). A spark transmitter was used with a standard 14-mm sparking plug at the focus of a reflector. The receiving microphone used a double bimorph Rochelle crystal at the focus of a five in paraboloid. The spark rate was 3 to 4 sec, and duration 1 to 1 1/2 μsec. Tables show the amplitude of the reflected signal at various frequencies for different objects.

2937

Bradfield, G., "Summarized Proceedings of Symposium on Applications of Ultrasonics," Proc. Phys. Soc. (London) B, 63, 305-322, 1950.

Recent advances in (a) the investigation of the fundamental structure of matter, (b) telecommunication and allied applications, and (c) use of mechanical forces set up by intense waves are surveyed. Derivation of elastic constants of matter are presented. Losses of energy incurred in propagating waves are surveyed and relaxation phenomena based on Maxwell's hypothesis of shear elasticity as a time function and on Kneser's treatment of loss due to delay in a storage process are represented.

Available sources of ultrasonic power are surveyed and the importance of barium titanate as a powerful and strongly coupled piezoelectric transducer is emphasized.

An expression for the receiver/transmitter power ratio in telecommunications systems is examined and optimum frequencies for various ranges deduced.

Accounts are given of experience with flaw detectors and echo-sounding, showing that these are becoming important industrially and in navigation; work on blind aids is found unpromising.

Advances in timing and time delay devices are described. The importance of the study of cavitation is pointed out. Results are discussed for killing bacteria, disintegrating proteins, emulsifying, soldering aluminum, and refining the crystalline structure in solidification of light alloys.

2938

Brandt, O., "Behavior of Suspended Matter in Vibrating Gases at Sonic and Supersonic Frequencies," Kolloid-Z., 76, 272-278, 1936.

A brief survey of previous work in this field is first given and is followed by the description of measurements concerning the velocity of aggregation when influenced by sonic and supersonic vibrations in static and flowing gases containing paraffin particles (i.e., paraffin fogs). Since such particles are undoubtedly spherical, all uncertainty in measurement is removed. The apparatus used and the experimental details are fully described. Separate sections deal with the period of fall of the particles, rate of change of particle size as obtained by optical measurements, and phenomena in flowing fogs of paraffinated gases. Comprehensive tables of data, diagrams and bibliography are included.

2939

Brandt, O., H. Freund, and E. Hiedemann, "Motion of Particles in a Sound Field," Z. Physik, 104, 511-533, 1937.

A theoretical and experimental study is made of the motion of particles in a sound field. The relation between the amplitudes of the particles and of a gas in which they are suspended is deduced; it appears that there is a limiting frequency, below which the particle or gas amplitudes are the same but above which the particle amplitude decreases and finally, for high frequencies, becomes zero. The radius of the particle and the frequency are so related that for similar values of the expression a^2v (a = amplitude, v = frequency), particles behave similarly. Photographs of the particle motion show good agreement with the above theoretical work. The fact that the gas and particle amplitude are different above the limiting frequency leads to calculable losses due to friction, and the absorption of sound passing through a dispersed system is calculated on this basis. The fact that above the limiting frequency particles having different radii also have different amplitudes leads to attractive forces between the particles. On this basis the coagulating effect of ultrasonic radiation is calculated. By observation of the light scattered from the particles, it is shown that the sound causes them to orient themselves in a manner depending upon their shape.

2940

Crawford, A. E., "Ultrasonic Engineering," Academic Press, New York, 344 pp., 1955.

After a very brief presentation of the theory of ultrasonic radiation and a chapter on cavitation in liquids, the next 100 pages are devoted to the treatment of the generation of high-intensity and high-frequency sound. The remaining 180-odd pages discuss the specific applications, including precipitation, emulsification, chemical action, metallurgical processing, coating of metals, as well as biological and medical applications. There is a final chapter on ultrasonic instruments and control gear.

The treatment is descriptive throughout, with a minimum of emphasis on analytic detail. For the most part the formulas are introduced from the technical literature without deduction, much of the analysis having been replaced by numerous clear and well-drawn graphs. The bibliography, though not extensive, is adequate for the engineering reader who wishes to follow up some special line. The style is clear and readable. The illustrations of ultrasonic equipment are excellent, as is the typography. The volume should find wide use among acoustical processing engineers.

2941

Curry, B., and E. Hsi, "Bibliography on Supersonics or Ultrasonics," Research Foundation, Oklahoma Agricultural and Mechanical College, Stillwater, 1949.

Contains about 650 entries, many with short abstracts, gathered from journals of abstracts in the period 1928-1949. Arranged under 72 subject headings, and also under individual authors. Physical, chemical, biological, and industrial aspects are covered. The bibliography has been deposited at a number of public and university libraries.

2942

Curry, B., E. Hsi, J. S. Ambrose, and F. W. Wilcox, "Bibliography, Supersonics or Ultrasonics 1926-1949 with Supplement to 1950," Research Foundation, Oklahoma Agricultural and Mechanical College, Stillwater, 1951.

This bibliography is a reissue (see the preceding abstract), with a supplement to 1950.

2943

Danner, P. A., E. Ackerman, and H. W. Frjngs, "Heating of Haired and Hairless Mice in High Intensity Sound Fields from 6 to 22 KC," J. Acoust. Soc. Am., 26, 731-739, 1954.

Experiments have been conducted to provide a comparison of sound absorption by haired and hairless mice in high intensity airborne sound fields. At 18-20 kc, threshold intensities for heating of the mice are 144 ± 2 db for haired animals and 155 ± 2 db for hairless animals. From 6-22 kc, effectiveness of the sound in heating the mice increased with frequency. Absorption coefficients computed from the data are higher at higher frequencies for both types of animals. Death time depends upon the intensity and frequency of the sound, the external covering of animals, and the portion of the animal exposed to the most intense part of the sound field. The configuration of the sound field and its relation to the results are discussed. Measurements of the field made with and without a hairless mouse showed increased distortion at higher frequencies of the sound field by the body of the mouse.

2944

Dehn, J., "Interference Patterns in the near Field of a Circular Piston," J. Acoust. Soc. Am., 32, 1692-1696, 1960.

A number of ultrasonic ring patterns, recorded photographically in the near field of a circular piston, are presented as the principal feature of this paper. In appearance, they resemble the diffraction patterns of light in front of a circular aperture, which appear in most textbooks on physical optics. First, the method of recording is commented upon. Then the positions of the central maxima and minima are shown to agree with the predictions of wave theory. And finally, a simple ray theory, based on a method first proposed by Schoch and capable of giving a qualitative picture of the field in front of the piston, is discussed.

2945

Emertron, Inc., "Scattering of Electromagnetic Waves by Ultrasonic Beams," Final Rept. No. 3, Silver Spring, Md., 112 pp., 1962.
AD-274 810.

Factors affecting the scattering of radio waves by sonic beams are discussed from the point of view of existing theory. A review of sonic sources is presented along with the detailed characteristics of the sonic generators investigated during the course of field experimentation. The millimeter wave communications equipment used as the electromagnetic source is also briefly described. Field experiments performed over an open range of 154 feet yielded no positive results in indicating that scattering of radio waves can be effected by means of sonic energy. These results cannot be considered absolutely definitive in the light of limitations imposed on the experiment by both sonic and radio equipment.

2946

Emertron, Inc., "Scattering of Electromagnetic Waves by Ultrasonic Beams," Quart. Prog. Rept. No. 2, Silver Spring, Md., 103 pp., 1962.
AD-274 809.

The results of laboratory investigations on sonic generators are reviewed. Field experiments to determine the feasibility of scattering electromagnetic waves by means of ultrasonic beams are described, along with a brief presentation of the characteristics of the radio communications equipment used in the evaluation program. The field experiments were conducted over an open range of 154 feet. No positive results were obtained. In view of the limitations imposed on the experiment by both the sonic and the radio equipment, these results cannot be considered absolutely definitive.

2947

Ernst, P. J., "Preliminary Survey in Connection with Use of Ultrasonic Methods for the Accurate Measurement of Rocket Velocities During the Burning Period," Final Rept., Temple Univ., Philadelphia, Pa., 10 pp., 1953.
AD-11 531.

Tests are reported which indicate the feasibility of using ultrasonic methods to make accurate measurements of rocket velocities during the burning period. Two methods are recommended. The echo-Doppler method uses either a small reflector fixed to the rocket nose or the flattened rocket nose for ultra-sound reflection. This method is considered applicable for velocities as high as half the speed of sound. The second method comprises the transmission of a signal from a sonic generator to a microphone on the rocket and the retransmission of a modulated radio signal to a detector. This method is applicable up to the speed of sound. An 8- to 25-kc range and a 50-w transmitter power appeared adequate. Test data are included as well as photographs of experimental setups.

2948

Ewer, D. W., H. Hartridge, and M. Wilkinson, "Acoustic Control in the Flight of Bats," Nature, 156, 692-693, 1946.

This is a group of letters to the editor citing the analogy between radar and the acoustic range and direction-finding ability of bats. The supersonic note emitted lasts about 0.01 sec, during which the leading edge travels about 10 feet on a round trip between a bat and an obstacle. It is suggested that since a bat could not perceive targets at ranges shorter than 5 feet by this process, the trailing edge rather than the leading edge of supersonic pulses may be utilized. It is also suggested that as the pulse repetition increases when a bat approaches an obstacle, the pulse duration time may decrease to much less than 0.01 sec, thereby permitting close range perception.

2949

Fridman, V. M., "Ultrasonics," Aerospace Tech. Intelligence Center, Wright-Patterson Air Force Base, Ohio, 66 pp., 1961.
AD-264 622.

An extensive study of ultrasonics technology is presented in handbook form. Applications to industrial research are presented and descriptions of equipment are given with photographs of various devices. Discussions of ultrasonics theory and principles of applications are stated at some length.

2950

Glickstein, C., "Basic Ultrasonics," John F. Rider Publisher, New York, 137 pp., 1960.

This book is divided into three parts: general theory, equipment, and applications, with a short glossary and an index. The "pictured text" method is used, with almost every page having a cartoon-like diagram occupying from about one-quarter to, in a few cases, well over one-half of the page. Scattered throughout the book are six sets of "Questions and Problems," each containing ten or twelve questions.

The book is suitable for technical institute or vocational school use. No mathematical background is required, but a fair knowledge of electronics is needed, especially for the equipment section. The diagrams help not only by enlivening the appearance but also by serving as a very effective means of emphasizing the main points of the textual material. The book could also serve those looking for a good elementary survey of ultrasonic equipment and applications. The section on sound in general physics courses could make stimulating supplementary reading material.

2951

Griffin, D. R., "How Bats Guide Their Flight by Supersonic Echoes," Am. J. Phys., 12, 342-345, 1944.

In the 18th century Jurine found that plugging the ears of bats caused them to lose most of their ability to avoid obstacles in the dark. His explanation was not generally accepted. Hartridge in 1920 suggested that bats made use of supersonic sounds for purposes of safety when flying, and Galambos and the author found that bats emit an intense supersonic cry of frequency varying between 30 and 70 kcs with maximum intensity about 50 kcs. When approaching an obstacle, bats emit cries, but their ability to avoid obstacles is much reduced when their ears are plugged or their mouths are gagged. The term echolocation is suggested for the bats' process, which is compared with the echometer used on a ship for depth-finding or for the location of schools of fish.

2952

Griffin, D. R., "Measurements of the Ultrasonic Cries of Bats," J. Acoust. Soc. Am., 22, 247-255, 1950.

The ultrasonic sounds emitted by bats have been analyzed with a system sensitive to frequencies from 1 to 150 kc. These sounds, used by the bats to detect obstacles by means of their echoes, consist of pulses about two msec long. Most of the measurements were made with the common little brown bat, Myotis 1. lucifugus; with this species the sound pressure at 40 to 55 kc, measured 5 to 10 cm from the animal's mouth, averaged 60 dynes/cm^2 (109 db on the conventional scale of sound pressure levels). The highest recorded intensity was 173 dynes/cm^2 (119 db). The frequency of the ultrasonic sound falls during each pulse by about one octave; the average frequency at the peak amplitude was 47.8 kc, while the average at the beginning of the pulse was 77.9 kc, and at the end 39.1 kc. Low frequency waves (about 10 kc) accompany the pulse, but their amplitude is a very small fraction (1/100 to 1/1000 or less) of the peak sound pressure at ultrasonic frequencies. The envelope form is variable; the emission is directional with most of the energy concentrated into the forward direction; and the pulses are commonly repeated at rates of 20 to 30 per second.

2953

Griffin, D. R., and H. Hartridge, "Supersonic Cries of Bats," Nature, 158, 46-48, 135, 1946.

Oscillograph studies have revealed no sign of any low-frequency component, audible to humans, in the bat's cry, so that the audible sounds mentioned by Hartridge are most likely transient components caused by the impulsive nature of the cry, which was found to be only 1-2 msec in duration, with a relatively rapid cut-off. There usually is a fall of frequency of nearly an octave during the pulse. Evidence is presented to show that the cry is not emitted through the nostrils, but that the nasal cavity may play a part in determining the envelope shape of the cry.

Hartridge raises several criticisms to Griffin's interpretations.

2954

Griffing, Virginia, and F. E. Fox, "Theory of Ultrasonic Intensity Gain due to Concave Reflectors," J. Acoust. Soc. Am., 21, 348-351, 1949.

A concave reflector can be used to concentrate a beam of plane ultrasonic waves in the focal region, where the intensity I_f if much larger than the intensity I_i in the plane wave. When the sound wavelength is small compared to the dimension of the beam and reflector, one can use the well-known Fraunhofer diffraction formulas to calculate the intensity gain, i.e., I_f/I_i. Expressions are derived for the maximum and average intensity gain in the zero-order image when the ultrasonic beam is circular or rectangular, together with formulas giving the total intensity falling upon circular or rectangular areas of arbitrary dimensions in the focal region.

2955

Groenewold, H. J., "Thermal Conditions in Sound Waves," Physica, 6, 303-312, 1939.

The question whether supersonic waves in He II are adiabatic or isothermal is discussed. Though the high conductivity of heat and the high frequency would suggest an isothermal behavior, the assumption of a long free path, smoothing out the heat transport, would lead back to adiabatic conditions.

2956

Hopwood, F. L., "High-Frequency Sound Waves," J. Sci. Instr., 6, 34-40, 1929.

High-frequency air waves are produced by Langevin's method, putting a massive electrode of lead and a light electrode of copper foil in contact with the two faces of a quartz disc and applying an alternating potential difference of 20,000 volts. The quartz disc dilates and contracts. A beam of air waves is formed at right angles to the disc. If this is horizontal, the formation of stationary wave-striae can be observed in coke-dust laid on glass in the path of the beam. Interference patterns, diffraction effects, attenuation, and the pressure of sound radiation are also demonstrated. These waves kill fish, as Langevin showed. They also break up red blood corpuscles, inhibit the electrical stimulation of a muscle-nerve preparation, and destroy the structure of fresh-water vegetation. If the beam is directed upwards in oil, a mound of oil is raised on the surface; this is in strong vibration, and this vibration can be communicated to liquids in test-tubes. The air dissolved in these liquids is liberated in bubbles. Calorific effects are easy to obtain.

2957

Hubbard, J. C., "Brief Survey of Supersonics," J. Acoust. Soc. Am., 4, 99-107, 1932.

A survey and bibliography of work on the various aspects of supersonic vibrations.

2958

Itterbeek, A. V., "Measurements with Ordinary Sound and Ultrasonics Carried Out in the Physical Laboratory of the University of Louvain," J. Acoust. Soc. Am., 29, 584-587, 1957.

This paper contains brief résumés of some of the acoustical research carried on at the University of Louvain during the year 1955-1956. Descriptions of apparatus and methods, and some interpretation of the results are given. Two different acoustical interferometers are described and illustrated. Their use for measuring sound speeds in various gases and for measuring extremely low temperatures is explained.

2959

Kittel, C., "Ultrasonic Research and the Properties of Matter," Repts. Progr. Phys., 11, 205-247, 1946-1947.

The theoretical treatment of the propagation of sound waves in gases, liquids, and solids is given and the expressions for the velocity of sound are derived. The theory of absorption in gases and liquids due to heat conduction, viscosity, and thermal relaxation is given. Reference is also made to absorption in solids caused by thermoelastic relaxation, scattering, plastic flow, thermal conductivity, structural relaxation, anharmonic coupling, and magnetic effects. A comprehensive review of the present status of measurements made on gases, liquids, and solids is given. The development of electronic pulsed-circuit techniques in the 1-30 mcs range is described, and the possibilities of extending the upper frequency limit are discussed. The use of ultrasonics in conjunction with radar is mentioned, together with recent industrial applications. A section on propagation in liquid He is included. Over 200 references are quoted.

2960

Klein, S., "Strong Demodulation in Air of Two Ultrasounds of Different Frequencies" (in French), Ann. Telecommun., 9, 21-23, 1954.

Two ultrasonic sound sources are situated 10 cm apart and facing each other. The frequency of audible sound is exactly the difference betwen the two ultrasonic frequencies. The intervening space is analyzed and it is shown that the audible sound arises at the nodes and antinodes of pressure of the ultrasonic stationary wave system. To obtain reproduction of music and speech two systems are indicated, one utilizing frequency and amplitude modulation, and the other, only frequency modulation. Circuit diagrams are given.

2961

Kolb, J., "New Developments in the Physics and Applications of Ultrasound," Acta Phys. Austriaca, 13, 234-261, 1960.

The paper deals briefly with recent progress in ultrasound. Reference is made to magnetostrictive transducers—nickel, useful up to 100 kcs, aluminum-iron alloys up to about 300 kcs, metallic oxides (NiO, CoO, FeO and Fe_2O_3)—and piezoelectric transducers—various forms of ceramic vibrators (barium titanate, clevite, zirconates, etc.) for still higher frequencies. Methods of producing extremely high ultrasonic frequencies (0.1-1 kmcs) using quartz vibrators are mentioned, and methods of display and measurement are discussed. The implications of ultrasonics in physics are considered particularly with reference to the velocity and attenuation characteristics of materials as a function of frequency, and to ultrasonic research at very low temperatures. In conclusion, the paper has a section dealing with the technical applications of ultrasonics (e.g. ultrasonic cleaning, generation of large amplitude vibrations by means of a $BaTiO_3$ transducer on a brass cone, ultrasonic drilling tools, ultrasonic soldering irons, etc.). Also described is an ultrasonic vibrator for the measurement of magnetic flux and flux-gradient.

2962

Kubanskiy, P. N., "Coagulating Mechanism of Acoustic Current" (in Russian), Zhur. Tekhn. Fiz., 24, 1049-1054, 1954.

The coagulating effect is not due only to the Bernoulli force and radiation pressure, but also to the acoustic current; i.e., Rayleigh's vortex circulation due to viscosity. Experiments are described to confirm the theoretical calculations.

2963

McConnell, R. A., "Analyzing Ultrasonic Pulses by the Split Reflector Method," J. Acoust. Soc. Am., 26, 563-565, 1954.

Frequency modulation within a carrier frequency pulse in the sonic microwave region is measured in this paper by comparing any span of several carrier cycles with every other such span along the length of the pulse. The method is especially suitable for modulation in the range between 0.1 and 5 percent.

2964

Merkulov, L. G., "Design of Ultrasonic Concentrations," Soviet Phys. Acoust., English Transl., 3, 246-255, 1958.

The horns considered are of conical, exponential and catenoidal form. Equations are derived for the calculation of their resonance dimensions and amplification coefficients. The internal volume of the horn is treated as a longitudinally vibrating rod of variable cross section, and the wavefront is assumed to remain plane during its passage through the horn. Intensity is also assumed to be uniform over the wavefront. For a trumpet long compared with its diameter these assumptions are shown to be valid enough; a catenoidal tube gives the greatest amplification. Experimental tests agree well with theory.

2965

Murty, J. S., "Theoretical Investigation on the Diffraction of Light by Superposed Ultrasonic Waves," J. Acoust. Soc. Am., 26, 970-974, 1954.

An analytical treatment for the calculation of intensities of diffraction orders in a general case of superposed sound waves of frequencies in the ratio of 1:n and having any phase difference Δ is given, proceeding from Raman and Nath's simplified theory for normal incidence. Because of the integral harmonic relationship between the frequencies of the sound waves superposed, a particular order may contain a number of combination ones in addition to the orders due to the individual sound waves. Fues theory, which gives a single expression for the intensity of a combination line, cannot be applied to this case.

Expressions are obtained for the intensities of the diffraction orders in the two specific cases of even and odd values of n. In the case of diffraction by two sound waves of frequencies of the ratio 1:2k + 1, expressions for the intensities of the orders suggest symmetry in diffraction for all values of Δ. But, when the superposed frequencies are in the ratio 1:2k, the expressions suggest asymmetry in diffraction for all values of $\lambda\Delta$, except $\pi/2$. When $\Delta = \pi/2$, the diffraction is, however, symmetrical.

By using the expressions, the intensities of the diffraction orders obtained by two sound waves of frequencies in the ratio 1:3 superposed in three different phases, 0, $\pi/2$, and π, are calculated for the values of $\nu_1 = 1$ and $\nu_3 = 1, 2,$ and 3.

2966

Neppiras, E. A., "Very High Energy Ultrasonics," Brit. J. Appl. Phys., 11, 143-150, 1960.

The field of high power ultrasonics covers the power region where irreversible changes can be produced in the medium. The more important effects and uses of high energy ultrasonics are listed in tabular form. The field is very large; useful applications now touch almost every industry. Approximate figures are quoted for the order of the ultrasonic intensity required in the various applications. In gases and liquids the intensities obtainable are severely limited. In liquids this limit is fixed by cavitation, which sets in at a rather low level. Cavitation can be avoided by pressurization, and then very high energies can be transmitted. But this is inconvenient and seldom used in practice. The field of very high energy ultrasonics is therefore practically confined to solids, as indicated in the table.

2967

O'Neil, H. T., "Theory of Focusing Radiators," J. Acoust. Soc. Am., 21, 516-526, 1949.

An approximate theory has been derived describing part of the sound field from a concave spherical radiator, vibrating with normal velocity; the radius a of the circular boundary is assumed to be large relative to the wave-length and large relative to the depth of the concave surface. The theory describes the distribution of pressure, particle velocity, and intensity along the axis of symmetry and in the vicinity of the focal plane, perpendicular to the axis at the center of curvature. It is shown that the ratio of the intensity at the center of curvature to the average intensity at the radiating surface is nearly equal to $(2\pi h/\lambda)^2$ where h is the depth of the concave surface and λ is the wave-length. This ratio can be made very large by suitable choice of dimensions, and the focusing is then very sharp. The point of greatest intensity is not at the center of curvature but approaches it with increasing $kh = 2\pi h/\lambda$, and the greatest intensity is not much greater than the intensity at the center of curvature except when kh is small. In the central part of the focal plane, at angle Θ from the axis, the pressure is approximately proportional to $(2/ka \sin \Theta)J_\ell(ka \sin \Theta)$, which is equivalent to the directivity function of a flat circular piston of radius a, for the region at large distance from the piston.

The calculations are in reasonable agreement with G. W. Willard's experimental data for a 5-mc concave quartz crystal, when allowance is made for the non-uniform normal velocity of the crystal.

2968

Pierce, G. W., and A. Noyes, Jr., "Transmission of Sound over Reflecting Surfaces," J. Acoust. Soc. Am., 9, 193-204, 1937.

The paper presents an experimental and theoretical discussion of acoustic signalling between a sending station and a receiving station near a plane reflecting surface, and is applicable to foghorn and submarine signalling. The experiments were made with a small-scale apparatus employing supersonic waves of a frequency of 67.5 kcs. It is shown that at grazing incidence the direct and reflected waves cancel, or partially cancel, as predicted by theory. The cancellation for propagation in air near a water surface, or near another surface of high sound velocity and high density, is found to be restricted to angles very near to grazing incidence.

On the other hand, theory predicts cancellation for much larger departures from grazing incidence if the reflecting surface has high density but low velocity; experimental curves for transmission over beach sand and certain other substances resemble such theoretical results very closely. Acoustic mirages caused by temperature gradients were studied experimentally, and their effects are shown to be of striking importance in modifying the above results.

2969

Richards, W. T., "Recent Progress in Supersonics," J. Appl. Phys., 9, 298-306, 1938.

The development of supersonics during the last five years is reviewed in both its theoretical and experimental aspects, and suggestions for future investigations are made. The review includes discussions of the propagation of supersonic sound in gases, liquids, and solids, the dispersion and absorption in polyatomic gases, and the effects of intense sonic and supersonic radiation.

2970

Richardson, E. G., "Recent Developments in Ultrasonics," Sci. Prog.,43, 605-615, 1955.

An account of academic researches. In gases, trains of waves are investigated with an ultrasonic interferometer. The difference of behavior of shock waves in air and carbon dioxide is shown. Liquids and solids are also considered.

2971

Saby, J. S., and H. A. Thorpe, "Ultrasonic Ambient Noise in Tropical Jungles," J. Acoust. Soc. Am., 18, 271-273, 1946.

A description of equipment, experimental procedure, and data obtained on field trips into the jungles of Panama. The acoustic intensity level of ambient, jungle background noise was monitored and measured for 24-hour periods. Data is reported on an intensity-per-cycle basis (db above 10^{-16} watts per cm^2) for the frequency range of 8-25 kc, and on a broad band basis for the two regions 0-10 kc and 15-25 kc. The band from 0-10 kc varies in intensity from about 50 to 60 db with a slight broad peak at nightfall. The region from 15-25 kc is at a much lower average intensity level, but with a peak rising to 45 to 55 db at nightfall. Observations and analysis of data indicate that most of the ultrasonic noise was made by insects.

2972

Seidl, F., "Special Properties and Effects of Ultrasonics," Phys. Blätt. (Germany), 18, 5, 207-215, 1962.

A nonmathematical résumé of basic facts. This introduction briefly treats some principles of production of ultrasound, optical experiments to make ultrasonic beams visible (with photographs), properties of ultrasound in liquids, and applications, primarily in the field of testing.

2973

Sette, D., "Ultrasonic Lenses of Plastic Materials," J. Acoust. Soc. Am., 21, 375-381, 1949.

The properties of certain plastic substances have been examined with the idea of using them to construct solid lenses for focussing ultrasonic radiation. Some experiments are described which illustrate the advantages offered by such lenses. The use of a plano-cylindrical lens permits a reduction to 1/10, and the use of a plano-spherical lens permits a reduction to 1/100 of the energy which must be emitted by a quartz crystal to produce a given intensity of ultrasonic radiation over a given region.

2974

Slaymaker, F. H., and W. F. Meeker, "Blind Guidance by Ultrasonics," Electronics, 21, 76-80, 1948.

The limitations due to different reflection characteristics of various surfaces and objects and to fluctuations in reflection, when a portable "radar" system is employed, are discussed. Simple pulse, simple FM and pulsed-FM systems, all embodying separate transmitting and receiving magnetostriction transducers, are compared. The latter, which employs an ultrasonic oscillator with sawtooth variation of frequency but has narrow-band transducers, is considered the best because it introduces no contradictory information and permits some distinction between objects at different points. One model, operating at 32 kcs with 10 valves, mainly of the subminiature type, for transmitter and receiver and using headphones, enables the presence of a person to be detected at 30 feet. Later equipment is also described.

2975

Strother, G. K., "Note on the Possible Use of Ultrasonic Pulse Compression by Bats," J. Acoust. Soc. Am., 33, 696-697, 1961.

The analogy between echo-location techniques used by bats and those used by radar is extended to the relatively new pulse compression radar technique. The hypothesis that the hearing mechanism of the bat contains a frequency-dependent time-delay network permits explanation of most of the anomalies associated with their behavior, including echo location by pulses which overlap in space.

2976

Vigoureux, P., "Ultrasonics," Chapman and Hall, London, 163 pp., 1950.

The technique of generating and receiving ultrasonic waves is introduced, but the discussion is restricted to general principles without details of apparatus and experimental procedure. A simplified theoretical treatment is given of the propagation of ultrasound in liquids; the effects of viscosity, thermal conduction, and scattering are described. Methods of measuring velocity and absorption are discussed, most attention being paid to the interferometer, optical-diffraction, and echo-pulse methods. The more important experiments made on liquids and gases by many experimenters during the past decade are described. Concerning common gases, it is concluded that, apart from heat conduction and viscosity, absorption arises largely from delay in attaining equilibrium between the translational, rotational, and vibrational energies of molecules; the equilibrium between the first pair is rapidly attained, so that vibration accounts for most of the absorption. The relaxation times of gases are not predictable, and can be determined only by investigating absorption peaks by ultrasonic techniques. The causes of absorption by liquids are not well understood, probably because the relaxation times are so short that sufficiently high test frequencies are not yet available. Apart from the references cited in the text, the bibliography is confined to papers published since Bergmann's book in 1937.

Ultrasonics, General and/or Unclassified
See Also—16, 134, 173, 513, 536, 547, 548, 560, 569, 578, 615, 828, 893, 894, 962, 1277, 1392, 1398, 1400, 2181, 2185, 2272, 2533, 2797, 4398, 4399

VELOCITY, SHOCK WAVE

2977

Berger, J., Th. Camion, and Ch. Perennes, "Theoretical Study of the Wave-Front Profile and of the Detonation Speed of Cylindrical Cartridges with Solid Explosive" (in French), Compt. Rend., 247, 1433-1436, 1958.

This theoretical study of the wavefront profile and of the detonation speed of cylinderical cartridges with solid explosive begins with a recall of the experimental results obtained by means of a revolving-drum camera. Studies of the outflow of the detonation products and the variations of the detonation speed with regard to the confinement that makes it possible to define the normal component of wave-speed. This study establishes a narrow connection between the front curvature, the wave-speed, and the hydrodynamic laws of the detonation products release.

2978

Birk, M., A. Erez, Y. Manheimer, and G. Nahmani, "The Electrical Conductivity of Shock- and Detonation-Waves, and the Measurement of the Velocity of the Waves" (in French), Compt. Rend., 238, 654-655, 1954.

When a detonation wave traverses an explosive it creates a very high density zone of ions; this is utilized to close an electrical circuit and indicate the passage of the detonation wavefront; a similar phenomenon characterizes aerial shock waves sufficiently powerful to generate a density of ions sufficient to permit electrical conduction. The part played by the surface of the electrodes and the intensity of the shock wave in the conduction has been studied by placing electrodes either in or near the explosive, and measuring the electrical conductivity by an oscillograph. It is considered that the fact that, in the explosive, the current intensity is a linear function of the p.d. justifies the introduction of the notion of an "ionization resistance." An increase of the electrode surface causes a decrease of this resistance, and a closer approach of the electrodes causes an increase of the current intensity.

Shock waves in air give analogous results, but the current intensity decreases rapidly with increase of distance from the charge. The relation between current intensity and p.d. is approximately linear. The "ionization resistance" is an exponential function of the distance from the charge. The velocities of shock waves in air have been measured by increasing the electrical conductivity in two ways; viz., by placing a reflector behind the probe and so increasing the pressure and temperature, and by enveloping the probe in about 50 mg of lead nitride that detonates immediately on arrival of the shock front. The second technique is the more effective, and by its aid the arrival of shock waves has been determined in air for values of the pressure up to $p/p_0 = 20$. The measurement of velocities has been achieved by the use of a spiral brush, whereby the spot is extinguished on passage of the shock wave by each probe.

2979

Birk, M., A. Erez, Y. Manheimer, and G. Nahmani, "On Electrical Conductivity in Detonation and Shock Waves, and the Measurement of Detonation and Shock Velocities," Bull. Res. Council Israel, 3, 398-413, 1954.

The electrical conductivity between two electrodes on the explosive or in the air close to it is investigated with a view to obtaining data pertaining to the design of probes. The conductivity between two electrodes on an explosive charge as well as the detonation and shock velocities were measured. Theoretically, relations are derived for the electron velocity and the current density; it is deduced that the gas in the detonation zone cannot be in a state of equilibrium.

Describes the apparatus used and the electronic circuit, and mentions a few applications.

2980

Bohn, J. L., F. H. Nadig, T. Korneff, and M. L. Harbold, "Investigation of Velocity and Attenuation of Shock and Acoustic Waves at Low Pressure, Development of Sensitive Total Radiation Detectors, Negative Point Corona Discharge and Exploding Wires," Final Rept., Physics Dept., Temple Univ., 138 pp., 1956.
AD-134 938.

Results are given for the velocity of shock waves under various conditions of ambient pressure and ambient temperature, and for various energies put into the exploding wire that was the source of the shock waves. Information is also given on several phenomena associated with the explosion of wires, and apparatus for multiple high speed photography, negative point-to-plane corona discharges, and experiments on total radiation detection using capacitor microphones.

2981

Camm, J. C., and P. H. Rose, "Electric Shock Tube for High Velocity Simulation," Res. Rept. No. 136, AVCO Everett Research Lab., Mass., 61 pp., 1960.
AD-282 729.

Shock tubes were developed capable of producing a gas sample of known conditions at velocities as high as 43,000 ft/sec. The driver of these shock tubes employs a capacitor bank which discharges electrical energy into helium, heating the helium to temperatures of 10,000-20,000°K, and raising the pressure to 10,000-20,000 psi. The high pressure bursts the scribed diaphragm and the resulting shock wave propagates into the test gas.

Extensive diagnostic techniques were employed in the resulting hot gas samples. The growth of these samples was observed optically, and correlations were achieved with theoretical calculations. The observed radiation was compared with and can be used to extend the known radiative properties of high-temperature air. Time-resolved luminous pictures and spectra were also taken to show the purity of the test gas.

The speed and attenuation of the shcok front were measured. The observed operation of this shock tube was compared to theoretical predictions, and although no precise correlation can be made, the driver-gas energy transfer and losses in the shock-tube boundary layer can be accounted for.

2982

Christian, R. H., and F. L. Yarger, "Equation of State of Gases by Shock Wave Measurements, I. Experimental Method and the Hugoniot of Argon," J. Chem. Phys., 23, 2042-2044, 1955.

An experimental method is described for the simultaneous measurement of the velocity of a plane shock through a gas and the associated particle velocity. Shocks are generated by a plate driven by a high-explosive system. The velocities are recorded by a high-speed rotating-mirror smear camera with a precision of about ±1/2%. Data are presented that define the Hugoniot of argon between 200 and 1100 Los Alamos atmospheres. These data are compared with the theoretically predicted Hugoniot.

2983

Deal, W. E., "Shock Hugoniot of Air," J. Appl. Phys., 28, 782-784 1957.

Experiments are described in which an explosive-driven plate sets up a strong shock in the air in contact with the plate. Plate velocity and air shock velocity are measured by means of a high-speed framing camera. A pressure-compression relation results from these measurements through use of the conservation equations of hydrodynamics. The experimental results up to pressures of 200 bars are compared to a calculated relation.

2984

Doring, W., "The Velocity and Structure of Very Strong Shock Waves in Gases" (in German), Ann. Physik, 5, 133-150, 1949.

Theoretical. If p_1 and p_2 are the pressures on either side of a one-dimensional shock wave in a homogeneous gas initially at rest, and ρ_1, ρ_2 the corresponding gas densities, the ratios p_2/p_1 and ρ_2/ρ_1 are related by the Hugoniot equation. For a diatomic molecule in which only translational and rotational degrees of freedom are excited, ρ_2/ρ_1 at first increases approximately linearly as p_2/p_1 increases from unity, tending to a constant value as $p_2/p_1 \to \infty$ ($\rho_2/\rho_1 \to 6$ if $\gamma = 1.4$).

In very strong shock waves, very high temperatures are attained, oscillational degrees of freedom are excited, and dissociation and even ionization may occur. The effect of these factors on the Hugoniot relation is discussed qualitatively in general, and the example of N_2 is worked out quantitatively in detail; in this case, ρ_2/ρ_1 rises to a maximum value of 10 to 20 for $p_2/p_1 \simeq 500$, and falls stepwise to approximately 7 as $p_2/p_1 \to \infty$.

Because dissociation and ionization are processes requiring a fairly large number of collisions, they do not occur at the shock front, but some little distance behind it. It is therefore to be expected that the temperature in an intense shock wave will be a maximum near the front of the shock, and will fall rapidly behind it as energy is absorbed in dissociation and ionization. This may explain experimental observation of a very narrow zone of high luminosity near the front of an intense shock wave.

2985

Duff, R. E., "The Use of Real Gases in a Shock Tube and Appendixes," Rept. No. 51-53, Eng. Res. Inst., Univ. of Mich., Ann Arbor, 136 pp., 1951.
ATI-98 954.

Reports progress in the research and development work on the use of real gases in a shock tube. The strongest shock wave that can be produced by a given initial pressure ratio across the diaphragm of a shock tube may be obtained by using hydrogen in the compression chamber. Expressions for the flow velocity produced by a rarefaction wave in a gas with temperature-dependent specific heat and in a van der Waals' gas were derived. It was shown that both of these departures from the ideal conditions assumed in the derivation of the Taub equation are negligible for hydrogen. They might be important, however, if a polyatomic gas were used in the compression chamber for a special investigation.

2986

Ericsson, U., "Explosive Shock Travel Times at Different Ambient Densities," Appl. Sci. Res. A, 5, 309-320, 1955.

An extension by dimensional analysis of the scaling law of explosives to include ambient air density and temperature is made and tested on photographic travel-time measurements of luminous and nonluminous shocks from TNT spheres in rarefied air. The initial shock velocity is found to be in approximate agreement with hydrodynamic calculations.

2987

Faulders, C. R., "The Speed of Propagation of a Magneto-Dynamically Driven Shock Wave" (in French), Compt. Rend., 254, 3490-3492, 1962.

The paper presents experimental results relating to the spatial variation of shock speed with distance travelled for a shock wave generated in a conventional electromagnetically driven shock tube. A simple, reasonably accurate theoretical explanation is given, using the normal shock relations together with equating magnetic forces caused by current flow to hydrodynamic pressure forces for a perfectly conducting gas.

2988

Glass, I. I., and W. A. Martin, "Experimental and Theoretical Aspects of Shock-Wave Attenuation," J. Appl. Phys., 26, 113-120, 1955.

Experimental results are presented of shock wave and contact-front velocity measurements in air, obtained in a 3-in.-×-3-in. wave interaction tube. A diaphragm pressure ratio range up to 10,000 was employed, while the distance was varied simultaneously from the origin to 142 in. beyond. It is shown that when shock-wave attenuation occurs, it consists of two portions: (a) a decrement due to formation, and (b) a further attenuation due to the distance traversed by the shock wave. Concurrently with the attenuation phenomenon, the contact region spreads with time and its front boundary accelerates. The increase in velocity consists of two portions: (a) an increment due to formation, and (b) a further rise in velocity with the distance travelled by the contact front. A satisfactory empirical relation is developed for the total shock-wave attenuation. A Rayleigh-type imcompressible pipe-flow analysis applied to the experimental results overestimates the attenuation for stronger shock waves.

2989

Guienne, P., and F. Bouniol, "Determination of the Velocity Field Behind a Detached Shock Wave" (in French), Compt. Rend., 243, 1479-1482, 1956.

It is considered that flow lines and Mach numbers characterizing the flow behind a detached shock wave, in the two-dimensional, supersonic flow of perfect fluid can be specified in terms of a single factor; namely, the specific mass, ρ, is determined, e.g., by interferometry. The theory of the subject is developed and illustrated by graphs derived from a practical interferometric example. The possible error is considered to be ± 0.015 in Mach number and $\pm 0.4^{\circ}$ in the direction of the velocity.

2990

Herpin, A., "On the Reflection of Shock Waves" (in French), Compt. Rend., 223, 276-278, 1946.

Formulae are given for the pressure of the gas after the passage of the wave, and for the velocity of propagation of the wave, assumed to be plane and moving in a cylindrical tube. Similar formulae are given for the reflected wave, and some numerical values are given for the ratios of the pressures, densities, and velocities of the wave and its reflection.

2991

Hey, J. S., J. T. Pinson, and P. G. Smith, "A Radio Method of Determining the Velocity of a Shock Wave," Nature, 179, 1184-1185, 1957.

A virtually continuous record of velocity relative to distance along the tube is obtained by measuring the change of frequency, due to Doppler effect, of radiowaves reflected from the shock front.

A dipole at the downstream end of the tube is used to transmit and receive at a frequency such that the reflection coefficient is increased by ionization in the following flow. A typical frequency for shock Mach numbers exceeding six in argon is 5000 Mcs. A directly calibrated oscillographic display is used.

2992

Hoenig, S.A., "Acceleration of Dust Particles by Shock Waves," J. Appl. Phys., 28, 1218-1219, 1957.

A particle is accelerated when it encounters a shock wave. The drag force is calculated and used to determine the time in which the particle attains a certain fraction of the shock-wave velocity. Integration gives the distance travelled in this time.

2993

Johansson, C. H., "The Influence of Velocity in Adiabatic Compression," Paper No. 37, Arkiv Mat. Astron. Fysik, 34A, 14 pp. 1948.

The adiabatic equation for a perfect equation for a perfect gas leads to erroneous results in rapid compression, as in detonation, and here the Hugoniot adiabatic must be used. This is due to the formation of a discontinuous wavefront that has an important influence. The problem is investigated mathematically, and the range of validity of the two forms of adiabatic relationship is examined. It is concluded that the usual equation may be used without noticeable error in all applications to the compression of a gas in a cylinder, provided the piston velocity is small compared with that of sound, but even in applications where wavefront velocities lower than those encountered in detonation are involved, serious error may be caused.

2994

Klein, E., "Air Shock Wave Velocities over Water," J. Acoust. Soc. Am., 21, 109-115, 1949.

A procedure was devised for determining the air blast pressures of the A-bomb at Bikini. In such a disturbance the air particles move with large and finite amplitudes; hence the propagated waves do not obey the ordinary laws of acoustics. By measuring the ratio of the air shock wave velocity to normal acoustic velocity, an indication may be obtained as to the peak pressure of the explosion. Blast waves in water, on the other hand, follow substantially the familiar acoustic laws and are propagated at a well-known velocity. Measurements of transit times made at identical positions for the air and for the water blast waves immediately yielded the desired air blast velocity in terms of the known velocity of sound in water. This procedure eliminated the need for simultaneous measurement of the continually shifting distances between buoys which carried observational equipment. However, careful positioning of the buoys was necessary in order to avoid their destruction and yet record the maximum possible air blast. These positions were calculated on the basis of an equivalent explosion from 20,000 tons of TNT. Since the measurements had to be made automatically and without human observers, special timing and recording systems were provided. All requirements for gathering the data were successfully met in the assembly of apparatus described herein.

2995

Knight, H. T., and R. E. Duff, "Precision Measurement of Detonation and Strong Shock Velocity in Gases," Rev. Sci. Instr., 26, 257-260, 1955.

Describes a simple system for determining the detonation velocity of strong shock waves, with temperatures above 3000°K, by using the conductivity behind the wave. Wave contact is made by two 0.036-in. wires set 0.1 in. apart in a Teflon plug mounted in the experimental tube. When a wave passes, signals are produced across a 30kΩ resistor in series with these wires, and a 0.001μf capacitor charged to 300 volts. Any number of circuits may be paralleled across a single-signal resistor if a diode is added to each circuit to prevent signal deterioration. The arrival time of a wave at a pin can be determined, with an accuracy of almost 10^{-8} seconds, from an oscilloscope record of the signals. The principal advantages of this system are excellent space resolution and very simple basic circuitry.

An amplifier is described which can be used with an individual pin circuit to fire a thyratron and extend the range of applicability of the system to waves with temperatures as low as 1000°K.

2996

Koch, B., "Reflection of Microwaves by Explosion Phenomena" (in French), Compt. Rend., 236, 661-663, 1953.

By using the Doppler-Fizeau effect, it is possible to detect the echoes of an electromagnetic wave from the explosive wave front. This method also makes possible to measure the speed of the explosive wave and the ionization of the gases in the explosion. A table gives seven experimental values of speeds thus determined, showing an average of 7994 ± 47 m/sec or ±0.6%.

2997

Lee, J. D., and R. M. Nerem, "Theory and Performance of a Shock Tube Having an Arc-Heated Driver," Aerodynamic Lab., Ohio State Univ. Research Foundation, Columbus, 29 pp., 1962.
AD-277 192.

The pertinent design features, theory of operation, and some initial results are described for a shock tube which utilizes an arc-discharge in the high-pressure driving chamber. The tube has a diameter of four inches, with a 16-inch long driver and a 35-foot driven section. Power stored in a 6000-volt, 200,000-joule capacitor bank is discharged across coaxial electrodes in the pre-pressurized driver chamber. The arrangement is analyzed by assuming perfect gas parameters to obtain driven shock Mach numbers as a function of initial pressures and energy of discharge. Both air and helium are used in the driver while air alone is used in the driven section. Shock Mach numbers up to 33 have been obtained to date. Wave speed is measured through the use of ionization gauges, and pressure by piezo-electric pickups.

2998

Lyon, D. A., "Some Geometry Associated with the Photographic Determination of Shock Front Velocity, I. Calculation of Shock Front Radius, II. A Method of Camera-Projector Calibration along a Single Image Line," Suffield Tech. Note No. 62, Suffield Experimental Station (Canada), 18 pp., 1962.
AD-282 635.

Formulae are developed for calculating the radius of shock fronts created by chemical explosions and measured photo-optically, under the assumption that the fronts are spherical. A method is described for simultaneously calculating the shock front radius and calibrating the total optical system, both along the direction of a marker line and both from a single photo frame. No data are included.

2999

Mitalas, R., and R. B. Harvey, "Peak Pressures from Distance/Time Data of an Expanding Spherical Shock Wave," Rept. No. IR-383-58, Suffield Experimental Station, Canada, 14 pp., 1958.
AD-204 209.

Given free-air radius versus time measurements of an expanding spherical shock wave, it is required to obtain the overpressures at the shock front at any distance within the radial limits of the measurements. The approach used is to fit an arbitrary equation to the data and then by differentiation to determine shock velocity as a function of distance or time. Overpressure is then easily determined.

3000

Muirhead, J. C., "Measurement of Air Velocities in the Shock Tube, I. From the Velocities of Rarefaction Waves," Rept. No. TL 88-59, Suffield Experimental Station, Canada, 13 pp., 1958.
AD-206 207.

The velocity of the moving air contained within weak plane shock waves has been determined from the velocities of forward and backward facing rarefaction waves passing through the shock waves. The results indicate air velocities greater than those predicted by the theory of Glass, Martin, and Patterson (AD-28 499), but are in qualitative agreement with the predictions of Trimpi and Cohen.

3001

Muirhead, J. C., D. W. Lecuyer, and F. L. McCallum, "A Method for the Observation of Air Movement in Shock Tube Flows Using Smoke Streams as Tracers," Rept. No. TL 32-59, Suffield Experimental Station, Canada, 7 pp., 1959.
AD-212 069.

A description is given of a method of producing stable and discrete streams of smoke in a shock tube, and of their use as tracers for the moving air contained within shock waves. Experimental measurements of air velocity and density show excellent agreement with those values predicted by theory, indicating that the smoke streams act as accurate and reliable tracers for the moving air. This method is applicable to studies in and about models as well as to undisturbed shock tube flows.

3002

Oliver, R. M., "Travel Times Through Shock Waves," Res. Rept. No. 17, Operations Res. Center, Univ. of Calif., Berkeley, 14 pp., 1962.
AD-283 782.

Two equations to relate velocity, density, flow rate, and travel time in a traffic stream are used. One is the familiar equation of continuity, the second is an integral equation expressing the conservation of fluid in terms of travel times in the fluid. A situation is investigated where rates of time-dependent flow into a bottleneck temporarily exceed its capacity. Expressions are found for queue sizes, the location and velocity of shock waves, and delays to travellers in the stream.

3003

Pugh, E. R., "Studies of the Phenomena Occurring in an Electromagnetic Shock Tube," Cornell Univ., Graduate School of Aeronautical Engineering, Ithaca, N. Y., 68 pp., 1962.
AD-276 650.

An electromagnetic shock tube was constructed, and the observed phenomena were explained assuming that the energy transferred to the driver section is stored in the form of magnetic energy. The velocity of the shock front and its rate of decay were measured and compared with theoretical predictions based upon the equations for infinite-conductivity magnetohydrodynamic flow. A Kerr-cell shutter camera was used to photograph the shock fronts, which were found to be jumbled, suggesting magnetic turbulence. A magnetic field was applied along the axis of the shock tube and its effect on the shock velocity and on the character of the shock front were explained by the interaction of the driver currents with the applied axial magnetic field.

A precursor wave was observed, and the gas velocity behind it was measured using the boundary layer on a probe placed along the axis of the shock tube. This value of the gas velocity and measured values of the wave velocity, gas density, and electric field strength are shown to be compatible with a wave-type mechanism.

3004

Savitt, J., and R. H. F. Stresau, "Velocity Attenuation of Explosive-Produced Air Shocks," J. Appl. Phys., 25, 89-91, 1954.

Describes a method for measuring the velocities of explosively produced air shocks using an electrical ionization probing system. The results of such measurements indicate that under varying conditions of confinement of explosive and air shock, the reciprocal of the air shock velocity varies linearly with the distance to the charge surface.

3005

Selberg, H. L., "The Dependence of the Detonation Velocity on the Shape of the Front," Paper 26, K. Norske Vidensk. Selsk. Forhandl. (Norway), 34, 124-128, 1962.

The author considers the initial development of a detonation front when the surface of initiation is of arbitrary shape. The analysis suggests that if the sum of the principal curvatures of the front is positive then the detonation speed increases with time, while if the sum is zero or negative the detonation speed remains equal to the Chapman-Jouguet value.

3006

Sichel, M., "The Calculation of Velocity and Temperature Profiles Through a Weak Normal Shock with an Expansion in Powers of a Shock Strength Parameter," Rept. 488, James Forrestal Research Center, Princeton Univ., N. J., 1959.
AD-233 800.

A series expansion in powers of shock strength was used to solve the Navier-Stokes equations for the velocity and temperature profiles of weak shock waves ($M_1 \leq 2$). This series, when compared with exact analytical solutions, was found to adequately predict the effects of variable Prandtl number and of variable viscosity. The velocity and temperature are expressed directly as functions of position and shock strength. Also discussed are the effects of the Prandtl number and the viscosity-temperature relation on the expansion coefficients. The shock is assumed to occur in a perfect gas with constant specific heats.

3007

Stoner, R. G., and W. Bleakney, "The Attenuation of Spherical Shock Waves in Air," J. Appl. Phys., 19, 670-678, 1948.

The peak pressure of the waves from small explosive charges was determined as a function of distance by measuring the velocity of propagation and applying the velocity-pressure relation derived from the Rankine-Hugoniot equations. The pressure-distance relations for the four principle charge types are given. The curve for spherical charges agrees with the Kirkwood theory, and the results for cylinders having various length diameter ratios indicate large dependence of pressure on charge shape.

3008

Thompson, L., and N. Riffolt, "Propagation of Shock Waves in Air. Part I"; Thompson, L., "____, Part II," J. Acoust. Soc. Am., 11, 233-254, 1938-1939.

From a consideration of conditions at the boundary of a source of shock in air, and of conditions at great distances, a formula of the Riemann type has been derived for the velocity of propagation of a finite pulse. The formula includes an additional constant, which provides the necessary flexibility to represent data obtained throughout the fields of sources consisting of detonating charges of explosives, and of other sources. The observations of wave displacements have been summarized in terms of an integral for reduced times, from which the constants of the function for velocity are immediately available. All distances are defined with reference to an equilavent dimension of the source, and the characteristics throughout the velocity field are obtainable from the characteristics of the source.

A table is given for the velocity of a condensation pulse, for representative boundary velocities, at various distances from the source out to points at which the velocity has decreased approximately to its asymptotic value (the normal velocity of sound). Results obtained by Wolff and Burlot for very large sources are shown for comparison on a plot of reduced times. Preliminary results, obtained with piezogauges, of experiments to determine relative pressures at the head of the wave are given in comparison with theoretical gauge pressures.

In Part II, using the Rankine-Hugoniot equations, formulae are obtained for density and pressure at the head of a shock wave; they are referred to the velocity of the wave as a parameter. Gauge pressures are defined in a form considered to represent the observations of pressure obtained in Part I. The function is used to calibrate the gauge, and a comparison of results by Rayleigh's pressure function is included. A discussion is given of the appropriate ratio of specific heats for condensation cycles as extremely short in duration as those of intense shock waves, with references to the literature bearing on the subject of the accumulation of molecular excitational energies in short intervals of time.

3009

Thornton, J. A., and A. B. Cambel, "The Effect of Radiation on Shock Velocity Attenuation in Electromagnetic Shock Tubes," Rept. No. AFOSR-1101, Northwestern Univ., Evanston, Ill., 55 pp., 1961.
AD-277 360.

Observations are reported in a study of effects of radiation on shock velocity attenuation in the conical electromagnetic shock tube. Included is a summary of findings which have appeared in the literature along with the approximate blast wave theory, which has become the primary method of making theoretical velocity-attenuation calculations. These published observations lead to the question of the effect of radiation on the velocity attenuation in a tube with highly reflective walls such as might be employed in a propulsion system; the approximate blast wave theory is adapted in developing a modified approximate method for calculating this effect. Approximate radiation equations are combined with the velocity-attenuation equations and a study is made of radiation factors which might influence the velocity attenuation. It is concluded that radiation will be an important factor only for strong shocks moving into a dense gas (approximately 1/10 atmosphere or greater, at room temperature).

A description of the electromagnetic shock tube is given, and a discussion of some velocity-attenuation experiments which are being conducted, in which no attenuation due to radiation has been noted. These experiments conducted at low velocities and densities thus agree with the predictions of the approximate blast wave theory modified to account for radiation effects.

3010

Waldron, H. F., "An Experimental Investigation of the Flow Properties Behind Strong Shock Waves in Nitrogen," Rept. No. 50, Inst. of Aerophys., Univ. of Toronto, Canada, 1958.
AD-162 004.

The flow properties behind strong shock waves in N were measured up to an incident shock of M = 13 and compared with calculated theoretical values. The shock-wave velocity, particle velocity, and speed of sound were measured from x-t Schlieren records. The pressure was recorded simultaneously with an S. L. M. quartz crystal gage. A plane contact front travelling at the particle speed was produced by the interaction of the incident shock wave with a perforated steel plate, and a weak spark was discharged in the uniform region between the incident shock wave and the contact front to produce a weak spherical wave from which the sound speed was obtained.

From the measured values of shock wave and particle velocity, the pressure, density, and enthalpy ratios were calculated. From the measured quantities and the theoretical values of the isentropic index, the temperature ratio and flow Mach number were also calculated. Attenuation of a shock wave over a distance of 18 ft from the diaphragm was investigated for an H-O and an H-O-He mixture as a driver gas. Spark ignition at the closed end of the tube, where a detonation wave was formed, produced an attenuation of 3.2% of the incident-shock Mach number per foot. A technique approximating constant volume burning was found to attenuate the shock wave at the rate of 1.3% per ft. Another form of burning the combustible gases, in which the diaphragm-rupturing process caused ignition, resulted in an attenuation of 2.5% per ft. The attenuation of the shock wave when cold H was used was 0.8% per ft.

3011

Wood, W. W., and J. G. Kirkwood, "Diameter Effect In Condensed Explosives, The Relation Between Velocity and Radius of Curvature of the Detonation Wave," J. Chem. Phys., 22, 1920-1924, 1954.

The limiting slope of the detonation velocity-wave front curvature locus for small velocity deficits is obtained under an assumption concerning the "reaction zone length" as related to the charge diameter and the radius of curvature of the wavefront. The model is an extension to two dimensions of von Neumann's classical theory of the plane wave detonation.

3012

Wright, H. V., "A Study of Shock-tube Phenomena," Interim Tech. Rept. No. DR-2, Inst. of Eng. Res., Univ. of Calif., Berkeley, 120 pp., 1957.
AD-201 390.

Among the most basic studies that can be made with the shock tubes are those of shock-front speed, pressure ratios across a shock front, and interaction of different waves—all which phenomena are most easily described by a wave diagram. This paper presents briefly the basic theory underlying the operation of a shock tube and outlines the procedure for the construction of a wave diagram. Wave diagrams are worked out for the specific cases of an open-ended shock tube and a closed-end shock tube, and are subsequently correlated with experimental results.

Velocity, Shock Wave
See Also—441, 927, 1112, 1221, 1226, 1234, 1346, 1790, 1805, 2025, 2037, 2275, 2376, 2827, 3024, 3031, 3079, 3428, 3432, 3434, 3450, 3467, 3474, 3477, 3478, 3479, 3485, 3494, 3495, 3498, 3520, 3521, 3779, 3845, 3868, 4006, 4039, 4082, 4094, 4105, 4125, 4133, 4188, 4219, 4220, 4246, 4253, 4266, 4293, 4300

VELOCITY, SOUND, MEASUREMENT

3013

Abbey, R. L., "The Velocity of Sound in Gases at Low Pressures," Australian J. Sci. Research A, 5, 223-225, 1952.

Previous work has been repeated with improved apparatus. It is found that the velocity of sound measured in a tube at pressures below 20 cm Hg increases rapidly towards low pressures. Increases of the order ten meters per second in the velocity of sound in air are observed below 5 cm Hg, the increase becoming smaller as the frequency increases. The effect on tube correction has been studied.

3014

Abbey, R. L., and G. E. Barlow, "The Velocity of Sound in Gases," Australian J. Sci. Research, A, 1, 176-189, 1948.

Carefully conducted laboratory measurements of sound speed were made in gases at pressures from one atm. down to 5 mm Hg (air, nitrogen, oxygen, carbon dioxide and methane). Theory, instrumentation, tube correction and results discussed and illustrated by diagrams, charts and tables.

3015

Bancroft, D., "Measurement of Velocity of Sound in Gases," Am. J. Phys., 24, 355-358, 1956.

Describes a method for determining the velocity of sound by observing the frequencies of radial oscillation of a gas confined in a spherical cavity. The accuracy appears to be comparable with that of the best methods available to date. A few preliminary results are quoted for argon, oxygen, and CO_2. The possibility of utilizing the measurements for determination of the absolute temperature of the ice point is discussed.

3016

Bate, A. E., "Velocity of Sound in Air Below 0^oC," J. Sci. Instr., 17, 68-69, 1940.

A method suitable for the determination of the velocity of sound at low temperatures is described. The value at -78.5^oC was found to be 283 meters per second.

3017

Caro, D. E., and L. H. Martin, "Velocity of Sound in Air at Low Pressures," Nature, 172, 363-364, 1953.

A significant increase in the velocity of sound has been reported below 15 cm Hg. New experiments are described; after correction, there is no variation of free-space velocity at 1000 and 250 cycles/sec, with pressure down to five mm Hg.

3018

Caro, D. R., and L. H. Martin, "The Velocity of Sound in Air at Low Pressures," Proc. Phys. Soc. (London) B, 66, 760-768, 1953.

Measurements of the velocity of sound in tubes have been made in air over a range of pressures extending down to five mm Hg at frequencies of 250 cps and 1000 cps. The method employed was to measure the time in transit of a sinusoidal pulse between two condenser microphones separated by a distance of approximately four meters. After tube and gas corrections were made it was found that the velocity was independent of pressure between five mm Hg and 760 mm Hg. The mean velocity obtained at 20^oC is 343.40 ± 0.02 meters per sec^{-1} which is in good agreement with the generally accepted value 343.42 ± 0.07 meters per sec^{-1} obtained by Hardy, et al. (1942), for dry air free from carbon dioxide. No evidence was found of the increase in velocity at low pressures observed by Abbey and Barlow (1948) and by Maulard (1949).

3019

Colwell, R. C., A. W. Friend, and D. A. McGraw, "Velocity of Sound," J. Franklin Inst., 251-255, 1939.

The original apparatus has been improved by the use of two microphones connected in parallel, and it is possible to adjust the pulses so that both peaks on the oscillograph screen appear on the same reference line. Determinations were made over a range from 2.5^oC to 29.6^oC. An alternative method has also been devised by which accurate measurements are possible over shorter distances. The sound sources employed were an electrically driven tuning fork and a calibrated audio-oscillator. Wavelengths were measured at frequencies 440, 880, 1000, 1320, and 1760. The velocity at 0^oC was 331.12 m/sec, and the change of velocity with temperatuer 0.60 m/sec/^oC.

3020

Colwell, R. C., A. W. Friend, and D. A. McGraw, "Velocity of Sound in Air," J. Franklin Inst., 225, 579-583, 1938.

A laboratory method. A valve and loudspeaker are worked off mains at 110 v and 60 cps so that each second, 60 short impulses are given to the loudspeaker. The sound impulses are picked up by a microphone, converted, amplified and then observed in a cathode-ray oscilloscope. The position of the microphone near the loudspeaker is adjusted so that the peak pulse falls on a vertical line at the center of the screen, and the position is marked. The microphone is now moved away about 18 feet and again adjusted. The displacement of the microphone is the distance the sound traveled in 1/60 sec. Measurements were made as a test of the method, and the average of 100 measurements, reduced to 0^oC was 331.54 m/sec. The walls of the room need to be covered with absorbing material to avoid echo effects.

3021

Colwell, R. C., A.W. Friend, and L. H. Gibson, "Velocity of Sound," J. Franklin Inst., 230, 749-754, 1940.

A new method for measuring the velocity of sound over short distances has been devised in which 60 pulses per second cause a sinusoidal curve to appear upon an oscilloscopic screen. As the receiving microphone is moved away from the sound oscillator, the crest of the sine curve moves across the oscilloscope, completing the circle in 1/60 sec. The actual velocity of the sound is easily calculated after the distance moved by the microphone has been measured. Application of the probability laws and of the error curve show that the method is very accurate, providing the frequency of the a-c supply is constant at 60 cps.

3022

Colwell, R. C., and L. H. Gibson, "Sound Velocities in Gases Under Different Pressures," J. Acoust. Soc. Am., 12, 436-437, 1940.

With a rapid succession of soundpulses and an oscilloscope it is possible to measure the velocity of sound over short distances. This article reports experiments using a gas-tight metal container enclosing a loudspeaker and a movable microphone. The pulses sent out by the loudspeaker were received by the microphone and translated into a sine wave on the oscillograph. Measurements were made upon air, N, and CO_2 at different pressures. The velocity did not vary with the pressure.

3023

Coulter, G. A., "The Effect of Dust-Laden Air upon a Sound Wave," Ballistic Research Lab., Aberdeen Proving Ground, Md., 1954.
AD-57 555.

A low-frequency sound wave (1300 cps) is propagated through a ten-foot section of three-inch diameter rotating pipe in which dust had previously been introduced. The time of arrival and the shape of the sound wave are recorded at the end of the pipe after the wave has passed through the dust-laden air. As a measure of relative dust density, the voltage output of a photocell looking at a point source of light through the dust-laden air is recorded as a function of time while the pipe is rotating. The travel time is measured with dust in the pipe and is compared to travel time in the absence of dust.

3024

Ginty, G., "Measurement of Sound Velocity in a Shock Tube," Ballistic Research Labs., Aberdeen Proving Ground, Md., 17 pp., 1954.
AD-52 047.

A direct method for the measurement of sound velocity in a shock tube is given, with correlation of results with the sound velocity calculated from simultaneous temperature measurements.

3025

Glass, I. I., "On the Speed of Sound in Gases," J. Aeron. Sci., 19, 286-287, 1952.

The speeds of sound in air, A, and CO_2, are determined by measuring head speed of the rarefaction waves in a shock tube. Results agree well with the values obtained from acoustic methods and from isentropic theory. Experimental arrangement and accuracy of method are briefly described.

3026

Grabau, M., "Velocity of Sound in Air," J. Acoust. Soc. Am., 5, 1-9, 1933.

This study of the velocity of sound in air involves the use of the magnetostriction oscillator in an experiment similar to those of G. W. Pierce and others, who used piezoelectric crystals as sources of sound. The wave system generated by the source is investigated by observing the reactions of the source when the sound waves are reflected back upon it from a movable reflector. The range of frequencies used extends from 20,000 to 70,000. The irregularities of the wave system near the source are studied in some detail. It is found that these irregularities vary with the frequency, as well as with the diameters of both the source and the reflector, and that they vanish at relatively large distances from the source. The values of the velocity of sound then obtained show no variations with respect to the frequency.

3027

Gutenberg, B., "The Velocity of Sound-Waves from Gun-Fire in Southern California," Trans. Am. Geophys. Union, 156, 1938.

Description of a sensitive instrument for recording changes in air pressure. Sound waves recorded by this short period Benioff barograph shown.

3028

Gutenberg, B., "The Velocity of Sound Waves and the Temperature in the Stratosphere in Southern California," Bull. Am. Meteorol. Soc., 20, 192-201, 1939.

Sound waves from gunfire in Southern California, about 33^{o} N lat., show travel times similar to those observed in Europe and Novaya Zemlya. The author concludes that the increase in temperature at 30 to 40 km altitude is approximately the same in these regions.

3029

Hardy, H. C., "Use of the Pierce Interferometer for Measuring the Absorption of Sound in Gases," J. Acoust. Soc. Am., 15, 91-95, 1943.

A rigorous derivation of Pielemeier's empirical equation for the absorption of sound in gases is obtained by making use of the principles of the Pierce ultrasonic interferometer and the quartz oscillator. The Pielemeier method gives a fair approximation when the reaction of the sound wave on the crystal is small; it enables both velocity and absorption to be measured. The limits of precision in its use were tested experimentally and agree with theory.

3030

Hardy, H. C., D. Telfair, and W. H. Pielemeier, "The Velocity of Sound in Air," J. Acoust. Soc. Am., 13, 226-233, 1941.

A rigorous equation is set up for the velocity of sound in gases. This is used to calculate the velocity of sound in dry air at standard conditions from data taken in independent measurements. The result of this calculation is 331.45 ± 0.05 meters per second. An extensive survey of previous reported measurements has been made. After proper corrections are taken into account, the weighted mean is 331.46 ± 0.05 meters per second. The results of very precise interferometer measurements by the authors give 331.44 ± 0.05 meters per second.

3031

Hersch, M., "Determinations of Local and Instantaneous Combustion from Acoustic Measurements in a Rocket Combustor and Comparison with Over-All Performance," NASA Tech. Note. No. D-1192, 21 pp., 1962.
AD-272 617.

Simultaneous local and instantaneous combustion conditions, overall characteristic exhaust velocity efficiencies, and local chamber efficiencies were determined for a 100-lb-thrust gaseous H_2 combustor burning either gaseous or liquid O_2 over an oxidant-fuel ratio (o/f) range of 3.2 to 10.0 at a chamber pressure of 200 lb/sq in. Combustion conditions were determined from measurements of the sound velocity at a single station in the chamber. Combustor performance varied with o/f from about 80 to 100 percent of theoretical for liquid O_2 and was about 92 percent and independent of o/f for gaseous O_2. The results of sound velocity measurements indicated the presence of random fluctuations of composition and temperature of the combustion gases. Losses in performance may therefore have been due to poor mixing and random burning fluctuations.

3032

Hixson, E. L., J. R. Gerhardt, and A. W. Straiton, "A Device for Continuous and Instantaneous Measurement of the Velocity of Sound Over Considerable Distances," Rept. No. 21, Eng. Res. Lab., Texas Univ., 15 pp., 1948.

Describes an instrument developed for measuring sound propagation velocity by introducing impulses created in a speaker and in a microphone into an oscilloscope, and presents schematic drawings. Measurements using a sound pulse frequency of 1000 cps and a repetition rate of 10 cps are reported and their results presented in terms of temperature and wind velocity components.

3033

Keesom, W. H., A. van Itterbeek, and J. A. vanLammeren, "Velocity of Sound in Oxygen Gas," Commun, 216d, Communs, Phys, Lab., Univ. Leiden, 996-1003, 1931.

By a method previously described the velocity of sound in oxygen gas is determined at 0°C and at temperatures between 164.63°K to 77.48°K, and at pressures between 0.1 and 1.0 atm. From the results c_p and c_v and their ratio c_p/c_v are determined. By extrapolation, the value of this ratio at zero pressure is obtained at various temperatures, and is found to be always slightly greater than 1.400. Whether or not this small deviation indicates a departure from classical dynamics cannot, however, be decided at present. If W is the velocity of sound, p the pressure, N, P, Q functions of temperature only, then $W^2 = N(1 + Pp + Qp^2)$. Values of N, P and Q are tabulated. The variation of W with pressure is not so great as in the case of hydrogen. From N is deduced a formula for the temperature variation of the second virial coefficient.

3034

Keesom, W. H., and J. A. van Lammeren, "Velocity of Sound in Nitrogen Gas," Commun. No. 221c, Communs. Kamerlingh Onnes Lab., Univ. Leiden, Proc. 35, 727-736, 1932.

The velocity of sound in nitrogen gas has been measured in the temperature-range extending from 0°C down to liquid nitrogen temperatures, in dependence on the pressure. Four resonators were used to get an idea of the validity of the formula of Kirchhoff-Helmholtz; the results were good. A curve B = f(1/T) (B being the second virial coefficient) has been calculated, holding from 150° down to 80°K. Also, the ratio c_p/c_v and the specific heats c_p and c_v were calculated.

3035

King, F. E., and J. R. Partington, "Velocity of Sound in Air, O_2 and CO_2 at High Temperatures, Temperature Coefficients of Molecular Heat," Phil. Mag., 9, 1020-1026, 1930.

The method and apparatus used for measurements of the velocity of sound in air, O_2 and CO_2 were similar to those previously employed, but the temperatures were higher (900° to 1200°C) except for air, for which measurements up to 1300°C have been given. Tables are given for the velocity of sound in each gas and for the molecular heats of CO_2 and O_2. In all three cases, the velocity increases with temperature. As regards the molecular heats for CO_2 and O_2, both gases show a gradual rise with temperature of C_v and C_p, but the ratio C_p/C_v decreases with increasing temperature.

3036

Kneser, H. O., "True Velocity of Sound in Air," Ann. Physik, 34, 665-668, 1939.

Accurate knowledge of the velocity of sound in air is necessary for many problems of applied acoustics and particularly in the cases of relative velocity measurements where air is used as the substance for comparison. The results of measurements of the velocity of sound in air, using single impulses and low and high frequencies, by Colwell, Friend and McGraw, Kukkamaki, Ladenburg and von Angerer, Hebb, Gruneisen and Merkel, Grabau, Pierce and Kao, are plotted and discussed. Reasons are given for the relatively low values of the velocity obtained by the single-impulse method. It is concluded that a reliable value for the velocity of sound in air at 0°C, the air being dry and free from CO_2, is 331.60 ± 0.05 meters per second. Below 300~ the velocity will be slightly less, owing to dispersion by oxygen, and should be 331.47 meters per second. In moist air this value should be used for frequencies up to about 3000~.

3037

Knotzel, H., and L. Knotzel, "Absorption and Dispersion of Sound in Oxygen" (in German), Ann. Physik, 2, 393-403, 1948.

For the frequency range 0.6-4.5 kcs the velocity of sound in O_2 contained in a tube was determined by comparing the resonant frequencies with those obtained with the tube full of dry air free from CO_2. The tests were made at 19°C and at atmospheric pressure. The resonant frequencies for the range from the fundamental up to the 12th harmonic wave were determined and the bandwidths giving 1/2 maximum amplitude were used to compute the absorption coefficients. Absorptions were measured for pure O_2 and O_2 diluted with small amounts of H_2O vapor or NH_3. Definite relations were established between the frequencies giving maximum absorption and the H_2O and NH_3 contents. The precise dispersion measurements agreed well with the theoretical values based on thermodynamics.

3038

Kukkamaki, T. J., "Velocity of Sound in Air," Ann. Physik, 31, 398-406, 1938.

The velocity of sound was determined from observations made with sound waves that started simultaneously in opposite directions along the same course. The distances chosen varied from 883 to 1319 meters and, of three series of measurements, two were made on land and one on a frozen lake (Lehijarvi) in Southern Finland. The sound was made by setting off one kg of high explosive. From a knowledge of the speed and direction of the wind a correction of the second order was made on each observation, and the final result for the speed of sound in dry, still air at 0°C is given as 330.77 ± 0.064 meters per second. The speed in CO_2-free air is reckoned at 330.79 meters per second. Comparing the above value with previous ones the author concludes that for explosive sounds of frequency less than 1000, the velocity under the given conditions is 330.8; for higher frequencies it is 331.7 meters per second.

3039

Lenihan, J. M. A., "The Velocity of Sound in Air," Acustica, 2, 205-212, 1952.

Measurements have been made of the velocity of sound in free air at a frequency of 13,500 cps. A small loudspeaker, connected to an oscillator, emitted sound which was received by a microphone, after travelling a distance determined by an accurate screw. The input waveform of the transmitter and the output waveform of the receiver were passed through pulse-shaping circuits and displayed together on the screen of a double-beam oscillograph. Movement of the transmitter, controlled by rotation of the screw, produced relative motion of the two traces on the oscillograph screen and the wavelength of the sound was determined by measuring the distance at which the two trains of pulses coincided on the screen. Corrections were applied for the effects of temperature, humidity and a number of less important factors. The final value for the velocity of sound at a frequency of 13,500 cps in dry air at a temperature of 273.16°K and a pressure of 1013.2 mb was 331.45 ± 0.04 meters per second.

3040

Lenihan, J. M. A., "Velocity of Sound in Free Air," Nature, 162, 656-657, 1948.

Describes the method and results of measurement of the velocity of sound in free air at a frequency of 13,500 cps (λ ~1 in). The mean value found for the velocity of sound at this frequency in dry air at a temperature of 273.16°K and pressure 1,013.2 mi, containing 0.03% of CO_2, was 331.45 ± 0.04 meters per second.

3041

Matta, K., and M. Mokhtar, "The Velocity of Sound in Vapors," J. Acoust. Soc. Am., 16, 120-122, 1944.

A form of Kundt's tube is employed in which a hot wire records the amplitude in the stationary-wave system. It is calibrated by the use of dry air and of oxygen. The results agree with those determined by other methods.

3042

Maulard, J., "On the Velocity of Sound in Air at Low Pressures" (in French), Compt. Rend., 229, 25-26, 1949.

It is observed experimentally that below pressures of 15 cm of Hg the velocity of sound in air increases according to an exponential law. The velocity is constant from atmospheric pressure to 15 cm Hg; at ten cm of Hg the velocity is 1.5% higher, and at four cm of Hg it is 4% higher than at atmospheric pressure. The measurements of velocity were made in a steel tube 2,743 cm long and of eight cm internal diameter, buried in the earth at a depth of 50 cm to maintain constant temperature conditions.

3043

Maxwell, H. N., and C. C. Alway, "A Determination of the Speed of Sound in Air," Am. J. Phys., 18, 192-193, 1950.

Velocity of sound in free space is measured by means of a loudspeaker emitting short sound pulses at 1/60-sec intervals, the distance to a microphone being adjusted so that the received sound pulse coincides accurately with a time-marker pulse on a cathode-ray oscillator. The distance between "speaker" and the microphone is then adjusted until the sound pulse coincides with another time-marker pulse. If m is the number of marker pulses passed over, the velocity is found by merely multiplying the distance by $\frac{60}{m}$. The results agree well with the generally accepted value of sound velocity in the open air.

3044

McLoughlin, R. C., and J. R. Chiles, Jr., "A Field Meter for Sound Velocity Measurements," J. Acoust. Soc. Am., 25, 732-734, 1953.

The travel time of sound across a fixed gap between diaphragms of transmitting and receiving transducers is recorded each 1/5000 second. From this the interdiaphragm velocity is computed. It is a function of both temperature and wind. Spurious travel time changes introduced by phase shifts in the receiver are minimized by using a 500-cps intelligence-signal amplitude modulating a 10-kcs carrier. Experimental errors when operating in air with interdiaphragm distances of three feet are less than two percent in the temperature range from 70° to 200°F, but the application of the instrument is not restricted to this range. A circuit for recording velocity directly on a paper tape is described. Although designed primarily for air, the unit is adaptable to other media. It should also be of special interest to the micrometeorologist.

3045

Muller, H., and E. Waetzmann, "Absolute Velocity Measurements with Hot Wires in Stationary Sound Waves," Z. Physik, 62, 167-179, 1930.

The constant cooling effect that a hot wire experiences through the air vibrations in a sound wave were again investigated according to the method of Goldbaum and Waetzmann. The discrepancy between the results obtained by the above-named workers and other observers was stated and discussed. Absolute measurements were made of the periodic cooling effect, and it was established that for the absolute measurement in sound waves of both the constant and periodic cooling effects on a heated wire, this can only be done successfully by taking special precautionary measures and for certain thicknesses of the wire. Full experimental and theoretical details are given.

3046

Ooura, H., "A Study on the Optical and the Acoustical Properties of the Snow Cover," International Union of Geodesy and Geophysics, Assoc. of Sci. Hydrology, Rome, 1954 (Transactions), 4, 71-81, 1956.

The snow cover does not always show perfectly diffused reflection (type E) for the incidence of light. There are the diffused specular reflection (type C) and another reflection (type A) such that the nearer 90° the angle of reflection, the higher the brightness of the snow cover becomes. By quantitative treatment, it was found that in reflection type E, the reflection from the deep places plays the main role while types C and A are due to the reflection from the shallow places whose depth is not more than ten times the size of the snow grain. The degree of polarization of reflected light for the incidence of the linearly polarized light increases with the angle of reflection and is nearly equal to the percentage of light reflected only at the boundary surface of the snow cover. The albedoes are in the range from 40 to 90%. The extinction coefficients in snow are in the range from 0.4 to 1.2/cm.

The relation between these values and the number of snow grains in unit volume was investigated. It was found that the sound wave propagates mainly in air among the snow grains with velocities about 180-300 m/sec. Velocity increases with the temperature and the grain snow surface is about 10-40% of the incident.

3047

Partlo, F. L., and J. H. Service, "Instantaneous Speeds in Air of Explosion Reports at Short Distances from the Source," Physics, 6, 1-5, 1935.

In the first series of measurements the source was one No. 6 blasting cap, while in the second series 1 lb of 50% nitroglycerin stick dynamite was used as source. A telephone carbon-button microphone was the receiver and was held fixed in location while shots were fired successively at 5, 8, 12.5, 25, 35, 50, 100 and 600-meter distances. A two-element string oscillograph was used for timing, one element recording the instant of firing, the other element recording the arrival of the wave at the microphone. The work was done at a time of no perceptible wind; air temperatures were measured carefully; no humidity measurements were made. Travel times could be read reliably to 10^{-4} sec, and distance measurements were at least correspondingly good. Instantaneous speeds were obtained by plotting time computed minus time observed against distance, and measuring slopes of the resulting curve. Since this work was incidental to seismic prospecting, the observations were not quite as numerous as those of von Angerer and Ladenburg. However, the results are similar, showing abnormally high speeds near the source. Also, the use of instantaneous speeds appears to show abnormally low speeds a little farther from the source, perhaps masked in the work of von Angerer and Ladenburg due to their use of average speeds instead of instantaneous speeds.

3048

Pielemeier, W. H., "Velocity of Sound in Air," J. Acoust. Soc. Am., 10, 313-314, 1938-1939.

Determination by capable investigators of the velocity of sound in dry air at 0°C ranges from 330.6 to 331.9 meters per second. Miller's value (331.36 ± 0.08) meters per second is probably the best for low-frequency (explosive) sounds. Part of this range of values may be due to dispersion. The CO_2 and

O_2 contents of air are sensitive to water vapor in this respect. The dispersion in air manifests itself as a small excess over the values for velocity calculated for given humidities and temperatures by means of Miller's classical formula. These calculated values of V for a given temperature are approximately a linear function of the vapor pressure. These and the observed values are plotted.

Other curves show how the dispersion frequencies in CO_2 and O_2 depend on the humidity. The observed value of V_0, the velocity of sound in dry air at 0^oC, calculated, by Miller's formula, from measurements at a given frequency and humidity depends somewhat on these existing conditions.

3049

Richards, V. T., and J. A. Reid, "Acoustical Studies, Part III. Rates of Excitation of Vibrational Energy in CO_2, CS_2 and SO_2," J. Chem. Phys., 2, 193-205, 1934.

Measurements were made on these gases at various pressures, temperatures and frequencies. Double collisions provide the predominant mechanism of excitation. The van der Waals or capillary forces follow the acoustical cycle without lag under the conditions of the experiments. The velocity of sound at 9 kc in CO_2 shows that a part of the heat capacity has already disappeared at this frequency. The remaining vibrational-energy terms disappear together from the acoustical cycle, their rates of excitation being sensibly equal. Considerable activational energy is necessary to excite the deformation vibration. The velocity of sound at 9 kc in CS_2 agrees well with that obtained by calculation from the results of band-spectral analysis and hence no important energy terms appear to be lacking at this frequency.

The symmetrical linear ($S \leftarrow C \quad S$) and the deformation ($S\downarrow C\uparrow S\downarrow$) vibrations leave the acoustical cycle together at high frequencies or at low pressures. Study of the dispersive region caused by this disappearance shows that the rates of excitation of the various energy states are identical within limit of error, and that thus the activational energy of collision is uniform throughout the dispersive region.

3050

Richards, W. T., and J. A. Reid, "Dispersion of Sound in Nitrogen Tetroxide," J. Chem. Phys., 1, 114-128, 1933.

Several types of sound dispersion in a dissociating gas are discussed. Einstein's expression for the velocity of sound in a dissociating gas has been modified to include heat-capacity dispersion. Accounts are given of measurements on the velocity of sound in nitrogen tetroxide. The range of temperature studied is 0^o to 30^oC, the range of pressure 132 mm to 670 mm, and the range of frequency 9 kc to 451 kc. The velocity of sound has been thus defined with an estimated error of ± 0.1 m/sec^{-1}. The maximum dispersion observed is about 5 m/sec^{-1}. Hence the rate constant of the dissociation reaction is $4.8 \times 10^4 \pm 0.5 \times 10^4$ at 25^oC and 260 mm. The activation energy obtained for the dissociation reaction is 13.9 ± 0.9 kcal. An upper limit for the heat capacity of nitrogen tetroxide being fixed by experiment, the effective molecular diameters for the activation process must be at least three times those for ordinary kinetic collisions.

3051

Richardson, E. G., "Absorption and Velocity of Sound in Vapors," Rev. Modern Phys., 27, 15-25, 1955.

A review of the work on this subject during the past fifteen years. The paper deals with the theory of interferometers of the Pierce, double-crystal, capillary tube, and hot-wire types. Discusses results of measurements at varying pressures in air, rare gases, triatomic molecules, and polyatomic molecules (organic vapors). Examines effects of temperature and of vapor mixtures.

Observations of velocity and absorption near the critical state for CO_2 as functions of pressure and frequency are dealt with in a later section of the paper, where there are also derivations of thermodynamical relationships that lead to expressions for the propagation of shock waves in vapors.

Concluded with a useful list of 100 references to current literature.

3052

Shields, F. D., and Kun Pal, Lee, "Sound Absorption and Velocity Measurements in Oxygen," Univ. of Mississippi, University, J. Acoust. Soc. Am., Letter to the Editor, 35, 251-252, 1963.

The tube method has been used to measure sound absorption and velocity in pure oxygen at 23.5^o, 208.7^o, and 301.3^oC. At the elevated temperatures, the absorption was in excess of the classical value. This was attributed to thermal relaxation of the vibrational energy. At 208.7^o and 301.3^oC, the peak value of the relaxation-absorption curve is estimated to fall at 100 ± 4 and 175 ± 13 cps/atm, respectively. These values correspond to relaxation times of 1.71×10^{-3} and 1.01×10^{-3} sec and are considerably longer than would be expected by interpolation from previous data at higher and lower temperatures.

3053

Shields, F. D., and R. T. Lagemann, "Tube Corrections in the Study of Sound Absorption," J. Acoust. Soc. Am., 29, 470-475, 1957.

The absorption and velocity of sound in argon, nitrogen, and carbon dioxide have been investigated over a range of frequency, pressure, and temperature conditions. A movable sound source and a stationary microphone were used, both employing the principle of the ribbon microphone, located inside glass tubing 1.73 cm in diameter. It was found that Kirchhoff's equations correctly predicted the absorption and velocity as the temperature was varied from 0 to 200^o C for argon and from 0 to 150^o C for N_2. Not only did the tube absorption vary as a function of $(f/p)^{1/2}$, but the factor incorporating the physical properties also appears to be valid. Certain earlier experiments have not agreed with the Kirchhoff predictions of the magnitude of the factor which depends on the physical properties, and the success in checking the theory is attributed to the use of improved data for the properties and to the use of precision bore tubing in the apparatus.

3054

Shilling, W. G., and J. R. Partington, "Velocity of Sound in Air, N_2 and O_2," Phil. Mag., 5, 920-939, 1928.

From measurement of the velocity of sound in chemically pure gases, the molecular heats of air, nitrogen, and oxygen have been determined over a temperature range of 0^oC to 1000^oC. Further measurements for air up to 1300^oC are added, and a reply is given to criticism of the method for determining the tube constant.

3055

Sinness, L. S., and W. E. Roseveare, "Dispersion of Sound in Oxygen," J. Chem. Phys., 4, 427-431, 1936.

The velocity of a 1000-cycle sound wave in oxygen of various degrees of humidity at 26.5^oC is measured. The velocity behavior indicates that the water molecules are effective in bringing the heat capacity of the first vibrational state of O_2 into equilibrium with the sound wave. The dispersion change in velocity amounts to 0.16%. Intensity measurements agree with velocity data in fixing the center of the dispersion region between 1 and 3 mm partial pressure of water, which agrees with the values calculated from Knudsen's studies of rates of decay at higher frequencies.

3056

Smith, P. W., Jr., "Measurement of the Velocity of Sound in Gases," Tech. Memo. No. 30, Acoust. Res. Lab., Harvard Univ., 130 pp., 1952.
AD-18 356.

An analysis is presented of a feed-back method for the precise measurement of the velocity of sound in gases at audio frequencies. The various random and systematic errors in the measurement of λ are determined. Experiments are described for the measurement of the velocity of sound in air; a value of 331.45 ± 0.05 meters per second was obtained for the velocity at standard conditions.

3057

Smith, P. W., Jr., "Precision Measurement of the Velocity of Sound in Air," J. Acoust. Soc. of Am., 25, 81-86, 1953.

Describes a method for the precise measurement of the velocity of sound in which the driving-point impedance of a loudspeaker connected to a closed tube of variable length is the frequency-controlling element of a bridge-stabilized oscillator. The operation of the system and the accuracy of measurement are analyzed. Results of measurements in air at 1 kc room temperature, and atmospheric pressure yield, when corrected to standard conditions, a velocity of 331.45 ± 0.05 meters per second.

3058

Smith, P. W., Jr., "Systematic Errors in Indirect Measurements of the Velocity of Sound," J. Acoust. Soc. Am., 24, 687-695, 1952.

An analysis is made of certain methods for measuring the velocity of sound. Specifically, attention is centered on those methods based upon measurements of the electrical driving-point impedance of the transducer and the observation of some phenomenon of that impedance, which is recurrent as the position of the reflector in the acoustic chamber is changed. Consideration is given to the influences of small losses in the propagation of sound in the chamber and of the existence of nonplane wave fronts. It is shown that such measurements can be subject to significant systematic errors arising from the method itself. The nature and magnitude of such errors are discussed.

3059

Smith, P. W., Jr., "The Velocity of Sound at Reduced Pressures," J. Acoust. Soc. Am., 23, 715, 1915.

A summary of a paper by Abbey and Barlow that describes measurements on the sound velocity in gases at one kcs and pressures between atmospheric and several mm of Hg. An acoustical feedback method was used from a dynamic speaker at one end of the tube containing the gas to a movable crystal microphone at the other end. Results are given for air, N_2, CO_2, O_2, and CH_4.

3060

Spakovskij, V., "Velocity of Propagation of Sound in Carbon Dioxide near the Critical State," Compt. Rend., 3, 31-34, 1934.

The velocity of propagation of sound in CO_2 gas at temperatures of 15, 20, 30, 31.5, 35, 40, and 50°C and at various pressures from 1 to 85 atmospheres, was measured. The values of the ratio of the thermal capacities at constant pressure and constant volume were calculated, and the causes of the small increase in the molecular thermal capacity at constant volume resulting from the pressure are discussed.

3061

Tucker, W. S., "The Determination of Velocity of Sound by the Employment of closed Resonators and the Hot-Wire Microphone," Phil. Mag., 34, 217-235, 1943.

A resonator consisting of two cavities connected by a narrow neck is employed. Sound is introduced by a telephone diaphragm forming the boundary of one enclosure, and temperature and response of the resonator to sound are indicated by the change in electrical resistance of a hot wire in the neck of the resonator. Frequency-response curves are obtained from which the true resonance-frequency maximum is obtained. Theoretical support is given to the existence of a linear relationship between velocity and resonance frequency for different gases. Determinations of velocity of sound for air saturated with water vapor were made and data obtained for calculation of γ. From this the velocity of sound in water vapor at 0°C was deduced. Results were also obtained for the velocity of sound in ether and acetone vapors by a similar process.

3062

van Itterbeek, A., "Velocity of Sound at Low Temperatures," Rev. Acoust., 2, 81-97, 1933.

A detailed description of the experimental methods employed by W. H. Keesom and the author for the determination of the velocity of sound in He, H_2 and O_2 at low temperatures. Temperatures were measured by a platinum thermometer and the frequency of the source was determined by registering on a rotating drum the vibrations of an Einthoven galvanometer, placed in the oscillator circuit, beside those of a tuning fork. For experiments at the boiling point of oxygen a modification of Quincke's method was employed, in which the length of tube is altered until resonance is obtained. While the apparatus was being cooled with liquid hydrogen a spontaneous emission of sound took place, necessitating, for mechanical reasons, the employment at lower temperatures of a resonator of constant length and of a source whose frequency was varied until resonance resulted (Thiessen's method). The modification of the apparatus necessary to determine the theoretically important variation of velocity with pressure is described and the paper concludes with a note on the resonator wall and end corrections.

3063

van Itterbeek, A., and P. Mariens, "Velocity and Absorption of Sound at Ordinary and Low Temperatures," Physica, 4, 609-616, 1937.

The absorption and velocity of sound in O_2, H_2, and CO have been measured as a function of pressure and temperature. The relaxation time for O_2 is calculated and found to vary inversely as the pressure at a temperature of about 13°C. A departure from this law occurs at higher temperatures; at low temperatures, the absorption coefficients are higher than those predicted by the classical formula. As in earlier measurements, absorption in H_2 is found to be very high. The absorption in this gas is unaffected by increasing the concentration of parahydrogen. Measurements made in CO, for which the vibrational energy is small at ordinary temperatures, also show deviations from the classical formula.

3064

van Itterbeek, A., and W. H. Keesom, "Velocity of Sound in Hydrogen Gas at Liquid Hydrogen Temperatures," Proc. Koninkl. Ned. Akad. Wetenschap Lab. Univ. Leiden, 34, 988-995, 1931.

The velocity of sound in hydrogen gas is determined by a method previously described at temperatures between 17.17°K and 20.42°K, and at pressures from 0.1 to 1.0 atmos. If W is the velocity of sound, p the pressure, $W^2 = N(1 + Pp + Qp^2)$. Values at different temperatures of the constants N, P, and Q are tabulated, and the ratio $(c_p/c_v)_{p=0}$, calculated from N, is sensibly constant over the whole temperature range.

3065

Walch, F. A., "Constancy of Velocity of Sound at Sonic Frequencies," Proc. Phys. Soc. (London), 48, 899-913, 1936.

A method of investigating whether there is any dispersion of sound waves in air at sonic frequency is described. It consists in comparing the waveform of a complex sound at different distances from the source. A technique for making the necessary collodion diaphragms has been worked out, and a simple but effective drum camera has been constructed. A controllable waveform is provided by two oscillators, one tuned to a fundamental and the other to a harmonic, locked into synchronism by close coupling. Frequencies from 250 to 1000 cps have been investigated. Velocities have been proved constant for the lower frequencies to within one in 500 and for the higher frequencies to within one in 1000.

3066

Warfield, C., "Tentative Tables for the Properties of the Upper Atmosphere," Tech. Note No. 1200, U. S. Nat'l. Advisory Comm. Aeron., 53 pp., 1947.

Considering all types of measurements made prior to 1947 a "tentative standard atmosphere" up to 120 km altitude has been constructed. "Most probable," "probable," "probable minimum," and "probable maximum" values are given. Among quantities listed in these tables against altitude are temperature, pressure, density, specific weight, coefficient of viscosity, speed of sound, and the mean free path of the air molecules.

3067

Webb, W. L., and K. R. Jenkins, "Speed of Sound in the Stratosphere," Special Rept. No. 37, Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 56 pp., 1960. AD-240 133.

The vertical structure of the speed of sound in the stratosphere is discussed from new meteorological data obtained in the recently activated meteorological rocket network. Data from sounding rockets are included. The obvious effects of thermal gradients and wind shears are indicated, and a number of observed cases are discussed.

3068

Weston, D. E., and I. D. Campbell, "Experiments on the Propagation of Plane Sound Waves in Tubes, I., The Adiabatic Region," D. E. Weston; "II., The Transition Region," D. E. Weston and I. D. Campbell, Proc. Phys. Soc. (London) B, 66, 769-774, 1953.

I. An experimental investigation using an acoustic interferometer with a magnetostriction source is described. Results on attenuation and velocity in tubes of radius 0.013 cm and upwards, from 10 to 20 kcs, and for a variety of tube materials and gases are given. These confirm a modified Kirchhoff's formulae. II. The velocity and attenuation of plane sound waves in tubes of radius 0.02 cm have been measured in the transition region between adiabatic and isothermal flow.

3069

White, J. E., "A Method for Measuring Source Impedance and Tube Attenuation," J. Acoust. Soc. Am., 22, 565-567, 1950.

If the active face, or acoustic output terminal, of a sinusoidal sound source moves as a plane piston, then the source can be characterized by a blocked pressure and an acoustic output impedance. If this piston is coupled to a microphone by means of a closed air column, the pressure at the microphone depends on the acoustic impedance of the microphone, on the impedance of the source, and on the air column. An expression for this pressure as a function of the length of the air column is developed, and data are presented which show how source impedance, tube attenuation, and other quantities may be obtained.

Velocity, Sound, Measurement
See Also—49, 75, 103, 106, 144, 147, 152, 159, 187, 194, 205, 278, 282, 411, 550, 569, 570, 592, 714, 794, 1046, 1061, 1111, 1146, 1182, 1190, 1215, 1278, 1295, 1331, 1362, 1418, 1419, 1420, 1421, 1422, 1423, 1425, 1447, 1458, 1466, 1471, 1475, 1498, 1523, 1524, 1525, 1806, 1839, 1853, 1855, 2045, 2046, 2084, 2124, 2125, 2183, 2374, 2489, 2490, 2491, 2492, 2677, 2826, 3010, 3076, 3101, 3129, 3141, 3142, 3155, 3169, 3172, 3219, 3220, 3224, 3245, 3274, 3275, 3276, 3277, 3291, 3987, 4082

VELOCITY, SOUND, THEORY

3070

Abraham, R., "The Sound Speeds of a Charged Fluid," Rept. No. 2767-4-T, College of Literature, Science, and the Arts, Univ. of Mich., Ann Arbor, 17 pp., 1960. AD-239 549.

Considers a charged perfect fluid with finite electrical conductivity, no heat conductivity, and variable dielectric capacity and magnetic permeability in the space-time of general relativity amid arbitrary Maxwellian fields. From the description of these fields by a pair of bivectors (skew symmetric tensors of order two) and a decomposition theorem for bivectors, a new description is obtained that generalizes the classical scheme. From the new scheme the characteristic equation is found; it shows that the fluid supports two modified sound waves and a modified contact surface.

3071

Beyer, R. T., "Acoustic Relaxation in a Van Der Waals Gas," J. Acoust. Soc. Am., 24, 714-715, 1952.

Expressions are given for the sound velocity and the absorption coefficient per unit wavelength of a van der Waals gas. Numerical calculations have been carried out for several triatomic gases. In general, the velocity corrections, under standard conditions, average about 0.5%, while the absorption corrections are two or three times larger.

3072

Bourgin, D. G., "Sound Propagation in Gas Mixtures," Phys. Rev., 34, 521-526, 1929.

An earlier treatment of the propagation of sound in mixtures of two gases is generalized and somewhat simplified. The essential point of the theory is the consideration of the internal energy variations by the assignment of fictitious internal state temperatures which, in the simplest case assumed here, are taken to be constant for each of the component gases. The long-wavelength velocity expression is directly interpretable as a Laplace formula for a gas of mean reciprocal mass and averaged specific heat. From a more general point of view, the velocity of propagation of infinitesimal waves is always given by the Laplace result, provided that a frequency variation of specific heats is recognized. Explicit mention is made of the detailed effect of viscosity and the two conductivities. Experimental data support the theory.

3073

Bourgin, D. G., "Velocity of Sound in an Absorptive Gas," Phys. Rev., 42, 712-730, 1932.

This paper continues the earlier mathematical work of the author, who is endeavoring to link up experimental facts concerning the propagation of sound in gaseous media with the atomic qualities of the system. The method is based on the theory that velocity propagation in a gas is conditioned by internal energy exchanges subject to lags, and the present paper postulates three sets of states to interpret results where the wave period is of the order of the lag for some states. Kneser's results for CO_2 are examined in the light of this theory.

3074

Brancato, G., "Velocity of Sound in the Atmosphere," Nuovo Cimento, 10, 169-171, 1933.

The small adiabatic oscillations of a perfect gas in a condition of isothermal equilibrium are examined theoretically without neglecting gravitation. It is found that the latter has no effect on the velocity of propagation of the disturbance.

3075

de Groot, S. R., "On the Thermo-Dynamical Theory of Relaxation Phenomena: Acoustical Relaxation, Appendix VI.," AFOSR-TN-58-233, Leyden State Univ., Netherlands, 13 pp., 1958. AD-154 136.

The thermodynamic theory of acoustical relaxation is reviewed. The theory is set up for a fluid in which heat conduction, viscosity, and a relaxation phenomenon may occur. Two approximations are considered. In the first, all irreversibility, except the relaxation, is neglected; in the second, the other irreversible phenomena are taken into account in the first order. In both cases expressions are derived for the velocity of sound. The well-known fact is established that for low frequencies, the relaxation gives rise to a contribution to the bulk viscosity.

3076

Dow, W. G., and N. W. Spencer, "Progress Report A3-January-February 1950 Progress Report," Eng. Res. Inst., Univ. of Mich., Ann Arbor, 26 pp., 1950. ATI-78 348.

Progress is reported on the Aerobee quided missile program. The warhead of the Aerobee No. 4 missile underwent final preparations for firing. The study of possible means of measuring ambient temperature in addition to the present means was continued. An investigation was initiated for determining more accurately the air density at the gage port opening as compared with the density actually measured by the particular ionization gage being employed. Equations for defining the velocity of sound are presented. Camera failures encountered in the firing of the Aerobee in December and errors encountered in pressure-gage calibration are discussed.

3077

Drzewiecki, S., "Velocity of Sound Determination Based on Kinetic Theory of Gases," Compt. Rend., 189, 122-125, 1929.

A graphical method of dealing with the molecular and translational velocity vectors is described, from which it is shown that the limiting speed of translation is $\sqrt{1/2}\ \bar{\Omega}$, where $\bar{\Omega}$ is the quadratic mean molecular velocity. For air, this gives the value 343 meters per second. When the initial shock of pressure is sufficient to cause the limiting speed to be attained the resulting wave becomes audible.

3078

Galatry, L., and J. Noury, "Possible Influence of Structural Relaxation Processes on the Velocity of Propagation of Sound at the Critical Point" (in French), J. Phys. Radium, 17, 375-376, 1956.

The velocity of sound measured as a function of pressure passes through a very sharp minimum in the critical region. This phenomenon is qualitatively explained by the fact that in this region the isothermal compressibility of fluids passes through a maximum. Divergence in recent observations of this effect show that it cannot simply be explained on the basis of the equations of state. It is now suggested by the authors that there exists a "liaison" between the particular properties of "structural relaxation" attributed to the critical state, and the possibility of an abnormal behavior of the velocity and of the absorption of sound in this region.

3079

Gross, R. A., and C. L. Eisen, "On the Speed of Sound in Air," Phys. Fluids, 2, 276-279, 1959.

In a high-temperature gas, the speed of sound depends upon the chemical composition, sound frequency, and chemical reaction rates. Two limiting sound speeds are normally distinguished: that of frozen or constant chemical composition, and the equilibrium sound speed. Equations to determine these two sound speeds are presented for a nitrogen-oxygen system and numerical data are presented for conditions behind a normal shock in air to a speed of Mach 20.

3080

Gutenberg, B., "The Speed of Sound in the Lowest Layers of the Atmosphere" (in German), Z. Geophysik 2, 101-106, 1926.

This theoretical article gives a method for calculating the speed of sound in the atmosphere; the speed is calculated up to 70 km, and from that deductions on the abnormal zone of audibility are indicated.

3081

Hardy, H. C., D. Telfair, and W. H. Pielemeier, "The Velocity of Sound in Air," J. Acoust. Soc. Am., 13, 226-233, 1941.

A rigorous equation is set up for the velocity of sound in gases. This is used to calculate the velocity of sound in dry air at standard conditions from data taken in independent measurements. The result of this calculation is 331.45 ± 0.05 meters per second. An extensive survey of previous reported measurements has been made. After proper corrections are taken into account, the weighted mean is 331.46 ± 0.05 meters per second. The results of very precise interferometer measurements by the authors give 331.44 ± 0.05 meters per second.

3082

Heil, O., "Velocity of Sound in Carbon Dioxide," Z. Physik, 74, 31-33, 1932.

The author, in a paper on extinction of fluorescence and passage from resonance series spectra to band spectra, has shown that molecules do not alter their rotation and vibration greatly during collisions. This result seems at first sight to be contradicted by Kneser's work, which shows that the velocity of sound in CO_2 depends on the frequency. The author shows, however, by considering the way in which a CO_2 molecule can be set into vibration on collision, in view of the fact that its three atoms are arranged in a straight line, that only one CO_2 molecule in a million can possibly supply sufficient energy to raise the vibrational energy by a vibrational quantum. This shows that Kneser's result is to be expected.

3083

Himpan, J., "The Calculation of Sound Velocity in Gases and Liquids by Means of a New Thermal Equation of State" (in German), Z. Physik, 141, 566-570, 1955.

A relation for the velocity of sound is derived from a modified form of Van der Waals' equation. The theory gives results that agree well with observations on CO_2.

3084

Jha, S., "On the Variation of the Velocity of Sound with the Pressure of the Gas," Bull. Patna Sci. Coll. Phil. Soc., 13, 148-154, 1943.

The velocity of sound in a perfect gas is $(\gamma p/\rho)^{1/2}$, and for real gases this is multiplied by a factor ϕ. Expressions for this factor are derived from the virial equations of state proposed by Kamerlingh Onnes, and values of ϕ are tabulated for H_2, O_2, and C_2H_4 at 0^oC.

3085

Kaspar'iants, A. A., "The Problem of Sound Wave Propagation in 'Van Der Waals' Gases and Liquids," Soviet Phys. Acoust., English Transl., 4, 336-343, 1959.

It is assumed that the medium in which sound waves are propagated obeys van der Waals' equation of state. Navier-Stokes' linear equations are applied to such a medium. The velocity of sound and the absorption coefficient are derived in a form convenient for further calculations. The differential equations of acoustic wave propagation may be used to find the spatial distribution of the acoustic field, allowing for the viscosity and thermal conductivity of the medium.

3086

Kneser, H. O., "Relation Between Sound Velocity and Absorption with Acoustic Relaxation" (in German), Ann Physik., 43, 465-469, 1943.

Formulas for the variation of sound velocity and absorption with frequency are derived by two independent methods. For a given temperature, experimental values may be plotted on a simple geometric semi-circular diagram. The relaxation time and the phase angle between pressure and contraction can be read off directly from this diagram. Results of absorption and velocity measurements with oxygen of varying purity and carried out by different observers closely agree with the predicted semi-circular diagram and corroborate the theory.

3087

Kneser, H. O., and O. Gauler, "Propagation of Sound in Partly Dissociated Gases," Physik. Z., 37, 677-684, 1936.

The velocity of sound in a partly dissociated gas is calculated, and the influence of pressure, temperature and frequency examined. The results are compared with measurements made upon N_2O_4. It is found that the behavior of this gas depends markedly upon its temperature. The measured and the calculated variations of velocity with pressure are found to agree well.

3088

Konstantinow, B. P., and I. M. Bronstein, "Applications of the Continuity Equation of the Energy in Acoustics" (in German), Physik. Z. Sowjetunion, 9, 630-640, 1936.

An equation for the energy density of the perfect gas is discussed. It is suitable for application in a particularly convenient form. The equation ultimately derived enables the propagation of sound to be described in a static inhomogeneous medium. Once more it is established that sound waves are propagated with adiabatic velocity, because such disturbances proceed sufficiently slowly. Problems involving additions of the second order are considered, and particularly in connection with the determination of the following magnitudes: density and flow of energy; sound pressure and average temperature increase in the sound field. In this respect, the necessity is proved for the careful testing of the usually accepted data for these quantities. The paper is mainly mathematical.

3089

Landau, L., and E. Teller, "Theory of Sound Dispersion" (in German), Physik. Z. Sowjetunion, 10, 34-43, 1936.

It is shown that the sound dispersion at temperatures which suffice for the excitation of several vibration quanta is given by the same formula as sound dispersion at temperatures where, at most, one vibration quantum is excited. Investigation is also made of the delivery of vibration energy in its dependence on the molecular velocity. Thus, it is established that only great velocities play a part, with which the pehnomenon proceeds classically. The dependence on temperature of the effect is determined.

3090

Leyden State University, "On the Thermodynamical Theory of Relaxation Phenomena: Acoustical Relaxation, Appendix VI.," Rept. No. AFOSR TN-58-233, Netherlands, 13 pp., 1958.
AD-154 136.

See entry 3075

3091

Luck, D. G. C., "Sound Velocity in Reactive Mixtures of Real Gases," Phys. Rev., 40, 440-444, 1932.

Einstein's derivation of the dependence of sound velocity on frequency in a mixture of chemically reacting ideal gases of negligible absorption has been extended to mixtures of real absorbing gases. The results show that deviations of experiment from the earlier theory are probably due to departure of the gases from ideal properties. They also show that absorption is probably strong enough to render reaction rate determination by velocity measurements impossible, but that direct absorption measurements may be of some use. It is shown that extraneous phenomena may hide those considered.

3092

Meixner, J., "General Theory of Sound Absorption in Gases and Liquids, Taking into Account Transport Phenomena" (in German), Acustica, 2, 101-109, 1952.

The author computes the complex velocity of sound—and hence the absorption and the dispersion of sound—for an arbitrary fluid medium in which internal transformations take place, including the contribution of transport phenomena (conduction of heat, diffusion, thermodiffusion, and fluid friction). Applying the thermodynamical theory of irreversible processes permits the derivation of general results without undertaking to exemplify the special nature of the internal transformations. Apart from the relaxation time, all of the quantities determining the complex velocity of sound are thermodynamical ones. One can find them for a special problem from an appropriate model by using the methods of statistical mechanics. With good approximation sound absorption due to transport phenomena may be added to that due to internal transformation in the whole frequency range. With respect to sound absorption by internal transformation only, there are eight diverse, but equivalent, equations from which all known results can be derived in a simple way.

3093

Northwood, T. D., and D. V. Anderson, "Velocity Considerations in Pulse Propagation," J. Acoust. Soc. Am., 22, 513-514, 1950.

A discussion of group velocity.

3094

O'Leary, A. J., "On a Derivation of the Equation for the Speed of Sound by W. W. Sleator," Am. J. Phys., 25, 115-116, 1957.

The purpose of the note is to point out two basic errors in a derivation of the equation for the speed of sound by W. W. Sleator (J. Opt. Soc. Am., 21, 187, 1931, and Am. J. Phys., 17, 51 and 178, 1949), which has recently been repeated in challenge of a contradictory derivation, both from the approach of conservation of energy. The crux of the situation is summarized by the author in the two questions: (1) What is the instantaneous power transmitted by a piston to air on one side of it? and (2) What is the change of internal energy of a side mass in a small adiabatic change of pressure from P to $(P + \Delta P)$?

3095

Pekeris, C. L., "The Propagation of a Pulse in the Atmosphere," Phys. Rev., 73, 145-154, 1948.

The previous investigation of the dispersion of long waves in the atmosphere [Proc. Roy. Soc. (London), 171A, 434-449, 1939] has been extended to shorter periods of the order of one minute. Both the phase velocity and group velocity have been determined. The results are applied to the interpretation of the pressure wave produced by the Great Siberian Meteor and to the pressure oscillations recorded by microbarographs in England.

3096

Primakoff, H., "The Translational Dispersion of Sound in Gases," J. Acoust. Soc. Am., 14, 14-18, 1942.

The translational dispersion is discussed from the standpoint of kinetic theory. An explicit relation is derived for the variation of sound velocity with frequency in monatomic gases: $V = V_0(1 - 5{\cdot}4\,\ell^2/\lambda^2)$, where ℓ is the m.f.p. and λ the wavelength. The possibility of experimental observation of translational dispersion is briefly discussed.

3097

Pusat, N., "The Velocity of Sound in a Real Gas as Function of the Pressure," Rev. Fac. Sci., Univ. Istanbul, Ser. A, 17, 46-60, 1952.

The formula for the velocity of sound in a real gas that shows a relaxation mechanism was calculated as function of pressure and frequency. This formula has been discussed specially for CO_2. The velocity of sound in the vapor of ethyl-formate was measured with an acoustical interferometer, and the theoretical conclusions were applied to the results. A mechanism of relaxation was found with a characteristic time constant of 1.9×10^{-8} sec, calculated for one atm pressure.

3098

Revenko, V. V., "Derivation of the Velocity of Sound on the Basis of Molecular-Kinetic Theory," Soviet Phys. Acoust. English Transl., 5, 257-258, 1959.

The author presents three expressions for calculating the velocity of sound in gases on the basis of molecular-kinetic theory. The first expression assumes that the velocity of sound is approximately equal to the average of chaotic molecular velocities in a unit volume of a gas in the direction of the propagating sound wave. This expression proves to be inaccurate by more than 30%. The other two expressions are for homogeneous and nonhomogeneous gases respectively, and are based on molecular-kinetic theory calculations of the velocity of molecules intersecting an imaginary, stationary cross section in the gas. These expressions permit calculation of sound velocities in gases to an accuracy of about 6%.

3099

Richardson, E. G., "The Velocity of Sound: A Molecular Property," Nature, 158, 296-298, 1946.

Briefly reviews the relaxation theory of the influence of molecular properties of a gas on the velocity of sound propagation at high frequencies; it is emphasized that the theory has not yet been independently confirmed by experiment. No evidence has been found of dispersion of velocity in liquids, though there is evidence of enhanced scattering. The "second velocity of sound in He II" can be explained on the simple basis of high thermal conductivity; that is, temperature changes propagate at rates close to the speed of sound.

3100

Rosemann, J., and V. Agosta, "Propagation of Sound in a Reacting Gas Mixture near Equilibrium," Rept. No. PRL-61-12, Polytech. Inst. of Brooklyn, N. Y., 32 pp., 1961. AD-259 695.

The significant results obtained in research are summarized. A generalized differential equation for the propagation of a pressure pulse is obtained; it is good for all values of the reaction rate. The physical significance of the two sound speed, equilibrium (ae) and frozen (af), is explained on the basis of this equation. For an instantaneous reaction, the state and composition variables are shown to be representable both physically and as solutions of the characteristic differential equations, as step functions; and the reaction rate, as an impulse function. Explicit expressions are obtained for ae and af.

3101

Sauer, F. M., "The Preshock Sound Velocity Field over Inorganic and Organic Surfaces, a Problem Analysis and Status Report," Interim Tech. Rept. No. AFSWP-420, Forest Service, Washington, D. C., 46 pp., 1954. AD-267 596.

Existing information concerning the development, during nuclear detonations, of preshock sound velocity fields caused by irradiation of inorganic and organic surfaces is analyzed. Experimental results are compared with available theoretical analyses and the influence of surface thermal properties is discussed. Surface temperatures calculated from theoretical results based on the assumption of a homogeneous media and using published thermal properties are inconsistent with temperatures measured during actual detonations. A vigorous experimental program appears necessary in view of the deficiencies of theoretical attack, expecially in the case of organic surface materials; specific recommendations on the objectives of such programs are presented. Conventional modes of convective heat transfer are shown to explain observed depths of thermal layers over inorganic surfaces if compressibility is considered.

3102

Schaaffs, W., "Computation of Molecular Radius From Molar Volume and Velocity of Sound," Z. Physik, 115, 69-76, 1940.

The author improves the accuracy of his formula for the evaluation of the molecular radius by substituting the adiabatic velocity of sound for the isothermal value. Furthermore, the differential quotient of the van der Waals term b by the density is no longer neglected.

3103

Schaaffs, W., R. Kuhnkies, and H. U. Woelk, "The Physical Interpretation of 'Molar Sound Volumes' and of Rao's Rule Included in It," Acoustica, 12, 222-229, 1962.

A critical review is given of the use of Rao's expression $u^{1/3}V$ (molar velocity of sound). In continuation of an earlier investigation it is shown that Rao's expression is part of a certain volume called molar sound volume. The molar sound volume is equal to the product of the radius of the molecule and the cross-section of the unit cell. The collision coefficient, which is of great significance in the propagation of sound, is contained in the molar sound volume. It is shown that with decreasing temperature the collision coefficient approximates the ideal value of four at absolute zero. The additivity of Rao's expression from atomic increments is poor; this is in contrast to the good additivity of the molecular volume per mole.

Molar velocity of sound is not an independent quantity of physical significance.

3104

Sleator, W. W., "Proof of the Expression $(E/\rho)^{1/2}$ for the Velocity of Sound by Use of an Equality of Energies," Am. J. Phys., 24, 15-18, 1956.

An argument is presented by which the velocity equation for sound waves in a gas is obtained as a result of equating the kinetic and potential energies per unit volume at the same time and position in the wave train.

3105

Smith, D. H., and H. J. Wintle, "The Propagation of Sound in Relaxing Gases in Tubes at Low Frequencies," J. Fluid Mech., 9, 29-38, 1960.

The frequency dependence of the velocity and the attenuation of sound waves in a gas which undergoes vibrational relaxation have been investigated theoretically. At low audible frequencies the attenuations due to viscosity, thermal conduction, and relaxation in the gas add linearly, while the velocity is the relaxation velocity diminished by the Helmholtz-Kirchhoff factor. The relations have been confirmed experimentally, and the free gas velocities of sound at zero frequency, one atm. pressure and $30^{0}C$, found for carbon dioxide, air and oxygen, are 270.57 ± 0.04 m/sec^{-1}, 349.18 ± 0.02 m/sec^{-1}, and 331.33 ± 0.03 m/sec^{-1}, respectively. The corresponding specific heats are $C_p/R = 4.537 \pm 0.008$ for carbon dioxide and $C_p/R = 3.547 \pm 0.003$ for oxygen.

3106

Smith, P. W., Jr., "Computation of the Velocity of Sound in Gases," Tech. Memo. No. 29, Acoust. Res. Lab., Harvard Univ., 28 pp., 1952.
AD-10 247

Summarizes a method for the precise computation of the velocity of sound in a real gas and of its variations with experimental conditions. Two problems are discussed, the inclusion of the effects of departures of the equation of state from the perfect gas law, and the computation of specific heats from spectroscopic data. The method is applied to air, and data are presented for the computation of the velocity in air under pressures between 720 and 820 mm Hg and temperatures between 0^{0} and $30^{0}C$. These results are summarized in the form of correction factors for the reduction to standard conditions of velocities measured at various frequencies and in this range of pressure and temperature.

3107

Stueckelberg, E. C. G., "Thermodynamics, Relativity and Sound Velocity," Helv. Phys. Acta (Switzerland), 35, 324-326, 1962.

In previous papers, the author has given a Lorentz-covariant formulation to the principle of positive entropy production. In this preliminary note it is asserted that if a covariant principle of thermodynamic equilibrium is adjoined, it can be shown, inter alia, that the velocity of sound is less than the velocity of light.

3108

Tabuchi, D., "Dispersion and Absorption of Sound in Gases in General Chemical Equilibrium," Mem. Res. Inst. Acoust. Sci., Osaka Univ., Japan, 2, 50-60, 1951.

Gases are considered theoretically which are in general chemical equilibrium, dissociation being included as a special case. It is assumed that the gas is ideal, the absorption of sound due to viscosity, thermal conduction and radiation is negligible, and that the transition between the translational and internal energies of the molecules occurs at infinite speed; that is, the specific heat of the gas is not dependent on the sound frequency. Equations are deduced for the velocity of sound and the absorption coefficient of the gas, and then the complex sound velocity is deduced from the acoustic characteristic equation. The theoretical values obtained by Einstein and Luck for dissociating gases are found in good agreement with those deduced in this paper.

3109

Tabuchi, D., "Dispersion and Absorption of Sound in Mixtures of Gases," Mem. Inst. Sci. Ind. Res., Osaka Univ., Japan, 9, 65-73, 1952.

This paper calculates the complex velocity of sound for gas mixtures containing molecules with an arbitrary number of vibrational levels and modes of vibration. Absorption due to viscosity and heat conduction is neglected, and it is assumed that there is no dispersion and absorption due to transitions between rotational quantum states. The results, it is claimed, are obtained in a simple form convenient for comparison with experiment.

3110

Vrkijan, V., "The Velocity of Sound in Gaseous Mixtures," Periodicum Math. Phys. Astron. (Yugoslavia), 2, 299-301, 1960.

Purports to show that a formula already published for the velocity of sound in mixtures of ideal monatomic gases holds for other gases provided their molecules have similar degrees of freedom. The specific heats of the individual gases are calculated in terms of the gas constants and, if both gases have the same number of degrees of freedom, they cancel, and the equation for the velocity of sound in the gaseous mixture then becomes identical with that for a mixture of monatomic gases. The equation only applies over the temperature range in which the specific heats are approximately constant.

3111

Vrkljan, V. S., "On the Calculation of Sound-Velocity in Gas Mixtures," Nuovo Cimento, 17, 845-849, 1961.

A new derivation is given of the relation for the velocity of sound in a mixture of ideal gases for which the ratio of specific heats and density is known. A formula is obtained that relates these magnitudes to the corresponding values for the individual constituents of the mixture.

3112

Vrkljan, V. S., "Calculation of Sound Velocity in Gas Mixtures, II.," Nuovo Cimento, 22, 189-190, 1961.

In an earlier paper it was shown that $C_j^2 = 3 (R/m_j)T_j$ ($j = 1, 2, \ldots n$), where C_j^2 is the mean value of the square of the velocity of propagation, m_j the (relative) molecular mass, and T_j the temperature of the individual gases of the mixture (the same as the temperature T of the gas mixture if the mixture is in its equilibrium). The object now is to show that this formula for the derivation of mean square velocity is not essential; the velocity is derived from consideration of data relating to the number of degrees of freedom, the specific heats, the masses of the molecules, and the densities of the constituent gases of the mixture.

Velocity, Sound, Theory
See Also—171, 216, 224, 235, 441, 451, 454, 550, 554, 573, 823, 868, 916, 942, 1464, 1474, 1493, 1535, 1546, 1547, 1549, 1754, 1849, 1912, 1946, 2084, 2188, 2220, 2276, 2906, 3036, 3048, 3049, 3058, 3129, 3291, 3337, 3349, 3365, 3549, 3740, 4000, 4324, 4345

VELOCITY, ULTRASONIC

3113

Bender, D., "Ultrasonic Velocity in N_2, NO, and CO Between 20° and 200°C, Measured by a New Method" (in German), Ann. Physik, 38, 199-214, 1940.

The temperature dependence of the velocity of sound at a frequency of 1000 kcs is measured by a modification of the Pierce interferometer in which the piezo-quartz is mounted between two fixed reflectors. The quartz is coupled inductively to the driving oscillator and vibrates at temperatures up to 500°C, but above 200°C the sound intensity is too weak to permit measurements. The results indicate that in N_2, CO, and NO, the region of anomalous dispersion of the sound velocity is shifted with increasing temperature towards higher frequencies.

3114

Bommel, H., "The Measurement of the Velocity and Absorption of Ultrasonics by an Optical Method," Helv. Phys. Acta, 18, 3-20, 1945.

The measurement of the velocity of ultrasonics in gases becomes more complex as the frequency increases on account of the interaction between source and receiver and other effects. In the optical method described, the Hg 4358Å line is passed through gas subjected to the action of the ultrasonics, and the diffraction pattern brought to a focus on a photographic plate by a concave mirror. The velocity V is obtained from the separation of the diffraction maxima. A range of 951-4755 kc is covered. A method is worked out theoretically whereby the absorption can be obtained from the separation of the diffraction maxima.

3115

Bommel, H., "On Measurement of Ultrasonic Velocity in Gases" (in German), Helv. Phys. Acta, 16, 423-425, 1943.

With hf, the usual sound interferometer method is inaccurate, and that of Debye and Sears, in which the sound waves act by diffraction on the light waves, was modified by employing two frequencies at the same time, enabling dispersion to be observed if present. In tests with CO_2, O_2, N_2, A, and air, no dispersion was observed in the frequency intervals between the fundamental and third or fundamental and fifth harmonic of a quartz crystal with a prime of 951 kcs. The known dispersion region in CO_2 was displaced by the application of pressure and the addition of another gas; and on testing in the interval 951-2,853 kcs, a change of velocity of 2% was measured with an accuracy of two in a thousand.

3116

Borgnis, F. E., "On the Theory of the Fixed-Path Interferometer," J. Acoust. Soc. Am., 24, 19-21, 1952.

Gives a general expression for the electric input impedance of the acoustic interferometer. From this expression formulas are derived for determining the velocity of sound by varying the frequency, or for determining changes in velocity due to variations of pressure, temperature, etc. Theory indicates that there is no need for the correction of the actual path length when the path ends at a nonperfect reflector, although papers dealing with the fixed-path interferometer commonly suggest such a need.

3117

Boyer, R. A., "Ultrasonic Velocities in Gases at Low Pressures," J. Acoust. Soc. Am., 23, 176-178, 1951.

An ultrasonic interferometer with high sensitivity is used to measure acoustic velocities in gases at 0°C, as the wavelength approaches the mean free path of the molecules. Measurements are made of velocity as a function of pressure down to about two mm of Hg, the frequency being kept constant at approximately 970 kcs. The following increases in velocity (at the lowest pressures) over that at standard conditions were observed: A, 27%; N_2, 16%; O_2, 20%; and air free of CO_2, 7%.

3118

Chuikin, E. I., "On the Application of the Impulse Method of the Determination of the Velocity of Ultrasound" (in Russian), Zh. Tekhn. Fiz., 24, 1125-1135, 1954.

A mathematical study of the effect of absorption on the shape of the transmitted pulse of ultrasound. It is shown that the pulse shape is considerably altered by absorption and that this may effect the value obtained for the velocity.

3119

Connor, J. V., "Ultrasonic Dispersion in Oxygen," J. Acoust. Soc. Am., 30, 297-300, 1958.

The velocity of ultrasonic waves in oxygen was measured at 40.6°C and 2 Mcs, with pressures ranging from one atm. to 0.35 cm Hg. Velocity dispersion was found at the lower pressures and is accounted for in part by rotational relaxation and at the lower pressures by the onset of the Stokes type of dispersion. The midpoint of the dispersion curve lies at 122 Mcs per atm, which corresponds to a relaxation time of 21.76×10^{-10} sec and to 13 as the average number of collisions necessary for the energy exchange. Consideration of the added translational dispersion effect establishes 12 as the average rotational collision number. A Hubbard-type sonic interferometer was used together with a strip recorder, several different tuning techniques being employed at the lowest pressures.

3120

Ener, C., A. F. Gabrysh, and J. C. Hubbard, "Ultrasonic Velocity, Dispersion, and Absorption in Dry, CO_2-Free Air," J. Acoust. Soc. Am., 24, 474-477, 1952.

The velocity dispersion and absorption of ultrasonic waves in dry, CO_2-free air were measured at 32°C, at 2 and 3 Mcs, at pressures ranging from 0.020 to one atm. Dispersion of the velocity was found beginning at 30 Mc/atm, increasing by 5% at 100 Mc/atm, accompanied by a large increase in absorption such that, at the higher limits of f/p reached, measurements became nearly impossible with the equipment used. The ratio $\alpha_{exp}/\alpha_{class}$ decreased from about 2.4 to 1.3, and C_v/R decreased from 2.5 to nearly 1.5 as f/p increased. The changes in velocity, absorption and internal specific heat are interpreted as the result of the slowing of energy exchange between translational and rotational states. Assuming that relations for relaxation of translational-vibrational exchange also hold for this case, the relaxation time for translational-rotational exchange as derived from the dispersion measurements has been found to be 2.29×10^{-9} sec. This corresponds to a frequency of the midpoint of the dispersion curve of 116 Mc/atm, and to 16 as the number per molecule of collisions required for an energy exchange between translational and rotational states. Absorption results were more difficult to secure; by using low frequency values, a relaxation time of about 3×10^{-9} sec was indicated, giving 87 Mc/atm as the f/p value of the midpoint of the dispersion curve, and 21 as the number of collisions required for the energy exchange.

3121

Greenspan, M., "Propagation of Sound in Five Monatomic Gases," J. Acoust. Soc. Am., 28, 644-648, 1956.

The speed and attenuation of sound at 11 mcs were measured in He, Ne, A, Kr, and Xe at various pressures between atmospheric and a few mm Hg; the results are compared with existing theories.

3122

Greenspan, M., "Rotational Relaxation in Nitrogen, Oxygen, and Air," J. Acoust. Soc. Am., 31, 155-160, 1959.

The speed and attenuation of sound at 11 mcs were measured in N_2, O_2, and dry air at various pressures between atmospheric and a few mm Hg. The rotational collision numbers were found to be: for N_2, 5.26 ± 0.05; for O_2, 4.09 ± 0.08; for air, 4.82 ± 0.18.

3123

Gutowski, F. A., "Ultrasonic Dispersion in a CO_2-H_2O Mixture," J. Acoust. Soc. Am., 28, 478-483, 1956.

The velocity of ultrasonic waves was measured in CO_2 containing 0.01 mole of water vapor at frequencies of 1001.8 kcs and 540.6 kcs in the range from 0.5 Mcs per atm. to 6 Mcs per atm. at 35.1°C. The mixture was prepared at one fixed CO_2 and H_2O pressure to give greater assurance of constant composition and was analyzed for water content by gravimetry. Variation of pressure within the interferometer was obtained by varying the rate of flow with a precision needle valve. Complete symmetry of current peak structure and, hence, a more accurate determination of wavelength were obtained by the technique of continually compensating for frequency shift due to the variation of acoustic impedance of the gas column. The velocity was found to vary from 286.2 m/sec at 6 Mcs per atm. to 278.1 m/sec at 0.5 Mcs per atm. The experimental points fit the curve for a single relaxation time of 3.03×10^{-7} sec, corresponding to an inflection frequency of 740 kcs per atm.

3124

Henderson, M. C., and L. Peselnick, "Ultrasonic Velocity and Thermal Relaxation in Dry CO_2 at Moderate Pressures," J. Acoust. Soc. Am., 29, 1074-1080, 1957.

The velocity and absorption of ultrasound in dry CO_2 were measured along the 50.8° isotherm with a Hubbard-type, variable-path, recording acoustic interferometer at six frequencies from 300 kcs to 7 mcs from 0.3 to 250 atm. (i.e., up to liquid densities). Velocity dispersion is clearly shown, in addition to the change in velocity attributable to the nonideality of the gas. The values of the frequency/density ratio f/ρ, at which the transition from $V_0{}^2$ to $V_\infty{}^2$ is half-completed as the pressure is lowered, and at which the maximum absorption per wavelength occurs, were measured whenever possible. From these determinations the relaxation time of the gas was determined as a function of the density. It proves to be inversely proportional to the density up to the highest density reached (0.8 g/ml), indicating that ternary collisions have not become important and that the number of binary collisions required to excite the internal vibrations does not vary with density. At 50.8° and 1 atm. the relaxation frequency $1/2\pi\tau$ is about 26 kcs and the number of collisions required to excite the molecule is 48,500. The extra absorption (in excess of the classical) remains a consequence of thermal relaxation up to liquid densities, and no new mechanism need be postulated to explain it. Further work at higher densities and other temperatures is in progress.

3125

Herzfeld, K. F., and T. A. Litovitz, "Absorption and Dispersion of Ultrasonic Waves," Academic Press, Inc., New York, 535 pp., 1959.

The text is divided into three roughly equal parts: A, the general theory of relaxation in fluids; B, gases; and C, liquids.

Part A begins from the Stokes-Navier equation of hydrodynamics, kinetic theory, and statistics. This part constitutes the mathematical formulation of the macroscopic aspects of the phenomena of absorption and dispersion, and is largely formal in character.

The parts devoted to gases and to liquids follow the same pattern: application of Part A to the particular state; a brief discussion of the appropriate methods of measurements; a summary of experimental results; and, finally, an attempt to survey the studies of the physical origins of the processes formally described in Part A. In many respects, those latter sections of Parts B and C are the most interesting portions of the book.

3126

Hodge, A. H., "Ultrasonic Velocity in Gases between 1 and 100 Atmospheres," J. Chem. Phys., 5, 974-977, 1937.

An acoustic interferometer of the resonator, or driven, type has been developed for the study of the behavior of ultrasonic waves in gases under pressures ranging from vacuum to several hundred atm.; measurements of acoustic velocity at several frequencies and in several gases at pressures ranging from 1 to 100 atm. have been made. Increase of velocity with pressure was found for air, N_2, He, and H_2, and a decrease for CO_2, with approximate pressure and velocity ranges as follows: air, 1-101 atm., 347-371 m/sec; N_2, 1-102 atm., 353-380 m/sec; CO_2, 1-63 atm., 270-198 m/sec. The He and H_2 were known to be impure. For them an increase in velocity nearly linear with pressure was found. Using frequencies from 88 to 499 kc, dispersion was found for CO_2, at atmospheric pressure, but almost entirely disappeared above 8 atm.

Demonstrates availability of this method for indirect determination of specific heats.

3127

Hubbard, J. C., "Acoustic Resonator Interferometer, Part II. Ultrasonic Velocity and Absorption in Gases," Phys. Rev., 41, 523-535, 1932.

The derivation of the equivalent electric network of the acoustic resonator interferometer in Part I of this paper has made it possible to develop the theory for the current in a simple resonant circuit in which the electrodes of the piezoelectric plate of the interferometer are connected to the terminals of the variable condenser. The special case of this theory is that in which the circuit is excited at a constant frequency determined by the crevasse frequency of the resonator plate in its given situation with respect to electrodes and associated circuit, when the acoustic path in the interferometer is detuned and the resonant circuit is tuned so that its resonant maximum occurs at the same frequency; the special case takes an especially simple form and leads to a direct procedure for determining ultrasonic velocity and absorption in a gas in terms only of current in the resonant circuit and path-length in the interferometer, all circuit and interferometer constants dropping out. The values of current as a function of pathlength obtained experimentally are in complete accord with the theory, and data for ultrasonic absorption in air and in CO_2 so far obtained agree with the meager data available by other methods. The role of the coefficient of reflection at the fluid-reflector surface is discussed.

3128

Hubbard, J. C., and A. H. Hodge, "Ratio of Specific Heats of Air, N_2, and CO_2 as a Function of Pressure by the Ultrasonic Method," J. Chem. Phys., 5, 978-979, 1937.

Hodge has made measurements of ultrasonic velocities at 27°C and pressures from one to 100 atm in air and N_2, and at one to 60 atm in CO_2. The results for air and N_2 combined with the respective compressibility data of Holborn and Otto for air at 27°C give values of γ between 1.406 at one atm and 1.580 at 100 atm, and for N_2, 1.403 at one atm to 1.564 at 100 atm. The acoustic velocities in CO_2 combined with the compressibility data of Amagat, give for γ at 27°C values from 1.304 at one atm to 3.524 at 60 atm. These and the other results between these limits are in excellent general agreement with the few findings available for comparison.

3129

Ishii, C., "Supersonic Velocity in Dry and Humid Air," Sci. Papers, Inst. Phys. Chem. Research (Tokyo), 201-208, 1935.

The theoretical and experimental formulae for the supersonic velocity in humid air, as found previously, were further tested by measurements of nodal strata formed by stationary waves in dry air and in air with definite humidity. Known values of humidity were obtained by using saturated aqueous solutions of Na and K salts. For frequencies from 288 kcs to 2892 kcs, the wavelength increases with the vapor pressure, e. The velocity V_h in humid air is, in terms of the velocity V_1 in dry air, $V_h = V_1(1 + Ae)$. The coefficient A decreases as the frequency increases, and since the velocity in dry air increases with the frequency, it is concluded that the effect of humidity diminishes with increase of frequency. It is thought that dispersion of velocity occurs with frequencies below 1000 kcs.

3130

Jatkar, S. K. K., "Supersonic Velocity in Air, Steam, CO_2 and CS_2," J. Indian Inst. Sci., 22A, 93-110, 1939.

The results of the present investigation are summarized in the following table:

	V		C_p	
	m/sec	γ	obs	cal
Steam (134°)	496.3	1.3295	8.26	8.26
CO_2 (25°)	269.6	1.3028	8.74	8.68
CO_2 (97.1°)	299.7	1.2899	8.94	8.93
CO_2 (97.1°)	220.1	1.2350	11.2	11.6

3131

Jatkar, S. K. K., "Supersonic Velocity in Gases, Part I," J. Indian Inst. Sci., 21A, 245-271, 1938.

As a preliminary to the measurement of the velocity of supersonic sound in the vapors of organic compounds, a study is made of the aberrations of supersonic interferometers used to determine wavelengths. Includes curves showing how the anode current of the quartz oscillator varies with the position of the reflector, and mapping irregularity of peak positions (corresponding to nodal planes). Investigates causes of these irregularities, and demonstrates that the best results are obtained when a somewhat narrow interferometer tube is used and the quartz is carefully positioned a short distance from the tube; under these conditions the wavelength is said to be obtainable with an accuracy of 1 in 700.

3132

Jatkar, S. K. K., "Supersonic Velocity in Gases and Vapors, Part II.," J. Indian Inst. Sci., 21A, 40, 455-465, 1938.

Presents records that show the complexity in waveform of sound propagating in gases and vapors in the Pierce interferometer. The complexity is due to variations in intensity and phase, which are caused by diffraction effects. The anomalous results obtained are thus due to experimental method, rather than to any characteristic of the physical situation, such as complexity of the molecule and its structure, or the attendant absorption and dispersion. As a result of many experiments, only the narrow-tube method has been found satisfactory for accurate determination of velocity. Values are given in meters per second for the velocity of sound at 49.42 kcs in a few typical gases, and for vapors in a 1-cm brass tube at 685 mm.

3133

Jatkar, S. K. K., "Supersonic Velocity in Gases and Vapors, Part III," J. Indian Inst. Sci., 21A, 477-487, 1938.

Working with tubes of varying diameters (1.25, 1.1, 0.97, 0.95, and 0.64 cm) and apertures, the distances between consecutive positions at which maximum reaction was shown at 49.47 kcs, were 0.426, 0.553, 0.708, 0.738, and 1.62 cm, respectively at 25°. The corresponding volumes are 0.522 cc for each tube, indicating that points of resonance depend on the integral volumes rather than on the wavelength, with a constant value for the conductivity of the neck. At 48.56 kcs the resonating volumes are integral numbers of 0.535 cm^3, showing that the volumes are inversely proportional to the squares of the frequencies, as required by the formula of the Helmholtz resonator. When the neck of the resonator was changed from 0.14 to 0.2 cm, the resonance peaks were inverted, showing that the presence of a tuned resonator increased the oscillation intensity of the crystal. The average interval (7.07 mm), observed between two consecutive positions at which the quartz oscillator was brought into oscillation, and that (7.08 mm) between two major peaks (Part I) in an open tube of 0.97 cm diameter when the oscillations of the crystal (49.47 kcs) were critically controlled, were due to volume resonance.

3134

Kao, P. T., "Speed of Ultrasonic Waves in Air," Compt. Rend., 193, 21-22, 1931.

Using Pierce's method, the author finds that inversions of the secondary maxima and of the plate-current maxima take place for positions of the reflector close to the quartz. The speed found is 331.85 mcs for frequencies between 40 and 1000 kcs. No appreciable dispersion was observed.

3135

Kinoshita, M., and C. Ishii, "Effect of Humidity on the Velocity of Supersonic Waves in Air," Bull. Inst. Phys. Chem. Research (Tokyo), 83-96, 1932.

The velocity V of waves, sonic or supersonic, in a real gas is calculated as $V = \sqrt{\frac{p}{\rho}\frac{\beta}{a}\gamma}$, where p is the pressure, ρ the density, a the expansion coefficient, β the pressure coefficient and γ the ratio of the specific heats. Treating both the air and the water vapor as real gases, V_h, the velocity in humid air, becomes $V_h = V_1(1 + 0.000210e)$, where V_1 is the velocity in dry air and e the vapor tension in mm Hg. The experimental result in the supersonic range, however, gave $V_h = V_1\{1 + (0.00023 \pm 0.00001)e\}$. An application of this relation to practical hygrometry is suggested.

3136

Kneser, H. O., "Theory of Dispersion of Sound and Dispersion of H. F. Sound-Waves in Carbon Dioxide," Ann. Physik, 11, 761-801; and 12, 1015-1016 (1932), 1931.

When a disturbance takes place in a gas, as during an adiabatic compression, a certain very small interval of time elapses before equilibrium of the external and internal energies is restored. The period of readjustment is determined by the life of the energy quantum and is accompanied by an increase in the speed of sound. With certain assumptions as to the exchange of quanta of energy during the collisions of molecules, a dispersion equation is derived for the propagation of sound in a gas. It contains one thermodynamically indeterminate term, namely, the life-period of the exciting energy. In the second paper the experimental measurements are described. The method adopted was that of Pierce. By the use of quartz oscillators with frequencies from 60,930 to 1,480,000, the speed of sound in CO_2 was measured relative to that in A. In the frequency range 10^5 to 6×10^5, the speed increases by 3.7%, and again becomes constant at a frequency of 12×10^5. There is good agreement between theory and experiment, if vibrational energy is taken in place of rotational energy. The life of the vibration quanta is calculated as $(1.0 \pm 1.2)10^{-5}$ sec. Other gases are being investigated.

3137

Meyer, E., and G. Sessler, "Sound Propagation in Gases at High Frequencies (100 to 600 kcs) and Very Low Pressures" (in German), Z. Physik, 149, 15-39, 1957.

Sound absorption and velocity values in argon, air, and hydrogen were measured in the f/p range 10^7 to 10^{11} cycles sec^{-1} atm^{-1}, using an interferometric method with condenser transducers (E. Meyer, Nuovo Cimento Suppl., 7, 248-254, 1950). Between 10^7 and 10^8 cycles sec^{-1} atm^{-1} the values in argon agree with the Stokes-Kirchhoff theory; in air, with the Burnett theory. Between 10^8 and 2×10^9 cycles sec^{-1} atm^{-1}, the values in argon and air and the velocity values in hydrogen agree better with the Burnett theory, and absorption measurements in hydrogen with the "super" Burnett theory. From 10^{10} to 10^{11} cycles sec^{-1} atm^{-1} the values agree with a molecular kinetic theory.

3138

Mokhtar, M., and E. G. Richardson, "Supersonic Dispersion in Gases, II. Air Containing Water Vapor," Proc. Roy. Soc. (London) A, 184, 117-128, 1945.

The apparatus and method of measurement are described. Curves are given showing the variation, at various frequencies, of the supersonic absorption coefficient μ and the supersonic velocity with the water vapor pressure. The results deduced are: (1) the velocity in dry air is independent of frequency; (2) the measured values for μ in dry air are several times larger than those calculated from the Stokes-Kirchhoff formula and indicate an approximately linear dependence on the frequency; (3) in humid air μ reaches a maximum, two or three times its value in dry air, at a vapor pressure which decreases as the frequency increases; (4) the maximum of dispersion in velocity decreases as the frequency increases.

3139

Overbeck, C. J., and H. C. Kendall, "Temperature and Frequency Effects on Ultrasonic Velocities in CO_2," J. Acoust. Soc. Am., 13, 26-32, 1941.

Ultrasonic velocity measurements in pure CO_2 gas were made at temperatures ranging from 25° to 530°C with frequencies from 27 to 147 kcs. Experimental variations published in earlier reports are traced to gas contamination and temperature gradient effects. Data are presented showing that the velocity is a function of both temperature and frequency. The velocity dependence on frequency becomes greater as the temperature is increased. This is due to an increased probability of the excitation of vibrational energy states as the temperature is raised. The results seem to show that the relaxation time for a transfer of energy from translational to vibrational states is longer than that for the transfer from translational to rotational states.

3140

Parbrook, H. D., and E. G. Richardson, "The Propagation of Ultrasonics in Gases under Pressure" (in French), Portugaliae Phys., 3, 127-138, 1954.

Measurements of ultrasonic velocity in carbonic acid and ethylene have been made using an interference method. The viscosities have also been measured, using the oscillating cylinder method, and the values compared with ultrasonic viscosities calculated according to the Stokes equation. The velocities at various temperatures show sharp minimal turning points in the region of 60-90 atm. (approx.) while the two viscosities become minimal in roughly the same pressure range. From these and other observations the authors conclude that a thermal relaxation process might account for the anomalous behavior. The paper is noteworthy for the extreme care which has been taken in the experimental work; for instance, the quartz crystal and the reflector are lined up by the Michelson interferometer method, and it is evident that the results are of a high order of accuracy.

3141

Parker, R. C., "Smoke Method of Measuring Supersonic Velocities," Proc. Phys. Soc. (London), 49, 95-104, 1937.

In view of certain criticisms brought against it, the smoke method used by Pearson has been further investigated. Various possible sources of error have been eliminated, and measurements of the velocity of sound have been made in air, O_2, and N_2 in the frequency range 92.2 to 801.7 kcs. The results are believed to be correct to within one part in 3000, and no evidence of dispersion in this range has been found. An explanation is given for Pearson's results.

3142

Pearson, E. B., "Behavior of Suspended Particles in Air, and Velocity of Sound at Supersonic Frequencies," Proc. Phys. Soc. (London), 47, 136-148, 1935.

In accordance with theory, particles of the size prevailing in ordinary cigarette smoke are found to act as obstacles in air vibrating at supersonic frequencies. This action leads to the formation, at the nodes in a resonance tube, of figures from which measurements of the wavelength can be made. These, with a knowledge of the frequency of each piezoelectric crystal used to maintain the oscillations, enable values of the velocity of the sound in air to be found at various frequencies in a range from 92.2 to 801.6 kcs. The values found show a definite dispersion of sound in this region, contrary to the results of previous experimenters with the Pierce acoustic interferometer. There are two maxima which are attributed to the separate effects of oxygen and nitrogen.

3143

Penman, H. L., "Effect of Temperature on Supersonic Dispersion in Gases," Proc. Phys. Soc. (London), 47, 543-548, 1935.

Measurements of wavelengths of supersonic radiation at frequencies between 40 and 140 kc have been made in CO_2, N_2O, and SO_2 at various temperatures from room temperature up to 200°C. The velocities at constant density (i.e., reduced to 0°C) have been calculated. When these are plotted against temperature, supersonic dispersion is shown by a sharp fall of velocity in CO_2 at a temperature which increases with the frequency of the source. The significance of these results in the light of the theories of supersonic dispersion which have been propounded is then discussed.

3144

Petralia, S., "Ultrasonic Interferometry in Gases, I" (in Italian), Nuovo Cimento, 7, 705-714, 1950.

After referring to the principal questions connected with the scattering of ultrasonic waves in gases, describes a variable-path interferometer which allows the determination of the propagation constants (velocity and absorption coefficients) of ultrasonic waves in gases and vapors, for frequencies between 50 and 2000 kcs, and discusses the experimental technique. Notes some preliminary measurements made in CO_2 (known to be dispersive) and in lighting gas, indicating that there is also velocity dispersion in this latter gas in the frequencies between 58 and 1400 kcs.

3145

Petralia, S., "Velocity and Absorption of Ultrasonics in Gases" (in Italian), Nuovo Cimento, 9 (Suppl. No. 1), 1-58, 1952.

This paper reviews the theory of ultrasonic dispersion, the molecular heats of vibration with reference to the absorption bands, and the experimental arrangements and methods together with results of measurements of the velocity and absorption in the more important gases and vapors. Comprehensive tables of values are given. 178 refs.

3146

Pielemeier, W. H., "Effect of Intensity on Supersonic Wave Velocity," J. Acoust. Soc. Am., 7, 37-38, 1935.

Further evidence is presented that supersonic waves in air have a velocity that depends on their intensity, and that this velocity approaches the limiting value $(\gamma P/\rho)^{1/2}$ at comparatively low intensities.

3147

Pielemeier, W. H., "Supersonic Dispersion and Absorption in CO_2," Phys. Rev., 41, 833-837, 1932.

Since supersonic velocity determinations in air near a crystal oscillator usually yield values in excess of the accepted value, V_0 = 331.6 m/sec, a similar effect with CO_2 was suspected. The velocity and the absorption coefficient were measured at frequencies beginning in the dispersion region, theoretically and experimentally investigated by Kneser, and extending beyond it to 2.09 megacycles. The author's velocity values are slightly less than Kneser's experimental values, but they fit his theoretically determined dispersion curve equally well. At the lowest frequency tested (303 kc) the absorption coefficient was found to exceed, by the greatest amount, its value computed from Lebedew's formula. This frequency is near the middle of the dispersion region where maximum absorption is expected. According to Pierce, the absorption becomes excessive also when this frequency is approached from lower values. The results are presented in tabular and in graphical form. A sharp absorption maximum appears at 217 kc.

3148

Pielemeier, W. H., "Supersonic Measurements in CO_2 at 0° to 100°C," J. Acoust. Soc. Am., 15, 22-26, 1943.

An attempt to harmonize the best data on the velocity and absorption of lf and hf sound waves CO_2. Velocity/temperature graphs are drawn, as are curves to show how the frequency for maximum absorption per wavelength depends on the water vapor concentration in the CO_2 at 1 atm pressure. Two distinct relaxation times are indicated for each concentration, and acetaldehyde is cited as a gas in which three relaxation times have been found.

3149

Pielemeier, W. H., "Ultrasonic Velocity and Absorption in Oxygen," Phys. Rev., 36, 1005-1006, 1930.

The velocity and absorption in oxygen at room-temperature were measured at five ultrasonic frequencies located in the two octaves, 316 to 1264 kcs. The observed velocities reduced to 0°C do not differ more than 0.2% from Dulong's observed value of V_0 for audible sound (317.2 Mcs). The theoretical value ($V_0 = (\gamma p/d)^{1/2}$) is 314.76 Mcs. The observed absorption values vary with frequency as expected, but the deviations from the theoretical values are greater than the velocity deviations.

3150

Pielemeier, W. H., and W. H. Byers, "Supersonic Measurements in CO_2 and H_2O at 98°C," J. Acoust. Soc. Am., 15, 17-21, 1943.

Following a previous method, the velocity and absorption were measured in CO_2 containing water vapor at 98°C. The apparent change in relaxation times from 28° to 98° was not entirely expected, and the minor absorption peaks were not rendered more prominent. The sp ht of CO_2 calculated from the results agrees with the values obtained from spectroscopic data and with reliable calorimetric results.

3151

Pumper, E. J., "Change of Velocity of H. F. Sound with Pressure" (in German), Physik. Z. Sowjetunion, 1, 300-310, 1935.

Reports measurements of the variation in the velocity of sound in dry air and CO_2 as the pressure is varied with sound having a frequency of 4.4×10^4~. The velocity increases with decreasing pressure—a change of 0.65% in the case of air and 2.2% in the case of CO_2 for a changein pressure from atmospheric to 1/50 atmosphere. Possible explanations of the results are discussed.

3152

Pusat, N., "The Velocity of Sound in a Real Gas as Function of the Pressure," Rev. Fac. Sci., Univ. Istanbul, Ser. A, 17, 46-60, 1952.

The formula for the velocity of sound in a real gas that shows a relaxation mechanism was calculated as function of pressure and frequency. This formula has been discussed specially for CO_2. The velocity of sound in the vapor of ethyl-formate was measured with an acoustical interferometer, and the theoretical conclusions were applied to the results. A mechanism of relaxation was found with a characteristic time constant of 1.9×10^{-8} sec, calculated for one atm pressure.

3153

Quigley, T. H., "An Experimental Determination of the Velocity of Sound in Dry CO_2 -Free Air and Methane at Temperatures Below the Ice Point," Phys. Rev., 67, 298-303, 1945.

The fixed-path acoustic interferometer was used. Acoustic resonance in a limited column of gas, coupled to a driven X-cut quartz crystal whose fundamental frequency is about 600 kcs, is produced by temperature variation. The procedure is such that differences in temperature readings, when the temperature is rising and when it is falling, are reduced to an amount in keeping with the other errors of measurement. No molecular acoustic dispersion has been observed, so that the results are made available with special reference to their value for computations of specific heats. The results are given, within experimental error, by the following formulae.
For air,

$$v^2 = 3.8762 \times 10^2 T + 806 + 1.8043 \times 10^5 T^{-1} - 2.0364 \times 10^7 T^{-2} + 3.007 \times 10^{-2} T^2$$

And for methane,

$$v^2 = 6.6176 \times 10^2 T + 1.0016 \times 10^6 T^{-1} - 1.3846 \times 10^8 T^{-2}$$

3154

Railston, W., and E. G. Richardson, "Effect of Pressure on Supersonic Dispersion in Gases,"Proc. Phys. Soc. (London), 47, 533-542, 1935.

Measurements of wavelengths by interferometer and hot-wire methods, and of absorption by hot-wire methods alone, have been made for supersonic radiation at frequencies between 40 and 2000 kcs in CO_2, N_2O and SO_2 at various pressures up to 2 atm. For the hot-wire method, a circuit which gives a linear relation between amplitude or particle velocity and response at constant frequency is described. The velocity-measurements in the two former gases may be reduced to a common curve by plotting them against the parameter (f/p). Although the observed velocity rise in the region where this parameter lies between 100 and 1000 is in accordance with the relaxation-time theory, the decrease in velocity at lower and higher values is not. In SO_2 the rise of velocity is in the neighborhood of 4000. The absorption in all three gases rises sharply at pressures below 400 mm of mercury.

3155

Reid, C. D., "Effect of Distance from the Source on the Velocity of Sound at Ultrasonic Frequencies," Phys. Rev., 37, 1147-1148, 1931.

Measurements of the velocity of ultrasonic waves have been made at a greater distance than heretofore. It is found to be independent of frequency within 0.01%, which is the error of measurement.

3156

Reid, C. D., "Velocity of Sound at Ultrasonic Frequencies Using Quartz Oscillators," Phys. Rev., 35, 814-831, 1930.

Reports measuring the velocity of sound at frequencies 40 to 216 kcs per sec., using quartz crystals as sound oscillators. The sound emitted travels to a movable reflector and then returns to the source. As the reflector is moved, the phase of the reflected sound changes, causing the plate current of the quartz oscillator to pass through a maximum value each time the reflector is moved a half wavelength (Pierce's method). The velocity was determined in air free from CO_2 at three values of humidity, viz., dry, 45% humidity at 20°C, and in air saturated with water vapor at 20°C. The velocity was found to decrease with increasing distance from the source, approaching asymptotically to a value 331.60 meters per sec at a distance of 45 cm from the source. The effect of humidity was found to be expressible by $V_H = V_O + 0.14H$, where V_O is the velocity in dry air at 20°C, and V_H is the velocity at any relative humidity H at 20°C.

3157

Richardson, E. G., "The Velocity of Sound: A Molecular Property," Nature, 158, 296-298, 1946.

Briefly reviews the relaxation theory of the influence of molecular properties of a gas on the velocity of sound propagation at high frequencies; it is emphasized that the theory has not yet been independently confirmed by experiment. No evidence has been found of dispersion of velocity in liquids, though there is evidence of enhanced scattering. The "second velocity of sound in He II" can be explained on the simple basis of high thermal conductivity; that is, temperature changes propagate at rates close to the speed of sound.

3158

Roy, A. S., and M. E. Rose, "Rotational Dispersion of Sound in Hydrogen," Proc. Roy. Soc. (London), 149A, 511-522, 1935.

The dispersion of sound in hydrogen is investigated. The results show that no variation of velocity occurs below frequencies of the order 10^6 cps. This is to be expected from the classical theory of Jeans as well as from the quantum treatment of the inelastic collision between two hydrogen molecules.

3159

Sessler, G., "Sound Absorption and Sound Dispersion in Gaseous Nitrogen and Oxygen at High Frequency Pressure Values," Acoustica, 8, 395-397, 1960.

Sound absorption and dispersion in nitrogen and oxygen at 20°C and at frequency/pressure (f/p) values of 10^6 to 10^9 cycles/atm have been measured. The method used is the interferometric arrangement described in an earlier paper (Meyer, E., and G. Sessler, Z. Physik, 149, 15-39, 1957). Reference is also made to a paper by Greenspan (J. Acoust. Soc. Am., 30, 672, 1958). Experimental values of the ratios of absorption α to dispersion β (α/β) are plotted as a function of the ratio f/p. For nitrogen the ratio α/β falls from 0.3 to 0.01 as the ratio f/p decreases from 10^9 to 10^7. For oxygen the experimental curve is much the same. The experimental results agree well with theory.

3160

Shields, F. D., "Thermal Relaxation in Carbon Dioxide as a Function of Temperature," J. Acoust. Soc. Am., 29, 450-454, 1957.

Sound absorption and velocity have been measured in carbon dioxide between 0 and 200°C. The relaxation absorption was isolated by subtracting the tube and classical absorptions from the measured absorption. The Kirchhoff equations, which had been justified previously by measurements in A and N_2, were used to make these corrections. From the relaxation absorption were determined the temperature variation of the thermal relaxation time, the transition probability, and the collision efficiency. The results indicate that, for the frequencies and pressures here employed, the relaxation absorption and velocity effects are a function of f/p. This means that only binary collisions are effective in transferring energy between the vibrational and translational modes. The relaxation theory with a single relaxation time for all the vibrational modes adequately predicts the observed absorption and velocity. It is estimated that a separation in the relaxation times of the two lowest modes by a factor of more than two could not have gone undetected at 100°C. The temperature variation of the collision efficiency was adequately predicted by the Landau-Teller equation.

3161

Stewart, E. S., "Dispersion of the Velocity and Anomalous Absorption of Sound in Hydrogen," Phys. Rev., 69, 632-640, 1946.

The velocity and absorption of sound in hydrogen were measured at 25°C at 3.855 and 6.254 mcs and at pressures of 1.00, 0.83, 0.67 and 0.50 atm. Dispersion of the velocity from 1321.9 m/sec to 1382.0 m/sec and anomalous absorption observed are interpreted as caused by molecular absorption induced by loss of the rotational degrees of freedom. Calculations place the inflection point of the dispersion curve at 10.95 Mcs the peak of the absorption curve at 10.0 Mcs from velocity data, and at 16.1 and 14.8 Mcs, respectively, from absorption data. The relaxation times for pressures of 1 atm. from the two sets of data are 1.9 and 1.7×10^{-8} sec. The f/p law is not strictly obeyed.

3162

Stewart, J. L., "A Variable Path Ultrasonic Interferometer for the Four Megacycle Region with Some Measurements in Air, CO_2, and H_2. Rev. Sci. Instr., 17, 59-65, 1946.

Alignment of the piston and crystal to the order of one light fringe was attained and maintained by employing Newton and Haidinger optical fringe systems. Velocities were measured to an accuracy of 0.1%, and absorption and reflection coefficients to 50% in air and CO_2. The limit of accuracy in both cases was determined by the length, as measured to one micron with a micrometer screw. Preliminary measurements on H_2 gave evidence of molecular dispersion between 4 and 8 mcs.

3163

Thaler, W. J., "The Absorption and Dispersion of Sound in Oxygen as a Function of the Frequency-Pressure Ratio," J. Acoust. Soc. Am., 24, 15-18, 1952.

The velocity and absorption of ultrasonic waves in oxygen were measured by means of an improved ultrasonic interferometer in the range from 1 to 100 Mcs atm. Dispersion of the velocity ranged from 333.14 m/sec to 357.22 m/sec at 30°C. The ratio ($\alpha_{exper}/\alpha_{class}$) dropped from 3.68 to 2.05, and the corresponding value of C_V/R dropped from 2.50 to 1.61. The increase in velocity and the decrease in ($\alpha_{exper}/\alpha_{class}$) is interpreted as caused by the slow exchange of energy between the translational and rotational degrees of freedom. The relaxation time for the rotation was 5.24×10^{-9} sec.

3164

Truesdell, C., "Nonlinear Absorption and Dispersion of Plane Ultrasonic Waves in Pure Fluids," J. Wash. Acad. Sci., 42, 33-36, 1952.

This paper points out that the mean-free-path argument of previous workers cannot be applied to liquids. While the two-term power series expansion for the absorption and dispersion coefficients is not accurate, the exact solution of the Navier-Stokes equations fits experiments very well.

3165

van Itterbeek, A., and J. Zink, "Measurements on the Velocity of Sound in Oxygen Gas Under High Pressure," Appl. Sci. Res. A, 7, 375-385, 1958.

Using the acoustical interferometer for high pressures described in an earlier publication, the velocity of sound in oxygen gas between one and 70 atm was measured as a function of pressure at different temperatures. From the experimental data the change of the ratio of the specific heats and the specific heats themselves, as a function of pressure at the different temperatures, were calculated.

3166

van Itterbeek, A., and P. Mariens, "Velocity and Absorption of Sound at Ordinary and Low Temperatures," Physica, 4, 207-215, 1937.

Experiments with ultrasonics are made on the velocity and absorption of sound in O_2, N_2, and H_2 at ordinary and low temperatures. The influence of a magnetic field perpendicular to the direction of propagation of the velocity and the absorption of sound in O_2 is studied. No influence is found on the velocity; the absorption, however, seems to decrease. At low temperatures, measurements are made at the boiling point of O_2. The dependence of the velocity and absorption of sound on pressure in O_2, N_2, and H_2 is studied. Concerning the velocity in O_2 and N_2, a good agreement with the Leiden measurements if found. The dependence on pressure, found for the absorption coefficient of O_2 and N_2, corresponds fairly well with the classical theoretical absorption. The values found for the absorption coefficient of H_2 show that at the boiling point of O_2 there is still a dispersion effect.

3167

van Itterbeek, A., and W. de Rop, "Measurements on the Velocity of Sound in Air Under Pressures up to 20 ATM Combined with Thermal Diffusion," Appl. Sci. Res. A, 6, 21-28, 1956.

An acoustical interferometer has been constructed to measure the velocity of sound in gases under high pressures and low temperatures. Velocity measurements have been carried out down to the boiling point of liquid propane. During the measurements the influence of thermal diffusion could be observed. A few measurements are done by measuring the change of the velocity as a function of time.

3168

van Itterbeek, A., W. de Rop, and G. Forrez, "Measurements on the Velocity of Sound in Nitrogen Under High Pressure," Appl. Sci. Res. A, 6, 421-432, 1957.

Using an acoustical interferometer for high pressures, the velocity of sound was measured in nitrogen gas between one and 75 atm as a function of pressure and at different temperatures.

The experimental data are compared with direct measurements on the equation of state of nitrogen gas. From the experimental results for the velocity, the change of the ratio of the specific heats and the specific heats themselves were calculated as a function of pressure, and at different temperatures.

3169

van Itterbeek, A., and W. van Doninck, "Measurements on the Velocity of Sound in Mixtures of Hydrogen, Helium, Oxygen, Nitrogen and Carbon Monoxide at Low Temperatures," Proc. Phys. Soc. (London), B, 62, 62-69, 1949.

By means of a quartz oscillator ultrasonic radiation is emitted into a gas at a pressure that can be varied. Experimental values of the velocity of sound for various concentrations of the constituent gases at various temperatures are recorded. These values refer to an ideal state of the mixture at zero pressure. Numerical values are given that enable the velocity under increased pressure to be calculated in accordance with a theoretical equation that involves a certain empirical relation between the second virial coefficient for the mixture and the corresponding virial coefficients for its components. This empirical relation is provided by measurements recorded in a previous paper. All the experimental results recorded are in agreement with the theoretical equation referred to except those relating to H_2-N_2 mixtures.

3170

van Itterbeek, A., and W. van Doninck, "On the Velocity of Propagation of Sound in Air, and in a Nitrogen-Hydrogen Mixture, at Low Temperatures, Calculation of the Specific Heats," Ann. Phys., 19, 88-104, 1944.

An ultrasonic experimental method is used. The acoustic interferometer and its associated electric circuit, and the apparatus for preparing the H_2-N_2 mixture, are described. A theoretical method is given, based on the equation of state $pv = RT(1 + \frac{B}{v} + \frac{C}{v^2} + \ldots)$. It is shown that the velocity of propagation (W) is given by the linear relation $W = W_0(1 + sp)$ where W_0 is a function of t and $s = \frac{B}{R} + \frac{1}{\lambda R}\frac{dB}{dT} + \frac{1}{2\lambda(\lambda + 1)}\frac{T}{R}\frac{d^2B}{dT^2}$.

Numerical results (experimental and theoretical) are presented in graphical and tabular form. For air, the velocity was measured between 79.15°K and 90.10°K (obtained by means of liquid oxygen) at pressures varying between 0.085 and 0.941 atm. The coefficient, B, for air is plotted as a function of T, and numerical values of W_0 are given. The specific heats for air are given as function of the pressure for T = 90°K and T = 80°K. Similar results are given for H_2-N_2.

3171

Vereshchagin, L. F., N. A. Yuzefovich, and A. V. Cheloviskii, "Measurement of the Speed of Ultrasound in Some Gases in a State of High Density," Soviet Phys. Doklady, 1962.

The results of measurements of the speed of ultrasound (3.5 Mc/sec) in nitrogen, argon, and helium at pressures up to 3500 atm are presented graphically. The coefficients of adiabatic heats for nitrogen as a function of pressure, computed from the results, are also shown graphically.

3172

Wallmann, M. -H., "Period of Readjustment of Heat Oscillations in CO_2 and Its Modification by Foreign Gases and Pressure," Ann. Physik, 21, 671-681, 1935.

The velocity of sound in CO_2, H_2, mixtures of these, and mixtures of CO_2 with the inert gases, is found by means of a piezoquartz oscillator, as has been done before by Kneser and others. For a pressure of 600 mm of Hg and 21°C, the dispersion in CO_2 leads to a determination of the period of readjustment of heat vibration as $\rho = 4.6 \times 10^{-6}$ sec. The velocity in pure hydrogen for frequencies 359,000 to 1,481,000 shows that it remains constant to 4% and is equal to the velocity in the audible region. The period of readjustment varies linearly with the percentage of H_2 present in CO_2 mixtures and is also inversely proportional to the pressure.

3173

Warner, G. W., "Frequency and Temperature Effect on the Velocity of Supersonic Waves in Gases," J. Acoust. Soc. Am., 9, 30-36, 1937.

An experimental study in which a modified Kundt's tube with movable reflector is used for producing standing waves. As the reflector is moved it passes through nodes and loops and the varying amount of energy reabsorbed by the electrical circuit is used to determine the wavelength by the reaction of a rf milliammeter in the energising circuit. In CO_2, N_2O, and SO_2, the velocity increases with increasing frequency but the increase is greater in CO_2 than in the other two gases. The velocity at any frequency is practically constant at all temperatures in N_2O and SO_2, but in CO_2 the curve is flat for the lower temperatures, rapidly decreases from 6-10 meters per second in the temperature range between 50° and 130°C, and again becomes constant at the higher temperatures.

3174

Wright, W. M., "The use of Amplitude Modulation for the Measurement of Ultrasonic Velocity Dispersion in Gases," Tech. Memo. No. 48, Acoust. Res. Lab., Harvard Univ., Cambridge, Mass., 42 pp., 1962.
AD-285 959.

Ultrasonic velocity dispersion in fluids is usually assessed by direct measurement of the speed of sound as a function of frequency. Greater accuracy might be achieved if a quantity proportional to the change of sound velocity with frequency could be measured. The mathematical theory for a dispersion-measurement method using transmission of an amplitude-modulated acoustic signal through a dispersive medium is examined for an idealized case. It is concluded that the proposed method has serious shortcomings. Two other schemes which might use properties of amplitude-modulated signals to measure acoustic velocity dispersion in gases are also considered briefly.

3175

Zartman, I. F., "Ultrasonic Velocities and Absorption in Gases at Low Pressures," J. Acoust. Soc. Am., 21, 171-174, 1949.

The improvements on an ultrasonic interferometer are discussed. As a result of these, a greater sensitivity to acoustic reactions is obtained and the reproducibility of the data is greatly improved. Velocity measurements in dried CO_2-free air, dried N_2 and dried H_2 are given. Amplitude absorption coefficients for H_2, N_2 and CO_2 are also included. Measurements are made over the temp. range from 9°C to 36·6°C and over the pressure range from 82.17 cm Hg to 0.45 cm Hg. The frequencies extend from approximately 500 kcs to 2.16 Mcs. A maximum value for the absorption in H, attributed to molecular absorption, is located at an f/p ratio of approximately 10 Mcs/atm.

3176

Zmuda, A. J., "Dispersion of Velocity and Anomalous Absorption of Ultrasonics in Nitrogen," J. Acoust. Soc. Am., 23, 472-477, 1951.

By means of the interferometer, the velocity and absorption of ultrasonic waves in N were measured at the frequency of 2.992 Mcs in the pressure range of 2.09 to 76 cm of Hg at a temperature of 29°C. A dispersion of velocity was found ranging from 354.3 m/sec to 364.4 m/sec. The ratio $\alpha_{exp}/\alpha_{class}$ dropped from 1.40 to 1.32, and the corresponding value of C_v/R dropped from 2.50 to 2.08. Theoretical values for the change in velocity and in the absorption ratio, calculated by applying the equations for the exchange of energy between translational and vibrational degrees of freedom, show good agreement with the observed values. The increase in velocity and the decrease in $\alpha_{exp}/\alpha_{class}$ is interpreted as due to the slow exchange of energy between the translational and rotational degrees of freedom. The relaxation time for rotation was found to be 1.2×10^{-9} sec.

Velocity, Ultrasonic
See Also — 91, 96, 117, 134, 147, 153, 263, 299, 305, 590, 808, 809, 810, 813, 828, 838, 839, 846, 944, 1061, 1134, 1140, 1143, 1145, 1244, 1334, 2275, 2969, 2970, 3064, 3212

VISCOSITY EFFECTS

3177

Alblas, J. B., "On the Diffraction of Sound Waves in a Viscous Medium," Appl. Sci. Res., Sect. A, 6, 237-262, 1957.

The theory of the diffraction of a sound wave at a half-plane barrier is extended to the case of propagation in a viscous medium. It is shown that the singularity in the velocity near the edge of the barrier, a characteristic feature of the classical second-order theory, disappears. In the neighborhood of the edge the velocity attains its maximum, the value of which is determined by a reciprocal power of the viscosity. In the far field a viscous wave occurs, the amplitude of which is proportional to the square root of the viscosity, in contrast to the second-order theory, where the introduction of a viscosity gives rise to a linear dependence.

3178

Andersen, W. H., and D. F. Hornig, "Shock Front Thickness and Bulk Viscosity in Polyatomic Gases," J. Chem. Phys., 24, 767-770, 1956.

The thickness of shock fronts in carbon dioxide and nitrous oxide gases has been measured by the light-reflectivity method. The thicknesses of these fronts agree with thicknesses predicted theoretically when only shear viscosity and heat conduction effects are considered. They demonstrate that the contribution of any real-bulk viscosity is small. The molecular vibrations are not excited in the shock front and hence the large sound absorption in these gases — in excess of that calculated using shear viscosity — can only come from the vibrational excitation process. Real-bulk viscosity in ideal gases is not a manifestation of vibrational excitation but only of the rotational excitation process.

3179

Broer, L. J. F., "Pressure Effects of Relaxation and Bulk Viscosity in Gas Motion," Appl. Sci. Res. A, 55-64, 1954.

A comparative study is made of the pressure effect of relaxation and bulk viscosity in stationary flow. It is shown that both stagnation pressure defects (Kantrowitz effect) and pressure distribution in small nozzles in principle constitute methods for distinguishing between the two theories. A discussion of the experimental data on carbon dioxide shows that in this case only the relaxation interpretation is possible.

3180

Biquard, P., "Ultrasonic Waves," Rev. Acoust. 1, 93-109, 1932.

A mathematical account of plane wave motion deriving from first principles expressions for the energy transmission associated with a sound wave and the decay of amplitude with distance due to viscosity and heat conduction. At 10°C and at a frequency of 160,000 cps, the effect of conduction on damping is, for water, 7000 times less than the effect of viscosity; whereas for air it is only three times less. The paper concludes with Langevin's deduction of the fact that the pressure exerted by sound radiation is equal to the energy density of that radiation.

3181

Bush, W. B., "The Hypersonic Approximation for the Shock Structure of a Perfect Gas with the Sutherland Viscosity Law," Rept. No. AFOSR-2257, Firestone Flight Sciences Lab., Calif. Inst. of Tech., Pasadena, 24 pp., 1962.
AD-275 884.

The classical Navier-Stokes treatment of the shock-wave structure is investigated for a perfect gas with constant specific heats. The viscosity of the gas is prescribed according to the Sutherland law. The Prandtl number is 3/4. The limiting forms of the solution as the upstream flow Mach number approaches infinity, with all other parameters held fixed, are studied. Two distinct asymptotic series are found for the portions of the shock adjacent to the uniform regions upstream and downstream of the shock, and these expansions are matched in an intermediate region of common validity. The leading terms of a uniformly valid expansion are obtained by combining elements from both expansions. Special attention is given to the entropy and the entropy-production rate in the shock wave.

3182

Chaing-Sheng, W., "Hypersonic Viscous Flow near the Stagnation Point in the Presence of Magnetic Field," J. Aero/Space Sci., 882-893, 1960.

Lighthill's constant-density solution for a sphere (J. Fluid Mech., Vol. 2,1-32, 1957) to which a magnetic field was added by Bush (J. Aero/Space Sci., Vol. 25, 685-90, 1958) is further generalized by including also the effects of viscosity. Constant fluid properties are assumed, which implies a very hot body. The shock wave is taken to be discontinuous, which means that the entire shock layer is not viscous. Self-similar solutions are found for the stagnation region behind a circular or spherical shock wave. The resulting ordinary differential equations were integrated numerically for a variety of cases.

3183

Clark, R. O., "A Study of Shock Wave Attenuation in Tunnels," Memo Rept. No. 1401, Ballistic Res. Labs., Aberdeen Proving Grounds, Md., 47 pp., 1962.
AD-278 595.

A theoretical investigation of shock wave expansion and viscous attenuation in a tunnel is described. In particular, relationships between the applied and transmitted shock pressure are presented for various entrance configurations and orientations. Shock tube data are given to verify the theory. Working equations and graphs are given to aid in the solution of other shock wave-tunnel problems, assuming a classical wave form for the shock wave and a constant tunnel cross-section.

3184

de Groot, S. R., "On the Thermo-Dynamical Theory of Relaxation Phenomena: Acoustical Relaxation, Appendix VI.," AFOSR-TN-58-233, Leyden State Univ., Netherlands, 13 pp., 1958.
AD-154 136.

The thermodynamic theory of acoustical relaxation is reviewed. The theory is set up for a fluid in which heat conduction, viscosity, and a relaxation phenomenon may occur. Two approximations are considered. In the first, all irreversibility, except the relaxation, is neglected; in the second, the other irreversible phenomena are taken into account in the first order. In both cases expressions are derived for the velocity of sound. The well-known fact is established that for low frequencies, the relaxation gives rise to a contribution to the bulk viscosity.

3185

Doak, P. E., "A Disucssion on the First and Second Viscosities of Fluids: Vorticity Generated by Sound," Proc. Roy. Soc. (London), A, 226, 7-16, 1954.

A revision is given of the basic theory of second-order effects caused by acoustic disturbances in a fluid, especially the vorticity giving rise to the ultrasonic wind, which was first explained by Eckart. The ultrasonic wind is produced by the interaction of the radiative and the non-radiative components of the acoustic motion. The wind speed is for the most part proportional to the acoustic attenuation coefficient. Wind speed measurements thus usually furnish no more information about the second coefficient of viscosity, or the bulk viscosity, than do other attenuation measurements.

It appears reasonable to regard the Stokesian bulk-viscosity coefficient as a parameter of intramolecular and intermolecular relaxation processes. It does not have a unique value for all frequencies. Provided other parameters, such as the coefficients of shear viscosity and heat conduction, and the specific heats are known independently, this effective bulk viscosity can be evaluated from any type of attenuation measurement. Measurements over sufficiently large frequency ranges can distinguish among the contributions of different relaxation processes to the effective bulk-viscosity coefficient.

3186

Gemant, A., "Frictional Phenomena," III-IV, J. Appl. Phys., 12, 718-734, 1941.

III. The part played by viscous forces in the absorption of acoustic waves traveling freely in the gas along with absorption due to heat conduction by the gas gives sound-absorption coefficients which, in nearly every case, are too small. Kneser's theory of a relaxation time explains the divergence as due to intramolecular vibrations, and the absorption in air is reduced by humidity because the water molecules reduce the relaxation time of the air molecules and shift the maximum absorption to higher frequencies. IV. The principles of room acoustics are discussed, and the sound-absorbing property of materials is explained on the basis of viscous processes in the pores of the material. Two methods are described for determining experimentally the acoustical resistance of a material: (1) The flow resistance is compared with that of a glass capillary; the units are placed in series and the same current of air is sucked through both; the pressure differences between the ends of the units are $\propto$ the respective resistances; experiment gave 14×10^3 for insulite and 18×10^3 for celotex, in absolute units. (2) The velocity of the gas is measured by means of a chemical indicator; the method is not suitable for low-resistance material. The properties of absorbents are discussed in relation to room acoustics.

3187

Hoff, L., "Volume Viscosity and Compressibilities from Acoustic Phenomena," J. Acoust. Soc. Am., 23, 12-15, 1951.

A phenomenological theory of volume viscoelasticity is formulated, resulting in an equation recently used by Hall. Application of this equation to the dispersion and absorption of sound in fluids is extended to the whole range of frequencies. Results of calculations of the volume viscosity and the instantaneous and relaxational compressibilities for gases and liquids from certain available absorption data are given. The bearing of this theory on the classical theory of hydrodynamics is pointed out.

3188

Huetz-Aubert, M., and J. Huetz, "Ultrasonic Absorption and Dispersion in Monatomic Gases: The Three Sources of Classical Irreversibility" (in French), J. Phys. Radium, 20, 7-15, 1959.

The study of dispersion and absorption effects, so called "classical effects" or effects of translation, since they affect the molecular degrees of freedom, is most useful for separating the global effects which are the only ones accessible to experiment, from those which are due to intramolecular relaxation. As this latter cannot affect the behavior of monatomic gases, the experimental control is easier if it is confined to these gases. Viscosity and conduction are the most important classical effects, but radiation leads to dispersion and absorption equations identical to those which are found by relaxation. Thus, irreversibiltiy does not essentially differ according to its inter- or intramolecular origin. It can be concluded that the theory of effects of translational absorption and dispersion is verified.

3189

Jarvis, S., Jr., "Note on the Papers: I. 'Combined Translational and Relaxational Dispersion of Sound in Gases,' by M. Greenspan; II. 'The Effects of Viscosity and Heat Conduction on the Transmission of Plane Sound Pulses,' by J. R. Knudsen," J. Acoust. Soc. Am., 27, 613, 1955.
See Also: Greenspan, M., J. Acoust. Soc. Am., 26, 70-73, 1954.
See Also: Knudsen, J. R., J. Acoust. Soc. Am., 26, 51-57, 1954.

For the "Becker" gas, the heat conductivity K and viscosities (μ, λ) satisfy $K = (2\mu + \lambda)C_p$; transient three-dimensional acoustic pressure disturbances are propagated according to a third-order equation derivable from the Navier-Stokes equations.

3190

Jorand, M., "Influence of Turbulence on the Attenuation of Sound in Free Air" (in French), Compt. Rend., 248, 1306-1308, 1959.

Classical theories fail to explain the observed sound attenuation. Better agreement is given by replacing the classical viscosity by an appropriate kinematic viscosity.

3191

Kaspar'iants, A. A., "On the Propagation of Sound Waves in a Viscous Gas in the Presence of Heat Conduction" (in Russian), Prikl. Mat. Meh., 18, 729-734, 1954.
See Also: Translation available from M. D. Friedman, 2 Pine Street, West Concord, Mass.

General solutions are obtained of linearized equations for viscous, thermally conducting perfect gases, assuming the velocity, condensation, etc., are proportional to $e^{i\sigma t}$, where σ is a constant.

3192

Keller, J. B., "Decay of Spherical Sound Pulses Due to Viscosity and Heat Conduction," J. Acoust. Soc. Am., 26, 58, 1954.

By combining the results of Kirchhoff and Knudsen, the effect of viscosity and heat conduction on a spherical sound pulse are found. A rectangular pulse becomes Gaussian, its peak moves with sound speed, its width increases proportionally to vt, and its amplitude decreases proportionally to $x^{-3/2}$, where x denotes radial distance from the origin. This behavior is exactly the same as that of a pulse in one dimension, except for an extra factor of 1/x which accounts for the spherical spreading.

3193

Kneser, H. O., "Compression- and Shear-Viscosity in Gases" (in German), Ann. Physik, 6, 253-256, 1949.

Not all the energy used in compressing a fluid is available on reexpansion. The energy absorbed may be expressed in terms of the compression viscosity ζ, the relation being similar to that between the shear-viscosity η and the energy used in shear deformation. In Stokes's theory of sound absorption the compression viscosity is neglected; its value can therefore be estimated from discrepancies between experimental observations and Stokes's theory. Available data on sound-absorption in He, Ar, H_2 and N_2 is examined from this point of view. It is found that for the monatomic gases $\zeta = 0$; for N_2 ζ is of the same order as η, while for H_2 ζ approx. = 60 η at low frequencies, decreasing rapidly with increasing frequency. These results are in general agreement with predictions from kinetic theory.

3194

Knudsen, J. R., "The Effects of Viscosity and Heat Conductivity on the Transmission of Plane Sound Pulses," J. Acoust. Soc. Am., 26, 51-57, 1954.

The dissipative effects of viscosity and heat conductivity are studied here in connection with the flow of a compressible fluid in a parallel channel or tube. Two kinds of waves or pulses are considered, and the distortion from the customary square wave is calculated. One observer at a fixed point on the channel, and two travelling with the wave, are seen to give information on the order of decay or dissipation of the wave with increasing time.

3195

Kohler, M., "The Volume Viscosity of Gases as a Gas-Kinetical Transport Phenomenon" (in German), Naturwissenschaften, 33, 251-252, 1946.

The volume viscosity μ is defined by $T_{ii} = p - \mu \text{div} \rightarrow v - 2\eta (d_{ii} - \frac{1}{3} \text{div } v)$, where the T_{ii} (i = 1, 2, 3) are the diagonal elements of the stress tensor, p = the pressure, $\vec{v} = (v_1, v_2, v_3)$ the velocity, η = the ordinary viscosity and $d_{ii} = \partial v_i/\partial x_i$. The Maxwell relation $\mu = 0$ is true only for a monatomic gas. A polyatomic gas, in which the oscillations are not excited and the rotations are fully excited, can be treated by representing the molecules as rough spheres. If $K = 4\pi I/MD^2$ is used as an expression for the density distribution in the sphere (I = moment of inertia, m = mass, D = diameter), this model gives:

$$\mu/\eta = (1 + \frac{13}{6} K)/10K > 0.336$$

The volume viscosity causes an increase in the absorption of sound. For $C_p/C_v = 4/3$ this amounts to more than 20% of the contribution due to viscosity and thermal conductivity. This result agrees with experiment.

3196

Kohler, M., "The Volume Viscosity of an Ideal Gas as a Kinetic Theory Transport Phenomenon" (in German), Z. Physik, 124, 757-771, 1948.

The macroscopic theory of fluid motion gives a stress tensor $p_{ij} = (p + \mu \text{ div } u)\, \delta_{ij} + \eta w_{ij}$ (η is the viscosity and w the shear tensor). The last term is α to the rate of volume expansion. The volume viscosity μ vanishes for a monatomic gas but not for molecules unless the mean energy for each internal degree of freedom is 1/2kT. A calculation of μ is made using the Chapman-Enskog method to first approximation, assuming that the molecules are perfectly elastic and rough spheres, with a parameter K (the ratio of the moment of inertia to that of a spherical shell), which indicates the distribution of mass. The result is $(\mu/\eta) = (9 + 13K)/60K$, showing that μ is of the same order of magnitude as η. The consequences in the propagation of sound and in energy dissipation are discussed.

3197

Kuckes, A. F., and U. Ingard, "A Note on the Acoustic Boundary Dissipation Due to Viscosity," J. Acoust. Soc. Am., 25, 798, 1953.

This mathematical note deals with the energy losses due to viscous dissipation in the regions close to boundaries of the sound field where large velocity gradients occur in the boundary layer. In the case of an aperture in a thin plate, almost the entire dissipation is associated with a region very close to the hole and the curved part of the boundary. The result is therefore strongly dependent on the value of surface resistance of the curved part.

3198

Latter, R., "Similarity Solution for a Spherical Shock Wave," J. Appl. Phys., 26, 954-961, 1955.

The point-source, spherical shock wave moving into a constant density γ-law gas is considered in the limit of infinite shock strength from the point of view of the Richtmyer-von Neumann viscosity technique. A similarity solution of this problem is shown to exist, and is obtained for various boundary conditions with $\gamma = 1.4$. The solutions are obtained analytically in that part of the flow field not involving viscosity, and numerically in the other parts of the flow field. It is found that whereas all discontinuities of the physical parameters are removed by the viscosity, there remain discontinuities in the slopes of these parameters at the shock front. It is indicated, moreover, that the complete flow field depends upon the form and magnitude of the viscosity.

3199

Lyubimov, G. A., "The Effect of Viscosity and Heat Conduction on the Flow of a Gas Behind a Severely Curved Shock Wave," Foreign Tech. Div., Air Force Systems Command, Wright-Patterson AFB, Ohio, 5 pp., 1962.
AD-270 763

Formulas are derived for the relation of stagnation temperatures and pressures behind and in front of a shock wave of any shape, by taking into account the viscosity and thermal conductivity of a gas.

3200

Meyer E., and W. Guth, "The Acoustic Viscous Boundary Layer" (in German), Acustica, 3, 185-187, 1953.

The acoustic viscous boundary layer is investigated for sound waves in air in the neighborhood of a rigid wall, using illuminated floating particles seen under a microscope.

3201

Mikhailov, G. D., "Distortion and Interaction of Sound Waves of Finite Amplitude in a Viscous Medium" (in Russian), Doklady Akad. Nauk SSSR, 109, 68-71, 1956.

Starting with the equation of continuity, the equation of motion (including bulk and shear viscosity), and the equation of state in isentropic form, the usual acoustic equations are derived. The sound pressure is calculated when the medium is viscous, and is excited at one frequency and also for the case of excitation with two different frequencies. For small viscosity and small distances from the source, for small viscosity and large distances from the source, and for viscosity in original equations only of the second order of smallness, the expressions for sound pressure take on familiar forms. It is claimed that there is qualitative agreement between theoretical and experimental results.

3202

Miles, J. W., "Dispersive Reflection at the Interface Between Ideal and Viscous Media," J. Acoust. Soc. Am., 26, 1015-1018, 1954.

The effects of viscosity and heat conduction (in the reflecting medium) in producing dispersive reflection of a plane wave at the plane interface separating two media are investigated. If the reflecting medium is treated as a condensed fluid, heat conduction is found to have no effect, while in first approximation, viscosity is found to produce no change in amplitude but rather a phase shift proportional to frequency (and therefore no phase distortion) at angles of incidence above critical and to produce no phase shift but amplitude distortion at angles below critical. This amplitude distortion is found to be important only in the neighborhood of a sharp wave front.

3203

Naugol'nykh, K. A., "Propagation of Spherical Sound Waves of Finite Amplitude in a Viscous Heat-Conducting Medium," Soviet Phys. Acoust., English Transl., 5, 79-84, 1959.

The form of a finite-amplitude wave alters as it is propagated because non-linear effects increase the steepness of the wave profile. If the medium is viscous and heat-conducting, these two properties tend to smooth out the profile and to decrease the velocity and temperature gradients. The effect of viscosity and heat conduction is, therefore, the opposite of the nonlinearity of the medium. The form of a finite amplitude wave in a viscous and heat-conducting medium will be determined by the ratio of nonlinear and dissipative (viscosity and heat conduction) effects. The author discusses propagation of spherical waves of finite amplitude produced by a harmonically pulsating sphere, whose radius is large compared with the emitted wavelength. The problem is dealt with using the Krylov-Bogolyubov method. Conditions when nonlinear effects become important are found.

3204

Pengelley, C. D., "Flow in a Viscous Vortex," J. Appl. Phys., 28, 86-92, 1957.

Equations have been derived for velocity, temperature, and pressure distribution in a two-dimensional compressible viscous vortex with a steady-state component of radial flow. Radial velocity has been assumed to be small compared with the tangential component, and heat transfer has been neglected. The equations are based upon the Navier-Stokes equation in its most general form, the first law of thermodynamics, and the gas laws. A reference radius has been defined where viscous stress is zero; from this, nondimensional forms have been set up and generalized charts prepared for ready visualization and numerical applications. Because of the classical concept of viscosity as used in the Navier-Stokes equation, results are strictly applicable to laminar flow only; a discussion is presented regarding possible application to turbulent flow.

3205

Rae, W. J., "Potential Flows in the Approximation of Viscous Acoustics" Cornell Univ. School of Aeron. Eng., Ithaca, N. Y., 107pp., 1960.
AD-236 743.

Steady, irrotational flows are studied in a linearized approximation, retaining the effects of dispersion and attenuation due to viscosity in the region outside the boundary layer. The differential equation for the velocity potential in this approximation is derived and discussed, and formal solutions for the flow around nonlifting, two-dimensional and axisymmetric bodies are found. Approximate evaluations of the formal solution reveal that throughout all of the subsonic, and most of the supersonic flow field, the inviscid solution is altered by a correction that is first-order in a viscosity parameter. In the supersonic cases, the familiar inviscid-wave pattern tends to be dispersed in the vicinity of the body, while at great distances from the body all disturbances decay. The rates of decay of pressure disturbances at these distances are found, and their relation to the inviscid, nonlinear treatment of the same problem is discussed.

In the course of the Fourier analysis of the problem, a Fourier transform that is not listed in any of the standard tables is evaluated, and this provides a closed-form solution to a boundary-value problem involving a certain third-order partial differential equation. Both of these results are thought to be new.

3206

Roy, A. K., "Estimation of the Critical Viscous Sublayer in Shock Wave Boundary Layer Interaction," Z. Angew. Math. Phys., 10, 82-89, 1960.

In a theory of the interaction between weak shock waves and boundary layers, Lighthill has pointed out that disturbances to the viscous forces (caused by the shock) are confined essentially to an inner sublayer. The author has estimated the thickness of this layer, and finds that it is of order 10% of the total boundary-layer thickness for a laminar layer and 1% for a turbulent layer. For turbulent layers, it is accordingly well within the laminar sublayer.

3207

Sakadi, Z., "Dispersion of Sound Waves, Considering the Effects of Heat Conduction and Viscosity," Proc. Phys.-Math. Soc. Japan, 23, 208-213, 1941.

This is a mathematical analysis in which the following assumptions are made: (1) the disturbance by the sound wave is very small, so that every quantity differs little from that of the static state; (2) there is only one excited state, and the number of excited molecules is very small compared with that of unexcited molecules. An addendum contains numerical data for CO_2 which show that consideration of conduction and viscosity introduces a small correction to the sound dispersion.

3208

Sedov, L. I., M. P. Michailova, and G. G. Chernyi, "On the Influence of Viscosity and Heat Conduction on the Gas Flow Behind a Strong Shock Wave," Rept. No. WADC-TN 59-349, 1959.
AD-227 413.

The authors investigate, mathematically, the influence of viscosity and heat conduction of a gas in supersonic flow past a small body. The specific case chosen is for the symmetric supersonic flow of a gas past a body of revolution or a planar profile with formation of a frontal detached shock wave.

3209

Skudrzyk, E., "The Theory of Internal Friction in Gases and Liquids, and Sound Absorption" (in German), Acta Phys. Austriaca, 2, 148-181, 1948.

The theories of sound attenuation due to viscosity and heat conduction, developed by Stokes and Kirchhoff, are inadequate to explain the experimental observations. Introducing the Boltzmann fundamental equation for gas theory, equations are derived for wave propagation in a viscous medium, the phase velocity and damping being derived from the complex sound velocity at a wide range of frequencies. Tables compare the "classical" values of sound absorption in various gases and in liquids with the "corrected" values.

3210

Soloveichik, R. E., "The Influence of the Viscosity of the Atmosphere on the Propagation of Sound" (in Russian), Izvest. Akad. Nauk SSSR, Ser Geograf. i Geofiz., 7, 339-343, 1943.

Reports an investigation of the problem of the influence of turbulent viscosity on the propagation of sound in the earth's atmosphere. The investigation shows that, taking this factor into account, use should be made of a variable coefficient of turbulent viscosity depending on the length of the sound wave. Satisfactory coincidence with the experiment is achieved, when the "law of 4/3," found empirically by Richardson and grounded on the theoretical work of A. M. Obukhov, is assumed for the coefficient of turbulent viscosity.

3211

Tisza, L., "Supersonic Absorption and Stokes' Viscosity Relation," Phys. Rev., 61, 531-536, 1942.

The reduction of the two viscosity coefficients to one according to Stokes' relation, $2\mu + 3\lambda = 0$, is not justified except for a monatomic gas. The generalization by reintroduction of the second independent viscosity coefficient, $k = 2/3\mu + \lambda$, makes it possible to develop the phenomenological theory of the absorption and dispersion of sound, in agreement with experiment completely analogous to the corresponding optical phenomena. The connection of the relaxation theory with classical hydrodynamics can be established and, in the case of polyatomic gases, k is expressed by the characteristic constant of this theory. The case of liquids is discussed. In polyatomic gases and liquids generally $k >> \mu$. Other hydrodynamical consequences of the introduction of k are discussed.

3212

Vick, G. L., "On the Propagation of Acoustic Waves in Gases at High Temperatures and Reduced Pressures," LMSD-49762, Lockheed Missiles & Space Div., Calif., 1959. AD-228 429.

Thermodynamic theory, as it applies to the propagation of acoustic waves in gases at elevated temperatures and reduced densities, is reviewed. The results of this study establish the applicability of acoustic methods to the measurement of gas temperature and to research on vibrational relaxation, dissociative relaxation, and viscosity phenomena under high-temperature, low density conditions. It is concluded that acoustic waves will be propagated with a dispersion of less than $a/a_0 = 1.1$ at frequencies below 1 mc at a temperature of 5000°K. Viscosity effects become predominant above 1 mc, resulting in greatly increased dispersion. Two absorption peaks occur at frequencies lower than 0.1 mc corresponding to vibrational and dissociative relaxation.

This study of dispersion and absorption indicates that the velocity of acoustic waves may be reliably used as a measure of gas temperature at frequencies below 1 mc; this could have wide application for shock-tube instrumentation. Measurements of acoustic attenuation below 0.1 mc would yield information concerning vibrational and dissociative relaxation. Viscosity effects may be studied from acoustic wave velocity data at frequencies above 1 mc; such acoustic wave measurements will be a powerful tool for research in the field of gas dynamics.

3213

Wu, T. Y. T., "Two-dimensional Sink Flow of a Viscous, Heat-conducting, Compressible Fluid; Cylindrical Shock Waves," Quart. Appl. Math., 13, 393-413, 1956.

The Navier-Stokes equations are given for the cylindrical sink flow of a viscous, heat-conducting, perfect gas, and the qualitative properties of the solutions together with a detailed calculation are discussed for the case of a flow of large Reynolds number. Solutions belonging to the supersonic branch all contain cylindrical shock-type flow in the transonic region of flow; these solutions gradually deviate from the inviscid supersonic branch, reach a minimum and then approach asymptotically the viscous subsonic branch. The results for shock strength and shock thickness are quite different from those of plane normal shock. Entropy variation of the fluid and the effect due to variation of viscosity coefficients are discussed.

3214

Zhumartbaev, M., "Absorption of Sound and the Width of Shock Waves in Relativistic Hydrodynamics," Soviet Phys. JETP, English transl., 37(10), 711-713, 1960.

The absorption coefficient of sound due to viscosity and heat conduction of the medium is derived in relativistic hydrodynamics. The structure of relativistic low-intensity shock waves is considered.

3215

Zoller, K. "On the Structure of the Compression Shock" (in German), Z. Physik, 130, 1-38, 1951.

In a previous treatment by Becker (Z. Physik, 8, 321 (1922)) the contributions of viscosity and thermal conductivity to the equations of conservation of mass, momentum, and energy through a stable plane shock wave were expressed in terms of only the first derivatives of the velocity and temperature of the gas-flow. In the present treatment, the viscosity and thermal conductivity are derived from the kinetic theory of a gas consisting of point-masses having an inverse-fifth-power law of repulsion; this is equivalent to expressing the viscosity and thermal conduction terms in the conservation equations as an infinite series of derivatives and their cross-products. The effects of 2nd-order derivatives and the cross-products of 1st-order derivatives have been taken into account in numerical solutions carried out for pressure-ratios $p_1/p_0 = 1.5$, 4.0 and 6.5 (where p_1 is the pressure behind the shock and p_0 the pressure before the shock). These calculations show that the thickness of the shock-front for $p_1/p_0 = 4.0$-6.5 is 2-3 times as large as would be expected on Becker's theory. It is pointed out, however, that for $p_1/p_0 = 6.5$, and to a lesser extent for $p_1/p_0 = 4.0$, the results are somewhat unreliable, because in these cases the effects of higher-order derivatives may not be negligible; but the computational labor involved in dealing with derivatives higher than second-order becomes prohibitive.

3216

Zubkov, A. I. and L. I. Sorkin, "The Effect of Viscosity on the Flow in the Region of a Straight Compression Shock," Trans. No. FTD-TT-62-172, Foreign Tech. Div., Air Force Systems Command, Wright-Patterson AFB, Ohio., 14 pp., 1962. AD-276 874.

Investigations were conducted on the physical picture of the flow in the region of a straight compression shock and the localization of the spearation that occurs as a result of the interaction between a straight compression shock and the boundary layer.

Viscosity Effects
See Also—44, 53, 65, 66, 76, 101, 142, 159, 180, 202, 205, 216, 223, 233, 234, 245, 248, 256, 299, 586, 590, 735, 782, 822, 907, 912, 932, 944, 1057, 1182, 1204, 1329, 1569, 1892, 1994, 2106, 2401, 2402, 2413, 2866, 2890, 2929, 3066, 3090, 3553, 3554, 3609, 3622, 3628, 3633, 3634, 3663, 3673, 3862, 4000, 4162, 4209, 4263, 4266, 4267, 4285, 4321, 4337

WAVE PROPAGATION, ABNORMAL, MEASUREMENT

3217

Anastassiades, M., D. Illias et al., "Observations Made at Athens Ionospheric Institute During the Series of Nuclear Weapon Tests at Novaya Zemlya Between Sept. 10 and Nov. 4, 1961," Sci. Rept. No. 2a 001, Univ. of Athens, Greece, 8 pp., 1962. AD-283 454.

During the series of Russian nuclear weapon tests in autumn 1961, the Ionospheric Institute of the National Observatory of Athens observed several phenomena in the upper and lower atmosphere over Athens. According to official information, the test range was Novaya Zemlya, a distance of about 4100 km from Athens. Evidently, this long distance creates a state of rather poor hopes for clear observations. In fact, among the nuclear explosions which occurred in the period from September 10, 1961, to November 4, 1961, only two (October 23 and October 30) show a distinct ionospheric disturbance which was measured in Athens. These two explosions were also recorded by microbarographs in Greece. An increase of radioactive fallout due to the nuclear weapon tests is also discussed.

3218

Angenheister, G., "The Problem of Sound Propagation" (in German), Z. Meteorol., 43, 467-471, 1926.

Review of some of early observations of the Notgemeinschaft Deutscher Wissenschaft research in acoustical phenomena from scientific series of explosions.

3219

Angenheister, G., "The Propagation Time of Sound for Long Distances, Part I," (in German), Z. Geophysik, 1, 314-327, 1925.

Speeds of propagation of normal and abnormal sound waves are tabulated and curves plotted. Several explosions in Germany cited for examples.

3220

Angenheister, G., "The Propagation Time of Sound for Long Distances, Part II (in German), Z. Geophysik, 2, 88-101, 1926.

Further comments and registrations of sound waves on the subject. The explosion at Wiener-Neustadt shows the form of the normal and abnormal zone of audibility developed from the presented theory.

3221

auf Kampe, H. J., "Results of Acoustic Measurement at Helogoland" (in German), Meteorol. Rundschau, 5, 99-105, 1952.

On April 18, 1947, 6000 tons of explosive were set off at Helgoland; normal and anomalous waves recorded at German stations are charted up to a distance of 440 km. Results are discussed in the light of upper winds and temperatures and the weather situation, and the paths of anomalous waves plotted, with some alternative solutions. Above tropopause at 10 km a rise of temperature is determined, to a value of nearly 50°C at 50 km.

3222

Chrzanowski, P., G. Greene, K. T. Lemmon, and J. M. Young, "Traveling Pressure Waves Associated with Geomagnetic Activity," J. Geophys. Res., 66, 3727-3733, 1961.

Travelling atmospheric pressure waves with periods from 20 to 80 sec and pressure amplitude from about 1 to 8 d/cm^2 were recorded at a microphone station at Washington, D. C., during intervals of high geomagnetic activity. Trains of these waves can be expected at Washington, from a quadrant approximately centered on north whenever the magnetic index K_p rises to a value above 5. Their horizontal phase velocity across the station is usually higher than the local speed of sound. During two "red" aurorae, clearly visible at Washington, and at lower latitudes, the 20- to 80-second-period waves were accompanied by longer period, higher pressure, and much slower-travelling pressure disturbances. Observational data on the wave systems are presented and discussed.

3223

Cox, E. F., "Abnormal Audibility Zones in Long Distance Propagation Through the Atmosphere," J. Acoust. Soc. Am., 21, 6-16, 1949.

Five thousand tons of high explosives detonated on Helgoland, April 18, 1947, created air pressure perturbations recorded on microbarographs between 66 and 1000 km SSE from the blast. Instruments responded to frequencies 0.05-5 cps. Arrival times of abnormal signals at six stations more distant than 220 km, supplemented by high altitude meteorological data and the assumption of negligible winds above 30 km, permit calculations of upper-atmosphere temperature. Temperatures agree with NACA values up to 42 km, but show a reduced gradient above that altitude, and a maximum value 294°K in the temperature hump between 30 and 70 km. This temperature maximum establishes a critical ray that is refracted to infinity. A new explanation for observed outer boundaries of abnormal zones is therefore proposed, and substantiated by recorded evidence of dispersion near the temperature maximum. In the signal received near the abnormal zone's outer boundary, high-frequency content predominates.

3224

Cox, E. F., "Microbarometric Pressures from Large High Explosive Blasts," J. Acoust. Soc. Am., 19, 832-846, 1947.

Detonated charges produced pressure waves recorded by subsonic-frequency microbarographs at distances 12.9 to 452 km. Observations showed both normal and abnormal signals at 182 and 292 km, no clear abnormal signals at 141or 89 km, no signals of any kind at 872 km. In the zone of normal audibility, average wave velocity between blast point and receiving station decreases slightly with charge weight; it is substantially the same as sound velocity. No consistent travel-time differences for the abnormal signals resulted from changing the charge weight between 3·2 and 250 tons TNT. Neither normal nor abnormal signal strengths were predictable from charge weight.

The largest abnormal signal properly recorded was a three-cycle wave train with peak-to-peak amplitude 220 microbars received 182 km from a 125-ton blast. Interpolated to apex pressure perturbation, this signal amplitude eliminates shock wave supersonic velocity as a logical explanation for abnormal audibility. Incident angles of abnormal rays are not calculable. However, if one assumes 182 km as the descent-distance for rays starting out horizontally, neglects wind effects, and accepts the apex temperatures measured by balloons, rough calculations of lower-stratospheric temperatures are possible. These establish 34 km as a minimum altitude at which ground temperature is reached.

3225

Cox, E. F., "Subsonic Frequency Dispersion in the Upper Atmosphere," J. Acoust. Soc. Am., 20, 549, 1948.

Abstract of paper read at Los Angeles meeting, December 1947. Discussion of abnormal sound data from Helgoland blast 1947.

3226

Cox, E. F., J. V. Atanasoff, B. L. Snavely, D. W. Beecher, and J. Brown, "Upper-Atmosphere Temperatures from Helgoland Big Bang," J. Meteorol., 6, 300-311, 1949.

Microbarographs situated 66 to 1000 km SSE from Helgoland recorded disturbances initiated by the 5000-ton TNT explosion on that island, April 18, 1947. Special balloons at four meteorological stations obtained weather data to 29.5 km altitude at blast time. Wind velocities are considered negligible up to balloon summits. Assuming negligible winds at higher altitudes, interval velocities of abnormal microbarometric signals permit calculations of upper-atmosphere temps. Temp. rises steeply from 221°K

upper-atmosphere temperatures. Temperature rises steeply from 221°K at 32 km to 285°K at 42.5 km, then more slowly to 294°K at 55 km, Very long period waves recorded beyond 400 km are believed to have returned from the second high-temperature region of the upper atmosphere. Arrival times are best matched by assuming a cold layer between 55 and 86 km, with lowest temperature 170°K extending from 64 to 79 km. A steep rise to 296°K at 86 km precedes a smaller gradient to 399°K at 172 km.

The authors do not have much confidence in findings for altitudes exceeding 100 km.

3227

Crary, A. P., "Investigation; of Stratosphere Compressional Wave Velocities by Studies of Refracted Waves from Explosive Sources — Part III: Alaska, January 1948, Latitude 65° North," AMC, Cambridge Research Labs., Mass., 17 pp., 1949. AD-73 073.

An investigation was made to determine the stratospheric compressional wave velocities in a high-latitude region; eleven tests were conducted in the Fairbanks, Alaska, area. Explosive charges were fired at the surface and a study was made of the stratosphere-refracted returns at locations 100 to 400 km away. Eight positive tests resulted, five recorded east of the source and three west. The apparent velocities ranged from surface velocity, about 320 to 400 meters per second. The average velocity of the returns was considerably greater in the easterly direction than in the westerly. The differences are thought to result from high westerly winds, reaching a maximum of 60 meters per second at 50-km altitude and probably decreasing sharply at 70 km. The north-south wind components are probably negligible.

3228

Crary, A. P., "Investigation of Stratosphere Compressional Wave Velocities by Studies of Refracted Waves from Explosive Sources — Part IV: Canal Zone, Latitude 9° North — July and August 1948." Geophys. Res. Rept., AMC, Cambridge Research Labs., Mass., 17 pp., 1949. AD-74 463.

Stratospheric compressional wave velocities were investigated near the Panama Canal Zone by studies of refracted waves from explosive sources. Bombs were dropped from an airplane at distances 100 to 400 km from a ground receiving station and the stratosphere-refracted waves received from the explosions were used to obtain information regarding the compressional wave velocities and winds in the stratosphere up to altitudes of 50 to 60 km.

Methods of operation and computations used are described, together with the results of each test. Eight tests resulted in a fairly good separation of stratospheric compressional wave velocities into temperature and wind effects. Averages of tests conducted in various regions areplotted, showing the variation of wave velocity with altitude. Variations of temperature, wind velocity, and azimuth with altitude are also shown.

3229

Donn, W. L., and M. Ewing, "Atmospheric Waves from Nuclear Explosions, II. The Soviet Test of 30 October 1961," J. Atmos. Sci., 19, 264-273, 1962.

Atmospheric waves from the Soviet nuclear test of 30 October 1961 are described for nine stations having wide global distribution. The records are characterized by waves which begin with the highest amplitudes and which show normal dispersion. These appear to be superimposed on a lower amplitude, long period train of waves which shows inverse dispersion. As shown on dispersion curves of group velocity against period, a maximum of group velocity is indicated by the Airy phase formed through the merging of the two dispersive trains. A more prolonged train of waves of nearly uniform period is attributed to higher modes. The direct waves from the epicentre to the stations give dispersion curves that indicate significant variation in atmospheric structure along different azimuths and probably along different segments of the same azimuth. The curves for waves which have travelled more than once around the earth represent better sampling of world-wide atmospheric conditions and give better agreement with preliminary theoretical models. The average speed of the first arrivals is 324 m/sec, comparing well with the maximum obtained for the Krakatoa eruption.

3230

Duckert, P., "Results of Acoustical Observations from Explosions at Oldebroek, December 15, 1932" (in German), Z. Geophysik, 10, 119, 1934.

A detailed discussion of explosion and subsequent sound records. Figure shows zones of audibility and where explosion waves were recorded.

3231

Freimann, L. S., "Experiments in Acoustical Sounding of the Stratosphere in the Arctic During the Second Polar Year" (in Russian), Proc. All-Union Conf. Study of the Stratosphere, Moscow-Leningrad, 99-104, 1938.

Results are reported of the1932-1933 investigations on the acoustical sounding of the stratosphere in the northern polar basin, where 28 special explosions were set off. The author determines anomalous sound propagation in the atmosphere, even without light for some weeks, and remarks on influence of wind and temperature.

3232

Gutenberg, B., "Interpretation of Records Obtained from the New Mexico Atomic Bomb Test, July16,1945," Bull. Seism. Soc. Am., 36, 327-330, 1946.

Brief interpretation of some of records of earth and air waves after the New Mexico explosion. Some data on direct sound waves along the ground and others through the stratosphere, as recorded at various stations: Tucson, Mount Wilson, Pasadena, etc. Speculation made as to an air wave similar to Krakatoa.

3233

Gutenberg, B., "Sound Propagation in the Atmosphere," in T. F. Malone, ed., Compendium Meteorol. Am. Meteorol. Soc., Boston, 366-375, 1951.

This is a detailed study of the theory of sound waves in gases, the equations for velocity of sound in quiet and in moving air, and the energy of sound waves in the atmosphere. Microbarographs and their limitations are discussed. Observations and records from microbarographs of sound propagation through the troposphere and the stratosphere, and abnormal audibility zones are also treated. Numerous illustrations show types of records, areas of abnormal audibility from explosions (Germany, 1925, and Vergiate, Italy, November, 1920), and travel time curves. Cross sections showing typical paths of sound waves, and temperature and sound velocity profiles from V-2 flights and other sound propagation data are included.

3234

Gutenberg, B., "The Velocity of Sound Waves and the Temperature in the Stratosphere in Southern California," Bull. Am. Meteorol. Soc., 20, 192-201, 1939.

Sound waves from gunfire in Southern California, about 33° N lat., show travel times similar to those observed in Europe and Novaya Zemlya. The author concludes that the increase in temperature at 30 to 40 km altitude is approximately the same in these regions.

3235

Hergesell, H., and H. Benndorf, "Experimental Exploration of Upper Atmospheric Layers," Physik Z., 30, 429-430, 1929.

H. Hergesell, in criticizing an earlier paper by H. Benndorf, states that most of the published facts were known for some time by a commission of experts on aerology, geophysics, and explosives. He suggests means for getting better results, including meteorological data, wireless time signals, choice and siting of stations, and the development of the theory. H. Benndorf replies.

3236

Hergesell, H., and P. Duckert, "Experimental Explosions Carried Out in Germany from April 1, 1923, to September 30, 1926" (in German), Linderberg, K. Preussisches Aeronautisches Observatorium, Arbeiten, 16, B-1-55; Ibid., D-1-32, 1929.

Detailed records of sound propagation from a series of explosions produced experimentally in Germany, and some aerological data are presented. Anomalous sound propagation is attributed to the existence of temperature layers in the upper air.

3237

Johnson, C. T., and F. E. Hale, "Abnormal Sound Propagation Over the Southwestern United States, "J. Acoust. Soc. Am., 25, 642-650, 1953.

Abnormal propagation of sound in the east-to-west and west-to-east directions has been studied throughout a period of one year. Experiments were carried out over the California-Arizona desert, using explosions of 1200 pounds of TNT. Returns of sound from altitudes of 30 to 50 km were consistently received to the east in winter and to the west in summer. Sounds that traveled to the high-temperature region at 80 to 100 km altitude were received about one-fifth of the time. Sounds were returned from the second region somewhat better to the east in summer and to the west in winter. An early abnormal wave was received at ranges greater than 400 km.

3238

Jones, R. V., "Sub-Acoustic Waves from Large Explosions," Nature, 193, 229-232, 1962.

The Krakatoa volcanic explosion, the great Siberian meteor, and the large Russian nuclear explosion at Novaya Zemlya are compared, and microbarographic records of the latter two are shown. Both direct and antipodal pressure waves are evident. The author calculates that the Krakatoa explosion was by far the largest of the three, and that the great Siberian meteor and the Russian nuclear explosion were each roughly equivalent to 30 megatons of TNT. He concludes that the meteor must have weighed about 30,000 tons.

3239

Kaplan, J., G. F. Schilling, and H. K. Kallman, "Methods and Results of Upper Atmosphere Research," Geophys. Res. Papers No. 43, Cambridge Res. Center, Massachusetts, 162 pp., 1955.
Also as Sci. Rept. No. 3, Inst. of Geophys., Univ. of Calif., Los Angeles, 1954.
AD-101 944.

Chapter 8 reviews temperature and wind velocity determinations between 30- and 180-km altitude by measurements of acoustic propagation. Some of the results reported by various authors (Crary, Kennedy, Cox, Whipple, Gutenberg) are shown in tables and diagrams.

3240

Kennedy, W. B., "Atmospheric Winds and Temperatures in the 30-to-60-Kilometer Region over Eastern Colorado as Determined by Acoustical Propagation Studies 31 October 1951 to 28 August 1952," Sci. Rept. No. 3, Denver Res. Inst., Univ. of Denver, Colo., 41 pp., 1954.
AD-28, 523.

Acoustical propagation studies were made to determine the seasonal variation of high-altitude winds and temperatures over eastern Colorado. Measurements were taken once a month during the period from 31 October 1951 through 28 August 1952. Operations were centered at latitude 39° N, longitude 103°40' W (near Limon), and extended radially about 200 km. A variation in the azimuth and distance from sound source to recorder positions permitted the separation of wind and temperature components of the observed upper-atmosphere sonic velocity gradients. The average wind vector obtained from treatment of the azimuth-shift information appeared to move clockwise as the seasons advanced.

3241

Kennedy, W. B., et al., "Atmospheric Winds and Temperatures to 55-Kilometers Altitude over Southwestern New Mexico as Determined by Acoustical Propagation Studies 0600-1020 MST 22 October 1952," Sci. Rept. No. 2, Denver Res. Inst., Univ. of Denver, Colo., 1952.
AD-18, 564.

As part of Operation T-Day, a cooperative effort of a number of agencies, an average of two measurements per day of upper atmosphere winds and temperatures was made during the period 20-24 October. Analyses of a portion of the large amount of data obtained has been completed and results are presented in this paper. The method of calculation employed was generally that synthesized and developed by A. P. Crary; however, a sound-velocity vs altitude model of the atmosphere recently developed at Denver Research Institute was also employed. Methods of calculation are discussed in detail.

Two goals were sought in the performance of this research: the first was to make observations concurrently with other participants in Air Force Operation T-Day for ultimate comparison and correlation; the second, to make observations with sufficient frequency so that the existence and extent of any diurnal variation of high altitude winds and temperatures can be determined.

Calculations of results of the diurnal study are not yet complete since these calculations require the availability of all results of the high-altitude wind and temperature measurements. One set of the ten measurements of upper atmosphere winds and temperatures is presented in this paper.

3242

Kennedy, W. B., and L. Brogan, et al., "Determination of Atmospheric Winds and Temperatures in the 30-60 km Region by Acoustic Means," Denver Res. Inst., Univ. of Denver, Colo., 1950-1954.

Thirteen quarterly progress reports and a final, summarizing report describe four years of experimental and theoretical research on the problem of determining winds and temperatures at high altitudes (30-60 km) from acoustic measurements. Acoustic energy from explosions of 200-lb charges of TNT was recorded at a number of points lying on a circle of 200 km radius around the firing site. From travel time and angle of arrival measurements of the acoustic wave front plus local wind and temperature data, the sound ray paths and the upper-level winds and temperatures, which caused these paths by refraction, were calculated. One method of calculation employed, with certain simplifications, was developed originally by A. P. Crary. Another method used assume that the sound velocity vs altitude structure in the upper air follows a hyperbolic-cosine curve. A new method of treating azimuth-shift data is also presented.

Annual and diurnal variations of high-altitude winds and temperatures were determined in Colorado and New Mexico. Winds were generally westerly and strong during the winter and easterly and of small magnitude during the summer. High-altitude temperatures increased while winds decreased as time advanced during daylight hours. Minimum temperatures and maximum winds generally occurred at about 1000 MST on any given day. As shown below, most of the reports in this series have AD or ATI numbers for use when ordering from DDC (formerly ASTIA).

Qtly. Prog. Rept. 1, June-August, 1950
" " " 2, September-November, 1950
" " " 3, December, 1950-February, 1951, ATI-109, 427
" " " 4, March-May, 1951
" " " 5, June-August, 1951, AD-8 990
" " " 6, September-November, 1951, AD-8 989
" " " 7, December, 1951-February, 1952, AD-38 760
" " " 8, March-May, 1952
" " " 9, June-August, 1952
" " " 10, September-November, 1952, AD-26, 714
" " " 11, December, 1952-February, 1953, AD-20 318
" " " 12, March-May, 1953, AD-31 806
" " " 13, June-August, 1953, AD-36 902
Final Report, 30 June 1954, AD-36 812

3243

Kennedy, W. B., L. Brogan, et al., "The Diurnal Variations of Atmospheric Winds and Temperatures in the 30- to 50-Kilometer Region over Southwestern New Mexico by Acoustical Propagation Studies 20-24 October 1952," Sci. Rept. No. 4, Denver Res. Inst., Univ. of Denver, Colo., 65 pp., 1954. AD-31 820.

Measurements of upper-atmosphere winds and temperatures were made by means of acoustic propagation studies. Ten measurements were made by employing the method of calculation synthesized and developed by A. P. Crary (J. Meteorol., 7, 233, 1950). A new method discussed by F. J. W. Whipple (Quart. J. Roy. Meteorol. Soc., 61, 285, 1935) is proposed for determining upper-level winds by use of azimuth-shift data. An analysis of results established that the upper atmosphere temperatures increased as the winds decreased with the advance of time of day through the daylight hours.

3244

Kennedy, W. B., L. Brogan, and N. J. Sible, "Further Acoustical Studies of Atmospheric Winds and Temperatures at Elevations of 30-60 Kilometers," J. Meteorol., 12, 519-532, 1955.

Results of firing 200-lb charges of TNT and recording the elevation and the azimuth of the sound wave by an array of microphones are described. Operations in Colorado, 31 October 1951-28 August 1952, confirmed the broad conclusions of the earlier Colorado series. Those conducted in New Mexico bihourly from 20-24 October 1952 (T-day) are fully treated. The winds and temperatures between 25 and 55 km are tabulated and plotted. The average wind was 23-39 meters per sec. from 242-276°, but there were marked fluctuations over very short periods. Temperature increased as wind decreased with advancing time of day.

3245

Krakatoa Committee, Royal Society of London, "On the Air Waves and Sounds Caused by the Eruption of Krakatoa in August, 1883, Part II. The Eruption of Krakatoa and Subsequent Phenomena," Trubner & Co., London, 57-88, 1888.

Lists the stations from which barometrical or other observations were received, with descriptions of recording instruments. Times of passage of air waves over each station are recorded and the velocities of air waves calculated. A section on sounds states the detonations were heard over nearly one-thirteenth of the earth's surface. A list of places at which the sounds were heard is given, including Rodriguez, nearly 3000 miles from Krakatoa. Detailed data are included.

3246

Kramer, H. P., and M. Rigby, "Selective Annotated Bibliography on Propagation of Acoustic and Explosion Waves in the Atmosphere," Meteorological Abstracts and Bibliography, 1, 670-686, 1950.

This bibliography contains 112 entries, each with an abstract or annotation, and covers the years from 1883 to 1950 inclusive. Most aspects of the propagation of sound in air are covered, with particular emphasis on anomalous sound propagation, meteorological factors affecting sound propagation, and determination of winds and temperatures from acoustic measurements.

3247

Mathur, L. S., "Reflection of Sound Waves from the Stratosphere over India in Different Seasons of the Year," Indian J. Meteorol. Geophys., 1, 24-34, 1950.

Three series of observations were made in India during the summer, fall, and winter of1946-47 to determine the trajectories of sound waves (from explosions) through the stratosphere. Two explosion centers and nine recording stations (in the form of a cross, with the axis along the line joining the two centers) were set up by the Meteorological Department, and their locations shown on a chart. Actual recorder records for ground and reflected waves are reproduced, and derived data are presented in tables and graphs.

In the summer better reception was obtained toward the south; whereas, after the monsoon season, and in the winter, better records were obtained to the north (up to 294 km) of the explosions. Records of the ground wave were obtained even in the "zone of silence." Trajectories are illustrated and temperatures and lapse rates in the stratosphere computed and plotted.

3248

Meisser, O., "Sound Propagation in the Atmosphere After Artificial Explosions" (in German), Physik. Z., 30, 170-175, 1929.

A partial review of a series of explosions to investigate acoustical phenomena and theories about the audibility regions of the atmosphere.

3249

Meisser, O., H. Martin, et. al., "Collection of Material on Sound Wave Records During the Explosion in Oldebroek, Holland" (in German), Z. Geophysik, 10, 145-158, 1934.

Records for different stations tabulated and illustrated.

3250

Meisser, O., H. Martin, et. al., "Contributions to the Sound Measurements of the Air" (in German), Z. Geophysik, 10, 158-166, 1934.

Reports time records, instrument traces, etc., of an explosion in Oldebroek, Holland.

3251

Mukherjee, S. M., "Landslides and Sounds Due to Earthquakes in Relation to the Upper Atmosphere," Indian J. Meteorol. Geophys., 3, 240-257, 1952.

A general discussion of the abnormal propagation of sound by earthquakes, with special reference to the earthquake of Aug. 15, 1950. A comprehensive survey of acoustical observations of this earthquake and some important previous ones is added. Travel times of abnormal sounds are computed, and their connection with the thermal structure of the upper stratosphere is briefly described.

3252

Murgatroyd, R. J., "Anaomalous Sound Reception Experiments," M. R. P. No. 346, Air Ministry, Meteorological Res. Committee, London, 19 pp., 1947.

Results of sixteen experiments in England between April, 1944, and April, 1945, in which recordings of sound received by anomalous paths from large explosions were utilized to obtain data on upper air winds and temperatures. Methods used and their limitations outlined. Results tabulated.

3253

Murgatroyd, R. J., "Wind and Temperature to 50 KM over England, Anomalous Sound Propagation Experiments, 1944-1945," Geophys. Mem. Meteorol. Off. (London), 30 pp., 1955.

The geometry of zones of audibility is set out. In sixteen experiments explosions at seven to ten points in England were recorded on lattices of microphones. Audibility (up to 387 km) and time of travel are tabulated. The experiments gave, with certain assumptions, the vertical distribution of temperature and winds of 18-50 km. Temperature at 50 km varied from 310°K in July and August to 264°K in January. Wind at 30-45 km changed from westerly 40-80 meters per sec. in winter to easterly < 20 meters per sec. in summer. Radiosonde measurements up to 18 km are given for comparison.

3254

Nature, "Air Waves from Experimental Explosions," 130, 1008-1009, 1932.

For meteorological research during the Polar Year, four explosions were made at Russian Harbor, Novaya Zemlya, and at Oldebroek, and undographs were used to record the air waves in Russia, Germany, and Holland, while sound-ranging apparatus was used in Great Britain. Reports already available indicate that the Oldebroek explosions were not heard over a large area. No records were obtained in Great Britain, but infrasonic waves seem to have occurred at Cambridge and Havering-atte-Bower, Essex.

3255

Reed, J. W. "Weather Determines Blast Prediction for Atom Tests," Weatherwise, 9, 202-204, 1956.

The mechanisms which produce damaging shock waves at a distance from a blast (such as created heavy damage to plaster and windows in Las Vegas, Nevada, 80 miles from point of an atomic bomb explosion in 1951) are outlined and illustrated. Reflection from surface inversions, from strong upper winds, or from the ozonosphere inversion are among the factors discussed. The tests in question produced reflections which hit the earth at 27, 54 and 81 miles, etc., from the nuclear testing site.

Pilot explosions two hours before a test recorded on a network of microbarographs are now used to anticipate dangerous conditions. Actual explosion records are also studied for future use.

3256

Regula, H., "Investigation of the High Stratosphere by Explosion Waves" (in German), Meteorol. Rundschau, 2, 263-267, 1949.

Zones of silence and abnormal audibility of explosions point to a strong inversion at 35 to 40 km. This is confirmed by V-2 ascents. The location of zones audibility exceeding 150 km, mainly to west in summer and east in winter, agrees with summer and winter winds, according to Scherhag (1948), from topography of 41 mb surface (ca. 22 km). These winds are considered, therefore, to represent the whole layer from 20-45 km. Further experiments should bring temperatures and winds up to 45 km into discussion of synoptic problems.

3257

Richardson, J. M., and W. B. Kennedy, "Atmospheric Winds and Temperatures to 50-Kilometers Altitude as Determined by Acoustical Propagation Studies—and Appendixes A Thru C—21 July 1950 Thru 31 May 1951," Sci. Rept. No. 1, Univ. of Denver, Colo., 42 pp., 1951.
ATI-171, 410.

During the period 21 July 1950 through 31 May 1951, there were, on the average, three measurements each month of upper-atmosphere winds and temperature were made by means of acoustical propagation studies. Field operations were centered in Wray, Colorado, and extended radially 200 km. A variation in azimuth and distance from sound source to recorder positions permitted the separation of wind and temperature components of the observed upper-atmosphere sonic velocity gradients. It was found that upper winds were generally westerly and of large magnitude during the winter, and easterly and of small magnitude during the summer, with wide fluctuations during the equinoctial periods. Short-term fluctuations in the wind vector were observed to be of the same order of magnitude as the vector itself. Above 25 km altitude, a doubly-periodic annual variation in temperature was observed.

3258

Ritter, F., "Contribution to the Observation of the Sound Wave Caused by the Explosion at La Courtine, May 1924" (in German), Z. Tech. Phys., 7, 152-154, 1926.

Sound and pressure waves produced by explosions at La Courtine were recorded at Berlin. The distance from the source of the waves was determined at 1162 km.

3259

Rothwell, P., "Sound Propagation in the Lower Atmosphere," J. Acoust. Soc. Am., 28, 656-665, 1956.

An account is given of experiments carried out in the lower troposphere to compare observations of the audible range and of the angle of sound descent from shell bursts at various heights (up to 10,000 feet) with calculations made from elaborately measured temperatures and winds. In stable conditions they agree satisfactorily.

Several cases were observed of anomalous propagation in which sound rays starting upward from the source are bent back to the earth. These showed the phenomena associated with larger-scale anomalous propagation, namely, inner and outer audibility zones, "zone of silence," and double or multiple reception of the single pulse from the source. From the experience gained in these experiments suggestions are made for (1) observation of the time interval between components of the usual double or multiple bangs from a single pulse-source, and for (2) observation of the sound from explosions in the air as well as on the ground to obtain more information than has been obtained hitherto from sound propagation about temperature and wind in the high atmosphere. Rocket explosions might be used for the latter purpose.

3260

Stewart, K. H., "Air Waves from a Volcanic Explosion," Meteorol. Mag., 88, 1-3, 1959.

Explosion of the volcano Bezyymyannaya Sopka in Kamchatka (55°57'N, 160°32'E) at 0611 GMT, March 30, 1956, was reported to have "exceeded several dozen times the strength of an explosion of an ordinary atom bomb." Reexamination of the microbarograph record at Kew Observatory for the day shows the arrival of the air wave, also traceable on the float and on the photo barographs. Eskdalemuir and Lerwick recordings also clearly featured the rapid (about 0.2 mb) pressure fall as tabulated here with clock corrections. Thermonuclear 0.2 mb pressure fall has been recorded at Kew Observatory. The difference between sound waves and "long" waves is considered in relation to propagation influenced by atmospheric temperature, and likewise the wave energy as influenced by elevation. In this case; the energy was found to be 1×10^{21} ergs.

3261

Thuronyi, G., "Selective Annotated Bibliography on Propagation of Acoustic and Explosion Waves in the Atmosphere," Meteorol. Abst. and Bibl., 10, 1072-1098, 1959.

This bibliography contains 122 entries, each with an abstract or annotation, and spans the years from 1950 to 1959 inclusive, plus a few entries from 1937 to 1949. Most aspects of the propagation of sound in air are covered. Emphasis is on acoustic propagation as a means for studying various properties of the atmosphere.

3262

Upper Atmosphere Rocket Res. Panel, "Pressures, Densities and Temperatures in the Upper Atmosphere," Phys. Rev., 88, 1027-1032, 1952.

Averaged and internally consistent values of atmospheric pressure, density, and temperature from the ground to an altitude of 219 km have been determined and compiled by the U. S. groups active in upper-atmosphere research by rockets. Additional relevant data by similar groups engaged in research on meteors and on the anomalous propagation of sound are also included, particularly in a brief discussion of variations of these three atmospheric parameters with time and with place.

3263

Visser, S. W., and J. Veldkamp, "Dutch Observations on the Helgoland Explosion" (in Dutch), Hemel en Dampkring, 45, 150-158, 1947.

An earlier reporting article covers the seismological effects; this covers the meteorological and acoustical observations made in Holland, including abnormal sound data originating from the Helgoland blast. It is indicated that southwest from Helgoland the inner boundary of the abnormal audibility zone may have been as close as 176 km.

3264

Whipple, F. J. W., "Air Waves from Experimental Explosions," Nature, 131, 138-139, 1933.

An accout of observations received at Kew Observatory from various stations in the south of England relating to experimental explosions made at Oldebroek in Holland on December 15, 1932. The aerial disturbance was appreciable over an area lying between the microphone stations at Hythe and Foulness and those at Nottingham, Birmingham, Cardiff, and Bristol. The most satisfactory observations were made at Cambridge, at times appropriate for normal transmission. Undograph records of the air waves were obtained in Germany to a distance of 225 km on the line from Oldebroek to Lindenberg; an abnormal zone was also observed in Germany. No waves were recognized on the undograph records in Holland.

3265

Whipple, F. J. W., "Audibility of Explosions and the Constitution of the Upper Atmosphere," Nature, 118, 309-313, 1926.

The results of hundreds of acoustic observations made on a series of four scheduled, experimental explosions are described and presented in map form to show zones of silence and primary and secondary zones of audibility. Corresponding wind and temperature data in the lower atmosphere were taken, but winds and temperatures at higher altitudes were a subject for speculation. Whipple assumes a negative temperature gradient from 0 to 12 km, an isothermal layer from 12 to about 32 km, and an increasing temperature from 32 km upwards. From this he calculates and shows in graph form a set of sound-ray paths that return to earth at distances comparable to the experimental results. The effects of winds on ray paths are described but not calculated.

3266

Whipple, F. J. W., "The Great Siberian Meteor and the Waves, Seismic and Aerial, Which it Produced," Quart. J. Roy. Meteorol. Soc., 56, 287-304, 1930.

Six microbarograms show pressure oscillations at British stations, June 30, 1908, the day of the fall of the Great Meteor north of Kansk, Siberia. Brief descriptive accounts at the time are translated from the Russian. The investigation made in 1921 by the geologist, Kulik, is noted, as are accounts from local sources on the meteor's appearance. The pressure and sound waves are reported to have broken windows, sucked up clods of earth, felled trees, etc. Seismological records are given for Irkutsk, Tashkent, Tiflis, and Jena, and reports of the shock as it was felt in surrounding regions. The microbarograms made in England are analyzed as to time and the speed of travel of the wave. The rate of travel of the air waves is discussed; equations are given for calculations of the energy of the air waves.

3267

Whipple, F. J. W., "On Phenomena Related to the Great Siberian Meteor," Quart. J. Roy. Meteorol. Soc., 60, 505-513, 1934.

Supplementary paper to 1930 work of this author. Air wave records are tabulated for additional European stations, as well as for Batavia and Washington. Barograms are reproduced. Records are discussed and the velocities of propagation of waves travelling in differing directions compared. Additional evidence is given regarding illumination of the sky during the nights following the meteor. A discussion, by S. K. Banerji, of shock waves is included, with equations.

3268

Whipple, F. J. W., "Propagation to Great Distances of Air Waves from Gunfire," J. Roy. Meteorol. Soc., 60, 80-88, 1934.

The object of the experiments, which are the picking-up by Tucker microphones of the sound from distant firing, usually at Woolwich, is to investigate the properties of the upper air. It is generally found that the waves take so long on their journey that they must have made a long detour through the upper atmosphere. The result of the experiments gives an estimate of the temperature in regions of the atmosphere for which no other method had been found up to the time of this report. Maps show places in England to which sounds have been carried on various occasions, and diagrams show the calculated temperature and velocity of sound with height in the atmosphere.

3269

Whipple, F. J. W., "The Propagation to Great Distances of Air-Waves from Gunfire, Progress of the Investigation During 1931," Quart. J. Roy. Meteorol. Soc., 58, 471-478, 1932.

Earlier gunfire experiments are continued and acoustic data reported. Tables show air temperatures and the velocities of sound as measured on the ground and as calculated for tropopause heights as well as for maximum altitudes of sound-ray paths. The calculations are based on measured travel times and determinations of the arrival angles of sound rays at microphone arrays. Presents several upper air temperature profiles, to altitudes of 50 km, as calculated from acoustic data.

3270

Whipple, F. J. W., "Researches on the Transmission of Air Waves at Great Distances," Gerlands Beitr, Geophys., 24, 72-75, 1929.

It is said that air-wave transmission over great distances may be due to high temperatures in the upper air. A brief report of some of British investigation on this matter is given, and a table shows the mean passage of air waves from the Isle of Grain to various points, together with measurements of ozone. No obvious relation is seen between the time of passage of waves and the amount of ozone or the meteorological conditions. Calculations can be made on temperatures of the upper air by using the angle of descent of the air wave. The audibility of meteors is briefly considered.

3271

Whipple, F. L., "Density, Pressure and Temperature Data Above 30 Kilometers," in G. P. Kuiper, ed., "The Earth as a Planet," Univ. of Chicago Press, 491-513, 1954.

A complete summary of the results of recent observations of upper-atmospheric pressure, density, and temperature as obtained from rocket firings. Earlier work is not reviewed. Diurnal, seasonal, and latitudinal variations are discussed, and the chief results tabulated by 2-, 5-, or 10-km levels up to 219 km and shown in graphic form. Meteor and sound-propagation data are consider briefly, also.

3272

Whipple, F. L., "Evidence for Winds in the Outer Atmosphere," Proc. Natl. Acad. Sci., U. S., 40, 966-972, 1954.

A review of the various methods used to obtain wind measurements for heights above 40 km. These include photographs of persistent trains from brighter meteors, radiometeor methods, motion of noctilucent clouds, auroral motion, nightglow activity, anomalous sound propagation, ionospheric reflection techniques, and the use of high-altitude rockets. The results obtained at the various levels and the seasonal and diurnal changes at some levels are discussed.

3273

Wolcken, K., "Sound Research in Polar Regions" (in German), Z. Geophysik, 10, 224-234, 1934.

Records observations of abnormal sounds during the winter solstice at 76° N lat. during polar year, 1932-1933. The observations are tabulated, and microbarograph registerings are reproduced. Differences, in summer and winter, of directions, frequencies, and forms of sound waves are noted. Recording stations were located on Franz Josef Land and Novaya Zemlya.

3274

Yamamoto, R., "Microbarographic Oscillations Produced by the Explosions of Hydrogen Bombs," Meteorol. Res. Inst., Kyoto Univ., Ser. 2, 14 pp., 1954.

Microbarographic records obtained at a tripartite storm microbarograph station at Shionomisaki in S. Central Japan, on March 27, 1954, showed speeds similar to those from Krakatoa and the Great Siberian Meteor (1908), which speeds approach the speed of sound, whereas those from storms travel at 1/10 to 1/5 that speed. Microbarograph records calculated at 30 other places in Japan also showed high velocities, and on Nov. 1, 1952, Mar. 1, 1954, Apr. 26, 1954, and May 5, 1954, showed similar characteristics. Map shows stations whose locations, observers, and instruments are described or listed. Characteristic microbarograms from Shionomisaki for the five occasions noted above indicate common origin, as can be seen in reproductions.

The conclusion from speed and direction calculations is that the waves originated at Bikini. Speeds are slightly less than that of sound, and increase in warm weather, whereas the Krakatoa wave was nearer the speed of sound. The latter wave traveled around the earth several times, but no note of the H-bomb waves doing so could be detected. No seismic waves, such as occurred in both the Krakatoa and Siberian meteor explosions, were detected. Mareograms (reproduced) did appear to show wave disturbances originating at Bikini, in all five cases. Periods of two minute followed by one minute waves were observed in both the Siberian meteor and Shionomisaki records. These confirm theoretical points involving a discontinuity at 40 km.

3275

Yamamoto, R., "Microbarographic Oscillations Produced by the Explosions of Hydrogen Bombs," Weather, 10, 321-325, 1955.

A short version of the article covered by the preceding entry.

3276

Yamamoto, R., "Microbarographic Oscillations Produced by the Explosions of Hydrogen Bombs in the Marshall Islands," Bull. Am. Meteorol. Soc., 37, 406-409, 1956.

The exact time that an oscillation (due to the explosion of a H-bomb) occurs on a microbarogram cannot be determined closer than five minutes, but where distances from the source are great (i.e., from 2000 to 5000 miles), the time and hence the rate of propagation of the pressure wave through the atmosphere can be determined to some degree of accuracy. Many records for 14 island stations (shown on a chart) in the Western Pacific were examined after explosions in February, 1952, and March, April, and May, 1954, and the speed of the wave toward the east was found to be greater by 50 meters per sec than that to the west, giving reasonable values for westerly winds in that vicinity and season. Stations located just to the west of Bikini showed no trace of the barometric oscillation. The mean value of speed of propagation was 336 meters per sec to the NE and 284 meters per sec to the NW.

3277

Yamamoto, R., "Microbarographic Oscillation Produced by the Soviet Explosion of a Hydrogen Bomb on November 22, 1955," Bull. Am. Meteorol. Soc., 38, 536-539, 1957.

Shida's microbarograms recorded on November 22, 1955, at Yonago, Okayama, and Kyoto, and tables giving the occurrence times of individual phases at these three points, observed values of propagation velocities of the waves by the hydrogen bomb explosion on the Marshall Islands, the Krakatoa explosion, etc., data on winds aloft from Yonago and Shionomisaki, time intervals between successive crests, and double amplitudes of the successive half-oscillations (mm Hg) are presented. On the basis of Namekawa's treatment of slightly dispersed internal gravitational waves, a formula is developed to estimate the distance from the explosion site in western Japan.

Wave Propagation, Abnormal, Measurement
See Also—401, 455, 522, 549, 557, 564, 844, 1113, 1155, 1168, 1300, 1418, 1419, 1420, 1421, 1422, 1423, 1427, 1431, 1434, 1482, 1483, 1484, 1489, 1491, 1523, 1524, 1554, 1565, 2069, 2121, 2124, 2363, 2485, 2514, 3095, 3291, 3293, 3294, 3298, 3307, 3308, 3312, 3323, 3337, 3351, 3354, 3358, 3365, 3370, 3535

WAVE PROPAGATION, ABNORMAL, SUBJECTIVE OBSERVATION

3278

Bartels, J., "Brief Review of the Physics of the Upper Atmosphere," Z. Tech. Phys., 13, 611-616, 1932.

The author reviews published facts relating to the upper atmosphere and conclusions that have been drawn from observations of clouds at high levels, twilight phenomena after volcanic outbursts, travel of meteros, the light of the night sky, the absorption of ozone and its variations, the propagation of sound waves to large distances, the production of aurorae, the propagation of electromagnetic waves, and variations of terrestial magnetism. He examines the theories put forward to account for the ionization layers at 100 and 220 kms. Variations of terrestial magnetism, of short and long periods, are discussed in their possible relation to dynamo action in the upper atmosphere and changes produced by solar disturbances.

3279

Berlage, H. P., "Audibility of the Detonations of a Semi-Volcanic Steam Explosion in Sumatra," Beitr. Geophys., 40, 369-370, 1933.

On June 24, 1933, at 21h. 54m. 35s. G. M. T., a violent earthquake took place in South Sumatra. In consequence the activity of a certain fumarole field was heightened; and this action culminated in a series of very violent explosions, especially at daybreak on July 10. The detonations of July 10 were heard at great distances; a map shows the stations from which the explosions were reported as having been heard. These extend 660 km, to Keboeman in Java, on one side, and 550 km, to Kuala Tungkal in Sumatra. A window pane was smashed in Batavia (305 km) in a zone of good audibility. An inner zone of radius 170 km round the center of explosion was marked by very poor audibility, and at places beyond this zone the sound appeared to come down to the observers.

3280

Berlage, H. P., "Some Remarks on Thunder Audible at a Great Distance" (in Dutch), Hemel en Dampkring, 54, 102-103, 1956.

See De Jong, J. J. G. (Hemel en Dampkring, 54, 102, 1956). The author gives further comments on the unusual thunder heard November 6-7, 1955. The speed of sound propagation and the inversion as factors in the audibility of the thunder are considered, but special attention is called to the possible role of prevailing wind conditions.

3281

Cave, C. J. P., "The Barisal Guns," Weather, 5, 149; comments by W. Hayes and J. Wadsworth, Ibid., 293; further comments by M. W. Chiplonkar and G. C. Wooldridge, Ibid., 425, 1950.

Correspondence initiated by C. J. P. Cave about unexplained booming noises in hot, still weather, known in the Ganges delta as "Barisal guns," and in Australia as "Hanley's guns."

Chiplonkar attributes the phenomena to subterranean noises transmitted through the stratosphere.

3282

Christy, M., "The Audibility of the Gunfire on the Continent at Chignal, Near Chelmsford, During 1917," Quart. J. Roy. Meteorol. Soc., 44, 281-284, 1918.

A diary of acoustic observations made by the author notes that gunfire on the continent near Chelmsford is audible in southeastern England from about May through August each year. This is an untechnical article and the author makes no attempt to explain the seasonal, acoustical phenomenon. Explanations and comments are offered in the very next article of the same journal volume by Whipple as an essential complement to Christy's report. See F. J. W. Whipple, Ibid., 285-289.

3283

Collignon, M., "Explosions at a Great Distance," Compt. Rend., 187, 357-359, 1928.

Continuation of a study of the properties of explosive sounds made in the open air. The audible harmonics observed arise from "infra-sounds" caused by explosions at distances greater than 120 km. Numerous observations have been made at a large number of stations with specific acoustical conditions in their surroundings, and the reduced observations (method not detailed) are shown in tabular form. Errata, ibid., 452.

3284

Davison, C., "The Sound of a Great Explosion," Quart. Revs. (London), 452, 51-60, 1917.

The first recognition of abnormal behavior of sound waves was in 1901, when noise from guns at Queen Victoria's funeral in London was heard at long distances but not near London. The first explanation of zone of silence attributed to an upward refraction of sound waves through the troposphere, followed by downward bending of the waves by increasing wind velocity at higher altitudes. A figure shows areas of sound.

3285

Davison, C., "The Sound-Waves and Other Air-Waves of the East London Explosion of January 19, 1917," Proc. Roy. Soc., Edinburgh, 38, 115-129, 1918.

A highly detailed report on the areas of audibility and zones of silence associated with an enormous explosion that occurred in East London, England. The report is in narrative style, essentially nontechnical, and presents the results from 725 queries made in 533 places to distances of as much as 150 miles from London. The nature of the sound in various locations and some of its side effects are described. Correlation of the silent zones and areas of audibility with wind and temperature profiles is only casual due to insufficient meteorological data.

3286

De Jong, J. J. G., "Thunder Audible at a Great Distance" (in Dutch), Hemel en Dampkring, 54, 102, 1956.

See Berlage, Ibid, 102-103. Thunder audible at a distance of 130 to 140 km from the center of a storm area at Den Helder was reported. The synoptic conditions over northwest Europe, coincident with the storm, which seemed to converge from a mist along the coast, are described. It is suggested that an inversion in the lower layer of the atmosphere served as a horizontal sounding board.

3287

Door, J. N., "The Long Range Effects of the Explosion at Wiener-Neustadt on June 7, 1912" (in German), Akad. Wiss. Wien, Kl. 122, 1683-1732, 1913.

Inner and outer audibility zones and zones of silence are distinguished. These are good, thorough, early observations of such acoustical phenomena.

3288

Fesenkov, V. G., "The Conditions of Falling of Sikhotealin Meteorite" (in Russian), Astron. Zh., 15, 190-200, 1948.

Reports of the meteor that fell in Siberia, February 12, 1947. Appearance, composition, accompanying rain of iron, speed of flight, angle of flight, explosion, and sound waves and effects are discussed. No tabulated data. A comparison is made with the Tungus meteorite of 1908 (the Great Siberian Meteor).

3289

Hubbard, B. R., "Influence of Atmospheric Conditions upon the Audibility of Sound Signals," J. Acoust. Soc. Am., 3, 111-125, 1931.

Summarizes the causes of the irregularity noticed in the audibility of fog signals. The observations and theories of various writers are quoted and the results of the test of fog-horns at Boston, carried out in Sept., 1930, are given. Striking instances are given of the unreliability of loudness observations for ascertaining distance; e.g., a fog signal that is audible for eight miles under favorable conditions may be just audible under other atmospheric conditions at a mile or less. The effect of "silent zones," due to the bending of the sound waves when temperature decreases normally upwards, is considered.

There are now few phenomena of fog signalling that cannot be explained in accord with generally recognized principles. The atmosphere is seldom homogeneous and aberrations in audibility may be due to any or all of three causes—wind, temperature, and humidity. The work of all investigators points to the first of these causes as the most important in causing inefficiency. The observed effects are illustrated by diagrams and tables summarizing the results obtained.

3290

Ives, R., "Apparent Relation of Aircraft Noise to Inversions," Bull. Am. Meteorol. Soc., 49, 149-150, 1959.

An investigation is reported in which aircraft noise was recorded in order to determine its relation to meteorological conditions. Under inversion conditions noise was found to be offensive when aircraft flew below the inversion and to be almost indetectable with aircraft above the inversion. Similar conditions were noted with stratus layers.

3291

Kolzer, J., "Observational Results on Sound Propagation for Short Distances and Conclusions on the Problem of Anomalous Propagation of Sound" (in German), K. Preussisches Meteorologisches Institut, Berlin, Abhandlungen, 10, 27 pp., 1932.

Theories on speed of sound, anomalous propagation, etc., are discussed in detail, with consideration given to meteorological conditions, instrument records, and observational data.

3292

Krakatoa Committee, Royal Society of London, "On the Air Waves and Sounds Caused by the Eruption of Krakatoa in August, 1883, Part II. The Eruption of Krakatoa and Subsequent Phenomena," Trubner & Co., London, 57-88, 1888.

Lists the stations from which barometrical or other observations were received, with descriptions of recording instruments. Times of passage of air waves over each station are recorded and the velocities of air waves calculated. A section on sounds states the detonations were heard over nearly one-thirteenth of the earth's surface. A list of places at which the sounds were heard is given, including Rodriguez, nearly 3000 miles from Krakatoa. Detailed data are included.

3293

Kulik, L. A., "The Meteorite of June 30, 1908, in Central Siberia," Publ. Astron. Soc. Pacific, Leaflet 109, 7 pp., 1938.

A report of an expedition to the place of occurrence. Includes a description of air waves in the immediate vicinity and as recorded on microbarographs in Europe, though no actual data are given.

3294

Maurain, C., "Propagation of Air Waves from the Experiments at La Courtine" (in French), Compt. Rend., 179, 1334-1337, 1924.

Zones of audibility for sound waves from this explosion are briefly described and explained. Figures illustrate the zones of audibility.

3295

Poisson, R. P., "Audibility of Thunder at Tananarive" (in French, English and Spanish summaries), Meteorol., 4th Ser., 19-25, 1951.

The methods for measuring the audibility of thunder and their reliability are discussed. Instances are cited in which thunder was heard at distance of 39 to 57 km from the point where lightning occurred.

3296

Reynolds, O., "On the Refraction of Sound in the Atmosphere," Phil. Trans. Roy. Soc. London, 166, 315, 1876.

This paper is remarkable for its time (1876). It is one of the earliest attempts at correlating wind and temperature gradients with the apparent refraction of sound rays in the atmosphere. The author writes in narrative style and uses no formal mathematical treatment. The presentation of subjective data from carefully controlled tests on land and sea, however, substantiates the conclusions drawn.

3297

Sandmann, B., "Observational Results on the Influence of the Acoustic Refraction Layer on the Propagation of Sound" (in German), Z. Geophys., 10, 200-215, 1934.

Detailed, well-illustrated investigation.

3298

Schaffers, V., "The Sound of Distant Gunfire," Nature, 107, 44-45, 1921.

The anomalies opposing a correlation of wind and temperature data with the seasonal variations in zones of audibility from distant gunfire of World War I are reviewed in this short report. The author suggests that refraction can account for only the upward bending of rays and subsequent zones of silence. He advocates diffraction near the earth's surface as the only satisfactory explanation for downward ray bending and secondary zones of audibility. It must be remembered that there was very little known about temperature and wind gradients at high altitudes in 1921.

3299

Scorer, R. S., "The Dispersion of a Pressure Pulse in the Atmosphere," Proc. Roy. Soc. (London) A, 201, 137-157, 1950.

The amplitude and form of a pressure oscillation, as related to the magnitude of and distance from a great explosion, are derived. The solution is compared with actual observations made at varying distances from the Great Siberian Meteorite, 1908, and the Krakatoa eruption, 1883.

3300

Taljaard, J. J., "How Far Can Thunder be Heard?" South Africa, Weather Bureau Newsletter, No. 35, 4; Weather 7, 245-246, 1952.

Thunder has been reported from sources 50-60 mi. distant (Germany) though usually 10 mi. is considered the extreme distance at which it is likely to be heard. Anomalous propagation might account for greater distances, as in the present instance. While visiting the Karroo district of South Africa on Feb. 7, 1952 (11:30 to 12:00h), the author heard thunder estimated to come from a source 60 to 70 mi. (or more) distant. Showers were reported at 11:30 at Witputs, 67 mi. from the observer. The base of clouds could not be seen with a flat horizon and a 3600-ft. cloud base (estimated from dry and wet bulb) would be at 73 mi.

3301

Temchenko, P. E., "Another Occurrence of Visible Propagation of Sound Waves in the Air" (in Russian), Priroda, 43, 113, 1954.

WAVE PROPAGATION, ABNORMAL, SUBJECTIVE OBSERVATION

Describes a case of visible propagation of a sound wave at a height of 50-100 m produced by the explosion of German bombs and observed by the author, at a distance of 4-5 km, during a raid of enemy bombers on the outskirts of Kerch (S. Crimea) in April, 1944. Air waves, similar to waves produced in water into which an object has been dropped, emanated from the upper cupola-shaped part of a smoke column at the moment of its mushrooming and spreading in concentric circles. The sound of a heavy explosion was heard at the moment when the wave reached the point where the observer stood.

3302

van Everdingen, E., "The Propagation of Sound in the Atmosphere," Proc. Acad. Sci. Amsterdam, 18, 933-960, 1915.

This paper, of historical interest, was written in 1915, and reviews the various theoretical and experimental approaches of that day on the anomalous propagation of sound in air. The theory of refraction of sound waves due to wind and temperature gradients is presented. Lack of temperature and wind data at high altitudes prevented accurate use of this theory in 1915. Other theories (now defunct), postulating a change in composition of the atmosphere with altitude, are reviewed. One of these predicted the existence of a gas, "geocoronium," five times lighter than hydrogen. Copious data on acoustic observations of various large explosions and volcanic eruptions is given in narrative and graphic form to demonstrate the existence of shadow zones and secondary areas of audibility.

3303

Ventosa, V., "The Anomalies of the Propagation of Sound," Ciel Terre, 19, 12 pp., 1898.

An interesting account of early observations of anomalous propagation and the zone of silence. Speculations include consideration of wind and temperature effects.

3304

Visser, S. W., and J. Veldkamp, "Dutch Observations on the Helgoland Explosion" (in Dutch), Hemel en Dampkring, 45, 150-158, 1947.

An earlier reporting article covers the seismological effects; this covers the meteorological and acoustical observations made in Holland, including abnormal sound data originating from the Helgoland blast. It is indicated that southwest from Helgoland the inner boundary of the abnormal audibility zone may have been as close as 176 km.

3305

Voznesenskii, A. V., "Falling of a Meteorite on June 30, 1908 in the Upper Part of Khatanga Basin" (in Russian), Mirovedenie, 14, 25-38, 1925.

The fall of this meteorite was recorded by Magnetic-Meteorological Observatory, Irkutsk, as a light earthquake. From these data, the place of fall was estimated to be in the upper part of Khatange River region, 893 km from Irkutsk. Earth tremblings were noted at other points in radius 800 km, and powerful air waves were observed over a radius of 900 km. Sounds of the explosion were heard at a distance of 1350 km. From evaluating various records, the size of the meteorite and the speed of its fall are estimated.

3306

Wegener, A., "The Detonated Meteor of April 3, 1916, 3 1/2 Hours After Noon in Kurhessen" (in German), Gesellschaft zur Beforderung der gesammten Naturwissenschaften, Marburg, 14, 1-83, 1917.

Reports detailed observations made of the incident at various points, including physical phenomena, the trail, etc., and the sound. Zones of silence observed after this occurrence between Narburg and Cassel. Two earlier instances cited, supporting the hypothesis of the occurrence of an outer zone of audibility.

3307

Wegener, A., "The Outer Audibility Zone" (in German), Z. Geophys., 1, 297-314, 1925.

A very complete account of outer audibility zones after cannonading, explosions, volcanic eruptions, meteor explosions, etc, with critical discussion of various explanations of this phenomenon. It is found that in central Europe the distance of the maximum sound intensity from the source varies between 120 km in February and about 240 km in August.

3308

Wegener, A., "The Outer Audibility Zone and Its Periodical Annual Variations" (in German), Z. Meteorol., 42, 261-266, 1925.

Compares distances at which sounds from explosions at Lyon (1918), Vergiate (1920), and Witten-Annen (1906) were audible by anomalous propagation in different seasons. Various explanations are offered.

3309

Whipple, F. J. W., "Audibility of Explosions and the Constitution of the Upper Atmosphere," Nature, 118, 309-313, 1926.

The results of hundreds of acoustic observations made on a series of four scheduled, experimental explosions are described and presented in map form to show zones of silence and primary and secondary zones of audibility. Corresponding wind and temperature data in the lower atmosphere were taken, but winds and temperatures at higher altitudes were a subject for speculation. Whipple assumes a negative temperature gradient from 0 to 12 km, an isothermal layer from 12 to about 32 km, and an increasing temperature from 32 km upwards. From this he calculates and shows in graph form a set of sound-ray paths that return to earth at distances comparable to the experimental results. The effects of winds on ray paths are described but not calculated.

3310

Whipple, F. J. W., "The Great Siberian Meteor and the Waves, Seismic and Aerial, Which it Produced," Quart. J. Roy. Meteorol. Soc., 56, 287-304, 1930.

Six microbarograms show pressure oscillations at British stations, June 30, 1908, the day of the fall of the Great Meteor north of Kansk, Siberia. Brief descriptive accounts at the time are translated from the Russian. The investigation made in 1921 by the geologist, Kulik, is noted, as are accounts from local sources on the meteor's appearance. The pressure and sound waves are reported to have broken windows, sucked up clods of earth, felled trees, etc. Seismological records are given for Irkutsk, Tashkent, Tiflis, and Jena, and reports of the shock as it was felt in surrounding regions. The microbarograms made in England are analyzed as to time and the speed of travel of the wave. The rate of travel of the air waves is discussed; equations are given for calculations of the energy of the air waves.

3311

Whipple, F. J. W., "Seasonal Variation in the Audibility of Distant Gunfire," Quart. J. Roy. Meteorol. Soc., 44, 285-289, 1918.

Explanations and comments are made on Christy's report (see Ibid., 281-284) on hearing gunfire across the English Channel each year from about May through August. Whipple notes that just the reverse seasonal variation in audibility occurs for listening areas to the east of the same gunfire. He argues that strong winds at very high altitudes (above 20 km) that change regularly with the seasons could cause corresponding variations in the refraction of sound waves, thus accounting for the seasonal shift in zones of audibility.

3312

Witkiewicz, W. J., "Scientific Studies of the Atmosphere" (in French), Editions de l'Observatoire Aerologique de Moscou, 2, 14-42, 1925.

An analysis of explosions at Moscow, May 9, 1920, showing symmetrical formation of outer audibility zones.

3313

Zamorskii, A. D., "Thunder During a Clear Sky" (in Russian), Meteorol. i Gidrol., 37-38, 1955.

In connection with a distant thunderstorm, a deafening thunder without any peals or lightning was heard in Leningrad on July 12, 1954, at 20 hours (Moscow time) on a sunny day with the clear sky near the zenith. A detailed description is given of the clouds before, during, and after the occurrence of this phenomenon. The distance of possible lightning was estimated at 500 m, but the height of rain clouds in part of the sky was approximately 5 km. Simultaneous weather observations at the Leningrad weather station are given. An analysis of the cloud front and rain conditions leads to the conclusion that the thunder was of distant origin.

3314

Zierl, H., "Audibility of the Explosion at Oppau in Bavaria on the Right Bank of the Rhine" (in German), Deut. Meteorol. Jahrb. (Berlin), 1922.

Abnormal sound propagation was noted after this explosion at Oppau, September 21, 1921, and is discussed here, with good references to early works on subject of abnormal sound propagation.

Wave Propagation, Abnormal, Subjective Observations

See also — 502, 514, 550, 707, 719, 1155, 1416, 1490, 1491, 1554, 1565, 2061, 2374, 2498, 2506, 2518, 3218, 3219, 3220, 3230, 3248, 3254, 3323, 3348, 3351, 3352, 3359, 3365, 3367, 3534, 3535, 4424, 4425

WAVE PROPAGATION, ABNORMAL, THEORY

3315

Arabadzhi, V. I., "On Anomalous Zones of Audibility" (in Russian), Meteorol. i Gidrol., 5, 21-31, 1946.

Presents thorough theoretical and empirical work leading to the following conclusions: the reception of acoustical waves from the stratosphere occurs because of inversion in refracted waves from the upper part of the inclined wave front with significant vertical extension; the seasonal change in radius of zones of anomalous audibility might explain the formation, during explosions in winter, of acoustical waves of higher frequency than in summer; the "east-west effect" might be explained by the influence of the wind regime on waves of different frequency. Strong skepticism about Wipple's theory of warm stratospheric temperatures as explanation of anomalous propagation is expressed. Sound speed through the ozone layer, about 21 km above the earth, would decrease because ozone is triatomic.

3316

Belov, A. I., "Theory of the Acoustical Sounding of the Atmosphere and Experimental Material Before 1932" (in Russian), Proc. All-Union Conference of the Study of the Stratosphere, 125-138, 1938.

Reviews observations of sound propagation after powerful explosions from 1920 to 1932. Aerological observations and the propagation of sound analyzed; scheme and instruments for further investigations outlined. Hypotheses suggested in the study of the acoustical phenomena, along with critical consideration of results of investigations.

3317

Brekhovskikh, L. M., "Focusing of Acoustic Waves by Means of Inhomogeneous Media," Soviet Phys. Acoust. English Transl., 2, 124-133, 1956.

The field of a pointed radiator in a lamellar nonuniform medium is represented in an intergral form in which reflection coefficients of plane waves occur. For sufficiently high frequencies coefficients of reflection can be calculated by the V.K.B. method. It is also possible to obtain, by a somewhat simpler procedure Haskell's, the equation for the caustic surfaces and to calculate the sound pressure near the cusp (examples given).

3318

Brekhovskikh, L. M., "Propagation of Sonic and Subsonic Waves in Natural Waveguides to Great Distances," Usp. Fiz. Nauk, 70, 351-360, 1960.

A review dealing with waveguides in the ocean and in the atmosphere, and with the change in form of sound impulses on propagation to great distances.

3319

Brekhovskikh, L. M., and V. A. Eliseevnin, "Propagation of (Acoustic) Waves in a Non-Uniform Waveguide," Soviet Phys. Acoust. English Transl., 6, 282-290, 1961.

A waveguide is considered whose properties vary along the propagation path. For a special case, the problem of propagation is solved both exactly and using the ray approximation. The present theory can be used in the analysis of long-distance propagation of acoustic and electromagnetic waves in natural waveguides. Possible generalizations of the results are indicated.

3320

Calvert, J. B., "Progress in the Calculation of the Sound Field in the Atmospheric Acoustic Duct," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 13-23, 1961.
AD-408 716

Calculation of sound intensity by ray-tracing from the source is severely limited in application. At very short ranges (less than 100 km) and for sufficiently short wavelengths ray-tracing methods are useful and simple. As the range and wavelengths increase the method becomes a very poor approximation, complexity of calculation sets in, and even a qualitative calculation of a signal form seems impossible. A more exact treatment by the normal wave analysis becomes necessary.

The signal is composed of a superposition of waves characteristic of the structure of the duct. One must first determine the configuration of the waves, and their dispersion (frequency vs velocity) characteristics. The phenomena are analogous to those in an electromagnetic waveguide. If the amount of excitation of the normal waves is known, the propagation to great distances may be followed with relative ease, since the normal waves propagate in a regular manner. It is therefore important to investigate the method in which acoustic sources excite the normal waves.

First, the field near the source (as if it were in a homogeneous medium) is determined. It may then be simplest to extend this solution by ray-tracing to moderate distances, taking into consideration significant changes in the signal characteristics in this region. Finally, the resulting intermediate signal is expanded in terms of the normal waves. In a practical case, this may be accomplished by numerical integration. A given source will then be specified by its normal-wave frequency spectrum and the times of emission. Reasonable and useful results may well be obtained by this method, even after ruthless simplification to permit a practical solution.

3321

Cox, E. F., "Sound Propagation in Air," in Handbuch der Physik (Encyclopedia of Physics), 48, 455-478, 1957.

This paper begins with a review of the basic laws of propagation of sound energy in air and explains why weak sound waves propagate with negligible distortion, while high amplitude sound waves distort and form shock fronts as they propagate. Expressions for shock wave velocity are given.

Meteorological factors affecting the speed and direction of sound rays are described, and the laws of sound ray refraction and reflection are reviewed. Absorption and dispersion of sound in real atmospheres are described. Formulas and graphs are given for determining attenuation with distance. Propagation of sound to great distances is treated in detail. Refraction in the troposphere and the formation of sound ducts at tropopause heights are described and documented. An excellent bibliography is included.

3322

Duckert, P., "Dispersion of Explosion Waves in the Atmosphere" (in German), Gerlands Beitr. Geophys., 1, 236-290, 1931.

Various aspects of the theory of longtitudinal waves in the atmosphere are taken up: the propagation speed of longitudinal waves in a gas; the spread of explosion waves in a calm, even, and horizontally stratified medium; in a windy such medium; in any stratified medium. Special solutions, by differential equations, are worked out for determining ray paths. A report is given of research on explosion-wave propagation by systematic detonations, instruments, methods, etc. Practical results of pressure registering and conclusions as to the construction of the atmosphere, including results of pure acoustical observations, are given. A possible explanation for the high speed of sound in the upper stratosphere, and of high temperatures there, is outlined, and the importance of air sounding in aerologic research stressed. A highly theoretical article.

3323

Fujiwhara, S., "On the Abnormal Propagation of Sound Waves in the Atmosphere," Bulletin No. 2, Central Meteorlogical Observatory, Japan, 1912.

Detailed reports of various Asama eruptions, as well as of some other lesser explosions. Tables and figures illustrate the spread of sound and air waves. Theories of sound propagation are treated in detail. The article is an interesting and valuable contribution to the study of sound propagation.

3324

Galbrun, H., "Propagation of a Sound Wave in the Atmosphere and the Theory of Zones of Silence" (in French), Gauthier-Villars et Cie, Paris, 352 pp., 1931.

A detailed theoretical work studying the effects of wind on sound propagation. The first part considers discontinuity in the movement of a fluid in relation to propagation of sound. Physics of sound waves and rays are discussed at length. The second part considers zones of silence, giving a detailed analysis and physical and geometrical aspects.

3325

Groves, G. V., "Geometrical Theory of Sound Propagation in the Atmosphere," J. Atmospheric Terrest. Phys., 7, 113-127, 1955.

Deals with the geometry of sound waves and rays propagated in a moving inhomogeneous medium, with particular reference to the atmosphere. The theory developed is, essentially, a generalization of that in geometrical optics for the propagation of light in an inhomogeneous isotropic medium to the case where the medium is in motion. Differential equations defining the wavefront and rays of a sound propagation in an inhomogeneous moving medium are derived, and then transformed by expressing the unit normal of the wavefront in terms of certain trace velocities.

With the equations in this form, an integral is immediately obtainable for sound propagated in the atmosphere by assuming that the velocity of sound and the wind-velocity vector are functions of height only. From this solution the law of refraction, the condition for total reflection of a sound ray, and the equations for the wavefront at any time are found. By way of example, the theory is applied to a simple velocity of sound vs. height relationship, and expressions are obtained for the range and time at which the abnormal propagation from a ground-level source returns to earth. Numerical results calculated from these formulae are found to be in accord with observations that have been made on this phenomenon.

3326

Gutenberg, B., "Effect of Low-Velocity Layers," Geofis. Pura Appl., 29, 1-10, 1954.

Effects of low-velocity channels in the atmosphere, the ocean and the solid earth are discussed. There are two major low-velocity channels in the atmosphere, one with its axis at the tropopause, and another at a height of about 80 km. They produce "zones of silence" and permit the transmission of waves involving the whole atmosphere.

Low-velocity layers in the ocean result from the combined effects of temperature, pressure and salinity. In the earth, the sudden decrease of velocity at the boundary of the core produces a low-velocity channel for elastic waves. In the earth's crust there are two major low velocity channels, one below the Mohorovicic discontinuity, the other at a depth of about 15 km. Misinterpretation of their effects has caused incorrect conclusions concerning the strûcture of the outer portion of the earth's mantle.

3327

Gutenberg, B., "On the Propagation of Sound in the Atmosphere" (in German), Naturwissenschaften, 14, 338-342, 1926.

The zone of silence after the Oppau explosion is illustrated. There is a brief discussion of von dem Borne's, Wegener's, Angenheister's, etc., theories of anomalous sound propagation. A figure shows paths of sound waves and speeds at different heights in the atmosphere. The theory of high upper air temperature is treated briefly.

3328

Gutenberg, B., "Speed of Sound and Temperature in the Stratosphere" (in German, with English summary), Gerlands Beitr. Geophys., 27, 217-225, 1930.

A theoretical article that gives a method of calculation for finding sound velocity in stratosphere, and thus for calculating temperature there. The reckoning process begins with the determination of incident angles of the abnormal sound rays as they strike the earth. Results from the registering of air waves show that the height at which temperature and velocity of sound begin to increase is not always the same.

3329

Haskell, N. A., "Asymptotic Approximation for the Normal Modes in Sound Channel Wave Propagation," J. Appl. Phys., 22, 157-168, 1951.

Asymptotic methods are used to find approximate solutions to the acoustic wave equation in a medium in which the velocity is a continuously variable function of one coordinate. It is shown that when the velocity function has a minimum, undamped normal-mode solutions exist and are closely analogous to the internally reflected waves in the case of a medium made up of discrete layers. By converting the sum of the high-order normal modes into an equivalent integral, it is shown that superposition of these modes leads to geometrical ray theory modified by diffraction in a manner that may be computed from the incomplete Fresnel and Airy integrals.

3330

Haskell, N. A., "Diffraction Effects in the Propagation of Compressional Waves in the Atmosphere," Geophys. Res. Papers, Air Force Cambridge Research Lab., Mass., 43 pp., 1950.
ATI-74 515.
See Also: Sci. Abstr., Sect. A, 1951.

Asymptotic methods are used to find approximate solutions of the acoustic wave equation in a medium where the velocity is a continuously variable function of one coordinate. It is shown that, when the velocity function has a minimum, undamped normal mode, solutions exist and that such solutions are closely analogous to the internally reflected waves in the case of a medium made up of discrete layers. By converting the sum of the high-order normal modes into an equivalent integral, it is shown that superposition of these modes leads to geometrical ray theory modified by diffraction in a manner that may be computed from the incomplete Fresnel and Airy integrals.

3331

Haurwitz, B., "Propagation of Sound Through the Atmosphere," J. Aeron. Sci., 9, 35-43, 1941.

Discusses the geometrical laws of sound propagation in a calm atmosphere, considering wind and temperature effects. The region of audibility around a source of sound is asymmetrical according to the wind. Zones of anomalous audibility around an explosion are explained by high temperatures in upper air.

3332

Hunt, J. N., R. Palmer, and W. Penney, "Atmospheric Waves Caused by Large Explosions," Phil. Trans. A, 252, 275-315, 1961.

This paper considers the harmonic oscillations of several simple model atmospheres. The oscillations are of two types. In the first, the kinetic energy per unit volume tends to zero at great heights; in the second, the kinetic energy per unit volume remains finite. A large explosion at ground level excites a spectrum of both types of oscillation. The pulse ultimately separates into two parts — a train of traveling waves which can be observed at ground level at great distances, and a train of traveling waves which disappears into the upper atmosphere. The complete range of experimental observations on the pressure oscillations caused by explosions of energies varying between 10^{20} and 10^{24} ergs can only be interpreted with model atmospheres having one or more sound channels (i.e., having at least one minimum in the temperature-height relationship of the atmosphere). In spite of the complexity of the phenomena, the theory throws light on some of the characteristic features of the observations. The average period of the largest waves is roughly proportional to the cube root of the energy released by the explosion. The amplitudes of the waves from large explosions can be calculated. Conversely, good records enable the size of the explosion to be estimated. The energy of the Siberian meteorite of 1908 was about 10^{16} cal, or 10 MT (T signifying a ton of tnt)

3333

Koenuma, K., "Waves Propagated in the Atmosphere," Memo. No. 6, Imp. Marine Obs., Kobe, Japan, 175-212, 1936.

Lamb's treatment is extended to waves of short period, such as a few minutes. Assuming air to be a compressible medium, the propagation of waves in the atmosphere with a uniform temperature gradient is discussed. It is shown that with a given velocity the effect of the temperature gradient is to increase the period and the wave length.

In the second part, waves incident on a discontinuous surface are investigated, and it is shown that at a surface of temperature discontinuity, the periods diminish as the temperature difference increases. Further, the wave length and the velocity increase with the height of the discontinuous surface, although for a height of a few km the period is nearly constant.

3334

Kolzer, J., "Observational Results on Sound Propagation for Short Distances and Conclusions on the Problem of Anomalous Propagation of Sound" (in German), K. Preussisches Meteorologisches Institut, Berlin, Abhandlungen, 10, 27 pp., 1932.

Theories on speed of sound, anomalous propagation, etc., are discussed in detail, with consideration given to meteorological conditions, instrument records, and observational data.

3335

Kolzer, J., "Questions of Anomalous Sound Propagation" (in German), Z. Geophysik, 10, 215-221, 1934.

A review of various theories with good references. The high-temperature theory of the upper atmosphere is favored. The importance of studying sound propagation to aerologic research is stressed.

3336

Massey, H. S. W., and R. L. F. Boyd, "The Upper Atmosphere," Philosophical Library, New York, 333 pp., 1959.

Of particular interest to acousticians is the chapter on sound transmission in the upper atmosphere. The propagation of explosive sounds originating on the ground, with anomalous transmission and zones of silence, is examined for what it reveals on the variation of temperature with height. Explosions in the upper air itself have been made possible with the use of rockets, and these explosions have been used to chart the distribution of wind and temperature. However, it seems that even more effective use of sound propagation (e.g., sound attenuation studies) could be made.

3337

Meisser, O., "Air Seismology" (in German), Handbuch der Experimentalphysik, 25, 211-251, 1930.

Calculations of the speed of sound are made through air layers by seismic method. Results of acoustic observations are discussed and sound paths calculated theoretically. Study of the physics of sound speeds at various altitudes gives further contribution to knowledge of the construction of the atmosphere. Detailed theoretical treatment is given sound propagation in still air and in moving air. Sound speed at different temperatures and in different gases is considered. Sound-registering apparatus is described. Results of scientific explosions are given for normal and abnormal propagation; gases and temperatures of the stratosphere are discussed.

3338

Pekeris, C. L., "Free Oscillations of an Atmosphere in Which Temperature Increases Linearly with Height," Tech. Note 2209, Natl. Advisory Comm. Aeron., 26 pp., 1950.

In an atmosphere in which the temperature increases linearly with height and at a constant rate, the acoustical propagation properties are radically different from those hitherto encountered in the theory of atmospheric tides. The phase velocity no longer approaches a limit with increasing period but increases linearly with the period. The region of maximum energy of the oscillation is shifted to increasingly higher elevations as the period is increased.

The bearing of these results on the resonance theory of atmospheric tides is discussed.

3339

Pekeris, C. L., "The Propagation of a Pulse in the Atmosphere," Phys. Rev., 73, 145-154, 1948.

The previous investigation of the dispersion of long waves in the atmosphere [Proc. Roy. Soc. (London), 171A, 434-449, 1939] has been extended to shorter periods of the order of one minute. Both the phase velocity and group velocity have been determined. The results are applied to the interpretation of the pressure wave produced by the Great Siberian Meteor and to the pressure oscillations recorded by microbarographs in England.

3340

Pekeris, C. L., "The Propagation of a Pulse in the Atmosphere," Proc. Roy. Soc. (London), A, 171, 434-449, 1939.

A highly theoretical discussion of the propagation of waves whose period is about an hour. As a result of theoretical deductions, the conclusion is drawn that, insofar as can be expected, the evidence from the Krakatoa wave is in favor of, rather than in contradiction to, the existence of the second mode. In the appendix there is given the distribution with height of the vertical velocities in the two modes of oscillation of a model atmosphere. At heights of the order of 100 km, these velocities are found to be in phase with the surface pressure for both modes.

3341

Perkins, B., Jr., P. Lorrain, and W. Townsend, "Forecasting the Focus of Air Blasts Due to Meteorological Conditions in the Lower Atmosphere," Rept. No. 1118, Ballistic Research Labs., Aberdeen Proving Ground, Md., 77 pp., 1961. AD-250 146.

Whenever explosions are used in testing or in experimental procedures, the sound waves that go beyond the limits of the installation may cause annoyance or damage. This is due to the focusing of the sound waves caused by meteorological conditions—atmospheric velocity gradients produced by variations with altitude of humidity, air temperature, and wind velocity.

Briefly, reviews the theory of sound propagation through the atmosphere, and then describes a simple method for evaluating sound-focusing factors and forecasting the location of the focus, if one is to be expected, as well as the intensity of the sound at the focus.

3342

Pfeffer, R. L., and J. Zarichny, "Acoustic-Gravity Wave Propagation from Nuclear Explosions in the Earth's Atmosphere," J. Atmos. Sci., 19, 256-263, 1962.

In order to account for certain characteristic features of the atmospheric-pressure oscillations produced by nuclear explosions, a numerical matrix method is used to solve the equations governing the horizontal propagation of acoustic-gravity waves in a stratified atmosphere. Solutions for various three- and four-layer models are found to be in qualitative agreement with the observations. In particular, they show normal dispersion (group velocity increasing with period) in the range of periods from 1 to 10 min, and inverse dispersion (group velocity decreasing with period) both at shorter periods and, for some models, at periods of the order of 5 to 15 min.

3343

Remillard, W. J., "The Acoustics of Thunder," Tech. Memo. No. 44, Acoust. Res. Lab., Harvard Univ., Cambridge, Mass., 145 pp., 1961.
AD-253 115.

A survey was made of the extensive literature on lightning and the meteorological conditions that exist during thunderstorms. Particular emphasis was placed on phenomena that might affect the generation, development, and propagation of thunder. It was then possible to formulate mathematical models of a lightning stroke and of the lower atmosphere; these models are consistent with the phenomena, and account for long duration (or roll) of thunder. The periods between the sudden, sharp, loud sounds (or claps) of thunder, which are predicted by these models, are shown to agree well with observational data.

Theoretical analysis predicts the existence of an invariant characteristic of the frequency spectra of thunder. A method was developed for obtaining such spectra, then a typical frequency spectra was deduced from the theoretical sound radiated by the model source, and the invariant characteristic (the product of the observation distance and the dominant frequency) was calculated. This value agrees well with the corresponding quantity taken from measurements of actual thunder.

3344

Rocard, Y., "Atmospheric Propagation of Powerful Acoustic Signals over Great Distances" (in French), Compt. Rend., 248, 3131-3132, 1959.

An extension of previous work to explain, for sound from nuclear explosions, the propagation over 400 km even with unfavorable wind and temperature distributions. The importance of size of explosion is emphasized.

3345

Rocard, Y., "The Focusing of Energy Caused by Irregular Sound Propagation" (in French), Compt. Rend., 246, 2111-2113, 1958.

Atmospheric temperature and wind speed variations can perturb the wave fronts from a sound source. A formula is developed for this effect and applied to the atmospheric conditions caused by thermonuclear explosions.

3346

Rocard, Y., "Focusing of Sound Energy in the Air Due to Wind Effects" (in French), Compt. Rend., 248, 538-540, 1959.

Theoretical addition to a previous note, to include the effect of large atmospheric disturbances.

3347

Rocard, Y., "Path of Sound Trajectories in the Upper Atmosphere" (in French), Compt. Rend., 247, 1973-1975, 1958.

A mathematical note suggesting that shock wave propagation may be a contributory factor in the anomalous distribution of sound from explosions.

3348

Sakai, T., "Anomalous Propagation of Sound Waves at a Short Distance," Proc. Phys. Math.Soc., Japan, 17, 240-273, 1935.

J. Kolzer has observed two cases of anomalous propagation of sound through the atmosphere; viz., when the velocity of the sound increases linearly with the height and then reaches a constant value, a wave can be observed that arrives before the wave that travelled along the earth's surface; and when the velocity decreases linearly with height and then reaches a constant value, there is a zone of silence succeeded by a region of audibility. Taking the case of two atmospheric strata and a cylindrical wave, the author shows that a wave in the upper medium is accompanied by another wave in the lower medium travelling along the surface of separation with the same speed. This wave is identified as the anomalous wave observed by Kolzer, and should only appear when the distance between the source and the observer is greater than a certain critical value. By substituting probable values in the formulae, results are obtained that agree with those observed by Kolzer. A phenomenon termed "multiple reflection shooting" is also predicted.

3349

Sakai, T., and S. Syono, "Propagation of Sound in the Atmosphere," Geophys. Mag. (Tokyo), 8, 205-218, 1935.

The anomalous propagation of sound over short distances cannot be explained by calculations based on geometric reflection and refraction. Accordingly the authors have abandoned the conception of sound rays and have used the wave equations. The problem is simplified by considering the atmosphere to consist of only two homogeneous layers, the upper layer extending to infinity. The effect of the wind is included as a correction to the main calculation and, it is stated, is not strictly allowed for. Despite these simplifications, however, the authors claim to have achieved some success in explaining several hitherto-unexplained phenomena in the propagation of sound over short distances.

3350

Sandmann, B., "Contributions to Propagation of Sound, in Particular to Sound Diffraction and Anomalous Propagation of Sound" (in German, English Summary), Gerlands Beit. Geophys., 28, 241-278, 1930.

The conditions which cause diffraction of sound in the free atmosphere are discussed. Meteorological conditions are treated at length in conjunction with sound propagation. Sections discuss: sound refraction in the air; dependence of sound intensity on meteorological conditions; refraction in relation to a zone of silence; favorable conditions for sound refraction at great heights in the atmosphere; further confirmation of the assumption of sound refractions as cause of anomalous propagation.

3351

Scheid, G., "Investigations of Sound Propagation over Short Distances" (in German), Deut. Wetterdienst, Ber., 4, 16 pp., 1956.

The first part of this study is a review of the most important studies of anomalous sound propagation over short distances, beginning with the investigations by R. Landenburg and F. Von Angerer, in 1913, on sound propagation in the free atmosphere. In Part 2, the author extends the characteristic sound propagation curves of Kolzer to heights of 1500 meters. It is shown that the resumption of the increase in sound velocity above the values at ground level is characteristic of anomalous sounds. The partial and complete return of the echo produced by the maximum velocity of the sound aloft is used to provide an explanation of the zone of anomalous audibility, in good agreement with the recordings. The increase in amplitude observed in the inner zone of second audibility is explained.

3352

Schrodinger, E., "On Acoustics of the Atmosphere" (in German), Physik. Z., 18, 445-453, Ibid., 567, 1917.

A discussion of the physics of anomalous propagation of sound after great explosions and of the kind of sound waves that travel at great altitudes. Numerous equations are given allowing for influences of air density, water-vapor pressure, inhomogeneity of air mass, heat conductivity, and length of sound wave. Absorption of sound waves in air depends on the ratio of sound wavelength to mean-free-path length of the gas molecules. Sound-energy absorption is illustrated per km of path in an isothermal atmosphere.

3353

Scorer, R. S., "The Dispersion of a Pressure Pulse in the Atmosphere," Proc. Roy. Soc. (London) A, 201, 137-157, 1950.

The amplitude and form of a pressure oscillation, as related to the magnitude of and distance from a great explosion, are derived. The solution is compared with actual observations made at varying distances from the Great Siberian Meteorite, 1908, and the Krakatoa eruption, 1883.

3354

Suring, R., "The Propagation of Sound" (in German), Hann-Suring Lehrbuch der Meteorologie, 5th ed., Willibald Keller, Leipzig, 1, 26-28, 1939.

A brief summary review of work and theories in normal and anomalous propagation of sound.

3355

Syono, S., "Anomalous Propagation of Sound at a Short Distance," Geophys. Mag. (Tokyo), 9, 175-194, 1935.

In a former paper the author explained by an approximate method some anomalous sound wave propagation phenomena described by J. Kolzer. The present paper, which is almost entirely mathematical, is concerned with making the treatment more rigorous by taking into account the effects of wind and absorption of the earth's surface.

3356

Takesada, Y., "On Sound Channel in Stratosphere," J. Geomagn. Geoelect. (Japan), 12, 171-174, 1961.

The sound channel is formed in accordance with the wind current and temperature distribution. When the sound ray has the same direction of propagation as the jet stream, the velocity minimum in the vertical distribution of the sound velocity exists to about 23 km in height. If the sound ray radiates from the ground, it is refracted at about 13 km in height, and comes back to the ground. When the sound ray has the opposite direction from the wind stream, the velocity minimum of the vertical sound velocity distribution occurs at the altitude of 12 km.

3357

Tolstoy, I., "Resonant Frequencies and High Modes in Layered Wave Guides," J. Acoust. Soc. Am., 28, 1182-1192, 1956.

When a boundary between two sections of a multi-layered waveguide becomes a pressure of particle-velocity node, the sections can be treated independently and the intersections of their characteristic curves define two infinite lattices of points that give the quasi-resonant and antiresonant propagation frequencies of the complete waveguide. The antiresonant lattice points also give the group velocity maxima corresponding to the frequencies for which the modes of the waveguide are strongly coupled to the characteristic modes of an individual layer or section of the guide. The resonant lattice points give the group velocity minima corresponding to a somewhat weaker coupling with the complementary section. In addition to clarifying the physics of guided waves in layered media, these lattices accelerate the numerical procedures and lead, in the case of high modes of propagation, to useful approximations and/ or simplifications of the exact solutions.

3358

Veldkamp, J., "On the Propagation of Sound Over Great Distances," J. Atmospheric Terrest. Phys., 1, 147-151, 1951.

The surface energy-density of the abnormal sound from big explosions is calculated for a special vertical temperature distribution in the atmosphere. It appears that, in agreement with measurements of Cox, et al. on abnormal sound from the Helgoland explosion, waves with frequencies as low as 0.1 cps can be bent back in the ionosphere at a height of 170 km with considerable intensity. Waves with frequences > 70 cps are practically totally absorbed in the upper stratosphere. Accurate measurement of the travel-time and intensity of abnormal sound could be used to give information on the temperature and pressure in the ionosphere.

3359

von dem Borne, G., "The Propagation of Sound After Great Explosions" (in German), Physik. Z., 11, 483-488, 1910.

Observations and theories of the anomalous sound propagation are presented. It is suggested that the idea that increased sound velocity at high altitudes is based on high concentration of lighter gases, mainly hydrogen and helium, is a theory no longer considered valid.

3360

Wegener, K., "Sound Waves in the Stratosphere" (in German), Meteorol. Z., 52, 504-505, 1935.

A brief discussion of stratospheric investigations that use sound waves.

3361

Wegener, K., et al., "The Problem of Sound Propagation over Great Distances" (in German), Meteorol. Z., 58, 289-294, 1941.

The behavior of sound waves in the stratosphere is considered. Sound waves are said to become Riemann shock waves in the stratosphere.

3362

Weston, V. H., "Gravity and Acoustic Waves," Can. J. Phys., 40, 446-453, 1962.

The spectrum of the gravity and acoustical waves are discussed for two general types of models of the atmosphere. The main emphasis is placed upon the discrete set of modes that are important in the propagation of energy, over long distances around the earth, from large explosions in the atmosphere.

3363

Weston, V. H., "The Pressure Pulse Produced by a Large Explosion in the Atmosphere, II," Can. J. Phys., 40, 431-445, 1962.

The pressure pulse produced by a large explosion in the atmosphere is investigated. A realistic model for the vertical temperature is taken, with two temperature ducts and the large temperature gradient in the thermosphere. The first three dominant modes, or free waves, are computed for the low-frequency range. The distribution of these modes to the head of the pressure pulse produced by a large explosion is calculated for a particular range. It is shown that the "high-frequency" phenomena previously observed is a superposition of relatively low-frequency modes. An increase in the altitude of the source produces a corresponding decrease in relative intensity of the higher-order modes, so that for an intense explosion at high altitudes, the low-frequency gravity-wave mode is dominant.

3364

Whipple, F. J. W., "Estimation of Heights Reached by Air-Waves Which Descent in Zones of Abnormal Audibility," Gerlands Beitr. Geophys., 31, 158-168, 1931.

Gutenberg has recently given an apparently simple procedure for dealing with the results of observations of the airwaves from explosions. It is here pointed out that Gutenberg's method must be unreliable, since the actual times of transmission of the air-waves from the source to the observing station are ignored. It is then shown how this defect in Gutenberg's method can be remedied.

3365

Whipple, F. J. W., "The Propagation of Sound to Great Distances," Quart. J. Roy. Meteorol. Soc., 61, 285-308, 1935.

Inner and outer zones of audibility are differentiated. Maps are given illustrating the audibility of explosions that occurred at various places: Boden, Sweden, January 11, 1933; and others in India and England. Reproductions of instrumental records of sound and explosion waves are analyzed. A discussion follows of how angles of descent are estimated. Methods are outlined for calculating times of passage of air waves, velocities of the waves, and heights of the trajectories. The Oldebroek explosions of December, 1932, are discussed as examples of conditions in winter. Diagrams show the velocity of waves according to temperature, etc., and trajectories of waves toward the east. Monsoon winds in the upper air are considered, as well as distribution of temperature over the globe; the passage of waves through rarefied atmosphere; the absorption of sound in the atmosphere; and the possibility of explaining high temperatures in the upper atmosphere by meridional transfer of air masses in the upper atmosphere opposite in direction to that at low altitudes.

3366

Whipple, F. J. W., "Temperature of the Atmosphere at Levels Accessible to Air-waves," Terrestrial Magnetism and Atm. Elec., 38, 13-16, 1933.

Vergard expresses the opinion that the propagation of sound to great distances cannot be due to the existence of a warm layer in the atmosphere above 40 km. The author of the present paper considers that this view is not sound and from observations carried out both in England and in Germany endeavors to show that sound waves penetrate above 40 km. The path of the sound wave on a particular occasion is calculated. The portions within the troposphere are shown to be definite. To account for the observed time of the passage of the sound wave the author considers that there is an upward temperature gradient above 33 km, reflection occurring at 44 km. Above this, temperature still increases. The latter part of the paper deals with some probable casues of this increase in temperature with height.

3367

Wiechert, E., "On Sound Propagation in the Atmosphere" (in German), Meteorol. Z., 43, 81-91, 1926.

Inner and outer audibility zones are described, along with normal and abnormal sound waves. Examples of anomalous sound-propagation observation are given for different observers after eight large explosions; distance and speed of travel of waves are considered. The theory is explained, with references and equations. Effect of wind considered, and examples are cited that show the influence of wind on audibility after different explosions.

3368

Wiechert, E., "Remarks on the Abnormal Propagation of Sound in the Air, Part I" (in German), Nachr. Ges. Wiss. Gottingen, Math.-Physik. Kl., 49-69, 1925.

Discusses refraction and differences in speed of sound waves in layers of stratosphere and gives an explanation of abnormal audibility zones depending on actual layers of the stratosphere and wind conditions. Temperature is considered important in view of the new Lindemann-Dobson theory of warm upper-air conditions.

3369

Wiechert, E., "Remarks on the Abnormal Propagation of Sound in the Air, Part II," Nachr. Ges. Wiss. Gottingen, Math.-Physik. Kl., 93-103; "Part III," Ibid., 201-211, 1926.

See preceding abstract.

3370

Witkiewicz, W. J., "On the Zones of Audibility from Explosion Waves" (in German), Meteorol. Z., 43, 91-96, 1926.

Explosions in Moscow (May, 1920) are discussed. Barograph records and zones of audibility are shown. Theories and equations are offered concerning various meteorological influences on the acoustic phenomena.

Wave Propagation, Abnormal, Theory
See Also — 440, 471, 478, 502, 514, 522, 549, 550, 554, 588, 725, 924, 1185, 1416, 1420, 1437, 1464, 1472, 1482, 1483, 1485, 1493, 1505, 1519, 1528, 1534, 1542, 1554, 1561, 1565, 1566, 1806, 1890, 1922, 1937, 1947, 2061, 2074, 2213, 2258, 2293, 2297, 2487, 2498, 2518, 2519, 3220, 3223, 3248, 3270, 3277, 3280, 3298, 3307, 3312, 3443, 3632, 3688, 3706, 3709, 3898, 4420, 4429, 4455

WAVE PROPAGATION, AMPLITUDE AND PHASE FLUCTUATION

3371

Bergmann, P. G., "Propagation of Radiation in a Medium with Random Inhomogeneities," Phys. Rev., 70, 486-492, 1946.

By means of the methods of geometrical optics, approximate formulae are derived that correlate the statistical properties of the inhomogeneities of the transmitting medium with the fluctuations to be expected in the signal level of radioactive energy. Through a further simplification of the formulae obtained, it is possible to predict the dependence of signal fluctuation on range without detailed knowledge of the statistical parameters of the microstructure of the transmitting medium.

3372

Berman, H. G., and A. Berman, "Effect of Correlated Phase Fluctuation on Array Performance," J. Acoust. Soc. Am., 34, 555-562, 1962.

The response of a uniform array of point detectors receiving cw signals is computed under the assumption that there are correlations in the fluctuations of the phase of the signals. General formulas are developed for various ranges of correlation. It is shown that the peak response of an array is not appreciably reduced until the magnitude of the fluctuations becomes large. If the fluctuations are strongly correlated over many receiving elements, the main lobe will be broadened.

3373

Bordelon, D. J., "Effect of Correlated Phase Fluctuation on Array Performance," J. Acoust. Soc. Am., 34, 1147, 1962.

It is shown that the expectation of the mean-square time-averaged response for a configuration of receivers is immediate from known statistical considerations.

3374

Bordoni, P. G., "Approximate Methods for Studying Sound-Sources" (in Italian), Pontif. Acad. Sci., Acta, 8, 61, 1944. See Also: Ric. Sci. Ricostruz., 15, 147-148, 1945.

The field radiated from a sphere is determined for velocity varying from point to point, in amplitude and phase, and in the case of specified pressure, as boundary conditions. On the basis of the results, more complicated boundary conditions can be dealt with by such approximate methods as screened loudspeakers.

3375

Bourret, R. C., "Directivity of a Linear Array in a Random Transmission Medium," J. Acoust. Soc. Am., 33, 1793-1797, 1961.

A simple derivation is given of the phase autocorrelation function of a monochromatic signal during transmission through a medium with random fluctuations of refractive index. The resulting phase coherence function is then applied to the theory of the linear array antenna to yield a formula for the degraded directivity pattern.

The analysis developed here was conceived primarily with reference to acoustic signals and sonar ranging systems, although it may be applied, mutatis mutandis, to a wider variety of acoustic and even electromagnetic problems. For concreteness, however, we shall employ a vocabulary appropriate to the case of sonar signals and antennas.

The problem to be considered is the following: Given a source of monochromatic radiation situated far enough from the receiving antenna to be considered a point source, what will be the response, as a function of bearing angle, of a linear array antenna to the signal if the transmission medium has small random irregularities of its refractive index?

3376

Brown, J. L., Jr., "Variation of Array Performance with Respect to Statistical Phase Fluctuations," J. Acoust. Soc. Am., 34, 1927-1928, 1962.

The effect of phase fluctuations on the mean-square time-averaged output of a discrete linear array is considered under the assumption that the fluctuations are governed by a Gaussian joint-probability density function. In particular, a closed-form expression is derived for the variance of the array output over the ensemble of phase variations.

3377

Chernov, L. A., "Correlation of Amplitude and Phase Fluctuations for Wave Propagation in a Medium with Random Irregularities," Soviet Phys. Acoust. English Transl., 1, 94-101, 1955.

The coefficient of correlation is calculated for amplitude and phase fluctuations at the reception point. It is shown that if the irregularities are large in scale, the autocorrelation between the amplitude (or phase) fluctuation at different reception points extends over a distance of the same order as the correlation between the fluctuations of the index of refraction in the medium.

3378

Chernov, L. A., "Correlation of Field Fluctuations," Soviet Phys. Acoust., English Transl., 3, 203-206, 1958.

Formulas are obtained, establishing a connection between the correlation function for field fluctuations and the self-correlation functions for fluctuations of level and phase.

3379

Chernov, L. A., "Correlation Properties of a Wave in a Medium with Random Inhomogeneities," Soviet Phys. Acoust., English Transl., 1956, 2, 221-227.

The work complements that described in an earlier paper. The coefficient of the longitudinal space autocorrelation of amplitude and phase fluctuation is calculated. This autocorrelation is shown to extend to a distance considerably greater than for the transverse case. The coefficient of the time autocorrelation of fluctuations of amplitude and phase is also determined. The paper is entirely theoretical.

3380

Dawes, J. G., "The Acoustic Blastmeter," J. Sci. Instr., 27, 123-127, 1950.

Describes a method for measuring and recording the speed of a rapidly changing blast of air. The method depends on the change in phase of an acoustic signal received at a point, the phase shift being a function of the velocity of the air between the sound transmitter and receiver. Tested in a laboratory gallery with a series of steady air blasts ranging from 25 to 125 fps, the method gave results closely corresponding to the air velocities measured by an independently calibrated orificemeter. It is capable of rapid response and of dealing with a wide range of air speeds. The article proposes use of the method for recording the changing speed of the air blast which precedes the flame of an explosion traveling along a gallery.

3381

Ellison, T. H., "The Propagation of Sound Waves Through a Medium with Very Small Random Variations in Refractive Index," J. Atmospheric Terrest. Phys., 2, 14-21, 1951.

A theoretical study of scattering in a field having a known, slightly variable refractive index, such as the atmosphere, first of an incident plane wave and secondly of a ray. It is found that "for a wave travelling in a statistically homogeneous medium where the scale of the variations in refractive index is suitably large compared with the wavelength but small compared with the path length, the variations in intensity produced by the medium are proportional to the cube of the path length for short paths, but directly proportional to it for long paths."

3382

Golitsyn, G. S., A. S. Gurvich, and V. I. Tatarskii, "Investigation of the Frequency Spectra of Amplitude and Phase Difference Fluctuations of Sound Waves in a Turbulent Atmosphere," Soviet Phys. Abstracts, October-December, 185-194, 1960.

The paper presents the results of an experimental investigation of the frequency spectra of amplitude and phase difference fluctuations for sound propagated in the layer of atmosphere near the surface of the earth. Comparison of the results of the measurements with theory (the latter based on Kolmogorov's turbulence scheme) shows that there is satisfactory agreement between the two.

3383

Harris, C. M., and L. Kirvida, "A Study of Phase Characteristics of 45 CPS-Sound Propagated in Air," Tech. Rept. No. 9, Columbia Univ., N. Y., 1958.
AD-202 835.

This report describes an experimental program aimed at delineating phase fluctuation effects of an inhomogeneous atmosphere on a 45-cps acoustic tone, as determined by two microphones in a phased array operating on a level terrain.

3384

Ingard, U., "Field Studies of Sound Propagation over Ground," Acoustics Lab., Mass. Inst. Tech., Cambridge, 1954.

The results of two sets of field studies of sound propagation over ground are presented. One study utilized pure tones, the levels of which were measured at various distances and different wind velocities. For the second study an airplane propeller served as the source with octave band levels measured over various ground covers, at different wind velocities and at several distances. The importance of wind is shown by the shadow formation obtained. Fluctuation of sound level was shown to increase with distance and frequency. For propagation over the ground, the effect of turbulence scatter was found to be small.

3385

Ingard, U., "A Review of the Influence of Meteorological Conditions on Sound Propagation," J. Acoust. Soc. Am., 25, 405-411, 1953.

The study of the different atmospheric effect indicates that in short-range sound propagation the attenuation by irregularities in the wind structure (gustiness) often is of major importance in comparison with humidity, fog, and rain, and ordinary temperature and wind refraction. However, the ground attenuation can be just as important as the gustiness, particularly when the sound source and the receiver are sufficiently close to the ground. The effect on the attenuation of the height of the source and the receiver off the ground is presented as a function of frequency for a typical ground impedance. The attenuation curve exhibits a maximum which in most cases lies at a frequency between 200-500 cps.

3386

Karavainikov, V. N., "Fluctuations of Amplitude and Phase in a Spherical Wave," Soviet Phys. Acoust., English Transl., 3, 175-186, 1958.

The correlation coefficient is established between fluctuations of amplitude and phase occurring in a spherical wave. Also obtained are the coefficients of longitudinal and transverse selfcorrelation of amplitudes and phases.

3387

Kirvida, L., and C. M. Harris, "A Study of Phase Characteristics of 45 CPS Sound Propagated in Air," Tech. Rept. No. TR-9, Electronics Res. Labs., Columbia Univ., N. Y., 44 pp., 1958. 1958.
AD-202 835.

An indication of the effect of phase fluctuations, which result from propagation of sound through inhomogeneous atmospheric conditions, was obtained on an acoustic phased array detection system. Sound from a 45-c pure tone source (located on the ground in rather flat terrain) was transmitted to two microphones at ground level, which were some distance away at approximately equal distances from the source. The acoustic signals received at each microphone were recorded on a two-channel magnetic tape as a function of time; for a given set of conditions, one such recording was made for each of five different spacings between the two microphones. Twenty-one sets of data (of five recordings each) were obtained for various atmospheric conditions and for different distances between the sound source and the microphones. These recordings provided a convenient method of storing the information from which the required phase characteristics were obtained. The following information was obtained: (1) the phase difference between the acoustic signals was plotted about the mean value for a 50-sec interval, for each of the 21 runs, (2) the autocorrelation function for each of the graphs was calculated for time intervals between 0 and 20 sec, (3) the mean square value of the phase difference about the mean value was computed, and (4) the rms values of the summed output of ten microphones spaced at half-wavelength intervals in the form of a linear array were computed and are an indication of the effect of atmospheric fluctuations on the operation of an acoustic phased array detection system for the meteorological conditions existing during our tests.

3388

Knudsen, V. O., "The Propagation of Sound in the Atmosphere—Attenuation and Fluctuations," J. Acoust. Soc. Am., 18, 90-96, 1946.

Following a summary of earlier work, experiments in progress to determine the absorption of audible sound in air containing different amounts of water vapour are outlined, and the importance of such data in connection with room acoustics, and public-address and sound-ranging systems is emphasized. Reference is also made to measurements, at frequencies between 500 and 4000 cps, of the attenuation of sound in air containing lycopodium spores, but it is shown that the agreement with values calculated from Epstein's equation is not very satisfactory. A laboratory investigation of previously observed fluctuations in the intensity of sound propagated through the atmosphere is described; the effect is attributed to temperature turbulence of the air. For frequencies between 8 and 16 kcs, the magnitude of the intensity fluctuations is proportional to the square of the sound frequency.

3389

Kraichnan, R. H., "On the Propagation of Sound in a Turbulent Fluid," Tech. Rept. No. 4, Acoustics Lab., Columbia Univ., N. Y., 23 pp., 1954.
AD-28 517.

Eikonal and continuity equations are derived for a sound wave propagating through a fluid in which there is a shear motion of low Mach number and a turbulence scale that is large compared to the soundwave length. A comparison between the eikonal equation and the Hamilton-Jacobi equation for a charged particle in a magnetic field revealed that the acoustic-ray paths are identical with the trajectories of the particles provided the magnetic field is proportional to the vorticity. Expressions are obtained in terms of correlation products of the turbulent flow for the attenuation and fluctuation in intensity of a sound beam scattered in a turbulent flow. Expressions are also derived for the phase and intensity fluctuations associated with the propagation of sound through large-scale turbulence. The differential cross section for the scattering of sound by turbulence is developed in a form suited to the treatment of anisotropic turbulence. A simple anisotropic distribution involving symmetry about a preferred vorticity axis is discussed.

3390

Krasil'nikov, V. A., "On the Propagation of Sound in a Turbulent Atmosphere," Compt. Rend., 47, 469-471, 1945.

On the basis of statistical theory of turbulence, an attempt is made to explain experimental results on fluctuations of the phase of sound waves in a turbulent atmosphere. Formulas based on Krasil'nikov (1945), Kolmogorov (1941), Obukhov (1941) and empirical data of Godecke (1935) and Findeisen (1936), show the dependence on the speed of the wind and on the 2/3 law of Kolmogorov.

3391

Krasil'nikov, V. A., and A. M. Obukhov, "Inhomogeneities of the Index of Refraction," Soviet Phys. Acoust. English Transla., 2, 103-110, 1956.

The review is concerned with the problem of waves and fluctuations in connection with atmospheric acoustics, hydroacoustic atmospheric optics and radiowave propagation in the troposphere. Among matters discussed are: the simple wave equations, effect of small non-uniformities, modification and solution of the equation for such conditions, diffraction effects, turbulent medium and its effects, micro-structure of a wind, the structural function of the temperature field, phase, amplitude shift in fluctuations. 23 refs. (21 Russian).

3392

Krasil'nikov, V. A., and K. M. Ivanov-Shits, "Some New Experiments on the Propagation of Sound in the Atmosphere" (in Russian), Dokl. Akad. Nauk SSSR, 67, 639-642, 1949.

Sound waves of frequency 3-5 kcs emitted by a 50W generator mounted on a mast eight meters high, were received by crystal microphones on similar masts 22, 45 and 67 meters from the generator. Fluctuations in phase and amplitude of the microphone signal were recorded. The mean-square phase fluctuation increases as $L^{1/2}$ (L = distance from generator to the receiver) while the mean-square fluctuation of log (amplitude) varies more rapidly than $L^{1/2}$, but less rapidly than L. The influence of L upon phase fluctuations is in agreement with theory (Krasil'nikov, Dokl. Akad. Nauk S.S.S.R., 58, 1353, 1947), but the log (amplitude) fluctuation is discrepant; theory predicts that it should vary as $L^{1/2}$. The discrepancy may be attributed to variation in curvature of the wavefront, which probably occurred in these experiments but was neglected in the theory.

3393

LaCasce, E. O., R. G. Stone, and D. Mintzer, "Frequency Dependence of Acoustic Fluctuations in a Randomly Inhomogeneous Medium," J. Appl. Phys., 33, 2710-2714, 1962.

When a series of uniform acoustic pulses is transmitted through a medium whose refractive index varies in a random manner, the pulses received vary randomly about an average amplitude. A theory developed by Mintzer predicts that the coefficient of variation V, defined as the fractional standard deviation of a series of pulses, is directly proportional to k(2π/acoustic wavelength, provided that the range from the source to receiver is greater than ka^2, where a is the correlation distance of the refractive index variations. In a scaled model experiment the refractive-index variations are caused by heating the medium (water) from below, thus causing turbulent convection. Observations show the linear dependence of V upon frequency for $r > ka^2$ as predicted by the theory. At the higher frequencies, observations indicate possible oscillations in V as it tends toward a frequency-independent value.

3394

Lindsay, R. B., "Compressional Wavefront Propagation Through a Simple Vortex," J. Acoust. Soc. Am., 20, 89-94, 1948.

The equations of propagation for a compressional wave through a moving medium are developed in vector notation. Application is made to the special case of a linear vortex of constant strength m in which the motion is irrotational. Differential equations are set up in general form for the wavefronts and rays. A simple approximation is derived for the distortion produced in an originally plane wavefront by transmission through the vortex. The results are in general agreement with observed fluctuation phenomena in acoustical propagation in air.

3395

Maa, D.-Y., "Fluctuation Phenomena in Room Acoustics," J. Acoust. Soc. Am., 18, 134-139, 1946.

Two types of fluctuational phenomena are discussed theoretically, utilizing the concept of normal modes of aerial vibration in the room. The fluctuation noise due to the random motion of air molecules is found to be a property of air alone, and independent of the room. On the other hand, the fluctuation during reverberation depends on both the room dimensions and its reverberation characteristics. Practical formulae for the magnitudes of the fluctuations are presented that agree well with previous experimental data. The ability of the blind to estimate room size with surprising accuracy is explained, and further investigations of the problem of room "liveness" as it relates to fluctuational phenomena as well as to its effect on the acoustical design of a room are suggested.

3396

Mintzer, D., "Wave Propagation in a Randomly Inhomogeneous Medium," Research Analysis Group, Brown Univ., Providence, R. I., Tech. Rept., 15 pp., 1953.
AD-14 331.

The propagation of sound pulses from a point source in a medium in which the index of refraction varies randomly was studied by means of the Born approximation to the wave equation. A first-order approximation was derived for the pressure in an acoustic pulse traveling in such a medium. The time average over the pulse length of the pressure amplitude was determined under the assumption that random changes of the index of refraction occurred between successive pulses. The expression obtained for the coefficient of variation for a series of pulses agreed with experiment.

3397

Mintzer, D., "Wave Propagation in a Randomly Inhomogeneous Medium, I," J. Acoust. Soc. Am., 25, 922-927, 1953.

A journal article based on the report covered by the preceding entry.

3398

Mintzer, D., "Wave Propagation in a Randomly Inhomogeneous Medium, II," J. Acoust. Soc. Am., 25, 1107-1111, 1953.

Journal article based on report covered by entry 3396.

3399

Mintzer, D., "Wave Propagation in a Randomly Inhomogeneous Medium, II," Research Analysis Group, Brown Univ., Providence, R. I., 13 pp., 1953.
AD-22 289.

The region of validity of the single-scattering approximation is found by considering the next higher approximation; it is valid for $k_0^2 a r \alpha^2 << 1$, where k_0 is the wave number of the incident sound, r is the range from source to observer, a is the mean size of the inhomogeneities and α is the rms value of the refractive index variations. Some approximate results are given for the case of wavelength large compared with inhomogeneity size. By considering the intensity variations, it is found that ray theory is valid for $(k_0 a^2/r) >> 1$, as has been found for plane waves.

3400

Mintzer, D., "Wave Propagation in a Randomly Inhomogeneous Medium, III," J. Acoust. Soc. Am., 26, 186-190, 1954.

Journal article based on report covered by preceding entry.

3401

Mintzer, D., "Wave Propagation in a Randomly Inhomogeneous Medium, III," Research Analysis Group, Brown Univ., Providence, R. I., 15 pp., 1954.
AD-28 451.

On the assumption that the correlation function of the refractive index inhomogeneities is expressible as the product of time- and space-dependent functions, the coefficient of variation for a series of sound pulses and the correlation function for successively received sound pulses are evaluated for arbitrary pulse length. The results showed the validity of the assumption that the refractive index at a point changes only between pulses for pulse lengths $T << \tau_0$ and $\alpha << c_0\tau_0$, where α and τ_0 are correlation constants and c_0 is the reference sound velocity. Furthermore, the correlation function for successive signals is equal to the time-dependent part of the refractive-index function for pulse lengths $T << \tau_0$ and $\alpha << c_0\tau_0$.

3402

Mittenthal, L., "Fluctuations of Scattered Noise," J. Acoust. Soc. Am., 30, 876-877, 1958.

The coefficient of variation of scattered sound is shown to be a decreasing function of the number of frequency components. The limit is found and the distribution of the rms value of scattered, narrowband random noise is shown to be a Dirac delta function.

3403

Obukhov, A. M., "The Influence of Weak Atmospheric Heterogeneities on the Dispersion of Sound and Light" (in Russian), Izv. Akad. Nauk SSSR, Ser. Geofiz., 155-165, 1953.

A mathematical investigation of the problem dealing with the spread of waves in a medium characterized by a pulsating coefficient of refraction; this problem is particularly relevant to the theory of stellar scintillation and to various aspects of atmospheric acoustics. The problem is solved by means of linearization of equations that are satisfied by the phase and logarithm of the moving wave. By means of specific examples the author shows the applicability of approximate geometrical theory and the kind of correlations arising in the calculation of diffraction effects.

3404

Obukhov, A. M., "On Propagation of Sound Waves in Eddying Flow," Compt. Rend., 39, 46-48, 1943.

Differential equations are set up and solved for acoustical propagation in turbulent air under conditions of small change in sound velocity, and quasi-stationary flow. This is an extension of the work of Andreev (1934).

3405

Odintsov, M. G., and I. G. Shaposhnikov, "On the Influence of Large Scale Turbulence on the Propagation of Sound in a Turbulent Medium" (in Russian), J. Tech. Phys. (USSR), 19, 1001-1009, 1949.

Theoretical. The effect of turbulence on sound-propagation depends on its scale: for small-scale turbulence (small compared with the wavelength of the sound) the effect is one of scattering and dispersion, but large-scale eddies cause distortion of the acoustic wavefront, which leads to periodic fluctuations in the intensity of the signal at a distant receiver (acoustic fading). An investigation is made of phenomena of the second type; the influence of source-receiver distance, of wavelength, and of the mean velocity of the turbulent medium are examined. It is assumed that source-receiver distance is >> dimensions of the source, that compressibility of the medium is negligible, and that the mean velocity of the medium is << that of sound. The equations of propagation give series solutions for $\bar{\theta}$, the phase-angle of the soundwave, and for $L = \bar{\pi}^2/\rho c$, where $\bar{\pi}$ is the mean pressure energizing the receiver during a short period, ρ the density of the medium, and c the velocity of sound.

The first two terms in these series are evaluated, and hence the mean-square-fluctuation in sound intensity is obtained. If ΔL represents the deviation of L from its mean value over a long period, $(\Delta L)_{av}^2$ is $\propto r^3$, where r is the source-receiver distance. An expression for the dependence of $(\Delta L)_{av}^2$ upon the correlation function between turbulent velocity fluctuations and distance is also given, but the further step of deriving the dependence of $(\Delta L)_{av}^2$ upon wavelength and the bulk velocity of the medium is not carried out. This further step is omitted because of uncertainty as to the way in which the correlation function is related to these two factors.

3406

Pennsylvania State University, "Atmospheric Physics and Sound," Final Rept., Dept. of Physics, Acoustics Lab., University Park, 288 pp., 1950.

This voluminous report contains a detailed account of the instrumentation developed, methods used, and results achieved at Pennsylvania State University in a five-year study aimed at investigating the production and propagation of sound, both sonic and ultrasonic, in the lower atmosphere, through the ground, and in other media. Chapter 7 "Micrometeorology and Atmospheric Acoustics," is a summary of results of temperature and wind velocity measurements (mostly with hot wire thermometers and aneomometers) made up to 50 feet from the ground in conjunction with sound intensity measurements. A definite correlation is found between sound signal fluctuations and inhomogeneities of temperature, but not of wind. Likewise no effect of snow cover on sound propagation was noted.

3407

Potter, D. S., and S. R. Murphy, "On Wave Propagation in a Random Inhomogeneous Medium," J. Acoust. Soc. Am., 29, 197-198, 1957.

This paper examines the calculation of the coefficient of variation in intensity for acoustical transmission in a randomly inhomogeneous medium. An equation for this coefficient is derived that is valid over the range of frequencies between the wave limit and the ray limit previously reported by other authors.

3408

Richardson, E. G., "The Fine Structure of Atmospheric Turbulence in Relation to the Propagation of Sound over the Ground," Proc. Roy. Soc. (London), 203, 149-164, 1950.

With the aid of hot-wire instruments, measurements have been made of the fluctuations of the wind in the lowest 50 feet of the atmosphere and, in particular, of the mean eddy diameter and of the ratio of vertical and cross-wind components in such fluctuations. It appears that the turbulent elements near the

3409

Skudrzyk, E., "Scattering in an Inhomogeneous Medium," J. Acoust. Soc. Am., 29, 50-60, 1957.

The standard mathematical procedure formally describes scattering by the superposition of a scattered pressure on the unscattered sound field. At low frequencies, because of the irregular distribution of the inhomogeneities, the phases of the scattered waves are at random, and scattering is an interference phenomenon. As the frequency increases, scattering becomes highly collimated in the forward direction and the phase differences decrease to zero. At this point, ray theory starts to apply. The scattered pressure, then, essentially describes only a phase change caused by the different sound velocities and the focusing and defocusing by the lens action of the patches. The medium in the neighborhood of the receiver can be shown to contribute only by focusing; the medium farther away, only by interference fluctuations. Focusing leads to normally distributed amplitude fluctuations, however, passes from normal to Rayleigh with increasing values of range.

3410

Suchkov, B. A., "Fluctuations of Sound Amplitude in a Turbulent Medium," Soviet Phys. Acoust., English Transl., 4, 84-90, 1958.

Fluctuations of amplitude of a sound spreading in a layer of the atmosphere near the ground were measured. The root-mean-square value of fluctuations appears to vary linearly with distance. A comparison is made of the magnitude of fluctuations, obtained directly from acoustic measurements, with that calculated from the vertical gradient of temperature and wind velocity. An attempt is made, using the experimental material obtained above, to determine the transverse correlation functions of the acoustical field.

WAVE PROPAGATION, AMPLITUDE AND PHASE FLUCTUATION

3411

Tatarskii, V. I., "Fluctuations of Sound Phase in a Turbulent Medium" (in Russian), Izv. Akad Nauk SSSR, Ser. Geofiz., 252-258, 1953.

The fluctuations of the sound phases received by two microphones situated in a turbulent medium are examined. Analysis is carried out in limits of geometric acoustics. The mean square of the fluctuations of phase difference is calculated with variable relationship between the base and the distance covered by sound in a turbulent medium.

3412

Tatarskii, V. I., "Theory of the Propagation of Sound Waves in a Turbulent Stream" (in Russian), Zh. Eksperim. i Teor. Fiz., 25, 74-80, 1953.

Examines in detail the problem of the scattering of sound waves for the case of isotropic turbulence in an incompressible liquid. Investigates the general form of the scattering indicatrix and develops for it an expression based on the formula $R_{rr}(\rho) = \bar{u}^2 \exp(-\rho\ell)/3$, where $\bar{u}^2$ is the mean square value of the pulsation velocity of the stream, ρ = one of the spherical coordinates of the point, and ℓ = the correlation scale characteristic of the average pulsation size. The analysis of this phenomenon, based on the scattering theory, yields the mean square fluctuations of the phase and amplitude of sound at large distances from the source.

3413

Tverskoi, N. P., "Acoustical Characteristics of Atmospheric Turbulence" (in Russian), Glavnaia Geofizicheskaia Observatoriia, Trudy, 54-60, 1958.

The turbulence of the atmosphere can be studied by observing the propagation of sound waves within it. An indirect means of evaluating atmospheric turbulence is the use of the oscillation of the phase difference of a sound wave passing through an atmospheric layer. The equation for the missing coefficient is

$$K_A = \frac{\sqrt{\overline{\Delta\phi}^2}}{A\frac{\omega}{\bar{c}^2}\left(\frac{L}{\ell_k}\right)^{1/2}} = \bar{u}_1\ell_k$$

[$\sqrt{\Delta\phi^2}$ = value of phase difference between the sound source and the sound wave, passing through mean characteristic distance (scale of correlation), L = distance covered by the sound wave in the region investigated, $\bar{c}$ = corresponding frequency and mean velocity of sound, $\bar{u}_p$ = mean pulsational velocity of sound].

An experimental design to determine these relationships is described and the results are presented in graphs. The mean square variability of the phase difference depends essentially upon the condition of the atmosphere, wind velocity, gradient wind, temperature, etc. The oscillation of the phase increased sharply with the wind velocity. The phase oscillation diminishes with increased height of wave propagation and of receiver placement.

Registration of pulsations of wind velocity for constant ω, $\bar{c}$, L and $\bar{\ell}$ provided data for determining $\bar{u}_p$ and ultimately A = a dimensionless magnitude which is equal to 5-6. The most characteristic values of turbulent structures occurring under different atmospheric conditions were determined by moving one sound receiver relatively to the other, which remains situated perpendicularly to the sound wave. The value $\bar{\ell}_k$ was found to be an adequate characteristic of the turbulence belonging to an atmospheric state. Further, the oscillation of the phase difference reflects the true turbulence of the atmosphere.

The turbulence coefficients computed by meteorological and acoustical means are compared and a close correlation is observed.

3414

Welkowitz, W., "Sound Fluctuations Caused by Turbulent Winds," Tech. Rept. No. 2, Columbia Univ., 1955. AD-77 478.

In this report data is presented from measurements taken with a fairly simple experimental system consisting of a wind-speed instrument, a wind-direction instrument, some microphones at one location, and a loudspeaker located some distance away. Numerous measurements were taken at a few frequencies over the course of a month, and the results appear to indicate that despite the simplicity of the experimental system some useful quantitative data on the fluctuations of received sound caused by turbulent winds have been obtained.

3415

Zverev, V. A., and I. K. Spiridonova, "Statistical Analysis of an Acoustic Field in the Atmosphere to Determine the Characteristics of Atmospheric Turbulence," Soviet Phys. Acoust., English Transl., 7, 346-351, 1962.

By measuring the correlation coefficient of an acoustic field in the atmosphere at scattered points, the inhomogeneity scale and mean-square-phase fluctuation were determined.

The measurements were performed by recording a signal at four points of the field simultaneously and processing the records. The processing included finding the mutual correlation functions of the field with a small averaging time, then subjecting them to spectral analysis with a large time constant. In the case of strong winds (of the order of 10-15 meters/sec) the inhomogeneity scales were of the order of 1.2-1.6 meters, the mean-square phase fluctuation of the order of 130-150°. The measurements were performed in the interval from 4 to 7 kc.

Wave Propagation, Amplitude and Phase Fluctuation
See Also — 12, 411, 420, 429, 460, 482, 488, 527, 554, 560, 667, 818, 823, 1086, 1299, 1321, 1381, 1382, 1390, 1391, 1398, 1401, 1445, 1538, 1545, 1557, 1916, 2147, 2151, 2155, 2156, 2180, 2184, 2269, 2817, 2927, 3680, 3681, 3682, 3688, 3691, 3712, 3722, 3739, 4147, 4210, 4398, 4399

WAVE PROPAGATION, BLAST/DETONATION

3416

Adamson, T. C., Jr., "On the Structure of Plane Detonation Waves," Phys. Fluids, 3, 706-714, 1960.

A steady planar detonation wave, considered to be a shock wave followed by a reaction zone, is studied with both irreversible and reversible first-order reaction kinetics. A perturbation solution with first-order transport effects is presented with sample calculations of temperature distributions for typical irreversible and reversible reaction cases; it is valid in the reaction zone for those cases where the ratio of the characteristic chemical time is small compared to one. Analysis of the solution shows that simple series solutions and hence the given perturbation solutions do not hold near the hot boundary for all possible final Mach numbers. In the irreversible reaction case, the perturbation solution is a valid approximation for final Mach numbers less then $(1 - B)^{1/2}$, where B is the ratio of characteristic times, the approximation becoming less accurate as the Mach numbers tend toward this limiting value. In the reversible reaction case, the perturbation solution is a valid approximation for final Mach numbers up to the Chapman-Jouguet value of unity, if the Mach number is based on the equilibrium speed of sound.

3417

Allen, H. J., and W. O. Ursenbach, "Fundamental Investigation of Air Blast and Ground Shock," Final Tech. Rept. No. 3, Inst. for the Study of Rate Processes, Univ. of Utah, Salt Lake City, 1958.
AD-202 213.

An investigation was conducted on factors influencing propagation of air blast and ground shock from charges similar to those fired during demolition activities. These charges ranged from 10 to 21,000 lb. Under given weather conditions, the greatest reduction of air blast was achieved by burying charges under dirt cover. The lowest pressure at which glass was broken by impact was 26.2 lb/sq ft for a used 2 × 2-ft-square commercial sash. Used windows were pulled from the sashes under rarefaction at pressures as low as 6.4 lb/sq ft. No pressures as great as this were found beyond 8,000 ft.

Three ground shock waves were found, namely direct ground shock, induced ground shock, and synchronous ground vibration. Direct ground shock was directly proportional to the two-thirds power of the explosive weight and inversely proportional to three-halves power of the distance when a crater was formed by the explosive. Induced ground shock was found to depend entirely on the air blast wave impacting the ground. The maximum displacement amplitude of induced ground shock was found when the frequency of the air blast wave was approximately equal to the natural frequency of the ground. Synchronous ground vibration was the result of coupling of the air blast wave with a wave in the ground to increase the displacement amplitude of the ground wave. No ground vibrations were detected that were sufficiently severe to cause even minor damage to any structure.

3418

Anderson, T. C., "On the Structure of Detonation Waves," Tech. Rept. No. MICH-4-M, Univ. of Mich., Ann Arbor, 19 pp., 1958.
AD-156 509.

A standing, normal detonation wave is considered in a mathematical formulation to determine whether the shock-produced temperature jump is sufficient in itself to make the heat transfer negligible, or whether the heat-transfer mechanism is important enough to include. The wave is assumed to be a shock followed by combustion, and the reaction is assumed to be first order, following the Arrhenius rate law. The equation describing the reaction is $C_1 \rightarrow c_2 C_2$, where C_1 is the reactant and C_2 is the product of the reaction and, hence, a two-component gas mixture is considered. In the formulation, diffusion is neglected so that a simple thermal theory may be studied, as in the deflagration theories.

3419

Austern, N., and J. K. Percus, "Propagation of Strong Blast in an Atmosphere of Varying Density," Rept. No. NYO-7970, Inst. of Math. Sci., Univ. of New York, 35 pp., 1957.
AD-145 546.

The engulfed gas, in the propagation of strong shock through a γ-law gas when $\gamma \approx 1$, is confined to a thin shell near the shock surface. Based upon this picture, several models are construted for the analysis of strong shock propagation in inhomogeneous media. This sequence of models utilizes successively more detailed pictures of the wave behind the shock. In order to assess the validity of the models, they are compared with a numerical perturbation calculation of a blast in an atmosphere with linear variation of density. It is found that the distortion of the shock front and the distribution of mass per unit shock surface are predicted with considerable accuracy by the models, whereas the transverse mass flow is sensitive to the details of the model picture.

3420

Ballistic Research Lab., "Information Summary of Blast Patterns in Tunnels and Chambers (Second Edition)," Memo Rept. No. 1390, Aberdeen Proving Ground, Md., 75 pp., 1962.
AD-274 228.

Military requirements for protective construction have in recent years included blast-hardened designs. This often means putting the construction deep underground and sets up requirements for information on the behavior of blast waves in such confined regions as tunnels and chambers. The Shock Tube Facility at the Ballistic Research Laboratories endeavored to obtain information on the behavior of blast waves in tunnels and chambers by instrumenting models of simple tunnel configurations with piezoelectric gages and subjecting the models to the blast wave from shock tubes. Data were obtained from models attached to the 24-in. circular tube, the 4 × 15 in. rectangular tube, and the high-pressure tube. A compilation of the test results is presented.

3421

Baum, F. A., et al., "Physics of an Explosion," T-1488 M, Dept. of the Army Corp of Engineers, U. S. Army Engineer Research and Development Labs, Fort Belvoir, Va., 133 pp., 1962.
AD-290 463.

The motion of the detonation products of explosions in air, in vacuum, in water and in soil is treated mathematically. Blast and shock-wave theory is developed, and the results are used to estimate blast damage and to predict crater size and shape for explosions in and on soils.

3422

Beare, H. T., "Observations on the Stability of the Canadian Army Development Establishment's Unrevetted Trenches When Subjected to Two Separate Blast Waves from 5 Ton Charges of TNT," Tech. Paper No. 220, Suffield Experimental Station, Canada, 6 pp., 1961.
AD-272 042.

A series of eight idealized trenches was exposed to blast waves from two separate detonations of five tons of TNT at Suffield Experimental Station, during the fall of 1960. The soil in which the trenches were dug was frozen at the time of these detonations. No basic theories, therefore, are applied to the results. A mechanical device for testing the relative movement of the trench covers was used with moderate success. The trial showed that trench covers with free edges perpendicular to the line of travel of the blast waves were more heavily damaged than those with the free edges parallel to the blast.

3423

Belliveau, L. J., and C. L. Karmel, "Characteristics of Shock Waves from Pentolite Spheres at High Altitudes by Sachs Scaling," Rept. No. 5696, Naval Ordnance Lab., White Oak, Md., 39 pp., 1957.
AD-151 401.

Sachs scaling is used to approximate the shock-wave characteristics from bare 50/50 spherical pentolite charges at the following burst altitudes: 10, 20, 30, 40, 50, 75, 100, and 150 kilofeet. The explosive weights used in compiling the original data at sea level ranged from one-half pound to eight pounds, and the scaled distance from 1.48 to 14.81 ft per $\sqrt[3]{\text{lb}}$. The following characteristics are scaled: peak face-on and peak side-on pressures, face-on and side-on impulses, positive duration, time of arrival, peak face-on minus peak side-on pressure, and the peak dynamic pressure ($1/2\ \rho u^2$). The results are presented as a series of plots for each quantity versus reduced distance, and tables of each quantity at arbitrary distances. Some cross plots are included for illustrative purposes.

3424

Berger, J., Th. Camion, and Ch. Perennes, "Theoretical Study of the Wave-Front Profile and of the Detonation Speed of Cylindrical Cartridges with Solid Explosive" (in French), Compt. Rend., 247, 1433-1436, 1958.

This theoretical study of the wavefront profile and of the detonation speed of cylinderical cartridges with solid explosive begins with a recall of the experimental results obtained by means of a revolving-drum camera. Studies of the outflow of the detonation products and the variations of the detonation speed with regard to the confinement that makes it possible to define the normal component of wave-speed. This study establishes a narrow connection between the front curvature, the wave-speed, and the hydrodynamic laws of the detonation products release.

3425

Berry, F. J., and M. Holt, "The Initial Propagation of Spherical Blast from Certain Explosives," Proc. Roy. Soc. (London) A, 224, 236-251, 1954.

The initial disturbance from the detonation of an uncased spherical charge of explosive, initiated at its center, is analyzed in full. The equations of unsteady spherical motion are solved in the neighborhood of the singularity at the origin of the air blast wave in the time-distance plane. Expansions are used in series of half-powers of the radial distance from this origin, with coefficients depending on the transverse coordinate. Two singular characteristics are found to start at this origin, and it is shown that the inner of these develops into a shock wave. This is identified as the secondary blast wave previously observed in experimental and numerical work. The wave is very weak at first, with a strength that initially is zero and then begins to grow in proportion to the radial distance. In the present paper the explosive gas is assumed to be polytropic, with $\gamma = 3$, but the method developed can be extended to apply to any type gas.

3426

Birk, M., A. Erez, Y. Manheimer, and G. Nahmani, "The Electrical Conductivity of Shock- and Detonation-Waves, and the Measurement of the Velocity of the Waves" (in French), Compt. Rend., 238, 654-655, 1954.

When a detonation wave traverses an explosive it creates a very high density zone of ions; this is utilized to close an electrical circuit and indicate the passage of the detonation wavefront; a similar phenomenon characterizes aerial shock waves sufficiently powerful to generate a density of ions sufficient to permit electrical conduction. The part played by the surface of the electrodes and the intensity of the shock wave in the conduction has been studied by placing electrodes either in or near the explosive, and measuring the electrical conductivity by an oscillograph. It is considered that the fact that, in the explosive, the current intensity is a linear function of the p.d. justifies the introduction of the notion of an "ionization resistance." An increase of the electrode surface causes a decrease of this resistance, and a closer approach of the electrodes causes an increase of the current intensity.

Shock waves in air give analogous results, but the current intensity decreases rapidly with increase of distance from the charge. The relation between current intensity and p.d. is approximately linear. The "ionization resistance" is an exponential function of the distance from the charge. The velocities of shock waves in air have been measured by increasing the electrical conductivity in two ways; viz., by placing a reflector behind the probe and so increasing the pressure and temperature, and by enveloping the probe in about 50 mg of lead nitride that detonates immediately on arrival of the shock front. The second technique is the more effective, and by its aid the arrival of shock waves has been determined in air for values of the pressure up to $p/p_0 = 20$. The measurement of velocities has been achieved by the use of a spiral brush, whereby the spot is extinguished on passage of the shock wave by each probe.

3427

Birk, M., A. Erez, Y. Manheimer, and G. Nahmani, "On Electrical Conductivity in Detonation and Shock Waves, and the Measurement of Detonation and Shock Velocities," Bull. Res. Council Israel, 3, 398-413, 1954.

The electrical conductivity between two electrodes on the explosive or in the air close to it is investigated with a view to obtaining data pertaining to the design of probes. The conductivity between two electrodes on an explosive charge as well as the detonation and shock velocities were measured. Theoretically, relations are derived for the electron velocity and the current density; it is deduced that the gas in the detonation zone cannot be in a state of equilibrium.

Describes the apparatus used and the electronic circuit, and mentions a few applications.

3428

Birk, M., Y. Manheimer, and G. Nahmani, "Note on the Propagation of Explosion-Produced Air Shocks," J. Appl. Phys., 1208, 1954.

Experimental results support Lin's theory of the propagation of cylindrical shock waves produced by the instantaneous release of energy along an infinite straight line, and its conclusion that the reciprocal shock velocity is a linear function of the square root of the time from the moment of energy release. The experiments are confined to the range of Mach numbers 7-14.

3429

Boyer, D. W., "An Experimental Study of the Explosion Generated by a Pressurized Sphere," J. Fluid Mech., 9, 401-429, 1960.

An experimental investigation of the explosions of two-inch diameter glass spheres under high internal pressure has been made. The spheres were initially filled with air or helium at 400 and 326 psi., respectively, and were exploded in air at atmospheric pressure. Experiments on the simulation of high-altitude explosions are also described. Schlieren and spark shadowgraph records of explosion phenomena, and pressure records of the reflection of the spherical shock wave at various radii, are presented.

An account of some initial experiments on the implosion of five-inch-diameter glass spheres is given. The results were not very satisfactory because of the failure of the spheres to shatter in a desirable manner while under an external pressure of 65 psi.

Numerical solutions to the air and helium-sphere explosions are described, and the experimental wave phenomena are shown to agree well quantitatively with the theoretical predictions, in that they exhibit all the main features that were predicted and are modified only be the physical limitations of the glass diaphragm. In practice, a formation process is associated with the spherical shock waves, resulting in initial shock velocities that are lower than the theoretical values.

3430

Brinkley, S. R., Jr., and J. G. Kirkwood, "Theory of the Propagation of Shock Waves from Cylindrical Charges of Explosive," Proc. Symp. Appl. Math., American Mathematical Society, N. Y., 1, 48-54, 1949.

The authors consider explosion waves from cylindrical charges when the explosion proceeds radially from the center-line of the charge, and when the explosion wave travels axially down the charge.

3431

Brinkley, S. R., Jr., and J. G. Kirkwood, "Theory of the Propagation of Shock Waves from Infinite Cylinders of Explosive," Phys. Rev., 72, 1109-1113, 1947.

The assumption of energy dissipation at a single shock is employed in the formulation of a pair of ordinary differential equations for peak pressure and shock-wave energy as functions of radial distance from the source of the shock wave produced by an ∞ cylinder of explosive along which a stationary detonation wave is travelling with finite velocity. The profile of the wave may be determined by means of an auxiliary integration. The theory takes proper account of the finite entropy increment of the fluid produced by the passage of the shock, and permits the use of the exact Hugoniot curve of the fluid in the numerical integration of the basic equations.

3432

Brode, H. L., "Blast Wave from a Spherical Charge," Phys. Fluids, 2, 217-229, 1959.

A description of the blast wave from the detonation of a spherical charge of TNT, based on the results of a numerical calculation. The equations of motion and the equations of state for TNT and for air are described. The pressures, densities, temperatures, and velocities are detailed as functions of time and radius. Space-time relations, energy and impulse histories are shown. A second shock is seen to originate as an imploding shock following the inward rarefaction into the explosion-produced gases, and a series of subsequent minor shocks are seen to appear in a similar manner, moving out in the negative phase behind the main shock.

3433

Brode, H. L., "A Calculation of the Blast Wave from a Spherical Charge of TNT," Res. Memo No. RM-1965, Rand Corp., Santa Monica, Calif., 61 pp., 1957.
AD-144 302.

The solution, on a high-speed computer, of the partial differential equations of hydrodynamic motion for the case of a center-detonated spherical charge of TNT is presented. Results are shown principally in graphical form, in which the second shock is seen to originate as an imploding shock following the inward rarefaction into the TNT gases. A series of minor shocks are generated in the same manner and are seen to move out in the negative phase behind the main shock.

3434

Brode, H. L., "Numerical Solutions of Spherical Blast Waves," J. Appl. Phys., 26, 766-776, 1955.

The strong-shock, point-source solution and spherical isothermal distributions were used as initial conditions for a numerical integration of the differential equations of gas motion in Lagrangean form. The von Neumann-Richtmyer artificial viscosity was employed to avoid shock discontinuities. The solutions were carried from 2,000-atm. to < 1/10-atm. peak overpressure. Results include overpressure, density, particle velocity and position as functions of time and space. The dynamic pressure, the positive and negative impulses of both dynamic pressure and static overpressure, positive and negative durations of pressure and velocity, and shock values of all quantities are also described for various times and radial distances. Analytical approximations to the numerical results are provided.

3435

Brode, H. L., "Theoretical Solutions of Spherical Shock Tube Blasts," Res. Memo No. RM-1974, Rand Corp., Santa Monica, Calif., 75 pp., 1957.
AD-206 491.

Calculations were carried out on two types of explosions that correspond to recent experimental work at the University of Toronto Institute of Aerophysics. These experiments involve the explosion of gas-filled glass spheres (initially) at room temperature and at pressures of around 20 atm. A description is given of the results of the calculations.

3436

Campbell, R. G., "Initial Wave Phenomena in a Weak Spherical Blast," J. Appl. Phys., 29, 55-60, 1958.

The initial waves created by the sudden release of a spherical volume of compressed air in a limitless environment of air at constant state are predicted analytically, using an iterative method of solution by characteristics for the case of a specific weak blast. Pressure-time records were obtained within the compressed air and in the immediate environment of the spherical blast during its early stages, using a pyramidal shock tube. The experimental results corroborate the existence and position in time and space of the inner and reflected shock waves predicted analytically. The present results for a weak spherical blast agree substantially with the analytical and experimental results obtained previously by other investigators for a considerably more powerful blast. The shock tube, in pyramidal or conical form, appears to offer considerable promise for further research on spherical blast phenomena.

3437

Chang, C. C., and Y. C. Whang, "Structures of Magnetohydrodynamic Detonation Waves," Rept. No. TDR-930 (2230-05) (TN-2), Aerospace Corp., Los Angeles, Calif., 17 pp., 1962.
AD-274 697.

Magnetohydrodynamic (MHD) detonation waves of electrically conductive gases and their structures are treated theoretically, with consideration given to reaction-energy release and transport properties. The energy release may be of thermonuclear origin for plasma of extremely high-temperature, or may be from chemical process for reactive gases under the influence of a specified magnetic field. With a simplified model of energy release and electric conductivity, the structures of the detonation waves are numerically calculated as examples. The preliminary results indicate that the MHD-detonation wave thickness is much larger than that of a MHD-detonation wave under the same upstream conditions. The coupling between the shock zone and the reaction zone is strong.

3438

Chertock, G., "Blast Transmission into Chambers," Rept. No. 1539, David Taylor Model Basin, Washington, D. C., 15 pp., 1961.
AD-270 513.

Equations are derived for the increase of pressure in a terminal room or chamber due to the propagation, through a duct system, of a transient pressure from an external blast-pressure wave. Numerical values for the peak pressure in the chamber are given in terms of the parameters of the blast-pressure wave and the characteristics of the duct-chamber system. The calculation of the relevant characteristics of the duct-chamber system is described and illustrated.

3439

Chinitz, W., L. C. Bohrer, and K. M. Foreman, "Properties of Oblique Detonation Waves," Rept. No. AFOSR TN-59-462, Fairchild Engine Div., Fairchild Engine and Airplane Corp., Farmingdale, N. Y., 10 pp., 1959.
AD-215 267.

The two-dimensional steady flow equations for oblique detonation waves are solved for the conditions across the wave in terms of the initial Mach number, the heat addition, and the wave angle. With an I.B.M. digital computer, the resulting equations are solved over a range of the independent variables. Graphs are presented that show the results of this computation.

3440

Collins, T. K., R. R. Doelle, and R. T. Keyes (for Explosives Research Group), "Measurements of Air and Ground Shock Disturbances Arising from Demolition Activities at Seneca Ordnance Depot," Rept. No. 1, Inst. for the Study of Rate Processes, Univ. of Utah, Salt Lake City, 1956.
AD-111 550.

Air shock propagation is discussed, including meteorological effects on directivity, range, etc. Blast damage is given with respect to size of blast and distance from it; both theoretical and experimental results are presented.

3441

Cook, M. A., "An Equation of State for Gases at Extremely High Pressures and Temperatures from the Hydrodynamic Theory of Detonation," J. Chem. Phys., 15, 518-524, 1947.

The hydrodynamic theory of detonation is derived in a convenient form by employing the general equation of state $pv = nRT + \alpha(T,v)p$. Two methods of solution of the general equations based on measured detonation velocity are discussed, and evidence is provided that the approximation $\alpha = \alpha(v)$ is valid. All explosives yet investigated show the same α versus v_2 curve, and detonation velocities for a wide range of explosives can be computed from it within experimental error. Data on the detonation properties of several explosives are presented and correlated with similar data obtained by other investigators.

3442

Cook, M. A., G. S. Horsley, R. T. Keyes, W. S. Partridge, and W. O. Ursenbach, "Detonation Wave Fronts in Ideal and Non-Ideal Detonation," J. Appl. Phys., 27, 269-277, 1956.

Extensive wave shape data are presented for various effectively unconfined explosives over wide ranges of diameter d, length L, density ρ_1, and physical conditions. Observed wave fronts were invariably spherical segments with radii of curvature R increasing at first directly with L(R = L), but eventually becoming steady at a constant value R_m/d between 0.5 and 4, depending on the charge diameter primarily through the ratio a_0/d (a_0 = reaction zone length). At the critical diameter of propagation (large a_0/d), R_m/d approached 0.5, and at large diameter (small a_0/d) it approached or levelled off at the upper limit of about four. The upper limit ($R_m/d \sim 4$) is apparently a restriction imposed by the fundamental nature of detonation of solid explosives with free boundaries.

3443

Cox, E. F., "Far Transmission of Air Blast Waves," Phys. Fluids, 1, 95-101, 1958.

A semi-acoustic theory of blast-energy propagation, incorporating Sachs' scaling modified for altitude of observation, gives excellent agreement with experiments, providing Hilliar's similarity principle is restricted to similar ambient (weather) conditions. Comparisons between this theory and experiments are made for free-air (no reflections) blast pressures; ground-level blast pressures in an isothermal, still atmosphere; and blast pressures under a linear temperature inversion.

3444

Dawes, J. G., "The Acoustic Blastmeter," J. Sci. Instr., 27, 123-127, 1950.

Describes a method for measuring and recording the speed of a rapidly changing blast of air. The method depends on the change in phase of an acoustic signal received at a point, the phase shift being a function of the velocity of the air between the sound transmitter and receiver. Tested in a laboratory gallery with a series of steady air blasts ranging from 25 to 125 fps, the method gave results closely corresponding to the air velocities measured by an independently calibrated orificemeter. It is capable of rapid response and of dealing with a wide range of air speeds. The article proposes use of the method for recording the changing speed of the air blast which precedes the flame of an explosion traveling along a gallery.

3445

Doelle, R. R., "Measurements of Air and Ground Shock Disturbances Arising from Demolition Activities at Black Hills Ordnance Depot," Rept. No. 10, Inst. for the Study of Rate Processes, Univ. of Utah, Salt Lake City, 48 pp., 1958.
AD-159 440.

Measurements were made of air and ground-shock intensities by means of a low-frequency, FM narrow-band microphone system and two velocity-type low-frequency seismometers. A Houston Technical Laboratories S-36 seismometer and a Southwest Industrial Electronics S-19 geophone were used to ascertain if the present demolition program was within limits of safety pertaining to the surrounding residences, and to recommend, if possible, a safe and convenient program for the depot. As much weather data as possible were collected during the survey. The recording sites for air and ground disturbances were located at radial distances of 3000 to 62,000 ft, generally downwind from the demolition area. Variable quantities of explosives, from 10,000 to 21,000 lb were detonated. In addition, various explosive setups, such as 4-ft suspended, surface, and dirt-cover shots, were used to determine the best type for the least air-blast propagation. The largest direct ground shock was a subsurface wave at least 80 times smaller than the index caution level for damage and 1160 times smaller than the displacement amplitude caution level for damage. The largest induced ground vibration was 17 times smaller than the index caution level for minor damage. Air-blast recordings were not significantly large. The use of dirt cover is advisable in reducing air-blast peak pressures.

3446

Doelle, R. R., "Measurements of Air and Ground Shock Disturbances Arising from Demolition Activities at Blue Grass Ordnance Depot," Rept. No. 3, Inst. for the Study of Rate Processes, Univ. of Utah, Salt Lake City, 1957.
AD-155 115.

Air and ground shocks were measured in the area surrounding the Blue Grass Ordnance Depot, Kentucky (5-1/2 mi from Richmond) to determine if the present demolition program is at safe range from the surrounding residences, and to recommend, if possible, a program within safe limits that would minimize the complaints and that could be conveniently followed by the depot. The nearest residence, site 6, is located approximately 2400 ft from the demolition area.

A low-frequency FM narrowband microphone system was used to record the sound wave from 2 to 10,000 cps at pressures as low as 0.01 lb/sq ft. Ground-shock recordings were taken with a Houston Technical Laboratories S-36 seismometer with a natural frequency of 2 cps and a South-West Industrial Electronics S-16 geophone with a natural frequency of 18 cps. The temperature, humidity, and wind vs altitude were determined with an aircraft. Explosive charges ranging from 10 to 500 lb on the surface or buried down to depth of 8 ft were detonated to determine the resulting air-shock pressures at locations of complainants. Results showed no evidence that any problem existed at Blue Grass Ordnance Depot arising out of ground-shock propagation. At distances beyond 3000 ft from the demolition range, no air-blast pressures greater than 2 lb/sq ft were observed. Vibrations recorded in structures were no greater in displacement or acceleration than disturbances created by normal living activity.

Loud noise occurring at long distances from demolition activities was attributed directly to the temperature, wind velocity, and direction in the atmosphere above the ground. It is considered possible to fire up to 500 lb under 8 ft of dirt cover without causing excessive air-blast pressures, exception at site 6. A limit of 100 lb under 6 ft of dirt cover is recommended.

3447

Doelle, R. R., "Measurements of Air and Ground Shock Disturbances Arising from Demolition Activities at Red River Arsenal," Rept. No. 8, Inst. for the Study of Rate Processes, Univ. of Utah, Salt Lake City, 1957.
AD-153 992.

Presents the results of demolition activities at Red River arsenal. The conclusions from these detonations are: (1) there is no problem resulting from ground shock propagation; (2) a 10,000-lb shot gives a pressure of 2.5 lb/sq ft at 8000 ft, is 1/4 of the level at which minor damage may begin to occur, and should be considered as a guide in handling demolition operations when adverse meteorological conditions exist; (3) loud noise at long distances may be attributed to temperature, wind velocity, and direction in the atmosphere above the ground; and (5) large quantities of explosive can be detonated during fair weather conditions with the use of adequate dirt cover.

3448

Doelle, R. R., "Measurements of Air and Ground Shock Disturbances Arising from Demolition Activities at Umatilla Ordnance Depot, "Rept. No. 7, Inst. for the Study of Rate Processes, Univ. of Utah, Salt Lake City, 1957.
AD-153 824.

Measurements were made of air- and ground-shock intensities caused by demolition activities in the vicinity of the Umatilla ordnance depot. The survey was conducted to determine whether the demolition program was within safety limits with regard to surrounding residences and depot operations, and to recommend a program well within safe limits that would minimize the number of complaints and that could be conveniently followed by the depot. In the demolition procedure, charges in a series were initiated by fuses whose lengths varied from charge to charge so as to give a 30-sec delay period between each detonation. The largest direct ground shock was a surface wave at least 14 times smaller than the index caution level for damage and 83 times smaller than the displacement amplitude caution level for damage. These recordings were obtained at 3000 ft from 3000-lb detonations. The direct ground waves attenuated to nonrecordable values at 27,000 ft for

200-lb detonations. The induced vibrations measured in various structures were greater for household movements than those induced from either air- or ground-shock impacts. The use of a dirt cover is advisable.

Survey results showed that the majority of complaints arising from demolition operations were attributed to adverse meteorological conditions rather than quantities of explosives detonated or the direct ground shock effects.

3449

Doelle, R. R., and W. O. Ursenbach, "Measurements of Air and Ground Shock Disturbances Arising from Demolition Activities at Various Ordnance Installations," Rept. No. 14, Inst. for the Study of Rate Processes, Univ. of Utah, Salt Lake City, 44 pp., 1958.
AD-162 825.

Presents general results obtained at 13 ordnance depots, together with some general recommendations for future demolition activities based upon the results. The survey teams found that ground shock was no problem at any of the depots for the present distances to structures from the demolition areas. However, to reduce complaints, some recommended program is necessary to reduce or control air blast that possibly has caused complaints at ordnance depots. Microphone systems were designed to measure pressure over the frequency spectrum of the sound waves associated with the detonated explosives. An FM tape recorder or pen-oscillograph recorder provided permanent means of storing and re-analyzing data. Meteorological data for sound-return computations were obtained from aircraft, piball, and weather stations.

Generally the direct ground shock could not be detected beyond 14,000 ft for charges of less than 100 lb. Induced vibrations resulting from normal activities and air-blast impact were measured in a variety of structures at different installations, with 18-cps-geophone and MB horizontal and vertical vibration instruments.

The first evidence of damage by ground shock was the cracking of plaster. This plaster damage was correlated to the air-acceleration index, which was proportional to the maximum acceleration of the structural vibrations; a threshold level for damage to weak plaster was found to be 0.1 g. In the field of damage by air blast, the first signs of damage was manifested by window breakage; a value of 10 psf was adopted as the peak pressure of air blast.

3450

Doring, W., "The Detonation Process in Gases" (in German), Ann. Physik, 43, 421-436, 1943.

A model detonation wave, consisting of a surge initiating the reaction behind it by increased temperature and pressure, is assumed, and a theory of detonation is developed. A state corresponding to the points on the Hugoniot curve below the point of minimum normal detonation velocity cannot exist behind a plane stationary detonation wave. After a certain period the velocity of propagation becomes equal to the normal detonation velocity, however small the speed of reaction. Initial larger velocities give rise to rarefaction waves, and subnormal velocities to compression waves. The effect of bounding walls may be to slow down the velocity to that of sound, depending on pipe diameter, reaction and detonation speed. Pulsations and spin may also result.

3451

Drummond, W. E., "Explosive Induced Shock Waves, I. Plane Shock Waves, II. Oblique Shock Waves," J. Appl. Phys., 28, 1437-1441, 1957; 29, 167-170, 1958.

The explosive production of shock waves in solids is analyzed in the approximation that third- and higher-order terms in the shock strength can be neglected, and a procedure is developed for calculating the attenuation of the shocks. Application is made to the problem of determining the equation of state of the burned explosive gas.

3452

Dubois, E., "Researches on the Waves from an Explosive Source," (in French), Mem. Artillerie Franc., 21, 369-393, 1947.

By means of a piezoelectric quartz crystal, the forces due to the instantaneous pressure on an obstacle from the waves derived from an explosure source were investigated. The pressure curve consisted of an excess pressure, followed by a depression and again by a weaker excess pressure. The mechanical action that should result on the obstacle has been determined. In addition, it is shown that, in the case of flat sources, there is a concentration of the emitted energy around the normal to the plane of the source.

3453

Erpenbeck, J. J., "Stability of Steady-State Equilibrium Detonations," Phys. Fluids, 5, 604-614, 1962.

The hydrodynamic stability of one-dimensional, steady, equilibrium detonation waves is investigated through solution of the initial-value problem for the detonation equations, linearized; in perturbation from the steady-state solution. A criterion for stability is then found depending on the sign of the real parts of the zeros of a certain function of the steady flow. Determination of stability for a specific case through this criterion would involve extensive, but entirely feasible, numerical computations. The hydrodynamic stability of states of chemical equilibrium is also proved, this problem being pertinent to equilibrium detonations from both physical and mathematical considerations.

3454

Favier, J., and C. Fauquignon, "Acceleration of a Shock-Wave, Causing Detonation of a Condensed Explosive" (in French), Compt. Rend., 1291-1294, 1959.

When a shock-wave causes detonation of a condensed explosive, an acceleration of this shock-wave exists in the zone preceding the capping stage of the detonation; this acceleration is continuous until the stable detonation regime is reached. This result permits to corroborate a thermic diagram of forming and maintenance of a detonation wave in an explosive. The experimental device consists of two cartridges of blasting agent, the one normally capped and called generating cartridge, the other uncapped and called receiving cartridge. The blasting agent used is a compound of hexogene and tolite; the actionless interposed substance is Plexiglas.

3455

Fleming, E. R., "A Solution to the Blast Wave Diffraction Problem," Rept. No. ES 40245 A, Douglas Aircraft Co., El Segundo, Calif., 71 pp., 1961.
AD-267 490.

An analysis is given of the diffraction of a blast wave during encounter with a subsonically traveling, two-dimensional airfoil of finite chord. The method of analysis employed is the conical flow technique of geometrical acoustics. Results are given in closed analytical form as well as numerically. Representative numerical results are compared with the results of the two-dimensional traveling gust theory.

3456

Fletcher, J. D., "A Nomogram for Calculating the Resulting Overpressure from the Detonation of Small-Yield High Explosives," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 44-49, 1961.
AD-408 716.

The use of a nomogram for the estimation of overpressure from small high explosive detonations is described. The nomogram is designed for use in situations where the sound velocity decreases linearly with altitude from the earth's surface to a given height—then increases with altitude to another given height above the earth's surface. The nomogram also calculates the distance of the inner boundary of the noise zone away from the detonation point. A case example is cited.

3457

Friedman, M. P., "A Simplified Analysis of Spherical and Cylindrical Blast Waves," J. Fluid Mech., II, 1-15, 1961.

Investigations into the behavior of the gas flow behind spherical or cylindrical blasts have shown that secondary shocks arise within the original detonation gases. The secondary shock, at first weak, is carried outward with the expanding gases. Subsequently it strengthens and bends back toward the origin, arriving there with high intensity.

By using some recently developed techniques in shock dynamics and extending them where necessary, a theory is developed by which the motion of the main shock wave, as well as the formation and subsequent motion of the secondary shock, are given by explicit formulae. In addition, a method for determining, also by explicit formulae, the location of the contact surface between the detonation gases and the outside atmosphere is given. The results of a specific problem, which has been solved by numerically integrating the total equations of motion, and has also been checked experimentally, are compared with the results of the present theory.

3458

Furrer, W., "Acoustics of Detonations and Gunblast" (in German), Schweiz. Arch. Angew. Wis. Tech., 12, 213-219, 1946.

The characteristics of such explosions are discussed and it is shown that the impulse can be calculated from the weight of explosive used. Experimental curves are shown indicating the variation in maximum pressure with distance and with weight of charge. The variation of wave velocity with distance from the muzzle is shown graphically. Very close to the muzzle the velocity is as high as 2000 meters per second, falling rapidly to 340 meters per second at a distance of one meter. Reference is made to the energy in the explosion wave and to the frequency spectrum of explosions. The oscillographic recording apparatus is described.

3459

Gerber, N., and J. M. Bartos, "Tables of Cylindrical Blast Functions for Gamma Equals 5/3 and Gamma Equals 7/5," Memo. Rept. No. 1376, Ballistic Res. Labs., Aberdeen Proving Ground, Md., 16 pp., 1961.
AD-269 832.

Tables of similarity functions defining the flow field behind expanding cylindrical shock waves are presented here for values of 5/3 and values of 7/5. A brief discussion includes the differential equations and boundary conditions for these functions together with an analytical solution for them.

3460

Goodrich, R. F., L. M. Hocking, and D. C. van Hulsteyn, "Atmospheric Propagations from a Nuclear Explosion," Final Rept. No. 2886-2-F, Radiation Lab., Univ. of Mich., Ann Arbor, 57 pp., 1962.
AD-277 565.

The pressure pulse at large distances from a nuclear explosion is investigated. A source representation is established which produces parameters characteristic of these explosions on a surface enclosing the source. An integral equation for the pressure is obtained in terms of a ring source Green's function, where the integration extends over the source. Pulse forms are obtained for explosions on the ground and in the atmosphere when various temperature models are considered. When the stratosphere is assumed to be either of the isothermal or thermospheric type, a general theory is established for determining the number of modes of propagation. In addition, a method for examining the dispersive effect of local winds is established.

3461

Greifinger, C., and J. D. Cole, "Similarity Solution for Cylindrical Magnetohydrodynamic Blast Waves," Memo. No. RM-3054-PR, Rand Corp., Santa Monica, Calif., 37 pp., 1962.
AD-278 473.

This analysis is primarily concerned with the interaction between the flow of an ionized gas and a magnetic field. The particular problem treated corresponds very closely to conditions existing in exploding wire experiments, and should prove useful in interpreting the results of such experiments.

3462

Grime, G., and H. Sheard, "The Experimental Study of the Blast from Bombs and Bare Charges," Proc. Roy. Soc. (London) A, 187, 357-380, 1946.

An electrical method was used for measuring the pressure in a blast wave, involving the use of piezo-electric gauges with CRO's. A detailed description of the apparatus is given. Measurements were made of the blast pressures produced by bare charges up to 2000 lb in weight, by German bombs and mines weighing from 50 to 1000 kg, and by British bombs of all sizes. The measured and calculated velocities of the blast wave agree well, and the observed and calculated rates of decay of maximum excess pressure agree reasonably well.

3463

Groves, T., "Air Blast Peak Overpressure from 5 Ton TNT Ground Burst Hemispherical Charges (1959)," Tech. Paper No. 205, Suffield Experimental Station, Canada, 30 pp., 1961.
AD-261 339.

A photo-optical method, supplemented by the use of pressure gauges, was used to obtain the relation between peak overpressure and distance for five 5 ton hemispheres made up of TNT blocks, detonated in contact with frozen and unfrozen prairie. Three of the charges, show virtually identical pressure-distance relations corresponding to a ground reflection coefficient of 1.76. The other two correspond to a reflection coefficient of 1.60.

3464

Gvozdena, L. G., "The Refraction of Detonation Waves Incident on the Boundary Between Two Gas Mixtures," Soviet Phys. Tech. Phys., English Transl., 6, 527-533, 1961.

Discusses one of the phenomena characteristic of detonation waves—the refraction of such a wave when it passes from one explosive mixture to another. By using a high-speed cinecamera, photographs were obtained of the phenomenon that takes place when a detonation wave moving through a medium capable of reaction passes through a boundary dividing this medium from an explosive or inert medium.

3465

Heap, J. C., "Bibliography on Various Topics Pertaining to Blast Effects," ANL-5792, Argonne Nat'l. Lab., Lemont, Ill., 23 pp., 1957.
AD-144 450

Contents:
Prevailing containment
Atomic explosions
Blast effects
Explosions
Explosives
Pressure vessels
Shelters
Shock waves
Structures
Submarine intermediate reactor-containers
Tanks

3466

Heybey, W. H., and S. G. Reed, Jr., "Weak Detonations and Condensation Shocks," J. Appl. Phys., 26, 969-975, 1955.

The absence of weak detonations in available experience is felt to pose a problem since the well-known rapid condensation processes encountered in the flow of expanding gases have all the characteristics and present, in fact, examples of weak detonations. As such, they would suggest that the initiation mechanism producing weak detonations will have to be different from that commonly adopted for strong detonations. The physical aspects of rapid condensation processes are discussed and compared with the conditions obtained by Friedrichs for the existence of weak detonations.

3467

Hill, R., and D. C. Pack, "An Investigation, by the Method of Characteristics, of the Lateral Expansion of the Gases Behind a Detonating Slab of Explosive," Proc. Roy. Soc. (London), A, 191, 524-541, 1947.

The phenomena occurring when an uncased explosive charge is detonated in a fluid medium are examined by hydrodynamical methods. Attention is focused chiefly on the pressure and velocity distributions in the gaseous products of the explosion, which expand laterally behind the detonation wave as it travels down the charge, the results being shown in graphical form. To simplify the problem, the charge, and the gas and fluid fields, were treated as 2-dimensional. The nature of the boundary conditions made it necessary to find explicit theoretical formulae for the gas field near the charge, and the analysis involved is given at length. For the problem in which the surrounding medium is air, the shape and position of the shock waves set up by the explosion are calculated. The shock waves are found to be straight to the nominal accuracy of the calculations (1 in 5,000) for six charge widths from their intersections with the block of explosive.

3468

Holt, M., "The Initial Behavior of a Spherical Explosion, I. Theoretical Analysis," Proc. Roy. Soc. (London), A, 234, 89-109, 1956.

The analysis of the disturbance near the source of a spherical blast from a polytropic explosive in which $\gamma = 3$, given by Berry and Holt (see entry 3425), is generalized to apply to an explosive gas and a surrounding medium governed by any equations of state. Most of the properties established in the special case are found to be generally true. In particular, a second blast wave is shown to be a consequence of the breakdown of continuous gas flow in the neighborhood of a singular characteristic. The complete field near the origin of blast can be determined from series expansions; except in the gas expansion zone, the coefficients in these expansions can be expressed in simple terms. The quantity defining the first departure of the second shock from the singular characteristic is given by an expression as simple as that in the polytropic case, although its derivation presents new difficulties.

The analysis shows that, for all types of explosive, the second shock is a second-order effect in terms of the square root of the time from the end of detonation. This contradicts the conclusion reached earlier by Wecken (1951) on the basis of less detailed analysis. Application to actual explosions is described in the following abstract.

3469

Holt, M., "The Initial Behavior of a Spherical Explosion, II. Applications to P.E.T.N. Charges in Air and Water," Proc. Roy. Soc. (London), A, 234, 110-115, 1956.

The initial fields of disturbance due to explosions of spherical charges of P.E.T.N. in air and water are calculated, using the analysis developed in Part I. The results in air compare favorably with earlier calculations (Berry and Holt, 1954; see entry 3425). It is found that in water the second blast wave immediately moves towards the center of the explosion, with very small initial strength.

3470

Indiana University, "Research in Mathematical Mechanics," Prog. Rept. 15 June-15 Sept. '57, Graduate Inst. for Mathematics and Mechanics, Bloomington, 7 pp., 1957.
AD-146 439.

Brief descriptions are given of published materials by Thomas on extended compatibility conditions for the study of surfaces of discontinuity in continuum mechanics (J. Math and Mech, 6:311-322), and the growth and decay of sonic discontinuities in ideal gases (J. Math and Mech, 6:455-469). Unpublished materials by Thomas (to appear in the J. Math and Mech) include the following topics: the propagation and decay of spherical blast waves, the decay of waves in elastic solids, the problem of the Lüders band, and the velocity of formation of Lüders bands.

3471

Ingram, L. F., "Air Blast Phenomena in an Arctic Climate," Office of the Chief, Army Research, Research and Development, Washington, D. C. (Paper presented at the 1962 Army Science Conference, 20-22 June 1962, at the U. S. Military Academy, West Point, N. Y.), 9 pp., 1962.
AD-286 639.

In 1960, 4- and 32-lb TNT spheres were fired at scaled burst heights over natural and processed snow on the Greenland Ice Cap at Camp Fistclench, where the snow cover is 100 ft deep. Air-blast pressure-time measurements were made at the surface to obtain height-of-burst information and at several elevations above the surface to determine Mach-triple-point loci. Surface pressure measurements were made at reduced horizontal distances. Pressure data were obtained for the range 2- to 100-psi peak overpressure. Results show that considerable energy is absorbed by snow, snow cannot be regarded as an ideal reflecting medium, and the Mach stem formation over snow is not essentially different from that over a rigid boundary.

3472

Jacobs, S. J., and A. D. Solem, "The 1961 International Colloquium on Detonation Waves Sponsored by the French Government," NOLTR 62-27, Naval Ordnance Lab., White Oak, Md., 20 pp., 1962.
AD-276 576.

About 100 scientists from eight countries attended the colloquium; major attendance came from France, Great Britain, and the U. S. Some 40 papers were presented, covering the following fields: initiation and transmission of detonation in solid explosives, detonation of solid explosives, detonation and shocks in gases, and shocks in solids. The general contents of the papers are summarized with comments on their pertinence to detonation studies in the U. S.

3473

Janus, R. J., "Graphs for Use in Obtaining Desired Mach and Reynolds Numbers in a Shock Tube," Rept. No. 1132, Ballistic Research Labs., Aberdeen Proving Ground, Md., 36 pp., 1958.
AD-161 075.

High-yield nuclear weapons having blast waves of long duration have increased the interest in the drag loading or objects exposed to air blast. Drag loading is a function of several flow parameters, of which two of the most important are Mach number and Reynolds number. In order to investigate drag loading in a shock tube it is necessary to be able to produce flows having given Mach and Reynolds numbers. This can be done by selecting the proper expansion-chamber pressure and shock overpressure. Graphs based on the Rankine-Hugoniot relations and Sutherland's equation provide a means of determining the shock strength and expansion-chamber pressure necessary to produce a flow having given Mach and Reynolds numbers. Graphs are presented of Mach number and Reynolds number as functions of shock strength, and the change in Reynolds number as a function of temperature and shock strength. The use of the graphs is explained, and examples are provided.

3474

Johansson, C. H., "Shock Waves in Gases at the Detonation of Brisant Explosives," Arkiv Mat. Astron. Fysik, 33A, Paper 13, 23 pp., 1946.

A paper, mainly theoretical, that deals with the propagation of detonation waves through gases. The detonation of an explosive involves its conversion into a heated mass of gas at high pressure, the temperature and pressure being of the order of 3,000°C and 10^5 atmospheres. At the instant of detonation the boundary surface has a velocity of the order of 10^4 meters per second. The state of the compression layer in the surrounding gas has been calculated on the assumption of an ideal gas—an assumption that appears to lead to correct results. Dissociation of atmospheric air is noticeable when the boundary velocity exceeds about 3,000 meters per second, and because of the energy thus consumed, the temperature increases rather slowly with the velocity, up to 8,000 meters per second, where the dissociation is nearly complete.

Further investigation proves that about half the work conveyed to the compression layer is consumed to give kinetic energy to the gas and the other half to increase the internal energy of the gas. A discussion follows on the velocity of propagation of the shock wave. For a detonation, the normal velocity of sound is a lower limit, to which is added a translational term owing to the expansion of the explosion. The translational term dominates near the origin of the explosion, while at greater distances the normal velocity of sound dominates.

3475

Johnson, O. T., J. D. Patterson, II, and W. C. Olson, "A Simple Mechanical Method for Measuring the Reflected Impulse of Air Blast Waves," Memo Rept. No. 1088., Ballistic Research Labs., Aberdeen Proving Ground, Md., 1957.
AD-149 358.

Describes a mechanical method for measuring the impulse imparted to a flat, rigid surface by the reflection (at 90°, or normal incidence) of an air-blast wave. The method consists in measuring the velocity at which a cylindrical plug of known mass is projected from a hole in a large rigid surface by the blast wave. With the velocity known, the impulse is computed by means of Newton's second law. Experimental results were obtained for spherical Pentolite explosive charges ranging from 1/4 to 2 lb and scaled distances from 0.5 to 2.5 $ft/lb^{1/3}$. The results showed the usefulness of the moving-plug technique for measuring reflected, scaled impulses close to explosive charges.

3476

Jones, D. L., "Strong Blast Waves in Spherical, Cylindrical and Plane Shocks," Phys. Fluids, 4, 1183-1184, 1961.

The writer machine-computes the dimensionless-energy parameter, first introduced by Taylor, that characterizes the spatial-temporal behavior of strong blast waves from a point source for spherical, cylindrical, and plane waves. He finds considerable disagreement between his exact computations and the approximate calculations of most other workers.

3477

Jones, G. H. S., and J. C. Muirhead, "Model Studies of Blast Effects, Part III. The Geometrical Scaling of Certain Effects in the Simple Trench at Various Model Scales," Rept. No. TL-109-59, Suffield Experimental Station, Canada, 1959.
AD-225 941.

This paper deals with an investigation of the scaling of air movements and the movement of shock fronts in a simple trench. A field study, using 1/4-scale and 1/10-scale models, and a shock-tube study, using 1/27-scale models, are reported. These are correlated with earlier work on the same and similar models. It is found that geometrical scaling may be applied with confidence to the movement of air in the smaller-sized models, and that the times of arrival of the shock fronts at the various gauges in the field models may be predicted from geometrically similar studies. In the field models, the resonant oscillation of the air columns in the trenches also appears to vary in period geometrically with the size of the model.

3478

Jones, G. H. S., and W. J. Slater, "Model Studies of Blast Effects, Part I. Plus Appendix, Shelters of Shock Waves in a Shock Tube and From 8 lb HE Charges," Rept. No. 154, Shuffield Experimental Station, Canada, 23 pp., 1959.
AD-225 937 and AD-225 936.

This paper deals with experiments on the entry of blast waves into trench-type shelters at 1/54-scale in a shock tube, and at 1/10-scale in the field (using 8-lb HE charges) at the 12-15 psi over-pressure level. The experimental techniques are described in some detail, and complete results are presented. A correlation is made between the shadowgraphs obtained in the shock tube and the records obtained using piezoelectric gauges in the field. The work covers three types of models, the simple trench, the parapet trench, and the fire trench, and details are given of the way the entry of the blast wave into the basic form of simple trench is modified by the addition of parapets and overhead protection.

3479

Jost, W., "Investigation of Gaseous Detonations and Shock Wave Experiments with Hydrazine," Rept. No. ARL 62-330, (Rept. on Research in Chemical Energetics), Goettingen Univ., Germany, 1962.
AD-278 292.

The implications of the Chapman-Jouguet condition are discussed and examined experimentally. Investigations of the shape of a detonation front and its dependence on the reaction are reported. Experiments were made to demonstrate the influence of turbulence in the unignited gas, and of obstacles to the gas flow upon the initiation time and distance for the development of a detonation. The detonation of pure hydrazine was checked. The velocities of detonation were found to be 2080 and 2100 meters per second at initial pressures of 1 atm and initial temperatures of 125°C and 135°C, respectively. The decomposition of N_2H_4 in reflected shock waves at extremely low oxygen concentration was examined. A mixture of 0.3% N_2H_4 with Ar containing less than 12 ppm O_2 was used.

The experimental range allowed for half-lives from 6 to 1000 μsec at a N_2H_4 density of 23 × 10 to the -8th power mole/cc, and a reaction pressure of 7.2 ± 0.7 atm. Preliminary evaluation of the data indicates a complex reaction and an apparent energy of activation of about 43 kcal/mole. Variation of the total gas pressure at the same hydrazine proportion seems to have little effect on the reaction rate. Reaction rates and extinction coefficients for N_2H_4 were obtained up to about 1300 K.

3480

Jouguet, E., "Explosion and Continuous Waves in Gases," Compt. Rend., 202, 796-799, 1936.

A mathematical study of explosion and continuous waves in CO_2, N_2, and A. The results obtained are intended for use in the investigation of the waves produced by a solid explosive detonating in a gaseous atmosphere.

3481

Jouguet, E., "Explosion Waves in Gases," Compt. Rend., 202, 1225-1229, 1936.

A study is made of the initial state of the wave immediately following an explosion in which the formulae of Taffanel and Dautriche are adopted for the propagation of detonations in explosive solids. Hugoniot's hypotheses are also discussed with respect to the impact of two fluid media, and modifications are suggested. Experimental and calculated values are given for the velocities of explosion waves produced in H_2 and CO_2, and are in excellent agreement.

3482

Jouguet, E., "Explosion Waves in Gases," Compt. Rend., 202, 1320-1322, 1936.

This paper supplements a previous publication (see previous abstract) with respect to hypotheses and results. Sec. 1 deals with the theory of the explosive wave in explosive solids, and discusses the value and limitations of the theory of Taffanel and Dautriche, which was utilized and extended by the present author. It is pointed out that the explosive wave is very probably a collision wave, and that incomplete combustion produces a medium which follows the wave and for which the theory is not well known. The author concludes that the above theory will give the form of the formula, but that the coefficients must be experimentally determined. The data of the previous paper have been calculated from this standpoint; viz., the velocities of the explosive wave and of the collision wave produced in the air.

Sec. 2 considers the velocity of the issuing collision wave and finds theory to be in agreement with experiment. Sec. 3 is devoted to an analytical discussion of the theory, and Sec. 4 deals with Hugoniot's hypotheses, which give qualitative results analogous to those found by the author.

3483

Kieffer, J., J. Dapoigny, and B. Vodar, "Nature and Process of Formation of Shock Waves Initiated by Detonation of an Explosive" (in French), Compt. Rend., 247, 577-580, 1958.

The possibilities of shocks of respectively greater or lesser velocity than the detonation wave (e.g., in penthrite) are discussed for a variety of substances whose experimental Hugoniots are given. In all cases the latter should take place, although at extremely high pressures the former may come into play for heavier substances.

3484

Kingery, C. N., J. H. Keefer, and J. D. Day, "Surface Air Blast Measurements from a 100-Ton TNT Detonation," Memo Rept. No. 1410, Ballistic Research Labs., Aberdeen Proving Ground, Md., 46 pp., 1962.
AD-285 599.

The free field pressure-time histories measured at selected distances from a 100-ton TNT surface burst are presented. Included are plots of overpressure, duration, impulse, arrival time, and dynamic pressure—all versus distance. The measured values are compared with predicted curves, which were prepared by scaling results from 5-ton and 20-ton surface bursts of the same geometrical shape and fired in the same general area. The geometrical shape is a simulated hemisphere which was constructed by stacking cast TNT blocks in a planned pattern.

3485

Kirkwood, J. G., and W. W. Wood, "Structure of a Steady-State Plane Detonation Wave with Finite Reaction Rate," J. Chem. Phys., 22, 1915-1919, 1954.

An analytical elaboration of von Neumann's model of the detonation wave is presented. A hydrodynamic argument for the well-known Chapman-Jouguet condition is advanced, and the sound speed to be used therein is identified as that obtained with frozen chemical equilibrium, in agreement with a recent result of Brinkley and Richardson. Possible situations in which the classical Chapman-Jouguet hypothesis might be incorrect are very briefly discussed.

3486

Klein, E., "Air Shock Wave Velocities over Water," J. Acoust. Soc. Am., 21, 109-115, 1949.

A procedure was devised for determining the air blast pressures of the A-bomb at Bikini. In such a disturbance the air particles move with large and finite amplitudes; hence the propagated waves do not obey the ordinary laws of acoustics. By measuring the ratio of the air shock wave velocity to normal acoustic velocity, an indication may be obtained as to the peak pressure of the explosion. Blast waves in water, on the other hand, follow substantially the familiar acoustic laws and are propagated at a well-known velocity. Measurements of transit times made at identical positions for the air and for the water blast waves immediately yielded the desired air blast velocity in terms of the known velocity of sound in water. This procedure eliminated the need for simultaneous measurement of the continually shifting distances between buoys which carried observational equipment. However, careful positioning of the buoys was necessary in order to avoid their destruction and yet record the maximum possible air blast. These positions were calculated on the basis of an equivalent explosion from 20,000 tons of TNT. Since the measurements had to be made automatically and without human observers, special timing and recording systems were provided. All requirements for gathering the data were successfully met in the assembly of apparatus described herein.

3487

Kochina, N. N., "The Characteristic Conditions near the Center of an Explosion, Giving Rise to Two Shock Waves" (in Russian), Dokl. Akad. Nauk SSSR, 126, 1216-1219, 1959.

A linearized theory of instantaneous explosion in a compressible fluid, developed by the author and Mel'nikova (Prikl. Mat. Meh., 22, 1, 1958), is applied here to the description of resulting shock waves, in terms of temperature and entropy of the medium.

3488

Kompaneets, A. S., "Point Detonation in an Inhomogeneous Atmosphere," Dokl. Akad. Nauk SSSR, 129, 989-992, 1960.

The propagation of a shock wave that originates in a detonation at a geometrical point is studied by means of an approximation method.

3489

Kramer, H. P., and M. Rigby, "Selective Annotated Bibliography on Propagation of Acoustic and Explosion Waves in the Atmosphere," Meteorological Abstracts and Bibliography, 1, 670-686, 1950.

This bibliography contains 112 entries, each with an abstract or annotation, and covers the years from 1883 to 1950 inclusive. Most aspects of the propagation of sound in air are covered, with particular emphasis on anomalous sound propagation, meteorological factors affecting sound propagation, and determination of winds and temperatures from acoustic measurements.

3490

Lawrence, R. W., "Mechanism of Detonation in Explosives," Geophysics, 9, 1-18, 1944.

Results of photographic work on the detonation of high explosives are presented and discussed, relative to hydrodynamic theory. Methods for determining strength and detonation velocity are described. The photographs illustrate the nature of detonation waves in explosives and of shock waves in air. The duration of the detonation waves in nitro-glycerin and blasting gelatin is $< 10^{-6}$ sec. and the duration of the shock waves in air is of the same order. The high temperature of shock waves predicted by theory is confirmed.

Photographs are included showing the propagation of detonation from one cartridge of blasting gelatin to another across air gaps and water gaps. In the latter case, no visible shock wave is produced in the water and the highly luminous after-burning is eliminated. Calculations indicate that pressures in the detonation wave may run to 140,000 atm and temperatures to 4,300°C. The shape of the detonation wavefront in a high-velocity explosive is planar, whereas in low-velocity explosives it is convex.

3491

Lewis, C. H., "The Blast-Hypersonic Flow Analogy Based upon Oshima's Quasi-Similarity Model," AEDC DN 61-158, Arnold Engineering Development Center, Arnold Air Force Station, Tenn., 21 pp., 1961.
AD-268 639.

The quasi-similarity model of Oshima was applied to the blast-hypersonic flow analogy, and comparisons were made with other blast-analogy solutions, real-gas solutions, and experiments. The shock shape is no better predicted by the quasi-similarity model than by other blast-analogy solutions. Hemisphere-cylinder surface pressures near the juncture of the nose and afterbody are better predicted by the quasi-similarity model, and the method yields the correct asymptotic value far downstream. The radial density distribution in the shock layer is well predicted over a small region of a hemisphere-cylinder.

3492

Lewis, C. H., "Plane, Cylindrical, and Spherical Blast Waves Based upon Oshima's Quasi-Similarity Model," AEDC TN 61-157, Arnold Engineering Development Center, Arnold Air Force Station, Tenn., 67 pp., 1961.
AD-268 654.

Numerical solutions are given for plane, cylindrical, and spherical blast waves in air based upon Oshima's quasi-similarity model. New solutions are given for plane and spherical waves in addition to the cylindrical solutions given previously by Oshima. The results for cylindrical flow do not agree with Oshima's results near the core of the explosion. These differences are discussed, and the precision of the present numerical solution is given. The results provide new data for investigating blast waves or the blast-hypersonic analogy.

3493

Lin, S. C., "Cylindrical Shock Waves Produced by Instantaneous Energy Release," J. Appl. Phys., 25, 54-58, 1954.

Taylor's analysis of the intense spherical explosion has been extended to the cylindrical case. It is found that the radius R of a strong cylindrical shock wave produced by a sudden release of energy E per unit length grows with time t according to the equation

$$R = S(\gamma)(E/\rho_0)^{-/4}t^{1/2}$$

where ρ_0 is the atmospheric density and $S(\gamma)$ is a calculated function of the specific heat ratio γ. For $\gamma = 1.4$, $S(\gamma)$ is found to be approximately unity. For this case, the pressure p_1 behind the shock wave decays with radius R according to the relation $p_1 = 0.216E/R^2$. Applying the results of this analysis to the case of hypersonic flight, it can be shown that the shock envelope behind a meteor or a high-speed missile is approximately a paraboloid given by $R = (D/\rho_0)^{1/4}(x/V)^{1/2}$, where D and V denote the total drag and the velocity of the missile, respectively, and x is the distance behind the missile.

3494

Manson, N., "A New Relation in the Hydrodynamical Theory of Explosive Waves" (in French), Compt. Rend., 246, 2680-2682, 1958.

By expressing the partial derivatives of the velocity of a Chapman-Jouguet explosion as functions of the volume and temperature or pressure of the initial and final states, the equation of state of the products is found in terms of the properties of the explosive.

3495

McFadden, J. A., "Initial Behavior of a Spherical Blast," J. Appl. Phys., 23, 1269-1275, 1952.

At time t = 0 a unit sphere containing a perfect gas at uniformly high pressure is allowed to expand suddenly into a homogeneous atmosphere. Solutions for short times later are sought by analytic (i.e., not numerical) methods. Viscosity and heat conduction are neglected. The particle velocity, sound speed and entropy are developed in powers of y, which is proportional to the time (more precisely, the distance moved by the head of the rarefaction wave in time t), with coefficients depending on a slope coordinate $q = (1/2N)[(2N - 1) + (1 - x)/y]$, where x is the radial coordinate, $N = (1/2)(\gamma + 1)/(\gamma - 1)$, and γ is the ratio of specific heats. The zero-order coefficients are the plane shock-tube solution. First-order corrections are derived for the various regions. Boundary conditions are approximated for small y at the surfaces of discontinuity, and the method for matching the solutions in the different regions is outlined. This matching process is carried out for the expansion of a diatomic gas into diatomic air.

3496

Melin, J. W., and A. R. Robinson, "The Analysis of the Dynamic Response of an Above-Ground Simply Supported Cylindrical Shell Subjected to Blast Loading," Illinois Univ., Urbana, 94 pp., 1961.
AD-272 956.

The purpose of this analysis is to determine the elastic response of an above-ground, simply-supported shell roof subjected to a blast loading. The analysis is divided into four parts: a review of the blast-loading phenomena, and an evaluation of the forces that might reasonably be expected to act on the structure; a derivation and discussion of the equations of motion of the shell; a development of a solution to the equations of motion that would be suitable for programing a digital computer; and a preliminary study to establish which parameters are most important, and the general effects of these parameters.

3497

Meyer, F., "The Production of Powerful Shock Fronts (in Blast-Waves) in Homologous-Solutions" (in German), Z. Naturforsch., 10a, 693-697, 1955.

Powerful, plane, nonstationary shock fronts, generated and propagated in a gas at rest, in the neighborhood of their blast-fronts, are compared with homologous solutions, and the observed general tendency of solutions to acquire a definite homology under the influence of such impact is discussed analytically.

3498

Muirhead, J. C., and F. L. McCallum, "Model Studies of Blast Effect, Part II. Plus Appendix, Shock Tube Observations on the Air Movement Associated with the Entry of Shock Waves into Trench Shelters," Rept. No. TL-109-59, Suffield Experimental Station, Canada, 8 pp., 1959.
AD-225 938 and AD-225 939.

The shock-wave air movement in models of the simple trench, parapet trench, and fire trench (facing both upstream and downstream with respect to the incident shock wave), have been studied, using smoke streams as tracers for the moving air. The results show that there is a definite tendency in all models for both the vertical and horizontal components of air velocity to decrease from top to bottom of the trenches. Judging the results on the assumption that a minimum wind intensity is desirable, the models were ranked in the following order: fire trench (facing downstream), parapet trench, simple trench, fire trench (facing upstream). The fire trench (facing downstream) was definitely superior, but the differences between the other three models were marginal.

3499

Nordberg, W., "Acoustic Phenomena Observed on Rocket-Borne High Altitude Explosions," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 233-244, 1961.
AD-408 716.

A series of high-explosive charges, ranging from one to four pounds in weight, have been exploded from aboard Aerobee and Nike-Cajun rockets at altitudes between 30 and 90 km. Although the main purpose of these experiments was to study temperatures and winds in the upper atmosphere, a number of interesting phenomena pertinent to the propagation of shock and sound waves in a highly rarified and inhomogeneous atmosphere were observed. The propagation of the shock in the immediate vicinity of the explosion was observed by the modulation that the shock wave produced on a ground-to-missile-to-ground doppler radio link. Preliminary results show that the theory developed by H. L. Brode for shock propagation in higher density atmospheres applies well to these upper-air explosions. Qualitative analysis of the intensities of the ground arrivals at the microphone array on the ground indicate that there are large variations of sound amplitudes with temperature gradients in the vicinity of the explosions. For a complete explanation of these variations a treatment more complex than simple refraction focusing and exponential attenuation with altitude will have to be employed.

3500

Olson, W., J. Patterson, and J. Williams, "The Effect of Atmospheric Pressure on the Reflected Impulse from Air Blast Waves," BRL Memo. Rept. No. 1241, Ballistic Research Laboratories, Aberdeen Proving Ground, Baltimore, 25 pp. 1960.
AD-234 998.

Reports measurements of reflected impulses in air blast waves generated by explosive spheres (up to one pound in weight) detonated under reduced ambient pressures simulating altitudes up to 100,000 ft. (8 mm of mercury). Analysis reveals that the data may be scaled according to Sachs' law.

3501

Oppenheim, A. K., and R. A. Stern, "Development and Structure of Plane Detonation Waves," Techn. Note No. 7, Univ. of Calif., Berkeley, 1960.
AD-233 940.

The current status of knowledge on the development and structure of plane detonation waves is critically reviewed. A comprehensive historical survey includes contemporary studies, current theories concerning the mechanism of the development of the process, and the analysis of the structure of the steady, plane-detonation wave.

3502

Oshima, K., "Self-Similar and Pseudosimilar Solutions of Blast Waves in Electrogasdynamics," Rept. No. 83-215, Univ. of Southern Calif. Engineering Center, Los Angeles, 37 pp., 1962.
AD-284 924

Using the electrogasdynamical equations and the Poisson equation, a characteristic length Re, which is proportional to the Debye length divided by an ionization rate of a gas, is defined. The length plays an important role in the electrogasdynamical blast wave. Since the classical gasdynamical blast wave with a constant energy contained in it has a characteristic length, Ro, which is defined by the constant energy, the essential parameters of the electrogasdynamical blast wave with a constant energy in it are Ro and Re, or the square of its ratio, Ao.

A self-similar solution of the electrogasdynamical blast wave is found. Its shock front propagates exponentially with time and its energy also increases exponentially with time. Several numerical calculations with various values of the parameter, Re, have been carried out. This solution contains a classical gasdynamical blast wave as a limiting case of Re approaches infinity.

3503

Ostroumov, G. A., "Approximation of a Point Detonation in Air by an Equivalent Spherical Radiator," Soviet Phys. Acoust., English Transl., 8, 156-159, 1962.

On the basis of published information on the solution of the nonlinear equations of gas dynamics and related machine computations, the author analyzes the properties of an acoustic radiator that at sufficiently great distances yields the same "weak" shock wave as a point detonation. It is found that the expansion law for the radiator coincides with the shock-wave expansion law in the initial stages of the process (volume increasing in proportion to the 6/5 power of the time). Its expansion rate, however, is smaller than that of a detonation by a factor of 1/7.4. The expansion of the piston stops short of the potential maximum mechanical level by a factor of 0.2448. The prospects of generalizing the results to other substances whose equations of state can be described in Tate form are discussed.

3504

Pack, D. C., "The Reflection and Transmission of Shock Waves, I. The Reflection of a Detonation Wave at a Boundary," Phil. Mag., 2, 182-188, 1957.

It is shown that for a shock wave advancing through any physically real barotropic medium the nature of the reflected wave is uniquely determined by the relative shock impedance of the medium through which the incident wave passes and the medium upon which it falls. A simple criterion is found for determining the nature of the reflection of a detonation wave at the end of a block of explosive. Particular attention is paid to the examples of an explosive in contact with a gas, water or solid surface. Certain approximations, which may be useful when there is a reflected shock wave, are discussed.

3505

Partlo, F. L., and J. H. Service, "Instantaneous Speeds in Air of Explosion Reports at Short Distances from the Source," Physics, 6, 1-5, 1935.

In the first series of measurements the source was one No. 6 blasting cap, while in the second series 1 lb of 50% nitroglycerin stick dynamite was used as source. A telephone carbon-button microphone was the receiver and was held fixed in location while shots were fired successively at 5, 8, 12.5, 25, 35, 50, 100 and 600-meter distances. A two-element string oscillograph was used for timing, one element recording the instant of firing, the other element recording the arrival of the wave at the microphone. The work was done at a time of no perceptible wind; air temperatures were measured carefully; no humidity measurements were made. Travel times could be read reliably to 10^{-4} sec, and distance measurements were at least correspondingly good. Instantaneous speeds were obtained by plotting time computed minus time observed against distance, and measuring slopes of the resulting curve. Since this work was incidental to seismic prospecting, the observations were not quite as numerous as those of von Angerer and Ladenburg. However, the results are similar, showing abnormally high speeds near the source. Also, the use of instantaneous speeds appears to show abnormally low speeds a little farther from the source, perhaps masked in the work of von Angerer and Ladenburg due to their use of average speeds instead of instantaneous speeds.

3506

Payman, W., D. W. Woodhead, and H. Titman, "Explosion Waves and Shock Waves, Part II. Shock Wave and Explosion Products Sent Out by Blasting Detonators," Proc. Roy. Soc. (London), A, 148, 604-622, 1935.

This paper continues previous work; it records a photographic examination of the shock wave and the products of detonation from blasting detonators suspended freely in the air, made by means of the Schlieren method and the wave-speed camera so that data could be obtained of the wave at extremely short intervals of time, after inception of detonation. The detonators used were of the fulminate-chlorate type in copper cases, and of the compound lead azide-tetryl type in aluminum and in paper cases. In the latter instances, the flame is sent out in advance of the main shock wave, and both forms of this detonator will ignite inflammable firedamp-air mixtures, unlike the copper-cased fulminate-chlorate detonator.

The explosive effect of a detonator is most marked along the axis of the detonator in the direction towards which the closed end is pointing, and is due to a large solid particle, presumably metal, sent off at high speed from the base of the detonator. The speed of the wave sent out and the volume of gases projected are greatest in a direction at right angles to the axis of the detonator, and may be a more important factor when the detonator is embedded in the explosive.

3507

Payman, W., and H. Titman, "Explosion Waves and Shock Waves, Part III. Initiation of Detonation of C_2H_4-O_2 and CO-O_2 Mixtures," Proc. Roy. Soc. (London), A, 152, 418-445, 1935.

So far, this series of papers has dealt mainly with nonmaintained or partially-maintained atmospheric shock waves, and only inidentally with the fully-maintained detonation wave. In the present article the initiation of detonation and the production of shock waves and their effect on the flame prior to the setting up of detonation are studied. The mixtures used are C_2H_4 and O_2, which detonate with ease, and of CO and O_2 which do so with comparative difficulty.

When shock waves are formed, they may push the flame forward at a lower speed than that at which they are passing through it, or they may retard the flame on meeting it after reflection from a closed end; hence in a closed system the flame may be made to oscillate. The shock waves do not necessarily travel throughout the unburnt gas at uniform speed relative to the wall of the tube, for the gas may be moving at varying velocities at different distances from the flame. Waves travelling from hot to cold gases diminish in speed, while they increase in speed on travelling from cold to hot gases; on meeting a flame they are partially reflected, with change of sign under suitable conditions, and are partially transmitted. On collision with a solid obstruction they are reflected, usually at a lower speed. Detonation may be set up either ahead of or, more usually, within the flame front, due to the effect of waves travelling in front of or from behind the flame, the collision or overtaking of wave and flame or wave and wave, or the collision of a wave with an obstruction or the closed end of the tube.

3508

Raizer, Yu. P., "Glow of Air During a Strong Explosion and the Minimal Brightness Effect of the Fireball" (in Russian), Zh. Eksperim, i Teor. Fiz., 34, 483-493, 1958.

The optical properties of air below 6000° are considered. It is shown that the absorption and radiation of visible light at temperatures between 6000° and 2000° are due to the presence of the nitrogen dioxide formed in air at these temperatures. Some optical effects observed in strong explosions are explained on this basis, such as the glow of air in a shock wave at low temperatures (down to 2000°), separation of the wave front from the boundary of the fireball when the temperature of the front is close to 2000°, and also the peculiar effect of the fireball's minimal brightness.

3509

Ray, G. D., "An Exact Solution of a Spherical Blast Wave Under Terrestrial Conditions," Proc. Natl. Inst. Sci. India A, 24, 106-112, 1958.

An exact solution was obtained to the equations for one-dimensional motion of a gas representing a spherical wave of explosion headed by shock. The shock moves with constant velocity and advances in a quiescent atmosphere of constant pressure and density. The solution is applicable to both weak and strong shocks.

3510

Rogers, M. H., "Analytic Solutions for the Blast-Wave Problem with an Atmosphere of Varying Density," Astrophys. J., 125, 478-493, 1957.

The adiabatic motion of a gas behind an infinitely strong shock wave is examined in the case when the density of the gas ahead of the shock front varies as a power of the distance from the origin. It is found that if the decrease in density is greater than a certain critical value, a discontinuity occurs in the gas at some point behind the shock front, and cavitation appears. A complete investigation is made for the case of spherically symmetric flows, and the nature of the discontinuity is examined in each case.

3511

Rogers, M. H., "The Propagation and Structure of Shock Waves of Varying Strength in a Self-Gravitating Gas Sphere," Proc. Roy. Soc. (London), A, 235, 120-136, 1956.

A general method is given for describing the motion of a spherically symmetric shock wave of varying strength in a gas where the density ahead of the shock front varies with distance from the center. The method applies only as long as the density does not become zero ahead of the shock front at any instant. The motion is initiated by a central explosion that liberates a given amount of kinetic energy. The density distribution ahead of the shock front is shown to have an important effect on the variation in the shock strength, and a first approximation to the equation of motion for the shock front is deduced. A particular example is worked out in detail, and it is shown that for certain density distributions the blast wave consists of a thin shell of gas while the remainder of the originial sphere is left intact.

3512

Ruegg, F. W., and W. W. Dorsey, "A Missile Techinque for the Study of Detonation Waves," J. Res. Natl. Bur. Std., 66C, 51-58, 1962.

The problems and effects of stabilizing combustion and detonation against hypersonic flow were investigated, using a 20-mm spherical missile in a stoichiometric mixture of H and air at rest. Combustion produced effects detectable by Schlieren shadow technique; measurements were made at Mach 4-6.5, and above pressures of 0.1 atm. Delayed ignition was noted and measured. The various effects found are described in detail and shown graphically, with Schlieren figures.

3513

Sakurai, A., "Decrement of Blast-Waves," J. Phys. Soc. Japan, 10, 1018, 1955.

Measured values of the decrement of the shock-front of blast waves and values calculated by Wolff's experimental formula and from an approximate theory, are compared graphically.

3514

Sakurai, A., "On Exact Solution of the Blast-Wave Problem," J. Phys. Soc. Japan, 10, 827-828, 1955.

It is shown that the method used by J. L. Taylor to obtain an exact solution of the equations for the initial stage of a spherical blast-wave, starting at a point source, is applicable to the corresponding problems involving cylindrical or plane blast-waves.

3515

Sakurai, A., "On the Propagation and Structure of the Blast Wave, I.," J. Phys. Soc. Japan, 8, 662-669, 1953.

Concerning blast waves with front surfaces of plane, cylindrical and spherical shape, the propagation velocity U and the distribution of hydrodynamical quantities are discussed. The solutions are constructed in the form of power series in $(C/U)^2$, where C is the sound velocity of undisturbed fluid. R, the distance of shock front from the charge, is represented as

$$\left(\frac{C}{U}\right)^2 \left(\frac{R_o}{R}\right)^{\alpha+1} = J_o\left[1 + \lambda_1\left(\frac{C}{U}\right)^2 + \frac{1}{2}\lambda_2\left(\frac{C}{U}\right)^4 + \dots\right]$$

where R_o is the characteristic length related to the energy of explosion, J_o and λ_i are constants and $\alpha = 0, 1, 2$ correspond to plane, cylindrical and spherical case, respectively. The first approximations for $\alpha = 0, 1$ are discussed. The solution is obtained numerically for the case of the adiabatic index $\gamma = 1.4$. The approximate solution is also considered.

3516

Sakurai, A., "On the Propagation and Structure of a Blast Wave, II.," J. Phys. Soc. Japan, 9, 256-266, 1954.

The second approximation is discussed. The solution for $\gamma = 1.4$ is obtained by a numerical method, using the results of the first approximation obtained in Part I. By use of this solution, U-R curves, distance-time curves and the changing feature of distributions of velocity, pressure and density behind the shock front are discussed. Further, the approximate solution of the equation is discussed by a refinement of the WKB method of Imai.

3517

Sauer, F. M., "The Preshock Sound Velocity Field over Inorganic and Organic Surfaces, a Problem Analysis and Status Report," Interim Tech. Rept. No. AFSWP-420, Forest Service, Washington, D. C., 46 pp., 1954.
AD-267 596.

Existing information concerning the development, during nuclear detonations, of preshock sound velocity fields caused by irradiation of inorganic and organic surfaces is analyzed. Experimental results are compared with available theoretical analyses and the influence of surface thermal properties is discussed. Surface temperatures calculated from theoretical results based on the assumption of a homogeneous media and using published thermal properties are inconsistent with temperatures measured during actual detonations. A vigorous experimental program appears necessary in view of the deficiencies of theoretical attack, expecially in the case of organic surface materials; specific recommendations on the objectives of such programs are presented. Conventional modes of convective heat transfer are shown to explain observed depths of thermal layers over inorganic surfaces if compressibility is considered.

3518

Selberg, H. L., "The Dependence of the Detonation Velocity on the Shape of the Front," Paper 26, K. Norske Vidensk. Selsk. Forhandl. (Norway), 34, 124-128, 1962.

The author considers the initial development of a detonation front when the surface of initiation is of arbitrary shape. The analysis suggests that if the sum of the principal curvatures of the front is positive then the detonation speed increases with time, while if the sum is zero or negative the detonation speed remains equal to the Chapman-Jouguet value.

3519

Smiley, R. F., and E. L. Krasnoff, "Unsteady Aerodynamic Forces on Subsonic Aircraft Exposed to Blast Gusts of Arbitrary Orientation," WADC Tech. Rept. No. 57-594, Allied Research Associates, Inc., Boston, Mass., 1958.

An analysis is made to establish equations for the transient aerodynamic blast loads produced by traveling blast waves striking subsonic aircraft. For the two-dimensional case, linearized thin airfoil theory is used to determine the lift growth variation as a function of subsonic airplane Mach number and supersonic blast propagation velocity for both head-on and tail-on blast contact conditions. For the three-dimensional case with arbitrary orientation of the blast wave, equations for the transient lift growth are obtained by semi-empirical modifications of the two-dimensional theory.

3520

Snay, H. G., "A Theory of the Shockwave Produced by a Point Explosion," Rept. No. 4182, Naval Ordnance Lab., White Oak, Md., 44 pp., 1957.
AD-151 663.

Approximate integrals of the spherical blast equations with variable isentropic exponents are derived. The distribuations of velocity, density and pressure within the sphere of disturbance are expressed in polynomials. These are used to calculate the "reduced energy" that is closely related to the relationship between shockwave peak pressure and distance. For very large distances, the well-known asymptotic behavior of weak shockwaves is obtained.

3521

Staniukovich, K. P., "Application of Particular Solutions of Gas Dynamics Equations to the Study of Detonation and Shock Waves," Compt. Rend. Acad. Sci. URSS, 52, 589-592, 1946.

The solutions given previously (Compt. Rend. Acad. Sci. URSS, 48, 1945) are used to study the pressure, density, and velocity for spherical detonation and shock waves. Graphs showing the variation of these parameters are drawn.

3522

Stoner, R. G., and W. Bleakney, "The Attenuation of Spherical Shock Waves in Air," J. Appl. Phys., 19, 670-678, 1948.

The peak pressure of the waves from small explosive charges was determined as a function of distance by measuring the velocity of propagation and applying the velocity-pressure relation derived from the Rankine-Hugoniot equations. The pressure-distance relations for the four principle charge types are given. The curve for spherical charges agrees with the Kirkwood theory, and the results for cylinders having various length diameter ratios indicate large dependence of pressure on charge shape.

3523

Suffield Experimental Station (Canada), "Scientific Observations on the Explosion of a 20 Ton TNT Charge, Volume One. General Information and Measurements," Rept. No. 203, Vol. 1, 76 pp., 1961.
AD-272 040.

A 20-ton block-built hemisphere of TNT was detonated on the ground, and air blast and ground shock measurements were taken. Teams from UK and USA laboratories were associated in the observations. One project of interest to the three countries was the establishment of a lane, radial from the charge, to provide a common ground in which each contributed piezo gauges and recording systems for comparisons of the readings obtained among the systems. The details of the construction and detonation of the charge, the range observations and procedures during the trial, the surface meteorological observations, and the air and ground scientific observations other than the shock overpressure measurements, are presented.

3524

Suffield Experimental Station (Canada), "Scientific Observations on the Explosion of a 20 Ton TNT Charge, Volume Two. Tripartite Blast Measurements," Rept. No. 203, 1961.
AD-272 033.

Air blast data obtained from the detonation of twenty tons of TNT are given. Shock overpressure observations made by the Tripartitite (US-Canada-UK) teams on the airblast are presented, and the various systems for recording the explosive phenomena are compared.

3525

Swigart, R. J., "Third-Order Blast Wave Theory and Its Application to Hypersonic Flow Past Blunt-Nosed Cylinders," J. Fluid Mech., 9, 613-620, 1960.

The inviscid flow behind a cylindrical blast wave and its analogy with hypersonic flow past blunt-nosed cylinders is considered. Sakurai (1953, 1954) obtained a solution for the flow field behind a propagating blast wave by expanding the flow variables in power series of $1/M^2$, where M is the blast wave Mach number, and determining the coefficients of the first two terms in the series. Here the work is extended to include third-order terms. Third-order theory is shown to improve the prediction of shock-wave shapes and surface-pressure distributions on hemisphere-cylinder configurations at M = 7.7 and 17.18.

3526

Taylor, G., "The Formation of a Blast Wave by a Very Intense Explosion, I. Theoretical Discussion," Proc. Roy. Soc. (London) A, 201, 159-174; "II. The Atomic Explosion of 1945," Ibid., 175-186, 1950.

Theoretical problems connected with the energy dissipation from an intensive explosion are treated in detail in Part I. The energy, form, and time of decay of the blast wave; similarity to sound wave propagation; heat energy remaining in the air after its return to atmospheric pressure; and comparison with blasts from high explosives, are determined mathematically and expressed in tables and graphs.

In Part II, the theoretical results are checked against measurements made from photographs of the 1945 atomic explosion in New Mexico, and calculations made for total energy, shock wave, rate of rise of hot air, etc.

3527

Taylor, J. L., "An Exact Solution of the Spherical Blast Wave Problem," Phil. Mag., 46, 317-320, 1955.

The author presents what he believes to be the first exact mathematical solution published on the spherical blast wave problem. The problem concerns an explosion wave in air, assumed to start at a point during the stage when the spherical shock wave is still strong. The solution is developed by straightforward deduction from the known general equations of motion.

3528

Thornton, J. A., and A. B. Cambel, "The Effect of Radiation on Shock Velocity Attenuation in Electromagnetic Shock Tubes," Rept. No. AFOSR-1101, Northwestern Univ., Evanston, Ill., 55 pp., 1961.
AD-277 360.

Observations are reported in a study of effects of radiation on shock velocity attenuation in the conical electromagnetic shock tube. Included is a summary of findings which have appeared in the literature along with the approximate blast wave theory, which has become the primary method of making theoretical velocity-attenuation calculations. These published observations lead to the question of the effect of radiation on the velocity attenuation in a tube with highly reflective walls such as might be employed in a propulsion system; the approximate blast wave theory is adapted in developing a modified approximate method for calculating this effect. Approximate radiation equations are combined with the velocity-attenuation equations and a study is made of radiation factors which might influence the velocity attenuation. It is concluded that radiation will be an important factor only for strong shocks moving into a dense gas (approximately 1/10 atmosphere or greater, at room temperature).

A description of the electromagnetic shock tube is given, and a discussion of some velocity-attenuation experiments which are being conducted, in which no attenuation due to radiation has been noted. These experiments conducted at low velocities and densities thus agree with the predictions of the approximate blast wave theory modified to account for radiation effects.

3529

Thuronyi, G., "Selective Annotated Bibliography on Propagation of Acoustic and Explosion Waves in the Atmosphere," Meteorol. Abst. and Bibl., 10, 1072-1098, 1959.

This bibliography contains 122 entries, each with an abstract or annotation, and spans the years from 1950 to 1959 inclusive, plus a few entries from 1937 to 1949. Most aspects of the propagation of sound in air are covered. Emphasis is on acoustic propagation as a means for studying various properties of the atmosphere.

3530

Travers, S., "Temperatures Attained by the Meeting of Detonation Waves" (in French), Compt. Rend., 237, 1492-1493, 1953.

While very high temperatures are attainable by the normal collision of shock waves in a neutral medium (e.g., 30,000°K in argon), it is shown, by application of the classical Rankine-Hugoniot adiabatic shock equation, that temperatures attainable by the direct collision of detonation waves at a temperature of 5000°K are unlikely to exceed 6000°K. It is suggested that to exceed 10,000°K the impact of explosive waves should occur in a rarefied atmosphere in which the velocity of expansion of the explosion products can exceed the limiting velocity of permanent flow of the products.

3531

Ursenbach, W. O., "Measurements of Air and Ground Shock Disturbances Arising from Demolition Activities at Ravenna Arsenal," Rept. No. 11, Inst. for the Study of Rate Processes, Univ. of Utah, Salt Lake City, 43 pp., 1958.
AD-155 331.

The measurements of air- and ground-shock disturbances arising from demolition activities at the Ravenna Arsenal showed that there is no hazard to any area through direct ground shock from detonation of high explosives at the demolition range. Reports by residents that loud noises have been heard and that windows have been rattled are probably correct and may be attributed to prevailing weather conditions. No pressures large enough to cause damages were measured during the survey. The maximum pressure measured was 2.90 lb/ft^2. Beyond 8000 ft all pressures were below 1.0 lb/ft^2. The most conservative estimates place the low level of damage from air blast at 10.0 lb/ft^2. Vibrations induced in structures from air blast were similar to those induced by normal household movement and local traffic.

3532

Ursenbach, W. O., "Measurements of Air and Ground Shock Disturbances Arising from Demolition Activities at San Jacinto Ordnance Depot," Rept. No. 2, Inst. for the Study of Rate Processes, Univ. of Utah, Salt Lake City, 1957.
AD-155 114

Air and ground shocks were measured in the area surrounding the San Jacinto Ordnance Depot, Texas to determine if the existing demolition program was within safe limits, and to recommend, if possible, a program that would be, that would minimize complaints, and that could be conveniently and economically followed by the depot. The nearest industrial plants were 3000 ft from the demolition area, while residences were located at somewhat greater distances. A low-frequency FM narrow-band microphone system was developed to record the sound wave from 2 to 10,000 cps at pressures as low as 0.01 lb/sq ft. Ground shock recordings were obtained by using a Houston Technical Laboratories S-36 geophone with a natural frequency of 2 cps. Vibrations in residences were recorded by using a South-West Industrial Electronics geophone with a natural frequency of 18 cps. Temperature, humidity, and wind vs. altitude were determined with an aircraft. During the course of the survey, the largest charge detonated was 52 lbs.

Results showed that there is no hazard to any area from direct ground shock for charges of the size detonated at San Jacinto Ordnance Depot. Reports by residents of loud noise from the blasts were probably correct and may be attributed to the prevailing weather conditions. No pressures large enough to cause damage were measured during the course of the survey. On the basis of the work performed at San Jacinto and other depots, there is no reason to expect damaging pressures beyond 2500 ft for the size charge being detonated at this depot.

3533

Ursenbach, W. O., "Measurements of Air and Ground Shock Disturbances Arising from Demolition Activities at Savanna Ordnance Depot," Rept. No. 6, Inst. for the Study of Rate Processes, Univ. of Utah, Salt Lake City, 1957.
AD-150 604.

Air and ground shock disturbances arising from demolition activities at Savanna Depot, Illinois, were measured to assess the safety of the current demolition program, and to recommend, if possible, a program for future activities which would be within safe limits and would minimize the number of complaints, and yet be economically and operationally feasible for the depot. The demolition ground is located in the low levels along the Mississippi River, approximately 3 1/2 miles south-southeast of the closest town, Bellevue, Iowa. There are no other settlements of much consequence closer than this city. A low-frequency FM narrow-band microphone system was used to record the sound wave at 2 to 10,000 cps, at pressures as low as 0.01 lb/sq ft. Ground shock recordings were obtained with a Houston Technical Laboratories S-36 geophone with a natural frequency of 2 cps; no vibrations were measured. Temperature, humidity, and wind vs. altitude were determined with an aircraft.

There was no hazard to any area from direct shock for charges up to 500 lbs, which was the largest detonated during the survey. Much larger charges could be safely detonated because the ground shock measurements at long distances were at least a factor of 1000 below the level required for damage; induced ground was also low enough to be of little concern. Reports by residents of nearby communities regarding loud blasts were attributed to the prevailing weather conditions. No pressures large enough to cause damage were measured. The highest pressure obtained was 0.85 lb/sq ft for a 50-lb shot under 2 ft of dirt and measured at 3000 ft. There is no reason to expect any damage from present demolition activity.

3534

Ursenbach, W. O., "Measurements of Air and Ground Shock Disturbances Arising from Demolition Activities at Sioux Ordnance Depot," Rept. No. 9, Inst. for the Study of Rate Processes, Univ. of Utah, Salt Lake City, 1958.
AD-153 993.

Presents the results of the measurements of air- and ground-shock disturbances arising from demolition activities at the Sioux Ordnance Depot. The following conclusions are drawn: there is no hazard to any area from direct ground shock for charges up to 6000 lb; the blasts heard in communities are attributable to prevailing weather conditions, and no pressure during the survey was large enough to cause damage.

3535

Ursenbach, W. O., "Measurements of Air and Ground Shock Disturbances Arising from Demolition Activities at Wingate Ordnance Depot," Rept. No. 13, Inst. for the Study of Rate Processes, Univ. of Utah, Salt Lake City, 1958.
AD-162 824.

Two surveys were conducted at the Wingate Depot (September, 1956, and December, 1957) when good conditions existed for demolition activity, and variations in weather gave rise to return to the ground of sound from detonations at long distances. Survey results show that direct ground shock represents no problem at the Depot. The highest index of acceleration recorded for the wave propagating directly through the ground was 0.000088 while the greatest displacement measured was 0.00014 inches.

These values are a factor of several hundred below the minimum level at which damage might occur. The highest acceleration index measured for vibrations induced in the ground by the impact of an air blast wave was 0.0014, while the highest displacement was 0.00011 inches. The existence and magnitude of these vibrations was entirely dependent on the magnitude of the air blast. The maximum air-blast pressure was 2.88 lb/sq ft for a 500 lb charge fired on the surface, 4000 ft from the point of measurement. Beyond 4000 ft no pressure greater than 1.0 lb/sq ft was measured. These pressures were well below a level necessary to cause damage. There is no hazard to any inhabited area or industrial concern from such charges as those detonated during the survey. Suggestions were made on the safety of the current demolition program.

3536

van Rossum, J. W. M., "Bibliography on Blast, Shock Waves and Allied Topics, Featuring Nuclear Explosions," Rept. No. TDCK 30050, Tech. Doc. Inform. Ctr., Krijgsmacht, Netherlands, 1962.
AD-276 958.

Entries include references to reports pertaining to characteristics of nuclear explosions—air burst, ground burst, and underwater burst—together with the response of structures to blast loading. Attenuation is paid to measurements, experimental techniques, and testing equipment. Many of the references in this report bear only a marginal relationship with the subject mentioned, but their findings are of interest in the over-all picture. References have been arranged chronologically with the latest references placed first. The bibliography is cross-referenced and has an author index.

3537

Weston, V., "The Pressure Pulse Produced by a Large Explosion in the Atmosphere," Radiation Lab., Univ. of Mich., Ann Arbor, 17 pp., 1961.
AD-263 023.
See Also: Can. J. Phys., 39, 933-1009.

The pressure pulse produced by a large explosion in the atmosphere is investigated. The explosion is represented in terms of the excess pressure and normal velocity on a closed surface, outside of which the hydrodynamical equations are linearized. The pulse is represented in terms of a Fourier transform of the associated harmonic frequency problem for which a ring-source Green's function is obtained in terms of an expansion of the discrete modes. It is shown that the excess pressure may be represented in terms of an integral (containing the Green's function) over the surface surrounding the source. The gravity-wave portion of the pressure pulse at the ground is computed for various altitudes, and for three models of the atmosphere. In calculating the head of the pulse, a new asymptotic technique is introduced that gives very good results for intermediate and long ranges.

3538

Whitham, G. B., "The Propagation of Spherical Blast," Proc. Roy. Soc. (London), A, 203, 571-581, 1950.

The attenuation of spherical shocks at large distances from the origin is investigated mathematically. To do this the author has developed a general theory of spherical wave motion at large distances, where the linearized approximations of the theory of sound are valueless owing to the divergence of the characteristics at infinity. In the case of disturbances small from the outset, this general theory is used to modify the linearized approximation to give a theory that is uniformly valid at all distances from the origin. For a weak explosion, a modified linear theory is used to show that behind the front shock an envelope of characteristics is formed, and hence a second shock must appear.

3539

Wood, W. W., and J. G. Kirkwood, "Diameter Effect In Condensed Explosives, The Relation Between Velocity and Radius of Curvature of the Detonation Wave," J. Chem. Phys., 22, 1920-1924, 1954.

The limiting slope of the detonation velocity-wave front curvature locus for small velocity deficits is obtained under an assumption concerning the "reaction zone length" as related to the charge diameter and the radius of curvature of the wavefront. The model is an extension to two dimensions of von Neumann's classical theory of the plane wave detonation.

3540

Zaydel', R. M., "Stability of Detonation Waves in a Gaseous Mixture," Foreign Tech. Div., Air Force Systems Command, Wright-Patterson AFB, Ohio, 8 pp., 1962.
AD-271 859.

The stability of the detonation wave with respect to small perturbations is examined, being of interest in explaining spin detonation. It is pointed out that at the shock front of the detonation there is an overcompression in whose range the combustion of the mixture is accelerated. It is noted that conditions of instability are found far from the limits of detonation.

3541

Zeldovich, J. B., and K. P. Staniukovich, "On the Reflection of a Plane Detonation Wave," Compt. Rend. Acad. Sci. URSS, 55, 587-590, 1947.

The mathematical theory of the reflection at an absolutely unyielding wall enables expressions to be derived for the explosion pressure, the velocity of sound in the products, and the impulse, on the standard theory of shock absorption. Assuming that pv^3 is constant not only along the isentropic but also along the Hugoniot adiabatic line, expressions are derived for the same three physical "constants."

Wave Propagation, Blast/Detonation—see also Wave Propagation, Abnormal
See Also—10, 464, 475, 490, 539, 561, 564, 587, 701, 702, 714, 757, 758, 864, 911, 920, 924, 928, 1217, 1354, 1362, 1364, 1405, 1416, 1417, 1447, 1467, 1471, 1484, 1501, 1519, 1534, 1551, 1561, 1633, 1748, 1780, 1781, 1782, 1792, 1798, 1806, 2118, 2128, 2306, 2363, 2364, 2374, 2380, 2519, 2919, 2986, 2993, 2999, 3008, 3218, 3224, 3223, 3232, 3235, 3245, 3254, 3264, 3274, 3275, 3276, 3277, 3314, 3342, 3358, 3362, 3363, 3401, 3608, 3648, 3649, 3656, 3824, 3845, 3976, 4013, 4047, 4048, 4051, 4118, 4125, 4136, 4201, 4263, 4271, 4280

WAVE PROPAGATION, BOUNDARY EFFECTS

3542

Antokolskii, M. L., "Reflection of Waves from a Rough Absolute Reflecting Surface" (in Russian), Dokl. Akad. Nauk SSSR, 62, 203-206, 1948.
ATI-137 914.

Experiments show that during the reflection of a lighter sound wave from a surface there exists not only a regularly reflected wave, but also a diffusion field created by the presence of surface roughness. Complete estimation of both diffusion and reflection fields is made only for the case where the surface roughnesses are small in comparison to the wavelength. This report refers to the regular reflection part of the field. The author determined the conditions at which this regular field has the nature of a normally reflected wave and computed the reflection coefficient in relation to the wavelength and angle of incidence. The transition from diffusion to regular reflection during a specific angle of incidence is a convenient means of determining the qualitative characteristics of a reflecting surface. The Kirchhoff law is the basic simplifying assumption in the calculation of surface characteristics.

3543

Arabadzhi, V. I., "Acoustical Characteristics of the Air Layer near the Ground" (in Russian), Uch. Zap., Leningr. Gos. Ped. Inst., 7, 87-91, 1957.

Investigations of sound propagation in the ground layer of the atmosphere over various natural surfaces are described. The measurements were made over a straight road, a flat grass field, a water surface, and a depression, with a microphone joined to an amplifier output by a millivoltmeter. Sound reflection from a dense grass cover, from a surface of cut grass, and from bushes and leaves was recorded at frequencies of 0.2-4.0 kcs. The effect of atmospheric temperature inhomogeneities upon sound attenuation was investigated by means of laboratory apparatus, which is described in detail. In these laboratory experiments attenuation coefficients between 10^{-5} and 10^{-4} cm^{-1} were obtained, which is in fair agreement with investigations made in the free atmosphere.

3544

Aroesty, J., "Strong Interaction with Slip Boundary Conditions," Rept. on Research on Aerodynamic Flow Fields, Univ. of Calif., 25 pp., 1961.
AD-269 539.

A solution to the problem of strong interaction between the shock wave and the boundary layer has been obtained for the case where velocity slip and temperature jump boundary conditions are consistent at the wall. It is shown that the addition of slip boundary conditions yields a correction of order (boundary-layer thickness/X) to the no-slip solution. Estimates are made of the effect of slip on induced pressures and skin friction for the case of the adiabatic wall. In addition, it is shown that the inclusion of slip boundary conditions does not change the energy transfer to the wall from the no-slip values.

3545

Asbridge, J. R., "An Interferometric Study of Shock Tube Boundary Layers," Tech. Rept. No. 14, Inst. Res., Lehigh Univ., Bethlehem, Pa., 97 pp., 1959.
AD-215 395.

Boundary layers in the hot-gas flow behind the shock wave on the walls of a rectangular shock tube were studied for eleven flow conditions, observing their density structure with a Mach-Zehnder interferometer. The boundary layers are observed to be thin and slowly growing at first, possessing the structure and growth rate predicted by Mirels for laminar layers. This laminar structure extends for only a limited distance behind the shock. Then the boundary-layer profile gradually becomes similar to that which has been observed for steady turbulent layers, although a systematic difference is detected for most flow conditions. The structure of the boundary layer during the transition from laminar to turbulent flow is observed to be consistent with the turbulent spot mechanism of transition, but no direct evidence for turbulent spots has been found. A Reynolds number for transition, based on the distance that the gas particles travel after being set in motion by the shock before becoming turbulent, is found to increase with increasing shock strength. Surface roughness effects can severely influence this transition Reynolds number. Free stream density variations coincident with the boundary-layer growth are observed and presented.

3546

Barger, R. L., "Reflection and Transmission of Sound by a Slotted Wall Separating Two Moving Fluid Streams," Rept. No. TN 4295, Natl. Advisory Comm. Aeron., Washington, D. C., 14 pp., 1958.
AD-160 215.

The reflection and transmission coefficients have been determined for a plane sound wave incident on a slotted wall separating two moving fluid streams. This acoustics problem is related to the aerodynamic problem of determining the tunnel-wall interference on an oscillating airfoil in a slotted-throat wind tunnel, in that the same boundary condition is involved, with one of the two streams at the boundary having zero velocity. In analysis, the wall with discrete slots is replaced by an equivalent homogeneous boundary.

3547

Barkhatov, A. N., "The Sound Field in a Medium with a Homogeneous Surface Layer," Soviet Phys. Acoust., English Transl., 4, 11-16, 1958.

The acoustic field is investigated for a space bounded by a surface layer over an extended medium, in which there is a constant negative gradient of the velocity of sound for various positions of the radiator. The results for geometrical and wave theories are compared.

3548

Biot, M. A., "Reflection on a Rough Surface from an Acoustic Point Source," J. Acoust. Soc. Am., 29, 1193-1200, 1957.

A simple solution is developed for the reflected waves on a rough surface from a simple harmonic point source. It is assumed that the roughness is represented by a distribution of hemispherical bosses whose size and mutual distance are small relative to the wavelength. It is shown that under these conditions the effect of the roughness is equivalent to a boundary condition for the wave equation. This boundary condition embodies the surface polarization and the mutual interaction of the bosses. If the generating source lies above the reflecting surface the reflected wave is found to be equivalent to that originating from concentrated and distributed image sources on a line situated below the specular image, with a magnitude decreasing exponentially with depth.

The case of small, vanishing roughness is discussed, together with the field intensity at large distance and grazing incidence. The effect of fluid viscosity is also evaluated.

3549

Brekhovskikh, L. M., "Surface Waves in Acoustics," Soviet Phys. Acoust., English Transl., 5, 3-12, 1959.

Investigates propagation of acoustic waves along various types of elastic surfaces, and develops expressions for surface-wave propagation velocity and particle velocity. It is shown that surface-wave propagation velocity is less than the propagation velocity in an unbounded medium. The boundary layer absorption due to thermal conduction becomes significant when the width or depth of corrugations in the boundary is small. This loss is negligible in air if all dimensions of boundary corrugations are considerably larger than $3.35/\sqrt{f}$ cm. For results of experiments based on the theory presented in this paper see K. M. Ivanov-Shits and F. V. Rozhin, "Investigation of Surface Waves in Air," Soviet Phys. Acoust., 5, 510-12, 1960.

3550

Brillouin, J., "Form and Propagation of Sound Waves in a Space Limited by Absorbing Surfaces," J. Phys. Radium, 10, 497-503, 1939.

Starting from the general velocity potential equation, an examination is made of various problems related to the propagation of forced vibrations in a space limited by absorbing surfaces. The absorption is defined by the impedance of the limiting surface. In the space limited by planes, nonuniform plane waves of special structure are shown to exist, with elliptical vibration in a plane containing the direction of propagation, amplitudes following an exponential law in the direction of the plane of the wave containing the elliptical trajectories, uniformity in the direction of the plane of the wave normal to the plane of the trajectories, phase velocity and velocity of energy propagation equal and less than the velocity of sound. These waves, in the space considered, play a similar part to that of plane uniform waves in spaces limited by rigid planes. The calculation finally gives, for spaces not totally enclosed, the different forms of progressive waves, with their phase-velocity and attenuation, and, for totally enclosed spaces, the forced vibrations.

3551

Brillouin, J., "Propagation of Plane Sound Waves near an Absorbing Surface," Rev. Acoust., 8, 97-109, 1939.

A mathematical examination of the types of waves that are compatible with the presence of a porous absorbing surface. A method producing the waves is suggested, and also a method for measuring the impedance of the absorbing surface. Erratum, Ibid., p. 202.

3552

Burgers, J. M., "On the Transmission of Sound Waves Through a Shock Wave," Proc. Koninkl. Ned. Akad. Wetenschap., 49, 274-481, 1946.

A study of the phenomena that occur when a shock wave is met by sound waves. Considers the case of a stationary shock wave forming the boundary between two regions, in one of which the gas moves with supersonic velocity, and in the other, with subsonic velocity. The boundary conditions are defined in the two cases where the sound wave is incident in the supersonic region and in the subsonic region. The peculiar system of wave motion produced, in which there may or may not be reflection at the boundary layer, is explained on the basis of entropy waves. When sound waves are superimposed on the shock wave, the change of entropy of the gas passing through it is no longer constant and a periodic field of entropy makes its appearance.

3553

Campbell, I. D., "The Transmission of a Plane Wave Between Parallel Plates," Acustica, 5, 298-302, 1955.

The transmission of a plane wave between infinite parallel plates is discussed theoretically, allowance being made for the effects of viscosity and thermal conduction. The use of an approximate method allows the attenuation and phase velocity to be deduced at all frequencies. Some experimental measurements are presented for comparison with the theory.

3554

Chernyi, G. G., "Integral Methods for the Calculation of Gas Flows with Strong Shock Waves," Appl. Math. Mech., 25, 138-147, 1961.

When a strong shock wave propagates through a gas, the density of the gas increases significantly. The region of disturbed motion next to the wave may be considered as a peculiar boundary layer that is in many ways analogous to the boundary layer in a viscous fluid. In the calculations of gas motion in this layer behind the shock wave, integral methods may be used that are basically similar to those used in the theory of boundary layers in a viscous fluid.

Gives a general approach to the use of integral methods in such problems as flows with strong shock waves, together with other examples of solutions.

3555

Curle, N., "The Influence of Solid Boundaries Upon Aerodynamic Sound," Proc. Roy. Soc. (London), A, 231, 505-514, 1955.

An extension is made to Lighthill's general theory of aerodynamic sound, so as to incorporate the influence of solid boundaries upon the sound field. This influence is twofold; that is, reflection and diffraction of the sound waves at the solid boundaries, and a resultant dipole field at the solid boundaries that are the limits of Lighthill's quadrupole distribution. It is shown that these effects are exactly equivalent to a distribution of dipoles, each representing the force with which unit area of solid boundary acts upon the fluid.

A dimensional analysis shows that the intensity of the sound generated by the dipoles should at large distances x be of the general form $I \propto \rho_0 U_0^6 a_0^{-3} L^2 x^{-2}$, where U_0 is a typical velocity of the flow, L is a typical length of the body, a_0 is the velocity of sound in fluid at rest, and ρ_0 is the density of the fluid at rest. Accordingly, these dipoles should be more efficient generators of sound than the quadrupoles of Lighthill's theory if the Mach number is small enough. It is shown that the fundamental frequency of the dipole sound is one-half of the frequency of the quadrupole sound.

3556

Duff, R. E., "The Interaction of Plane Shock Waves and Rough Surfaces," J. Appl. Phys., 23, 1373-1379, 1952.

Shock-tube experiments have been conducted to determine the effect of surface roughness on shock waves in N passing over the surface. Shock retardation was measured for a series of two- and three- dimensionally rough surfaces at shock strengths from $\xi = 0.1$ to $\xi = 0.9$. The first-order approximation was made so that the volume between the positions of the shock wave, with and without the rough surface present, multiplied by the specific energy behind the undisturbed shock wave, represented energy dissipated by the roughness. The space rate of energy dissipation is presented as a function of the average particle size of the rough surface.

It is also shown that the curvature of the shock wave in the vincinity of the surface depends on the roughness of the surface, the length of roughness covered, and the strength of the shock wave. In addition, the hundreds of measurements of shock wave contours made in this investigation showed that there is a random fluctuation of $1/15^{\circ}$ in the angle of incidence of the primary shock wave. This fluctuation is presumably caused by the details of the diaphragm rupture even though measurements were made 14 ft from the diaphragm in a shock tube with a 2×7 in. cross-section.

3557

Ellinwood, J. W., L. Trilling, and J. F. White, "Shock-Wave Oscillations in Supersonic Flow," Tech. Note No. 57-409, Rept. on Flight Control Technical Requirements, Instrumentation Lab., Mass. Inst. of Tech., Cambridge, 61 pp., 1957.
AD-213 868.

Results are presented of three investigations of oscillating shock waves. "Oscillating Shock Boundary Layer Interaction," by Leon Trilling, is a theoretical study in which a shock wave with a laminar boundary layer is investigated. It is found that for any local Mach number above 1.5, and for any Reynolds number, there is a combination of frequency and shock strength for which shock oscillations are neutrally stable. Stability boundaries are presented.

"Experiments in Oscillating Shock Boundary Layer Interaction," by Joseph Frederick White, describes the design and testing of a mechanism to generate oscillating shock waves in a wind tunnel. Some preliminary measurements obtained with this mechanism are presented, and experimental requirements for a more comprehensive program are suggested.

"Unsteady Lifting Airfoils at High Subsonic Speeds," by John Webster Ellinwood, is a theoretical study of unsteady aerodynamic forces and critical frequencies for airfoils at small angles of attack oscillating in nonviscous flows. A theory based on a simplified mathematical model is derived, and a sample calculation is presented and discussed.

3558

Fage, A., and R. F. Sargent, "Shock-Wave and Boundary-Layer Phenomena near a Flat Surface," Proc. Roy. Soc. (London), A, 190, 1-20, 1947.

Shock-wave and turbulent boundary-layer phenomena near the smooth, flat, metal floor of a specially designed supersonic tunnel are studied from traverses made with pitot, static-pressure, and surface tubes, and from direct-shadow and Toplerstriation photographs. Near-normal and oblique shock-wave systems, with or without a bifurcated foot, are considered.

3559

Fletcher, C. H., A. H. Taub, and W. Bleakney, "The Mach Reflection of Shock Waves at Nearly Glancing Incidence," Rev. Mod. Phys., 23, 271-286, 1951.

The interaction of a plane shock wave in air with a plane rigid wall involves (1) a regular reflection in which the incident shock is followed by a reflected shock that joins the incident shock wave at the wall; and (2) Mach reflection in which the reflected shock wave meets the incident shock at a triple point or line at some distance from the wall, and is joined to it by a third shock wave (usually curved) called the Mach shock.

The mathematics of the Mach reflection of shock waves at nearly glancing incidence is here developed by linearizing both the differential equation of wave propagation and the boundary condition. The methods employed by Bargmann, by Lighthill, and by Ting and Ludloff (J. Roy. Aeronaut. Soc., 18, 143, 1951) are discussed, and their results compared with experimental results. Preliminary experiments have shown qualitative agreement with Bargmann's results. Experimental evidence indicates that the observed slip streams are density discontinuities, and occur in the reflection of any shock at suitable angles not in the region of near-glancing incidence. For strong incident shocks, there is agreement between the observed shock configuration and that required by the local three-shock theory.

The slip stream in the case of weak incident shocks, where the configuration violates the local three-shock theory, appears, experimentally, to be a sharp density discontinuity; a calculation similar to that of Ting and Ludloff, but for weak shocks, would show a broad region of changing density. The fundamental problem of Mach reflection of weak shocks has not yet been solved.

3560

Gadd, G. E., "Interactions Between Normal Shock Waves and Turbulent Boundary Layers," Aeron. Res. Council Rept. Memo. No. 3262, 66 pp., 1961.

A theory, involving a simple new method for turbulent boundary layers, is presented for interactions between normal shocks and turbulent boundary layers on flat surfaces. Experiments in a pipe confirm the theory's general validity. Effects on separation of convex-surface curvature and sweepback of the shock are then considered.

3561

Gottlieb, P., "Sound Source near a Velocity Discontinuity," J. Acoust. Soc. Am., 32, 1117-1122, 1960.
AD-248 126.

The far-field solution for a line and a point source near a tangential velocity discontinuity has been calculated by summing (integrating) the plane waves that make up the source. The exact field integrals were evaluated approximately by the stationary-phase method, and this approximation gives the far field. It was found that the sound was strongly peaked in some directions, and considerably reduced in others. This angular dependence is shown graphically for certain cases. The physical significance of these results is discussed for both subsonic and supersonic motions, and the relationship to the jet-noise problem is suggested.

3562

Gvozdena, L. G., "The Refraction of Detonation Waves Incident on the Boundary Between Two Gas Mixtures," Soviet Phys. Tech. Phys., English Transl., 6, 527-533, 1961.

Discusses one of the phenomena characteristic of detonation waves—the refraction of such a wave when it passes from one explosive mixture to another. By using a high-speed cinecamera, photographs were obtained of the phenomenon that takes place when a detonation wave moving through a medium capable of reaction passes through a boundary dividing this medium from an explosive or inert medium.

3563

Hartunian, R. A., "Shock Curvature Due to Boundary Layer Effects in a Shock Tube," Rept. No. TDR-594(1217-01) TN-1, Aerospace Corp., Los Angeles, Calif., 16 pp., 1960.
AD-267 907.

The analysis and results of a two-dimensional, linearized treatment, including real gas effects, are presented. An expression for shock shape as a function of shock Mach number and initial pressure of the test gas is presented. Results are compared with available experimental data obtained in argon at low shock strengths and in air at high shock Mach numbers. Within the scatter of the data in the latter experiments, there is relatively good agreement with theory, while theory falls approximately 30 + or - 10% above the data in argon. Some disagreement is attributed to application of the two-dimensional theoretical result to axisymmetric shock tubes of finite dimensions used in the experiments.

3564

Henson, J. R., and J. E. Robertson, "Methods of Approximating Inviscid Jet Boundaries for Highly Underexpanded Supersonic Nozzles," AEDC TDR 62-7, Arnold Engineering Development Center, Arnold Air Force Station, Tenn., 51 pp., 1962.
AD-275 641.

Methods of approximating inviscid boundaries of jets exhausting from axisymmetric supersonic nozzles into a quiescent atmosphere and moving streams have been developed. Jet shapes from two typical afterbody configurations were calculated for various flight conditions. Good agreement with available theoretical and experimental data was obtained. A step-by-step calculational procedure is given.

3565

Holder, D. W., C. M. Stuart, and R. J. North, "The Interaction of a Reflected Shock with the Contact Surface and Boundary Layer in a Shock Tube," Rept. No. 22891, Aeronautical Res. Council, Great Britain, 20 pp., 1961.
AD-273 535.

The experiment was designed to investigate the departures of the hypersonic shock tunnel operated by the reflected-shock technique from the simple theoretical model, by providing photographs illustrating the interaction of the reflected shock with the boundary layer and with the contact region. Results were obtained for representative values of primary shock Mach number, using hydrogen as the driving gas and nitrogen as the driven gas. The work demonstrates that there are striking differences between the observed flows and those assumed in inviscid theory, and predictions of the theory. These are particularly marked in connection with the disturbances reflected from the contact surface, and with the motion of the shock transmitted through the contact surface when the primary-shock Mach number is high.

On the other hand, the motion of the contact surface, after meeting the reflected shock, agrees reasonably with theoretical predictions. As far as the operation of shock tunnels is concerned, the results are not discouraging, especially at the tailored condition, where there appears to be reasonable agreement with the promising predictions of theory. It is noted, however, that because of the low pressure levels employed, the present results are in some respects dissimilar to those observed in other shock-tunnel investigations.

3566

Hollyer, R. N., and R. E. Duff, "The Effect of Wall Boundary Layer on the Diffraction of Shock Waves Around Cylindrical and Rectangular Obstacles," Rept. 50-2, Engineering Research Inst., Univ. of Mich., Ann Arbor, 37 pp., 1950.
ATI-93,085.

An investigation is made of the effect of wall boundary layer on the diffraction of shock waves around cylindrical and rectangular obstacles. It was revealed that the wall boundary layer does not seriously influence the diffraction of shock waves around obstacles placed on the wall. The very weak Mach intersection that develops in front of the rectangular block is the only noticeable perturbation caused by the wall. The boundary layer along the wall exerts little influence on the diffraction phenomena, because the layer is very thin during the early stage of the flow.

3567

Ingard, U., "Influence of Fluid Motion Past a Plane Boundary on Sound Reflection, Absorption, and Transmission," J. Acoust. Soc. Am., 31, 1035-1036, 1959.
AD-226 926.

The effect of fluid motion past a plane boundary on the reflection and absorption of sound is equivalent to an increase of the normal acoustic impedance of the boundary by a factor $(1 + M \sin \theta)$, where θ is the angle of incidence of the sound wave, and M is the Mach number of the flow velocity component in the incidence-reflection plane of the wave. Similarly, the acoustic energy flux perpendicular to the boundary and the flow is shown to be increased by the same factor. Reflection and transmission coefficients of a thin solid interface between a fluid in motion and one at rest are given. Furthermore, some comments on the problem of transmission in ducts are given. For propagation between two plane parallel boundaries with the same acoustic admittance, for sufficiently small values of the admittance, the sound pressure attenuation constant of the fundamental mode is modified approximately by the factors $(1 + M)^{-2}$ and $(1 - M)^{-2}$ for downstream and upstream propagation, where M is the flow Mach number.

3568

Ivanov-Shits, K. M., and F. V. Rozhin, "Investigation of Surface Waves in Air," Soviet Phys. Acoust. English transl., 5, 510-512, 1960.

An apparatus was designed to observe traveling surface waves in air. A battery of loudspeakers transmitted sound over an aluminium grill onto a rigid reflector. Theory suggests that surface waves originating beneath the grill should show a pressure variation obeying P_0e-az-ihx, where a is the attenuation factor and h the wave number of the surface. Measurements were made between 200 and 500 cps because at lower frequencies the waves have small attenuation and velocity dispersion and at higher frequencies they become concentrated into a thin layer. A rapid-response level recorder connected mechanically with a microphone enables the acoustic pressure to be measured along the three perpendicular directions. From such records the velocity and attenuation of the waves were determined and compared with calculated quantities.

3569

Kessler, H. C., Jr., "Equivalent Eulerian Boundary Conditions for Finite-Amplitude Piston Radiation," J. Acoust. Soc. Am., 34, 1958-1959, 1962.

A method is presented for replacing the Lagrangian boundary condition, which occurs in the analysis of finite-amplitude radiation from vibrating pistions, by an approximately equivalent condition that permits the analysis to be carried out in Eulerian form.

3570

Khaskind, M. D., "Propagation of Acoustic and Electromagnetic Waves in a Half-Space," Soviet Phys. Acoust., English Transl., 5, 467-484, 1960.

The propagation of acoustic and electromagnetic waves in a half-space is considered, where the impedance at the boundary of the half-space is given in the form of an arbitrary complex number. The solution is based on the introduction of a functional combination that reverts to zero at the boundary of the half-space. Expressions for the acoustic and electromagnetic potential are found in terms of this functional combination in different cases, taking into account the asymptotes, which depend on the specific values of the impedance.

3571

Kuckes, A. F., and U. Ingard, "A Note on the Acoustic Boundary Dissipation Due to Viscosity," J. Acoust. Soc. Am., 25, 798, 1953.

This mathematical note deals with the energy losses due to viscous dissipation in the regions close to boundaries of the sound field where large velocity gradients occur in the boundary layer. In the case of an aperture in a thin plate, almost the entire dissipation is associated with a region very close to the hole and the curved part of the boundary. The result is therefore strongly dependent on the value of surface resistance of the curved part.

3572

Lambert, R. F., "Acoustical Propagation of Higher Order Modes in the Region of Cutoff," J. Acoust. Soc. Am., 27, 790-791, 1955.

Experimental data on the amplitude of transverse particle velocity associated with the (1.0) mode of rectangular tube for frequencies in the region of cutoff are presented. The distance decay from the source is exponential for frequencies investigated in the range $f/f_c \leq 0.998$, where f is the frequency of excitation and f_c is the mode cutoff frequency. At cutoff, the amplitude drops to the fraction 1/e of its value at the source over a distance interval equal to about eight times the tube width. For frequencies above $f/f_c = 1.01$, the progressive wave pattern appears fully developed. Data for comparing theoretical and measured values of attenuation for frequencies below cutoff are also presented.

3573

Lane, C. A., "Acoustical Streaming in the Vicinity of a Sphere," J. Acoust. Soc. Am., 27, 1082-1086, 1955.

Recent studies have led to a satisfactory understanding of the details of acoustical streaming in the vicinity of a cylinder. Similar studies have now been completed for a sphere. In general, the steady flow around a sphere and the characteristic parameters are very much like what has been found for the cylinder. An experimental verification of the theory has been attempted by comparing the observed dc boundary-layer thickness with that found from the theory. This is summarized in a curve δ_{dc}/δ_{ac} vs. a/δ_{ac}, where δ_{dc} is the dc boundary-layer thickness, δ_{ac} is the ac boundary-layer thickness, and a is the radius of the sphere.

3574

Lawhead, R. B., and I. Rudnick, "Acoustic Wave Propagation Along a Constant Normal Impedance Boundary," J. Acoust. Soc. Am., 23, 546-549, 1951.

An expression is obtained for the amplitude and phase of an acoustic wave above a boundary due to a point source on or near a boundary which exhibits a constant, normal, specific, acoustic impedance. This is shown to be a special case of the solution for an isotropic medium with constant, characteristic, acoustic impedance; specifically, one in which the ratio of the propagation constant in the upper medium to that in the lower approaches 0. A material which obeyed a constant, normal, impedance, boundary condition was constructed from ordinary drinking straws. Measurements of amplitude and phase as a function of receiver position along and above the boundary showed good agreement with theory. The nature of the approximations involved in the solution is discussed and shown to be an adequate representation of the sound field for distances greater than one wavelength from the source.

3575

Lawhead, R. B., and I. Rudnick, "Measurements on an Acoustic Wave Propagated Along a Boundary," J. Acoust. Soc. Am., 23, 541-545, 1951.

The sound field of a point source located at a plane boundary was measured both with respect to its amplitude and phase characteristics. This was done for a very high impedance boundary and one composed of material which is relatively absorbing. The fields were calculated; for the latter material, calculations were based on measured values of impedance and propagation constant, and found to agree well with those measured.

3576

Lighthill, M. J., "The Diffraction of Blast, I.," Proc. Roy. Soc. (London) A, 198, 454-470, 1949.

The behavior of a plane shock of any strength traveling along a wall, when it reaches a corner where the wall turns through a small angle δ, is investigated mathematically by use of a linearized theory of anisentropic flow. At a convex corner pure diffraction occurs; at a concave corner Mach reflection. The shape of the shock and the pressure distribution over the wall are calculated for a variety of shock Mach numbers from 1 to ∞. The connection for weak shocks with acoustic theory is displayed.

3577

Lighthill, M. J., "The Diffraction of Blast, II.," Proc. Roy. Soc. (London) A, 200, 554-565, 1950.

The head-on encounter of a plane shock of any strength with a solid corner of angle $\pi - \delta$ is investigated mathematically, when δ is small, by a method similar to that of Part I.

3578

Lisman, H., "Dependence of Transmission of Shock Waves on Sharpness of Boundary of Two Media," Eng. Rept. E-1114, Evans Signal Lab., Signal Corps Eng. Labs., Delmar, N. J., 7 pp., 1953.
AD-12, 162.

The pressure amplitudes of an acoustic wave and of two shock waves are traced from one layer of air through a boundary into another layer under the condition that the ratio of the acoustic velocity in the first medium to that in the second is $(0.875)^{1/2}$. Another calculation is made for the case of an intermediate layer such that the ratio of velocities in adjacent layers is $(0.875)^{1/4}$. Transmission across the boundary of two media, in the case of shock waves, is improved if a stepwise transition is made. The energy loss across a boundary becomes greater as the shock strength increases, and the percent of improvement of energy transmitted for stepwise transmission is greater for strong shocks than for relatively weaker one.

3579

Ludford, G. S. S., "The Propagation of Waves Along and Through a Conducting Layer of Gas," J. Fluid Mech., 9, 119-132, 1960.

Two related questions concerning the transmission of electromagnetic waves are considered:

(1) The reflexion and transmission of plane waves at a perfectly conducting layer of gas in an otherwise nonconducting atmosphere, when there is a uniform external magnetic field perpendicular to the layer. Here the main result is that a layer of finite depth h is an almost perfect filter, being transparent to waves of frequency $n\pi A_0/h$(A_0 = Alfven velocity, n an integer).

(2) The existence of plane surface waves for such a finite layer. There is always one such wave, and for certain ranges of frequency there are two. The first becomes 'choked' at the filter frequencies, its velocity first tending to zero and then jumping to a finite value. The second chokes at the frequencies $n\pi A_0 a_0/h\sqrt{(a_0^2 + A_0^2)}$ (a_0 = acoustic velocity).

3580

Mark, H., "The Interaction of a Reflected Shock Wave with the Boundary Layer in a Shock Tube," Tech. Memo No. TM 1418, Natl. Advisory Committee for Aeronautics, Washington, D. C., 128 pp., 1958.
AD-155 060.

By theoretical analysis the existence of several different types of interaction in different ranges of initial shock Mach number is predicted. This analysis is verified experimentally. The most complicated interaction is studied in detail, and a model is proposed. The features of the phenomenon are analyzed, based on this model, and are checked experimentally. The case of interaction with a turbulent boundary layer is also considered. A method is proposed whereby the effect of the laminar-boundary-layer interaction on the strength of the reflected shock may be calculated, and a comparison with experimental results is presented.

3581

Mason, W. P., "The Propagation Characteristics of Sound Tubes and Acoustic Filters," Phys. Rev., 31, 283-295, 1928.

The process of measuring the propagation characteristics of uniform sound tubes and acoustic filters is complicated by the reflections that may occur at the ends of these structures. The present paper applies some theoretical results on the effect of reflections, obtained in a previous paper, to the measurement of the propagation characteristics of tubes and acoustic filters. In making these measurements, the device to be measured is inserted in an acoustic transmission system, and the resulting changes in the magnitude and phase of the transmitted wave are measured. The actual observations are made in electrical circuits connected by loudspeakers to the terminals of the acoustic system. The impedance of the acoustic system at the point of insertion is made an acoustic resistance.

For measurements on straight tubes, the acoustic resistance used are of such a value as to prevent any appreciable reflections from the ends of the tubes, and as a result, the propagation characteristics of an infinite tube are obtained. The results of the measurements on straight tubes indicate that the Helmholtz-Kirchhoff law is valid, while the results of measurements on acoustic filters agree well with the theoretical results obtained previously.

3582

Mauterer, O., "A Study of Shock Waves Moving over a Transversely Slotted Wall," Rept. No. GA/ME/61-5, Air Force Inst. of Tech., Wright-Patterson Air Force Base, Ohio, 81 pp., 1961.
AD-267 503.

Investigates the effect on a shock wave of passing a pair of transversely slotted test plates in the top and bottom walls of a rectangular shock tube. Particular attention was paid to the shock strength, defined for this study as the pressure ratio across the shock. The shock wave's response to the disturbance was verified by Schlieren photography. The slot width, slot-entrance radius, effective slot depth, and strength of the incident shock wave were varied to determine the effects of these parameters.

The attenuation was found from pressure-measuring transducer data, which was recorded photographically. The time to establish the quasi-steady outward flow of air through the openings determined the extent of attenuation. When the slot width or slot entrance radius were large, the reflected shock waves generated at the disturbance were sufficiently strong to delay the mass flow out of the opening; thus, the attenuation was reduced. The attenuation increased as the effective slot depth was decreased. Schlieren photography verified the formation of the reflected shock waves and of the rarefaction waves associated with the loss of mass behind the wave.

3583

Mawardi, O. K., "On Acoustic Boundary Layer Heating," J. Acoust. Soc. Am., 26, 726-731, 1954.

The conventional investigations of the propagation of sound waves in conduits, when the effect of dissipation through friction and conduction of heat through the walls is taken into account, assume that the fluctuating part of the temperature of the gas vanishes at the boundaries. This is in essence a first-order approximation. Very different effects, however, are expected when sound-order terms are considered. The purpose of the present paper is to discuss in detail the nature of the solution obtained from a second-order approximation.

3584

Mawardi, O. K., "Some Notes on the Measurement of Acoustic Impedance," J. Acoust. Soc. Am., 28, 351-356, 1956.

Works out the theory of a plane-wave method for measuring acoustic impedance in a tube. The effect on the measurement of irregularities in the surface of the sample has also been investigated. It is shown that the measured impedance differs from that of the average impedance evaluated at the surface of the specimen. A number of recommendations for the method of preparation of a sample are also given.

3585

Meecham, W. C., "Propagation of Radiation in an Inhomogeneous Medium near an Irregular Surface," J. Acoust. Soc. Am., 25, 1012, 1953.

The intensity of a sound wave propagated in a surface channel is derived, using the concepts of ray acoustics and taking into account the roughness of the surface. The attenuation due to rough-surface scattering is found, and calculations are made for several types of surface reflections.

3586

Meecham, W. C., "A Statistical Model for the Propagation of Radiation in Refraction Ducts Bounded by Rough Surfaces," Rept. No. 1936-3-T, Engineering Research Inst., Univ. of Mich., Ann Arbor, 175 pp., 1954.
AD-50 974.

The model, which is in the form of an integrodifference equation, is redrived by a detailed consideration of the average amount of energy reflected by an element of surface per second per element of angle. The basic equation is derived from the wave equation after applying a number of restricting assumptions, the most important of which are that the frequency is sufficiently high or the surface sufficiently rough to reflect primarily diffuse radiation from the surface; that the properties of the material medium vary sufficiently slowly that geometrical optics can be used to treat the propagation of radiation within the volume; and that the surface is such that an individual reflection can be treated through the use of physical optics.

Two methods for solving the basic equation are given. The first is a solution by iteration; the second depends upon taking the Laplace transform of the equation. Existence, uniqueness, and continuity properties of the solution are shown. A numerical example is given, and plots of field strength vs. range are presented for various positions of the source and receiver. The attenuation of the field depends strongly upon the fraction of the energy trapped within the duct after a surface reflection.

3587

Meyer E., and W. Guth, "The Acoustic Viscous Boundary Layer" (in German), Acustica, 3, 185-187, 1953.

The acoustic viscous boundary layer is investigated for sound waves in air in the neighborhood of a rigid wall, using illuminated floating particles seen under a microscope.

3588

Miles, J. W., "Dispersive Reflection at the Interface Between Ideal and Viscous Media," J. Acoust. Soc. Am., 26, 1015-1018, 1954.

The effects of viscosity and heat conduction (in the reflecting medium) in producing dispersive reflection of a plane wave at the plane interface separating two media are investigated. If the reflecting medium is treated as a condensed fluid, heat conduction is found to have no effect, while in first approximation, viscosity is found to produce no change in amplitude but rather a phase shift proportional to frequency (and therefore no phase distortion) at angles of incidence above critical and to produce no phase shift but amplitude distortion at angles below critical. This amplitude distortion is found to be important only in the neighborhood of a sharp wave front.

3589

Mirels, H., "Attenuation in a Shock Tube Due to Unsteady-Boundary-Layer Action," Rept. No. 1333, Nat. Advis. Com. Aeron., Washington, D. C., 19 pp., 1956.
AD-158 942.

A method is presented for obtaining the attenuation of a shock wave in a shock tube due to the unsteady boundary layer along the shock-tube walls. It is assumed that the boundary layer is thin relative to the tube diameter and that it induces one-dimensional longitudinal pressure waves whose strength is proportional to the vertical velocity at the edge of the boundary layer. The method is shown to be in reasonably good agreement with existing experimental data.

3590

Mirels, H., and J. Hamman, "Laminar Boundary Layers Behind Strong Shock Moving With Nonuniform Velocity," Phys. Fluids, 5, 91-96, 1962.

The laminar boundary layer behind a strong shock moving with nonuniform velocity into a stationary fluid was investigated. In particular, two-dimensional and axisymmetric boundary layers behind plane, cylindrical, and spherical shocks, which move according to the power law $x_s = Ct^m$, were considered. The wall boundary layers associated with blast waves are special cases of the class of problems treated. It was assumed that the fluid is a perfect gas, that viscosity is proportional to temperature, and that the wall-surface temperature is small relative to the temperature in the free stream. The resulting boundary-layer equations were simplified by expanding the dependent variables in powers of a nondimensional distance measured from the shock. The zero-order flow corresponds at each instant to a two-dimensional boundary layer behind a shock wave moving with uniform velocity. Numerical solutions of the first-order equations were found for several cases of interest, and the results for wall shear and heat transfer are tabulated and discussed.

3591

Myer, H. G., "Radiation from Shock-Heated Air, Part I. Equilibrium Radiation," Rept. No. 6130-0001-NU-P01, Space Technology Labs., Inc., Los Angeles, Calif., 33 pp., 1961.
AD-269 741.

Presents a computational procedure giving equilibrium radiative heat transfer rates to the surface of a shock-engulfed vehicle. The local transfer rates are obtained in terms of the local temperature and density at the outer edge of the boundary layer and an effective thermal layer. The computed radiative transfer rates around a typical entry vehicle are presented. A computational procedure for the nonequilibrium radiation is presented in Part II.

3592

Nyborg, W. L., "Acoustic Streaming near a Boundary," J. Acoust. Soc. Am., 30, 329-339, 1958.

An approximate solution is developed for sonically-induced steady flow near a fluid-solid interface. The result is valid, subject to stated conditions, for the flow near any portion of surface in the vicinity of which the irrotational oscillatory velocity distribution U_α is known. The principal condition on the validity is that the acoustic boundary layer parameter $(\nu/\omega)^{1/2}$ (where ω is the angular frequency and ν is the kinematic viscosity coefficient for the fluid) should be small compared to the scale of U_α. Applications of the general result are made to special situations, one case of particular interest being that of a small source near a rigid plane. The conclusion is reached that small compressible bodies, and especially resonant gas bubbles, resting on boundaries are likely sites of pronounced microstreaming in a sound field.

3593

Pack, D. C., "The Reflection and Transmission of Shock Waves, I. The Reflection of a Detonation Wave at a Boundary," Phil. Mag., 2, 182-188, 1957.

It is shown that for a shock wave advancing through any physically real barotropic medium the nature of the reflected wave is uniquely determined by the relative shock impedance of the medium through which the incident wave passes and the medium upon which it falls. A simple criterion is found for determining the nature of the reflection of a detonation wave at the end of a block of explosive. Particular attention is paid to the examples of an explosive in contact with a gas, water or solid surface. Certain approximations, which may be useful when there is a reflected shock wave, are discussed.

3594

Pack, D. C., "The Reflection and Transmission of Shock Waves, II. The Effect of Shock Waves on an Elastic Target of Finite Thickness," Phil. Mag., 2, 189-195, 1957.

An examination is made of the variation with time of the pressure and velocity in an elastic target of finite thickness subject to the impact of a shock wave. The cycle of reflections and transmissions at the boundaries of the target is described in detail.

3595

Pierce, G. W., and A. Noyes, Jr., "Transmission of Sound over Reflecting Surfaces," J. Acoust. Soc. Am., 9, 193-204, 1937.

The paper presents an experimental and theoretical discussion of acoustic signalling between a sending station and a receiving station near a plane reflecting surface, and is applicable to foghorn and submarine signalling. The experiments were made with a small-scale apparatus employing supersonic waves of a frequency of 67.5 kcs. It is shown that at grazing incidence the direct and reflected waves cancel, or partially cancel, as predicted by theory. The cancellation for propagation in air near a water surface, or near another surface of high sound velocity and high density, is found to be restricted to angles very near to grazing incidence.

On the other hand, theory predicts cancellation for much larger departures from grazing incidence if the reflecting surface has high density but low velocity; experimental curves for transmission over beach sand and certain other substances resemble such theoretical results very closely. Acoustic mirages caused by temperature gradients were studied experimentally, and their effects are shown to be of striking importance in modifying the above results.

3596

Press, F., and J. Oliver, "Model Study of Air-Coupled Surface Waves," J. Acoust. Soc. Am., 27, 43-46, 1955.

Flexural waves generated in a thin plate by a spark source are used to investigate properties of air-coupled surface waves. Both ground shots and air shots are simulated in the model. Effects of source elevation, fetch of air pulse, and cancellation by destructive interference are studied.

3597

Press, F., and M. Ewing, "Theory of Air-Coupled Flexural Waves," J. Appl. Phys., 22, 892-899, 1951.

The theory of air-coupled flexural waves in a floating ice sheet is derived for the case of an impulsive point source situated either in the air or in the water. It is found that new branches are introduced to the dispersion curve of flexural waves as a result of coupling with compressional waves in the atmosphere. Experimental data are briefly reviewed.

3598

Rae, W. J., "Potential Flows in the Approximation of Viscous Acoustics" Cornell Univ. School of Aeron. Eng., Ithaca, N. Y., 107pp., 1960.
AD-236 743.

Steady, irrotational flows are studied in a linearized approximation, retaining the effects of dispersion and attenuation due to viscosity in the region outside the boundary layer. The differential equation for the velocity potential in this approximation is derived and discussed, and formal solutions for the flow around nonlifting, two-dimensional and axisymmetric bodies are found. Approximate evaluations of the formal solution reveal that throughout all of the subsonic, and most of the supersonic flow field, the inviscid solution is altered by a correction that is first-order in a viscosity parameter. In the supersonic cases, the familiar inviscid-wave pattern tends to be dispersed in the vicinity of the body, while at great distances from the body all disturbances decay. The rates of decay of pressure disturbances at these distances are found, and their relation to the inviscid, nonlinear treatment of the same problem is discussed.

3599

Rocard, Y., "Guided Sound Waves" (in French), Compt. Rend., 232, 485-487, 1951.

Discusses the propagation of sound in an indefinite cylinder of radius a constituted by a medium in which the velocity of sound is c_1, while outside the radius a is a medium in which the velocity of sound is c. It is shown that, provided $c_1 < c$, longitudinal waves are propagated along the oz axis inside the radius a without producing appreciable radial propagation in the medium c — the energy being mainly confined in the cylinder of radius a. This applies whether the axis of the cylinder is straight or curved.

3600

Roy, A. K., "Estimation of the Characteristic Velocity for the Propagation of the Disturbance Up-Stream in Shock Wave Boundary Layer Interaction Problems," Proc. Nat. Inst. Sci. India A, 26, 19, 1961.

In shock boundary-layer problems, considerations of the whole of the boundary layer is not important. On similarity considerations and utilizing existing experimental data, Roy calculated (1959) the thickness of the critical viscous sublayer (a fraction of the total boundary layer thickness), which is important for the propagation of the disturbance up-stream in such problems. In the present paper, following the method of Roy, the Mach number of the characteristic flow in the region of this viscous sublayer is estimated and found to lie between the limits 0.15 and 0.6 (in cases of flow with or without separation).

3601

Roy, A. K., "Estimation of the Critical Viscous Sublayer in Shock Wave Boundary Layer Interaction," Z. Angew. Math. Phys., 10, 82-89, 1960.

In a theory of the interaction between weak shock waves and boundary layers, Lighthill has pointed out that disturbances to the viscous forces (caused by the shock) are confined essentially to an inner sublayer. The author has estimated the thickness of this layer, and finds that it is of order 10% of the total boundary-layer thickness for a laminar layer and 1% for a turbulent layer. For turbulent layers, it is accordingly well within the laminar sublayer.

3602

Rudinger, G., "Effect of Boundary-Layer Growth in a Shock Tube on Shock Reflection from a Closed End," Phys. Fluids, 4, 1463-1473, 1961.

The pressure behind a shock wave propagating in a duct of constant area increases slightly with time as a result of the growing boundary layer. This rise is considerably magnified by the shock reflection from the closed end of the duct. Analysis of the local interaction of the reflected shock with the boundary layer yields information on the shock configuration, but the combined effects of the waves produced by the growing boundary layer along the entire shock tube must be considered to obtain the state of the gas behind the reflected shock.

The theory of the flow field behind the incident shock is modified to allow for effects, in addition to boundary-layer growth, that cause deviations from an ideal shock-tube flow. Experimental observations of the pressure ratios up to about 4.5 agree satisfactorily with the computed results, and estimates for stronger shock waves are presented.

3603

Rudnick, I., "The Propagation of an Acoustic Wave Along A Boundary," J. Acoust. Soc. Am., 19, 348-356, 1947.

The sound field of a point source near the boundary of two media cannot be obtained by an acoustic-ray approach. In fact, such an approach, which utilizes the reflection coefficient for plane waves, leads to completely contradictory results at grazing incidence. A more rigorous solution is obtained, the procedure followed being exactly similar to that initiated by Sommerfeld to derive the electromagnetic field of a vertical dipole situated near a conducting plane. The solution shows that when the boundary medium has a high real specific acoustic impedance, non-zero fields are obtained at all points along the boundary. For bounding media adequately described by simple porosity theory, the acoustic pressure at the boundary $\propto 1/(\text{distance})^2$ and $1/(\text{frequency})^2$, at reasonably large distances and low frequencies. There appear to be decreased phase velocities along the boundary. Some calculations of the sound pressure as a function of height above a Quietone surface show, amoung other things, the presence of a minimum occurring some distance above the boundary. At large distances from the source there are very large decreases in amplitude as the receiver height is increased in the region above this minimum.

3604

Rudnick, I., "Errata: The Propagation of an Acoustic Wave Along a Boundary," J. Acoust. Soc. Am., 20, 149, 1947.

Emends the article covered by entry 2603.

3605

Samuels, J. C., "On Propagation of Waves in Slightly Rough Ducts," J. Acoust. Soc. Am., 31, 319-325, 1959.

The problem of the propagation of harmonic signals in a slightly rough duct is investigated. The analysis is made tractable by the assumption that the heights of the roughness peaks are small compared to the average separation of the duct walls. Both acoustic and electromagnetic waves are treated. In the case of a duct with harmonic roughness, it is found that waves are not scattered upstream if the frequency of the transmitted signal exceeds certain critical values related to the natural modes of the wave guide and the wavelengths of the wall roughness. It is also found that the scattered signals are amplified whenever the frequency of the transmitted signal is equal to any of a series of critical frequencies determined by the natural modes of the guide and the spectrum of the wall roughness. Statistically rough walls are also treated, and specific results worked out for roughness functions having Dirac delta-function correlation or exponential correlation.

3606

Schoch, A., "Reflection, Refraction and Diffraction of Sound," Trans. by F. J. Berry, Ministry of Supply, Armament Research Establishment, 77 pp., 1953.
AD-116 801.

The present state of theory and experiment on the reflection, refraction, and diffraction of sound is very thoroughly presented in this book-length paper. After a brief introduction, the work begins with a comprehensive review of fundamentals including the dynamics of sound waves in homogeneous media, Huygens' Principle, boundary conditions, and uniqueness of solutions. The various situations involving reflection and refraction are then treated, including plane waves at a plane interface, free boundary layer waves along a plane interface, nonplanar waves at a plane interface, plates, and laminated media. Finally, diffraction is treated as phenomena resulting from the presence of curved boundaries. The diffracting properties of cylindrical, spherical, and more complex obstacle shapes are investigated. An extensive bibliography containing 144 references is included.

3607

Schvchenko, V. V., "Irregular Acoustic Waveguides," Soviet Phys. Acoust., English Transl., 7, 392-397, 1962.

Equivalent uniform-waveguide cross-section eigenfunctions are introduced in general form. They are then used in the method of cross sections to obtain the equations for irregular waveguides. An approximate solution is found for the problem of determining the field in a slightly irregular waveguide.

3608

Shreffler, R. G., and R. H. Christian, "Boundary Disturbances in High-Explosive Shock Tubes," J. Appl. Phys., 25, 324-331, 1954.

High-velocity disturbances are observed to propagate along the walls of a high-explosive-operated shock tube in advance of the plane shock. Experiments are presented that determine the dependence of the geometry, energy and velocity of the disturbance on such variables as the gas contained in the shock tube, the shock strength, and the roughness and composition of the supporting boundary. A model is constructed to explain the flow within the disturbance. Arguments are presented that show the disturbance to result from radiation originating in the luminous plane shock.

3609

Sichel, M., "A Study of the Leading Edge of a Shock Induced Boundary Layer," Rept. No. 540, James Forrestal Research Center, Princeton, N. J., 115 pp., 1961.
AD-260 911.

Presents an investigation of the flow at the leading edge of the boundary layer generated by a weak shock wave moving past a flat plate. It is postulated that the leading edge flow can be divided into a shear layer near the wall dominated by the transverse viscous shear and into a free stream or shock region, outside the shear layer, that is dominated by the longitudinal viscous stress. By expanding flow parameters in the shock-strength parameter and by stretching coordinates, simplified equations for the shear layer and the shock region were derived from the Navier-Stokes or continuum equations. Such a shock-strength expansion was also applied to the normal shock in the free stream and the results were found to agree excellently with exact analytical solutions of the Navier-Stokes equations. The vertical velocity generated within the shear layer is of sufficient magnitude to affect the shock region flow; therefore, the two regions interact. Outside the shear layer there is a region of non-Hugoniot flow where the shock is not normal or oblique but where the shock structure is two-dimensional. An approximate solution of the leading edge interaction was obtained by replacing the shock region with an oblique shock, which is approximately matched to the shear layer.

3610

Stewartson, K., "On the Interaction Between Shock Waves and Boundary Layers," Proc. Cambridge Phil. Soc., 47, 545-553, 1951.

The effect on the boundary-layer equations of a shock wave of strength ϵ has been investigated, and it is shown that separation occurs when $\epsilon = 0(R^{-2/5})$ (R = Reynolds number of boundary layer). The boundary-layer assumptions are then investigated and shown to be consistent. It is inferred that separation will occur if a shock wave meets a boundary and the above condition is satisfied.

3611

Tartakovskii, B. D., "Sound Transmission Layers" (in Russian), Dokl. Akad. Nauk SSSR, 75, 29-32, 1950.

The article works out algebraically and diagrammatically a solution to the problem of rendering the boundaries of different media fully conductive. An examination of the method of propagation of plane waves through similar layers leads to a study of the conditions under which sound energy is transmitted without loss through the boundary separating two different media, between which the sound transmission layers are situated. The formulae advanced are held to prove that, in principle, any medium can be rendered fully conductive by a combination of layers consisting of materials whose applicability can be tested by means of a graph in which coordinates are placed on a logarithmic scale. Graphs are also given illustrating energy-conductivity calculation for a given case and the dependence of conductivity upon angle of incidence. Ernst's conclusions as to the behavior of certain layers independently of the law of distribution of their wave-resistances are incidentally judged to be erroneous.

3612

Tolstoy, I., "Resonant Frequencies and High Modes in Layered Wave Guides," J. Acoust. Soc. Am., 28, 1182-1192, 1956.

When a boundary between two sections of a multi-layered waveguide becomes a pressure of particle-velocity node, the sections can be treated independently and the intersections of their characteristic curves define two infinite lattices of points that give the quasi-resonant and antiresonant propagation frequencies of the complete waveguide. The antiresonant lattice points also give the group velocity maxima corresponding to the frequencies for which the modes of the waveguide are strongly coupled to the characteristic modes of an individual layer or section of the guide. The resonant lattice points give the group velocity minima corresponding to a somewhat weaker coupling with the complementary section. In addition to clarifying the physics of guided waves in layered media, these lattices accelerate the numerical procedures and lead, in the case of high modes of propagation, to useful approximations and/ or simplifications of the exact solutions.

3613

Trilling, L., "On Thermally Induced Sound Fields," J. Acoust. Soc. Am., 27, 425-431, 1955.

The sound fields induced in a real gas by variations in boundary temperature are examined to illustrate how the pressure, temperature, and vorticity modes of motion interact. The pressure mode describes the irrotational propagation of longitudinal disturbances; the temperature mode, convective heat diffusion; and the vorticity mode, the diffusion of vorticity introduced at boundaries by the no-slip condition (boundary layer).

The plane sound wave from a rise in instantaneous wall temperature is a sharp pulse, traveling at sonic speed and proportional to the inverse fourth root of the acoustic Reynolds number based on distanced travelled; its thickness grows as the square root of elapsed time. Along a wall, it generates a boundary layer whose friction coefficient is proportional to the inverse square root of the acoustic Reynolds number based on distance from the front. The resulting effective wall slope induces a secondary circular pressure pulse generated by the foot of the plane wave; because this source moves at sonic speed, a pressure singularity appears that comes from the contributions piled up since the beginning of the motion.

3614

Urusovskii, I. A., "Scattering of Sound on a Non-Uniform Sinusoidal Surface with Normal Acoustic Admittance," Soviet Phys. Acoust., English Transl., 5, 362-369, 1960.

Approximately solves the problem of scattering of sound by an inclined sinusoidal surface with normal acoustic admittance. The exact integral equation that describes the field on the surface was solved approximately; the field above the surface was found from the field on the surface using Green's formula. The region of applicability of the solution obtained in this way does not depend on the properties of the incident acoustic field of a given frequency; for example, the solution obtained for an incident plane wave is valid for all angles of incidence.

3615

Vajnshtejn, L. A., "The Theory of Sound Waves in Open Tubes," in Translations by J. Shmoys, "Propagation in Semi-Infinite Waveguides," Rept. EM-63, Inst. of Math. Sci., New York Univ., Chap. IV, 29 pp., 1954.
AD-36 349(d).

A rigorous solution is given for the problem of radiation, from the open end of a pipe, of a symmetric sound wave propagated in the tube, toward the end. The reflection coefficients of various modes from the open end are calculated as well as the conversion coefficients from one mode to another. Graphs of absolute values, and phases of these coefficients, and also of the end correction for the dominant piston-like mode, are presented. The radiation characteristics of the open-ended tube are investigated. The theory is generalized to asymmetric modes. Excitation of waves in open tubes is considered. The resonance curve of a cylindrical resonator of finite length, open at one end, is calculated, and the theoretical results are compared with experimental data.

3616

Weston, D. E., "The Theory of Propagation of Plane Sound Waves in Tubes," Proc. Phys. Soc. (London), B, 66, 695-709, 1953.

The propagation of plane sound waves in gases in tubes can be divided into three main types, depending on the radius and frequency involved. These types are described as narrow-tube, wide-tube, and very-wide-tube propagation. The phase velocity, attenuation, and cross-section profile of particle velocity, etc., are investigated theoretically, and their interrelation pointed out.

The factors affecting the validity of Kirchhoff's formulae are considered, and the theory is applied to some recent work.

3617

Weston, D. E., and I. D. Campbell, "Experiments on the Propagation of Plane Sound Waves in Tubes, I., The Adiabatic Region," D. E. Weston; "II., The Transition Region," D. E. Weston and I. D. Campbell, Proc. Phys. Soc. (London) B, 66, 769-774, 1953.

I. An experimental investigation using an acoustic interferometer with a magnetostriction source is described. Results on attenuation and velocity in tubes of radius 0.013 cm and upwards, from 10 to 20 kcs, and for a variety of tube materials and gases are given. These confirm a modified Kirchhoff's formulae. II. The velocity and attenuation of plane sound waves in tubes of radius 0.02 cm have been measured in the transition region between adiabatic and isothermal flow.

3618

Zakkay, V., and E. Krause, "Boundary Conditions at the Outer Edge of the Boundary Layer on Blunted Conical Bodies," Rept. No. ARL 62-386, Polytechnic Inst. of Brooklyn, N. Y., 21 pp., 1962. AD-278 017.

Presents a method for predicting the variation of Mach number that prevails at the outer edge of the boundary layer of a blunt conical body. The method consists of solving the mass-flow equation as given by the similar solutions of Lees. The mass-flow equation is integrated, and an expression for the distance at which the local Mach number reaches the conical value is given. In the analysis, the static pressure is assumed to be constant over the entire portion of the cone, and the properties at the outer edge of the boundary layer are calculated from the final solution. Finally, the analysis is compared with some of the experimental results available in the literature. It is indicated that good agreement was obtained by this comparison.

Wave Propagation, Boundary Effects

See Also—7, 12, 17, 20, 32, 36, 41, 43, 372, 488, 541, 737, 750, 765, 768, 769, 770, 775, 837, 852, 903, 908, 956, 992, 997, 999, 1018, 1019, 1027, 1032, 1086, 1191, 1195, 1304, 1547, 1552, 1754, 1757, 1794, 1890, 1896, 1901, 1910, 1937, 1949, 1982, 1983, 1984, 1985, 1988, 1990, 1991, 1993, 1994, 1995, 2002, 2004, 2008, 2011, 2012, 2023, 2025, 2038, 2058, 2064, 2187, 2206, 2220, 2222, 2401, 2402, 2454, 2484, 2557, 2586, 2819, 2826, 2827, 2845, 2855, 2856, 2883, 2885, 2886, 2890, 2896, 2899, 2900, 2911, 3008, 3101, 3216, 3474, 3519, 3622, 3638, 3639, 3663, 3688, 3699, 3749, 3752, 3762, 3769, 3775, 3779, 3793, 3795, 3820, 3821, 3825, 3832, 3833, 3854, 3861, 3903, 3905, 3908, 3957, 3988, 4022, 4077, 4088, 4101, 4115, 4210, 4313, 4328, 4331

WAVE PROPAGATION, FINITE AMPLITUDE

3619

Augenstein, B. W., "Passage of Finite Amplitude Pressure Waves Through Temperature Discontinuities," Phys. Rev., 75, 521-522, 1949.

A theoretical discussion whose objects are to derive the transmission properties of isentropic pressure waves of large amplitude through temperature discontinuities between two gaseous masses; and to linearize the results for very small amplitude waves, and thereby show that the usual equations of acoustic theory result. The results of the investigation have been extended, using graphical methods, to the cases of ratio of specific heats γ different on the two sides of the interface, and shock waves (nonisentropic state changes through the pressure waves) incident on the interface both with constant γ and varying γ. Within prescribed limits the isentropic wave theory gives results differing by only a few percent from the values obtained by the use of exact shock-wave theory.

3620

Blackstock, D. T., "Finite-Amplitude Motion of a Piston in a Shallow, Fluid-Filled Cavity," J. Acoust. Soc. Am., 34, 796-802, 1962.

Presents a theoretical treatment a piston's motion of in a fluid-filled cavity. Emphasis is on the steady-state response of the piston to a sinusoidal driving force. Effects of finite amplitude and finite length of the cavity are taken into account; frictional damping is also considered. It is found that if the piston is driven hard enough in the neighborhood of resonance, the motion is markedly influenced by the nonlinearity of the equation of state (pressure-density relation) of the fluid. The fluid-filled cavity behaves as a nonlinear spring. The theoretical results show how measurements of the piston motion might be used to obtain data on the coefficients of the most important nonlinear terms in the equation of state of the fluid. Push-pull as well as single-sided piston-cavity systems are analyzed.

3621

Blackstock, D. T., "Propagation of Plane Sound Waves of Finite Amplitude in Nondissipative Fluids," J. Acoust. Soc. Am., 34, 9-30, 1962.

An extensive theoretical treatment is presented of the problem of plane progressive sound waves (simple waves) produced by continuous, high-amplitude motion of a piston in a lossless, semi-infinite tube. The fluid in the tube is assumed to be nondissipative; liquids as well as perfect gases are considered. The analysis is given in both Eulerian and Lagrangian, coordinated. Earnshaw's exact solution in parametric form is first given for arbitrary piston motion. Special attention is then given to the case of sinusoidal piston motion. Approximate but explicit power- and Fourier-series solutions for this case are derived from the exact solution. A low-amplitude nonlinear theory of simple waves is proposed. In this theory nonlinear effects are considered in a simple yet general manner.

A brief analysis of shock formation is also given. It is shown that the generally accepted formula for the distance at which the shock forms when the piston motion is sinusoidal is rigorously correct only under very special circumstances.

3622

Blackstock, D. T., "Propagation and Reflection of Plane Sound Waves of Finite Amplitude in Gases," Tech. Memo No. 43, Acoust. Res. Lab., Harvard Univ., Cambridge, Mass., 222 pp., 1960. AD-242 729.

A review is given of propagation of waves of arbitrary amplitude in nondissipative fluids, propagation of infinitesimal waves in dissipative fluids, and propagation of waves of arbitrary amplitude in dissipative fluids. In addition, the following subjects are considered: the equations of hydrodynamics for plane, one-dimensional flow; the propagation of simple waves in a nondissipative perfect gas; propagation in a viscous, thermally conducting perfect gas; the reflection and transmission of lossless plane waves, including shock formation in the presence of a rigid wall; and suggested avenues for further research.

3623

Burnett, W., and E. Ackerman, "Propagation Distortion of Bands of Large Amplitude Acoustic Noise, I. Theoretical Analysis of the Plane Wave Case," Rept. on The Generation, Propagation, Action, and Control of Acoustic Energy, Penn. State Univ., University Park, 49 pp., 1960.
AD-243 671.

The problem of the propagation of finite amplitude sound waves from a noise source is considered. After a review of the history of the problem, second-order techniques are developed and applied to the problem of noise less than an octave wide at the generator. Five cases of qualitatively different propagation behavior can be distinguished, depending on the ranges of frequencies and sound-pressure levels. For three of the five cases the second-order techniques developed are adequate. Unsuccessful attempts at more general solutions are briefly summarized in the appendix, along with suggestions for extending the analyses and increasing the validity of the final solutions.

3624

Cook, B. D., "New Procedure for Computing Finite-Amplitude Distortion," J. Acoust. Soc. Am., 34, 941-946, 1962.

Describes an iterative process for calculation of the distortion of plane finite-amplitude sound waves in a dissipative, nondispersive medium. The method of calculation is a discrete-interval process of considering the distortion of the wave propagating through a small distance, correcting for absorption within this distance, and then considering this new wave, etc. It is necessary to use a high-speed electronic computer to obtain the spectral composition of the wave. The iterative process allows calculations beyond the discontinuity distance. The spatial composition is used for the calculation of absorption coefficients describing the loss of energy from the total wave and from the fundamental component. These absorption coefficients, which are functions of distance from the source, are found to be remarkably different.

3625

Embleton, T. F. W., "The Propagation and Reflection of Sound Pulses of Finite Amplitude," Proc. Phys. Soc. (London), B, 69, 382-395, 1956.

Discusses experimental results covering many aspects of the propagation and reflection of finite-amplitude sound pulses and weak shock fronts. These are compared with theory and show amongst other features (a) that an N-shaped wave form tends to shorten on reflection and (b) that a shock front disappears on reflection at an open-ended tube.

3626

Fay, R. D., "Corrected Analysis of Plane Finite Waves," J. Acoust. Soc. Am., 34, 1269-1270, 1962.

When the errors in a previous paper are corrected and the method of attack is somewhat modified, a remarkably straightforward analysis yields an expression for the attenuation of repeated sawtooth waves. The expression agrees substantially with those obtained by other methods.

3627

Fay, R. D., "Oppositely Directed Plane Finite Waves," J. Acoust. Soc. Am., 29, 1200-1203, 1957.

The analysis is carried out in terms of particle velocities expressed as Mach numbers. In general, the pertinent quantities are expressed in relation to the infinitesimal values by a power series of these Mach numbers in which two powers are retained. To this order of approximation, the particle velocity is the vector sum of the particle velocities of the isolated component waves, and the speed of propagation in each direction has an increment proportional to the vector difference of these particle velocities. The general behavior of the sound field may be predicted from these two relations.

3628

Fay, R. D., "Plane Sound Waves of Finite Amplitude," J. Acoust. Soc. Am., 3, 222-224, 1931.

The principal object of the analysis is to find the change in type of periodic plane sound waves of finite amplitude propagated in free air. A solution to the exact equation of motion is obtained as a Fourier series. Owing to the nonlinear relation between pressure and specific volume there is a gradual transfer of energy from components of lower frequency to those of higher frequency. Since higher frequencies are attenuated more than lower by viscosity effects, there is always a stable wave form, so that the decrease in relative magnitude of any component due to viscosity is compensated by the relative increase due to nonlinearity. The stability varies with intensity. There is no permanent waveform, but the stable wave will change its form more gradually than any other of the same intensity and wavelength. The change of type of any wave is towards this stable form. There is a marked departure from the sinusoidal in the stable type even for waves of very moderate amplitude.

3629

Fay, R. D., "Spherical Waves of Finite Amplitude," J. Acoust. Soc. Am., 31, 1377, 1379, 1959.

Presents a method for the analysis of spherical waves of finite amplitude. An example of the application of the method is given for the case of repeated shock waves.

3630

Fay, R. D., "Successful Method of Attack on Plane Progressive Finite Waves," J. Acoust. Soc. Am., 28, 910-914, 1956.

The characteristic feature of the method is that at any point in the sound field the conservation criteria are expressed in terms of the instantaneous values of the speed of propagation, the particle velocity, the excess pressure, and excess density. These criteria, together with the adiabatic assumption, determine explicit relations between any two of these quantities. Excess pressure and excess densities are here defined as departures from the equilibrium values that exist at the instant when the particle velocity is zero. For waves of finite amplitude these equilibrium values, as well as the speed of propagation, are found to depend on the intensity. The increment in the speed of propagation does not agree with that obtained by classical methods of analysis. The discrepancy is found to be due to the omission in the classical forms of the continuity criterion of a term that specifies the effect of the rate of change in the speed of propagation.

3631

Fyfe, I. M., and K. Klotter, "Nonlinear Problems of One-Dimensional Wave Propagation in Gases, Treated by the Ritz Method," WADC Tech. Rept. No. 58-293, Stanford Univ., Calif., 66 pp., 1958.
AD-155 880.

The feasibility of applying the Ritz method to nonlinear acoustic wave propagation problems was investigated. The problem of a plane wave propagation in a gas column within the length of a finite tube closed at one end with a piston oscillating at the other is treated as an example (using the Eulerian as opposed to the Lagrangian viewpoint). A series solution is assumed for the velocity potential and the unknown coefficients are found by means of the Ritz method. The results from a four-term series are compared with experimental evidence. Symmetrical, spherical wave propagation falls into the category of problems involving only one space coordinate. The functional is found in a form suitable for applying the Ritz method to serve such problems. Consideration is also given to the Lagrangian viewpoint, and the functional is found for plane wave propagation, by using Hamilton's principle.

3632

Ghiron, E. F., "Anomalies in Acoustic Wave Propagation of Large Amplitude," Alta Frequenza, 4, 530-581, 1935.

This paper considers, from initial conditions, the propagation of plane acoustic waves, without assuming the ordinary hypothesis that the amplitude of the wave is negligible compared with the length. It shows how the velocity of propagation, until interrupted by discontinuities, remains always that given by the ordinary theory. The existence is stressed of a functional relationship between the velocity and the dilatation in a layer of the medium in which the wave is propagated. It is deduced that a sinusoidal wave is necessarily deformed during propagation, the deformation continuing to grow until a point is reached where the wave becomes discontinuous. This has an analogy in submarine waves at great depth. By calculating the form assumed by a sinusoidal sound wave as distance from source increases, a measure of the distortion introduced as propagation continues is obtained, and, probably in a quite new form, an expression is obtained for the pressure of acoustic radiation in a system of plane progressive waves of similar form.

3633

Gol'dberg, Z. A., "Propagation of Plane Acoustic Waves of Finite Amplitude in a Viscous Heat-Conducting Medium," Soviet Phys. Acoust., English Transl., 5, 117-119, 1959.

The problem is to examine, in Lagrange variables x and t, the acoustic field set up for $x > 0$ by the plane vibrating about $x = 0$ along the x axis. The initial and boundary conditions are displacement of particles of the medium $u(x, t) = 0$ for $t \leq 0$, and $u(0, t) = f(t) = a(1 - \cos \omega t)$ for $t > 0$. In the analysis, only waves flowing from the plane in the positive x direction are considered, i.e., no reflection.

3634

Gol'dberg, Z. A., "The Propagation of Plane Waves of Finite Amplitude," Soviet Phys. Acoust., English Transl., 3, 340-347, 1957.

Considers the propagation of the waves in a viscous, heat-conducting medium. Also studies the criterion indicating when an explosion can be taken as a plane wave, and an estimate is made of the distance from the source to the onset of plane wave conditions. An expression is derived for the absorption coefficient for the case where an explosion is impossible, and for the case where it is possible.

3635

Gol'dberg, Z. A., "Second Approximation Acoustic Equations and the Propagation of Plane Waves of Finite Amplitude," Soviet Phys. Acoust., English Transl., 346-350, 1956.

A solution has been given by Eckart (Phys. Rev., 73, 68-76, 1948) for the second-approximation acoustic equations. In an entirely theoretical paper the present author gives a more accurate solution. The case of the adiabatic propagation of the plane waves of finite amplitude is also examined.

3636

Hargrove, L. E., "Fourier Series for the Finite Amplitude Sound Waveform in a Dissipationless Medium," J. Acoust. Soc. Am., 32, 511-512, 1960.

A general expression is derived for the Fourier coefficients describing the change in waveform of an initially sinusoidal plane progressive acoustic wave of finite amplitude in a dissipationless medium. The first four Fourier coefficients are graphically presented for distances up to that of discontinuity.

3637

Helfer, H. L., "Waves of Finite Amplitude in an Infinite Homogeneous Medium," Astrophys. J., 119, 34-41, 1954.

Demonstrates the existence of a particular class of finite waves in an infinite homogeneous medium when the gravitational effect of the fluctuation is included. Stationary, progressive, and solitary waves are all permitted solutions. It is shown that the Jeans critical length, valid for determining the maximum wavelength of stable infinitesimal density fluctuations, adequately represents the effective lengths of these disturbances, provided that the development of the density fluctuations is always along the same adiabatic. Departure from this requirement, as, for example, in the occurrence of shock waves, may result in stable fluctuations of dimensions considerably in excess of the Jeans criterion.

3638

Isakovich, M. A., "Non-Linear Effects in some Acoustic Problems," Soviet Phys. Acoust., English Transl., 6, 321-325, 1961.

Discusses nonlinear effects (quadratic corrections) in the Sturm-Liouville problem and in the problem of propagation in a waveguide. Shows that in contrast to propagation in an infinite space, the secular terms are absent in the solutions, with the exception of degenerate cases. This absence of secular terms is due to dispersion.

3639

Kastner, L. J., "Propagation of Pressure Fluctuations of Large Amplitude in Air Columns," Phil. Mag., 32, 206-224, 1941.

A test of the accuracy of the Helmholtz-Kirchhoff equation for waves in which the average peak amplitude was about 5 in. of Hg above the mean pressure in the pipe. An oscillating piston in a cylinder supplied the pressure pulse to a tube in which the vibrations were built up. The results, using tubes of different diameter and length and different piston speeds, are discussed. The velocity of propagation of pressure waves in air produced in a pipe excited by a piston is independent of frequencies between 20 and 150 cps and appears to diminish at a greater rate with decrease of pipe diameter than for cases when the amplitude is very small. The waves are attenuated as they travel along the pipe and when they are reflected at the ends. The open-end and closed-end reflection coefficients are the more important of these, and their product does not vary greatly with changes of pipe diameter.

3640

Keller, J. B., "Finite Amplitude Sound Waves," J. Acoust. Soc. Am., 25, 212-216, 1953.

Exact solutions of the one-dimensional gas dynamic equations, representing periodic sound waves of finite amplitude, are obtained for a particular medium. The progressive wave from a vibrating piston and the standing wave in a closed tube are examined in detail. Limits on the amplitude of the sound wave are found in order to avoid shocks or cavitation.

3641

Kessler, H. C., Jr., "Equivalent Eulerian Boundary Conditions for Finite-Amplitude Piston Radiation," J. Acoust. Soc. Am., 34, 1958-1959, 1962.

A method is presented for replacing the Lagrangian boundary condition, which occurs in the analysis of finite-amplitude radiation from vibrating pistions, by an approximately equivalent condition that permits the analysis to be carried out in Eulerian form.

3642

Laird, D. T., E. Ackerman, et al., "Spherical Waves of Finite Amplitude," WADC Tech. Rept. No. 57-463, Penn. State Univ., University Park, 125 pp., 1957.
AD-130 949.

Large-amplitude pressure waves in air are distorted during propagation due to the nonlinear nature of the differential equations describing the motion of gases. The present report investigates the propagation, the distortion of wave shape and frequency spectrum, and the formation of shocks for spherical symmetrical waves generated by a pulsating sphere. As no exact solution is known, the boundary value problem is numerically integrated. For this purpose two perturbation methods are developed in this report. The first is a conventional type of perturbation; the second is a perturbation in the characteristics. Using these, one may solve the equations numerically for a pulsating sphere providing that the velocity amplitude at the sphere does not exceed 0.4 normal velocity of sound, and also that, at its smallest limit the radius is not decreased from equilibrium by more than a factor of two. The solution may be extended beyond the formation of iterated shock waves by this method. The results are presented for an illustrative number of radii, amplitudes, and frequencies, in dimensionless form.

3643

Lester, W., "On the Theory of the Propagation of Plane, Finite Amplitude Waves in a Dissipative Fluid," J. Acoust. Soc. Am., 33, 1196-1199, 1961.

The dissipationless theory for harmonic generation in an initially sinusoidal, plane, finite-amplitude wave is used as a basis for calculation of the harmonic components of such a wave in a fluid with dissipation. The assumption used is shown to lead approximately to the relationships of the Fox and Wallace theory. The result is given as a Fourier series, with graphs of the first few harmonic components for two specific cases. The series representation is valid for distances $X \leq L$, where L is the discontinuity distance for the dissipationless case.

3644

Mendousse, J. S., "Nonlinear Dissipative Distortion of Progressive Sound Waves at Moderate Amplitude," J. Acoust. Soc. Am., 25, 51-54, 1953.

The first part of this investigation deals with the case of a simple-harmonic wave that eventually becomes distorted into a relatively stable shape resembling that of a sawtooth wave with rounded-off corners. A simplified picture-theory is developed, in which the wave is idealized as consisting of a nondissipative linear portion of length λ_1, and a dissipative simple-harmonic portion of length λ_2. The amplitude A of the distorted wave and its rate of absorption α_A are computed from the dissipative wavelength $2\lambda_2$ and from the "build-up distance" $L = N\lambda$, at which stability of shape is achieved, both λ_2 and N being regarded as experimental data. Tests of the theory are made by using shadowgrams of waves generated in air by piezoelectric quartz at the frequency of 0.405 megacycle.

The second part of the paper presents an approximation treatment of the classical wave equation, in which either of two different transformations of variables lead to a quasi-linear differential equation of the type

$$\partial^2 z/\partial y^2 = \partial z/\partial x + \partial(z^2)/\partial y$$

In the first transformation, more suitable for periodic waves, x is used for the distance from the source and y for the time, while the reverse holds in the second transformation, which is more suitable for shock waves. An exact solution is given for the case of the simple-harmonic source already discussed in the first part.

3645

Starting with the equation of continuity, the equation of motion (including bulk and shear viscosity), and the equation of state in isentropic form, the usual acoustic equations are derived. The sound pressure is calculated when the medium is viscous, and is excited at one frequency and also for the case of excitation with two different frequencies. For small viscosity and small distances from the source, for small viscosity and large distances from the source, and for viscosity in original equations only of the second order of smallness, the expressions for sound pressure take on familiar forms. It is claimed that there is qualitative agreement between theoretical and experimental results.

3646

Naugol'nykh, K. A., "Propagation of Spherical Sound Waves of Finite Amplitude in a Viscous Heat-Conducting Medium," Soviet Phys. Acoust., English Transl., 5, 79-84, 1959.

The form of a finite-amplitude wave alters as it is propagated because non-linear effects increase the steepness of the wave profile. If the medium is viscous and heat-conducting, these two properties tend to smooth out the profile and to decrease the velocity and temperature gradients. The effect of viscosity and heat conduction is, therefore, the opposite of the nonlinearity of the medium. The form of a finite amplitude wave in a viscous and heat-conducting medium will be determined by the ratio of nonlinear and dissipative (viscosity and heat conduction) effects. The author discusses propagation of spherical waves of finite amplitude produced by a harmonically pulsating sphere, whose radius is large compared with the emitted wavelength. The problem is dealt with using the Krylov-Bogolyubov method. Conditions when nonlinear effects become important are found.

3647

Oda, F., and E. Ackerman, "Propagation Distortion of Bands of Large-Amplitude Acoustic Noise, II. An Experimental Investigation of Certain Plane Wave Cases," Penn. State Univ., University Park, 25 pp., 1960.
AD-243 944.

The equipment requirements for experimental studies of finite-amplitude distortion of noise bands is compared with similar requirements for pure tone studies. Based on this comparison, the equipment was assembled for noise-band studies, including a specially constructed ionophone (corona-type loudspeaker). Frequencies used at the ionophone were in the 15- to 50-kc range. The overall sound pressure levels were varied from 110 to 135 db re 0.0002 bars. It was possible to verify theoretical predictions for two of the regions described in a previous report.

3648

Otterman, J., "Effect of Finite-Amplitude Propagation in the Rocket-Grenade Experiment for Upper-Atmosphere Temperature and Winds," Rept. No. 2387-34-T, Eng. Res. Inst., Univ. of Mich., 15 pp., 1958.
AD-162 059.

This report presents an estimate of the effect of the finite-amplitude propagation on the travel times of pressure waves from explosions to the ground, and a method for taking this effect into account in the data reduction of the rocket-grenade experiment for upper-atmospheric temperature and winds.

3649

Otterman, J., "Finite-Amplitude Propagation Effect on Shock-Wave Travel Times from Explosions at High Altitudes," J. Acoust. Soc. Am., 31, 470-474, 1959.

In this paper, a method is described for calculating the effect of the finite-amplitude propagation on the travel times of pressure waves from explosions at high altitudes to the ground. Numerical results are presented for explosions of 2-lb and 4-lb H. E. charges at altitudes ranging from 15 to 95 km. Vertical propagation is assumed in the calculations. This work has been carried out in order to improve the systematic accuracy of the rocket-grenade experiment for upper-atmospheric temperature and winds. The significance of the finite-amplitude propagation in this experiment is discussed.

3650

Penney, W. G., and H. H. Pike, "Shock Waves and the Propagation of Finite Pulses in Fluids," Repts Progr. Phys., 13, 46-82, 1950.

This paper is a review of theoretical work, much of it unpublished and contained in several Ministry of Home Security reports. Shockwave relationships are considered, and the refraction, reflection, and diffraction of plane shock waves are discussed.

3651

Polyakova, A. L., "A Plane Sound Wave of Finite Amplitude in a Moving Medium," Soviet Phys. Doklady, English Transl., 6, 344-345, 1961.

Riemann solutions describing the propagation of plane sound waves of finite amplitude (shock waves) in a moving medium are summarized and discussed for three cases of relative motion involving medium, source, and observer.

3652

Polyakova, A. L., "Propagation of Finite-Amplitude (Sound) Waves in Relaxing Media," Soviet Phys. Acoust., English Transl., 6, 356-359, 1961.

The propagation is considered in the second approximation, and it is shown that if $\rho_1/\rho_0 < 2\Delta c/c_0$, that is, if the amplitude is less than a value characteristic of dispersion and relaxation absorption, then the behavior of the second harmonic will be determined primarily by absorption. In this case, the effects due to phase shifts (as the result of dispersion) appear only at frequencies near $\omega\tau = 1/\sqrt{2}$, when the influence of dispersion reaches a maximum; the influence of absorption, a minimum.

3653

Polyakova, A. L., S. I. Soluyan, and R. V. Khokhlov, "Propagation of Finite Disturbances in a Relaxing Medium," Soviet Phys. Acoust., English Transl., 8, 78-82, 1962.

The authors deduce some simplified aerodynamical equations applicable to relaxing media for small Mach numbers and moderate dissipation in the medium. The approximate equations are then used to investigate the structure of a steady-state flow front. This is found to be the same as the structure of a shock-wave front in a medium with internal degrees of freedom, a problem which has been solved by alternate methods.

3654

Powell, A., "Distortion of Finite Amplitude Sound Wave," J. Acoust. Soc. Am., 32, 886, 1960.

A simple, approximate method yielding results of good accuracy is given for finding the time-dependent Fourier components of an initially sinusoidal sound wave of finite amplitude.

3655

Quade, W., "Theory of Plane Gas Waves of Finite Amplitude" (in German), Z. Angew. Math. Mech., 25/27, 215-232, 1947.

Theory is simplified by taking as dependent variable the longitudinal displacement, as this satisfies a Monge-Ampere differential equation, the integral of which can be given in a closed form by the method of characteristics without any integration. This applies to both isothermal and adiabatic changes of state. The Riemann-Hugoniot phenomenon finds its geometrical expression in the appearance of a return edge within the integral surface of displacement.

3656

Reed, S. G., Jr., "Note on Finite Amplitude Propagation Effects on Shock Wave Travel Times from Explosions at High Altitude," J. Acoust. Soc. Am., 31, 1265, 1959.

Considers the consequences of taking into account the energy loss, in addition to lengthening the over-pressure phase, of a weak shock wave traveling vertically downward in an exponentially stratified atmosphere.

3657

Riabouchinsky, D., "On a Paradox Noted by Mr. Garrett Birkhoff" (in French), Compt. Rend., 231, 1269-1271, 1950.

G. Birkhoff (Hydrodynamics, Princeton, 1950) has pointed out that two characteristic equations are used in the theory of propagation of sound waves of finite amplitude through a compressible fluid; in one case the pressure α (density)$^{-1}$ and in the other α (density)^2. This apparent inconsistency is explicable, in the opinion of the author, by the fact that the former equation represents only an approximation to the true flow of a fluid, in which the flow is treated as almost isentropic. This approximation treatment breaks down when energy is dissipated at some point in the flow field; e.g., in a shock wave. A study of the difference between the approx. solution and the true flow then serves to locate and define the energy dissipation.

3658

Rocard, Y., "Propagation of Sound Waves of Finite Amplitude," Compt. Rend., 196, 161-164, 1933.

Considers the necessity of taking into account the finite amplitude of sound waves under certain conditions. The equation for the propagation of finite-amplitude waves passing along an exponential horn is soluble.

3659

Romanenko, E. V., "Experimental Investigation of the Propagation of Finite-Amplitude Spherical Waves," Soviet Phys.-Acoust. English Transl., 5, 101-105, 1959.

Gives the designs of the radiator and the receiver built by the author, and some results of an investigation of the propagation of waves with pulsed emission at f = 1.15 mcs and pressure amplitude at the radiator's surface up to 26 atm. The theoretical and the experimental results agree satisfactorily.

For determining the frequency response of receivers, over a wide range of frequencies, the author presents a method based on the change of shape of a finite-amplitude wave during propagation.

3660

Rudnick, I., "On the Attenuation of High Amplitude Waves of Stable Saw-Tooth Form Propagated in Horns," J. Acoust. Soc. Am., 30, 339-342, 1958.

The attenuation is studied theoretically. The shock associated with each wave is assumed to be weak. An expression for the power loss for a generalized horn is obtained. Two quantities, the limiting particle velocity amplitude and the limiting power which is transmitted per unit throat area, occur in the solution. For long, gently tapering horns these are the limits toward which the particle velocity and power tend as the input to the throat is increased. Uniform-bore tubes, and exponential and conical horns, are discussed as particular examples of the general case.

3661

Rudnick, I., "On the Attenuation of a Repeated Sawtooth Shock Wave," J. Acoust. Soc. Am., 25, 1012-1013, 1953.

A formula which describes the space rate of change of amplitude of a repeated finite amplitude sawtooth wave is derived by applying the Rankine-Hugoniot shock relations. Experimental evidence agrees on the form of the amplitude change but gives lower rates of change than indicated by the formula.

3662

Rudnick, I., "Theory of the Attenuation of Very High Amplitude Sound Waves," Tech. Rept. 1, Soundrive Engine Co., Los Angeles, Calif., 21 pp., 1952.
AD-21 268.

The propagation of continuous plane progressive sound waves with pressure variations of the order of one-tenth the average pressure is discussed. Shocks are shown to develop at the leading front of each wave after several wavelengths of propagation regardless of the initial wave form. The attenuation of the repeated shocks was derived from shock wave theory with the assumption that the resulting stable wave form is sawtooth in character. In writing $p_2/p_1 = 1 + \delta$, where $p_1 - p_2$ is the pressure discontinuity at the shock, it is shown that

$$\frac{1}{\delta} - \frac{1}{\delta_0} = \frac{\gamma + 1}{2\gamma} \cdot \frac{X - X_0}{\lambda}$$

where δ_0 is the value of δ at the distance X_0, γ is the ratio of specific heats, and λ is the wavelength of the sound. The result was compatible with previously published studies of the attenuation of single N-shaped waves. Fay's solution (J. Acoust. Soc. Am., 2, 222, 1931) of the hydrodynamic equations, including the effects of viscosity, which shows the stable waveform to be a sawtooth, may be extended to yield the derived attenuation rate.

3663

Saenger, R., and G. Hudson, "Periodic Shock Waves in Resonating Gas Columns," J. Acoust. Soc. Am., 32, 8, 961-970, 1960.

When an oscillating piston forces the enclosed gas in a Kundt tube to vibrate with a finite amplitude near an acoustic resonance frequency of the gas column, shock waves are generated that travel periodically back and forth in the tube. The gas heats, and its mean pressure rises. In this paper, a theory of the steady-state motion of the gas in its fundamental mode has been devised, which includes the dissipative effects of wall friction and heat conduction to the tube walls. The dependence of shock strength, mean temperature, and mean pressure on piston amplitude, tube length, gas viscosity, and heat conductivity predicted by the theory are in good qualitative agreement with the small number of experimental data available at present.

3664

Schlemm, H., "Schlieren Optical Investigation on Large-Amplitude Airborne Sound Waves in Tubes," Acustica, 10, 237-245, 1961.

A plane sound wave of large amplitude and low frequency becomes deformed in its passage along a pipe until a weak shock front is set up. The pressure jumps in the shock wave can be photographed by a schlieren method and measured on an oscillograph. The schlieren pictures also enable investigation of the characteristics of the wave front at an obstacle.

3665

Senkevich, A. A., "The Effect of the Amplitude of an Acoustic Radiator on the Shape of the Radiated Wave," Soviet Phys. Acoust., 4, 103-104, 1958.

The author shows that, for waves of finite amplitude, apart from dispersion and distortions due to nonlinearity of the hydrodynamic equations and of the equation of state, it is necessary to take into account the effect of finiteness of the source's amplitude when the latter emits higher harmonics.

3666

Shao-sung, F., "Reflection of Finite Amplitude Waves," Soviet Phys. Acoust. English Transl., 6, 488-490, 1961.

The paper considers the problem of reflection of a finite amplitude wave in the case when it impinges on the wall at an angle of $\pi/4$. The results, obtained by the method of successive approximations correct to the second approximation inclusive, reveal the following: (1) appearance of a wave of twice the frequency, the amplitude of which increases with distance; this wave is reflected according to linear acoustic laws; (2) the appearance of a wave with a frequency 2ω, with no increase in amplitude and having circular symmetry.

3667

Soluyan, S. I., and R. V. Khokhlov, "Finite Amplitude Acoustic Waves in a Relaxing Medium," Soviet Phys. Acoust. English Transl., 8, 170-175, 1962.

From the approximate equations of relaxation, gas dynamics solutions are obtained describing the periodic process in two limiting cases, $\omega\tau \ll 1$ and $\omega\tau \gg 1$. With these solutions as a starting point, the formation and resorption of discontinuities in wave propagation from a source are investigated, and the spatial extent (scale) of these effects is determined. A qualitative picture is given for the propagation of finite-amplitude acoustic waves as $\omega\tau$ varies from zero to infinity; this description is based on the spectral approach to the nonlinear process.

The entire discussion is valid for small Mach numbers and moderate dissipation of energy in the medium, in accord with the nature of the approximation equations. No limitations are placed on the value of the Reynolds number.

3668

Taub, A. H., "Wave Propagation in Fluids," in E. U. Condon and H. Odishaw (eds.), "Handbook of Physics," McGraw-Hill, New York, 50-63, 1958.

This theoretical treatment of wave propagation in ideal fluids develops equations describing fluid wave motion with the help of the laws of conservation of mass, momentum, and energy. The cases of small disturbances (e.g., acoustic waves), interactions of waves of small amplitude, small disturbances in shallow water, plane waves of finite amplitude, formation and decay of shocks in one dimension, spherical waves of finite amplitude, and effects of viscosity and heat conduction are treated analytically.

3669

Thomas, T. Y., "The Growth and Decay of Sonic Discontinuities in Ideal Gases," Graduate Inst. for Appl. Math., Univ. of Indiana, Bloomington, 15 pp., 1958.
AD-215 633.

Discusses an ideal gas, devoid of viscosity and thermal conductivity, whose behavior is governed by the following system of nonlinear differential equations

$$\rho \frac{\partial v_i}{\partial t} + p_{ji} + \rho v_K v_{i,K} = 0, \quad \frac{\partial \rho}{\partial t} + \rho_{,K} v_K + \rho v_{K,K} = 0$$

$$\frac{\partial \rho}{\partial t} - \rho v_K \frac{\partial v_K}{\partial t} - \rho v_j v_K v_{i,K} + \gamma p v_{K,K} = 0$$

where t denotes the time, p the pressure, ρ the density, v_i the components of velocity of the gas and γ is the gas constant.

3670

Thuras, A. L., R. T. Jenkins, and H. T. O'Neil, "Extraneous Frequencies Generated in Air Carrying Intense Sound Waves," J. Acoust. Soc. Am., 6, 173-180, 1934-1935.

This paper deals with theoretical development and experimental results on the generation of sum and difference frequencies and harmonics in air carrying intense sound waves. Measurements were made at the exits of tubes and horns into which two high-intensity pure tones were introduced. The measurements are cited in support of the theory that the non-linearity of air as a compressible medium is a cause of both intermodulation and harmonic distortion at high levels of acoustic pressure.

3671

Unwin, J. J., "Production of Waves by Sudden Release of a Spherical Distribution of Compressed Air in the Atmosphere," Proc. Roy. Soc. (London), A, 178, 153-170, 1941.

An attempt is made to develop a method for dealing with solutions of problems connected with the production of waves by spherical concentrations of compressed air. Starting from the general equations for three-dimensional, spherically symmetrical flow in a homogeneous compressible medium having constant entropy everywhere, a process has been devised to apply step-by-step calculations over small intervals of time to investigate the general features of such a motion. A complete solution is worked out for a not-very-intense initial distribution of pressure, and various indirect checks indicate that the results are reasonably accurate.

As distinct from plane or spherical sound wave theory, it is found that a train of waves passes away from the center of disturbance, the amplitudes and wavelengths falling off from wave to wave. Furthermore, as distinct from finite-amplitude plane-wave theory, which shows that any wave must eventually become a shock wave, the waves obtained in the finite-amplitude spherical-wave case show no indication of becoming shock waves and, indeed, show towards the closing stages of the calculation a similarity to sound-wave propagation. The method is applicable to any spherically symmetrical motion up to such a time as the formation of a shock wave takes place, and then fails, owing to the assumption of constant entropy.

3672

Weibull, W., "Waves in Compressible Media," Acta Polytech., Phys. App. Math. (Kgl. Tek. Hogskol. Handl.), 37 pp., 1948.

The basic equations requiring conservation of mass, of momentum, and of energy; the equations of state for various media; and the formulae for normal shock waves are formulated. Two quantities, P = a + v and Q = a - v, where a is a function of the pressure only and v is the particle velocity, are introduced. Their general properties, including the boundary conditions, are deduced. The change of the waveform, the superposition, and the reflection of plane continuous waves of finite amplitude are investigated.

3673

Werner, W., "The Theory of Plane Waves of Finite Amplitude in Ideal Gases with Viscosity and Heat Conductivity," Ann. Phys., Germany, 7, 28-44, 1961.

The equations of motion lead to a single partial differential equation of the fifth order. Three types of particular solution are presented, and are applied in various physical contexts.

3674

Zarembo, L. K., "Nonlinear Distortion of Plane Waves in a Nondissipative Medium," Soviet Phys. Acoust., English Transl., 7, 149-153, 1961.

The author performs a Fourier analysis of the Riemann solution to the hydrodynamical equations for a plane periodic wave of arbitrary shape. The initial spectrum of the wave at x = 0 is assumed to be arbitrary, but with the reservation that there are no weak discontinuities in the wave. The wave spectrum for x > 0 is determined, correct to the first-order variables with respect to Mach number. The nonlinear interaction of the components of the initial spectrum in general leads to a change in the amplitude, frequency, and phase characteristics of the spectrum. The distance at which these changes become significant (interspersion length) is determined.

Special cases of spectra are discussed, showing that given identical periods and Mach numbers, the nonlinear distortion of nonmonochromatic waves is proportional to the width of the spectrum and is therefore greater than in the monochromatic case. Nonlinear interaction leads to spreading of the spectrum of finite width in both directions and, in some cases, to such mixing of the spectrum within the initial band that inside that band a tendency toward uniform distribution of the spectral density will be observed.

WAVE PROPAGATION, FINITE AMPLITUDE

Wave Propagation, Finite Amplitude
See Also——34, 131, 180, 199, 200, 296, 384, 429, 441, 560, 903, 983, 996, 997, 1151, 1152, 1215, 1232, 1368, 1890, 2128, 2139, 2183, 2260, 2363, 3008, 3808, 3822, 3824, 3875, 3961, 3962, 4133

WAVE PROPAGATION, INHOMOGENEOUS MEDIUM

3675

Altenburg, K., and S. Kastner, "Wave Propagation in Stratified Media for Normal Incidence, and Its Application to Circuit Theory, Electromagnetic Waves, Optics, Acoustics, Wave Mechanics, and to Mechanical and Electrical Quadripole Networks" (in German), Ann. Physik, 13, 1-43, 1953.

The topic phenomena, in the one-dimensional case, have the same two simultaneous first-order linear partial differential equations (or simultaneous difference equations) with constant coefficients, for which the general periodic solutions containing three complex constants, are obtained for a homogeneous (or discrete) medium. The transparency, reflection (and normal modes) for a set of finite layers (or discrete elements) are treated by a matrix method. Applications include anti-reflection films, transmission lines, concentric Lecher lines, tunnel effect, vibrations of infinite chain of coupled mass points, etc. Analogue computers for one type of system are discussed in terms of a system more amenable to experimentation. 67 refs.

3676

Austern, N., and J. K. Percus, "Propagation of Strong Blast in an Atmosphere of Varying Density," Rept. No. NYO-7970, Inst. of Math. Sci., Univ. of New York, 35 pp., 1957. AD-145 546.

The engulfed gas, in the propagation of strong shock through a γ-law gas when $\gamma \approx 1$, is confined to a thin shell near the shock surface. Based upon this picture, several models are construted for the analysis of strong shock propagation in inhomogeneous media. This sequence of models utilizes successively more detailed pictures of the wave behind the shock. In order to assess the validity of the models, they are compared with a numerical perturbation calculation of a blast in an atmosphere with linear variation of density. It is found that the distortion of the shock front and the distribution of mass per unit shock surface are predicted with considerable accuracy by the models, whereas the transverse mass flow is sensitive to the details of the model picture.

3677

Barkhatov, A. N., and I. Shmelev, "Experimental Investigations into the Waveguide Propagation of Sound in Laminar-Inhomogeneous Media," Soviet Phys. Acoust., EnglishTransl., 5, 414-418, 1960.

A procedure for the laboratory simulation of a waveguide in laminar-inhomogeneous media is presented. The results of an experimental investigation of the sound field in media in which the axis of the waveguide lies both on the surface of the inhomogeneous fluid and below it are cited. The fields in the region of the first geometric shadow and in the region of the first caustic are studied in detail. In the latter case a comparison is made between the experimental data and theory.

3678

Bergmann, P. G., "Propagation of Radiation in a Medium with Random Inhomogeneities," Phys. Rev., 70, 486-492, 1946.

By means of the methods of geometrical optics, approximate formulae are derived that correlate the statistical properties of the inhomogeneities of the transmitting medium with the fluctuations to be expected in the signal level of radioactive energy. Through a further simplification of the formulae obtained, it is possible to predict the dependence of signal fluctuation on range without detailed knowledge of the statistical parameters of the microstructure of the transmitting medium.

3679

Blokhintzev, D., "The Acoustics of an Inhomogeneous Moving Medium," Translated by R. T. Beyer, and D. Mintzer, Research Analysis Group, Brown Univ., Providence, R. I., 161 pp., 1952. AD-7675.

This is an English translation of a Russian book. It comprises comprehensive mathematical treatments of the following general topics: Chap. I, The acoustic equations for an inhomogeneous moving medium; Chap. II, Propagation of sound in the atmosphere and in water; Chap. III, Moving sound sources; Chap. IV, Sound excitation by flow. Ray acoustics, zones of silence, the effects of atmospheric turbulence, scattering, and shock wave propagation are thoroughly treated within these chapters.

3680

Blokhintzev, D., "The Propagation of Sound in an Inhomogeneous and Moving Medium, I," J. Acoust. Soc. Am., 18, 322-328, 1945.

The wave equations are established, and special cases are considered. A generalization of Kirchhoff's theorem (Huygens' principle) is given for a moving medium. The general equations of acoustics are considered in the approximation of geometrical acoustics, and, finally, the equations are generalized for the case of a medium containing a salt solution (sea water).

3681

Blokhintzev, D., "The Propagation of Sound in an Inhomogeneous and Moving Medium, II," J. Acoust. Soc. Am., 18, 329-334, 1945.

Several applications of the theory developed in Part I are set forth, e.g., the propagation of sound in a turbulent medium, and propagation through a shock wave.

3682

Bourret, R. C., "Stochastically Perturbed Fields, with Applications to Wave Propagation in Random Media," Nuovo Cimento, 26, 1-31, 1962.

The statistical properties of a classical field propagating through a random, inhomogeneous medium are analyzed by a method in which the random medium is described by the two-point (bilocal) correlation function of its random characteristic, e.g., refractive index, potential, convective velocity, etc. A scheme of diagrams is introduced to classify the types of interaction between the propagating field and the random background. Equations for the one- and two-point fields are given, and the wave dispersion and attenuation they imply are discussed. The analysis is very similar to the Tamm-Dancoff theory of one- and two-nucleon propagators with virtual meson dressing and interaction, with the correlation function here playing the role of the meson field. A number of results obtained through the use of the method are described and various projected applications are cited.

3683

Brekhovskikh, L. M., "Field of a Point Source of Radiation in a Stratified-Inhomogeneous Medium, I. Integral Form of the Solution" (in Russian), Izv. Aka. Nuak SSSR, Ser. Fiz., 13, 505-514, 1949.

A generalization of former work of the author (Doklady Akad. Nauk SSSR, 48, 422, 1945; Izvest. Akad. Nauk SSSR, Ser. Fiz., 10, 491, 1946; and with P. A. Ryazin, Bull. Acad. Sci. URSS, Phys. Ser., 10, 285-305, 1946) by including propagation of waves in a stratum bounded not only by sharp but also by washed-out surfaces of separation. As in the earlier work, the problem is treated for the electromagnetic in parallel with the acoustic case. The integral solution involving Bessel functions is transformed into another, involving Hankel functions; i.e., the expression of the plane wave, and is supplemented by yet another, representing the spherical wave. The author then uses Weyl's well-known method introducing the Hertz vector for obtaining phase relations and Fresnel reflection coefficients. The usefulness of the solution is shown by four cases and a supplement adds the existence and uniqueness theorems.

3684

Brekhovskikh, L. M., "Field of a Point Source of Radiation in a Stratified-Inhomogeneous Medium, II. Discussion of the Solution" (in Russian), Izv. Akad. Nauk SSSR, Ser. Fiz., 13, 515-533, 1949.

The author shows that the solution obtained in the first part is of practical use, and not only suitable for idealized problems. The integral representing spherical waves is resolved into plane waves and so-called inhomogeneous waves, the latter formally equivalent to plane waves, but with complex angles of incidence. The integral solution is evaluated by complex integration, the expressions obtained representing the "discrete" and "continuous" wave spectrum of the problem. A comprehensive analysis of the lateral waves by a method of the author published earlier (Izvest. Akad. Nauk SSSR, Ser. Fiz., 10, 491, 1946), and of the discrete spectrum, is followed by two practical examples, the second of which represents the case of a plane waveguide with walls of finite thickness.

3685

Brekhovskikh, L. M., "Field of a Point Source of Radiation in a Stratified-Inhomogeneous Medium, III. Average Laws of Attenuation" (in Russian), Izv. Akad. Nauk SSSR, Ser. Fiz., 13, 534-545, 1949.

The two kinds of waves emitted by the source (i.e., those of the "discrete" spectrum and the two lateral waves) are damped according to two different laws: the first of the form $\exp(-\beta_\ell r)/\gamma r$, and the second of the form $\exp(-\gamma_i r)/r^2$, where the two coefficients β_ℓ, γ_i are imaginary. The physical character of the damping process is also different in the two cases: in the first case, energy leaks through the boundary layers; in the second, the waves are absorbed in the boundary layers. At a great distance from the source the field is determined by the least damped wave of the discrete spectrum, or by the lateral waves; at short distances, however, other waves of the discrete spectrum become important, too, whereas the lateral waves have only a negligible influence. The field in the layer has a complicated interference structure owing to the superposition of the waves of the discrete spectrum. The formulas of Parts I and II permit averaging processes, which simplify the picture and make physical sense.

3686

Brekhovskikh, L. M., "A New Method of Solving the Problem of a Point Source of Radiation in a Stratified-Inhomogeneous Medium" (in Russian), Izv. Akad. Nauk SSSR, Ser. Fiz., 13, 409-420, 1949.

The theory is developed in parallel for the acoustical and electromagnetic cases, and does not use the wave equation, which in this case would lead to insurmountable difficulties, but works from Hertz's vector of an elementary dipole. The basic difficulty of the investigation consists in the fact that the medium and the wave possess different symmetries. This can be overcome, however, by resolving the spherical wave into plane waves and analyzing the behavior of the individual plane waves.

A close analogy between the problem considered and diffraction phenomena is observed, and the method followed in the latter case also proves its value here. There is no objection to resolving the original wave into wavelets having the same symmetry as the object on which they are diffracted, or, in the case considered here, as the stratified medium. The method yields the discrete spectrum, lateral waves, and other characteristics of this particular case.

3687

Brekhovskikh, L. M., "On a Case of Propagation of Sound in a Non-Homogeneous Medium" (in Russian), Dokl. Akad. Nauk SSSR, 87, 715-718, 1952.

(See also Wilson and Curran, Phil. Mag., 40, 631-636, 1949.)

Analyzes the acoustic field in a nonhomogeneous stratified medium in which the velocity of sound depends as follows on the coordinate z; $c = c_0$ for $0 \leq z \leq h$, and $c = c_0/[1 + 2a(z - h)]^{1/2}$ for $h \leq z \leq \infty$, remaining constant in planes at right angles to the z axis. The boundary $z = 0$ is assumed to be totally reflecting, and the source has a point form. The special case of $h = 0$ was dealt with by Pekeris (J. Acoust. Soc. Am., 18, 295-315, 1946) and Morse (J. Acoust. Soc. Am., 22, 857-860, 1950).

3688

Brekhovskikh, L. M., "Propagation of Sound in Inhomogeneous Media, Survey," Soviet Phys. Acoust., English Transl., 2, 247-255, 1956.

The indicated topic of this paper is a very broad one. It includes the propagation of sound in solid bodies, liquids and gases. The inhomogeneities may be caused by foreign inclusions, by temperature, velocity and concentration gradients, and by the granular structure of the substance. Such different phenomena as super-long-range propagation of sound in the atmosphere and in the ocean over distances of hundreds and thousands of kilometers, the scattering of sound by inhomogeneities of a turbulent nature in the atmosphere, the absorption of sound waves in blankets placed upon the walls of special sound-absorbent chambers that are used for acoustical measurements, the propagation of ultrasonic waves in polycrystals and in emulsions, etc.—all of this is included in the propagation of sound in inhomogeneous media. Also included in this subject is the scattering of sound waves at uneven surfaces and at surfaces whose impedance varies from point to point.

3689

Brekhovskikh, L. M., "Waves in Stratified Media" (in Russian), Izd. Akad. Nauk SSSR, Moscow, 502 pp., 1957.

This general but detailed text on wave motions of all types in stratified media treats radio and light (electromagnetic) waves in liquids and gases at great length; reflection and refraction of spherical waves and propagation in stratified media in detail; and sound waves in particular. Sound waves in liquids and gases are treated on a theoretical and empirical basis with numerous nomograms and schematic diagrams (pp. 325-359 and 445-458). The special case of acoustical propagation in a three-layer medium is treated on pp. 343-347 and group velocities on pp. 349-350. Focusing of sound waves is discussed on pages 455-458. Much of the work is based on the author's own research in underwater propagation (1954-56).

3690

Brekhovskikh, L. M., and I. D. Ivanov, "Concerning One Type of Attenuation of Waves Propagating in Inhomogeneously-Stratified Media," Soviet Phys. Acoust., English transl., 1, 23-31, 1957.

The propagation is considered of waves in a layer bounded on one side by a nonuniform medium in which the velocity of propagation falls off with distance from the layer boundary. It is shown that in these conditions propagation is associated with an additional weakening caused by energy being "siphoned off" from the waves into the nonuniform medium. The full theory of the effect is given and its magnitude determined.

3691

Chernov, L. A., "The Effect of Fluctuations of the Diffraction Pattern of a Focusing System," Soviet Phys. Acoust., English Transl., 3, 385-393, 1957.

General formulas are derived that determine the average distribution and the distribution of fluctuations in the diffraction pattern created by a focusing system when fluctuations are present in the incident wave. The general formulas are investigated for the two limiting cases of large and small fluctuations.

3692

Chernov, L. A., "Propagation of Sound in a Statistically Heterogeneous Medium" (in Russian), Zh. Ekesperim. i Teor. Fiz., 24, 210-213, 1953.
Transl. available from M. D. Friedman, 2 Pine St., West Concord, Mass.

A differential equation is developed for the distribution function of rays in a medium endowed with random inhomogeneities; the medium is considered to be macroscopically homogeneous and isotropic. The irregular variations of the perperties of the medium are assumed to take place at a fairly slow rate. Formulae are derived for the mean square of the deviation of a ray from its original direction.

3693

Dean, E. A., "Sound Transmission Loss for Near-Vertical Atmospheric Propagation," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 224-232, 1962.
AD-408 716.

The sound transmission loss in the upper atmosphere is formulated. It is divided into divergent, refractive, and absorption losses, which are derived for an inhomogeneous, moving, layered medium. This calculated loss is then compared to the measured loss for high-altitude grenade detonations (30-90 km), using the data from rocket-grenade experiments performed at Fort Churchill, Churchill, Canada. As expected, an excess loss is found for the lower altitude grenades; however, the actual loss is less than the calculated loss at the higher altitudes.

3694

Dean, E. A., "The Wavelength Limits of Atmospheric Ray Acoustics," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 7-12, 1961.
AD-408 716.

The investigation of the assumptions used in the derivation of the eikonal equation furnishes the wavelength requirements which must be satisfied if the ray description of sound is to be accurate. These requirements are then applied to propagation in a layered inhomogeneous atmosphere of typical structure. It is found that the most exacting requirement, neglecting wind shear and the change in temperature gradient at the tropopause, is the change in pressure due to the gravitational field.

3695

Duckert, P., "Dispersion of Explosion Waves in the Atmosphere" (in German), Gerlands Beitr. Geophys., 1, 236-290, 1931.

Various aspects of the theory of longtitudinal waves in the atmosphere are taken up: the propagation speed of longitudinal waves in a gas; the spread of explosion waves in a calm, even, and horizontally stratified medium; in a windy such medium; in any stratified medium. Special solutions, by differential equations, are worked out for determining ray paths. A report is given of research on explosion-wave propagation by systematic detonations, instruments, methods, etc. Practical results of pressure registering and conclusions as to the construction of the atmosphere, including results of pure acoustical observations, are given. A possible explanation for the high speed of sound in the upper stratosphere, and of high temperatures there, is outlined, and the importance of air sounding in aerologic research stressed. A highly theoretical article.

3696

Eckart, G., "Study of Acoustic Wave Echoes in the Stratified Region of the Troposphere" (in French), Acustica, 2, 256-262, 1962.

This paper uses the methods of Bremmer[1,2] and Schelkunoff.[3] The influence of those terms which spoil the analogy with electric waves[4] becomes apparent.

[1]Philips Research Repts., 4, 1-19 and 189-205, 1949.

[2]Physica, 15, 593-608, 1949.

[3]Quart. Appl. Math., 3, 348-355, 1946.

[4]Eckart and Lienard, Acustica, 2, 157-161, 1952.

3697

Eckart, G., and P. Lienard, "Incomplete Analogy of the Characteristic Electrical and Acoustic Impedances and Consequences Relative to Echo in Stratified Continuous Media" (in French), Acustica, 2, 157-161, 1952.

The characteristic acoustic impedance of a medium is defined by analogy with the corresponding quantity for electric waves. In the latter case, there is no internal reflection in a continuously stratified medium, provided the characteristic impedance remains constant, but this is not true for sound waves, so that a stratified atmosphere should reflect sound and produce echoes under all circumstances.

3698

Ellison, T. H., "The Propagation of Sound Waves Through a Medium with Very Small Random Variations in Refractive Index," J. Atmospheric Terrest. Phys., 2, 14-21, 1951.

A theoretical study of scattering in a field having a known, slightly variable refractive index, such as the atmosphere, first of an incident plane wave and secondly of a ray. It is found that "for a wave travelling in a statistically homogeneous medium where the scale of the variations in refractive index is suitably large compared with the wavelength but small compared with the path length, the variations in intensity produced by the medium are proportional to the cube of the path length for short paths, but directly proportional to it for long paths."

3699

Friedman, B., "Wave Propagation in Hydro-Dynamics and Electrodynamics," Natl. Bur. Std. (U. S.), Appl. Math. Ser., 15, 13-17, 1951.

Paper presented at the Symposia on Modern Calculating Machinery and Numerical Methods, Los Angeles, July, 1948. The technical difficulties described arise from: "(1) wave propagation in an inhomogeneous medium, (2) existence of complicated boundary conditions, (3) nonlinearity of the appropriate equations, (4) the prescription of boundary conditions on a free boundary and therefore an unknown boundary." It is stated that problems (2) and (3) should be capable of solution with existing calculating machines.

3700

Gazarian, Iu. L., "The Problem of Waveguide Propagation of Sound in Inhomogeneous Media," Soviet Phys. Acoust., English Transl., 2, 134-138, 1958.

The paper derives and investigates the field of a point source spherical emitter located in a laminarly-inhomogeneous medium in which the velocity of sound varies according to the law indicated by Epstein.

3701

Gazarian, Iu. L., "Waveduct Propagation of Sound for One Particular Class of Laminarly-Inhomogeneous Media," Soviet Phys. Acoust., English Transl., 3, 135-149, 1958.

The paper derives an integral representation for the field of a point spherical harmonic radiator located in a medium where the velocity of sound varies according to the Epstein law. An investigation is made of the case of waveduct propagation. A solution is found for the waveduct propagation that occurs in an inhomogeneous half-space having an absolutely reflecting boundary in the case where the axis of the waveduct lies on the boundary.

3702

Givens, M. P., W. L. Nyborg, and H. K. Schilling, "Theory of the Propagation of Sound in Scattering and Absorbing Media," J. Acoust. Soc. Am., 18, 284-295, 1946.

The theory predicts that curves of physical transmission loss against distance should be convex upward if the sound is detected bv means of a directional microphone directed toward the source, and concave upward if perpendicular to a line from the source. The theory also predicts the directionality of sound in the medium and is applied to transmission through forests and through open air containing inhomogeneities.

3703

Groves, G. V., "Geometrical Theory of Sound Propagation in the Atmosphere," J. Atmospheric Terrest. Phys., 7, 113-127, 1955.

Deals with the geometry of sound waves and rays propagated in a moving inhomogeneous medium, with particular reference to the atmosphere. The theory developed is, essentially, a generalization of that in geometrical optics for the propagation of light in an inhomogeneous isotropic medium to the case where the medium is in motion. Differential equations defining the wavefront and rays of a sound propagation in an inhomogeneous moving medium are derived, and then transformed by expressing the unit normal of the wavefront in terms of certain trace velocities.

With the equations in this form, an integral is immediately obtainable for sound propagated in the atmosphere by assuming that the velocity of sound and the wind-velocity vector are functions of height only. From this solution the law of refraction, the condition for total reflection of a sound ray, and the equations for the wavefront at any time are found. By way of example, the theory is applied to a simple velocity of sound vs. height relationship, and expressions are obtained for the range and time at which the abnormal propagation from a ground-level source returns to earth. Numerical results calculated from these formulae are found to be in accord with observations that have been made on this phenomenon.

3704

Harris, C. M., and L. Kirvida, "A Study of Phase Characteristics of 45 CPS-Sound Propagated in Air," Tech. Rept. No. 9, Columbia Univ., N. Y., 1958.
AD-202 835.

This report describes an experimental program aimed at delineating phase fluctuation effects of an inhomogeneous atmosphere on a 45-cps acoustic tone, as determined by two microphones in a phased array operating on a level terrain.

3705

Hoffman, W. C., "Extremely Low Frequency Waves in an Inhomogeneous Hydromagnetic Medium and Geomagnetic Micropulsations," Math. Note No. 248, Boeing Scientific Research Labs., Seattle, Wash., 16 pp., 1962.
AD-273 492.

Describes a new type of wave motion that can exist in an inhomogeneous hydromagnetic medium at extremely low frequencies under certain conditions on the conductivity gradient of the medium. The basic hydromagnetic equations consist of Maxwell's equations, Ohm's Law, and equation of motion for a nonviscous medium, and the equation of continuity.

3706

Karal, F. C., and J. B. Keller, "Elastic Wave Propagation in Homogeneous and Inhomogeneous Media," J. Acoust. Soc. Am., 31, 694-705, 1959.

A general method is developed for the solution of the linearized equations of elasticity for both homogeneous and inhomogeneous media. This method yields solutions that describe propagating waves, which may be pulses, rapidly changing wave forms, or periodic waves. It is not restricted by the usual considerations, which depend upon separation of variables. The solution consists of a series of terms, the first of which describes the wave motion predicted by geometrical optics. Subsequent terms account for certain types of diffraction effect. The series is not necessarily convergent but is presumably asymptotic to the solution.

3707

Kastner, S., "The Reflection and Transmission of a Plane Sound Wave Incident at any Angle on a Layer-System Viscoelastic Medium, II" (in German), Ann. Physik, 19, 102-115, 1956.

Materials may be classified acoustically into two groups: those in which compression and shear waves appear (Group A) and and those in which compression and shear waves can be propagated (Group B). The reflection and transmission of plane waves through a layered system of viscoelastic material of Group A was discussed in Part I; in this part, the propagation of waves through a layered system composed of four different arrangements of Group A and Group B materials is considered theoretically.

3708

Kastner, S., "The Reflection and Transmission of a Plane Sound Wave Incident at any Angle on a Layered Viscoelastic Medium" (in German), Ann. Physik, 18, 190-219, 1956.

The propagation of a sound wave through an infinite viscoelastic medium is discussed theoretically. The treatment is then extended, using a matrix notation, to a system of n parallel plane layers of viscoelastic material; from the chain matrix of the system, expressions are derived for the reflected and transmitted waves as a function of the incident wave.

3709

Kay, I., "New Equation for the Asymptotic Field Amplitude in a Two-Dimensional Inhomogeneous Medium," J. Acoust. Soc. Am., 33, 1085-1090, 1961.

The geometrical or high-frequency approximation to solutions of the two-dimensional wave equation in an inhomogeneous medium is considered. A new ordinary differential equation for a quantity that is inversely proportional to the geometrical high-frequency field intensity (the square of the field amplitude) is derived. This equation, along with the standard ray and phase equations, form a system from which a complete wave solution in the high-frequency asymptotic limit can be calculated numerically, through the use of a differential analyzer. The examples of a homogeneous medium and a plane, stratified inhomogeneous medium are discussed, and the results of the preceding analysis are verified in these two special cases.

3710

Keilis-Borok, V. I., "Asymmetric Interference Waves in a Layered Medium" (in Russian), Dokl. Akad. Nauk SSSR, 107, 533-536, 1956.

Earlier work (V. I. Keilis-Borok, Doklady Akad. Nauk SSSR, 87, 25, 1952; 95, 733, 1954) on axially symmetric interference waves in a multi-layered semispace is generalized to include non-symmetric oscillations. For the latter the displacement divides into waves of two types composed of different numbers of harmonics and distinguished in dispersion and resonance properties. Waves of the first type are analogous to the axially symmetric waves. The displacements lie in a vertical radial plane. Waves of the second type have horizontal tangential displacements; in special cases they are Love waves.

3711

Khaikovich, I. M., and L. A. Khalfin, "The Effective Dynamic Parameters for Sound Propagation in Inhomogeneous Media," Soviet Phys. Acoust., English Transl., 4, 280-286, 1958.

The paper investigates the effect of inhomogeneities, distributed in a homogeneous medium in the form of a rectangular lattice, on the dynamic parameters that characterize the propagation of sound waves. Equations are obtained for calculating the effective parameters of the nonuniform medium. It is shown that the presence of inhomogeneities leads to dispersion and absorption.

(Errors made by Khaikovich and Khalfin are discussed by Ratinskaya in an article covered by entry number 3740.)

3712

Kharanen, V. Ya., "On the Spreading of Sound in Media with Random Fluctuations in Refractive Index" (in Russian), Dokl. Akad. Nauk SSSR, 88, 253-256, 1953.

Derives a theoretical expression for the deviation of a sound wave passing through a region with random fluctuation of refractive index in terms of the Markov process and the autocorrelation coefficient for the refractive index. It is suggested that this may provide an explanation of the absorption plane over the sea.

3713

Kirvida, L., and C. M. Harris, "A Study of Phase Characteristics of 45 CPS Sound Propagated in Air," Tech. Rept. No. TR-9, Electronics Res. Labs., Columbia Univ., N. Y., 44 pp., 1958. 1958.
AD-202 835.

An indication of the effect of phase fluctuations, which result from propagation of sound through inhomogeneous atmospheric conditions, was obtained on an acoustic phased array detection system. Sound from a 45-c pure tone source (located on the ground in rather flat terrain) was transmitted to two microphones at ground level, which were some distance away at approximately equal distances from the source. The acoustic signals received at each microphone were recorded on a two-channel magnetic tape as a function of time; for a given set of conditions, one such recording was made for each of five different spacings between the two microphones. Twenty-one sets of data (of five recordings each) were obtained for various atmospheric conditions and for different distances between the sound source and the microphones. These recordings provided a convenient method of storing the information from which the required phase characteristics were obtained. The following information was obtained: (1) the phase difference between the acoustic signals was plotted about the mean value for a 50-sec interval, for each of the 21 runs, (2) the autocorrelation function for each of the graphs was calculated for time intervals between 0 and 20 sec, (3) the mean square value of the phase difference about the mean value was computed, and (4) the rms values of the summed output of ten microphones spaced at half-wavelength intervals in the form of a linear array were computed and are an indication of the effect of atmospheric fluctuations on the operation of an acoustic phased array detection system for the meteorological conditions existing during our tests.

3714

Konstantinow, B. P., and I. M. Bronstein, "Applications of the Continuity Equation of the Energy in Acoustics" (in German), Physik. Z. Sowjetunion, 9, 630-640, 1936.

An equation for the energy density of the perfect gas is discussed. It is suitable for application in a particularly convenient form. The equation ultimately derived enables the propagation of sound to be described in a static inhomogeneous medium. Once more it is established that sound waves are propagated with adiabatic velocity, because such disturbances proceed sufficiently slowly. Problems involving additions of the second order are considered, and particularly in connection with the determination of the following magnitudes: density and flow of energy; sound pressure and average temperature increase in the sound field. In this respect, the necessity is proved for the careful testing of the usually accepted data for these quantities. The paper is mainly mathematical.

3715

Krasil'nikov, V. A., and A. M. Obukhov, "Inhomogeneities of the Index of Refraction," Soviet Phys. Acoust. English Transla., 2, 103-110, 1956.

The review is concerned with the problem of waves and fluctuations in connection with atmospheric acoustics, hydroacoustic atmospheric optics and radiowave propagation in the troposphere. Among matters discussed are: the simple wave equations, effect of small non-uniformities, modification and solution of the equation for such conditions, diffraction effects, turbulent medium and its effects, micro-structure of a wind, the structural function of the temperature field, phase, amplitude shift in fluctuations. 23 refs. (21 Russian).

3716

LaCasce, E. O., R. G. Stone, and D. Mintzer, "Frequency Dependence of Acoustic Fluctuations in a Randomly Inhomogeneous Medium," J. Appl. Phys., 33, 2710-2714, 1962.

When a series of uniform acoustic pulses is transmitted through a medium whose refractive index varies in a random manner, the pulses received vary randomly about an average amplitude.

A theory developed by Mintzer predicts that the coefficient of variation V, defined as the fractional standard deviation of a series of pulses, is directly proportional to k(2π/acoustic wavelength, provided that the range from the source to receiver is greater than ka^2, where a is the correlation distance of the refractive index variations. In a scaled model experiment the refractive-index variations are caused by heating the medium (water) from below, thus causing turbulent convection. Observations show the linear dependence of V upon frequency for $r > ka^2$ as predicted by the theory. At the higher frequencies, observations indicate possible oscillations in V as it tends toward a frequency-independent value.

3717

Levin, M. L., "On the Dispersion of Sound in a Slightly Non-Homogeneous Medium" (in Russian), Zh. Tekhn. Fiz., 21, 937-939, 1951.

The author points out that the theory of sound propagation developed by Rayleigh in paragraph 296 of his Theory of Sound could not be applied to a nonhomogeneous medium because it omits the last term in the continuity equation $\partial\rho/\partial t + \rho \operatorname{div} \vec{v} + \vec{v}\nabla\rho' = 0$, where ρ is the density of the medium, ρ' is a small variation of ρ, and $\vec{v}$ is the velocity of the medium at a given point; and, furthermore, because in the Euler equation $\partial\vec{v}/\partial t = -(\nabla p')/\rho$, where p' is a small variation of the pressure, it assumes that p is proportional to the compression at a given point (the "local" compression) while in actual fact it should be proportional to the compression in a given portion of the moving medium (the "material compression") which differs from the former in a nonhomogeneous medium. The author then gives a wave equation and its solution for a slightly nonhomogeneous medium, and shows that the solution given by Rayleigh is a particular case of this more general solution.

3718

MacLean, W. R., "On the Theory of Wave Propagation in Non-Homogeneous Media," Rept. R-876-54, Microwave Research Inst., Polytechnic Inst. of Brooklyn, N. Y., 16 pp., 1954. AD-48 339.

In using Huygens' principle in a homogeneous medium, one naturally invokes a Green function of the type

$$\frac{\epsilon^{-j\beta r}}{r}$$

For a nonhomogeneous medium, one would seek some curvilinear path length to substitute for r. The present paper shows how this may be done and what approximations are involved. The reciprocity relation of the approximate Green function is also derived. The results are applicable to both acoustic and electromagnetic propagation.

3719

Mariani, J., and W. Magnus, "The Exponential Solution for the Homogeneous Linear Differential Equation of the Second Order," Res. Rept. No. BR-37, Inst. Math. Sci., Univ. of N. Y., 17 pp., 1961. AD-254 788.

A linear second order differential equation may be considered as a 2×2 system of first-order equations. The question is whether the solutions of this system can be written in the form exp omega where omega is a 2×2 matrix. A motivation for the problem is given, based on the question of defining lump constants for an inhomogeneous layer. Conditions necessary for the existence of omega are given for a variety of circumstances. Applications are for wave propagation of acoustic and electromagnetic energies in inhomogeneous media.

3720

Masterov, E. P., "Waveguide Propagation of Sound in Layered Inhomogeneous Media," Soviet Phys. Acoust. English Transl. (New York), 5, 339-343, 1960.

The waveguide propagation of sound in a medium of refractive index (n) is discussed; n^2 obeys a bi-exponential law

$$n^2(z) = p^2 + (1 - p^2 + q)e^{-az} - qe^{-2az}$$

where p, q and a are parameters that determine the distribution of the refractive index.

3721

Masterov, E. P., and V. N. Murottseva, "An Example of Antiwaveguide Propagation of Sound in Laminar-Inhomogeneous Media," Soviet Phys. Acoust., English Transl., 6, 335-339, 1961.

A case of the aintiwaveguide propagation of sound in a laminar-inhomogeneous space is investigated, where in this space the square of the index of refraction increases with height according to a square law. The investigation is made for the case of a perfectly reflecting boundary, located in the horizontal plane where the index of refraction is a minimum.

3722

Meecham, W. C., "On Radiation in a Randomly Inhomogeneous Medium," Rept. No. 6120-0040-RU-000, Space Technology Labs., Inc., Los Angeles, Calif., 23 pp., 1961. AD-266 184.

The point source solution in a random inhomogeneous medium is considered. It is found that energy is transferred from the average to the fluctuation field at a rate dependent upon the long wavelength components of the random fluctuation in the medium. The phase velocity of the average solution is lowered. Both of these characteristics are dependent to lowest order on second-order scattering processes, single scattering producing no average effect. The behavior of the average solution is directly analogous to the result for propagation in a medium composed of discrete scatterers placed at random. An example is worked out, a Gaussian correlation function for the medium fluctuation; both the change in the phase velocity and the loss in the rate of energy from the average beam are found.

3723

Milne, E. A., "Sound Waves in the Atmosphere," Phil. Mag., 42, 96-114, 1921.

This paper deals with the kinematics of the propagation of sound waves through a medium (such as the atmosphere) in which the velocity of the medium and the velocity of sound in the medium vary from point to point. The subject is taken up in connection with the location of aircraft by sound. Sections take up: equations of propagation; the general refraction formula for stratified media; application to a point source in the atmosphere; total reflection and the range of audibility; cases of limited audibility, etc.

3724

Mintzer, D., "Wave Propagation in a Randomly Inhomogeneous Medium," Research Analysis Group, Brown Univ., Providence, R. I., Tech. Rept., 15 pp., 1953. AD-14 331.

The propagation of sound pulses from a point source in a medium in which the index of refraction varies randomly was studied by means of the Born approximation to the wave equation. A first-order approximation was derived for the pressure in an acoustic pulse traveling in such a medium. The time average over the pulse length of the pressure amplitude was determined under the assumption that random changes of the index of refraction occurred between successive pulses. The expression obtained for the coefficient of variation for a series of pulses agreed with experiment.

3725

Mintzer, D., "Wave Propagation in a Randomly Inhomogeneous Medium, I," J. Acoust. Soc. Am., 25, 922-927, 1953.

A journal article based on the report covered by the preceding entry.

3726

Mintzer, D., "Wave Propagation in a Randomly Inhomogeneous Medium, II," J. Acoust. Soc. Am., 25, 1107-1111, 1953.

Journal article based on report covered by entry 3396.

3727

Mintzer, D., "Wave Propagation in a Randomly Inhomogeneous Medium, II," Research Analysis Group, Brown Univ., Providence, R. I., 13 pp., 1953.
AD-22 289.

The region of validity of the single-scattering approximation is found by considering the next higher approximation; it is valid for $k_0^2 a r \alpha^2 << 1$, where k_0 is the wave number of the incident sound, r is the range from source to observer, a is the mean size of the inhomogeneities and α is the rms value of the refractive index variations. Some approximate results are given for the case of wavelength large compared with inhomogeneity size. By considering the intensity variations, it is found that ray theory is valid for $(k_0 a^2/r) >> 1$, as has been found for plane waves.

3728

Mintzer, D., "Wave Propagation in a Randomly Inhomogeneous Medium, III," J. Acoust. Soc. Am., 26, 186-190, 1954.

Journal article based on report covered by preceding entry.

3729

Mintzer, D., "Wave Propagation in a Randomly Inhomogeneous Medium, III," Research Analysis Group, Brown Univ., Providence, R. I., 15 pp., 1954.
AD-28 451.

On the assumption that the correlation function of the refractive index inhomogeneities is expressible as the product of time- and space-dependent functions, the coefficient of variation for a series of sound pulses and the correlation function for successively received sound pulses are evaluated for arbitrary pulse length. The results showed the validity of the assumption that the refractive index at a point changes only between pulses for pulse lengths $T << \tau_0$ and $\alpha << c_0\tau_0$, where α and τ_0 are correlation constants and c_0 is the reference sound velocity. Furthermore, the correlation function for successive signals is equal to the time-dependent part of the refractive-index function for pulse lengths $T << \tau_0$ and $\alpha << c_0\tau_0$.

3730

Ohyama, N., "Propagation of Shock Waves in Inhomogeneous Medium, IV. Second Order Approximation," Progr. Theoret. Phys., Japan, 26, 251-262, 1961.

Ono, Sakashita, and Yamazaki derived a first-order approximation formula for the propagation of shock waves in an inhomogeneous medium by extending Chisnell's method. In this paper, corrections to their formula are obtained by taking into account the effects of the second-order reflected waves. The calculation is restricted to the case of the strong shock limit, and it is shown that the rate of growth of the shock strength obtained by the first approximation is little influenced, so far as the strong shock limit is concerned, by taking the effects of the second-order waves into consideration.

3731

Ono, Y., "Propagation of Shock Waves in Inhomogeneous Gases, III. Spherical Shock Waves," Progr. Theoret. Phys., Japan, 24, 825-829, 1960.

The propagation of spherical shock waves in the stellar interior is considered, extending the method developed in Parts I and II. A differential equation of the shock strength is derived, which can be applied to any stellar models. It is found that the spherical damping effect is pronounced near the center of stars, and this guarantees the stability of the stellar core in general. In the envelope, this effect becomes negligible, and it is justified to treat the shock waves near the stellar surface as plane.

3732

Ono, Y., S. Sakashita, and H. Yamazaki, "Propagation of Shock Waves in Inhomogeneous Gases, I," Progr. Theoret. Phys., Japan, 23, 294-304, 1961.

Chisnell's method of shock propagation is generalized for the case of inhomogeneous gravitating gases. The relation between shock strength and initial pressure is derived to the first approximation, using a polytropic index as parameter. The strength of a shock wave, which is generated near the center and progresses outwards, increases rapidly, being proportional to some inverse power of pressure near the surface. Applying the results to the Eddington model, some speculation concerning the origin of nova explosions is made.

3733

Parker, E. N., "The General Theory of Compressional Waves in a Fluid and Its Application to Specific Problems," Tech. Rept. No. III, Inst. for the Study of Rate Processes, Univ. of Utah, Salt Lake City, 26 pp., 1951.
ATI-166 143.

An attempt is made to obtain a physical insight into the process of producing longitudinal waves in a compressible medium. The author of this report was interested in obtaining the results in their most general form and in understanding in detail their significance. Thus, much space is devoted to discussing the notions and concepts involved. In the end, a general inhomogeneous wave equation giving the velocity potential of the radiative velocities in the medium in terms of the velocity of the medium is obtained. To the usual order of approximation used in acoustical problems, the emission of radiation is found to be invariant to whatever velocity field the medium may possess, depending only on the pressure fluctuations. The resulting general theory, expressed mathematically as an inhomogeneous wave equation, is useful in handling such problems as the production of noise by the solar chromosphere. It is shown in this case that the granules do not produce enough noise to account for the temperature of the chromosphere and corona.

3734

Pekeris, C. L., "Note on the Scattering of Radiation in an Inhomogeneous Medium," Phys. Rev., 71, 268-269; erratum, 457, 1947.

An expression is derived for the scattering of a plane sound wave when it passes through a medium in which the velocity of sound fluctuates slightly and irregularly about a mean value.

3735

Poeverlein, H., "Addendum to 'Waves in Anisotropic Conditions of Propagation' " (in German), Naturforsch., 6a, 55, 1951.

Notes that Cotte has shown earlier the differences between the wave, index, and normal surfaces of matter waves, and the corresponding surfaces in light optics; and also that he noted the influence of the choice of vector potential on the form of the wave surfaces.

3736

Poeverlein, H., "Waves in Anisotropic Conditions of Propagation" (in German), Z. Naturforsch., 5a, 492-499, 1950.

A theoretical discussion of the index surface defined by Hamilton and MacCullagh (1837) and the principle that the ray direction is normal to this surface. The ideas are applicable not only in crystal optics but in general to waves in anisotropic media, e.g., radio waves in the ionosphere. Examples treated here are sound waves in air and the motion of electrons in a magnetic field.

3737

Potter, D. S., and S. R. Murphy, "On Wave Propagation in a Random Inhomogeneous Medium," J. Acoust. Soc. Am., 29, 197-198, 1957.

This paper examines the calculation of the coefficient of variation in intensity for acoustical transmission in a randomly inhomogeneous medium. An equation for this coefficient is derived that is valid over the range of frequencies between the wave limit and the ray limit previously reported by other authors.

3738

Pridmore-Brown, D. C., "Sound Propagation in a Temperature- and Wind-Stratified Medium," J. Acoust. Soc. Am., 34, 438-443, 1962.

The general linearized equations governing the propagation of sound in a dissipationless temperature- and wind-stratified medium are derived. A formal integral expression is given for the field of a point-source located in such a medium, when it is bounded by an absorbing plane under conditions which lead to the formation of a shadow zone. This integral yields the following approximate (high-frequency) expression for the decay rate within the shadow

$$|p| = (B/r) \exp [-(n/c)f^{1/2}(-c' - U' \cos \phi)^{2/3} r]$$

Here p is the acoustic pressure, r is radial distance from the source, B is independent of r, f is frequency in cps, c is sound speed, c' and U' are sound- and wind-speed gradients at the ground surface, ϕ is the angle between the wind direction and the direction of sound propagation, and n is equal to 5.93 for a pressure-release boundary and to 2.58 for a hard boundary.

3739

Priimak, G., "Correlation Function of a Signal Passing Through a Medium with Randomly Moving Inhomogeneities," Translated by: M. D. Friedman, No. P-157 from Izv. Vysshikh Uchebn. Zavedenii, Radiofiz., 778-788, 1961.
AD-252 208.

The problem of the correlation function of a signal passing through a medium with randomly moving inhomogeneities is analyzed. The present analysis is made directly for the acoustical case, although it refers in equal measure to radiowave propagation.

3740

Ratinskaya, A., "Remarks on the Effective Dynamic Parameters of Inhomogeneous Media During Propagation of Sound Waves," Soviet Phys. Acoust., English Transl., 6, 127-129, 1961.

Attention is drawn to errors made in two recent papers by Khaikovich and Khalfin on density and velocity of sound in inhomogeneous media.

One of the two papers in which these errors were made is covered by entry number 3711. The other is I. M. Khaikovich and L. A. Khalfin, "The Effective Dynamical Parameters of Inhomogeneous Elastic Media During the Propagation of Plane Longitudinal Waves" (in Russian), Izv. Akad. Nauk SSSR, Ser. Geofiz., 4, 505-515, 1959.

3741

Seckler, B. D., and J. B. Keller, "Asymptotic Theory of Diffraction in Inhomogeneous Media," J. Acoust. Soc. Am., 31, 206-216, 1959.

Some boundary value problems are considered for the reduced wave equation in media having planar or cylindrical stratification. They are solved exactly and the solutions are expanded asymptotically for high frequencies by using the method of stationary phase in conjunction with the WKB method and the Watson transformation. The asymptotic expansions are compared with the corresponding diffracted fields found by using the geometrical theory described in the companion article, "Geometrical Theory of Diffraction in Inhomogeneous Media" (see Abstract 770). In all cases the asymptotic expansions agree completely with the corresponding results derived by the geometrical theory, thus verifying this theory.

3742

Seckler, B. D., and J. B. Keller, "Diffraction in Inhomogeneous Media," Res. Rept. MME-7, Inst. of Math. Science, New York Univ., New York, 68 pp., 1957.
AD-155 157.

A geometric method is presented for finding the field in inhomogeneous media containing smooth convex bodies. The field due to a plane wave in an unbounded medium is constructed by introducing complex rays in the refraction shadow. Fermat's principle is extended to explain the occurrence of certain diffracted rays in the boundary problems. Then by modifying the law of conservation of energy, the field along the diffracted rays is obtained in addition to the field on the geometric lit region. Certain diffraction coefficients and decay exponents are introduced and general formulas are obtained for them. The theory is then applied to several problems in which the medium is plane or cylindrically stratified, and the boundary is planar or circular. Expressions are determined for the exact solution to various boundary problems corresponding to these special problems. Asymptotic forms are obtained by using the method of stationary phase in conjunction with the WKB method and Watson transformations. The geometrical theory is verified, at least in these cases. Two shorter articles based on this report are in J. Acoust. Soc. Am., 31, 192-205 and 206-216 (see Abstracts 768 and 770).

3743

Seckler, B. D., and J. B. Keller, "Geometrical Theory of Diffraction in Inhomogeneous Media," J. Acoust. Soc. Am., 31, 192-205, 1959.

The geometrical theory of diffraction is described. It is used to to determine the diffracted fields in inhomogeneous media. Cases in which such media contain smooth convex bodies are treated. The theory employs an extension of Fermat's principle, which yields diffracted rays. The field associated with each ray is calculated by energy considerations. This requires the introduction of diffraction coefficients and decay exponents. General formulas for these quantities are given in terms of local properties of the medium and of the body.

3744

Skudrzyk, E., "Scattering in an Inhomogeneous Medium," J. Acoust. Soc. Am., 29, 50-60, 1957.

The standard mathematical procedure formally describes scattering by the superposition of a scattered pressure on the unscattered sound field. At low frequencies, because of the irregular distribution of the inhomogeneities, the phases of the scattered waves are at random, and scattering is an interference phenomenon. As the frequency increases, scattering becomes highly collimated in the forward direction and the phase differences decrease to zero. At this point, ray theory starts to apply. The scattered pressure, then, essentially describes only a phase change caused by the different sound velocities and the focusing and defocusing by the lens action of the patches. The medium in the neighborhood of the receiver can be shown to contribute only by focusing; the medium farther away, only by interference fluctuations. Focusing leads to normally distributed amplitude fluctuations, however, passes from normal to Rayleigh with increasing values of range.

3745

Stocker, P. M., "Shock Refraction in a Stratified Medium," Rept. No. B 31/58, Armament Research and Development Establishment, Great Britain, 17 pp., 1958.
AD-209 975.

If an initially plane shock enters a region of uniform pressure in which the sound speed varies in a direction perpendicular to the direction of propagation, the shock will be refracted and pressure gradients will arise behind the shock. The shock shape and the flow field behind the shock are found in the case where the density jump through the shock is large compared with the density variations ahead of it.

3746

Tatarskii, V. I., "Criterion of the Applicability of Geometrical Optics to Problems of the Propagation of Waves Through a Medium Characterized by Slight Refractive Index Variations" (in Russian), Zh. Eksperim. i Teor. Fiz., 25, 84-86, 1953.

Ellison's method (J. Atmospheric and Terrest. Phys., 2, 14-21 (1951) is used for obtaining a more general criterion to establish the coincidence of wave-functions resulting from the solutions of the two fundamental equations involved. It is shown that conditions $\lambda << \ell$, and $\lambda L << \ell^2$ (where λ is the length of the propagated wave, ℓ is the mean size of inhomogeneities, and L is the path of wave in the inhomogeneous medium) are sufficient for ensuring the coincidence of both the amplitudes and phases in the geometrical and wave solutions.

3747

Tatarskii, V. I., "Theory of the Propagation of Sound Waves in a Turbulent Stream" (in Russian), Zh. Eksperim. i Teor. Fiz., 25, 74-80, 1953.

Examines in detail the problem of the scattering of sound waves for the case of isotropic turbulence in an incompressible liquid. Investigates the general form of the scattering indicatrix and develops for it an expression based on the formula $R_{rr}(\rho) = \bar{u}^2 \exp(-\rho\ell)/3$, where $\bar{u}^2$ is the mean square value of the pulsation velocity of the stream, ρ = one of the spherical coordinates of the point, and ℓ = the correlation scale characteristic of the average pulsation size. The analysis of this phenomenon, based on the scattering theory, yields the mean square fluctuations of the phase and amplitude of sound at large distances from the source.

3748

Thrane, P., "Some Hydrodynamical Properties of Simple Atmospheric Oscillations with Applications to the Semidiurnal Oscillation," Geofys. Publikasjoner, 18, 36 pp., 1951.

The linearized hydrodynamical equations, including that for energy, are applied to certain types of simple oscillations, resembling tidal waves but created by periodical supply and removal of heat. It is shown that the variation in the heat supplied can be computed if the pressure wave is known. If the phase angle of the pressure wave at sea level is independent of latitude, and if changes of state, including the adiabatic and the isothermal, are piezotropic, the phase angle must be independent of latitude but variable with height.

For a barotropic model atmosphere, a simple form of oscillation with a 24-hour period, considered by Margules and others to satisfy the linearized equations, does not agree with the exact hydrodynamical equations. An examination is made of the properties of oscillations with 12-hour or 24-hour periods, but limited to a region near the Pole. A fundamental difference in the hydrodynamical properties of the two oscillations is indicated quite apart from resonance. Nonlinear perturbation equations with terms of first and second order are applied to derive certain oscillation properties. Approximate values of the variation of the heat supplied and the vertical velocity in the semidiurnal oscillation are obtained, the pressure wave being known. The possibility of explaining this wave as a nonresonant oscillation resulting from thermal processes is discussed. The flux of heat through a model atmosphere having no other motion than that from the combined diurnal and semidiurnal oscillation is considered, and a possible explanation of the preponderance of the semidiurnal oscillation is indicated.

3749

Tolstoy, I., "Note on the Propagation of Normal Modes in Inhomogeneous Media," J. Acoust. Soc. Am., 27, 274-277, 1955.

Given a wave duct with continuously variable parameters extending from y = 0 to y = H, the reflection coefficients for originally plane down-going and up-going waves are written in the form $\mathcal{R}\downarrow = -\exp(2i_\chi\downarrow)$ and $\mathcal{R}\uparrow = -\exp(2i_\chi\uparrow)$, respectively. It is then shown that the characteristic equation governing the dispersion of undamped normal modes in the medium is $\chi\downarrow + \chi\uparrow = m\pi$, m being an integer defining the mode number. $\chi\downarrow$ and $\chi\uparrow$ are solutions of nonlinear first-order differential equations. If the medium consists of n homogeneous layers of finite thickness, the differential equation is replaced by a recursion relation, and the characteristic equation shown above includes one additional term.

3750

Veldkamp, J., "Propagation of Sound Waves in the Sea and in the Atmosphere" (in Dutch), Ned. Tijdschr. Natuurk., 16, 281-289, 1950.

A review of theoretical and experimental work.

3751

Wing, G. M., "Mathematical Aspects of the Problem of Acoustic Waves in a Plane Stratified Medium," Quart. Appl. Math., 19, 309-319, 1962.

The paper is concerned with the problem of acoustic waves in layered media. In particular, the specific problem of a point source of acoustic radiation of a single frequency situated above a perfectly reflecting plane surface is considered, the source being in a medium of constant density and sound speed. A plane interface above the source and parallel to the reflector separates this medium from another infinite medium of constant properties. The pressure distribution at any point in the media is solved in the paper by the introduction of a mathematical device that avoids ambiguities in the solution.

Wave Propagation, Inhomogeneous Medium
See Also—28, 429, 431, 441, 488, 538, 560, 627, 628, 629, 745, 765, 800, 852, 925, 1381, 1382, 1505, 1530, 1538, 1565, 1885, 1915, 1920, 1922, 1932, 1937, 1938, 1939, 1957, 1958, 2000, 2026, 2038, 2125, 2147, 2160, 2175, 2222, 2269, 2272, 2844, 2858, 2876, 2907, 3329, 3342, 3352, 3357, 3403, 3488, 3547, 3586, 3877, 3945, 4147, 4241, 4242

WAVE PROPAGATION, INTERACTION EFFECTS

3752

Appleton, J. P., and H. J. Davies, "Theoretical Investigation of the Sound Field Produced Downstream of a Choked Two-Dimensional Channel Due to Unsteady Upstream Entropy Fluctuations," Rept. No. 20126, Aeron. Res. Council, Great Britain, 10 pp., 1958.
AD-216 135.

The two-dimensional flow considered is that of an ideal, compressible fluid bounded by two rigid, nonconducting, parallel walls of infinite extent. A shock wave normal to the rigid boundaries divides the flow into subsonic and supersonic regimes. In the supersonic region a normal static temperature variation, which is sectionally invariant but fluctuates periodically with time, when convected through the shock wave, results in a perturbation of the flow in the subsonic region. By assuming that the magnitude of the fluctuations of the static temperature are small, an expression for the acoustic pressure fluctuation in the downstream part of the gas is deduced.

3753

Aroesty, J., "Strong Interaction with Slip Boundary Conditions," Rept. on Research on Aerodynamic Flow Fields, Univ. of Calif., 25 pp., 1961.
AD-269 539.

A solution to the problem of strong interaction between the shock wave and the boundary layer has been obtained for the case where velocity slip and temperature jump boundary conditions are consistent at the wall. It is shown that the addition of slip boundary conditions yields a correction of order (boundary-layer thickness/X) to the no-slip solution. Estimates are made of the effect of slip on induced pressures and skin friction for the case of the adiabatic wall. In addition, it is shown that the inclusion of slip boundary conditions does not change the energy transfer to the wall from the no-slip values.

3754

Arsenin, V. Ya., and N. N. Yanenko, "Interaction Between Shock Waves and Traveling Waves" (in Russian), Dokl. Akad. Nauk SSSR, 109, 713-716, 1956.

A mathematical analysis of the effect of the shock waves on the compressional and expansional traveling waves expressed in Riemannian form $p = A \exp (\pm v/c)$; $u = (v \pm c)t + f(v)$, where p = gas pressure, v = velocity, u = Eulerian coordinate, $c = \sqrt{p/\rho}$ (ρ = density), A = a constant, and $f(v)$ = a function of v, for different values of the Riemannian invariants $r = c.\ln\rho + v$ and $s = -c.\ln\rho + v$.

3755

Barach, J. P., "Interaction Between a Magnetic Field and an Electrically Produced Shock Wave," Phys. Fluids, 4, 1474-1477, 1961.

Shock flows of speeds up to 1 cm/μ sec in krypton were observed to interact with a magnetic field of 5700 gauss. A reflected shock was observed and deceleration of the flow measured. Gas flows of up to Mach 63 are produced by an annular electric shock tube powered by a capacitor discharge of long time-constant. A radial magnetic field geometry provides closed paths within the gas flow for the induced currents. The speed of the wave reflected off the magnetic field is found to increase slightly with interaction strength. The flow momentum lost per particle as the flow traverses the field region is calculated, and is compared to the impulse delivered each particle by the magnetic field. Approximate agreement is found over a wide range of experimental conditions, validating the magnetohydrodynamic picture of the interaction and the use of the scalar gas conductivity.

3756

Bellin, J. L. S., and R. T. Beyer, "Scattering of Sound by Sound," J. Acoust. Soc. Am., 32, 339-341, 1960.

An attempt was made to determine the presence of scattering resulting from the nonlinear interaction of two finite-amplitude sources, operating in water. Experiments were performed with two beams crossed at right angles and also in the nonperpendicular case. A detector crystal, tuned to the summation frequency (13.4 Mc) of the two sources (7.4 Mc and 6.0 Mc), and pivoted about a point above the interaction region, was used to investigate the scattered field. The results, applicable to sound in air as well as sound in water, indicated no scattered sound above the noise level of the detection system. The lack of scattered sound is in agreement with the theoretical considerations of Westervelt, but is contrary to the predictions of Ingard and Pridmore-Brown.

3757

Bourret, R. C., "Stochastically Perturbed Fields, with Applications to Wave Propagation in Random Media," Nuovo Cimento, 26, 1-31, 1962.

The statistical properties of a classical field propagating through a random, inhomogeneous medium are analyzed by a method in which the random medium is described by the two-point (bilocal) correlation function of its random characteristic, e.g., refractive index, potential, convective velocity, etc.. A scheme of diagrams is introduced to classify the types of interaction between the propagating field and the random background. Equations for the one- and two-point fields are given, and the wave dispersion and attenuation they imply are discussed. The analysis is very similar to the Tamm-Dancoff theory of one- and two-nucleon propagators with virtual meson dressing and interaction, with the correlation function here playing the role of the meson field. A number of results obtained through the use of the method are described and various projected applications are cited.

3758

Brillouin, J., "Interference Between Waves Having a Modulated Frequency," Rev. Gen. Elec., 40, 434-441, 1936.

The beats that are formed when two frequency-modulated waves interfere are explained, and the use of warble tones for acoustical measurements is examined. The production of a frequency-modulated tone by motion of the source or by rotating reflectors is described. The possibility of using the interference system to locate sound sources is also mentioned.

3759

Burgers, J. M., "On the Transmission of Sound Waves Through a Shock Wave," Proc. Koninkl. Ned. Akad. Wetenschap., 49, 274-481, 1946.

A study of the phenomena that occur when a shock wave is met by sound waves. Considers the case of a stationary shock wave forming the boundary between two regions, in one of which the gas moves with supersonic velocity, and in the other, with subsonic velocity. The boundary conditions are defined in the two cases where the sound wave is incident in the supersonic region and in the subsonic region. The peculiar system of wave motion produced, in which there may or may not be reflection at the boundary layer, is explained on the basis of entropy waves. When sound waves are superimposed on the shock wave, the change of entropy of the gas passing through it is no longer constant and a periodic field of entropy makes its appearance.

3760

Burgers, J. M., "The One-Dimensional Propagation of Pressure-Disturbances in an Ideal Gas" (in Dutch), Verslag. Gewone Vergader. Afel. Natuurk., Ned. Akad. Wetenschap., 52, 476-484; 560-570, 1943.

Studies the propagation of compression and expansion waves in an ideal gas, contained in a semiinfinite cylindrical tube that is closed at one end by a movable piston. The effects of friction, heat conduction, and radiation are neglected. The piston, at the instant $t = 0$, is suddenly set into motion with the constant velocity V; at the instant $t = t_1$ the motion is suddenly stopped. At $t = 0$ a discontinuous compression wave (Riemann shock wave) is generated; at $t = t_1$ an expansion wave is formed, which will overtake the shock wave after a certain interval of time. From this instant the intensity of the shock wave begins to diminish, this process being accompanied by the formation of reflected compression waves of small intensity, and of frontiers at which the entropy of the gas changes. The interaction between the compression waves, the entropy frontiers and the original expansion waves is considered, and a construction is given which makes it possible to obtain an approximate picture of the most important features of the resulting wave system.

3761

Carriere, Z., "Criterion of Sound Sensitivity of Gas Jets and Flames" (in French), J. Phys. Radium, 8, 225-233, 1947.

Combining Rayleigh's theory of the inst .lity of laminar motion of a fluid with a knowledge of the velocities of flow and of sound propagation, it is possible to obtain a general differential equation, with a singular solution, for the movement of viscous fluids. This equation is sufficient to explain known facts in the behavior of sound-sensitive gas jets and flames. The author gives an explanation of the sensitivity of very small flames of luminous gas, such as acetylene. The insensitiveness of the flame of a candle sets a problem for which the solution has suggested certain paradoxical observations. A case not less paradoxical is that of the sensitivity of an old Auer burner, which is explained by the theory.

3762

Cheng, Sin-I, and I. D. Chang, "On the Mixing Theory of Crocco and Lees and Its Application to the Interaction of Shock Wave and Laminar Boundary Layer, Part II. Results and Discussion," Rept. No. 376, James Forrestal Research Center, Princeton, N. J., 1957.
AD-148 042.

The procedure developed in Part I is used to determine the critical strength of the incident shock wave required to produce incipient separation of a laminar boundary layer over a flat plate for the range of Re from $1\text{-}15 \times 10^5$, and for the range of free stream Mach number M from 1.5 to 4.0. Nineteen cases have been integrated. Simple correlations of the results for the separation-pressure ratio and the critical-pressure ratio are obtained as $C_p = p/p_o = a(M-b)\,(R_{e_s} \times 10^{-6}) - c$.

Comparison with two sets of available experimental data shows agreement in general, but no quantitative conclusions can be affirmed without the guidance of more detailed and extensive experimental information. It is suggested that this form of correlation may be obtained for the nonflat plate problems according to the mixing theory.

3763

Dean, L. W., III, "Interactions Between Sound Waves," J. Acoust. Soc. Am., 34, 1039-1044, 1962.

Exact solutions for the interaction between two concentric cylindrical waves and between two concentric spherical waves are presented. The scattered-pressure amplitude in the far field is shown to be constant in the cylindrical case and to be proportional to $r^{-1} \ell hr$ in the spherical case, where r is the distance to the source of primary waves.

A near-field solution is derived for the scattered waves generated when two sharply defined, plane-wave beams of square cross section intersect at right angles. A comparison is made of the theory with recent experiments in which beams of circular cross section were used. It is concluded that if the scattered waves do exist neir amplitudes are at least 40 db below those that are predicted by this theory.

When a hard object is placed in the region of intersection, scattered waves are observed. This effect can be explained by the fact that with the addition of the hard object (a cylinder) the primary waves have components of the same symmetry. These components are the waves scattered from the primary beams by the object. Evidence is presented to show that these components, having the same symmetry, interact strongly in the volume surrounding the object.

3764

De Boer, E., "Acoustic Interaction in Vented Loudspeaker Enclosures," J. Acoust. Soc. Am., 31, 246-247, 1959.

In the design of vented loudspeaker enclosures the acoustic interaction between the two radiating openings is usually left out of the discussion. This letter will show how a simple, yet adequate, representation of this interaction can be obtained. The ideas presented here are not new, but in view of its implications, the method deserves some further discussion.

3765

Dosanjh, D. S., and T. M. Weeks, "Interaction of Traveling Shock Wave with Turbulent Flow Fields," Final AROD Rept. No. 1897:3, Res. Inst., Syracuse Univ., N. Y., 1962.
AD-275 631.

Experimental investigations of the interaction between a traveling shock wave and opposing jet flow were made. The shock-jet flow interactions were optically recorded, using all three standard optical techniques (shadowgraph, schlieren and interferometer). The characteristics of shock distortions, the interaction field density and nature of the discrete wavelet radiation (its wavelength, strength, and decay), including the observed reflection of the radiation wavelets from the downstream side of the main shock front, were evaluated.

3766

Drummond, W. E., "Interaction of Nonuniform Shock Waves," J. Appl. Phys., 28, 76-85, 1957.

The basic interactions of nonuniform shock waves in one-dimensional steady flow, are analyzed by mapping into the hodograph plane, neglecting effects of third and higher orders in the shock strength. The resulting equations are linear and can be solved by straightforward numerical calculation.

3767

D'yakov, S. P., "Interaction of Shock Waves with Small Perturbations, Part I" (in Russian), Zh. Eksperim. i Teor. Fiz., 33, 948-961, 1957.

Interaction of oblique shock waves of arbitrary intensity with small perturbations was considered, in a linear approximation, in the framework of a two-dimensional stationary problem. The flow behind the shock wave was assumed to be supersonic. The general results were applied to the study of interaction with weak discontinuities, weak shock waves, and interfaces of two media that differ only slightly in their acoustical properties.

3768

D'yakov, S. P., "Interaction of Shock Waves with Small Perturbations, Part II" (in Russian), Zh. Eksperim. i Teor. Fiz., 33, 962-974, 1957.

Discussion of interaction of small perturbations with a shock wave of arbitrary intensity within the framework of a two-dimensional stationary problem in the case of subsonic flow behind the shock wave. A solution was found to the problem of the interaction of a weak and a weak-tangential discontinuity with the shock wave. In both cases, the weak-tangential discontinuity formed behind the shock wave possessed a logarithmic singularity.

3769

Fabian, G. J., "Hypersonic Research Summary," Final Rept., Cornell Aeronautical Laboratory, Inc., Buffalo, N. Y., 24 pp., 1960.
AD-238 152.

Investigations in the following areas are reported in summary: wave superheater, chemical nonequilibrium in high-temperature gas flows, radiation probe, sound propagation in an excited or dissociated gas, boundary-layer phenomena in high-temperature gas flows, molecular interactions at high temperatures.

3770

Ford, C. A., and I. I. Glass, "On the Interaction of Two Similarly-Facing Plane Shock Waves," J. Appl. Phys., 25, 1549-1550, 1954.

Describes two methods of generating and showing the interaction of two similarly-facing plane shock waves, alternative to that described by Laporte and Turner. Both utilize the schlieren technique; in the first, the overtaking shock waves are formed by double refraction of a plane shock wave at an air-helium interface, while the second method uses three shock tube chambers at successively higher pressures.

3771

Franks, W. J., "Interaction of a Shock Wave with a Wire Screen," Tech. Note No. 13, Inst. of Aerophys., Univ. of Toronto, Canada, 39 pp., 1957.
AD-140 429.

The head-on collision of a plane shock wave with a wire-mesh screen in air has been studied experimentally in the shock tube. Two screens of 8 mesh, 50% blockage, and 30 mesh, 62% blockage, were used with incident-shock-pressure ratios up to 12. Interferometric and wave-speed camera studies enabled the resulting wave system and detailed flow parameters to be determined for both nonchoked and choked flow through the screens. At low incident-shock strength, nonchoked flow results, and the wave system consists of a reflected shock and a transmitted shock followed by a contact surface. With choked flow through the screens at higher incident-shock strengths, the flow expands to supersonic speed behind the screen and this supersonic region is terminated by a normal shock moving downstream. Simple one-dimensional models of the interaction are proposed for nonchoked and choked cases on the basis of the observed wave systems. Calculated transmitted and reflected shock strengths and choking Mach numbers based on these models agree well with the experimental results.

3772

Friend, W. H., "The Interaction of a Plane Shock Wave with an Inclined Perforated Plate," UTIA Tech. Note No. 25, Inst. of Aerophys., Univ. of Toronto, Canada, 1958.
AD-212 115.

The interaction of a plane shock wave with an inclined perforated plate has been studied experimentally in a shock tube. Four 1/8-inch-thick steel plates of 50% blockage were used, with an incidence range of 45^{o} to 90^{o}, in 15^{o} intervals, and an incident shock pressure ratio range of 2 to 12 in intervals of 2. The two-dimensional interaction was recorded on shadow and schlieren photographs. Weak incident-shock waves produced two main wave elements, the reflected and transmitted shock waves, and a turbulent contact surface. Strong incident-shock waves caused choked flow at the minimum plate cross section, and a supersonic region downstream of the plate terminated by an additional travelling shock wave. The calculated results for the transmitted, reflected, and auxiliary shock strengths and their inclinations, as well as the precritical flow-choking Mach number and contact-front inclination agree well with the experimental results.

3773

Furduev, V. V., "Interference and Coherence of Acoustic Signals," Soviet Phys. Acoust., English Transl., 5, 110-115, 1959.

Acoustic interference is observed in speech and music where two identical signals, separated by a time interval, are superimposed upon one another. In contrast to optical interference, the resulting acoustic signal changes with time, both in magnitude and sign. These changes are described by the author by means of a self-correlation function and an exponential weighting function. Interval of coherence of natural vibrations are also discussed.

3774

Gadd, G. E., "Interactions Between Normal Shock Waves and Turbulent Boundary Layers," Aeron. Res. Council Rept. Memo. No. 3262, 66 pp., 1961.

A theory, involving a simple new method for turbulent boundary layers, is presented for interactions between normal shocks and turbulent boundary layers on flat surfaces. Experiments in a pipe confirm the theory's general validity. Effects on separation of convex-surface curvature and sweepback of the shock are then considered.

3775

Gogosov, V. V., "Interactions of Magnetohydrodynamic Waves," Appl. Math. Mech., 25, 678-693, 1961.

The interactions of magnetohydrodynamic waves, fast and slow shocks, fast and slow expansion waves, and also interactions of magnetohydrodynamic waves with plane, ideally conducting walls, are examined. The medium is assumed ideally conducting. No restrictions are imposed on the parameters of the medium.

3776

Gogosov, V. V., "Interaction of Magnetohydrodynamic Waves with Contact and Vortex Discontinuities," App. Math. Mech., 25, 277-290, 1961.

The following interactions of magnetohydrodynamic waves are discussed: fast and slow shock waves; and fast and slow expansion waves, with vortex and contact discontinuities. The medium is assumed to be ideally conducting. No restrictions are imposed on the parameters of the medium. The possible combination of waves is determined.

3777

Green, R. B., "Geometrical Optics Approximations for the Effects of Shock Waves on Spherical Geometrics," Rept. No. 768-9, Antenna Lab., Ohio State Univ., Research Foundation, Columbus, 31 pp., 1959.
AD-231 915.

The scatter effects of the shock wave under suitable circumstances, which are easily attained in practice, are shown to significantly alter the echo area of the object producing them, and, in many cases, completely determine the observed echo area. It is shown possible to determine radar return from an object moving at very high speed by its associated shock wave; thus the radar return will be independent of the intrinsic radar properties of the object (at rest) causing the shock wave. To illustrate shock wave effects on echo area, the echo area of a sphere (one meter in radius) traveling through the atmosphere (altitude = 161,000 ft) over a range of speeds (M = 10 to M = 15) are determined for 18 kmc radar. It was found that, because of the physical conditions to which the air in the shock wave is subjected, the shock wave will contain a large number of ions and can be described as a plasma. The plasma distribution about a sphere is assumed to be the same as for the stagnation point. Only approximations based on geometrical optics are considered. Expressions for back scatter from the dielectric sphere and for the metallic sphere with a homogeneous shell are considered, as well as the bistatic echo areas. Some expressions are derived for a system suitable for modeling in laboratory configurations involving shock waves.

3778

Hain, K., "Interaction of Two Powerful One-Dimensional Shock Waves" (in German), Z. Naturforsch., 11a, 329-339, 1956.

The two types of possible interaction between two powerful one-dimensional shock waves, namely, collision and overtaking, are discussed mathematically for the case of waves which have already attained their asymptotic stable form, corresponding to the homologous distribution factor K = 0.39. In the case of collision, for which, up to the present, only an approximate solution has been derived, numerical calculations show that the development of shock waves with time is essentially independent of the initial Mach number, and that all shock waves practically disappear after reaching the same homologous distance, ξ = -0.7, from the point of collision. In the case of overtaking waves, calculations show that the stability of the homologous solution corresponding to K = 0.39 is renewed after the waves meet, the whole wave distribution very quickly reverting to this homologous distribution.

3779

Hakkinen, R. J., I. Greber, and others, "The Interaction of an Oblique Shock Wave with a Laminar Boundary Layer," NASA Memo No. 2-18-59W, Washington, D. C., 49 pp., 1959.
AD-213 639.

The results of some experimental and theoretical studies of the interaction of oblique shock waves with laminar boundary layers are presented. Detailed measurements of pressure distribution, shear distribution, and velocity profiles were made during the interaction of oblique shock waves with laminar boundary layers on a flat plate. From these measurements a model was derived to predict the pressure levels characteristic of separation and the length of the separated region.

3780

Hanish, S., "The Interaction Mechanical Radiation Impedance Between Two Pistons Arbitrarily Oriented in Space Without a Baffle," Rept. No. 5789, Naval Research Lab., Washington, D. C., 5 pp., 1962.
AD-276 658.

Two pistons, with enclosed backs, located on the imaginary surface of a geometric sphere and generating sound in a coupling-fluid medium, interact with each other mechanically. Neglecting scattering effects, and restricting the analysis to the evaluation of the acoustic pressure over the second piston face due to the motion of the first piston, an equation is derived for the interaction mechanical radiation impedance coefficient between these two pistons without baffles. The derived formula is compared with the known formula for the interaction impedance between two pistons in a rigid spherical baffle. Although the derived formula is in the form of an infinite series, no actual numerical computation is performed because of the complexity of the terms in the series.

3781

Hardy, H. C., "Unsolved Basic Physical Research Problems in the Field of Noise," J. Acoust. Soc. Am., 24, 767-768, 1952.

Many of the basic unsolved problems in noise research could be attacked by the application of statistical mathematics and techniques instead of use of the conventional sine wave approaches. Such techniques could be applied to many sound radiation and diffraction problems. The fields of hydrodynamics and acoustics should be brought closer together, which would result in better understanding of the noise of a turbulent medium. Among the various unsolved noise measurement problems are the design of meters for measuring transients, intensity meters and better sound level meters. Several other basic projects are mentioned briefly.

3782

Hazel, H., "Beat Notes, Combination Tones and Side-Bands," Phil. Mag., 19, 103-114, 1935.

Following a brief discussion of the Helmholtz-Koenig controversy and the more recent side-band controversy, an account is given of experimental work bearing on these questions. It is shown that there is a difference between beat tones and differential tones. Beat tones, produced by simple addition of frequencies, elicit no response in detecting devices tuned to their frequency. Combinational tones or sidebands have objective existence if peak response in a linear periodic circuit is used as the criterion of existence. These derived frequencies are produced by modulation, which is the multiplication of one periodic disturbance by another. Modulation can be secured either in linear or nonlinear circuits. Sound waves do not appreciably modulate one another in air and their sources do not give appreciable modulation even when mechanically coupled.

The Helmholtz-Koenig combinational tone controversy was due to misunderstanding of the conditions for modulation and to failure of the experimenters to make the receiving devices independent of the ear. The sideband controversy was based on vague definitions of physical existence and upon the illegitimate use of nonlinear elements in detecting apparatus.

3783

Hendricks, C. D., C. Gruber, et al., "Research into Some of the Basic Physics of Shock Wave Phenomena," Final Rept. No. AFCRL 62-580, Electrical Eng. Res. Lab., Univ. of Ill., Urbana, 82 pp., 1962.
AD-284 483.

Presents an analysis of the interaction of electromagnetic waves in the frequency range 2.5 to 30 kilomegacycles/sec with the ionizing shock front. The modes and degrees of coupling between the shock wave and the electromagnetic wave, and methods for controlling this coupling, are considered, using electromagnetic power levels sufficiently high to permit experiment without appreciably disturbing the environment. The transfer of thermal energy in the region of the shock front is considered, as well as the relative degrees of ionization attainable in shock waves in the equivalent environment of the upper atmosphere up to 100 miles. The experiments for the most part were carried out in the 4 in. × 15 in. × 35 ft aluminum, combustion-driven shock tube.

Shock waves were produced in the range from Mach 6 to Mach 22, with initial atmospheric gas pressure in the vicinity of 1 mm Hg. The experiments themselves consisted of propagating a very high level C band microwave pulse in the end of the shock tube opposite to the direction of shock-wave travel. The microwave signal consisted primarily of a single 2-μ sec pulse. The microwave measurements consisted of propagating a low-level 30 kmc signal across the shock tube in the wide dimension and observing transmitted and reflected signal amplitudes and the phase shift in the transmitted signal, compared with a reference phase.

3784

Hershberger, W. D., E. T. Bush, and G. W. Leck, "Thermal and Acoustic Effects Attending Absorption of Microwaves by Gases," RCA Rev., 7, 422-431, 1946.

Fifteen gases strongly absorb microwaves. Measurement techniques are described, and the theoretical interpretation of the observed absorption for some of the simpler molecules is given. Thermal conversion is shown by confining an absorbing gas in a cavity resonator that communicates with a U-tube. A 12-in. deflection of the U-tube column is obtained when the average input power is 10W. Acoustic conversion is shown by exposing a gas-filled balloon to a modulated microwave field. The absorbing gas may be confined in an organ pipe closed at one end by a piezoelectric crystal. This organ pipe is resonant electromagnetically to the impressed microwave frequency and acoustically to the modulation frequency; it has a square law response and detects 10 milliwatts.

3785

Hessel, A., N. Marcuvitz, and J. Shmoys, "Scattering and Guided Waves at an Interface Between Air and a Compressible Plasma," Res. Rept. No. PIBMRI-953-61, Microwave Res. Inst., Polytechnic Inst. of Brooklyn, N. Y., 21 pp., 1961.
AD-273 149.

The problem considered is that of radiation by a uniform magnetic-current line-source parallel to a rigid-plane interface between free space and a compressible plasma. The line source is located in the free-space region. The plasma is assumed to be a compressible electron gas with no drift and no dc magnetic field. Small signal theory is used. Reflection and transmission coefficients for a plane electromagnetic wave incident on the interface from the free-space side are calculated. The interface is found to support a surface wave, whose properties are examined. This surface wave, unlike the corresponding one for incompressible plasma, does not have a high-frequency cut-off. Expressions for all (electromagnetic and acoustic) field components excited by the line are obtained.

3786

Holder, D. W., C. M. Stuart, and R. J. North, "The Interaction of a Reflected Shock with the Contact Surface and Boundary Layer in a Shock Tube," Rept. No. 22891, Aeronautical Res. Council, Great Britain, 20 pp., 1961.
AD-273 535.

The experiment was designed to investigate the departures of the hypersonic shock tunnel operated by the reflected-shock technique from the simple theoretical model, by providing photographs illustrating the interaction of the reflected shock with the boundary layer and with the contact region. Results were obtained for representative values of primary shock Mach number, using hydrogen as the driving gas and nitrogen as the driven gas. The work demonstrates that there are striking differences between the observed flows and those assumed in inviscid theory, and predictions of the theory. These are particularly marked in connection with the disturbances reflected from the contact surface, and with the motion of the shock transmitted through the contact surface when the primary-shock Mach number is high.

On the other hand, the motion of the contact surface, after meeting the reflected shock, agrees reasonably with theoretical predictions. As far as the operation of shock tunnels is concerned, the results are not discouraging, especially at the tailored condition, where there appears to be reasonable agreement with the promising predictions of theory. It is noted, however, that because of the low pressure levels employed, the present results are in some respects dissimilar to those observed in other shock-tunnel investigations.

3787

Hollingsworth, M. A., and E. J. Richards, "On the Sound Generated by the Interaction of a Vortex and a Shock Wave," Rept. No. 18257, Aeronautical Res. Council, Great Britain, 18 pp., 1956.
AD-140 844.

Recent work by Ribner has been utilized to estimate the distribution of intensity in the sound wave resulting from the interaction between a vortex and a shock wave. The specific objectives were to obtain the order of magnitude of the sound pressures obtained and the dependence of their magnitude upon shock strength and vortex strength. The distribution is compared with a Schlieren photograph of the interaction. Based on the analysis, the sound pressures are found to increase steadily with both Mach number and vortex strength. Particular estimates of sound levels depend critically upon the flow conditions, but curves are attached for a typical wind-tunnel case indicating very intense sound levels for small-percentage velocity fluctuations.

3788

Ingard, U., "Simple Examples of Magnetomechanical Wave Motion," J. Acoust. Soc. Am., 31, 1033-1034, 1959.

The phase velocity on a periodic line consisting of coupled mass elements (coils) in a magnetic field is shown to be analogous to the phase velocity of a transverse Alfven wave in a conducting, incompressible fluid. As another example of the magnetomechanics of a simple distributed system, the motion of a conducting string in a magnetic field is discussed.

3789

Ingard, U., and G. C. Maling, "Noise Generated by Two Interacting Air Jets," J. Acoust. Soc. Am., 31, 1031-1033, 1959.

It has been observed that the excess noise generated as a result of the interaction or mixing of two small air jets is considerably greater than the noise produced by the individual jets. The interaction noise produced by jets that lie in the same plane has been measured for jet intersection angles between 0 and 180°. Similar measurements have been made as a function of jet separation by using two jets that intersect at a 90° angle but do not lie in the same plane.

3790

Johnson, W. R., "The Interaction of Plane and Cylindrical Sound Waves with a Stationary Shock Wave," Rept. No. 2539-8-T, Doctoral Thesis, Eng. Res. Inst., Univ. of Mich., Ann Arbor, 133 pp., 1957.
AD-146 197.

This investigation theoretically treats the problem of the interaction of plane and cylindrical sound waves with a stationary shock wave. The linearized Euler differential equations and the corresponding linearized shock conditions serve as the fundamental laws for this study. Plane-wave solutions to the differential equations are found, and the analogues of Snell's laws of reflection and refraction are determined, together with the "Fresnel" formulae. Integral solutions to the differential equations corresponding to incident cylindrical waves are then found from the plane-wave solutions by a method devised by H. Weyl (Ann. Physik, 60, 481, 1919). These integrals are investigated to determine the reflected and refracted field of a line source. Generalizations of the theory for moving shocks and point sources are set up but not investigated in detail.

3791

Johnson, W. R., and O. Laporte, "Interaction of Cylindrical Sound Waves with a Stationary Shock Wave," Phys. Fluids, 1, 82-94, 1958.

The interaction is investigated by a method analogous to that used by Weyl in his treatment of the propagation of radiowaves over the surface of a plane earth. The incident cylindrical sound wave is represented as a superposition of plane sound waves of varying direction. Each of the plane waves in this superposition interacts with the shock giving rise to a previously determined distortion of the shock front and reflected or refracted wave field; the cylindrical wave causes a disturbance that may be written in integral form as a superposition of these plane waves. The resulting interaction integrals are evaluated asymptotically to give explicit formulae for the distortion of the shock, the sound field, and the entropy-vorticity wave.

3792

Kestin, J., and L. N. Persen, "The Effect of a Standing Sound Field on a Slow Stream Discharged from a Porous Wall," Interim Tech. Rept. No. ARL-169 (Rept. on Research on Aerodynamic Flow Fields), Brown Univ., Providence, R. I., 25 pp., 1961.
AD-278 373.

Discusses the flow pattern that results when a stationary sound field is created outside an infinite plane wall through which a fluid is slowly discharged. It is shown that the field can be obtained as a simple superposition of the secondary flow field, calculated by H. Schlichting, and the velocity of discharge. Flow patterns are sketched, and one of them is compared with a photograph obtained by R. M. Fand and J. Kaye under sufficiently similar conditions. The agreement between the two patterns is very satisfactory.

3793

Kitowski, J. V., "The Effect of Sound on the Lift of an Airfoil," Master's thesis, Texas A. and M. Coll., College Station, 36 pp., 1962.
AD-275 638.

The effect of sound on the lift of an airfoil, as determined by the pressure-distribution method, was investigated. The tunnel speed, frequency of sound, power output of the audio-oscillator, and incidence of the airfoil are the parameters that were varied in this investigation. It was found that applied sound caused an increase in lift ranging from 18.2 to 39.4% at 19° angle of attack and 13.6 to 32.9% at 20° angle of attack in the range of speeds tested.

3794

Klein, S., "Strong Demodulation in Air of Two Ultrasounds of Different Frequencies" (in French), Ann. Telecommun., 9, 21-23, 1954.

Two ultrasonic sound sources are situated 10 cm apart and facing each other. The frequency of audible sound is exactly the difference betwen the two ultrasonic frequencies. The intervening space is analyzed and it is shown that the audible sound arises at the nodes and antinodes of pressure of the ultrasonic stationary wave system. To obtain reproduction of music and speech two systems are indicated, one utilizing frequency and amplitude modulation, and the other, only frequency modulation. Circuit diagrams are given.

3795

Kontorovich, V. M., and A. M. Glutsyuk, "Transformation of Sound and Electromagnetic Waves at the Boundary of a Liquid Conductor in a Magnetic Field," Zh. Eksperim. i Teor. Fiz., 41, 1195-1204, 1961.

See Also: Soviet Phys. JETP English Trans.

Calculates the electromagnetic field that arises when a sound wave strikes the boundary between a conducting liquid and a nonconducting medium in a weak magnetic field. The amplitude of the sound waves diverging from the interface on which electromagnetic waves are incident is also determined.

3796

Kulsrud, R. M., "Effect of Magnetic Fields on Generation of Noise by Isotropic Turbulence," Astrophys. J., 121, 461-480, 1955.

Lighthill's (1952) and Proudman's (1952) results on the generation of aerodynamic noise by isotropic turbulence are generalized to include magnetic effects. It is found that if there are only turbulent magnetic fields present, and no constant magnetic field, the magnetic turbulence generates sound very efficiently and considerably increases the generation of sound by kinetic turbulence. If there is a constant magnetic field, hydromagnetic waves are generated instead. For the modified sound mode of the hydromagnetic waves, a result similar to the case of no general field is obtained. No energy is generated into the Alfven and modified Alfven waves unless the energy density of the magnetic field is greater than the energy density of the kinetic turbulence. Expressions are found for the rate of noise generated per unit mass, and these results are applied to the problem of heating the chromosphere and the corona.

3797

Lauvstad, V., and S. Tjtta, "Problem of Sound Scattered by Sound," J. Acoust. Soc. Am., 34, 1045-1050, 1962.

The sound generated by the nonlinear interaction of two sound beams of high intensity, arranged to cross each other perpendicularly, is computed to the first order of interaction. Several of the assumptions and specializations in previous treatments of this problem, whose effects on the result it is hard to estimate, are avoided. The interaction is supposed to take place in the Fraunhofer zone of both beams.

Some results are valid. For instance, the Doppler angles computed and measured by Ingard and Pridmore-Brown are found without any strict specializations of the primary beams and the interaction region.

Estimates of the amplitudes of the generated pressure, governing rather wide ranges of frequencies of the primary beams, seem to agree with the previous apparently strongly differing results. This correspondence is brought forward by an amplitude factor, depending on the frequencies of the primary beams.

In the high-frequency limit, the destructive interference among the quadropoles, which cause the generated sound, dominates the results and gives an over-all zero value of the generated pressure, in accordance with Westervelt's treatment.

3798

Lin, S. C., "Ionization Phenomenon of Shock Waves in Oxygen-Nitrogen Mixtures," Res. Rept. No. 33, AVCO Research Lab., Everett, Mass., 23 pp., 1958.
AD-201 912.

An experimental method is described for the study of ionization phenomenon associated with shock waves in gases. By proper choice of experimental conditions, this method should allow a direct and unambiguous determination of the electron density and the averaged electron-molecule (and atom) interaction cross section as a function of distance behind the shock front. Preliminary results obtained for shock waves in a number of oxygen-nitrogen mixtures are presented.

3799

Ludford, G. S. S., "The Propagation of Waves Along and Through a Conducting Layer of Gas," J. Fluid Mech., 9, 119-132, 1960.

Two related questions concerning the transmission of electromagnetic waves are considered:

(1) The reflexion and transmission of plane waves at a perfectly conducting layer of gas in an otherwise nonconducting atmosphere, when there is a uniform external magnetic field perpendicular to the layer. Here the main result is that a layer of finite depth h is an almost perfect filter, being transparent to waves of frequency $n\pi A_0/h$(A_0 = Alfven velocity, n an integer).

(2) The existence of plane surface waves for such a finite layer. There is always one such wave, and for certain ranges of frequency there are two. The first becomes 'choked' at the filter frequencies, its velocity first tending to zero and then jumping to a finite value. The second chokes at the frequencies $n\pi A_0 a_0/h\sqrt{(a_0^2 + A_0^2)}$ (a_0 = acoustic velocity).

3800

Mark, H., "The Interaction of a Reflected Shock Wave with the Boundary Layer in a Shock Tube," Tech. Memo No. TM 1418, Natl. Advisory Committee for Aeronautics, Washington, D. C., 128 pp., 1958.
AD-155 060.

By theoretical analysis the existence of several different types of interaction in different ranges of initial shock Mach number is predicted. This analysis is verified experimentally. The most complicated interaction is studied in detail, and a model is proposed. The features of the phenomenon are analyzed, based on this model, and are checked experimentally. The case of interaction with a turbulent boundary layer is also considered. A method is proposed whereby the effect of the laminar-boundary-layer interaction on the strength of the reflected shock may be calculated, and a comparison with experimental results is presented.

3801

Maurin, J., and L. Medard, "Remote Freezing (Congelation à Distance) of a Super-Cooled Cloud by Shock Waves" (in French), Compt. Rend., 225, 432-434, 1947.

It was known qualitatively that fog particles would be solidified by waves produced by a klaxon, a siren, or a rifle. Tests were carried out at Mont-Lachat by the ignition electrically of 50g of penthrite to obtain quantitative measurements of the rate of freezing produced by the shock waves. It was found that a small drop would be frozen by a pressure discontinuity of 10^5g/cm^2/sec.

3802

Mawardi, O. K., "Aero-Thermoacoustics (The Generation of Sound by Turbulence and by Heat Processes)," Repts. Progr. in Phys., 19, 156-186, 1956.

An analysis of the general equations of the motion of a viscous compressible fluid leads to the identification of three modes (vorticity, compression and entropy modes) of energy associated with the fluid. Interaction between these modes gives rise to acoustical phenomena, of which some are of great interest to the study of aircraft noises. The first part of this report deals with acoustical effects resulting from the interaction of a vorticity and a compression mode. It considers in detail the generation of sound from turbulence as encountered in a jet and in a boundary layer, and the scattering of sound from turbulence.

In the remaining part, the interaction of the entropy mode with the compression mode is discussed. Special emphasis has been placed on the study of heat-maintained vibrations as encountered in Rijke's phenomenon and in flame-driven oscillations. The article concludes with a speculative discussion of acoustical phenomena in which the couplings between the three modes are equally important.

3803

Mawardi, O. K., "On Thermoacoustic Transduction in a Potential Flow," J. Acoust. Soc. Am., 28, 239-245, 1956.

The interaction between an acoustic field and a thermal field is worked out for the case of a sound wave propagating down a channel in which the convection of heat occurs in a potential flow. The analysis, restricted to inviscid fluids, shows that the magnitude of the sound wave is reinforced as it propagates through the thermal field. The extent of this reinforcement is given in the form of an amplification factor that depends on the parameter of the flow and on the frequency of the sound wave.

3804

Menzel, D. H., and D. Layzer, "Interaction of Electro-Magnetic and Acoustic Waves in an Ionized Medium," Final Rept. No. 1, D. H. Menzel, Cambridge, Mass., 1959. AD-231 255.

A reformulation and critical discussion of ionospheric cross-modulation shows that the main predictions of the current theory depend on the assumptions that the effect is small enough to justify a linearized description; and that certain average properties of the electrons, such as the electron temperature, the (mean) collision frequency, and the rate of cooling of the electron gas by collisions between electrons and gas-molecules, are related in a way that does not depend on the modulation frequency. A theory of ionospheric cross-modulation is developed on the first assumption alone.

3805

Mickelsen, W. R., and L. V. Baldwin, "Aerodynamic Mixing in a High-Intensity Standing-Wave Sound Field," J. Acoust. Soc. Am., 29, 46-49, 1957.

Aerodynamic mixing is fundamentally important in many fluid flow processes, some of which have intense superimposed sound fields. The effect of a transverse sound field on the temperature field downstream from a line source of heat was investigated both analytically and experimentally. In moderately intense sound fields, the temperature field is affected only in the time-mean sense. In intense sound fields, the heat wake is substantially deformed so that both the time-mean and instantaneous temperatures are considerably reduced.

3806

Morrone, T., "Excitation of Acoustical Waves in a Plasma," Rept. No. PIBMRI-893-61, Microwave Research Inst., Polytechnic Inst. of Brooklyn, N. Y., 24 pp., 1961. AD-266 098.

Investigates the possibility of putting significant amounts of power into the acoustical wave by a suitable choice of parameters characterizing the plasma and the incident wave. The parameters are plasma density, collision frequency, angle of incidence, and electromagnetic wave frequency. The conclusion reached is that under ordinary laboratory conditions it is not possible to transfer significant power to the acoustical wave, and that in problems of propagation in a plasma, acoustical wave considerations may be neglected with very little error. The conclusions are based on a small-signal linear analysis, and are subject to the model of the plasma assumed, i.e., a neutral, weakly ionized, uniform plasma with electron, ion, and neutral temperatures equal except for small perturbations. In an appendix the assumptions and development that lead to the dynamical equations used in this analysis are discussed, and a quantitative estimate is made of the region where the small signal analysis is valid. Above a certain power level the equations become nonlinear.

3807

Oppenheim, A. K., and P. A. Urtiew, "Vector Polar Method for Shock Interactions with Area Disturbances," Tech. Note. No. DR 4, Univ. of Calif., 1959. AD-220 405.

The application of the vector polar method to the study of interactions between plane traveling shock waves and area disturbances involves the introduction of steady flow polars. The study covers first the interaction of shock waves with single area disturbances, that is, divergences or convergences placed between two constant area tubes. Resulting wave systems for the whole field of area ratios, R, and incident shock Mach numbers, M_i, are described. Representative cases are evaluated by the vector-polar method and the regimes of solutions delineated on the R - M_i diagrams for perfect gases with constant specific heats. Then interactions with convergent-divergent nozzles are treated in a similar manner. The solutions obtained by the vector-polar method are shown to compare favorably with analytical and experimental results obtained by other investigators who studied the interactions of shocks with a variety of obstacles, such as grids and gauzes, in shock tubes.

3808

Pfriem, H., "On Superposition of Undamped Plane Gas Waves of Large Amplitude," Akust. Z., 7, 56-65, 1942.

Reports derivation of the simultaneous, nonlinear differential equations characterizing the wave form in the range of superposition of two plane gas waves moving in opposite directions. Using Riemann's method, these are reduced to a second-order linear differential equation, the solution of which may be found for perfect gases. After passing the range of superposition, the two pressure waves have the same waveform as if propagated in space without mutual interference, but distortions within the range of superposition influence the resultant field.

3809

Tellmien, W., "Research on Investigation of the Interaction of Sound and Turbulence," Max-Planck Institute, Germany, 1957. AD-154 138.

The scattering of sound by turbulence in the atmosphere was investigated both theoretically and experimentally, and the results of one year's work are presented in this report. The elementary process of scattering by one turbulent eddy is treated theoretically. Fields of flow are then postulated, in which the vortices are placed statistically according to an arbitrary distribution function that controls direction of axes, size, and circulation of the vortices. The choice of distribution function permits treatment of isotropic as well as nonisotropic turbulence.

The section of the report on experimentation describes the mechanical and electronic apparatus that was developed for controlling and measuring the degree of turbulence, the average size of the eddies, and the velocity profile of the mean flow. Preliminary measurements were made throughout the audio range and up to frequencies of about 200 K cps.

3810

Polachek, H., and R. J. Seeger, "On Shock-Wave Phenomena: Interaction of Shock Waves in Gases," Proc. Symp. Appl. Math., 1, Am. Math. Soc., N. Y., 119-144, 1949.

A detailed summary of the existing mathematical theory.

3811

Powell, A., "One-Dimensional Treatment of Weak Disturbances of a Shockwave," Rept. No. 20125, Aeronautical Research Council, Great Britain, 12 pp., 1958. AD-207 233.

A shockwave enters a region of fluid initially at rest; the shockwave motion is disturbed by interaction with soundwaves or temperature fluctuations. The resultant soundwaves and temperature changes behind the shock are discussed. The Appendix outlines a corrected version of an earlier treatment which considered an initially stationary shockwave. Numerical values of the interaction coefficients up to $M_1 = 5$ are given.

3812

Pritchard, R. L., "Mutual Acoustic Impedance Between Radiators in an Infinite Rigid Plane," J. Acoust. Soc. Am., 32, 730-737, 1960.

A series solution has been obtained for the mutual acoustic impedance between two identical circular disks vibrating in an infinite plane. Under simplifying conditions, the resistive and reactive components of the mutual impedance can be expressed in terms of a simple trigonometric function. The problem was formulated in terms of Bouwkamp's method of integrating over real and complex angles the square of the directional characteristic (relative sound pressure at a large fixed distance) to yield the total radiation impedance. Integrals involved here are similar to a type previously evaluated by Stenzel, and may be expressed in terms of a double series containing Bessel functions of integral and half-integral order. Numerical values of the mutual acoustic impedance obtained by this method for two rigid disks are in good agreement with values obtained by Klapman by direct integration of the pressure at the surface of the disks. The acoustic self impedance and mutual impedance may also be calculated by the same methods for a more general type of circular disk having a prescribed radially symmetric velocity distribution.

To illustrate the applicability of these results, the total acoustic loading upon an array of circular disks is calculated by taking into account the mutual acoustic impedance between the disks comprising the array. Numerical results are given for a circular array of seven identical disks having a small radius, relative to a wavelength, and vibrating uniformly in a common, rigid plane.

3813

Rhude, D. P., "Transmission of an Electro-Magnetic Wave Through a Hypersonic Shock Wave," Rept. No. GE-59A-9, Air Force Inst. Tech., Wright-Patterson Air Force Base, Ohio, 64 pp., 1959.
AD-214 679.

Hypersonic vehicles traversing the earth's atmosphere create a highly ionized shock region of heated and compressed air. The classical solution for electro-magnetic ionospheric propagation may be best adapted to propagation through shock regions by introducing a complex dielectric constant. Shock-region propagation may be considered the cumulative effect of cascaded homogeneous dielectric walls. The resultant equation may be solved by a digital computer if shock-region temperature and density distribution are available. Calculations indicate that transmission is possible with less than 3 db loss if the incident frequency is greater than 20% of the maximum plasma-resonant frequency.

3814

Ribner, H. S., "The Sound Generated by Interaction of a Single Vortex with a Shock Wave," Rept. No. 61, Inst. of Aerophys., Univ. of Toronto, 20 pp., 1959.
AD-230 719.

Investigates the passage of a columnar vortex broadside through a shock. The vortex is decomposed (by Fourier transform) into plane sinusoidal shear waves disposed with radial symmetry. The plane sound waves produced by each shear waveshock interaction, known from previous work, are recombined in the Fourier integral. The waves possess an envelope that is essentially a growing cylindrical sound wave, partly cut off by the shock. The sound wave is centered at the transmitted (and modified) vortex, and the peak pressure attenuates inversely as the square root of the growing radius. The strength varies smoothly around the arc, from compression at one shock intersection to rarefaction at the other shock intersection. Comparison is made with results of a shock-tube investigation and heuristic theory by Hollingsworth and Richards in England.

3815

Roy, A. K., "Estimation of the Characteristic Velocity for the Propagation of the Disturbance Up-Stream in Shock Wave Boundary Layer Interaction Problems," Proc. Nat. Inst. Sci. India A, 26, 19, 1961.

In shock boundary-layer problems, considerations of the whole of the boundary layer is not important. On similarity considerations and utilizing existing experimental data, Roy calculated (1959) the thickness of the critical viscous sublayer (a fraction of the total boundary layer thickness), which is important for the propagation of the disturbance up-stream in such problems. In the present paper, following the method of Roy, the Mach number of the characteristic flow in the region of this viscous sublayer is estimated and found to lie between the limits 0.15 and 0.6 (in cases of flow with or without separation).

3816

Roy, A. K., "Estimation of the Critical Viscous Sublayer in Shock Wave Boundary Layer Interaction," Z. Angew. Math. Phys., 10, 82-89, 1960.

In a theory of the interaction between weak shock waves and boundary layers, Lighthill has pointed out that disturbances to the viscous forces (caused by the shock) are confined essentially to an inner sublayer. The author has estimated the thickness of this layer, and finds that it is of order 10% of the total boundary-layer thickness for a laminar layer and 1% for a turbulent layer. For turbulent layers, it is accordingly well within the laminar sublayer.

3817

Sakurai, A., "The Flow Due to Impulsive Motion of a Wedge and Its Similarity to the Diffraction of Shock Waves," J. Phys. Soc. Japan, 10, 221-228, 1955.

An analysis is performed to clarify the nonuniform region of the air flow caused by impulsive motion of a wedge with small vortex angle. It is shown that the present problem is quite similar to the well-known problem of the interaction of a shock wave and a wedge. By use of this similarity, some cases of wedges without small vortex angles are discussed.

3818

Schilz, W., "Investigation of the Interaction Between the Sound Field and Flow in a Duct Coated with Porous Absorbers and Helmholtz Resonators," Acustica, 11, 137-151, 1961.

Sound attenuation in ducts with absorbent coating of the walls is strongly dependent on the direction and velocity of the air flow. The change of attenuation is brought about by a change of the characteristic properties of the absorbing material and by the deformation of the phase surface of the sound field caused by the air flow. Calculated values of the attenuation, with both effects taken into account are in good agreement with experimental values. The sound amplification mechanism in a duct coated with undamped Helmholtz resonators is explained in the interaction between the soundfield and the turbulence of flow. Conversion of flow energy into sound energy is effected by synchronization of the turbulence. Under favorable circumstances this synchronization leads to the formation of a stable pseudosound wave. Pseudosound and sound interact at the resonator necks.

3819

Soehngen, E. E., and J. P. Holman, "Experimental Studies on the Interaction of Strong Sound Fields with Free Convection Boundary Layers," ARL TR 60-323, Aeronautical Research Lab., Wright Air Development Div., Wright-Patterson Air Force Base, Ohio, 1961.
AD-249 104.

Experiments were conducted on the interaction of strong sound fields with free convection boundary layers on horizontal, heated cylinders of 0.750-inch diameter. The interaction effects were observed through the measurements of the total heat transfer from the cylinders to air under the influence of different types of sound environments. Three different types of sound fields were employed for the experiments: (1) standing plane waves generated by loudspeakers in an anechoic chamber; (2) traveling plane wave fields generated by a mechanical siren in an anechoic duct; and (3) constant pressure or diffuse sound fields generated by a mechanical siren in a reverberant chamber. In all cases the generated sound was monochromatic. The frequencies covered a range from approximately 1000 to 6000 cps at sound intensities ranging from 0 to 152 db. The temperature difference between the test cylinder and air was varied between 20° and 250°F.

3820

Sprott, A. L., "The Effect of Strong Progressive Sound Waves on Free Convection Heat Transfer from a Horizontal Cylinder in Air," Rept. No. GAE-59-22, Air Force Inst. of Tech., Wright-Patterson Air Force Base, Ohio, 1959.
AD-227 506.

An experimental investigation was made of the effect of progressive soundwaves on the free-convection heat-transfer coefficient, h, from a horizontal cylinder in air. Forty nine test runs were made over a range of frequencies from 1000 to 5000 cps and a sound-pressure-level range of 121 to 150 db. Shadow-photographs were taken at each combination of frequency and sound pressure tested. A critical sound pressure level below which no change in heat transfer occurred was observed. The value of this level ranged from 131 to 137 db, depending on frequency. The heat-transfer coefficient was found to increase in a highly nonlinear manner with increasing sound-pressure level above the critical. The maximum change in h observed was 184.5% at a sound-pressure level of 149.5 db and a frequency of 3220 cps. Shadow-photographs revealed a flow-separation phenomenon, which was determined to be the controlling factor in the increase of heat transfer. A periodic shedding of the separated flow regions as vortices was observed. A 16-mm motion picture was made of these effects in continuous sequence.

3821

Sprott, A. L., J. P. Holman, and F. L. Durand, "An Experimental Study of the Interaction of Strong Sound Fields with Free Convection Boundary Layers," Aeronautical Research Lab., Ohio, 26 pp., 1960.
AD-236 027.

It is demonstrated experimentally that strong progressive sound fields may interact with a free convection boundary layer on a horizontal cylinder in such a manner as to produce increases in heat transfer rates of the order of 100%. Shadowgraph flow visualization studies indicate that the mechanism of the interaction is such that a separated-flow region is produced on the upper side of the cylinder. No effect on the boundary layer or heat transfer is observed until the sound intensity is raised above a certain critical value. For the experiments described in the paper, the critical sound-pressure level ranged from 134 to 138 db. In a qualitative analysis of the experimental results it is postulated that the increase in heat transfer is the result of an interaction of the phenomenon of acoustical streaming with the free-convection boundary layer. It is also believed that the mechanism of thermoacoustic transduction may be applicable.

3822

Stepanov, N. S., "A Parametric Effect in Acoustics," Soviet Phys. Acoust., English Transl., 8, 104-106, 1962.

Discusses the interaction of a weak acoustic wave with a stronger wave with simple parameters of time, an ideal medium, and one coordinate in space.

3823

Stewartson, K., "On the Interaction Between Shock Waves and Boundary Layers," Proc. Cambridge Phil. Soc., 47, 545-553, 1951.

The effect on the boundary-layer equations of a shock wave of strength ϵ has been investigated, and it is shown that separation occurs when $\epsilon = 0(R^{-2/5})$ (R = Reynolds number of boundary layer). The boundary-layer assumptions are then investigated and shown to be consistent. It is inferred that separation will occur if a shock wave meets a boundary and the above condition is satisfied.

3824

Stocker, P. M., "On a Problem of Interaction of Plane Waves of Finite Amplitude Involving Retardation of Shock-Formation by an Explosive Wave," Quart. J. Mech. Appl. Math., 4, 170-181, 1951.

When dealing with an inviscid perfect gas with constant specific heats in the ratio 5/3, the interaction of a receding simple compression wave and an advancing, centered, simple expansion wave is calculated by the method of characteristic coordinates. The time is found by which the interaction delays the formation of a limit line. Shock formation can be delayed considerably but not indefinitely.

3825

Strehlow, R. A., and A. Cohen, "Comment on Reflected Shock Wave Studies," J. Chem. Phys., 28, 983-985, 1958.

Schlieren photographs show an acceleration and bifurcation of reflected shocks. These result from interaction with the boundary layer, and the bifurcation is greater for gases with low heat capacity ratio, γ. Criticizes determinations of dissociation energies and interpretation of the acceleration as vibrational relaxation by Toennies and Greene.

3826

Talbot, G. P., "Shock Bifurcation in a Heated Layer," Rept. No. (B)23/58, Armament Research and Development Establishment (Great Britain), 12 pp., 1958.
AD-204 828.

A specific example of shock-thermal layer interaction is considered, and the formation of a second shock is demonstrated. The time at which this shock first appears, its location, and its orientation are calculated. The equations governing the motion of the main shock in the thermal layer were obtained, and were solved numerically on the automatic high-speed digital computer AMOS, using the numerical method of characteristics.

3827

Taylor, L., "The Oblique Shock-Compression Wave Intersection in Shock Refraction," Tech. Rept. No. 531-1, Penn. State Univ., College of Chem. and Phys., Univ. Park, 77 pp., 1954-1957.
AD-209 801.

The one-dimensional interaction of a shock wave overtaking a compressional wave traveling in the same direction was treated theoretically. Interferograms of a special case of shock-wave refraction at grazing incidence along the interface of two gases were obtained, in which the intersection of the retransmitted compressional wave and the slow incident shock approximates the theoretical situation. Interferograms were also shown for a similar configuration in which there is an incident shock presented to the "slow" gas layer only. This resulted in a diffracted fast gas signal and consequently a weaker retransmitted wave. Qualitative and quantitative comparisons were made between theory and experiment where possible; they were found to agree well.

3828

Tellmien, W., "Research on Investigation of the Interaction of Sound and Turbulence," Rept. AFOSR TN-58-236, Max-Planck-Inst., Germany, 34 pp., 1958.
AD-154 138.

Investigation was made of the elementary process of the scattering of sound by a vortex and of the dependence of the scattering properties on the characteristic parameters of the problem. Consideration is given to superposition of the effects of elementary scattering in a field of flow in which the vortices are statistically distributed due to an arbitrarily given distribution function controlling direction of the axis, and the size and circulation of the vortices. This case represents the turbulent motion. Because the distribution function can be chosen arbitrarily one can treat, for instance, isotropic as well as nonisotropic turbulence.

3829

Tonning, A., "Scattering of Electromagnetic Waves by an Acoustic Disturbance in the Atmosphere," Appl. Sci. Res., Sec. B, 6, 401-421, 1957.

The variations in density associated with an acoustic wave are shown to influence the propagation of an electromagnetic wave. The variation in electric permittivity of the atmosphere, caused by an acoustic wave, is expressed by the power density of the wave. Under the assumption that the acoustic waves are spherical, the scattered field at large distances is given in terms of definite integrals that are evaluated by means of the stationary-phase method. The limiting case of plane acoustic waves is discussed, and two numerical examples are given.

3830

Trilling, L., "On Thermally Induced Sound Fields," J. Acoust. Soc. Am., 27, 425-431, 1955.

The sound fields induced in a real gas by variations in boundary temperature are examined to illustrate how the pressure, temperature, and vorticity modes of motion interact. The pressure mode describes the irrotational propagation of longitudinal disturbances; the temperature mode, convective heat diffusion; and the vorticity mode, the diffusion of vorticity introduced at boundaries by the no-slip condition (boundary layer).

The plane sound wave from a rise in instantaneous wall temperature is a sharp pulse, traveling at sonic speed and proportional to the inverse fourth root of the acoustic Reynolds number based on distanced travelled; its thickness grows as the square root of elapsed time. Along a wall, it generates a boundary layer whose friction coefficient is proportional to the inverse square root of the acoustic Reynolds number based on distance from the front. The resulting effective wall slope induces a secondary circular pressure pulse generated by the foot of the plane wave; because this source moves at sonic speed, a pressure singularity appears that comes from the contributions piled up since the beginning of the motion.

3831

Urick, R. J., "Radiation Impedance Study," Status Rept. No. 122, Chesapeake Instr. Corp., Shadyside, Md., 8 pp., 1960.
AD-243 126.

Progress is reported on a study of impedance interactions of transducer arrays. A theoretical treatment of the problem in terms of finite, spherical sources is presented, and the results of computations on sample arrays are given. The theoretical approach and the method of computation is believed to be much simpler and more amenable to practical results than previous theoretical treatments of the problem. Measurements of impedance using a specially designed transducer are presented. With the surface-reflected image as the second source, the impedance data agrees well with the theory in terms of absolute magnitude, but the phase angle of the impedance appears to differ by amounts ranging from 10° to 30°. The source of this difference is as yet unknown, but additional measurements are being made. A second transducer is being assembled for direct pair-measurements in the near future.

3832

Vas, I. E., "A Detailed Study of the Interaction of a 14° Shock Wave with a Turbulent Boundary Layer at $M = 2.9$," Rept. No. 296, James Forrestal Res. Center, Princeton, N. J., 8 pp., 1955.
AD-210 241.

A detailed study was made of the two-dimensional interaction between a shock wave and a turbulent boundary layer. The shock was generated by a 14° wedge located in the free stream at a Mach number of 2.92. Total head profiles were taken of the entire interaction region. The separation region extended about 6 1/2 boundary-layer thicknesses in length and 3/4 boundary-layer thickness in height. The maximum reverse velocity measured was 0.39 M. The pressure at the separation point was about 2.1 times the free-stream static pressure. The pressure at which separation occurred was also determined for wedges varying from 8° to 13°. No separation was evidenced for the 8° shock-generating case. The pressure ratio at separation was found to be relatively independent of shock strength.

3833

Vas, I. E., and S. M. Bogdonoff, "Interaction of a Shock Wave with a Turbulent Boundary Layer at $M = 3.85$," Rept. No. 294, James Forrestal Research Center, Princeton, N. J., 9 pp., 1955.
AD-201 644.

Results are given of an experimental investigation of the interaction between incident shock waves and a turbulent boundary layer at $M = 3.85$. The pressure ratio across the shock wave was varied from 1.5 to 3.0. Schlieren and shadowgraph pictures were taken, static pressures were measured along the wall, and the separation pressure ratio determined. The phenomena observed were, in general, similar to those observed at $M = 2.92$. For low incident shock pressure ratios (on the order of 1.8) the pressure along the wall rose smoothly to a maximum value with no separation. For a shock pressure ratio greater than about 2.2, an inflection point occurred in the static-pressure distribution and separation was observed. For incident-shock pressure ratios equal to or greater than 2.6, the overall phenomenon remained similar, only the scale of the interaction changed. The measured pressure ratio at the separation point was 2.4 as compared to a value of about 2.1 at M = 2.92.

3834

Werner, J. E., "Shockwave-Turbulence Interaction, Investigations in a Shock Tube," Rept. No. AFOSR TR 59-46, Inst. for Cooperative Res., Johns Hopkins Univ., Baltimore, Md., 134 pp., 1959.
AD-214 847.

Various aspects of the shock-turbulence interaction problem were investigated analytically and experimentally. The model of a cellular vortex field with a discrete front convected through a shock wave was studied theoretically. Expressions were derived for the unsteady pressure disturbance on the downstream face of the shock, and the displacement of the shock wave itself as the vortex field is carried through it by the mean flow. The interaction of a shock with a random-velocity fluctuation field was also considered. The relationship between pressure fluctuation and shock displacement was explored. In particular, the pressure-fluctuation level is found to depend on shock displacement, turbulence scale, and turbulence intensity. Techniques for measuring these three quantities in a shock tube are the subject of the experimental work. The constant temperature hot-wire anemometer was used to measure turbulence intensity, spectra and scale, while shock displacement measurements were made with the aid of shadowgraph pictures. A comparison was made between measured and theoretically derived shock displacement, and order-of-magnitude agreement is found.

3835

Werner, J. E., "Unsteady Interaction of a Shock Wave with a Cellular Vortex Field," J. Fluid Mech., 10, 195-208, 1961.

The transient effects generated when a shock wave is suddenly disturbed by a field of cellular vortices have been studied. Both the pressure disturbance on the shock and the local shock velocity are found to be strong functions of the cell geometry. Disturbances are resolved into transient components and sinusoidal components of constant amplitude. The transients are found to die out as $t^{-3/2}$, t being the interaction time, except for one particular case of the cell geometry for which they diminish as $t^{-1/2}$. Furthermore, the analysis indicates that the initial magnitude of the transient components may be quite appreciable in comparison with the sinusoidal component. The theory is extended to treat the convection through the shock of a single column of vortex cells.

3836

Westervelt, P. J., "Scattering of Sound by Sound," Brown Univ., Providence, R. I., 5 pp., 1956.
AD-138 758.

Owing to the inherent nonlinearity of the equations of motions for a perfect fluid, two or more sound waves passing through a common region generally will interact with one another and give rise to scattered waves. In this paper, a source function is obtained for the lowest order scattering process, which is quadratic in the primary-field variables. This function is rewritten in a form that demonstrates that no scattered waves exist outside the region of interaction of two sound beams intersecting each other at right angles. Furthermore, it is demonstrated that no such scattered waves exist when the two beams intersect at the angle

$$\theta = -\cos^{-1}\left[1/2\rho_0 c_0^{-2}\left(\frac{d^2 p}{d\rho^2}\right)\rho = \rho_0\right],$$

where ρ, c, and p stand for the density, sound velocity and pressure, respectively, and the subscript 0 means ambient values of these quantities.

The interfering effect of pseudo-sound, induced by radiational pressure, is suggested as an explanation for the results of Ingard and Pridmore-Brown, who have reported recently what they believe to be scattered waves from the interaction region of two sound beams intersecting each other at right angles.

3837

Westervelt, P. J., "Scattering of Sound by Sound," J. Acoust. Soc. Am., 29, 199-203, 1957.

Journal article based on preceding article.

3838

Westervelt, P. J., "Scattering of Sound by Sound," J. Acoust. Soc. Am., 29, 934-935, 1957.

Earlier studies of the mutual nonlinear interaction of two plane waves of sound are extended to encompass the arbitrary directions of travel of one wave with respect to the other; an exact solution to the first-order scattering process is obtained.

3839

Werner, W., "The Theory of Plane Waves of Finite Amplitude in Ideal Gases with Viscosity and Heat Conductivity," Ann. Phys., Germany, 7, 28-44, 1961.

The equations of motion lead to a single partial differential equation of the fifth order. Three types of particular solution are presented, and are applied in various physical contexts.

Wave Propagation, Interaction Effects
See Also—17, 235, 384, 527, 541, 725, 760, 763, 766, 864, 883, 884, 913, 914, 929, 994, 1239, 1277, 1465, 1905, 1909, 1956, 1959, 1960, 2029, 2142, 2143, 2144, 2152, 2183, 2185, 2186, 2265, 2453, 2475, 2484, 2706, 2797, 2877, 2909, 2992, 3003, 3010, 3201, 3216, 3461, 3530, 3556, 3557, 3602, 3680, 3681, 3846, 3853, 3861, 3876, 4013, 4022, 4079, 4108, 4136, 4161, 4221, 4280, 4312

WAVE PROPAGATION, MAGNETOHYDRODYNAMIC

3840

Akasofu, S., "Dispersion Relation of Magneto-Hydrodynamic Waves in the Ionosphere and Its Application to the Shock Wave," Sci. Repts. Tohoku Univ., Fifth Ser., (Geophysics), 8, 24-40, 1956.

In this paper, the dispersion relation for longitudinal and transverse propagation of the magneto-hydrodynamic waves in full ionospheric conditions is obtained according to Schluter's momentum balance equation. Then a retarded sound-type shock wave is studied according to the conclusion given above. It is shown that some rapid varying irregular features of the h'-f curve on the ionograms, which have vertical and horizontal motion, may be attributed to a retarded sound-type shock wave.

3841

Barach, J. P., "Interaction Between a Magnetic Field and an Electrically Produced Shock Wave," Phys. Fluids, 4, 1474-1477, 1961.

Shock flows of speeds up to 1 cm/μ sec in krypton were observed to interact with a magnetic field of 5700 gauss. A reflected shock was observed and deceleration of the flow measured. Gas flows of up to Mach 63 are produced by an annular electric shock tube powered by a capacitor discharge of long time-constant. A radial magnetic field geometry provides closed paths within the gas flow for the induced currents. The speed of the wave reflected off the magnetic field is found to increase slightly with interaction strength. The flow momentum lost per particle as the flow traverses the field region is calculated, and is compared to the impulse delivered each particle by the magnetic field. Approximate agreement is found over a wide range of experimental conditions, validating the magnetohydrodynamic picture of the interaction and the use of the scalar gas conductivity.

3842

Bleviss, Z. O., "A Study of the Structure of the Magnetohydrodynamic Switch-on Shock in Steady Plane Motion," J. Fluid Mech., 9, 49-67, 1960.

The structure of the steady magnetohydrodynamic switch-on shock wave is investigated for several orderings of the four diffusivities involved in the problem. The various orderings are approximated to by allowing one or more of the appropriate diffusivities to approach zero, and approximate solutions that are uniformly valid to order unity are sought. In general, singular perturbation problems are encountered, the number occurring (from zero to a maximum of three) depending upon the ordering of the diffusivities and the magnitude of the downstream of the shock. Where necessary, the approximate solutions are rendered uniformly valid to first order by the insertion of boundary layers, for which the approximate equations are determined to first order. For most of the cases considered, the limiting forms of the integral curves are determined and they are sketched in appropriate three-dimensional phase spaces.

3843

Chang, C. C., and Y. C. Whang, "Structures of Magnetohydrodynamic Detonation Waves," Rept. No. TDR-930 (2230-05) (TN-2), Aerospace Corp., Los Angeles, Calif., 17 pp., 1962.
AD-274 697.

Magnetohydrodynamic (MHD) detonation waves of electrically conductive gases and their structures are treated theoretically, with consideration given to reaction-energy release and transport properties. The energy release may be of thermonuclear origin for plasma of extremely high-temperature, or may be from chemical process for reactive gases under the influence of a specified magnetic field. With a simplified model of energy release and electric conductivity, the structures of the detonation waves are numerically calculated as examples. The preliminary results indicate that the MHD-detonation wave thickness is much larger than that of a MHD-detonation wave under the same upstream conditions. The coupling between the shock zone and the reaction zone is strong.

3844

Chasen, L., "Bibliography on Magnetohydrodynamics," T.I.S. Rept. No. R605D300, General Electric Co., Philadelphia, 1960.
AD-235 868.

A bibliography on magnetohydrodynamics is presented, representing a search of open literature and company documentary reports of essential references in the areas of magnetohydrodynamics, plasma physics, electric discharge-plasmas, and high-temperature research published from 1954 to 1959. A total of 195 references are listed alphabetically by author or corporate author.

3845

Daniels, F., S. Bauer, and A. Harris, "Vertically Traveling Shock Waves in the Ionosphere," J. Geophys. Res., 65, 1948-1950, 1960.

Atomic explosions have provided a means of studying hydromagnetic phenomena and the results have shown that two waves are propagated, the retarded sound wave and one, or a combination, of the other two hydromagnetic modes. The velocity of the faster wave confirms the view that the density of the whole gas rather than that of the ions alone should be used in computing the velocities of hydromagnetic waves.

3846

Dolder, K., "Experiments on the Passage of Shock Waves Through Magnetic Fields," AERE Rept. No. Z/R 2722, Atomic Energy Research Establishment, 13 pp., 1958.
AD-210 814L.

A combustion-driven shock tube was used to generate a rapidly moving stream of partially ionized argon of known density and electrical conductivity, which passed axially through the magnetic field of a short circular coil. Thus it was possible to study conditions necessary for the field to modify the initial motion of the ionized gas (i.e., for magnetohydrodynamic interaction to occur). High-speed photographic techniques were used to observe the luminous gas flow and, with the aid of pick-up coils, currents induced in the gas were estimated.

3847

Faulders, C. R., "The Speed of Propagation of a Magneto-Dynamically Driven Shock Wave" (in French), Compt. Rend., 254, 3490-3492, 1962.

The paper presents experimental results relating to the spatial variation of shock speed with distance travelled for a shock wave generated in a conventional electromagnetically driven shock tube. A simple, reasonably accurate theoretical explanation is given, using the normal shock relations together with equating magnetic forces caused by current flow to hydrodynamic pressure forces for a perfectly conducting gas.

3848

Fong, M. C., L. E. Bollinger, and R. Edse, "Magnetohydrodynamic Effects on Exothermal Waves, I. Theoretical Problems on a Macroscopic Scale, II. Experimental Study with Hydrogen-Oxygen Detonation Waves," Rept. on Research on Combustion Kinetics, Rocket Res. Lab., Ohio State Univ., Columbus, 90 pp., 1961.
AD-269 280.

Various problems associated with the macroscopic magnetohydrodynamic effects on an exothermal wave were treated on the basis of one-dimensional flow considerations. A steady exothermal wave traveling in an ionized medium under the influence of a transverse magnetic field was found to display properties similar to those of a classical detonation or deflagration wave. For a hydromagnetic exothermal wave, it was found that a discontinuity either in thermodynamic quantities or in magnetic field strength appears as soon as the flow reaches the transition region.

3849

Gogosov, V. V., "Disruption of a Non-Progressive Magnetohydrodynamic Shock Wave," Soviet Phys. Doklady, English Transl., 1962.

A solution of the appropriate dynamical equations is said to be progressive if it depends continuously on the parameters in terms of which the initial and boundary conditions are expressed. The present note concerns processes in which a shock wave is turned into a combination of progressive disturbances and self-similar waves of rarefaction. The theory of this change of flow-pattern is discussed and illustrated by diagrams.

3850

Gogosov, V. V., "Interactions of Magnetohydrodynamic Waves," Appl. Math. Mech., 25, 678-693, 1961.

The interactions of magnetohydrodynamic waves, fast and slow shocks, fast and slow expansion waves, and also interactions of magnetohydrodynamic waves with plane, ideally conducting walls, are examined. The medium is assumed ideally conducting. No restrictions are imposed on the parameters of the medium.

3851

Gogosov, V. V., "Interaction of Magnetohydrodynamic Waves with Contact and Vortex Discontinuities," App. Math. Mech., 25, 277-290, 1961.

The following interactions of magnetohydrodynamic waves are discussed: fast and slow shock waves; and fast and slow expansion waves, with vortex and contact discontinuities. The medium is assumed to be ideally conducting. No restrictions are imposed on the parameters of the medium. The possible combination of waves is determined.

3852

Greifinger, C., and J. D. Cole, "Similarity Solution for Cylindrical Magnetohydrodynamic Blast Waves," Memo. No. RM-3054-PR, Rand Corp., Santa Monica, Calif., 37 pp., 1962.
AD-278 473.

This analysis is primarily concerned with the interaction between the flow of an ionized gas and a magnetic field. The particular problem treated corresponds very closely to conditions existing in exploding wire experiments, and should prove useful in interpreting the results of such experiments.

3853

Griem, H. R., "Study of Shock Propagation in a Rare-Field Plasma, Interaction of Shock Waves with Magnetic Fields and Basic Laws of Magneto-Gas-Dynamics," Final Rept., Univ. of Maryland, College Park, 26 pp., 1961.
AD-272 821.

Mach 20-70 shock waves are produced by rapid ohmic heating from fast capacitor discharges between electrodes inserted into two opposing ends of a T-shaped tube, or from electrodeless discharges in a cylindrical tube surrounded by a single turn coil of a magnetic compression apparatus. With T-tubes, the shock waves propagate into about 1 mm Hg of hydrogen or helium that is pre-excited and ionized by the ultraviolet radiation from the discharge. With magnetic compression, about 0.1 mm Hg of hydrogen is pre-ionized and a slowly varying magnetic bias field is established by another capacitor discharge. Spectroscopic determinations of the equilibrium conditions behind the shock fronts in T-tubes were made, and are in progress for the cylindrically imploding shock waves in the magnetic compression experiment.

Some insight into the structure of the shock fronts was gained from the rise-times of spectral line intensities. The shock-heated plasma in the T-tubes is apparently in local thermal equilibrium and could therefore be used as a thermal light source for the determination of Stark broadening parameters of hydrogen and helium lines.

3854

Gundersen, R. M., "Magnetohydrodynamic Shock Propagation in Non-Uniform Ducts," MRC Tech. Summary Rept. No. 287, Mathematics Research Center, Univ. of Wisconsin, Madison, 21 pp., 1961.
AD-274 629.

Perturbation is produced when an initially plane magnetohydrodynamic shock wave encounters an area variation, the problem being linearized on the basis of small area-variations. To ensure that all changes in the behavior of the shock are caused by the nonuniform area, it is assumed that the area variations are confined to the region x = 0 while to the left of the section x equals 0 (say), the tube is of constant area, and the initially plane shock propagates through this portion with constant speed. The fluid in front of the shock is assumed at rest. When the shock meets the area variation, it is perturbed, the shock strength is altered, and the subsequent flow is nonisentropic. There are two distinct contributions to the disturbance, namely a permanent perturbation caused directly by the area change and a transient disturbance, due to reflection from the shock of the permanent perturbation, which propagates with velocity.

3855

Gundersen, R. M., "The Non-Isentropic Perturbation of a Centered Magnetohydrodynamic Simple Wave," MRC Tech. Summary Rept. No. 280, Mathematics Research Center, Univ. of Wisconsin, Madison, 11 pp., 1961.
AD-273 247.

Since the equations governing the motion of a perfectly conducting compressible fluid belong to the class of reducible hyperbolic equations, it is possible to build up a theory of simple waves that is rather parallel to that of ordinary gas dynamics. For a monatomic gas, analogs of the Riemann invariants can be determined explicitly. Because of the existence of a relation between the induction and the local speed of sound, valid for uniform or simple wave flows, it is possible to reduce the number of governing equations so that previous results may be extended to determine the nonisentropic perturbation of a centered magnetohydrodynamic simple wave.

3856

Gundersen, R. M., "Non-Uniform Magnetohydrodynamic Shock Propagation, with Special Reference to Cylindrical and Spherical Shock Waves," MRC Tech. Summary Rept. No. 310, Mathematics Research Center, Univ. of Wisconsin, Madison, 35 pp., 1962.
AD-275 706.

Previous work on nonuniform shock propagation in monatomic conducting gases is generalized to an arbitrary value of the adiabatic index. Specifically, the perturbation generated when an initially uniform hydromagnetic shock of arbitrary strength impinges on an area variation is determined, the problem being linearized on the basis of small area variations. When the shock encounters the area change, the shock strength is altered, and the subsequent flow is nonisentropic. There are two distinct contributions to the perturbation, namely, a permanent perturbation due to the area change and a transient reflected disturbance, and expressions for these are obtained.

A first-order relation between area change and shock strength is obtained and integrated numerically to give an area-shock strength relationship valid for channels with finite continuous area variation. Particular area distributions are utilized to discuss converging cylindrical and spherical hydromagnetic shocks. The present theory includes results on nonuniform gas dynamic shock propagation as a special case.

3857

Herlofson, N., "Magneto-Hydrodynamic Waves in a Compressible Fluid Conductor," Nature, 165, 1020-1021, 1950.

When the forces due to elastic compression are taken into account, there is, in addition to the two magnetohydrodynamic waves, a third wave that is essentially a sound wave disturbed by electromagnetic forces. If the magnetohydrodynamic velocity $V = H|\sqrt{(4\pi\rho)}$ is small compared with the velocity U of sound, the velocity of propagation is approximately $\sqrt{(U^2 + V^2 \sin^2 \phi)}$, where ϕ is the angle between the wave normal and the magnetic field.

3858

Hoffman, W. C., "Extremely Low Frequency Waves in an Inhomogeneous Hydromagnetic Medium and Geomagnetic Micropulsations," Math. Note No. 248, Boeing Scientific Research Labs., Seattle, Wash., 16 pp., 1962.
AD-273 492.

Describes a new type of wave motion that can exist in an inhomogeneous hydromagnetic medium at extremely low frequencies under certain conditions on the conductivity gradient of the medium. The basic hydromagnetic equations consist of Maxwell's equations, Ohm's Law, and equation of motion for a nonviscous medium, and the equation of continuity.

3859

Kanwal, R. P., and C. Truesdell, "Fluid and Magnetic Distortion Carried by Magnetosonic Waves," Phys. Fluids, 5, 368-369, 1962.

It is shown that the disturbances of magnetic distortion and fluid distortion carried by a magnetosonic wave are related in exactly the same way as are the disturbances of fluid spin and the density of the electrical current.

3860

Kontorovich, V. M., and A. M. Glutsyuk, "Transformation of Sound and Electromagnetic Waves at the Boundary of a Liquid Conductor in a Magnetic Field," Zh. Eksperim. i Teor. Fiz., 41, 1195-1204, 1961.

See Also: Soviet Phys. JETP English Trans.

Calculates the electromagnetic field that arises when a sound wave strikes the boundary between a conducting liquid and a nonconducting medium in a weak magnetic field. The amplitude of the sound waves diverging from the interface on which electromagnetic waves are incident is also determined.

3861

Kornhauser, E. T., "Electroacoustic Coupling at the Boundary of an Ionized Medium," J. Acoust. Soc. Am., 33, 1764-1767, 1961.

It is noted that an electromagnetic wave incident upon the boundary of an ionized medium in the presence of a transverse magnetic field will excite, in addition to the reflected and transmitted electromagnetic waves, a reflected sound wave and a transmitted modified sound wave. It is shown that the power coupled into these acoustic waves is proportional to the magnetohydrodynamic coupling parameter $\beta = \sigma B^2/\omega\rho$ and to the ratio of sound velocity to light velocity. Finally it is pointed out that electromagnetic transmission through a thin ionized layer may take place by means of this modified sound wave even though the layer thickness is large compared to the electromagnetic skin depth, but the efficiency of transmission will be very low for weak magnetohydrodynamic coupling.

3862

Kulikovskii, A. G., and G. A. Lyubimov, "On the Structure of an Inclined Magnetohydrodynamic Shock Wave," Appl. Math. Mech., 25, 171-179, 1961.

A theoretical fast- and slow-wave analysis of the flow within the shock-wave zone for a perfect gas, allowing for the dissipative effects of magnetic viscosity and second kinematic viscosity.

3863

Kulsrud, R. M., "Effect of Magnetic Fields on Generation of Noise by Isotropic Turbulence," Astrophys. J., 121, 461-480, 1955.

Lighthill's (1952) and Proudman's (1952) results on the generation of aerodynamic noise by isotropic turbulence are generalized to include magnetic effects. It is found that if there are only turbulent magnetic fields present, and no constant magnetic field, the magnetic turbulence generates sound very efficiently and considerably increases the generation of sound by kinetic turbulence. If there is a constant magnetic field, hydromagnetic waves are generated instead. For the modified sound mode of the hydromagnetic waves, a result similar to the case of no general field is obtained. No energy is generated into the Alfven and modified Alfven waves unless the energy density of the magnetic field is greater than the energy density of the kinetic turbulence. Expressions are found for the rate of noise generated per unit mass, and these results are applied to the problem of heating the chromosphere and the corona.

3864

Levy, R. H., "Exact Solutions to a Class of Linearized Magnetohydrodynamic Flow Problems," Res. Rept. No. 124, AVCO Everett Research Labs., Mass., 25 pp., 1961.
AD-274 388.

A general discussion of the properties of magnetohydrodynamic flows at low conductivity is given, and then attention is restricted to the class of such flows that satisfies the following conditions: the flow is steady, two-dimensional, inviscid, and only slightly perturbed from uniform conditions; the magnetic-field vector is also two-dimensional and lies in the plane of the flow; the distortion of the applied field by the induced currents is negligible; the physical boundaries on the flow are one or two infinite plates parallel to the flow direction; the conductivity of the fluid is a scalar quantity, but may vary in a restricted manner with position. With these assumptions, the perturbations to the flow are calculated exactly for arbitrary magnetic fields for the cases in which the undisturbed flow is either incompressible or supersonic. Illustrative examples for simple magnetic fields are treated and evaluated. Another particular example is used to show the effect of spatially-varying conductivity on the flow.

The limits of the applicability of these results are discussed, and general conclusions regarding the nature of the flow perturbation are drawn.

3865

Levy, R. H., "Exact Solutions to a Class of Two-Dimensional Magnetohydrodynamic Flow Problems at Low Conductivity," Rept. No. AMP 70, AVCO Everett Research Lab., Mass., 59 pp., 1961.
AD-274 287.

Exact solutions are presented to a number of small-perturbation, magnetohydrodynamic-flow problems. The conditions under which the solutions are obtained are that the flow is two-dimensional, and is only slightly perturbed from a uniform flow; the magnetic-field vector is also two-dimensional and lies in the plane of the flow; the distortion of the applied field by the induced currents is neglected; physical boundaries on the flow are one or two infinite plates parallel to the flow direction; and the conductivity of the fluid is a scalar quantity, but may vary with position. With these assumptions, the perturbations to the flow are calculated for various magnetic fields (chiefly those due to a current flowing in a single wire, and a linear dipole) for incompressible, subsonic, and supersonic free-stream speeds. Calculations of the pressure on the walls and other quantities are presented for illustrative examples, including cases in which the conducitivity is not uniform throughout the flow.

3866

Marshall, W., "The Structure of Magnetohydrodynamic Shock Waves," Proc. Roy. Soc. (London), A, 233, 367-376, 1955.

The equations describing the detailed structure of magnetohydrodynamic shocks are derived and their solutions discussed in the special cases of high or low electrical conductivity. For high conductivity the shock front has a width of several mean free paths. For low conductivity, if the initial magnetic field is smaller than a certain critical value, a sharp shock is preceded by a wide region in which the field, velocity and temperature change slowly; if the field is larger than this critical value, no sharp shock occurs, and all the variables change slowly over a wide region. A small double layer of charge is built up on the shock front as a result of the Hall effect.

3867

Ministry of Aviation (Great Britian), "A Bibliography on Magnetohydrodynamics, Including Plasmas," Rept. No. TIL/BIB45, 35 pp., 1960.
AD-245 267.

Descriptors: Magnetohydrodynamics; Plasma physics; Bibliography; Great Britain; Hypersonic flow; Shock waves.

3868

Mitchner, M., "Magnetohydrodynamic Flow in Shock Tube," Rept. No. LMSD-5071, Lockheed Aircraft Corp., Sunnyvale, Calif., 35 pp., 1958.
AD-211 506.

Examines the effect of a transverse magnetic field on the motion of a perfectly conducting fluid in a shock tube. A generalized form of the Riemann invariant for the continuous motion of such a fluid is combined with the conservation equations for a magnetohydrodynamic shock to obtain an exact description of the fluid motion in a shock tube in terms of arbitrary initial conditions. The fluids are assumed to have constant specific heat ratios.

Qualitatively, the effect of the magnetic field is equivalent to that of a pressure, but quantitatively the effect is always greater than merely the hydrodynamic-pressure equivalent of the appropriate Maxwell stress. A magnetic field in the high-pressure region alone can produce shocks having Mach numbers for typical laboratory conditions, of the order of hundreds, and in general agrees with available experimental results. A magnetic field in the low pressure region results in weaker, but higher-velocity shocks.

3869

Pai, S. I., "Cylindrical Shock Waves Produced by Instantaneous Energy Release in Magnetogas Dynamics," Tech. Rept. No. BN-120, Institute for Fluid Dynamics and Applied Mathematics, Univ. of Maryland, College Park, 27 pp., 1958.
AD-154 116.

Reports analysis of the behavior of a cylindrical shock wave produced by instantaneous energy release along a straight line of infinite extent in a conducting gas subjected to a magnetic field with circular lines of force. Initially the gas is at rest and has constant temperature. Both the initial density and the initial magnetic field H_{θ_0} are assumed to be inversely proportional to some power of the radial distance r. It was found that similar solutions exist only if H_{θ_0} is proportional to 1/r. Similar solutions for various initial density distributions have been obtained. Numerical examples are given for constant initial density.

The magnetic field has great influence on the pressure distribution but little influence on the density distribution within the shock. The pressure near the shock front is increased by the magnetic field, while that near the center of the region is decreased. In general, the magnetic field increases the flow velocity within the cylindrical shock.

3870

Polovin, R. V., and K. P. Cherkasova, "Disintegration of Non-evolutional Shock Waves," Soviet Phys. JEPT, English Transl., 1961.

An investigation of the disintegration of a magnetohydrodynamic shock wave with a small density discontinuity. The initial shock wave is a compression wave for which all boundary conditions are satisfied and the entropy increases. If the initial shock wave is evolutional, it cannot disintegrate. A nonevolutional shock wave can disintegrate into six magnetohydrodynamic waves (either shock waves or self-similar waves, depending on the magnitude and direction of the initial magnetic field).

3871

Pugh, E. R., "Studies of the Phenomena Occurring in an Electromagnetic Shock Tube," Cornell Univ., Graduate School of Aeronautical Engineering, Ithaca, N. Y., 68 pp., 1962.
AD-276 650.

An electromagnetic shock tube was constructed, and the observed phenomena were explained assuming that the energy transferred to the driver section is stored in the form of magnetic energy. The velocity of the shock front and its rate of decay were measured and compared with theoretical predictions

3872

RCA Defense Electronic Products, "Theoretical Study of Hydromagnetic Stability and Turbulence, Volume II. Investigations and Detailed Results," Ann. Tech. Rept. No. AFSWC TDR 62-12, Moorestown, N. J., Vol. 2, 1962.
AD-276 932.

Describes fourteen investigations of the smooth and perturbed motion of bomb-debris plasma expanding into an ionized atmosphere and magnetic-field background. An abstract of each investigation is provided.

3873

Research Lab. of Electronics, "Magnetohydrodynamics and Energy Conversion," Progr. Rept. No. 5, Mass. Inst. of Tech., Cambridge, 30 pp., 1961.
AD-272 657.

Includes a theoretical analysis of magnetoacoustic waves that are reflected and refracted at an interface. Also presents theory on magnetohydrodynamic and electrohydrodynamic surface shocks and antishocks. Describes progress on development of a parametric generator, and gives results of velocity-profile measurements on hydromagnetic flows of mercury in closed channels.

3874

Thibault, R., "Zemplen's Theorem in Magnetohydrodynamics," Compt. Rend., 255, 834-836, 1962.

Zemplen's entropy theorem is applied to magnetogasdynamic shock waves, utilizing the Weyl thermodynamic inequalities. This shows that the difficulties found in a discussion of improper weak shocks are removed when this shock type is considered directly and not as a limiting problem.

3875

Tjøtta, S., "On Magneto-Hydrodynamic Shock Waves," Paper No. 8, Arbok. Univ. Bergen Mat.-Naturv. Ser., Norway, 12 pp., 1962.

Discusses the propagation of a magnetohydrodynamic wave of finite amplitude. The magnetic field and the density are such as to make the gyrofrequency for ions and electrons small compared with the collision frequency for the particles. With propagation perpendicular to the magnetic field, it turns out that a simple differential equation (Burger's equation) can be obtained for the wave motion by linearizing the diffusion terms and taking into account the nonlinear effects in a first approximation in the Mach number. This equation can be solved exactly. The structure of the shock wave is discussed briefly.

3876

Tverskoi, B. A., "On the Influence of a Magnetic Field on the Increase of Amplitude of Acoustic Waves with Decrease of Density," Dokl. Akad. Nauk SSSR, 144, 338-340, 1962.

A wave equation for gravitational oscillations of ionized gas in an isothermal atmosphere in the presence of a magnetic field is solved in terms of hypergeometric functions. The results may be applicable to the solar atmosphere.

3877

Weinberg, S., "Eikonal Method in Magnetogydrodynamics," Phys. Rev., 126, 1899-1909, 1962.

The eikonal method is extended to waves of several components propagating in inhomogeneous anisotropic media. Formulae are derived for the motion of wave packets, the change in amplitude along a ray path, and the corrections due to diffraction. The method is applied to pure magnetohydrodynamic disturbances, and the problem of computing ray paths in the ionosphere is discussed in some detail. One result is that the fraction of the energy of an isotropic disturbance that eventually gets as low as 200 km drops from 0.99 at 200 km to 0.2 at 450 km, rises again to 0.99 at 700 km, drops to 0.5 at 3000 km, and continues dropping at greater altitudes. Energy trapped between 200 km and 700 km oscillates around 450 km with period 8.5 sec (at the geomagnetic equator). The eikonal method is also applied to a very general problem involving coupled magnetohydrodynamic, electrodynamic, and acoustic modes.

Wave Propagation, Magnetohydrodynamic
See Also—2490, 3182, 3579, 3785, 3788, 3806, 3813, 4051, 4108, 4179, 4208, 4255

WAVE PROPAGATION, MOVING MEDIUM

3878

Bateman, H., "Sound Rays as Extremals," J. Acoust. Soc. Am., 2, 468-475, 1930.

This is a mathematical paper in which equations are developed, representing a general form of Doppler's principle, applicable when the source of sound, the receiver and the medium are all in motion.

3879

Blokhintzev, D., "The Acoustics of an Inhomogeneous Moving Medium," Translated by R. T. Beyer, and D. Mintzer, Research Analysis Group, Brown Univ., Providence, R. I., 161 pp., 1952.
AD-7675.

This is an English translation of a Russian book. It comprises comprehensive mathematical treatments of the following general topics: Chap. I, The acoustic equations for an inhomogeneous moving medium; Chap. II, Propagation of sound in the atmosphere and in water; Chap. III, Moving sound sources; Chap. IV, Sound excitation by flow. Ray acoustics, zones of silence, the effects of atmospheric turbulence, scattering, and shock wave propagation are thoroughly treated within these chapters.

3880

Blokhintzev, D., "The Propagation of Sound in an Inhomogeneous and Moving Medium, I," J. Acoust. Soc. Am., 18, 322-328, 1945.

The wave equations are established, and special cases are considered. A generalization of Kirchhoff's theorem (Huygens' principle) is given for a moving medium. The general equations of acoustics are considered in the approximation of geometrical acoustics, and, finally, the equations are generalized for the case of a medium containing a salt solution (sea water).

3881

Blokhintzev, D., "The Propagation of Sound in an Inhomogeneous and Moving Medium, II," J. Acoust. Soc. Am., 18, 329-334, 1945.

Several applications of the theory developed in Part I are set forth, e.g., the propagation of sound in a turbulent medium, and propagation through a shock wave.

3882

Brekhovskikh, L. M., "Propagation of Sound in Inhomogeneous Media, Survey," Soviet Phys. Acoust., English Transl., 2, 247-255, 1956.

The indicated topic of this paper is a very broad one. It includes the propagation of sound in solid bodies, liquids and gases. The inhomogeneities may be caused by foreign inclusions, by temperature, velocity and concentration gradients, and by the granular structure of the substance. Such different phenomena as super-long-range propagation of sound in the atmosphere and in the ocean over distances of hundreds and thousands of kilometers, the scattering of sound by inhomogeneities of a turbulent nature in the atmosphere, the absorption of sound waves in blankets placed upon the walls of special sound-absorbent chambers that are used for acoustical measurements, the propagation of ultrasonic waves in polycrystals and in emulsions, etc.—all of this is included in the propagation of sound in inhomogeneous media. Also included in this subject is the scattering of sound waves at uneven surfaces and at surfaces whose impedance varies from point to point.

3883

Chernov, L. A., "The Acoustics of a Moving Medium, A Survey," Soviet Phys. Acoust., English Transl., 4, 311-317, 1958.

This review is selective and reflects the personal interests of the author. The topics dealt with are: propagation of sound in the presence of winds; the principle of reciprocity and the eikonal equation; the ray and wave treatments of the nonuniform moving media (including Blokhintsev's work); scattering of sound and of shock waves; generation and propagation of sound in turbulent media; moving sound sources; sound generation by plates, ellipsoids, and cylinders; infrasound (6-13 cps) discovered in seas; sound sources in moving media, and their protection from winds.

3884

Chuang, F. K., "The Supersonic Motion of a Chaplygin Gas," Sci. Sinica (Peking), 4, 277-296, 1955.

The supersonic motion of a Chaplygin gas—a hypothetical gas whose density varies linearly with the pressure—is discussed mathematically. The Chaplygin application to supersonic flow is used (see Karman and Tsien, J. Aeron. Sci., No. 12), and it is shown that the equations can be reduced to wave equations; the method used by Christianovich can be regarded as a special case of the present treatment. The practical significance of the paper is that as the pressure-variation in the flow field is small, the actual pressure-specific volume graph can be replaced by tangents at points on the graph. It is shown that the Chaplygin approximation does not give satisfactory solutions in the slightly-supersonic region of flow; in such case the equations of motion are reduced to the Tricomi equations, and a general solution in the hodograph plane is obtained.

3885

Dean, E. A., "Sound Transmission Loss for Near-Vertical Atmospheric Propagation," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 224-232, 1962.
AD-408 716.

The sound transmission loss in the upper atmosphere is formulated. It is divided into divergent, refractive, and absorption losses, which are derived for an inhomogeneous, moving, layered medium. This calculated loss is then compared to the measured loss for high-altitude grenade detonations (30-90 km), using the data from rocket-grenade experiments performed at Fort Churchill, Churchill, Canada. As expected, an excess loss is found for the lower altitude grenades; however, the actual loss is less than the calculated loss at the higher altitudes.

3886

Etkin, B., G. K. Korbacher, and others, "Acoustic Radiation from a Stationary Cylinder in a Fluid Stream (Aeolian Tones)," J. Acoust. Soc. Am., 29, 30-36, 1957.

The equation for the radiated sound associated with body forces in a fluid is applied to the flow past a circular cylinder. The sound field is found to be related to the oscillating lift and drag forces that act on the cylinder. Quantitative predictions are made of the directionality and intensity of the field. Some experiments were conducted both inside and outside a wind tunnel. Overall sound pressure levels and sound spectra were measured with various cylinders mounted in the test section. There is a qualitative agreement between the theory and the experimental results.

3887

Etkin, B., and H. S. Ribner, "Canadian Research in Aerodynamic Noise," Review No. 13, Inst. of Aerophysics, Univ. of Toronto, Canada, 1958.
AD-203 662.

Canadian research on flow noise and some aspects of the aircraft noise problem is described. Specific experimental and/or theoretical investigations include: aeolian tones; boundary layer noise (rigid and flexible walls); effects of boundary layers and noise on aircraft structures; distribution of noise sources along a jet; ground run-up mufflers; transmission of sound from, and acoustic energy flow in, a moving medium; sound generated by interaction of a vortex with a shock wave.

3888

Fraenkel, L. E., "A Cylindrical Sound Pulse in a Rotating Gas," Guggenheim Aeronautical Lab., Calif. Inst. of Tech., Pasadena, 13 pp., 1958
AD-221 371.
See Also: J. Fluid Mech., 5, 637-649, 1959.

A sound pulse is propagated into a gas that initially has solid-body rotation and constant temperature, the initial pressure and density increasing outwards like e^x, where x is the square of a certain dimensionless radial coordinate. The perturbations are due to a source-like disturbance on the axis of symmetry, which begins to act at time t = 0. Most attention is paid to source strengths, which vary in time like a Dirac pulse or a step function, but the following remarks apply generally. Immediately behind the wave front the perturbation velocity and temperature decay like $e^{-1/2x}$, while the (absolute) perturbation pressure and density grow like $e^{1/2x}$ (the relative pressure and density increments, which are referred to local conditions in the undisturbed state, then also decay like $e^{-1/2x}$). The rotation also introduces oscillations in flows which, with the same disturbance at the origin and no rotation, at a given point would vary monotonically with time.

3889

Franken, P. A., and U. Ingard, "Sound Propagation into a Moving Medium," J. Acoust. Soc. Am., 28, 126-127, 1956.

In the study of transmission of sound into a moving medium, if flow speeds larger than twice that of sound are allowed, the analysis indicates at least formally the existence of two critical angles between which total reflection occurs. A discussion of the corresponding behavior of the angle of refraction and the reflection coefficient is presented.

3890

Galbrun, H., "Propagation of a Sound Wave in the Atmosphere and the Theory of Zones of Silence" (in French), Gauthier-Villars et Cie, Paris, 352 pp., 1931.

A detailed theoretical work studying the effects of wind on sound propagation. The first part considers discontinuity in the movement of a fluid in relation to propagation of sound. Physics of sound waves and rays are discussed at length. The second part considers zones of silence, giving a detailed analysis and physical and geometrical aspects.

3891

Gottlieb, P., "Sound Transmission Through a Velocity Discontinuity," J. Acoust. Soc. Am., 31, 1036-1037, 1959.
AD-239 009.

The attenuation of a sound wave in a gaseous or liquid medium having steady flow, with the flow gradient normal to the flow lines, is approximated by three different methods. The first method approximates the steady flow by layers of constant velocity and applies the boundary conditions of Ribner at each interface. The second method uses the analytic solution for the continuous flow. The last method is similar to the first but uses the boundary conditions of earlier authors. It is found that the first and second methods give the same answer, and this answer disagrees with that obtained by the third method.

3892

Groves, G. V., "Geometrical Theory of Sound Propagation in the Atmosphere," J. Atmospheric Terrest. Phys., 7, 113-127, 1955.

Deals with the geometry of sound waves and rays propagated in a moving inhomogeneous medium, with particular reference to the atmosphere. The theory developed is, essentially, a generalization of that in geometrical optics for the propagation of light in an inhomogeneous isotropic medium to the case where the medium is in motion. Differential equations defining the wavefront and rays of a sound propagation in an inhomogeneous moving medium are derived, and then transformed by expressing the unit normal of the wavefront in terms of certain trace velocities.

With the equations in this form, an integral is immediately obtainable for sound propagated in the atmosphere by assuming that the velocity of sound and the wind-velocity vector are functions of height only. From this solution the law of refraction, the condition for total reflection of a sound ray, and the equations for the wavefront at any time are found. By way of example, the theory is applied to a simple velocity of sound vs. height relationship, and expressions are obtained for the range and time at which the abnormal propagation from a ground-level source returns to earth. Numerical results calculated from these formulae are found to be in accord with observations that have been made on this phenomenon.

3893

Ingard, U., "Influence of Fluid Motion Past a Plane Boundary on Sound Reflection, Absorption, and Transmission," J. Acoust. Soc. Am., 31, 1035-1036, 1959.
AD-226 926.

The effect of fluid motion past a plane boundary on the reflection and absorption of sound is equivalent to an increase of the normal acoustic impedance of the boundary by a factor $(1 + M \sin \theta)$, where θ is the angle of incidence of the sound wave, and M is the Mach number of the flow velocity component in the incidence-reflection plane of the wave. Similarly, the acoustic energy flux perpendicular to the boundary and the flow is shown to be increased by the same factor. Reflection and transmission coefficients of a thin solid interface between a fluid in motion and one at rest are given. Furthermore, some comments on the problem of transmission in ducts are given. For propagation between two plane parallel boundaries with the same acoustic admittance, for sufficiently small values of the admittance, the sound pressure attenuation constant of the fundamental mode is modified approximately by the factors $(1 + M)^{-2}$ and $(1 - M)^{-2}$ for downstream and upstream propagation, where M is the flow Mach number.

3894

Institute of Aerophysics, "Annual Progress Report for 1957," Rept. No. TL-96-57, Univ. of Toronto, Canada, 128 pp., 1957.
AD-147 414.

Reviews are presented of research in the mechanics of rarefied gases, unsteady-flow shock tubes, steady-flow wind tunnels, aerodynamic noise, propulsion, and airplane dynamics and aeroelasticity.

3895

Institute of Aerophysics, "Fluid Mechanics," Rept. No. TL 40-58, Inst. of Aerophysics, Univ. of Toronto, Canada, 123 pp., 1958.
AD-212 047.

A review is presented of research in the mechanics of rarefied gases, unsteady-flow shock tubes, aerodynamic noise, aerodynamics of propulsion, and dynamics of flight.

3896

Kanwal, R. P., "Absorption of Sound Waves in a Uniform Stream," MRC Tech. Summary Rept. No. 25, Math. Res. Ctr., Univ. of Wisconsin, Madison., 7 pp., 1958.
AD-161818.

The absorption of sound waves in a stream moving with a uniform velocity is discussed. Both the vorticity waves and expansion waves are considered. The propagation of linearized vorticity waves is independent of bulk viscosity and heat conduction; therefore, Lin's analysis (On Periodically Oscillating Wakes in the Oseen Approximation, Studies in Mathematical Mechanics, presented to Richard von Mises, 1954, Academic Press, Inc., N. Y.) for the vorticity waves in an incompressible perfect fluid for cylindrical waves is shown to describe the absorption of these waves in the general class of fluids considered. These results are then extended to three-dimensional flows. With respect to the expansion waves it is shown that the absorption and dispersion of these waves is governed by Langevin's generalization of Kirchhoff's biquadratic equation.

3897

Keller, J. B., "Reflection and Transmission of Sound by a Moving Medium," J. Acoust. Soc. Am., 27, 1044-1047, 1955.

The reflection and transmission of sound by a moving medium are investigated theoretically and the reflection and transmission coefficients are determined. These coefficients are found to depend only upon that component of the velocity of the medium which lies in the plane of incidence. The reflection coefficient increases with the velocity of the moving medium until a velocity is reached at which total reflection occurs. Total reflection persists until a still higher velocity is reached, above which the reflection coefficient decreases as the velocity increases.

3898

Kornhauser, E. T., "Ray Theory for Moving Fluids," J. Acoust. Soc. Am., 25, 945-949, 1953.

The generalized eikonal equation for moving fluids is obtained from a very simple physical argument. Elementary solutions for uniformly moving media are discussed. A generalized form of Snell's law is derived, and it is specialized in three separate ways to yield formulae useful for solution of problems in stratified media. Examples of its application are given in each case.

3899

Kraichnan, R. H., "Electromagnetic Analogy to Sound Propagation in Moving Media," J. Acoust. Soc. Am., 27, 527-530, 1955.

An analogy is developed between the paths of sound rays in fluids undergoing shear flow and electron trajectories in magnetic fields. If the Mach number of the flow is small, and the characteristic eddy size is large compared to the sound wavelength, the ray paths coincide with electron trajectories in a magnetic field everywhere parallel and proportional to the vorticity vector. The ratio of the magnitude of the magnetic field to the electron momentum is determined by $eH/Pc_0 = \psi/c$, where H = magnetic field; P = electron momentum; e = electron charge; c_0, c = velocities of light and sound; ψ = vorticity. Mathematically, the analogy is implied by the similarity between the eikonal equation for the sound rays and the Hamilton-Jacobi equation for the electrons. Simple illustrations of the correspondence are given.

3900

Kraichnan, R. H., "On the Propagation of Sound in a Turbulent Fluid," Tech. Rept. No. 4, Acoustics Lab., Columbia Univ., N. Y., 23 pp., 1954.
AD-28 517.

Eikonal and continuity equations are derived for a sound wave propagating through a fluid in which there is a shear motion of low Mach number and a turbulence scale that is large compared to the soundwave length. A comparison between the eikonal equation and the Hamilton-Jacobi equation for a charged particle in a magnetic field revealed that the acoustic-ray paths are identical with the trajectories of the particles provided the magnetic field is proportional to the vorticity. Expressions are obtained in terms of correlation products of the turbulent flow for the attenuation and fluctuation in intensity of a sound beam scattered in a turbulent flow. Expressions are also derived for the phase and intensity fluctuations associated with the propagation of sound through large-scale turbulence. The differential cross section for the scattering of sound by turbulence is developed in a form suited to the treatment of anisotropic turbulence. A simple anisotropic distribution involving symmetry about a preferred vorticity axis is discussed.

3901

Krasil'nikov, V. A., and V. I. Tatarskii, "Dispersion of Sound in Turbulent Flow" (in Russian), Dokl. Akad. Nauk SSSR, 90, 159-162, 1953.
Translation available: U. S. Natl. Sci. Found., NSF-tr-121.

On the assumptions that (1) a turbulent flow can be described by the equations of motion of an incompressible viscous fluid, (2) in an incompressible fluid, the dispersions by temperature irregularities and velocity fluctuations, respectively, are independent, and (3) the fluctuations of the velocity of flow v are considerably smaller than the speed of sound c in the medium, it is shown that the wave equation of sound in the moving medium, neglecting acceleration, can be reduced to $\Delta\psi - \partial^2\psi/c^2\partial t^2 = 2v\partial^2\psi/c^2\partial x_i\partial t$, where ψ is the potential function of the sound field. This equation is solved by the method of successive approximations. Expressions are derived for the effective range of sound dispersion in the solid angle of $d\Omega$ per unit of distance travelled by the incident sound wave and for the dispersion coefficient. The coefficient of "backward dispersion" is constant at high frequencies. It is possible that the dispersion of sound by the acceleration field may afford a better explanation of the damping of infrasonic sound waves in the atmosphere than that afforded by the present theory of dispersion due to viscosity and thermal conductivity.

3902

Lambert, R. F., "Acoustic Filtering in a Moving Medium," J. Acoust. Soc. Am., 28, 1057-1058, 1956.

Formulations of one-dimensional sound propagation in a homogeneous, progressively moving medium are applied to calculations of recurrent filter characteristics of a side-branch tube attached to the sidewall of an air duct. The complex propagation constants and characteristic impedance are functions of the flow Mach number. Therefore, the insertion loss is dependent upon flow, but relative changes with flow depend upon the terminating impedance levels as well as upon geometry. Neglecting dissipation, the linear system is found nonreciprocal with respect to phase shift.

3903

Lapin, A. D., "Influence of Motion of the Medium on the Propagation of Sound in a Waveguide with Volume Resonators in the Walls," Soviet Phys. Acoust., English Transl., 7, 360-363, 1961.

The problem of sound propagating in a waveguide with a volume resonator in the wall is examined on the assumption that the medium contained in the waveguide is moving with a constant velocity. The acoustic fields in the waveguide and in the resonator are sought in the form of an expansion in appropriate eigenfunctions. Matching of these fields at the boundary between waveguide and resonator leads to an infinite system of algebraic equations with constant coefficients. This system of equations is solved by a numerical reduction method for certain values of the Mach number and waveguide and resonator parameters. It is sought to determine how the Mach number influences the efficiency of operation of the resonator in the waveguide as a reflector of sound. A comparison is drawn between theory and experiment.

3904

Laslett, L. J., "On the Electromagnetic Analogy to Sound Propagation," J. Acoust. Soc. Am., 28, 724, 1956.

Refers to a paper by R. H. Kraichnan, who has drawn attention to an interesting correspondence between the paths of sound rays in fluids undergoing shear flow and the trajectories of charged particles in magnetic fields. To establish the analogy it is assumed (1) that the eddy size is large compared with the sound wavelength, and (2) the velocity of the fluid flow is small by comparison with the velocity of sound. Use is made of the Hamilton-Jacobi theory of particle dynamics, the associated principle of Fermat, and that of least action. Extending Kraichnan's analysis, the auther indicates how sound rays are influenced by the fluid motion.

3905

Lighthill, M. J., "Methods for Predicting Phenomena in the High-Speed Flow of Gases," J. Aeron. Sci., 16, 69-83, 1949.

A synopsis of compressible fluid dynamics. It treats successively the foundations of the subject, the boundary layer, isentropic flow, plane waves, and the differences between steady sub- and supersonic flow; the perturbation methods of solution, including the linearized theory of supersonic flow in its many ramifications, are described and compared with more exact work in certain cases, and the theory of characteristics is outlined.

3906

Lindsay, R. B., "Compressional Wavefront Propagation Through a Simple Vortex," J. Acoust. Soc. Am., 20, 89-94, 1948.

The equations of propagation for a compressional wave through a moving medium are developed in vector notation. Application is made to the special case of a linear vortex of constant strength m in which the motion is irrotational. Differential equations are set up in general form for the wavefronts and rays. A simple approximation is derived for the distortion produced in an originally plane wavefront by transmission through the vortex. The results are in general agreement with observed fluctuation phenomena in acoustical propagation in air.

3907

Lyamshev, L. M., "Some Integral Equations in the Acoustics of a Moving Medium," Soviet Phys. Doklady, English Transl., 6, 410-412, 1961.

For the acoustics of moving media, it is possible to derive equations that to some extent are analogous to equations of reciprocity, although, of course, the principle of reciprocity does not apply in moving media. The solutions to these equations relate volume sources and surface forces acting on thin elastic bodies in a moving medium to the sound fields caused by the sources and by vibration of the elastic bodies.

3908

Mawardi, O. K., "Measurement of Flow Velocities in Wind Tunnels by Acoustic Methods," Acustica, 4, 114-116, 1954.

A paper given at the Congress of the International Commission of Acoustics, Netherlands, 1953.

An acoustic method is proposed for the evaluation of the average flow-velocity in wind tunnels. The method is based on an estimate of the effect of a mean velocity of the medium on the time of arrival of a sound signal. The effect of the boundary layer on the propagation of sound waves is discussed. The results obtained by the method are expected to yield a reasonably good accuracy.

3909

Metz, A., "The Deflection of Waves by the Motion of the Propagating Media" (in French), Compt. Rend., 248, 1615-1617, 1959.
See also : Compt. rend., 245, 827-829, 1957.

The deflection of waves at the interface between two media, one of which moves with velocity v relative to the other, is given by cosec i - cosec r = v/c, where c is the propagation velocity, supposedly the same in the two media. This result is used to criticize Datzeffs' modified hypothesis of ether drift.

3910

Metz, A., "Refraction and Total Reflection of Waves in Media in Motion," Compt. Rend. Acad. Sci. (Paris), 250, 3591-3592, 1960.

The theory of the refraction and reflection of a plane acoustic wave when passing from one medium to another in which the wave velocity is different is discussed for the case in which there is relative motion between the two media.

3911

Metz, A., "The Total Reflection of Waves in Moving Media," Compt. Rend. Acad. Sci. (Paris), 250, 3796-3804, 1960.

Previous papers have shown that sound waves or ultrasonic waves propagated in media undergo refraction and total reflection not only when they pass from one medium to another where the speed of propagation is different, but also when the media are moving relative to one another. General formulae relating to these phenomena were given previously and the present paper derives a more exact formula relating to the propagation of waves under such conditions. Formulae derived in previous papers are used without detailed explanation.

3912

Monin, A. S., "Characteristics of the Scattering of Sound in a Turbulent Atmosphere," Soviet Phys. Acoust. English Transl., 7, 370-373, 1962.

Proceeding from the complete set of equations for the acoustics of a moving inhomogeneous medium, an expression is derived for the effective cross section of sound scattering by turbulent inhomogeneities of the atmosphere; the expression is valid, correct to components whose relative smallness is of the order of the square of the Mach number for turbulent motion. This expression shows specifically that right-angle scattering does not occur, and back scattering happens as the result of turbulent temperature irregularities but not of velocity irregularities.

3913

Muller, E. A., and K. R. Matschat, "The Scattering of Sound by a Single Vortex and by Turbulence," Rept. No. AFOSR TN-59-337, Max-Planck-Institut für Stroemungsforschung, Germany, 50 pp., 1959.
AD-213 658.

As an elementary model for the scattering of sound by turbulence, the scattering of a plane sound wave as it passes through a single vortex of finite radius is investigated. The angular intensity distribution and the total power of the scattered sound are explicitly calculated in terms of the circulation and the radius of the vortex, the wave length of the incident sound wave, and the inclination angle between the direction of propagation of the incident wave and the axis or the vortex. The results of the single-vortex theory are applied to scattering by turbulence. The turbulent flow is represented by statistically distributed vortices. Isotropic and extreme nonisotropic turbulence are considered. The total scattering power turns out to be proportional to the 5th or 2nd power of the frequency of the incident sound wave, depending on whether the frequency is low or high.

3914

Nordberg, W., "Sounding Rocket Experiments for Meteorological Measurements," Rept. No. 382, Advisory Group for Aeronautical Res. and Dev., Paris, 19 pp., 1961.
AD-285 790.

Papers presented at the AGARD Specialists Meeting, on the Use of Rocket Vehicles in Flight Research, at the Kurhaus Hotel, 18-21 July 1961, Scheveningen, Holland.

The importance of meteorological rocket-sounding in the upper atmosphere is reviewed. The falling-sphere density-measuring techniques, static pressure tubes, and ionization pressure gages, as well as the rocket-grenade experiments where temperatures and winds are determined acoustically, were used most successfully to make these measurements. Winds were also measured by means of dispersing sodium in the upper atmosphere. Pronounced wind patterns, variable with season and latitude, were found to exist up to 100 km. At certain levels and latitudes abrupt changes in wind structure were encountered. Although the flow of air at a given time and altitude is uniform from the point of view of general global atmospheric circulation, there were observations of phenomenal wind shears on a smaller scale.

Temperatures, pressures, and densities also follow a definite seasonal and latitudinal pattern. Large-scale meteorological disturbances can be detected in these patterns, and since they are not subjected to obscurations found near the earth's surface, their study is of particular interest. The discovery, through the use of these techniques, of a very irregular behavior of the 60-to-80-km region at high latitudes in wintertime suggests that dynamic processes are of paramount interest in the upper mesosphere.

3915

Polyakova, A. L., "A Plane Sound Wave of Finite Amplitude in a Moving Medium," Soviet Phys. Doklady, English Transl., 6, 344-345, 1961.

Riemann solutions describing the propagation of plane sound waves of finite amplitude (shock waves) in a moving medium are summarized and discussed for three cases of relative motion involving medium, source, and observer.

3916

Powell, A., "Fluid Motion and Sound," Annual Summary Rept. No. 60-51, Univ. of Calif., Los Angeles, 5 pp., 1960. AD-239 941.

Summaries of papers on the instability of jets, edge tones, aeolian tones, turbulent jet noise, boundary-layer noise, and propagation problems.

3917

Powell, A., "Propagation of a Pressure Pulse in a Compressible Flow," J. Acoust. Soc. Am., 31, 1527-1535, 1959.

A one-dimensional treatment of the propagation of a pressure pulse through a channel carrying a compressible flow is given. The method consists of summing the multiple linear reflections of increasing order, then giving the transmission and reflection coefficients in the form of power series whose terms depend only on the entry and exit Mach numbers of the mean flow. The series fails to converge under certain circumstances, but there is nothing corresponding to this in the equivalent results obtained from before and after steady-state considerations.

Both methods are shown to fail at a sonic throat, where, it is suggested, the assumption of one-dimensional perturbations is no longer tenable.

3918

Powell, A., "Theory of Sound Propagation Through Ducts Carrying High-Speed Flows," J. Acoust. Soc. Am., 32, 1640-1646, 1960.

The important problem of sound propagation in ducts carrying compressible subsonic flows is analyzed on the basis that the motion is one-dimensional. The multiple reflection method is extended to the case of sinusoidally varying pressure waves, and a general integral formulation is developed. It is complicated because the total reflected wave, particularly, and the total transmitted wave must depend upon the time delay incurred by the propagation of infinitesimal reflections from along the length of the duct, and this depends upon the shape of the duct. It is shown how certain exact solutions can be obtained, and these are given for the wave strengths composed of wavelets having undergone single, double and triple reflections. The frequency plays the strongest role in the reflected wave, and when the singly reflected wavelets dominate, it introduces a factor

$$[\sin(\Omega_\chi)/\Omega_\chi]\, e^{-i\Omega\chi}$$

on the zero-frequency reflection, Ω being proportional to the frequency, and it and χ being dependent upon the change of Mach number at the ends of the duct.

By contrast, the transmitted wave is hardly affected by frequency. The analytical results apply to almost-conical ducts, either convergent or divergent, with the incident wave propagating with or against the flow direction. An approximate method based upon the analytical results is demonstrated for ducts of other form.

3919

Ribner, H. S., "Note on Acoustic Energy Flow in a Moving Medium," Tech. Note No. 21, Inst. of Aerophysics, Univ. of Toronto, Canada, 8 pp., 1958. AD-154 265.

Both acoustic energy density and energy flow are known to be modified by motion of the medium, as in a jet. Similarities and discrepancies in the formulas of three investigators are compared in order to infer a correct formulation. Examples of applications show how variations in the velocity of a stream carrying plane sound waves can change the "linear theory" acoustic energy density from positive through zero to negative, with corresponding changes in the energy flow.

3920

Ribner, H. S., "Reflection, Transmission, and Amplification of Sound by a Moving Medium," J. Acoust. Soc. Am., 29, 435-441, 1957.

The reflection and transmission process is analyzed for plane sound waves originating in air at rest and impinging obliquely on a plane interface with a moving stream. Use of a moving reference frame provides transformation to an equivalent aerodynamic problem of flows past a wavy wall—the rippled interface. The angles of incidence, reflection, and refraction are identified with the Mach angles. The angular relations and the amplitude relations (coefficients of reflection and transmission) are evaluated in closed form. In a graph, three zones can be distinguished in the plane of angle of incidence vs. Mach number of the moving medium: ordinary reflection and transmission, total reflection, and amplified reflection and transmission. Included are three loci of infinite reflection, i.e., self-excited waves. The energy balance is examined, and the source of amplification is concluded to be the energy of the moving stream. In appendices the results are generalized (1) for the case of two moving media and (2) for differing density and speed of sound in the two media.

3921

Richter, G., "On the Energy Flow in a Sound Field in an Flowing Medium" (in German), Z. Physik, 125, 98-107, 1948.

The energy flow in the medium is studied from two different points of view: (1) following the course of one and the same particle of matter, (2) observing the flow across a fixed surface. The distinction between the two points of view is negligible for small motions, but important in relation to ultrasonic waves near cavitation limit, and to explosive waves of great intensity. The theoretical results worked out are illustrated by an application to plane waves subject to Hookes' pressure law.

3922

Rocard, Y., "Propagation of Sound in a Variable Wind" (in French) Compt. Rend., 244, 1339-1341, 1957.

Sound propagation in a variable wind is shown, theoretically, to consist of ordinary sound waves of amplitude depending upon the wind velocity gradient in the direction of propagation.

Suggests a method for measuring turbulence.

3923

Rudnick, I., "Acoustic Transmission Through a Fluid Lamina," J. Acoust. Soc. Am., 17, 245-253, 1945-1946.

The acoustic wave equation is derived for a moving fluid medium, such as air, in which all changes follow an adiabatic law, and it is shown that this equation may be written in a form that is very similar to the usual wave equation. The transmission and reflection coefficients for a fluid lamina in uniform motion are derived; it is only the component of motion in the direction of incidence that affects these coefficients. Measurements are reported on the transmission coefficients of a nonturbulent thermal lamina in air whose motion has no component in the plane of incidence, from 2-14 kcs and angle of incidence 0°-89°.

These measurements are compared with those calculated for a theoretically approximated lamina, and are in reasonable agreement. It is shown that there is considerable transmission for angles greater than the critical angles, and that for very thin lamina the transmission coefficient is a uniformly decreasing function of frequency.

3924

Saito, O., "On Some Exact Solutions of the Two-Dimensional Steady Flow of Compressible Fluid," J. Phys. Soc. Japan, 6, 248-254, 1951.

In continuation of previous work (J. Phys. Soc. Japan, 5, 201-2, 1950), in which a new method of solving the differential equations of two-dimensional steady flow of compressible fluid was discussed, some details of the mode for solving the equations are filled in, and two exact solutions of the equations are discussed. One solution represents supersonic flow, the other subsonic flow. Velocity, q, and stream function, ϕ, are used as independent variables. In general, an infinite value of the velocity gradient or stream-line cusps occur only in curved supersonic flows.

3925

Spees, A. H., "Acoustic Doppler Effect and Phase Invariance," Am. J. Phys., 24, 7-10, 1956.

Attention is called to the usefulness of the Doppler effect in introducing the idea of invariance with respect to coordinate transformation. The invariant property of the phase of a sound wave with respect to Galilean transformation is applied to several Doppler effects including that resulting from transverse motion of source and detector in a moving medium.

3926

Tatarskii, V. I., "Theory of the Propagation of Sound Waves in a Turbulent Stream" (in Russian), Zh. Eksperim. i Teor. Fiz., 25, 74-80, 1953.

Examines in detail the problem of the scattering of sound waves for the case of isotropic turbulence in an incompressible liquid. Investigates the general form of the scattering indicatrix and develops for it an expression based on the formula $R_{rr}(\rho) = \bar{u}^2 \exp(-\rho\ell)/3$, where $\bar{u}^2$ is the mean square value of the pulsation velocity of the stream, ρ = one of the spherical coordinates of the point, and ℓ = the correlation scale characteristic of the average pulsation size. The analysis of this phenomenon, based on the scattering theory, yields the mean square fluctuations of the phase and amplitude of sound at large distances from the source.

3927

Trimmer, J. D., "Sound Waves in a Moving Medium," J. Acoust. Soc. Am., 9, 162-164, 1936-1937.

A theoretical approach is made to the problem of the behavior of sound waves in a pipe through which the medium is moving in a unidirectional flow with uniform velocity V. Calculation indicates the resonances of pipes to be affected by the steady flow, so that the resonance peaks are flattened, while the separation between nodal points is reduced by the factor $1 - (C/c)^2$.

3928

Whitham, G. B., "A Note on Group Velocity," J. Fluid Mech., 9, 347-352, 1960.

The kinematic approach to group velocity given in Lighthill & Whitham (1955) for one-dimensional waves is extended to cover the general three-dimensional case. The ideas have particular bearing on the theory developed by Ursell (1960) for treating steady wave patterns on nonuniform, steady flows of fluids.

Although this note was written in ignorance of the fact, all the main ideas presented here are implicit in sections 66 and 67 of the book by Landau & Lifshitz (1959). However, these ideas do not seem to be well known to fluid dynamicists, and it was suggested to the author by the editor that a useful purpose would still be served by publishing this note as an expository article amplifying the paragraphs in Landau & Lifshitz. It also serves the original purpose of providing a supplement to Ursell's paper.

Wave Propagation, Moving Medium
See Also—345, 488, 588, 826, 859, 934, 1381, 1465, 1467, 1758, 1953, 1962, 2061, 2160, 2161, 2171, 2272, 2453, 2464, 2465, 2484, 2736, 2818, 2846, 2868, 2880, 2886, 2891, 2893, 2906, 2907, 2920, 3000, 3329, 3337, 3564, 3733, 3739, 3752, 3761, 3832, 3993, 4024, 4154, 4176, 4193, 4195, 4209

WAVE PROPAGATION, MOVING SOURCE

3929

Armour Research Foundation, "Theoretical Investigations of Sonic Boom Phenomena," WADC Tech. Rept. No. 57-412, Armour Research Foundation, Chicago, Ill., 231 pp., 1957.
AD-130 883.

A theoretical investigation was made to determine the pressure- and shock-wave characteristics due to a body (i.e., aircraft) in arbitrary motion. In addition, the propagation of these shocks through the atmosphere has been studied, and the effects of many such parameters as Mach number, acceleration, altitude, and slenderness ratio have been determined.

3930

Astapovich, I. S., "The Power of the Sound Detonations of the Choulak-Kurgan Bolide," Byul. Turkin, FAN SSSR, 77-80, 1946.
Translation No. F-TS-8844/III, Air Technical Intelligence Center, Wright-Patterson Air Force Base, Dayton, Ohio, 7 pp.
AD-111 033.

The acoustical field produced by a meteorite's entry into the atmosphere is theoretically devolved. Mathematical evidence for the production of a shock wave followed by a decay similar to a thunder peal is shown. Detailed evidence of the Chalak-Kurgan bolide's entry and acoustical field is documented.

3931

Bateman, H., "Sound Rays as Extremals," J. Acoust. Soc. Am., 2, 468-475, 1930.

This is a mathematical paper in which equations are developed, representing a general form of Doppler's principle, applicable when the source of sound, the receiver and the medium are all in motion.

3932

Bloch-Dassault, P., "On the Acoustics of Supersonic Motion" (in French), Compt. Rend., 237, 1123-1126, 1953.

Discusses the origin and nature of the detonations produced by aircraft at supersonic speeds, referring particularly to the occurrence of double supersonic bang. The possibility that these two shock waves have their origin in different parts of the airplane is excluded, as it does not agree with observation. The explanation developed in the present paper derives from the classical work of Esclangon (Acoustiques des canons et des projectiles, 1925, and Compt. Rend., 237, 361, 1953; he discusses supersonic flight of projectiles), and is now applied to supersonic flight of aircraft.

The two sound pulses arise from the spherically-spreading sound wave with normal velocity of sound, and from the conical pressure-surface spreading from the nose of the aircraft with a velocity that depends on the Mach number. The time interval between arrival of the two pressure waves at an observer on the ground will depend on the relative positions, etc., of the observer and the aircraft.

3933

Blokhintzev, D., "The Acoustics of an Inhomogeneous Moving Medium," Translated by R. T. Beyer, and D. Mintzer, Research Analysis Group, Brown Univ., Providence, R. I., 161 pp., 1952.
AD-7675.

This is an English translation of a Russian book. It comprises comprehensive mathematical treatments of the following general topics: Chap. I, The acoustic equations for an inhomogeneous moving medium; Chap. II, Propagation of sound in the atmosphere and in water; Chap. III, Moving sound sources; Chap. IV, Sound excitation by flow. Ray acoustics, zones of silence, the effects of atmospheric turbulence, scattering, and shock wave propagation are thoroughly treated within these chapters.

3934

Brillouin, J., "Interference Between Waves Having a Modulated Frequency," Rev. Gen. Elec., 40, 434-441, 1936.

The beats that are formed when two frequency-modulated waves interfere are explained, and the use of warble tones for acoustical measurements is examined. The production of a frequency-modulated tone by motion of the source or by rotating reflectors is described. The possibility of using the interference system to locate sound sources is also mentioned.

3935

Chernov, L. A., "The Acoustics of a Moving Medium, A Survey," Soviet Phys. Acoust., English Transl., 4, 311-317, 1958.

This review is selective and reflects the personal interests of the author. The topics dealt with are: propagation of sound in the presence of winds; the principle of reciprocity and the eikonal equation; the ray and wave treatments of the nonuniform moving media (including Blokhintsev's work); scattering of sound and of shock waves; generation and propagation of sound in turbulent media; moving sound sources; sound generation by plates, ellipsoids, and cylinders; infrasound (6-13 cps) discovered in seas; sound sources in moving media, and their protection from winds.

3936

Diamond, M., and A. B. Gray, "Accuracy of Missile Sound Ranging," Tech. Rept. No. 110, Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 14 pp., 1961.
AD-264 856.

This report presents a technique for determining the impact point of missiles by the detection of the shock wave generated during a missiles descent. It includes the instrumentation and computations involved and an error analysis.

3937

Ernst, P. J., "Preliminary Survey in Connection with Use of Ultrasonic Methods for the Accurate Measurement of Rocket Velocities During the Burning Period," Final Rept., Temple Univ., Philadelphia, Pa., 10 pp., 1953.
AD-11 531.

Tests are reported which indicate the feasibility of using ultrasonic methods to make accurate measurements of rocket velocities during the burning period. Two methods are recommended. The echo-Doppler method uses either a small reflector fixed to the rocket nose or the flattened rocket nose for ultra-sound reflection. This method is considered applicable for velocities as high as half the speed of sound. The second method comprises the transmission of a signal from a sonic generator to a microphone on the rocket and the retransmission of a modulated radio signal to a detector. This method is applicable up to the speed of sound. An 8- to 25-kc range and a 50-w transmitter power appeared adequate. Test data are included as well as photographs of experimental setups.

3938

Fleischmann, L., "Generalized Formula for Doppler Effect," J. Opt. Soc. Am., 29, 302-304, 1939.

The formula for the Doppler effect is worked out for the case when source and observer are both moving in any manner in flat space. The change in frequency, when the source is moving along a straight line with constant velocity relative to a fixed observer and when the source passes at a given minimum distance from the latter, is worked out, and it is shown that there is no finite jump of frequency as the point of minimum distance is passed through. Moreover, the change of frequency is not the same as that found on the assumption that the source is at rest and the observer is moving along a straight line passing at a given minimum distance from the source. The case of motion of the observer under gravity relative to a fixed source is also worked out in detail.

3939

Groves, G. V., "Trajectory Determination of a Supersonic Body by Acoustical Observations," J. Atmospheric Terrest. Phys., 12, 17-25, 1958.

A theory is developed for deriving the trajectory of a body moving at supersonic speeds through the atmosphere from observations on the times of arrival of its shock wave at a number of microphones at known points on the ground, wind and temperature effects being taken into account. It is shown that with $3n + 4$ microphones, the position, velocity, acceleration, etc., up to the nth derivative of the spatial coordinates of the body with respect to time can be found at some determined instant of time. Hence, with seven microphones, the position and velocity of the body at a certain instant of time can be found, although four microphones are seen to be adequate for a more approximate determination of these quantities. Particular consideration is given to the method of solution in the seven-microphone case.

3940

Honl, H., "On the Sound Field of a Point-Shaped Sound Source in Uniform Translatory Motion," Tech. Memo. No. 1362, Translated by M. L. Mahler, Natl. Advisory Comm. Aeron., Washington, D. C., 44 pp., 1954.
AD-36 527.

A rigorous treatment of the sonic field due to a point source moving through a stationary medium at subsonic and supersonic velocities. The two- and three-dimensional cases are solved by Fourier integrals. If the propagation of sound waves is assumed independent of the motion of the source, the sonic field can be drawn by simple geometry using Huyghen's principle. The latter geometric method is shown to yield approximately correct results, but discrepancies between the rigorous and approximate method occur, especially at supersonic speeds.

3941

Hubbard, H. H., and D. J. Maglieri, "An Investigation of Some Phenomena Relating to Aural Detection of Airplanes," Tech. Note 4337, NASA, Washington, D. C., 49 pp., 1958. AD-205 675.

Conventional noise-level measurements consisting of broad- and narrow-band frequency analyses were made for static ground tests of an unmodified and modified single-engine airplane. Also, listening data with the aid of ground observers were obtained in flight during cruise as well as for take-offs, landings, and power-off glides. The test results indicate that the external noise-level characteristics of the airplane, the propagation phenomena relating to the conditions of the problem, and the ambient or background noise conditions at the location are all significant factors in aural detection by ground observers.

3942

Kamrass, M., and K. D. Swartzel, "Evaluation of the Noise Field Around Jet-Powered Aircraft," Noise Control, 1, 30, 1955.

Following a review of the factors which affect the ground-level noise from aircraft in flight, a technique is discussed which permits the prediction of ground noise levels, and which indicates flight patterns that will permit minimum noise levels for those areas requiring that such annoyance be held to a minimum.

3943

Kusukawa, K., "On the Theory of Shock Waves Produced by a Rigid Cone Moving Through an Elastic Medium with Supersonic Velocities," J. Phys. Soc. Japan, 6, 166-167, 1951.

The field of flow around a slender conical obstacle is calculated by a method similar to that used for a wedge. Values of the strain at the wall of a cone of semi-angle 5° are tabulated for Mach number M = 1.06 to M = 2.92.

3944

Kusukawa, K., "On the Theory of Shock Waves Produced by a Rigid Wedge Moving Through an Elastic Medium with Supersonic Velocities," J. Phys. Soc. Japan, 6, 163-165, 1951.

Using linearized equations appropriate to the condition of small strain, formal solutions are found for the field of flow around a wedge moving with supersonic velocity. Two special cases considered: are irrotational flow and flow of a deformable incompressible fluid. It is shown that the formal solution for the first case implies that η, the coefficient of friction between the fluid and the wedge, is defined by

$$\eta = \mu \sin (2\alpha - \gamma)/[\lambda + \mu \cos 2(\alpha - \gamma)]$$

where α is the semi-angle of the shock wave attached to the apex of a wedge of semi-angle γ; λ and μ are Lame's constants. Such a solution is physically possible because $0 < \eta < \mu/(\lambda + \mu) < 1$.

A formal solution is possible in the second case, but as it implies a shearing force acting in the direction of the velocity of flow, it is physical unrealizable. A numerical solution for $\gamma = 5^{\circ}$ is given; it is found that in this case the minimum difference in transverse strain across the shock front occurs at Mach number M = 1.36.

3945

Lansing, D. L., "Some Effects of Flight Path upon the Distribution of Sonic Booms," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 24-43, 1961. AD-408 716.

In the proposed paper the acoustic theory of the propagation of sound in an inhomogeneous atmosphere is applied to determine the effect of flight path upon the distribution of sonic booms on the ground. The equations from which the shock-wave pattern is obtained are reduced to a form that can be readily applied to an arbitrary flight path along which the velocity vector at several positions is known. The theory is applied to determine the sonic-boom distribution for several typical flight maneuvers. In each case the ground areas over which above-normal overpressures may be expected are indicated. The results obtained are of interest in connection with sonic-boom flight-test programs, military aircraft operations, and the flight corridor of the proposed supersonic transport.

3946

Lienard, P., "On the Sound Field Produced by a Point Source in Rectilinear Uniform Motions at Supersonic Speed in a Perfect Fluid" (in French), Compt. Rend., 228, 910-912, 1949.

Analytical expressions and the characteristics of the sound field produced by a source at supersonic velocity are derived, with reference to axes attached to the source.

3947

Lienard, P., "On the Sound Pressures Received by an Observer in Relative Motion with Reference to a Point Source in Uniform Rectilinear Motion at Supersonic Velocity in a Perfect Fluid" (in French), Conpt. Rend., 228, 1108-1110, 1949.

This is an extension of the previous work of G. Richter (Z. Physik, 125, 98-107, 1948). It is shown that, when the source is moving at supersonic velocities, the moving observer receives two distinct waves, which appear to come from opposite directions and whose frequencies are modified by the Doppler effect.

3948

Lilley, G. M., R. Westley, A. H. Yates, and J. R. Busing, "The Supersonic Bang," Nature, 171, 994-996, 1953.

The double (occasionally triple) bang heard when an airplane passes through the sound barrier is explained by consideration of movements of bow and tail waves relative to the plane at different Mach numbers.

3949

Lina, L. J., and D. J. Maglierei, "Ground Measurements of Airplane Shock-Wave Noise at Mach Numbers to 2.0 and at Altitudes to 60,000 Feet," NASA Tech. Note No. D-235, Washington, D. C., 25 pp., 1960. AD-233 657.

Measurements of sonic-boom intensities were made for flights at altitudes to 60,000 ft and Mach numbers to 2.0. The measurements were made on the ground near the flight tracks. Effects of altitude, flight-path angle, Mach number, and atmospheric refraction at the cutoff Mach number were investigated. The effects of airplane size and weight were determined by a comparison of measurements made from one flight of a supersonic bomber with data for the supersonic fighter that was used for most of the tests.

3950

Lyster, H. N. C., "A Review of Theoretical and Experimental Information Relating to the Sonic Boom," Aero. Rept. No. LR-313, Natl. Aeronautical Establishment, Canada, 1961.

Sonic boom theory (originated by Whitham) was reviewed and comparisons were made with experimental data. Cutoff Mach number (below which no shock wave reached the ground) has been shown to be primarily a function of altitude and climb-path angle. Variations of boom intensity with Mach number and with altitude were examined. The volume effect appears to predominate for altitudes below the tropopause. Proper estimation of the total intensity when the lift effect is appreciable awaits additional data from large supersonic aircraft. Conversely, designing an aircraft for minimum boom intensity when volume and all-up-weight are fixed remains a complex problem for which only general rules may be given.

3951

Maglieri, D. J., and D. L. Lansing, "Sonic Booms from Air-Craft in Maneuvers," Sound, 2, 39, 1963.

Ground-pressure measurements are presented for fighter aircraft in various maneuvers involving accelerations along the track and perpendicular to it. Complex wave patterns, and so-called "superbooms," in which pressure buildups occur, are presented for some representative cases. Results obtained from an array of ground measuring stations are correlated with tracking and weather information and with theory. Computed ground-pressure patterns show good agreement with measurements for some specific maneuvers.

3952

Maglieri, D. J., and H. H. Hubbard, "Ground Measurements of the Shock-Wave Noise from Supersonic Bomber Airplanes in the Altitude Range from 30,000 to 50,000 Feet," Tech. Rept. No. D-880, NASA, Washington, D. C., 24 pp., 1961.
AD-260 635.

Shock-wave ground-pressure measurements have been made for supersonic bomber airplanes in the Mach number range between 1.24 and 1.52, for altitudes between 30,000 and 50,000 feet, and for a gross-weight range between 83,000 and 120,000 pounds. The measured overpressures were generally higher than would be predicted by theory, which accounts only for volume effects. There is thus a suggestion that lift effects on sonic-boom intensity may be significant for this type of airplane within the altitude range of the present tests.

3953

Maglieri, D. J., H. H. Hubbard, and D. L. Lansing, "Ground Measurements of the Shock-Wave Noise from Airplanes in Level Flight at Mach Numbers to 1.4 and at Altitudes to 45,000 Feet," Rept. No. NASA TN-D-48, NASA, Washington, D. C., 38 pp., 1959.
AD-225 816.

Time histories of noise pressures near ground level were measured during flight tests of fighter-type airplanes over fairly flat, partly wooded terrain for M = 1.13 to 1.4 and at altitudes from 25,000 to 45,000 ft. Atmospheric soundings and radar-tracking studies were made for correlation with the measured noise data. The measured and calculated values of the pressure rise across the shock wave were generally in good agreement. There is a tendency for the theory to over-estimate the pressure at locations remote from the track and to underestimate the pressures for conditions of high tailwind at altitude. The measured values of ground-reflection factor averaged about 1.8 for the surfaces tested as compared to a theoretical value of 2.0. Two booms were measured in all cases. The observers also generally reported two booms; but in some cases, only one boom was reported. The shock-wave noise associated with some of the flight tests was judged to be objectionable by ground observers, and in one case the cracking of a plate-glass store window was correlated in time with the passage of the airplane at an altitude of 25,000 ft.

3954

Martin, M. H., and G. B. Jackson, "The Sound Waves Generated by a Particle at Supersonic Speed," Schweiz. Arch. Angew. Wiss. Tech., 16, 114-119, 1950.

The manner in which the sound wave moves through space as the particle moves along its path is considered first for the case of a particle moving at constant speed along a horizontal straight line. The general problem for a particle moving along a curvi-linear path with nonconstant speed is examined—the wavefront being shown to be convex for the decelerating particle and concave for the accelerating particle. The particular problem of a particle moving under the action of gravity and air-resistance only is considered for cases where the limiting velocity is sub- and supersonic. The assumptions made are briefly reviewed.

3955

Meyer, R. E., "On the Propagation of Aerodynamic Disturbances Far from a Body Rising Through the Atmosphere," Res. Memo. No. RM-2927-PR, RAND Corp., Santa Monica, Calif., 35 pp., 1962.
AD-278 487.

The far-field of a body rising vertically at supersonic speed is studied, using the acoustic approximation to obtain an insight into the effect that the atmospheric density stratification has on the propagation of the shocks and pressure waves generated by the body. Apart from the density stratification per se, the gravitational acceleration is found to have a major influence when the waves are followed over heights of several miles or more. The absolute pressure and density perturbations due to the body decrease with height while the velocity and particle displacement increase. The decay of the perturbation behind the shock is oscillatory, in contrast to its monotonic character in a uniform medium. At any point at considerable height and distance from the flight path, the air will experience a sudden, surprisingly large, upward and outward displacement, followed by a reversal and oscillatory decay in time. The natural decay of the perturbation with distance from the body is counteracted by certain effects. The acoustic results obtained usually give a reliable picture of the wave propagation up to heights of the order of 50 km.

3956

Obata, J., and Y. Yosida, "Sounds Emitted by Aircraft," Rept. No. 59, Aeron. Res. Inst., Tokyo Imp. Univ., 185 pp., 1930.
See Also: Proc. Phys. Math. Soc. Japan, 12, 80-92, 1930.

Describes the electrical methods used for recording the sounds emitted by various types of aircraft. These included a bomber, a chaser, a reconnaissance machine and a small dirigible. Straight-line flights and vertical turns were made. The sounds are generally very complex in nature, overtones being predominant in most cases. At short distances the exhaust sound predominates, while at longer distances the propeller provides the greater part of the sound, the fundamental and second harmonic being predominant. Different aeroplanes equipped with the same kind of engine gave different records. The pitch of the fundamental depends far more on the number of cylinders per bank than on the total number of cylinders in the engine.

A large number of the records obtained are reproduced in the paper.

3957

Oestreicher, H. L., "The Field of a Spatially Extended Moving Sound Source," Aero Medical Lab., WADC, 39 pp., 1955. AD-80 295.

The rigorous determination of the field of a spatially extended sound source moving with subsonic speed in a viscous compressible gas is formulated as an initial-boundary value problem of a system of linear partial-differential equations. This system reduces to a single equation of the second order with variable coefficients, if the medium is a perfect gas and the motion of the gas around the source a potential flow. The construction of a fundamental solution that fulfills a generalized radiational condition in infinity, and a generalization of Helmholtz's formula for this partial differential equation allow the representation of the sound field as a series of generalized multipoles. The field of a sufficiently small source of arbitrary shape with boundary conditions appropriate for the acoustical case, and its relation to the concept of a moving simple source, dipole, etc., are investigated. Errors in the existing literature are pointed out.

3958

Oestreicher, H. L., "Field of a Spatially Extended Moving Sound Source," J. Acoust. Soc. Am., 29, 1223-1232, 1957.

The rigorous determination of the field of a spatially extended sound source moving with subsonic speed in a viscous compressible gas is formulated as an initial-boundary value problem of a system of linear partial-differential equations. This system reduces to a single equation of the second order with variable coefficents, if the medium is a perfect gas and the motion of the gas around the source a potential flow. For steady motions and harmonic sources, the equation becomes elliptical if time is eliminated. Generalizations of Green's identity and Helmholtz's formula for this partial differential equation allow the representation of the sound field as a series of generalized multipoles. The field of a sufficiently small source of arbitrary shape with boundary conditions appropriate for the acoustical case and its relation to the concept of a moving simple source, dipole, etc., are investigated.

3959

Oestreicher, H. L., "Supplementary Notes to 'Field of a Spatially Extended Moving Sound Source,'" J. Acoust. Soc. Am., 30, 480-481, 1958.

See preceding abstract.

3960

Pike, E. W., "A Search for Means to Detect Distant, Low-Flying Aircraft," Tech. Rept. No. 161, Lincoln Lab., Mass. Inst. of Tech., 107 pp., 1957. AD-150 868.

The problem set is the detection, by a ground-based observer, of an aircraft 40 miles distant, perhaps 100 feet above the terrain, and at least 1000 feet below the observer's mask. The modes of interaction of the aircraft with its immediate surroundings, and the modes of transmission of this disturbance to the observer, can be listed exhaustively. There are 18 physically possible systems, and each can be evaluated confidently from data in the open literature. Only one, an extremely large uhf radar, has even marginal operational possibilities. The others fail by factors larger than 10^5 to provide adequate clutter rejection or sufficient signal strength to override the unavoidable noise. The probability of overlooked possibilities is negligible. The systems studied are based on the following interactions: static gravitational force; vector gravitational force; scattering of cosmic rays; sound generated by lift forces.

3961

Randall, D. G., "Methods for Estimating Distributions and Intensities of Sonic Bangs," Tech. Note No. Aero. 2524, Royal Aircraft Establishment, Great Britain, 53 pp., 1957. AD-157 507.

Describes methods recently developed for estimating distributions and intensities of sonic bangs. They are applied to several interesting flight maneuvers, and the results are discussed in detail. The effect on sonic-bang distributions and intensities of refraction (caused by the temperature gradient existing in the actual atmosphere) is also considered.

3962

Rao, P. S., "Supersonic Bangs, Part II," Rept. No. FM 2295, Aeron. Res. Council. Great Britain, 22 pp., 1955. AD-161 286.

The nonlinear theory of supersonic bangs, for a body accelerating along a straight path, is extended to include curved paths. The basic theory remains the same. The important parameter that appears in the theory is the acceleration component along the ray, the rays being lines drawn from points on the flight path at an angle $\cos^{-1}(1/M)$ with the direction of motion. It is found that the only essential effect of the curvature of the path is in the modification of this acceleration component to include a term due to the transverse acceleration. With this modification, the main results are formally the same as in the previous paper. The strength of the bow shock is obtained, and it is found that the effect of the curvature of the path is more pronounced at points on the inside of the curve, and in general it becomes greater as the distance from the body increases.

A simple asymptotic formula is obtained that predicts the strength of the shock, with an error of less than 5% at distances of the order of a hundred body-lengths. Finally, the theory is compared and contrasted with the recent work by Warren.

3963

Richtmyer, R. D., "Detached-Shock Calculations by Power Series, I," NYO-7973, Inst. Math. Sci., Univ. of New York, 49 pp., 1957. AD-150 033.

A method is described for calculating the flow of an inviscid, ideal gas between a blunt body moving at high Mach number and the detached shock that precedes it. The method is based on power-series expansion in two space variables about a point on the shock. Special Univac routines for formal calculation with power series have been developed; they include an interpretive routine of such a nature that the partial differential equations that determine the coefficients of the power series can be transcribed directly into a pseudocode. An important feature of the method is the use of special floating-decimal subroutines in which the possible loss of significant digits by cancellation is continually monitored. Test calculations that have been made with the method are reported. The results appear to indicate that the method has considerable promise for fluid-dynamical problems of this kind, but further development in certain directions is indicated.

3964

Ritter, A., R. Struble, and W. D. Parsons, "Theoretical Investigations of the Sonic Boom," Quart. Progr. Rept. No. 1, Armour Res. Foundation, Chicago, Ill., 33 pp., 1956. AD-213 001.

The problem of constructing and interpreting the linearized velocity potential for an accelerating body is investigated. Physical considerations concerning the buildup of pressure disturbances at sonic velocity are presented.

WAVE PROPAGATION, MOVING SOURCE

3965

Rott, N., "The Acoustic Field of a Rapidly Moving Source of Sound" (in German), Mitt. Inst. Aerodyn. E. T. H., Zurich, 9, 1945.

Following a historical survey, including Doppler's results and the fundamental acoustic equations with their solutions, discussions and formulae are presented on the acoustic field in parallel flow, on the field of a moving source of sound in an emitter-centered coordinate system, and on complete reflection at an infinite plane.

3966

Schwartz, R. N., and J. Eckerman, "Shock Location in Front of a Sphere as a Measure of Real Gas Effects," J. Appl. Phys., 27, 169-174, 1956.

Spheres were fired at supersonic speeds into monatomic gases and into chlorine gas. The position of the shock wave that forms in front of the sphere depends on the Mach number and gas state before and after crossing the shock wave. Measurements of position made in monatomic gases agree fairly well with aerodynamic theory. As the shock position depends on the actual gas state attained, and thus on molecular excitation times, measurements in more complicated gases than the monatomic can give information as to amount and rates of excitation. The vibrational energy excitation in chlorine was singled out for study. This excitation involves a well-known rate process. By carrying out shock-position measurements at several different pressures, it is possible to infer the order of magnitude of the vibrational relaxation time in chlorine; the present results are in agreement with shock-tube measurements of the relaxation time.

3967

Walters, A. G., "On the Propagation of Disturbances from Moving Sources," Proc. Cambridge Phil. Soc., 47, 109-126, 1951.

The concept of the Green's vibrational function given earlier (Walters, ibid., 45, 69-80, 1949) is used to obtain a general expression for the disturbance from a point source. The potential due to transient sources of sound moving with subsonic and supersonic velocities is derived from this. It is found that the Doppler effect for a supersonic source differs from that for a subsonic source. In the former case it is found that two frequencies are heard simultaneously from a source emitting a note of one frequency. The theory is applied to determine some solutions of the two-dimensional equation of supersonic, irrotational compressible flow, corresponding to the flow around an aerofoil; the entropy changes at the shock wave are taken into consideration.

3968

Webb, W. L., and A. L. McPike, "Sound Ranging Technique for Determining the Trajectory of Supersonic Missiles," Progr. Rept. Nos. 1 and 2, White Sands Signal Corps Agency, White Sands Proving Ground, N. Mex., 6 pp. and 23 pp., 1955.

These two reports are part of a series, the rest of which is classified. These reports describe the application of the Signal Corps GR-8 sound ranging system to the Sonic Observation of the Trajectory and Impact of Missiles (SOTIM). It was found that missiles traveling at supersonic speeds generate shock fronts which are easily observed over wide areas around the missile's trajectory. Analysis of the acoustic signals determined the location and speed of missiles at certain points along their trajectories. Furthermore, this data has been utilized to describe the manner in which pressure waves propagate over long distances through the earth's atmosphere.

3969

Young, W. H., "Tactical Use of Shock Waves from Aircraft," Rept. No. DR 1808, Bureau of Aeronautics, Navy Dept., Washington, D. C., 11 pp., 1958.
AD-204 249

Considers the possible tactical use of shock waves produced by supersonic aircraft. The effects upon light structures, camouflage, and helicopters on the ground and in the air were examined in particular. A graph is presented that indicates the estimated overpressures produced by an aircraft as a function of the distance from its flight path. Shown on this chart are the estimated minimum overpressures required to damage the items of interest. More test work is necessary to evaluate the probable effectiveness of shock wave attacks. It appears that some damage to light structures is probable, but damage to aircraft is improbable.

Assuming that damage can be produced which is equal or slightly superior to that estimated, there is the question whether it is sufficient to be economically feasible. The airplane must be flown within a few hundred feet of its target to be effective. The shock wave attack may prove useful against secondary targets and targets of opportunity after using "live" ammunition against a primary target. Although difficult to evaluate, the harassment of personnel by low-flying supersonic aircraft should be considerable.

3970

Zatzkis, H., "Sound Field of a Moving Cylinder and a Moving Sphere," J. Acoust. Soc. Am., 26, 169-173, 1954.

Most investigations of the sound field of a moving source deal only with point sources. We have examined the sound field of finite sources, moving with constant velocity. The simplest possible vibrators have been chosen, viz., a pulsating circular cylinder and a pulsating sphere. The solution is an infinite series in terms of Mathieu functions in the two-dimensional case, and in terms of prolate ellipsoidal functions in the three-dimensional case. Besides the rigorous solutions, asymptotic formulas valid for large distances away from the source are given.

3971

Zatzkis, H., "The Sound Field of a Moving Source," J. Acoust. Soc. Am., 25, 897-898, 1953.

The sound field generated by an ellipsoidal vibrator, moving with constant velocity, is examined. The solution has the form of an infinite series. The first term of the series agrees with the solution for a point source established by previous investigators.

Wave Propagation, Moving Source
See Also—200, 401, 522, 709, 720, 861, 863, 867, 868, 870, 1353, 1580, 1637, 1663, 1674, 1680, 1715, 1737, 2061, 2306, 2464, 2817, 2868, 2912, 3777, 4163, 4216

WAVE PROPAGATION, PROGRESSIVE

3972

Arsenin, V. Ya., and N. N. Yanenko, "Interaction Between Shock Waves and Traveling Waves" (in Russian), Dokl. Akad. Nauk SSSR, 109, 713-716, 1956.

A mathematical analysis of the effect of the shock waves on the compressional and expansional traveling waves expressed in Riemannian form $p = A \exp(\pm v/c)$; $u = (v \pm c)t + f(v)$, where p = gas pressure, v = velocity, u = Eulerian coordinate, $c = \sqrt{p/\rho}$ (ρ = density), A = a constant, and $f(v)$ = a function of v, for different values of the Riemannian invariants $r = c.\ln\rho + v$ and $s = -c.\ln\rho + v$.

3973

Brillouin, J., "Form and Propagation of Sound Waves in a Space Limited by Absorbing Surfaces," J. Phys. Radium, 10, 497-503, 1939.

Starting from the general velocity potential equation, an examination is made of various problems related to the propagation of forced vibrations in a space limited by absorbing surfaces. The absorption is defined by the impedance of the limiting surface. In the space limited by planes, nonuniform plane waves of special structure are shown to exist, with elliptical vibration in a plane containing the direction of propagation, amplitudes following an exponential law in the direction of the plane of the wave containing the elliptical trajectories, uniformity in the direction of the plane of the wave normal to the plane of the trajectories, phase velocity and velocity of energy propagation equal and less than the velocity of sound. These waves, in the space considered, play a similar part to that of plane uniform waves in spaces limited by rigid planes. The calculation finally gives, for spaces not totally enclosed, the different forms of progressive waves, with their phase-velocity and attenuation, and, for totally enclosed spaces, the forced vibrations.

3974

Brillouin, J., "Transient Radiation from Sound Sources and Connected Problems" (in French), Ann. Telecommun., 5, 160-172, 1950.

Mathematical. The problem of progressive wave coexisting with a stationary field in a medium is reviewed, with a survey of the framing of such a problem mathematically. Special note is made of the difficulties in the representation of discontinuities. General formulae are developed expressing the flux, and the radiated and stationary energy densities; these are applied to examples. The discontinuities created at the front and the end of a wave train are then treated and the results applied to a sinusoidal oscillator. The behavior of a rigid sphere subjected to certain types of external forces is examined, and the question of diffraction is briefly treated, with note taken of some practical consequences.

3975

Broer, L. J. F., "On the Propagation of Energy in Linear Conservative Waves," Appl. Sci. Res., A2, 329-344, 1951.

This paper is concerned with the question of when and why the rate of energy propagation in a system of waves equals the group velocity. By the method of stationary phase it is shown that equality holds for traveling waves without dissipation whenever this method applies. Why this result can be obtained by this kinematical method is investigated by a discussion of simple harmonic waves. It is shown that the choice of an expression for the energy density to be used in connection with a given wave equation is restricted by the conservation of energy in such a way that the average rate of work done divided by the average energy density always equals the group velocity. Finally, some examples of wave motion are discussed to illustrate the derived formulae.

3976

Carrus, P. A., P. A. Fox, F. Haas, and Z. Kopal, "The Propagation of Shock Waves in a Stellar Model with Continuous Density Distribution," Astrophys. J., 113, 496-518, 1951.

Aims at investigating the properties of progressing waves that arise if a compressible-gas configuration, in which the density ρ_0 diminishes with increasing distance r from the center, as $\rho_0 \sim r^{-5/2}$ is disturbed from its state of equilibrium by an instantaneous central explosion. It is shown that if this explosion has been sufficiently energetic for the outgoing disturbance to possess the characteristics of a shock wave, the central part of the configuration will be effectively evacuated by the explosion up to a certain distance from the center, depending on the amount of energy liberated by the initial explosion. If the release has been instantaneous (and, in consequence, the total energy of the wave motion is independent of the time t), the inner boundary of the flow (enclosing the empty core) becomes, by definition, a surface of contact discontinuity.

3977

Chrzanowski, P., G. Greene, K. T. Lemmon, and J. M. Young, "Traveling Pressure Waves Associated with Geomagnetic Activity," J. Geophys. Res., 66, 3727-3733, 1961.

Travelling atmospheric pressure waves with periods from 20 to 80 sec and pressure amplitude from about 1 to 8 d/cm^2 were recorded at a microphone station at Washington, D. C., during intervals of high geomagnetic activity. Trains of these waves can be expected at Washington, from a quadrant approximately centered on north whenever the magnetic index K_p rises to a value above 5. Their horizontal phase velocity across the station is usually higher than the local speed of sound. During two "red" aurorae, clearly visible at Washington, and at lower latitudes, the 20- to 80-second-period waves were accompanied by longer period, higher pressure, and much slower-travelling pressure disturbances. Observational data on the wave systems are presented and discussed.

3978

Chrzanowski, P., J. M. Young, G. Green, and K. T. Lemmon, "Infrasonic Pressure Waves Associated with Magnetic Storms," J. Phys. Soc. Japan, 17, Supplement A-II, 9-13, 1962.

Cosmic Ray and Earth Storm Conference, Kyoto, 1961, IL joint sessions. Pressure waves with predominant periods between 20 and 80 seconds and amplitudes up to 8 d/cm^2 were recorded with a quadrilateral microphone array near Washington, D.C., during intervals of high magnetic activity. These waves have a trace velocity along the earth's surface higher than the local speed of sound and show diurnal-directional properties consistent with a source on the night side of the earth. A high degree of association with large values of the planetary magnetic index K_p is established.

3979

Fay, R. D., "Oppositely Directed Plane Finite Waves," J. Acoust. Soc. Am., 29, 1200-1203, 1957.

The analysis is carried out in terms of particle velocities expressed as Mach numbers. In general, the pertinent quantities are expressed in relation to the infinitesimal values by a power series of these Mach numbers in which two powers are retained. To this order of approximation, the particle velocity is the vector sum of the particle velocities of the isolated component waves, and the speed of propagation in each direction has an increment proportional to the vector difference of these particle velocities. The general behavior of the sound field may be predicted from these two relations.

3980

Fay, R. D., "Successful Method of Attack on Plane Progressive Finite Waves," J. Acoust. Soc. Am., 28, 910-914, 1956.

The characteristic feature of the method is that at any point in the sound field the conservation criteria are expressed in terms of the instantaneous values of the speed of propagation, the particle velocity, the excess pressure, and excess density. These criteria, together with the adiabatic assumption, determine explicit relations between any two of these quantities. Excess pressure and excess densities are here defined as departures from the equilibrium values that exist at the instant when the particle velocity is zero. For waves of finite amplitude these equilibrium values, as well as the speed of propagation, are found to depend on the intensity. The increment in the speed of propagation does not agree with that obtained by classical methods of analysis. The discrepancy is found to be due to the omission in the classical forms of the continuity criterion of a term that specifies the effect of the rate of change in the speed of propagation.

3981

Hargrove, L. E., "Fourier Series for the Finite Amplitude Sound Waveform in a Dissipationless Medium," J. Acoust. Soc. Am., 32, 511-512, 1960.

A general expression is derived for the Fourier coefficients describing the change in waveform of an initially sinusoidal plane progressive acoustic wave of finite amplitude in a dissipationless medium. The first four Fourier coefficients are graphically presented for distances up to that of discontinuity.

3982

Hubbard, J. C., J. A. Fitzpatrick, B. T. Kankovsky, and W. J. Thaler, "Distortion of Progressive Ultrasonic Waves," Rev., 74, 107-108, 1948.

Spark shadow photographs have been taken of one-millimeter sound waves in air, and a microphotometer trace is used to show the change in waveform. Preliminary results obtained with waves in water, glycerine, and CCl_4 may account for the discrepancy in measured values of ultrasonic absorption.

3983

Ivanov-Shits, K. M., and F. V. Rozhin, "Investigation of Surface Waves in Air," Soviet Phys. Acoust. English transl., 5, 510-512, 1960.

An apparatus was designed to observe traveling surface waves in air. A battery of loudspeakers transmitted sound over an aluminium grill onto a rigid reflector. Theory suggests that surface waves originating beneath the grill should show a pressure variation obeying P_oe-az-ihx, where a is the attenuation factor and h the wave number of the surface. Measurements were made between 200 and 500 cps because at lower frequencies the waves have small attenuation and velocity dispersion and at higher frequencies they become concentrated into a thin layer. A rapid-response level recorder connected mechanically with a microphone enables the acoustic pressure to be measured along the three perpendicular directions. From such records the velocity and attenuation of the waves were determined and compared with calculated quantities.

3984

Keller, J. B., "Decay of Spherical Sound Pulses Due to Viscosity and Heat Conduction," J. Acoust. Soc. Am., 26, 58, 1954.

By combining the results of Kirchhoff and Knudsen, the effect of viscosity and heat conduction on a spherical sound pulse are found. A rectangular pulse becomes Gaussian, its peak moves with sound speed, its width increases proportionally to vt, and its amplitude decreases proportionally to $x^{-3/2}$, where x denotes radial distance from the origin. This behavior is exactly the same as that of a pulse in one dimension, except for an extra factor of 1/x which accounts for the spherical spreading.

3985

Keller, J. B., "Finite Amplitude Sound Waves," J. Acoust. Soc. Am., 25, 212-216, 1953.

Exact solutions of the one-dimensional gas dynamic equations, representing periodic sound waves of finite amplitude, are obtained for a particular medium. The progressive wave from a vibrating piston and the standing wave in a closed tube are examined in detail. Limits on the amplitude of the sound wave are found in order to avoid shocks or cavitation.

3986

Kieffer, J., and J. Dapoigny, "Progressive Plane Waves in a Continuous Medium" (in French), J. Phys. Radium, 18, 359-360, 1957.

Using a simple diagrammatic presentation, the progressive-wave systems that are possible in a continuous medium are derived, and their properties are defined.

3987

Kluge, M., "Velocity of Sound," Arch. Tech. Messen, 3, T61, 1934.

A survey of methods for measuring the velocity of sound in different media is given. The methods are grouped into direct methods, involving a measurement of the time taken for the sound wave to travel a specified distance, either by an oscillographic method or by Kunze's method (which makes use of the orientation effects which accompany binaural listening); and indirect methods.

3988

Lippert, W. K. R., "Method of Measuring and Analyzing Wave Motion," Acustica, 12, 125-139, 1962.

The method of determining the propagation parameters of wave motion in an acoustical medium was tested by taking as a model a sample consisting of numerous cylindrical tubes in parallel. Standing and progressive waves before and behind the sample in a duct system with a nonreflecting terminal were measured at many frequencies, whence a complete set of propagation parameters was derived. A refinement of the method was suggested, which serves to eliminate unwanted losses outside the sample, and the achievable improvement in determining the attenuation constant of wave motion in the tube sample is demonstrated and discussed in detail.

The theory of a variant form of the general method is derived, which permits a complete set of propagation parameters to be found from resonance curves of the magnitudes of the characteristic factors only. Experimental results of this novel resonance method and of the extended general method agree well with the corresponding propagation parameters computed by the classical theory.

3989

Mendousse, J. S., "Nonlinear Dissipative Distortion of Progressive Sound Waves at Moderate Amplitude," J. Acoust. Soc. Am., 25, 51-54, 1953.

The first part of this investigation deals with the case of a simple-harmonic wave that eventually becomes distorted into a relatively stable shape resembling that of a sawtooth wave with rounded-off corners. A simplified picture-theory is developed, in which the wave is idealized as consisting of a nondissipative linear portion of length λ_1, and a dissipative simple-harmonic portion of length λ_2. The amplitude A of the distorted wave and its rate of absorption α_A are computed from the dissipative wavelength $2\lambda_2$ and from the "build-up distance" $L = N\lambda$, at which stability of shape is achieved, both λ_2 and N being regarded as experimental data. Tests of the theory are made by using shadowgrams of waves generated in air by piezoelectric quartz at the frequency of 0.405 megacycle.

The second part of the paper presents an approximation treatment of the classical wave equation, in which either of two different transformations of variables lead to a quasi-linear differential equation of the type

$$\partial^2 z/\partial y^2 = \partial z/\partial x + \partial(z^2)/\partial y$$

In the first transformation, more suitable for periodic waves, x is used for the distance from the source and y for the time, while the reverse holds in the second transformation, which is more suitable for shock waves. An exact solution is given for the case of the simple-harmonic source already discussed in the first part.

3990

Miller, C. W., and G. B. Thurston, "Measurement of the Acoustic Field of Radiating Circular and Rectangular Apertures and a Scattering Circular Disk," Oklahoma State Univ. Research Foundation, Stillwater, Master's Thesis, 82 pp., 1961. AD-260 799.

Describes the results from measurements of the acoustical field of radiating circular and rectangular apertures and of the scattering around a circular disk. The field parameters determined include the pressure, the phase of the pressure, the pressure gradient, and the phase of the pressure gradient. Measurements described are for sonic frequencies in air. Short tone-bursts were used in the measurements. The measurement technique described is that of synthesis and analysis of a continuous electrical signal that is in coincidence with a selected portion of the signal representing the pulsed acoustic-field variable. Measured results are compared with the results from simple elementary theoretical analyses of the cases considered.

3991

Pachner, J., "Investigation of Scalar Wave Fields by Means of Instantaneous Directivity Patterns," J. Acoust. Soc. Am., 28, 90-92, 1956.

A method is presented for determining the traveling and standing components of an arbitrary scalar wave field from the measured instantaneous values of the field on the surface of two spheres surrounding the emitter.

3992

Pachner, J., "On the Dependence of Directivity Patterns on the Distance from the Emitter," J. Acoust. Soc. Am., 28, 86-90, 1956.

A method is developed for easily determining the directivity pattern in an arbitrary distance from the emitter from measured instantaneous values of the field in other distances. Numerical computation is facilitated by the tables put together in this paper.

3993

Powell, A., "Propagation of a Pressure Pulse in a Compressible Flow—Coda," J. Acoust. Soc. Am., 32, 1116, 1960.

As explained previously (J. Acoust. Soc. Am., 31, 1527-1535, 1959), the disturbances due to the progress of an initially step-like pressure wave down a channel carrying a compressible flow can be analyzed by a multiple reflection method. For the final transmitted and reflected pressures, this yields a power-series expansion, successive terms representing the effect of higher-order reflections. It is now shown that the coefficients of these series are connected to Euler's and Bernoulli's numbers, respectively, and convenient expressions for the coefficients are given. When n is not small, the coefficient $c^n \approx 2(2/\pi)^{n+1}$. The infinite-power series are shown to have sums simply like sechx and tanhx, respectively. This provides an easy means for numerical evaluation, and gives simple criteria for the accuracy of the approach, using the leading term of each of the series. When reflections of all orders are taken into account, the results are analytically identical to those of the before-and-after steady-flow method.

3994

Rudnick, I., "Theory of the Attenuation of Very High Amplitude Sound Waves," Tech. Rept. 1, Soundrive Engine Co., Los Angeles, Calif., 21 pp., 1952. AD-21 268.

The propagation of continuous plane progressive sound waves with pressure variations of the order of one-tenth the average pressure is discussed. Shocks are shown to develop at the leading front of each wave after several wavelengths of propagation regardless of the initial wave form. The attenuation of the repeated shocks was derived from shock wave theory with the assumption that the resulting stable wave form is sawtooth in character. In writing $p_2/p_1 = 1 + \delta$, where $p_1 - p_2$ is the pressure discontinuity at the shock, it is shown that

$$\frac{1}{\delta} - \frac{1}{\delta_0} = \frac{\gamma + 1}{2\gamma} \cdot \frac{X - X_0}{\lambda}$$

where δ_0 is the value of δ at the distance X_0, γ is the ratio of specific heats, and λ is the wavelength of the sound. The result was compatible with previously published studies of the attenuation of single N-shaped waves. Fay's solution (J. Acoust. Soc. Am., 2, 222, 1931) of the hydrodynamic equations, including the effects of viscosity, which shows the stable waveform to be a sawtooth, may be extended to yield the derived attenuation rate.

3995

Salmon, V., "Generalized Plane Wave Horn Theory," J. Acoust. Soc. Am., 17, 199-211, 1945-1946.

By the use of dimensionaless variables and simplifying transformations, Webster's plane wave horn equation is recast into a form permitting separation of the effects of horn contour and frequency. A generalized expression for the admittance also displays this separation. Further interrelations among the variables are developed which permit the formal synthesis of a horn from a given conductance or susceptance function. The conditions for realizability of the horn thus synthesized are discussed. Several applications of the results are presented, including a comparison with Freehafer's exact theory for the hyperbolic horn.

3996

Schoch, A., "On the Question of the Impulse of a Sound Wave" (in German), Z. Naturforsch., 7a, 273-279, 1952.

The first section deals with the wave equation and its solution for a unidimensional progressive sound wave. Then follow sections dealing with the radiation pressure and impulse of a progressive wave, radiation pressure and energy-density, and the case of the unrestricted three-dimensional wave. It is concluded that in the case of a progressive sound wave a wave-pocket possesses a very definite impulse, whereas in a periodic stationary wave the impulse is, on the average, zero.

3997

Sprott, A. L., "The Effect of Strong Progressive Sound Waves on Free Convection Heat Transfer from a Horizontal Cylinder in Air," Rept. No. GAE-59-22, Air Force Inst. of Tech., Wright-Patterson Air Force Base, Ohio, 1959. AD-227 506.

An experimental investigation was made of the effect of progressive soundwaves on the free-convection heat-transfer coefficient, h, from a horizontal cylinder in air. Forty nine test runs were made over a range of frequencies from 1000 to 5000 cps and a sound-pressure-level range of 121 to 150 db. Shadow-photographs were taken at each combination of frequency and sound pressure tested. A critical sound pressure level below which no change in heat transfer occurred was observed. The value of this level ranged from 131 to 137 db, depending on frequency. The heat-transfer coefficient was found to increase in a highly nonlinear manner with increasing sound-pressure level above the critical. The maximum change in h observed was 184.5% at a sound-pressure level of 149.5 db and a frequency of 3220 cps. Shadow-photographs revealed a flow-separation phenomenon, which was determined to be the controlling factor in the increase of heat transfer. A periodic shedding of the separated flow regions as vortices was observed. A 16-mm motion picture was made of these effects in continuous sequence.

3998

Sprott, A. L., J. P. Holman, and F. L. Durand, "An Experimental Study of the Interaction of Strong Sound Fields with Free Convection Boundary Layers," Aeronautical Research Lab., Ohio, 26 pp., 1960.
AD-236 027.

It is demonstrated experimentally that strong progressive sound fields may interact with a free convection boundary layer on a horizontal cylinder in such a manner as to produce increases in heat transfer rates of the order of 100%. Shadowgraph flow visualization studies indicate that the mechanism of the interaction is such that a separated-flow region is produced on the upper side of the cylinder. No effect on the boundary layer or heat transfer is observed until the sound intensity is raised above a certain critical value. For the experiments described in the paper, the critical sound-pressure level ranged from 134 to 138 db. In a qualitative analysis of the experimental results it is postulated that the increase in heat transfer is the result of an interaction of the phenomenon of acoustical streaming with the free-convection boundary layer. It is also believed that the mechanism of thermoacoustic transduction may be applicable.

3999

Sturrock, P. A., "Energy-Momentum Tensor for Plane Waves," Phys. Rev., 121, 18-19, 1961.

A general form is established for the energy-momentum tensor for plane waves propagating in a homogeneous medium, the field equations of which are derivable from a quadratic Lagrangian function. Energy density and momentum density are proportional to frequency and the wave vector, the coefficient of proportionality being action density. Energy flow and momentum flow are related to energy-density and momentum density by the group velocity. The relation between momentum density and the wave vector is valid even in a nonlinear system. For a wave packet, one finds that the total energy is related to frequency and the total momentum to the wave vector by the total action of the packet, in close analogy with corresponding relations of quantum mechanics.

4000

Westervelt, P. J., "The Mean Pressure and Velocity in a Plane Acoustic Wave in a Gas," J. Acoust. Soc. Am., 22, 319-327, 1950.

The one-dimensional wave equation is discussed to the second order of approximation by means of a transformation that carries the equation from the Eulerian to the Lagrangean form. Airy's Lagrangean solution to this equation has been shown by Fubini to be an excellent approximation to an exact solution of Earnshaw's equation of motion; therefore, Airy's solution is chosen as the basis for much of this discussion. An expression for the local mean hydrostatic pressure in a plane progressive wave is obtained by transforming Airy's solution from particle to local coordinates.

In a similar way, the particle velocity in fixed coordinates is shown to possess a time-independent component proportional to, and in a direction opposite to, the intensity vector. This dc counter-velocity is predicted without recourse to viscous forces, and is compatible with zero average mass velocity. For a sound-pressure level of 151 db in air there should exist a steady particle velocity of 1 cm/sec. Small particles suspended in the field can, under certain circumstances, acquire this velocity. An approximate treatment is suggested for handling second-order effects arising from stationary field configurations. The influence of viscosity is discussed qualitatively.

4001

Zarembo, L. K., "Nonlinear Distortion of Plane Waves in a Non-dissipative Medium," Soviet Phys. Acoust., English Transl., 7, 149-153, 1961.

The author performs a Fourier analysis of the Riemann solution to the hydrodynamical equations for a plane periodic wave of arbitrary shape. The initial spectrum of the wave at $x = 0$ is assumed to be arbitrary, but with the reservation that there are no weak discontinuities in the wave. The wave spectrum for $x > 0$ is determined, correct to the first-order variables with respect to Mach number. The nonlinear interaction of the components of the initial spectrum in general leads to a change in the amplitude, frequency, and phase characteristics of the spectrum. The distance at which these changes become significant (interspersion length) is determined.

Special cases of spectra are discussed, showing that given identical periods and Mach numbers, the nonlinear distortion of nonmonochromatic waves is proportional to the width of the spectrum and is therefore greater than in the monochromatic case. Nonlinear interaction leads to spreading of the spectrum of finite width in both directions and, in some cases, to such mixing of the spectrum within the initial band that inside that band a tendency toward uniform distribution of the spectral density will be observed.

Wave Propagation, Progressive
See Also—34, 47, 53, 56, 95, 180, 255, 374, 401, 894, 920, 976, 992, 1007, 1011, 1032, 1809, 1879, 1885, 1886, 1887, 1890, 1894, 1897, 1899, 2158, 2177, 2183, 2600, 2782, 2807, 3344, 3394, 3480, 3481, 3482, 3616, 3632, 3637, 3651, 4290, 4312, 4381, 4401

WAVE PROPAGATION, SHOCK, GENERATION

4002

Astapovich, I. S., "The Power of the Sound Detonations of the Choulak-Kurgan Bolide," Byul. Turkin, FAN SSSR, 77-80, 1946.
Translation No. F-TS-8844/III, Air Technical Intelligence Center, Wright-Patterson Air Force Base, Dayton, Ohio, 7 pp.
AD-111 033.

The acoustical field produced by a meteorite's entry into the atmosphere is theoretically devolved. Mathematical evidence for the production of a shock wave followed by a decay similar to a thunder peal is shown. Detailed evidence of the Chalak-Kurgan bolide's entry and acoustical field is documented.

4003

Bernstein, B., H. B. Hall, et al., "On the Dynamics of a Bull Whip," J. Acoust. Soc. Am., 30, 1112-1115, 1958.

Discusses the production of the cracking sound made by a bull whip. Photographic evidence shows that the crack is produced by the tip of the whip exceeding the speed of sound and giving off shock waves, rather than by the whip slapping itself. This evidence includes motion pictures as well as still shadow pictures which show the tip shedding shock waves. There follows a mathematical discussion of an idealized bull whip, with attention to the problem of how the free end of this mechanism achieves a high velocity while the end held in the hand moves relatively slowly. A mathematical solution is given in which it is assumed that a discontinuity in tension propagates down the whip.

4004

Camm, J. C., and P. H. Rose, "Electric Shock Tube for High Velocity Simulation," Res. Rept. No. 136, AVCO Everett Research Lab., Mass., 61 pp., 1960.
AD-282 729.

Shock tubes were developed capable of producing a gas sample of known conditions at velocities as high as 43,000 ft/sec. The driver of these shock tubes employs a capacitor bank which discharges electrical energy into helium, heating the helium to temperatures of 10,000-20,000°K, and raising the pressure to 10,000-20,000 psi. The high pressure bursts the scribed diaphragm and the resulting shock wave propagates into the test gas.

Extensive diagnostic techniques were employed in the resulting hot gas samples. The growth of these samples was observed optically, and correlations were achieved with theoretical calculations. The observed radiation was compared with and can be used to extend the known radiative properties of high-temperature air. Time-resolved luminous pictures and spectra were also taken to show the purity of the test gas.

The speed and attenuation of the shcok front were measured. The observed operation of this shock tube was compared to theoretical predictions, and although no precise correlation can be made, the driver-gas energy transfer and losses in the shock-tube boundary layer can be accounted for.

4005

Campbell, R. G., "Initial Wave Phenomena in a Weak Spherical Blast," J. Appl. Phys., 29, 55-60, 1958.

The initial waves created by the sudden release of a spherical volume of compressed air in a limitless environment of air at constant state are predicted analytically, using an iterative method of solution by characteristics for the case of a specific weak blast. Pressure-time records were obtained within the compressed air and in the immediate environment of the spherical blast during its early stages, using a pyramidal shock tube. The experimental results corroborate the existence and position in time and space of the inner and reflected shock waves predicted analytically. The present results for a weak spherical blast agree substantially with the analytical and experimental results obtained previously by other investigators for a considerably more powerful blast. The shock tube, in pyramidal or conical form, appears to offer considerable promise for further research on spherical blast phenomena.

4006

Carriere, Z., "Exploration, by Means of a Whip, of the Two Faces of a Sound Wall" (in French), Cahiers Phys., 63, 1-17, 1955.

The production and characteristics of the sound barrier produced by the cracking of a whip, defined as the geometrical surface separating infra- and super-sonic regions of sound propagation, are illustrated and discussed. The illustrations show the origin and successive instantaneous forms of the shock wave, and illustrate the marked curvature and feeble development of the supersonic trajectory, together with the apparent contour of the terminal node generator, in the rear of which no trace of a wave occurs. It is considered that the double-report heard when an airplane breaks through the sound barrier is satisfactorily explained, in respect to the very short interval of time separating the two reports and, more especially, their very slight difference of intensity, by considering reflection by the ground; multiple echoes are possible. Other matters discussed include the dynamics of the launching of the crack of a whip by a launching pulley, the effect of the mass of the whip-cord, and methods of measuring and recording the extremely high velocities occurring, of the order 1000 meters/sec.

4007

Cox, R. N., and D. F. T. Winter, "A Theoretical and Experimental Study of an Intermittent Hypersonic Wind Tunnel Using Free-Piston Compression," ARDE Rept. No. (B) 9/61, Armament Research and Development Establishment, 1961.
AD-264 914.

Recounts the development of the hypersonic gun tunnels at ARDE, and studies their performance. Presents calculations of the various phases of piston motion, including the starting motion and shock formation, the multiple shock reflection between the piston and the end of the barrel, and the piston deceleration. Reports the development of an analytical method for calculating the piston motion; this method is compared with a numerical calculation based on the method of characteristics.

Includes estimation of the stagnation enthalpy achieved in the tunnel, and considers real gas effects, bore friction, and boundary layer growth. Presents experimental results of the pressure-time history of the tunnel operation, as well as the results of tunnel stagnation measurements and working section conditions.

4008

David, E., "Physical Processes in Electric Wire Explosions," Feltman Res. Eng. Labs., Picatinny Arsenal, Dover, N. J., 1959.
AD-226 831.

A typical example of a medium-heavy wire explosion is worked out in order to demonstrate the various successive physical processes which occur in it. A current of several thousand amperes heats the material of the wire in a little more than 10 μsec to almost 10,000°C. Inertial forces, initially supported by magnetic forces, keep it almost stationary in the process. The axial pressure rises to several thousand atm. They lead to an explosive expansion, in the beginning of which the material, now a compressed gas, becomes nonconductive and interrupts the current. The expanding metallic vapor propels an air shock wave (explosive wave). In a few microseconds it rarefies to such an extent that a normal gas discharge ignites in it.

4009

Drummond, W. E., "Explosive Induced Shock Waves, I. Plane Shock Waves, II. Oblique Shock Waves," J. Appl. Phys., 28, 1437-1441, 1957; 29, 167-170, 1958.

The explosive production of shock waves in solids is analyzed in the approximation that third- and higher-order terms in the shock strength can be neglected, and a procedure is developed for calculating the attenuation of the shocks. Application is made to the problem of determining the equation of state of the burned explosive gas.

4010

Duff, R. E., "The Use of Real Gases in a Shock Tube and Appendixes," Rept. No. 51-53, Eng. Res. Inst., Univ. of Mich., Ann Arbor, 136 pp., 1951.
ATI-98 954.

Reports progress in the research and development work on the use of real gases in a shock tube. The strongest shock wave that can be produced by a given initial pressure ratio across the diaphragm of a shock tube may be obtained by using hydrogen in the compression chamber. Expressions for the flow velocity produced by a rarefaction wave in a gas with temperature-dependent specific heat and in a van der Waals' gas were derived. It was shown that both of these departures from the ideal conditions assumed in the derivation of the Taub equation are negligible for hydrogen. They might be important, however, if a polyatomic gas were used in the compression chamber for a special investigation.

4011

Favier, J., and C. Fauquignon, "Acceleration of a Shock-Wave, Causing Detonation of a Condensed Explosive" (in French), Compt. Rend., 1291-1294, 1959.

When a shock-wave causes detonation of a condensed explosive, an acceleration of this shock-wave exists in the zone preceding the capping stage of the detonation; this acceleration is continuous until the stable detonation regime is reached. This result permits to corroborate a thermic diagram of forming and maintenance of a detonation wave in an explosive. The experimental device consists of two cartridges of blasting agent, the one normally capped and called generating cartridge, the other uncapped and called receiving cartridge. The blasting agent used is a compound of hexogene and tolite; the actionless interposed substance is Plexiglas.

4012

Ford, C. A., and I. I. Glass, "On the Interaction of Two Similarly-Facing Plane Shock Waves," J. Appl. Phys., 25, 1549-1550, 1954.

Describes two methods of generating and showing the interaction of two similarly-facing plane shock waves, alternative to that described by Laporte and Turner. Both utilize the schlieren technique; in the first, the overtaking shock waves are formed by double refraction of a plane shock wave at an air-helium interface, while the second method uses three shock tube chambers at successively higher pressures.

4013

Glass, I. I., and L. E. Heuckroth, "Head-On Collision of Spherical Shock Waves," Phys. Fluids, 2, 542-546, 1959.

Presents some experimental results of colliding shock waves and the associated spherical flows generated by the blasts from two high-pressure gas spheres. Glass spheres, two inches in diameter, with their centers located nine inches apart, containing air or helium up to 500 psi, were used to produce the explosions. Instantaneous spark shadowgrams, multispark schlieren photographs, and wave-speed schlieren records of the radius-time plane indicate that this method can be used successfully to study such interactions.

4014

Greber, I., "Strong Shock Waves in Polyatomic Gases," MIT Rept. No. 56-83, Mass. Inst. of Tech, Cambridge, 22 pp., 1956. AD-94 845.

A summary of current literature on shock waves in gases. Primary attention is focused on the structure of strong shock waves in a polyatomic gas, particularly air, and the generation of strong shock waves in shock tubes. The increase of shock strengths obtainable from simple configurational modifications of the basic shock tube is shown.

4015

Jones, W. A., F. L. McCallum, and J. C. Muirhead, "Suffield Experimental Station Shock Tube Instrumentation, IX. The Use of Conventional Shock Tubes for the Generation of Very Low Pressure Waves," Suffield Tech. Note No. 92, Suffield Experimental Station, Canada, 9 pp., 1962. AD-282 634.

Describes modifications made in conventional shock tubes in order to obtain very low pressure waves. The modifications derive from two different approaches; first, improving the diaphragm-breaking mechanism of a constant cross-section shock tube in order to obtain good wave generation at low pressure, and, second, using a small cross-section compression chamber driving a larger cross-section expansion chamber.

4016

Jones, W. A., F. L. McCallum, and J. C. Muirhead, "Suffield Experimental Station Shock Tube Instrumentation, X. Modification of Shock Wave Valves to Allow Independent Control of Shock Wave Overpressures and Positive Durations," Suffield Tech. Note No. 94, Suffield Experimental Station, Canada, 5 pp., 1962. AD-284 953.

Describes modifications made in the actuating system of a shock-wave valve to allow independent control of shock wave overpressures and positive durations. By restricting the outward flow of air from the actuating chamber, the main valve piston can be made to re-seal before the compression chamber has been fully exhausted, and by altering the amount of flow restriction from the actuating chamber, the positive duration of the shock wave can be varied. For shock wave overpressures up to 20 psi, variation in the duration can be effected without significantly altering the overpressure of the shock wave. This system has an additional advantage in that it prevents the main piston from striking the end of the actuating chamber, which is a possible source of damage to the valve.

4017

Jones, W. A., F. L. McCallum, and J. C. Muirhead, "Suffield Experimental Station Shock Tube Instrumentation, XI. The Use of Shock Wave Valves with Compression Chamber Overpressures of 100 to 600 psi," Suffield Tech. Note No. 95, Suffield Experimental Station, Canada, 15 pp., 1962. AD-288 214.

Experiments were conducted to assess the performance of shockwave valves at compression chamber overpressures up to 600 psi. A second shock, apparently caused by wave interactions within the chamber, greatly increased peak shock overpressures obtained from a particular compression chamber overpressure and especially affected the overpressure of reflected waves. However, the second shock can create a wave shape which is undesirable for many purposes, and suggestions for its removal are made. The experiments also showed that excessive restrictions on the flow from the actuating chamber result in decreased shockwave overpressures. While the shock wave valve performed well, as the pressures indicate, the report makes clear that not all aspects of its operation are clearly understood and defined.

4018

Jones, W. A., and J. C. Muirhead, "Suffield Experimental Station Shock Tube Instrumentation, XII. The Generation of Two Distinct Shock Waves in a Single Expansion from a Single Compression Chamber," Tech. Note No. 981, Suffield Experimental Station, Canada, 11 pp., 1962. AD-288 215.

Describes a method for obtaining from a single compression chamber two or more distinct shock waves in a single expansion chamber. A shock wave valve is used to open, close, re-open, and re-close the compression chamber of a compressed-air-driven shock tube, thus allowing the formation of two or more distinct shock waves.

4019

Kieffer, J., J. Dapoigny, and B. Vodar, "Nature and Process of Formation of Shock Waves Initiated by Detonation of an Explosive" (in French), Compt. Rend., 247, 577-580, 1958.

The possibilities of shocks of respectively greater or lesser velocity than the detonation wave (e.g., in penthrite) are discussed for a variety of substances whose experimental Hugoniots are given. In all cases the latter should take place, although at extremely high pressures the former may come into play for heavier substances.

4020

Kusukawa, K., "On the Theory of Shock Waves Produced by a Rigid Cone Moving Through an Elastic Medium with Supersonic Velocities," J. Phys. Soc. Japan, 6, 166-167, 1951.

The field of flow around a slender conical obstacle is calculated by a method similar to that used for a wedge. Values of the strain at the wall of a cone of semi-angle 5^o are tabulated for Mach number M = 1.06 to M = 2.92.

4021

Kusukawa, K., "On the Theory of Shock Waves Produced by a Rigid Wedge Moving Through an Elastic Medium with Supersonic Velocities," J. Phys. Soc. Japan, 6, 163-165, 1951.

Using linearized equations appropriate to the condition of small strain, formal solutions are found for the field of flow around a wedge moving with supersonic velocity. Two special cases considered: are irrotational flow and flow of a deformable incompressible fluid. It is shown that the formal solution for the first case implies that η, the coefficient of friction between the fluid and the wedge, is defined by

$$\eta = \mu \sin (2\alpha - \gamma)/[\lambda + \mu \cos 2(\alpha - \gamma)]$$

where α is the semi-angle of the shock wave attached to the apex of a wedge of semi-angle γ; λ and μ are Lame's constants. Such a solution is physically possible because $0 < \eta < \mu/(\lambda + \mu) < 1$.

A formal solution is possible in the second case, but as it implies a shearing force acting in the direction of the velocity of flow, it is physical unrealizable. A numerical solution for $\gamma = 5^o$ is given; it is found that in this case the minimum difference in transverse strain across the shock front occurs at Mach number M = 1.36.

4022

Laponsky, A. B., and R. J. Emrich, "Observation of Shock Formation and Growth," J. Appl. Phys., 24, 1383-1388, 1953.

Transient one-dimensional flows have been produced by accelerating a piston in a gas-filled tube. Accelerations of the order of 2.5×10^4 meters/sec^2 produced shocks within 5 meters of the initial piston position. The piston was propelled pneumatically. Shocks formed at the head and in the interior of the compression waves. By optically detecting the piston and shock positions and recording the corresponding times on a rotating drum chronograph with microsecond accuracy, the properties of the compression wave and of the resulting shock were determined. The formation and growth of shocks were calculated from the compression-wave measurements using the method of characteristics and the assumptions employed by Chandrasekhar and Friedrichs. The observed and calculated shock properties were in reasonably good numerical agreement. Consistent lagging of the observed behind the calculated shock positions (order of 0.05 meter at 5 meters from initial piston position) is attributed to the interaction of the flow with the tube walls.

4023

Lee, J. D., and R. M. Nerem, "Theory and Performance of a Shock Tube Having an Arc-Heated Driver," Aerodynamic Lab., Ohio State Univ. Research Foundation, Columbus, 29 pp., 1962.
AD-277 192.

The pertinent design features, theory of operation, and some initial results are described for a shock tube which utilizes an arc-discharge in the high-pressure driving chamber. The tube has a diameter of four inches, with a 16-inch long driver and a 35-foot driven section. Power stored in a 6000-volt, 200,000-joule capacitor bank is discharged across coaxial electrodes in the pre-pressurized driver chamber. The arrangement is analyzed by assuming perfect gas parameters to obtain driven shock Mach numbers as a function of initial pressures and energy of discharge. Both air and helium are used in the driver while air alone is used in the driven section. Shock Mach numbers up to 33 have been obtained to date. Wave speed is measured through the use of ionization gauges, and pressure by piezo-electric pickups.

4024

Legras, J., "Application of Lighthill's Method to a Plane Supersonic Flow" (in French), Compt. Rend., 233, 1005-1008, 1951.

The method of analysis developed by Lighthill and by Whitman (Proc. Roy. Soc. London A, 201, 89-108, 1950) is applied to determine, more especially, the shock waves produced by an obstacle placed in a plane supersonic flow stream, both in the neighborhood of, and remote from, the object. A first approximation, valid throughout the whole stream, is derived.

4025

Luthringer, G., "Estimated Performance Characteristics of the ARL 30-inch Hypersonic Wind Tunnel at M 18," Rept. No. ARL-176, Aeronautical Research Lab., Office of Aerospace Research, Wright-Patterson Air Force Base, Ohio, Rept. for July-Aug 61, on Research on Aerodynamic Flow Fields, 14 pp., 1961.
AD-277 952.

Predicted values of the important performance parameters for the Aeronautical Research Laboratory's new thirty-inch (nozzle-exit diameter) hypersonic wind tunnel are discussed. Included are curves giving the tunnel's Reynolds numbers per unit length, flight Reynolds number (with simulation capability indicated), degrees supersaturation, mass flow rates, normal shock recovery pressures, vacuum system characteristics, and running times.

4026

Payman, W., and H. Titman, "Explosion Waves and Shock Waves, Part III. Initiation of Detonation of C_2H_4-O_2 and CO-O_2 Mixtures," Proc. Roy. Soc. (London), A, 152, 418-445, 1935.

So far, this series of papers has dealt mainly with nonmaintained or partially-maintained atmospheric shock waves, and only inidentally with the fully-maintained detonation wave. In the present article the initiation of detonation and the production of shock waves and their effect on the flame prior to the setting up of detonation are studied. The mixtures used are C_2H_4 and O_2, which detonate with ease, and of CO and O_2 which do so with comparative difficulty.

When shock waves are formed, they may push the flame forward at a lower speed than that at which they are passing through it, or they may retard the flame on meeting it after reflection from a closed end; hence in a closed system the flame may be made to oscillate. The shock waves do not necessarily travel throughout the unburnt gas at uniform speed relative to the wall of the tube, for the gas may be moving at varying velocities at different distances from the flame. Waves travelling from hot to cold gases diminish in speed, while they increase in speed on travelling from cold to hot gases; on meeting a flame they are partially reflected, with change of sign under suitable conditions, and are partially transmitted. On collision with a solid obstruction they are reflected, usually at a lower speed. Detonation may be set up either ahead of or, more usually, within the flame front, due to the effect of waves travelling in front of or from behind the flame, the collision or overtaking of wave and flame or wave and wave, or the collision of a wave with an obstruction or the closed end of the tube.

4027

Perry, R. W., and A. Kantrowitz, "The Production and Stability of Converging Shock Waves," J. Appl. Phys., 22, 878-886, 1951.

The experimental production of high temperatures and pressures by means of these converging shocks depends on their stability of form. A converging wave is said to be stable if it approaches perfect cylindrical or spherical shape, thus damping out random disturbances as it propagates. L. G. Smith's experimental work on Mach reflection is applied to show that these converging waves are stable for the shock range ($M \leq 2.4$) covered by his experiments. Smith's work and the theoretical work of Lighthill indicate that the stability decreases greatly at high Mach numbers. The simplest experimental method of achieving a cylindrical converging shock is by the use of a shock tube with a converging channel. This, however, results in the hottest region of the gas being in close thermal contact with the cold walls.

An axially symmetric shock tube has been designed and constructed that produces a complete, converging cylindrical shock rather than just a sector; and in the tube, the region of convergence is comparatively well isolated thermally from the walls. It has been found possible to converge a moderate strength shock wave ($M = 1.7$) sufficiently to produce considerable luminosity at the center of convergence. Schlieren photographs are presented showing various phases of the formation and stability of these converging waves.

4028

Russell, D. A., "Orifice Plates in a Shock Tube," Phys. Fluids., 5, 499-500, 1962.

Describes experimental results obtained in a study of the effects of area change near the diaphragm of a shock tube. The ideal theory agreed with experiments except where a nonsteady secondary shock wave was predicted; for this case, good agreement was obtained with a theoretical model replacing the secondary shock by a stationary compression (Fanno-process) region. The area changes were obtained easily by the use of interchangeable orifice plates, which provide a convenient means of controlling the shock Mach number.

4029

Russo, A. L., and A. Hertzberg, "Modifications of the Basic Shock Tube to Improve Its Performance," Rept. No. AD-1052-A-7, Cornell Aeron. Lab., Inc., Buffalo, N. Y., 43 pp., 1958. AD-162 251.

Considers basic modifications which would improve the performance of shock tubes in producing higher shock strengths and extend the use of hydrogen in generating strong shock waves in air. These modifications are the double-diaphragm driver with monatomic buffer gases and an area contraction at the diaphragm station. The results of this investigation indicate that the use of a shock tube with an area contraction and the proper monatomic buffer gas will permit the generation of strong shock waves, using cold hydrogen as a driver gas, with overall pressure ratios comparable to those required for combustion drivers. It is also shown that, by using a buffer gas with the proper atomic weight, the downstream diaphragm pressure ratio may be controlled to minimize the mass of the downstream diaphragm.

4030

Schwartz, R. N., and J. Eckerman, "Shock Location in Front of a Sphere as a Measure of Real Gas Effects," J. Appl. Phys., 27, 169-174, 1956.

Spheres were fired at supersonic speeds into monatomic gases and into chlorine gas. The position of the shock wave that forms in front of the sphere depends on the Mach number and gas state before and after crossing the shock wave. Measurements of position made in monatomic gases agree fairly well with aerodynamic theory. As the shock position depends on the actual gas state attained, and thus on molecular excitation times, measurements in more complicated gases than the monatomic can give information as to amount and rates of excitation. The vibrational energy excitation in chlorine was singled out for study. This excitation involves a well-known rate process. By carrying out shock-position measurements at several different pressures, it is possible to infer the order of magnitude of the vibrational relaxation time in chlorine; the present results are in agreement with shock-tube measurements of the relaxation time.

4031

Seigel, A. E., "Theoretical Study of the Effect of the Non-Ideality of a Dense Shocktube Driver Gas with Special Reference to Non-Uniform Shocktubes," Ballistics Res. Rept. No. 5, Naval Ordnance Lab., White Oak, Md., 1957. AD-162 932.

It is shown that the performance of a dense driver gas in a shocktube may be considerably different from an ideal driver gas as a result of the attractive and repulsive forces that exist between the gas molecules. An amazing result of the density effect is that at moderately high densities the nonideality may decrease the driving efficiency in a uniform shocktube, while in a nonuniform shocktube it increases the driving efficiency.

4032

Shunk, R. A., "Shock Formation from Strong Compression Waves," Tech. Rept. No. 11, Inst. of Res., Lehigh Univ., Bethlehem, Pa., 60 pp., 1958. AD-162 006.

Strong compression waves in a gas are produced in a tube by accelerating a light piston. The shock that forms and grows out of the compression wave, and the changing form of the compression wave are observed by optical methods. Approximate methods of calculating the shock formation and growth are inadequate for compression waves whose density ratio is two or more in sulfur hexafluoride gas. A wave-diagram method is presented that correctly predicts the essential features.

4033

Smy, P. R., "Electromagnetic Shock Tube Capable of Producing a Well-Formed Shock Wave of Low Attenuation," Nature, Great Britain, 193, 969-970, 1962.

Description of a variation on the electromagnetically driven shock tube designed to avoid the severe shock attenuation usually encountered. Shock attenuation and secondary shock formation are minimized by using a dense driver gas. Here it is high pressure nitrogen separated from the channel by a plastic diaphragm, and initiated by discharging a condenser bank into the driver section.

4034

Teel, G. D., "Proceedings of the Fourth Shock Tube Symposium 18-20 April 1961," Rept. No. 1160, Ballistic Res. Labs., Aberdeen Proving Ground, Md., 476 pp., 1962. AD-274 039.

Contents:

NOL model nuclear airblast simulator.
The soil filled shock tube.
A shock tube modified to produce sharp-rising overpressures of 400-msec duration.
A high-explosive-operated shock tube with facilities for testing structures.
Volume detonation in shock tubes.
High pressure loading device for evaluating blast closure performance.
Techniques for producing long-duration loads in the NCEL blast simulator.
Arc heating technique for shock tube driver.
Pressure and heat-transfer instrumentation used in the NOL hypersonic shock tunnels.
Measurements in the hypersonic shock tunnel at I.S.L.
Shock wave decay in tunnels.
Republic 24-inch hypervelocity wind tunnel.

4035

Timbrell, V., "Generation of Weak Shock Waves," Nature, 172, 540-541, 1953.

Because of the nonlinearity of the pressure-volume relationship for air, different parts of a sound wave of finite amplitude travel at different velocities. The wave distorts as it advances and shock-fronts may be produced. Sound pulses that distort at a rate convenient for investigation of the phenomenon are generated by discharging a condenser through the moving coil of a loudspeaker. The author shows that a modification of the Stokes theoretical construction for the distortion agrees closely with experimental results.

4036

Wittliff, C. E., and M. R. Wilson, "Shock Tube Driver Techniques and Attenuation Measurements," Rept. No. Ad-1052-A-4, Cornell Aeron. Lab., Buffalo, N. Y., 34 pp., 1957. AD-136 531.

The development of the hypersonic shock tunnel at the Cornell Aeronautical Laboratory, Inc. has been accompanied by a study of various techniques for producing strong shock waves to drive the shock tunnel. This study makes possible the description of the technique and the relative efficiency of different driver gases, and of the resultant attenuation of the shock wave in the low pressure tube. It is shown that as the strength of the shock wave increases so does the amount of attenuation. Furthermore, the more efficient a given driver technique in producing a shock wave, the larger the degree of attenuation that is observed. A survey of the presently available theories on shock wave attenuation indicates that the theories do not accurately predict the attenuation of shock waves having Mach numbers greater than two, whereas all of the experimental data reported herein are for shock wave Mach numbers greater than four. This serves to illustrate the need for a better understanding of the attenuation of strong shock waves.

4037

Woods, B. A., "Performance Estimates for the R. A. E. High Pressure Shock Tube," Tech. Note No. Aero 2560, Royal Aircraft Establishment, 1958. AD-202 047.

Estimates are made of the performance of the RAE 6-in. high-pressure shock tube with various driver gases, over a range of pressure ratios giving shock numbers from M = 6 to 22. The calculations are based on a simplified model of shock-tube flow, in which the working fluid (argon-free air) is assumed to be always in chemical equilibrium, and the driver gas (either hydrogen, or the products of combustion of a hydrogen-oxygen mixture) is assumed to behave as an ideal gas with constant specific heats. Results are presented in graphical form and comprise charts that show the changes in state across normal shock waves in argon-free air, give the relationship between shock-wave Mach number and diaphragm-pressure ratio under various initial conditions, and show the aerodynamic properties of the shock-induced flows, both in the uniform-sectioned shock tube and when it is expanded in a divergent nozzle through an area ratio of 225 and to a flow of M = 7.

Wave Propagation, Shock, Generation
See Also—495, 496, 520, 1112, 1202, 1204, 1222, 1234, 1235, 1781, 2277, 2306, 2340, 2362, 2367, 2376, 2381, 2982, 3003, 3433, 3463, 3479, 3506, 3513, 3520, 3557, 3565, 3621, 3663, 3846, 3853, 3869, 3932, 4039, 4047, 4048, 4054, 4059, 4070, 4117, 4176, 4224, 4230, 4279

WAVE PROPAGATION, SHOCK, MEASUREMENT

4038

Air Force Special Weapons Center, "Proceedings of Second Shock Tube Symposium 5-6 March 1958," Rept. No. SWR TM-58-3, Kirtland Air Force Base, N. Mex., 1958. AD-211 239.

Contents:

Shock tube wind tunnel research at U. S. Naval Ordnance Laboratory.
Shock tube studies of blast pressures behind frangible wall panels.
A comparison of shock tube and field test data on the pressure buildup behind frangible walls.
Some results of a shock tube for biomedical investigation.
Experimentation with the General Electric six-inch shock tunnel.
Pressure-time history in a chamber subjected to shock wave filling through an orifice.
Determination of the time history of the flow field about blunt bodies in a shock tube.
Some experiments with periodic shocks.
On the effect of attenuation on gas dynamic measurements made in shock tubes.
Generation of pressure wave forms through the detonation of explosive charges.
Problems in the use of piezo-gages for shock tube instrumentation.
Determination of the dynamic response characteristics of pressure-measuring systems utilizing shock tube testing techniques.
High temperature effects in shock structure.
Shock wave calculations for high temperature gases.
Heat transfer measurements on a hemisphere-cylinder in the Lockheed three-inch shock tube.
A particular application of a conventional shock tube for the study of transient ignition and combustion in subsonic flow.
One-dimensional shock waves from an axially symmetric electrical discharge.

4039

Allen, W. A., J. M. Mapes, and E. B. Mayfield, "Shock Waves in Air Produced by Waves in a Plate," J. Appl. Phys., 26, 1173-1176, 1955.

A shadowgraphic technique was used to measure surface motion of a series of steel plates while they deform under impact caused by 1/2-inch-diameter steel cylinders fired into their back surfaces at about 2,800 feet per second. The strength of the air shock produced when an initial longitudinal wave in a plate strikes the free surface of the plate was inferred from the measured shock-wave velocity in the air. The shock strength was related to particle velocity of the surface of the plate. The results are compared to previous work involving contact explosions of small charges on plates.

4040

Alpher, R. A., and H. D. Greyber, "Calculation of Shock Hugoniots and Related Quantities for Nitrogen and Oxygen," Phys. Fluids, 1, 160-161, 1958.

The Hugoniots are given as graphs of density ratio against pressure ratio for points behind the shock fronts. A complete report is available on application to the authors. It gives details of degrees of dissociation, single and double ionization, and Mach numbers, in addition to the graphical data.

4041

Andersen, W. H., and D. F. Hornig, "Shock Front Thickness and Bulk Viscosity in Polyatomic Gases," J. Chem. Phys., 24, 767-770, 1956.

The thickness of shock fronts in carbon dioxide and nitrous oxide gases has been measured by the light-reflectivity method. The thicknesses of these fronts agree with thicknesses predicted theoretically when only shear viscosity and heat conduction effects are considered. They demonstrate that the contribution of any real-bulk viscosity is small. The molecular vibrations are not excited in the shock front and hence the large sound absorption in these gases—in excess of that calculated using shear viscosity—can only come from the vibrational excitation process. Real-bulk viscosity in ideal gases is not a manifestation of vibrational excitation but only of the rotational excitation process.

4042

Anderson, W. H., and D. F. Hornig, "Structure of Shock Fronts in Various Gases," Tech. Rept. No. 8, Metcalf Res. Lab., Brown Univ., Providence, R. I., 12 pp., 1958.
AD-162 486.

The optical reflectivity of shock fronts in A, N_2, 0_2, CO, CO_2, N_20, CH_4, NH_3, Cl_2, and HCl were studied. The thickness of shock fronts in A up to M = 1.55 is in agreement with the theory of Gilbarg and Paolucci. The rotational relaxation time is about 5.5 collisions in N_2 and equal to or less than that in the other gases. However, for stronger shocks N_2 does not appear to reach rotational equilibrium in the shock front and a qualitative theoretical discussion of this phenomenon is presented. In HCl there appears to be overexcitation of rotation in the shock front. There is no vibrational excitation of any of the gases.

4043

Asbridge, J. R., "An Interferometric Study of Shock Tube Boundary Layers," Tech. Rept. No. 14, Inst. Res., Lehigh Univ., Bethlehem, Pa., 97 pp., 1959.
AD-215 395.

Boundary layers in the hot-gas flow behind the shock wave on the walls of a rectangular shock tube were studied for eleven flow conditions, observing their density structure with a Mach-Zehnder interferometer. The boundary layers are observed to be thin and slowly growing at first, possessing the structure and growth rate predicted by Mirels for laminar layers. This laminar structure extends for only a limited distance behind the shock. Then the boundary-layer profile gradually becomes similar to that which has been observed for steady turbulent layers, although a systematic difference is detected for most flow conditions. The structure of the boundary layer during the transition from laminar to turbulent flow is observed to be consistent with the turbulent spot mechanism of transition, but no direct evidence for turbulent spots has been found. A Reynolds number for transition, based on the distance that the gas particles travel after being set in motion by the shock before becoming turbulent, is found to increase with increasing shock strength. Surface roughness effects can severely influence this transition Reynolds number. Free stream density variations coincident with the boundary-layer growth are observed and presented.

4044

Ballard, H. N., and D. Venable, "Shock-Front-Thickness Measurements by an Electron Beam Technique," Phys. Fluids, 1, 225-229, 1958.

Describes an electron-beam densitometer for investigating the structure of a shock front in low-density gases. The parameters measured by this technique are directly related to those parameters used in the accepted definition of shock front thickness. Hence the interpretation of the data is direct; no model of the shock front structure must be assumed and no theoretical treatment of non-equilibrium flow conditions is needed. An approximate method of data reduction is used for treating preliminary results. The measured value of the thickness of a Mach 4 shock in argon is about three mean free paths, measured in terms of the undisturbed gas. This technique provides a new tool for investigating relaxation phenomena behind shock waves.

4045

Belliveau, L. J., and C. L. Karmel, "Characteristics of Shock Waves from Pentolite Spheres at High Altitudes by Sachs Scaling," Rept. No. 5696, Naval Ordnance Lab., White Oak, Md., 39 pp., 1957.
AD-151 401.

Sachs scaling is used to approximate the shock-wave characteristics from bare 50/50 spherical pentolite charges at the following burst altitudes: 10, 20, 30, 40, 50, 75, 100, and 150 kilofeet. The explosive weights used in compiling the original data at sea level ranged from one-half pound to eight pounds, and the scaled distance from 1.48 to 14.81 ft per $\sqrt[3]{\text{lb}}$. The following characteristics are scaled: peak face-on and peak side-on pressures, face-on and side-on impulses, positive duration, time of arrival, peak face-on minus peak side-on pressure, and the peak dynamic pressure ($1/2\ \rho u^2$). The results are presented as a series of plots for each quantity versus reduced distance, and tables of each quantity at arbitrary distances. Some cross plots are included for illustrative purposes.

4046

Bennett, F. D., "Cylindrical Shock Waves from Exploding Wires," Rept. No. 1035, Ballistic Res. Labs., Aberdeen Proving Ground, Md., 24 pp., 1958.
AD-162 922.

A simple technique has been found for rendering visible the shock wave formed by an exploding wire after the shock separates from the luminous contact surface. A small, plane mirror is placed just behind the wire so as to be perpendicular to the axis of the optical system. Thus the reflected image of the wire explosion coincides with the disturbance itself when seen through the slit by the camera lens. Rotating mirror pictures taken under these conditions show very clear outlines of the parabolic shock wave as it propagates ahead of the luminous contact surface. The separation of the shock and the contact surface is completed in about one microsecond. Beyond this time the shock is clearly non-luminous and ordinarily would not be visible.

Comparison of shock trajectories with predictions from the similarity solutions for strong shock waves show that the shock receives additional energy while traversing the early part of its path. After this phase both shock and contact surface accurately obey a parabolic law over intervals of several microseconds.

4047

Bennett, F. D., "Flow Fields Produced by Exploding Wires," Rept. No. 1075, Ballistic Res. Labs., Aberdeen Proving Ground, Md., 24 pp., 1959.
AD-218 578.

Experimental evidence suggests that the strong shock waves produced by exploding fine cylindrical wires, after an initial transitional phase, closely follow trajectories of the parabolic type characteristic of similarity flows. Shock data obtained in air at a sequency of pressures below atmospheric show large deviations from the $\rho^{-1/4}$ dependence on ambient density, yet in a limited time interval, they indicate approximately the expected parabolic shock trajectories.

In view of the work on similarity flows, the author discusses whether the data may be represented by other similarity flows, and whether this is in the cylindrical case a convergence to a particular flow such as is found by numerical means for the case of strong plane shocks.

4048

Bennett, F. D., "Shock Producing Mechanisms for Exploding Wires," Rept. No. 1161, Ballistic Res. Labs., Aberdeen Proving Ground, Md., 34 pp., 1962.
AD-275 002.

Single-fringe interferograms are presented of copper wires 0.004 inch in diameter exploded at 20 kv into argon at ambient pressures of 1/8, 1/16 and 1/32 atm. Discernible features include a compressive-head shock wave, an arc plasma, a weak plasma wave, and the expanding metal wire. On the basis of certain plausible assumptions it is seen that the arc plasma has a temperature of about 2.5 ev; but its leading edge, a region not in the thermal equilibrium, has electron temperatures of approximately 100 ev and is the boundary of an electron-driven shock wave.

4049

Bennett, F. D., and D. D. Shear, "Shock Waves from Exploding Wires at Low Ambient Densities," Rept. No. 1152, Ballistic Research Labs., Aberdeen Proving Ground, Md., 34 pp., 1961.
AD-271 165.

The recently discovered technique of streak interferometry was applied to study four-mil copper wires exploded into argon at reduced pressures. Typical interferograms at 1/16 atm show an intensely luminous, peripheral arc formed in an annulus several mm from the wire. When filters are used to diminish the diffuse light from the glow, clear fringes can be reduced in the entire glowing region. Near the tip, measured fringe-shifts are negative, indicating the presence of electrons. No shock wave is seen. During an interval of about 1 μsec, fringe-shifts near the periphery of the expanding glow change to positive values and a compressional shock wave can be seen to separate and propagate ahead. Estimates obtained from approximate interferogram reductions indicate electron densities as high as 10^{18}/cc in the annular region of the arc.

A sequence of interferograms at pressures 1/16 atm to 1 atm is presented, and implications for the mechanism of shock production are discussed.

4050

Birk, M., Y. Manheimer, and G. Nahmani, "Note on the Propagation of Explosion-Produced Air Shocks," J. Appl. Phys., 1208, 1954.

Experimental results support Lin's theory of the propagation of cylindrical shock waves produced by the instantaneous release of energy along an infinite straight line, and its conclusion that the reciprocal shock velocity is a linear function of the square root of the time from the moment of energy release. The experiments are confined to the range of Mach numbers 7-14.

4051

Blamont, J. E., J. Hieblot, and E. Selzer, "Chemical Explosion in the High Atmosphere" (in French), Compt. Rend., 252, 3317-3318, 1961.

Some preliminary results are presented of the Veronique rocket explosion at 157 km over Algeria on 18 June 1960. The main object of the explosion was to study the shock waves produced in the high atmosphere, but a sodium cloud was also produced on the ascent from 143 km upwards. The results are grouped under the headings optical, acoustic, and magnetic.

4052

Bleakney, W., and A. H. Taub, "Interaction of Shock Waves," Rev. Mod. Phys., 21, 584-605, 1949.

The phenomenon considered is the reflection of a plane shock wave from a rigid plane wall. The shock wave may be generated by bursting a plane diaphragm separating a high-pressure chamber from a shock-tube of rectangular section. Propagation of the shock is examined through windows on opposite sides of the tube by shadow-photography, the Schlieren technique, or interferometry. The light source used is a spark of short duration; successive sparks may be used to investigate time-variation of the flow.

The phenomena of reflection depend on the angle of incidence α (α = 0 means normal incidence) and the pressure rise P_2/P_1 across the shock wave. For given P_2/P_1, the incident (I) and reflected (R) waves intersect at the wall when $\alpha \leq$ a limiting value α_s; when $\alpha \geq$ another limiting value α_0, I and R intersect at a triple point 0 some distance from the wall. Between 0 and the wall a Mach bridge wave (M) is formed. The theory of regular reflection (when I and R intersect at the wall) is presented: it is shown that for given P_2/P_1 regular reflection can occur only for $\alpha < \alpha_e$. This theoretical value α_e agrees, to within limits of exponential error, with the observed value α_s, but there exists a small range of values $\alpha_e < \alpha < \alpha_0$ for which the reflection phenomena are obscure. Mach reflection can at present be treated theoretically only by making additional assumptions regarding conditions around the point 0. If it is assumed that conditions are uniform in each of the 3 zones (IOR), (IOM), and (ROM), serious discrepancies exist between theory and experiment. These can be overcome by assuming a Prandtl-Meyer (angular) density-variation in the zone (IOM), but it is difficult to see how such a variation could occur ahead of the Mach bridge wave.

In an appendix, recent interferometric studies are reviewed. These show that in the zones (IOM) and (IOR), conditions are very uniform, but that in the zone (ROM) there is a density variation somewhat like the Prandtl-Meyer type.

4053

Camm, J. C., and J. C. Keck, "Experimental Studies of Shock Waves in Nitrogen," Res. Rept. No. 67, AVCO Research Lab., Everett, Mass., 18 pp., 1959.
AD-227 525.

Radiative relaxation behind shock waves in pure N is being studied to determine rate constants for recombination of N atoms. The radiation was measured as a function of wavelength for conditions corresponding to T = 6600°K with $\rho = 0.018\ \rho_0$ and T = 6300°K, with $\rho = 0.12\ \rho_0$. The most prominent radiation in the wavelength interval studied is associated with the N_2^+ (1-) and N_2(1+) bands. The intensity histories exhibit strong overshoot in the shock front for both bands, and the peak to equilibrium intensity ratio was measured. Preliminary analysis of the final approach to equilibrium indicates that at 6400°K the recombination rate constant for N atoms is $< 0.3 \times 10^{-32}$ cm^6/sec, when N_2 is the catalyst and 2.4×10^{-32} cm^6/sec when the N is the catalyst.

4054

Carlson, H. W., "A Wind-Tunnel Investigation of the Supersonic Boom," Aero/Space Eng., 18, 38-39, 1959.

A study of the formation and propagation of shock fronts has been made by means of wind-tunnel tests of very small models made at the Langley four-foot supersonic pressure tunnel. The purpose was to investigate, independently and under controlled conditions, the effects of various airplane components for both the lifting and nonlifting cases. Typical results are shown graphically. It appears that, while the far-field conditions are dependent to a large degree on the normal area distribution, they are also sensitive to model attitude for bodies that depart greatly from axial symmetry.

4055

Christian, R. H., and F. L. Yarger, "Equation of State of Gases by Shock Wave Measurements, I. Experimental Method and the Hugoniot of Argon," J. Chem. Phys., 23, 2042-2044, 1955.

An experimental method is described for the simultaneous measurement of the velocity of a plane shock through a gas and the associated particle velocity. Shocks are generated by a plate driven by a high-explosive system. The velocities are recorded by a high-speed rotating-mirror smear camera with a precision of about $\pm 1/2\%$. Data are presented that define the Hugoniot of argon between 200 and 1100 Los Alamos atmospheres. These data are compared with the theoretically predicted Hugoniot.

4056

Christian, R. H., R. E. Duff, and F. L. Yarger, "Equation of State of Gases by Shock Wave Measurements, II. The Dissociation Energy of Nitrogen," J. Chem. Phys., 23, 2045-2049, 1955.

The results of equation-of-state measurements made behind strong shock waves in nitrogen are consistent only with the higher of the two spectrosopically acceptable values of the dissociation energy of nitrogen, 9.764 ev.

4057

Clouston, J. G., A. G. Gaydon, and I. I. Glass, "Temperature Measurements of Shock Waves by the Spectrum-Line Reversal Method," Proc. Roy. Soc. (London) A, 248, 429-444, 1958.

By using a photomultiplier and cathode-ray oscillograph responsive only to changes in light signal, the sodium-line reversal technique, commonly used for measurement of flame temperature, has been adapted for time-resolved studies of temperatures behind the shock waves produced by a bursting diaphragm. The sensitivity of the method is discussed; temperatures can be determined to about $\pm 30^{\circ}C$. General agreement between calculated and observed temperatures is obtained, but both air and oxygen show a high-temperature region due to burning at the interface with the hydrogen driver gas. In nitrogen at around $2400^{\circ}K$, a low-temperature region close to the shock front may be attributed to a vibrational energy lag of the order of 100 μsec, the sodium excitation following the effective vibrational temperature rather than the translational temperature of the nitrogen. In oxygen, evidence for a dissociation relaxation effect is obtained for shocks giving temperatures of around $2500^{\circ}K$; this produces an abnormally high temperature near the front. Other irregularities in temperature in the uniform flow is only about half that expected for a real inviscid gas.

4058

Clouston, J. G., A. G. Gaydon, and I. R. Hurle, "Temperature Measurements of Shock Waves by Spectrum-Line Reversal, II. A Double-Beam Method," Proc. Roy. Soc. (London) A, 252, 143-155, 1959.

The sodium-line reversal method previously described (See Entry Number 1193), which uses a photomultiplier and oscillograph, has been modified, producing a system that makes it possible to determine temperatures rather higher than that of the background source. Two light beams are now employed, and interference filters are used in front of the photomultipliers instead of a spectrograph. In one beam the background source is viewed directly, through the shock tube, and in the other beam the background source is viewed through the shock tube by a mirror system with a neutral filter interposed to reduce its effective brightness temperature. With a suitably chosen temperature for the background, one oscillograph trace indicates absorption and the other indicates emission of the sodium lines. It is thus possible, from the records of a single shock, to determine the temperature history of the shock wave to about $\pm 20^{\circ}C$.

Nitrogen and oxygen again show relaxation effects near the front. Temperatures in argon tend to be low, owing to radiative disequilibrium; excitation processes in argon are discussed.

Also reports on experiments employing a single-beam method, using a carbon arc as background and following reversal of the indium blue line. Temperatures up to $3600^{\circ}K$ have been measured in shocks through nitrogen, but the time resolution is not good.

4059

Cole, A., and O. Laporte, "A Study of Cylindrical Shock Waves in a Sector Shock Tube," Rept. No. 02539-26-T, Coll. of Literature, Science, and the Arts, Univ. of Mich., Ann Arbor, 132 pp., 1961.
AD-268 465.

Cylindrical shock waves were produced in the sector shock tube under controlled laboratory conditions. With a compression chamber of 6-in. radius, the cylindrical shocks were well-formed if the diaphragm pressure ratio, Z, was 200 or less, while the occurrence of distorted shocks increased as Z increased above 200. Schlieren light screens, used as shock-wave sensors for time-of-arrival data, failed to operate for very weak shock waves, Z = 4, and for strong shocks in a low density gas, rho = 2 cm Hg. With pressures as low as one micron, resistance thermometers have been used as shock-wave sensors for another shock tube in this laboratory. An empirical equation of the form t = to + b rc or r = a(t - to)n was found to fit the data for most of the cylindrical shock waves investigated. Experimental data compared favorably with theoretical results.

4060

Cowan, G. R., and D. F. Hornig, "The Experimental Determination of the Thickness of a Shock Front in a Gas," J. Chem. Phys., 18, 1008-1018, 1950.

Equations are developed from which the density profile of a shock front may be calculated from a knowledge of its reflectivity as a function of wavelength and angle of incidence. The reflectivities of shock fronts of shock-pressure ratio $p_2/p_1 = 1.71$ have been measured in N at initial pressure, p_1, equal to 85, 68, and 42 lb/in^2. From the change of reflectivity with wavelength, the thickness of the fronts was found to be 1.8×10^{-5} cm, 2.0×10^{-5} cm, and 3.2×10^{-5} cm, with an accuracy of 25%. An independent but less accurate check was provided by the change of reflectivity with initial pressure, yielding a thickness of 1.5×10^{-5} cm for $p_1 = 85$ lb/in^2. The weighted mean value, 1.7×10^{-5} cm, for $p_1 = 85$ lb/in^2 is significantly greater than that calculated from the theory of Thomas (1.0×10^{-5} cm).

4061

Criborn, C. O., "Determination of Pressure-Time Curves of the Shock Wave by a New Method," Appl. Sci. Res., A, 3, 225-236, 1952.

Describes an experimental technique which is based on the dependence upon air pressure of the corona discharge current between a positively charged ring and a pointed probe on its axis. A ring approx. 6 mm dia. at 3-4 kV gives a discharge current of 50-100 μ A when the pressure is 1 atm, falling to 10 μ A at 2 atm; the time variation of current is recorded on an oscillograph, and hence the pressure variation may be deduced from previous static calibration. The method is capable of accurate measurement of pressures as low as 0.01 atm, and is not very sensitive to changes in atmospheric temperature or humidity. Advantages claimed for this technique are: (a) freedom from shock reflection at the measuring surface ensures direct measurement of static pressure; (b) natural gauge oscillations are unimportant; (c) the dimensions of the gauge can be kept small.

4062

Deal, W. E., "Shock Hugoniot of Air," J. Appl. Phys., 28, 782-784 1957.

Experiments are described in which an explosive-driven plate sets up a strong shock in the air in contact with the plate. Plate velocity and air shock velocity are measured by means of a high-speed framing camera. A pressure-compression relation results from these measurements through use of the conservation equations of hydrodynamics. The experimental results up to pressures of 200 bars are compared to a calculated relation.

4063

de Boer, P. C. T., "The Curvature of Shock Fronts in Shock Tubes," Tech. Note No. BN-297, Doctoral Thesis, Inst. for Fluid Dynamics and Applied Mathematics, Univ. of Maryland, College Park, 1962.
AD-286 675.

The investigation was undertaken in order to analyze certain difficulties experience with shock-tube measurements of high resolution on relaxation phenomena behind shock waves, making use of the so-called integrating schlieren method. The topic of major interest is the curvature of the shock waves, and most attention is concentrated on the curvature effects to be expected under circumstances where no relaxation occurs. Some forms of interference between the two effects were briefly treated.

4064

Dolder, K., "Experiments on the Passage of Shock Waves Through Magnetic Fields," AERE Rept. No. Z/R 2722, Atomic Energy Research Establishment, 13 pp., 1958.
AD-210 814L.

A combustion-driven shock tube was used to generate a rapidly moving stream of partially ionized argon of known density and electrical conductivity, which passed axially through the magnetic field of a short circular coil. Thus it was possible to study conditions necessary for the field to modify the initial motion of the ionized gas (i.e., for magnetohydrodynamic interaction to occur). High-speed photographic techniques were used to observe the luminous gas flow and, with the aid of pick-up coils, currents induced in the gas were estimated.

4065

Dow, W. G., H. C. Early, and A. A. Horak, "V-2 Experiment for Measuring Upper Atmosphere Temperature by Means of a Shock Wave," Eng. Res. Inst., Univ. of Michigan, Ann Arbor, 21 pp., 1948.

Describes an attempt to measure temperature by measuring the angle of shock wave produced about a conic object traveling at a very high velocity.

4066

Duff, R. E., "The Interaction of Plane Shock Waves and Rough Surfaces," J. Appl. Phys., 23, 1373-1379, 1952.

Shock-tube experiments have been conducted to determine the effect of surface roughness on shock waves in N passing over the surface. Shock retardation was measured for a series of two- and three- dimensionally rough surfaces at shock strengths from ξ = 0.1 to ξ = 0.9. The first-order approximation was made so that the volume between the positions of the shock wave, with and without the rough surface present, multiplied by the specific energy behind the undisturbed shock wave, represented energy dissipated by the roughness. The space rate of energy dissipation is presented as a function of the average particle size of the rough surface.

It is also shown that the curvature of the shock wave in the vincinity of the surface depends on the roughness of the surface, the length of roughness covered, and the strength of the shock wave. In addition, the hundreds of measurements of shock wave contours made in this investigation showed that there is a random fluctuation of $1/15^{\circ}$ in the angle of incidence of the primary shock wave. This fluctuation is presumably caused by the details of the diaphragm rupture even though measurements were made 14 ft from the diaphragm in a shock tube with a 2×7 in. cross-section.

4067

Duff, R. E., and R. N. Hollyer, Jr., "The Diffraction of Shock Waves Through Obstacles with Various Openings in Their Front and Back Surfaces," Rept. 50-3, Engineering Res. Inst., Univ. of Mich., Ann Arbor, 54 pp., 1950.
ATI-94 435.

The results are presented of a photographic investigation of shock-wave diffraction through models with various openings in their front and back surfaces. A method for determining the strength shock waves by measurements of limiting Mach configurations is discussed.

4068

DuMond, J. W. M., E. R. Cohen, W. K. H. Panofsky, and E. Deeds, "A Determination of the Wave Forms and Laws of Propagation and Dissipation of Ballistic Shock Waves," J. Acoust. Soc. Am., 18, 97-118, 1946.

Experiments to ascertain the waveforms and laws of propagation and dissipation of ballistic shock waves to large distances (80 yds) from the bullet trajectory are described. Calibres 0.30 and 0.50 in., 20 and 40 mm were studied. In every case an N-shaped wave profile was observed consisting of a sudden rise in pressure ("head discontinuity") followed by an approximately linear decline to a pressure about equally far below atmospheric, and then a second sudden return ("tail discontinuity") to atmospheric pressure. The peak amplitudes of this disturbance are found to diminish about as the inverse 3/4 power of the miss-distance (perpendicular distance from the trajectory) while the period T' (measured between the discontinuous fronts) increases about as the 1/4 power of the miss-distance for calibres 0.30, 0.50, and 20 mm. For 40 mm shells the amplitude decays about as the inverse 0.9 power of miss-distance over the range studied.

A theory taking account of the dissipation of the N-wave energy into heat is developed to explain the observed behavior. A method of measuring absolute N-wave amplitudes by observing the rate of change of period T' with propagation is described. The theory posits that among distance, amplitude, and period at large distances from the bullet trajectory there is an absolute relationship in which no arbitrary constants appear.

4069

Fage, A., and R. F. Sargent, "Shock-Wave and Boundary-Layer Phenomena near a Flat Surface," Proc. Roy. Soc. (London), A, 190, 1-20, 1947.

Shock-wave and turbulent boundary-layer phenomena near the smooth, flat, metal floor of a specially designed supersonic tunnel are studied from traverses made with pitot, static-pressure, and surface tubes, and from direct-shadow and Toplerstriation photographs. Near-normal and oblique shock-wave systems, with or without a bifurcated foot, are considered.

4070

Fay, J. A., and E. Lekawa, "Ignition of Combustible Gases by Converging Shock Waves," J. Appl. Phys., 27, 261-266, 1956.

Hydrogen-oxygen and hydrogen-air mixtures were ignited by converging cylindrical shock waves, using the apparatus devised by Perry and Kantrowitz, and the minimum strength shock wave necessary for ignition was determined. The enthalpy increase in the wake of the shock wave within a cylinder of diameter equal to the quenching distance and of unit height was calculated and found to be comparable with the minimum spark-ignition energy divided by the quenching distance. An analysis of the unsteady heat-conduction problem lends support to the choice of the quenching distance as the significant dimension of the region over which heat addition is effective in causing ignition.

4071

Franks, W. J., "Interaction of a Shock Wave with a Wire Screen," Tech. Note No. 13, Inst. of Aerophys., Univ. of Toronto, Canada, 39 pp., 1957.
AD-140 429.

The head-on collision of a plane shock wave with a wire-mesh screen in air has been studied experimentally in the shock tube. Two screens of 8 mesh, 50% blockage, and 30 mesh, 62% blockage, were used with incident-shock-pressure ratios up to 12. Interferometric and wave-speed camera studies enabled the resulting wave system and detailed flow parameters to be determined for both nonchoked and choked flow through the screens. At low incident-shock strength, nonchoked flow results, and the wave system consists of a reflected shock and a transmitted shock followed by a contact surface. With choked flow through the screens at higher incident-shock strengths, the flow expands to supersonic speed behind the screen and this supersonic region is terminated by a normal shock moving downstream. Simple one-dimensional models of the interaction are proposed for nonchoked and choked cases on the basis of the observed wave systems. Calculated transmitted and reflected shock strengths and choking Mach numbers based on these models agree well with the experimental results.

4072

Friend, W. H., "The Interaction of a Plane Shock Wave with an Inclined Perforated Plate," UTIA Tech. Note No. 25, Inst. of Aerophys., Univ. of Toronto, Canada, 1958.
AD-212 115.

The interaction of a plane shock wave with an inclined perforated plate has been studied experimentally in a shock tube. Four 1/8-inch-thick steel plates of 50% blockage were used, with an incidence range of 45^{o} to 90^{o}, in 15^{o} intervals, and an incident shock pressure ratio range of 2 to 12 in intervals of 2. The two-dimensional interaction was recorded on shadow and schlieren photographs. Weak incident-shock waves produced two main wave elements, the reflected and transmitted shock waves, and a turbulent contact surface. Strong incident-shock waves caused choked flow at the minimum plate cross section, and a supersonic region downstream of the plate terminated by an additional travelling shock wave. The calculated results for the transmitted, reflected, and auxiliary shock strengths and their inclinations, as well as the precritical flow-choking Mach number and contact-front inclination agree well with the experimental results.

4073

Glass, I. I., and L. E. Heuckroth, "Head-On Collision of Spherical Shock Waves," Phys. Fluids, 2, 542-546, 1959.

Presents some experimental results of colliding shock waves and the associated spherical flows generated by the blasts from two high-pressure gas spheres. Glass spheres, two inches in diameter, with their centers located nine inches apart, containing air or helium up to 500 psi, were used to produce the explosions. Instantaneous spark shadowgrams, multispark schlieren photographs, and wave-speed schlieren records of the radius-time plane indicate that this method can be used successfully to study such interactions.

4074

Glass, I. I., and W. A. Martin, "Experimental and Theoretical Aspects of Shock-Wave Attenuation," J. Appl. Phys., 26, 113-120, 1955.

Experimental results are presented of shock wave and contact-front velocity measurements in air, obtained in a 3-in.-× -3-in. wave interaction tube. A diaphragm pressure ratio range up to 10,000 was employed, while the distance was varied simultaneously from the origin to 142 in. beyond. It is shown that when shock-wave attenuation occurs, it consists of two portions: (a) a decrement due to formation, and (b) a further attenuation due to the distance traversed by the shock wave. Concurrently with the attenuation phenomenon, the contact region spreads with time and its front boundary accelerates. The increase in velocity consists of two portions: (a) an increment due to formation, and (b) a further rise in velocity with the distance travelled by the contact front. A satisfactory empirical relation is developed for the total shock-wave attenuation. A Rayleigh-type imcompressible pipe-flow analysis applied to the experimental results overestimates the attenuation for stronger shock waves.

4075

Greene, E. F., and D. F. Hornig, "The Shape and Thickness of Shock Fronts in Argon, Hydrogen, Nitrogen, and Oxygen," J. Chem. Phys., 21, 617-624, 1953.

Measurements of shock-front thicknesses in A by the reflectivity method have been extended to Mach 2.09, and the shape of the front has been investigated by comparing the experimental results with the reflectivity expected on the basis of five simple models for the density change through the front. The thicknesses agree with Zoller's calculations, but for the strongest shocks they are considerably greater than those of other theoretical estimates. The magnitude and form of the reflectivity (as a function of $\lambda/L \cos \theta$) of shock fronts in three diatomic gases have been used to study the rate of equilibration of rotational with translational energy. H requires more than one hundred and fifty collisions for this equilibration, while N and O equilibrate much more rapidly. For the latter two gases, there is evidence that at least two relaxation times are involved in the equilibration.

4076

Griffith, W., D. Brickl, and V. Blackman, "Structure of Shock Waves in Polyatomic Gases," Phys. Rev., 102, 1209-1216, 1956.

Describes the results of experiments using a shock tube and interferometer to study the role of vibrational relaxation in shock structure. Shocks of Mach number up to five have been observed in air, A, N_2, CH_4, CO_2, N_2O, and CCl_2F_2. In air and nitrogen below about $M_1 = 2$ and in argon the validity of the Rankine-Hugoniot relation using constant specific heat has been established within experimental accuracy. Above $M_1 = 2$ in both air and N_2, the observed density corresponds only to partial equilibrium, with no appreciable excitation of vibrational modes occurring, for example, for at least 150 μsec at 900°K. Both CH_4 and CCl_2F_2 show fast adjustment with relaxation times less than 1 μsec to the expected final state. In CO_2 and N_2O, vibrational relaxation times are observed to be in reasonable agreement with published data.

The downstream state, however, is at a lower density than required for complete equilibrium and the possibility of separate relaxation times for each vibrational mode is suggested; the valence vibrations adjust at least 100 times more slowly than do the bending modes. Added traces of water vapor reduce the visible adjustment greatly, but leave the final state unaltered. The catalytic effect of water vapor in speeding equilibration seems therefore to be limited to the bending modes.

4077

Groenig, H., and H. D. Weymann, "Measurements of the Boundary Layer Thickness and Relaxation of Ionization Behind Strong Shock Waves with a New Capacitive Probe," Tech. Note No. 1, Technische Hochschule, Aachen, Germany, 22 pp., 1958. AD-154 294.

This report deals with the measurements of the thickness of the boundary layer with a capacity probe. This probe, inserted flush into the wall of the shock tube to avoid any disturbances in the flow, is sensitive to the thickness of the boundary layer when the gas in the undisturbed flow is ionized. The experimental results for argon at Mach numbers between five and ten show the usefulness of the probe for measuring the thickness of the boundary layer, the relaxation time of ionization and the coefficient of diffusion. The experiments were carried out in argon because high Mach numbers could be achieved in argon even with a small shock tube.

4078

Ludford, G. S. S., "The Propagation of Waves Along and Through a Conducting Layer of Gas," J. Fluid Mech., 9, 119-132, 1960.

Two related questions concerning the transmission of electromagnetic waves are considered:

(1) The reflexion and transmission of plane waves at a perfectly conducting layer of gas in an otherwise nonconducting atmosphere, when there is a uniform external magnetic field perpendicular to the layer. Here the main result is that a layer of finite depth h is an almost perfect filter, being transparent to waves of frequency $n\pi A_0/h$ (A_0 = Alfven velocity, n an integer).

(2) The existence of plane surface waves for such a finite layer. There is always one such wave, and for certain ranges of frequency there are two. The first becomes 'choked' at the filter frequencies, its velocity first tending to zero and then jumping to a finite value. The second chokes at the frequencies $n\pi A_0 a_0/h\sqrt{(a_0^2 + A_0^2)}$ (a_0 = acoustic velocity).

4079

Hayman, L. O., Jr., and R. W. McDearmon, "Jet Effects on Cylindrical Afterbodies Housing Sonic and Supersonic Nozzles Which Exhaust Against a Supersonic Stream at Angles of Attack from 90 Degrees to 180 Degrees," NASA Tech. Note No. D-1016, Washington, D. C., 49 pp., 1962. AD-273 312.

Tests were conducted at a free-stream Mach number of 2.91 and at free-stream Reynolds numbers, based on body diameter, of 0.15 and 0.30 times 10 to the 6th power. The range of the ratio of jet-total pressure to free-stream static pressure investigated was from jet-off to about 400. The data showed that, in general, variation of the ratio of jet-total pressure to free-stream static pressure, jet-exit Mach number, and ratio of jet-exit diameter to body diameter had large influences on the body pressures on the windward halves of the afterbodies and negligible influences on the leeward pressures. There was a negligible effect of Reynolds number on the body pressures. The ratio of jet-total pressure to free-stream static pressure also had a large influence on the base pressures at all angles of attack. Schlieren studies showed details of the shock-wave structure caused by the jet and the extent of the interference flow fields.

4080

Hendricks, C. D., C. Gruber, et al., "Research into Some of the Basic Physics of Shock Wave Phenomena," Final Rept. No. AFCRL 62-580, Electrical Eng. Res. Lab., Univ. of Ill., Urbana, 82 pp., 1962. AD-284 483.

Presents an analysis of the interaction of electromagnetic waves in the frequency range 2.5 to 30 kilomegacycles/sec with the ionizing shock front. The modes and degrees of coupling between the shock wave and the electromagnetic wave, and methods for controlling this coupling, are considered, using electromagnetic power levels sufficiently high to permit experiment without appreciably disturbing the environment. The transfer of thermal energy in the region of the shock front is considered, as well as the relative degrees of ionization attainable in shock waves in the equivalent environment of the upper atmosphere up to 100 miles. The experiments for the most part were carried out in the 4 in. × 15 in. × 35 ft aluminum, combustion-driven shock tube.

Shock waves were produced in the range from Mach 6 to Mach 22, with initial atmospheric gas pressure in the vicinity of 1 mm Hg. The experiments themselves consisted of propagating a very high level C band microwave pulse in the end of the shock tube opposite to the direction of shock-wave travel. The microwave signal consisted primarily of a single 2-μ sec pulse. The microwave measurements consisted of propagating a low-level 30 kmc signal across the shock tube in the wide dimension and observing transmitted and reflected signal amplitudes and the phase shift in the transmitted signal, compared with a reference phase.

4081

Hollyer, R. N., Jr., and R. E. Duff, "Growth of the Turbulent Region at the Leading Edge of Rectangular Obstacles in Shock Wave Diffraction—Project M720-4," Rept. 51-2, Engineering Research Inst., Univ. of Mich., Ann Arbor, 22 pp., 1951. ATI-159 407.

This report presents the results of an investigation of the growth of the vortex or turbulent region at the leading edge of a rectangular block following the passage of a shock wave over the block. The primary purpose of the study is to determine the dependence of the growth upon the various parameters of the problem—namely, model height, shock strength, and flow velocity. The length of the block is assumed to be infinite. A representative sequence of schlieren photographs of the phenomenon under investigation is included.

4082

Huber, P. W., "Tables and Graphs of Normal-Shock Parameters at Hypersonic Mach Numbers and Selected Altitudes," Tech. Note No. TN 4352, NASA, Washington, D. C., 26 pp., 1958. AD-207 565.

Tables and graphs of normal-shock parameters are presented for real air in thermal and chemical equilibrium at conditions ahead of the shock corresponding to six selected altitudes and for temperatures behind the shock from 2,000°K to 11,000°K. The altitudes used represent the boundaries of the isothermal layers in that part of the earth's atmosphere applicable to aerodynamic flight; that is, below an altitude of 300,000 ft. The altitude data and the real-air thermodynamic data used are reliable for application to this range of altitudes.

For each altitude, the author presents tabulated values of the normal-shock Mach numbers, flight velocity, enthalpy behind the shock, and ratios of real to ideal values of pressure, density, temperature, and velocity of sound as functions of the temperature behind the shock. Graphs are presented to show the variation of the normal-shock parameters with flight Mach number and altitude, and some discussion of the dependence of the parameters on the initial pressure and temperature is given. A method for adapting the data to the case of oblique shocks is included.

4083

Johannesen, N. H., H. K. Zienkiewicz, et al., "Experimental and Theoretical Analysis of Vibrational Relaxation Regions in Carbon Dioxide," Rept. No. 23348, Aeron. Res. Council, 17 pp., 1961.
AD-277 281.

The density distribution in the relaxation regions of shock waves in CO_2 was determined in the Mach-number range 1.4 to 4.0, using an interferometer. The overall density ratios were found to agree with the theoretical final equilibrium values. Detailed analysis of the relaxation regions showed that the simple relaxation equation is inadequate because the relaxation frequency depends on departures from equilibrium as well as on temperature.

4084

Jones, L. M., "Atmospheric Phenomena at High Altitudes—Final Report—Sept. 1, 1950 to Dec. 31, 1951," Eng. Res. Inst., Univ. of Mich., Ann Arbor, 43 pp., 1952.
ATI-139 592.

A final report on atmospheric phenomena at high altitudes, including a summary of previous progress reports. The shock wave experiment for temperature is reviewed, and the falling-sphere experiment for ambient density and temperature is presented. Photographs, illustrations, and table accompany the report.

4085

Jones, L. M., "Atmospheric Phenomena at High Altitudes—Quarterly Rept. 12—Feb. 14 to May 13, 1950," Eng. Res. Inst., Univ. of Mich., Ann Arbor, 27 pp., 1950.
ATI-82 241.

Reports progress in research work concerned with atmospheric phenomena at high altitudes. The work consisted in shock-angle experiments for V-2 and Aerobee missiles, shock-wave curvature investigations, Aerobee firings, preparation of sample bottles, and analyses of helium and neon. No reports were issued during the interval period, but this report looks toward a report on the results of the shock-wave-angle experiment on V-2 missile No. 56 (see entry number 4086).

4086

Jones, L. M., "Atmospheric Phenomena at High Altitudes—Quarterly Rept. 13—May 14 to Aug. 31, 1950," Eng. Res. Inst., Univ. of Mich., Ann Arbor, 25 pp., 1950.
ATI-98 179.

Reports progress in research on atmospheric phenomena at high altitudes. Includes announcement of a report on the results of the shock-angles experiment for ambient temperature performed on V-2 No. 56.

Covers progress of work, including receipt of data from a wind-tunnel investigation of shock-wave curvature; calculation of results; continuation of the preparation of probe Aerobees SC-15 and SC-17, and of sampling Aerobees SC-13 and SC-17; the analysis of a blend of air and 10 ppm of helium; continued investigation into the source of nitrogen oxides in upper-air samples, and the devising of a method for measuring ambient density and hence ambient temperature by measuring the drag of a falling sphere.

4087

Jones, L. M., and H. W. Neill, "Atmospheric Phenomena at High Altitudes, Final Progress Report for the Period July 15, 1946 to August 31, 1950," Eng. Res. Inst., Univ. of Mich., Ann Arbor, 162 pp., 1950.
ATI-98 180.

The program involved the measurement, by rockets, of the fundamental variables in the upper atmosphere that have meteorological significance. The major laboratory effort was applied to the preparation of flight instrumentation and experimentation subsidiary to the experiments. Three of the more important related developments have been the construction and operation of a selective-absorption gas analyzer, the investigation of shock-wave curvature, and the development of a magnetic recorder.

4088

Karanian, A. J., "Characteristics of Normal Shock Waves in the Throats of Precompression Inlets," Rept. No. R-0955-20, United Aircraft Corp., East Hartford, Conn., 101 pp., 1957.
AD-155 349.

Investigations were conducted to obtain information for the design of constant-area throat sections that can be employed in supersonic precompression inlets to obtain high-pressure recovery. Measurements of shock length, pressure recovery across the shock, and diffuser-exit flow characteristics were obtained for average throat Mach numbers from 1.3 to 2.5, and for various boundary-layer thicknesses. Models with straight throats having perforations, boundary-layer removal scoops, or various mixing devices were tested in an evaluation of methods for reducing shock length. Models with curved throats having various turn angles and rates of turn were also tested.

Some of the configurations were tested at Reynolds numbers, based on throat diameters, of approximately 0.4 and 2.2 million to determine the effect of Reynolds number on the shock-wave characteristics in a constant-area throat. The measured effect of Reynolds number on both shock length and pressure recovery across the shock could be predicted from the differences in the boundary-layer displacement thickness approaching the shock. The length of the shock in the curved throat was either greater or less than that in the straight throat depending on the location of the shock relative to the beginning and end of the turn; however, in all cases the pressure recoveries of the curved-throat configurations were less than those of equal-length straight-throat configurations. It was determined that the length of the shock can be reduced to zero by the use of boundary layer bleed and to approximately 50 percent of its original length by the use of vortex generators.

4089

Katsanis, D. J., "Diffusion in Expanding Electrically Neutral Gases with Large Pressure Gradients, Part III: Shock Tube Experiments," Memo Rept. No. M62-4-3, Pitman-Dunn Labs. Group, Frankford Arsenal, Philadelphia, 44 pp., 1962.
AD-278 199.

An attempt was made to evaluate, by experiment, the accuracy of theoretical estimates of mass diffusion effects in the expansion of a binary mixture of gases in a shock tube. The results of calculations for mass diffusion effects on ideal shock tube flow of a binary compression chamber gas are compared with experimental data.

4090

Knight, H. T., and R. E. Duff, "Precision Measurement of Detonation and Strong Shock Velocity in Gases," Rev. Sci. Instr., 26, 257-260, 1955.

Describes a simple system for determining the detonation velocity of strong shock waves, with temperatures above 3000°K, by using the conductivity behind the wave. Wave contact is made by two 0.036-in. wires set 0.1 in. apart in a Teflon plug mounted in the experimental tube. When a wave passes, signals are produced across a 30kΩ resistor in series with these wires, and a 0.001μf capacitor charged to 300 volts. Any number of circuits may be paralleled across a single-signal resistor if a diode is added to each circuit to prevent signal deterioration. The arrival time of a wave at a pin can be determined, with an accuracy of almost 10^{-8} seconds, from an oscilloscope record of the signals. The principal advantages of this system are excellent space resolution and very simple basic circuitry.

An amplifier is described which can be used with an individual pin circuit to fire a thyratron and extend the range of applicability of the system to waves with temperatures as low as 1000°K.

4091

Laponsky, A. B., and R. J. Emrich, "Observation of Shock Formation and Growth," J. Appl. Phys., 24, 1383-1388, 1953.

Transient one-dimensional flows have been produced by accelerating a piston in a gas-filled tube. Accelerations of the order of 2.5×10^4 meters/sec^2 produced shocks within 5 meters of the initial piston position. The piston was propelled pneumatically. Shocks formed at the head and in the interior of the compression waves. By optically detecting the piston and shock positions and recording the corresponding times on a rotating drum chronograph with microsecond accuracy, the properties of the compression wave and of the resulting shock were determined. The formation and growth of shocks were calculated from the compression-wave measurements using the method of characteristics and the assumptions employed by Chandrasekhar and Friedrichs. The observed and calculated shock properties were in reasonably good numerical agreement. Consistent lagging of the observed behind the calculated shock positions (order of 0.05 meter at 5 meters from initial piston position) is attributed to the interaction of the flow with the tube walls.

4092

Lin, S. C., "Ionization Phenomenon of Shock Waves in Oxygen-Nitrogen Mixtures," Res. Rept. No. 33, AVCO Research Lab., Everett, Mass., 23 pp., 1958.
AD-201 912.

An experimental method is described for the study of ionization phenomenon associated with shock waves in gases. By proper choice of experimental conditions, this method should allow a direct and unambiguous determination of the electron density and the averaged electron-molecule (and atom) interaction cross section as a function of distance behind the shock front. Preliminary results obtained for shock waves in a number of oxygen-nitrogen mixtures are presented.

4093

Lin, S. C., "Rate of Ionization Behind Shock Waves in Air," Res. Note No. 170, AVCO Res. Lab., Everett, Mass., 18 pp., 1959.
AD-234 031.

The electron-density profile behind normal shock waves in air at density corresponding to an altitude of 250,000 ft (initial shock-tube pressure p_1 = 20 microns Hg) and in the velocity range 10,000 < U < 25,000 ft/sec has been measured. The preliminary results, which agreed grossly with a theoretical prediction by Lin and Teare (Bull. Am. Phys. Soc. II, 4, 195, 1959), indicated that at satellite velocity (U ≈ 25,000 ft/sec), thermal ionization process will be completed at a distance of about 1 cm behind the shock front; while at a velocity of 15,000 ft/sec the corresponding distance will be about 10 cm. At other altitudes the corresponding ionization distance may be scaled inversely to the atmospheric density since all the collision processes that govern the initial rise of the electron-density profile are binary.

4094

Lin, S. C., R. A. Neal, and W. I. Fyfe, "Rate of Ionization Behind Shock Waves in Air, I. Experimental Results," Res. Rept. Note No. 105, AVCO Research Lab., Everett, Mass., 63 pp., 1960.
AD-265 948.

Extremely fast rates, observed at normal air densities, keep the electron-density profile behind strong shock waves beyond the spatial resolution of most ionization detectors that can be used for quantitative measurements. This difficulty is removed through the use of a 24-inch diameter, low-density shock tube, which allows experiments to be performed at densities lower than the ordinary shock-tube operating density by a factor of 100. By using such a shock tube, together with microwave reflection and magnetic induction probes, the electron-density profile behind normal shock waves in air at initial pressures between 0.02 and 0.2 mm Hg and in the velocity range of 15,000 to 23,000 ft/sec has been experimentally determined.

It was found that the electron-density rises rapidly behind the shock front without much incubation to a transient peak value that is considerably higher than that corresponding to the final equilibrium value. At a shock velocity of 23,000 ft/sec, the distance required to reach 90% of the transient-peak electron density was found to be only about ten times the viscosity mean free path of the undisturbed gas ahead of the shock. At a shock velocity of 15,000 ft/sec, the corresponding distance was found to be approximately 50 times the initial mean free path.

4095

Lobb, R. K., "Experimental Measurement of Shock Detachment Distance on Spheres Fired in Air at Hypervelocities," Naval Ordnance Lab., White Oak, Md., Brussels, 1962.
AD-284 378.

Studies were made of the shock-detachment distance on spheres fired in a small aerophysics range. Investigations of this type can yield accurate information about the variables in the thermodynamic state of high-temperature air in equilibrium, as well as a check of the calculated values available in the literature. Moreover, if the density is sufficiently low, the shock-detachment distance becomes a measure of the lag in the exchange between the energy of translational motion and the internal modes and chemical reactions.

4096

Losev, S. A., and A. T. Osipov, "Study of Nonequilibrium Phenomena in Shock Waves," Foreign Tech. Div., A. F. Systems Command, Wright-Patterson AFB, Ohio., 84 pp., 1961.
AD-268 874.

A survey is presented of the basic methods and the results of theoretical and experimental study of the various relaxation phenomena in shock waves. A theoretical examination of the equilibrium establishment is discussed according to individual degrees of freedom; the examination is made on the basis of the kinetic theory of gases. The experimental study of the state of the gas in shock waves is then discussed. The method using shock tubes is examined. Only endothermic processes in gases are examined.

4097

Lun'kin, Yu. P., "Measurement of Entropy in the Relaxation of a Gas Mixture Behind a Shock Wave," Soviet. Phys. Tech. Phys., English Transl., 6, 810-814, 1962.

The author considers the relaxation of a two-component mixture behind a shock wave. It is shown that in weak shock waves the consecutive excitation of translational, rotational, and oscillatory degrees of freedom can be accompanied by increasingly large or small changes in entropy, depending on the amount of monatomic component. In strong shock waves the consecutive excitation of the various degrees of freedom is always accompanied by increasingly small changes in entropy.

4098

Maglieri, D. J., and D. L. Lansing, "Sonic Booms from Air-Craft in Maneuvers," Sound, 2, 39, 1963.

Ground-pressure measurements are presented for fighter aircraft in various maneuvers involving accelerations along the track and perpendicular to it. Complex wave patterns, and so-called "superbooms," in which pressure buildups occur, are presented for some representative cases. Results obtained from an array of ground measuring stations are correlated with tracking and weather information and with theory. Computed ground-pressure patterns show good agreement with measurements for some specific maneuvers.

4099

Maglieri, D. J., and H. H. Hubbard, "Ground Measurements of the Shock-Wave Noise from Supersonic Bomber Airplanes in the Altitude Range from 30,000 to 50,000 Feet," Tech. Rept. No. D-880, NASA, Washington, D. C., 24 pp., 1961. AD-260 635.

Shock-wave ground-pressure measurements have been made for supersonic bomber airplanes in the Mach number range between 1.24 and 1.52, for altitudes between 30,000 and 50,000 feet, and for a gross-weight range between 83,000 and 120,000 pounds. The measured overpressures were generally higher than would be predicted by theory, which accounts only for volume effects. There is thus a suggestion that lift effects on sonic-boom intensity may be significant for this type of airplane within the altitude range of the present tests.

4100

Maglieri, D. J., H. H. Hubbard, and D. L. Lansing, "Ground Measurements of the Shock-Wave Noise from Airplanes in Level Flight at Mach Numbers to 1.4 and at Altitudes to 45,000 Feet," Rept. No. NASA TN-D-48, NASA, Washington, D. C., 38 pp., 1959. AD-225 816.

Time histories of noise pressures near ground level were measured during flight tests of fighter-type airplanes over fairly flat, partly wooded terrain for M = 1.13 to 1.4 and at altitudes from 25,000 to 45,000 ft. Atmospheric soundings and radar-tracking studies were made for correlation with the measured noise data. The measured and calculated values of the pressure rise across the shock wave were generally in good agreement. There is a tendency for the theory to over-estimate the pressure at locations remote from the track and to underestimate the pressures for conditions of high tailwind at altitude. The measured values of ground-reflection factor averaged about 1.8 for the surfaces tested as compared to a theoretical value of 2.0. Two booms were measured in all cases. The observers also generally reported two booms; but in some cases, only one boom was reported. The shock-wave noise associated with some of the flight tests was judged to be objectionable by ground observers, and in one case the cracking of a plate-glass store window was correlated in time with the passage of the airplane at an altitude of 25,000 ft.

4101

Mark, H., and M. J. Mirtich, "Transition in Shock-Tube Boundary Layers," Phys. Fluids, 5, 251-253, 1962.

Reports an investigation of the influence of the cold front on the transition from laminar to turbulent boundary layers. The arrival of the cold front is measured by a thin film gauge on a model mounted in the center of a tube three inches in diameter. The boundary layer transition is measured by the same type gauge mounted in the tube wall. Measurements are made between $5.3 < M_s < 7.03$ with the initial pressures p_1 of 1, 2.5, and 10 mm Hg. For the conditions of the two lower values of p_1, the result was that the cold front arrived before the transition in the boundary layer occurred (350 μsec versus 235 μsec as an example).

Although this appears to contradict Hooker's measurements and conclusions (he determined the duration of the hot flow by radiation), the authors claim consistency on the following ground. If the cold front extends a central "finger" in the hot flow or is otherwise wrinkled (due to the slow opening of the diaphragm), it would explain their measurements as well as Hooker's. The cold finger would absorb the radiation and would indicate cold-front arrival. At the higher pressure (p_1 = 10 mm Hg), the cold front arrives later than the transition occurs. It is argued that the cold front (even a planar one) as a wave-originating-and-reflecting surface would effect the transition, which should decrease later in the shock-tube flow history. With a number of thin-film gauges at five-inch intervals, the transition time increases later in the history of the flow. Therefore, the authors believe that the wall-mounted gauge in Hooker's investigation was indicating transition affected by the contact surface rather than the arrival of the contact surface itself.

4102

Martin, W. A., "An Experimental Study of the Boundary Layer Behind a Moving Plane Shock Wave," UTIA Rept. No. 47, Inst. of Aerophysics, U. of Toronto (Canada), 1957. AD-149 136.

The shock-tube boundary layer between the initial shock wave and the contact region was investigated by shadowgraph, schlieren, and interferogram photographs, and by thin-film thermometer measurements. The region was almost completely occupied by a turbulent boundary layer. An interferometer was used to determine the nature of this turbulent boundary layer for shock pressure ratios of 2.75 and 8. Comparison with theory was made of experimental density profiles, boundary layer thickness, calculated temperature and velocity profiles, displacement and momentum thicknesses, and local skin friction. The velocity profiles at higher Reynolds number and for a shock pressure ratio of 2.75 indicated better conformity with a 1/5 power law than with a theoretical 1/7-power law. All the experimental profiles conformed to a 1/5-power law at a shock pressure ratio of 8. The assumption that the wall temperature was constant was substantiated by measurements with a thin Au-film resistance thermometer.

4103

Mauterer, O., "A Study of Shock Waves Moving over a Transversely Slotted Wall," Rept. No. GA/ME/61-5, Air Force Inst. of Tech., Wright-Patterson Air Force Base, Ohio, 81 pp., 1961. AD-267 503.

Investigates the effect on a shock wave of passing a pair of transversely slotted test plates in the top and bottom walls of a rectangular shock tube. Particular attention was paid to the shock strength, defined for this study as the pressure ratio across the shock. The shock wave's response to the disturbance was verified by Schlieren photography. The slot width, slot-entrance radius, effective slot depth, and strength of the incident shock wave were varied to determine the effects of these parameters.

The attenuation was found from pressure-measuring transducer data, which was recorded photographically. The time to establish the quasi-steady outward flow of air through the openings determined the extent of attenuation. When the slot width or slot entrance radius were large, the reflected shock waves generated at the disturbance were sufficiently strong to delay the mass flow out of the opening; thus, the attenuation was reduced. The attenuation increased as the effective slot depth was decreased. Schlieren photography verified the formation of the reflected shock waves and of the rarefaction waves associated with the loss of mass behind the wave.

4104

Mitalas, R., and R. B. Harvey, "Peak Pressures from Distance/Time Data of an Expanding Spherical Shock Wave," Rept. No. IR-383-58, Suffield Experimental Station, Canada, 14 pp., 1958.
AD-204 209.

Given free-air radius versus time measurements of an expanding spherical shock wave, it is required to obtain the overpressures at the shock front at any distance within the radial limits of the measurements. The approach used is to fit an arbitrary equation to the data and then by differentiation to determine shock velocity as a function of distance or time. Overpressure is then easily determined.

4105

Monroe, L. L., "Investigation of the Transmission of a Shock Wave Through an Orifice," Memo. No. 46, Guggenheim Aeronautical Lab., Calif. Inst. of Tech., Pasadena, 54 pp., 1958.
AD-208 658.

A shock wave propagating in air in a shock tube was reflected from an orifice plate, and the strength or Mach number of the transmitted wave was measured for incident-shock Mach numbers ranging between three and nine for several types of orifices. The measured values of transmitted shock strength are compared with predicted values based on a theoretical one-dimensional flow model for both an ideal gas and a real gas. The agreement between the measured values of transmitted-wave Mach number and the theoretically predicted values is good in the Mach-number range investigated for a wedge-type orifice at an ambient shock-tube pressure of 5.0 mm Hg, and also for a conical-type orifice at an ambient shock-tube pressure of 2.5 mm Hg. For both orifices the ratio of outlet area to inlet area is 7.67.

The data also indicate that for a wedge-type orifice of area ratio of 23.0 and for a plate-type (free expansion) orifice of area ratio 23.0 possible boundary-layer and shock-wave interactions downstream of the orifice result in measured values of transmitted-wave Mach number somewhat greater than that predicted by the one-dimensional flow model. Investigation of the conical orifice with an area ratio 7.67 at a low ambient pressure in the shock tube (0.4 mm Hg) also yields measured values of transmitted-wave Mach number greater than that predicted by the one-dimensional flow model.

4106

Muirhead, J. C., "On the Movement of Small Objects in a Shock Tube," Rept. No. TL-69-58, Suffield Experimental Station, Canada, 20 pp., 1958.
AD-201 382.

The shock tube has been used to investigate the movement of small objects by a weak plane-shock wave. Shadowgraphs have been obtained showing the movement of small glass beads, alone, in the presence of obstacles, and in a layer of similar beads. From these preliminary experiments a qualitative picture of the mechanism involved in their rising has been developed.

4107

Nordberg, W., "Acoustic Phenomena Observed on Rocket-Borne High Altitude Explosions," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 233-244, 1961.
AD-408 716.

A series of high-explosive charges, ranging from one to four pounds in weight, have been exploded from aboard Aerobee and Nike-Cajun rockets at altitudes between 30 and 90 km. Although the main purpose of these experiments was to study temperatures and winds in the upper atmosphere, a number of interesting phenomena pertinent to the propagation of shock and sound waves in a highly rarified and inhomogeneous atmosphere were observed. The propagation of the shock in the immediate vicinity of the explosion was observed by the modulation that the shock wave produced on a ground-to-missile-to-ground doppler radio link. Preliminary results show that the theory developed by H. L. Brode for shock propagation in higher density atmospheres applies well to these upper-air explosions. Qualitative analysis of the intensities of the ground arrivals at the microphone array on the ground indicate that there are large variations of sound amplitudes with temperature gradients in the vicinity of the explosions. For a complete explanation of these variations a treatment more complex than simple refraction focusing and exponential attenuation with altitude will have to be employed.

4108

Patrick, R. M., and M. Camac, "Experimental Investigation of Collision-Free Shocks and Plasmas," Res. Rept. No. 122, AVCO Everett Research Lab., Everett, Mass., 38 pp., 1961.
AD-274 218.

Investigation of the structure of a shock wave provides an excellent opportunity for studying the dissipation processes in collision-free plasmas. Measurements of the magnetic field have shown that the magnitude of the field change across the shock agrees with that expected from the conservation equations. The electron temperature was estimated to be above ten electron volts based on the ultraviolet radiation intensity and the ratio of bound-bound and free-free radiation. Measurements of the heat transfer from the plasma to the shock-tube wall indicates that less than 1/10 of the gas energy is dissipated to the walls; thus, there is good containment of the shock-heated plasma for a time large (50 times) compared to the shock-rise transit time. The results of these experiments show that the collision-free thickness is inversely proportional to the Alfven Mach number of the shock. The radiation emitted by the shock-heated plasma has been measured over a large range in plasma density; these results, together with those for the magnetic field, jump across the shock, and show that the performance of the MAST can be predicted by a theory which assumes infinite plasma conductivity.

4109

Pennsylvania State University, "Bibliography on Shock and Shock-Excited Vibrations, Volume I. Introduction and Abstracts of Technical Papers," Tech. Rept. No. 3, Coll. of Engineering and Architecture, University Park, 1957.
AD-200 830.

This bibliography consists of three parts. The main body of the text consists of an introduction and abstracts of 1168 technical papers on subjects related to shock motion and its measurement. This is followed by Part II, which consists of abstracts summarizing six subdivisions of the field: Dynamic Behavior of Materials Under Impulsive Loads; Dynamic Behavior of Structures Under Impulsive Loads; Impact Testing Devices; Instrumentation for Measuring Impulsive Forces and Motions; The Shock-Spectrum Approach to Impact Problems; Mathematical Methods for Investigating Dynamic Behavior of Structures Under Impulsive Loading. The final part consists of an appendix that includes an author index, a subject index, and information concerning the search that resulted in these abstracts. The abstracts are mainly of patents and of papers that have been published in technical journals. A few government reports are also included. Originally, it was planned to include abstracts of all pertinent government documents in this publication. However, it now appears desirable to publish these separately in a subsequent volume, because of the bulk of the material and the necessary time required to process it.

4110

Pugh, E. R., "Studies of the Phenomena Occurring in an Electromagnetic Shock Tube," Cornell Univ., Graduate School of Aeronautical Engineering, Ithaca, N. Y., 68 pp., 1962.
AD-276 650.

An electromagnetic shock tube was constructed, and the observed phenomena were explained assuming that the energy transferred to the driver section is stored in the form of magnetic energy. The velocity of the shock front and its rate of decay were measured and compared with theoretical predictions

4111

Reed, J. W., "Shock Propagation at Large Distances," Proc. of the Symposium on Atmospheric Acoustic Propagation, U. S. Army Signal Missile Support Agency, White Sands Missile Range, N. Mex., 1, 3-6, 1961.
AD-408 716.

It is usually assumed that weak shock waves (overpressure 1 psi) are propagated adiabatically and acoustically. In a homogeneous atmosphere this gives overpressure inversely proportional to distance from an explosion and inversely proportional to the square root of distance from a supersonic projectile. An opposing theory was proposed by DuMond et al. in 1946 to show that entropy changes in a shock front would cause explosive overpressures to decay like $(\text{distance})^{-3/2}$ and projectile bow waves to decay like $(\text{distance})^{-3/4}$. A few bits of experimental evidence show that neither scheme is exactly correct. Measurements at low overpressures over large distances free of refractive effects are necessary to accurately resolve the true propagation decay laws. This requires vertical shock paths through a real atmosphere. Project Banshee tests will allow measurements where blast pressure differences between the two predictions are more

4112

Romba, J. J., and P. Martin, "The Propagation of Air Shock Waves on a Biophysical Model," Tech. Memo No. 17-61, Human Eng. Lab., Aberdeen Proving Ground, Md., 26 pp., 1961.
AD-264 932.

Shock-wave characteristics were studied in the field about and within the body of Rhesus monkey. Measurements were obtained in free air atop the animal's head, in the mid-brain and the lower thorax, with distance and position of the explosive varied in relation to the animal's body. The study of shock-wave transmission from one body level to another was accomplished and the complexity of shock-wave energy distribution in the field of the organism was emphasized. Shock-wave forms were observed to be uniquely characteristic of the medium through which shock wave transmission occurred. In addition, body tissue was found to greatly attenuate the shock wave. The study of shock-wave characteristics in and about biophysical media is believed to be relatively unexplored.

4113

Rose, P. H., and W. Nelson, "On the Effect of Attenuation on Gas Dynamic Measurements Made in Shock Tubes," Res. Rept. No. 24, AVCO Everett Res. Lab., Everett, Mass., 41 pp., 1958.
AD-212 016.

Considers the attenuation of the shock strength of strong shock waves produced in air in high-pressure shock tubes, and presents data on the attenuation experienced in several sizes of shock tubes over a large range of conditions. Reports experiments performed to measure directly the critical-flow quantities to establish the trends and limits of the changes in the properties of the shock-compressed air; the measurements consist mainly of static-pressure, as well as histories of X-ray densities behind moving normal shock waves in shock tubes. The results are analyzed and the effect on some of the gas dynamic measurements are estimated.

4114

Rudnick, I., "Measurements of the Attenuation of a Repeated Shock Wave," Tech. Rept. No. 3, Soundrive Engine Co., Los Angeles, Calif., 19 pp., 1953.
AD-10, 268.

The rate of attenuation of large-amplitude sound waves in the 30- to 200-cps range was measured as a function of distance along a tube 10 inches in diameter and 60 feet long connected to a siren. The waves approximated a saw-toothed wave form. Expressions are developed for the attenuation caused by the tube walls and by the shock character of the wave. The effect of dc flow of air through the tube is evaluated.

4115

Ruetenik, J. R., Divone, L. V., "Interferometric Measurements of the Boundary-Layer Growth in the MIT-WADC 8- by 24-Inch Shock Tube," WADC Tech. Rept. No. 58-594, Aeroelastic and Structures Res. Lab., Mass. Inst. of Tech., Cambridge, 61 pp., 1958.
AD-205 074.

Interferometric measurements of the boundary layer on a shock-tube wall in the region of the compressed gas were made. The particle Mach number behind the shock was 0.16-0.67. Primary emphasis was on laminar measurements, although several transitional and turbulent profiles are presented. The aim was to check the theoretical boundary layers that have been employed in theories of shock-attenuation and flow-variation behind the shock. In addition this work provides a basis for correction to optical measurements, and an estimation of the thickness of the wall boundary layer over a wide range of test conditions.

4116

Safronov, B. G., G. G. Aseev, and Yu. S. Axovskii, "The Propagation of Successive Shock Waves," Soviet Phys. Tech. Phys., English Transl., 6, 777-781, 1962.

Reports investigation of the propagation of shock waves in hydrogen, air, and argon, where they were initiated by an oscillating damped discharge. The sequence of shock waves, corresponding to half-period current discharges, was observed. The results for the first wave are compared with the theoretical relations. The difference between the propagation of the first and that of subsequent shock waves is explained qualitatively.

4117

Scala, S. M., L. Talbot, and B. B. Cary, "High Altitude Shock Wave Structure, Part I. Shock Wave Structure with Rotational and Vibrational Relaxation; Part II. A Shock Tube Study of the Thermal Dissociation of Nitrogen," TIS Rept. No. R62SD32, Space Sciences Lab., General Electric Co., Philadelphia, Pa., 130 pp., 1962.
AD-285 619.

A theoretical model is developed for the structure of a shock wave in a diatomic gas that includes rotational and vibrational relaxation phenomena. The experiments were carried out in a combustion-driven shock tube, and data for vibrational relaxation times and dissociation rates were obtained for nitrogen. This report includes estimates of the distribution of translational temperature through a normal shock wave; they neglect relaxation phenomena. Realistic values of the thickness of the shock transition also were obtained. Coupling between the internal degrees of freedom was investigated. Combustion-generated shock was used for shock-structure studies; the relative efficiency of nitrogen atoms and molecules was determined. The data indicate that at temperatures to $6000^{\circ}K$ in pure nitrogen, vibrational relaxation and dissociation may be treated in an uncoupled manner. The data were compared with those obtained by earlier investigators.

4118

Schall, R., and G. Thomer, "X-Ray Flash Photographs of Shock Waves in Solid, Liquid and Gaseous Media" (in German), Z. Angew. Phys., 3, 41-44, 1951.

Intense shockwaves were generated by detonating explosive pellets or by suddenly vaporizing metallic foil with a heavy electric current. The density variation within the shock can be evaluated from the photographic density of an X-ray shadowgraph, and if the shock propagation velocity is known, the pressure distribution can be calculated from the Rankine-Hugoniot equations. An examination of the propagation of intense shocks in ethyl ether, acetone, ethyl alcohol, and water shows that at high compression (corresponding to a twofold density increase) the difference in compressibility of the four liquids is much reduced, whereas at lower pressures the compressibility of ether is 3.6 times that of water. Under these conditions the ratio falls to approximately 1.4. The pressure behind the intersection of two shockwaves is much greater than in either separately; use is made of this principle to extend the pressure region under examination.

A study of the density distribution in a detonation wave is described, in which the effect of explosive-grain size upon reaction-zone thickness was examined. To achieve adequate X-ray absorption by gases, it is necessary to load the gas with heavy atoms; the addition of methyl iodide was found effective. This technique was applied to an investigation of the density distribution in a plane shock wave in air; a further study on the behavior of cylindrically expanding and collapsing waves clearly demonstrated the marked increase in density and in velocity of the collapsing wave as its radius approaches zero.

4119

Schlemm, H., "Schlieren Optical Investigation on Large-Amplitude Airborne Sound Waves in Tubes," Acustica, 10, 237-245, 1961.

A plane sound wave of large amplitude and low frequency becomes deformed in its passage along a pipe until a weak shock front is set up. The pressure jumps in the shock wave can be photographed by a schlieren method and measured on an oscillograph. The schlieren pictures also enable investigation of the characteristics of the wave front at an obstacle.

4120

Schwartz, R. N., and J. Eckerman, "Shock Location in Front of a Sphere as a Measure of Real Gas Effects," J. Appl. Phys., 27, 169-174, 1956.

Spheres were fired at supersonic speeds into monatomic gases and into chlorine gas. The position of the shock wave that forms in front of the sphere depends on the Mach number and gas state before and after crossing the shock wave. Measurements of position made in monatomic gases agree fairly well with aerodynamic theory. As the shock position depends on the actual gas state attained, and thus on molecular excitation times, measurements in more complicated gases than the monatomic can give information as to amount and rates of excitation. The vibrational energy excitation in chlorine was singled out for study. This excitation involves a well-known rate process. By carrying out shock-position measurements at several different pressures, it is possible to infer the order of magnitude of the vibrational relaxation time in chlorine; the present results are in agreement with shock-tube measurements of the relaxation time.

4121

Semenov, S. S., "Method of Verifying the Equation of State of Gases at High Temperature" (in Russian), Dokl. Akad. Nauk SSSR, 114, 841-844, 1957.

The ratio of densities before and behind a shock wave is derived from measurements of shock-wave angle. Measurements in air and nitrogen are compared with theoretical calculations. Photographs of shock waves in air from a wedge and from a half-wedge are reproduced.

4122

Smith, W. R., "Mutual Reflection of Two Shock Waves of Arbitrary Strengths," Phys. Fluids, 2, 533-541, 1959.

Experiments were performed in air on the mutual reflection of a pair of weak shock waves of strength $\xi = 0.915$. The strengths of the shock waves were measured interferometrically. The regular reflection data agreed with the weak-shock regular reflection solution for the flow, and terminated at the extreme angle α_e; Mach reflection was found for larger angles.

Four sets of experiments were performed in air with pairs of mutually reflecting shock waves of unequal strengths. The strengths of these shock waves were also measured interferometrically. The regular data agreed with the weak-shock regular reflection solution for the flow. Mach reflection was found to occur for angles larger than the extreme angle. The experiments failed to resolve any of the difficulties concerned with Mach reflection.

4123

Stoner, R. G., and W. Bleakney, "The Attenuation of Spherical Shock Waves in Air," J. Appl. Phys., 19, 670-678, 1948.

The peak pressure of the waves from small explosive charges was determined as a function of distance by measuring the velocity of propagation and applying the velocity-pressure relation derived from the Rankine-Hugoniot equations. The pressure-distance relations for the four principle charge types are given. The curve for spherical charges agrees with the Kirkwood theory, and the results for cylinders having various length diameter ratios indicate large dependence of pressure on charge shape.

4124

Teng, R. N., "Investigation of Spherical Shock Waves in a Shock Tube," Sci. Rept. No. 62-1, Fluid Dynamics Res. Lab., Mass. Inst. of Tech., Cambridge, 30 pp., 1962.
AD-282 372.

A shock tube was constructed for investigating spherical shock waves in various atmospheres. The shock tube was carefully calibrated for its performance throughout the designed operating range. Thin-film heat transfer gauges were employed to measure the speed of the incident shock wave. Shadowgraph technique was used to establish the geometry of the spherical shock waves which were produced either by allowing the center portion of the incident shock to enter an orifice and then to expand into a spherical shock wave at the entrance of the orifice, upon reflection from the end; or by causing the high-temperature, high-enthalpy gas behind the reflected shock wave to expand through a conical nozzle. Attempts were made to measure the speed of the spherical shock waves.

4125

Thompson, L., "Shock Waves in Air and Characteristics of Instruments for Their Measurements," J. Acoust., Soc. Am., 12, 198-204, 1940.

Discussion of the properties of shock waves is followed by a short account of Hugoniot's method of treatment, which offers certain advantages over the classical theory. Using the Hugoniot velocity for the shock wave in combination with the dynamic equation of condition, the equations for pressure and density are stated in terms of wave velocity. A table is given containing numerical estimates of certain characteristics of shock waves at various distances from sources of great intensity, ranging from the firing of a rifle to the explosion of 1,000 lb of TNT. With simultaneous measurements of both amplitudes it is believed possible to deduce not only the ratio of specific heats for these cycles but also that equation for pressure-density relation which describes the conditions existing in these transient states. Various possible methods of measuring condensation and compression are discussed. Apparatus is illustrated and described for obtaining a dynamic calibration of piezo-electric pressure gauges.

4126

Turner, E. B., A. C. Hunting, and A. C. Kolb, "The Passage of Shock Waves over a Rectangular Block at Various Angles," Rept. 53-1, Eng. Res. Inst., Univ. of Mich., Ann Arbor, 28 pp., 1953.
AD-21 421.

The passage of shock waves over a rectangular block was studied by obtaining fringe shifts about a two-dimensional 1 × 2-in. rectangular model at a shock strength of 1.62 with a Mach-Zehnder interferometer. The block was mounted with the long side at 15°, 30°, 45°, and 60° angles to the incident shock. Photographs were taken at τ = 2/3, 1, 1.5, 2.5, and 4 (where τ is the time interval between the passage of the incident shock over the lead edge of the model and the instant of taking the picture, in units of the time for the incident shock to travel a distance equal to one block-height). Several additional times were included for 45° which are to be compared with the results from a three-dimensional glass-block model. Double exposures were taken of the flow and no-flow fringes instead of separate flow and no-flow interferograms. The inherent fringe-shift error in this method was considered to be less than one-fourth of a fringe width. The positions of shocks, contact surfaces, and rarefaction fronts on the fringe-shift diagrams were not considered adequately accurate for quantitative measurements.

4127

Turner, E. B., A. C. Hunting, and W. R. Johnson, "Three-Dimensional Observations on the Passage of Shock Waves over a Rectangular Block," Rept. 1720:4-1-T, Eng. Res. Inst., Univ. of Mich., Ann Arbor, 14 pp., 1954.
AD-34 065.

A 3-dimensional interferometric technique devised by D. K. Weimer and described in AD-13,660 utilizes an optically polished glass block not completely spanning the test section of the shock tube. A glass block of the same outside dimensions and thickness is then placed in the same relative position in the compensating chamber of the interferometer. In this way three-dimensional effects can be observed. Glass blocks were cemented both to the test-section window and to the compensator window, and sharp monochromatic fringes and contrasting white-light fringes could be obtained simultaneously inside the block and in the outside field. Cementing the blocks to the windows showed these additional advantages: The fringe shifts could be obtained both inside and outside of the block with one shot; the model could be mounted at any angle to the incident shock wave; and the flow could be studied all about the model. The flow patterns of the blocks tested are shown for various values of the time interval between passage of the incident shock over the lead edge of the model and the instant of taking the picture. The inadequacy of the results indicated the future use of shock tubes with a test section width of at least four inches, and a block with opposite faces polished accurately plane-parallel.

4128

Vas, I. E., "A Detailed Study of the Interaction of a 14° Shock Wave with a Turbulent Boundary Layer at M = 2.9," Rept. No. 296, James Forrestal Res. Center, Princeton, N. J., 8 pp., 1955.
AD-210 241.

A detailed study was made of the two-dimensional interaction between a shock wave and a turbulent boundary layer. The shock was generated by a 14° wedge located in the free stream at a Mach number of 2.92. Total head profiles were taken of the entire interaction region. The separation region extended about 6 1/2 boundary-layer thicknesses in length and 3/4 boundary-layer thickness in height. The maximum reverse velocity measured was 0.39 M. The pressure at the separation point was about 2.1 times the free-stream static pressure. The pressure at which separation occurred was also determined for wedges varying from 8° to 13°. No separation was evidenced for the 8° shock-generating case. The pressure ratio at separation was found to be relatively independent of shock strength.

4129

Vas, I. E., and S. M. Bogdonoff, "Interaction of a Shock Wave with a Turbulent Boundary Layer at M = 3.85," Rept. No. 294, James Forrestal Research Center, Princeton, N. J., 9 pp., 1955.
AD-201 644.

Results are given of an experimental investigation of the interaction between incident shock waves and a turbulent boundary layer at M = 3.85. The pressure ratio across the shock wave was varied from 1.5 to 3.0. Schlieren and shadowgraph pictures were taken, static pressures were measured along the wall, and the separation pressure ratio determined. The phenomena observed were, in general, similar to those observed at M = 2.92. For low incident shock pressure ratios (on the order of 1.8) the pressure along the wall rose smoothly to a maximum value with no separation. For a shock pressure ratio greater than about 2.2, an inflection point occurred in the static-pressure distribution and separation was observed. For incident-shock pressure ratios equal to or greater than 2.6, the overall phenomenon remained similar, only the scale of the interaction changed. The measured pressure ratio at the separation point was 2.4 as compared to a value of about 2.1 at M = 2.92.

4130

Vasil'ev, L. A., S. S. Semenov, and E. A. Tarantov, "Study of the Physical Processes in a Shock Tube with the Aid of High Speed Photography," Library Transl. No. 817 of Izv. Akad. Nauk SSSR, Otd. Teckn. Nauk, 186-188, 1957, Royal Aircraft Establishment, Great Britain, 7 pp., 1959.
AD-219 518.

A conventional Schlieren system coupled to a high-speed ciné camera is used to picture the flow once every 10 μsec, up to a total of 7600 frames; the frame size is 3.6 min by 4.8 min and the exposure frequency is constant to better than 0.2%. With high contrast film (γ = 0.7), it is shown theoretically and experimentally that effective photographic exposure times down to 5 μsec are possible. Since the transmission loss is 90%, an intense light source is necessary; a momentarily overloaded mercury discharge lamp is satisfactory in the present case.

Flow over a wedge-shaped model in a shock-tube working section is examined. Weak expansion waves are obscured somewhat by the self-luminosity of the flow. While flow is developing, variation of the oblique shock-wave angle occurs, attributable to relaxation processes; further variations are observed on passage of the contact region. The measured-flow Mach number (from shock angle) and measured density ratio across the shock wave may be used to determine the dissociation energy of the gas, and hence the ratio of its specific heats.

4131

Wada, I., and R. Matsuzaki, "Heat Gauge Records on Shock Tube End-Plate," J. Appl. Phys., Japan, 1, 65-66, 1962.

It is shown that the reflected shock temperature T_5 can be determined from the initial temperature T_1 and the temperature of a thin-film platinum resistance gauge if the thermal conductivities, densities, and specific heats of the gas and of the glass supporting the film are known. Experimental results and a theoretical curve are compared up to $T_5/T_1 = 1.8$.

4132

Waldron, H. F., "An Experimental Investigation of the Flow Properties Behind Strong Shock Waves in Nitrogen," Rept. No. 50, Inst. of Aerophys., Univ. of Toronto, Canada, 1958. AD-162 004.

The flow properties behind strong shock waves in N were measured up to an incident shock of M = 13 and compared with calculated theoretical values. The shock-wave velocity, particle velocity, and speed of sound were measured from x-t Schlieren records. The pressure was recorded simultaneously with an S. L. M. quartz crystal gage. A plane contact front travelling at the particle speed was produced by the interaction of the incident shock wave with a perforated steel plate, and a weak spark was discharged in the uniform region between the incident shock wave and the contact front to produce a weak spherical wave from which the sound speed was obtained.

From the measured values of shock wave and particle velocity, the pressure, density, and enthalpy ratios were calculated. From the measured quantities and the theoretical values of the isentropic index, the temperature ratio and flow Mach number were also calculated. Attenuation of a shock wave over a distance of 18 ft from the diaphragm was investigated for an H-O and an H-O-He mixture as a driver gas. Spark ignition at the closed end of the tube, where a detonation wave was formed, produced an attenuation of 3.2% of the incident-shock Mach number per foot. A technique approximating constant volume burning was found to attenuate the shock wave at the rate of 1.3% per ft. Another form of burning the combustible gases, in which the diaphragm-rupturing process caused ignition, resulted in an attenuation of 2.5% per ft. The attenuation of the shock wave when cold H was used was 0.8% per ft.

4133

Werth, G. C., and L. P. Delsasso, "Attenuation of Repeated Shock Waves in Tubes," J. Acoust., Soc. Am., 26, 59-64, 1954.

As very intense sound waves propagate, the wave-shape changes into one of sawtooth form producing abrupt rises in pressure called shock fronts. This waveform distortion into so-called repeated shock waves is caused by the nonlinearity of the medium. The objective of this study has been to obtain experimental facts relative to the propagation of repeated shock waves in tubes and to compare these with existing theory. An intense sound source was constructed and appropriately coupled to a series of measuring tubes. Observations were made on the velocity and attenuation of fully developed shock waves for a variety of gases, for pressure amplitudes as great as 0.25 atm, and for a fundamental frequency range of from 400 to 1200 cps. The data were compared with previous theoretical work, particularly that of Rudnick. Agreement was found in the general aspects of the theory; the exact magnitude of the effect remains to be explained. This discrepancy between theory and experiment may be resolved by considering in greater detail the absorptive processes involved.

4134

Willett, J. E., and D. L. Lehto, "Normal Shock (Rankine-Hugoniot) Relations for Various Altitudes from Sea Level to 300,000 Feet," Rept. No. 6075, Naval Ordnance Lab., White Oak, Md., 1958. AD-202 403.

The normal shock (Rankine-Hugoniot) relations are presented in tabular form for altitudes ranging from sea level to 300,000 feet in 50,000 feet intervals. The range of shock temperatures extends from 288.16°K to 316,228°K for sea level; for each of the other altitudes, the range extends from 2000°K to 316,228°K, or to the temperature at which radiation pressure and radiation energy become important (whichever is the lower). A discussion of the effects of altitude on the normal shock relations is included.

4135

Wilson, J., "A Shock-Tube Measurement of the Recombination Rate of Oxygen," Cornell Univ. Graduate School of Aeron. Eng., Ithaca, N. Y., 67 pp., 1962. AD-276 626.

The recombination rate of oxygen was measured in a shock tube. The shock tube is unconventional in that airfoils have been inserted to expand the flow, and a constant-area channel placed behind the airfoils; thus the shock tube is effectively a low-expansion-ratio shock tunnel. The gas in the tube is first dissociated and set in motion by the shock wave, then flows through the expansion waves created by the airfoils, and is cooled, and finally enters the constant-area channel, where it recombines. Measurement of the degree of dissociation along the constant area channel enables one to calculate the recombination rate of the oxygen atoms. The measured recombination rate constants are compared with those obtained by reflecting the known dissociation-rate constants through the equilibrium constant.

4136

Woodhead, D. W., and R. Wilson, "Mach Waves in Shock Wave Systems from Detonating Explosives," Nature, 160, 672-673, 1947.

Schlieren photographs have been taken with a rotating mirror camera; they show Mach waves originating in the intersection at obtuse angles of two shock waves, one from the sides and the other from the end of a cylindrical charge. The Mach waves traverse an annular cone or funnel, but the shape and disposition depend on the shape of the charge.

4137

Wray, K., J. D. Teare, et al., "Relaxation Processes and Reaction Rates Behind Shock Fronts in Air and Component Gases," Res. Rept. No. 83, AVCO Res. Lab., Everett, Mass., 30 pp., 1959. AD-234 034.

Nonequilibrium phenomena in normal shocks are summarized. Three classes of experiments are described: absorption of ultraviolet radiation, emission of optical radiation, and microwave absorption and reflection. The use of these measurement techniques in unraveling the complex phenomena that occur in the nonequilibrium region of normal shocks is outlined. The current values used to correlate the experimental data for the chemical and electronic-rate constants are quoted.

WAVE PROPAGATION, SHOCK, MEASUREMENT

4138

Yamanaka, C., H. Wada, and Y. Yamamura, "The Electron and Ion Temperatures in Shock Tubes Measured by the Pulse Probe Methods and the Streak Photography," Technol. Rept. Osaka Univ., 10, 303-310, 1960.

Preliminary report of experiments on a magnetically driven shock tube.

Wave Propagation, Shock, Measurement
See Also—218, 464, 495, 500, 519, 522, 621, 696, 713, 740, 741, 862, 928, 951, 952, 996, 997, 1112, 1115, 1185, 1187, 1189, 1191, 1195, 1197, 1203, 1206, 1215, 1222, 1225, 1229, 1239, 1372, 1519, 1737, 1782, 1790, 1798, 1803, 1842, 1852, 1970, 2072, 2124, 2265, 2277, 2306, 2339, 2340, 2362, 2367, 2376, 2381, 2663, 2819, 2849, 2970, 2978, 2980, 2985, 2986, 3000, 3001, 3008, 3417, 3436, 3440, 3445, 3446, 3447, 3448, 3449, 3463, 3473, 3475, 3477, 3478, 3479, 3498, 3506, 3507, 3512, 3513, 3531, 3532, 3533, 3534, 3535, 3536, 3580, 3602, 3649, 3755, 3765, 3770, 3801, 3814, 3825, 3845, 3853, 3894, 3895, 3955, 4006, 4014, 4027, 4028, 4032, 4036, 4145, 4221, 4223, 4296

WAVE PROPAGATION, SHOCK, THEORY

4139

Adamskii, V. B., "Integration of a System of Auto-Simulating Equations for the Problem of a Short-Duration Shock in a Cold Gas," Soviet Phys. Acoust., English Transl., 2, 1-7, 1956.

The system of equations is derived and studied in general form for any adiabatic parameter γ. The power index, upon which the Lagrangian solution depends, may be found by numerical computation from a particular point to that of the initial conditions. A value is deduced for the index and graphs obtained of the physical quantities in Euler and Lagrange coordinates by numerical computation for a diatomic gas ($\gamma = 7/5$).

4140

Alpher, R. A., and R. J. Rubin, "Normal Reflection of Shock Waves from Moving Boundaries," J. Appl. Phys., 25, 395-399, 1954.

The problem of the reflection of a shock wave from a moving boundary is examined in an idealized one-dimensional treatment. The headon collision of an incident step shock wave and a piston moving at constant velocity into a gas at rest are considered in detail. The calculation involves the headon collision of two shock waves and the subsequent reflection of an altered transmitted wave from the piston. The reflected pressure is calculated for a range of incident shock strengths and piston speeds. For a stationary piston, both the absolute and excess reflected pressures are at most eight times the absolute or excess pressure of the incident shock wave (with $\gamma = 7/5$).

With a moving piston, however, this limiting factor is greater than eight, but finite for finite piston speed and infinite incident shock strength, and is infinite for infinite piston speed and finite incident shock strength. This last result holds even in the limit of the incident wave's being an acoustic pulse.

The method of solution for shock-wave interaction with a piston receding at constant velocity is also indicated. Although the shock is strengthened on passing through the piston rarefaction wave, the reflected overpressure is less than that resulting from the same initial shock wave reflecting from a stationary piston.

4141

Anisimov, S. I., "Attainment of Oscillatory Equilibrium Behind a Shock Wave," Soviet Phys., Tech. Phys., English Transl., 6, 1089-1090, 1962.

An integral expression for the vibrational relaxation of one dimensional gas flow behind a plane shock wave as a function of density is derived from conservation equations and a simple kinetic relaxation equation. The integral expression is shown to include all approximate numerical solutions which were obtained recently by Blythe under the limiting assumptions of constant vibrational relaxation time and vibrational heat capacity, and which are based upon a numerical integration method for the problem given by Johannesen (J. Fluid Mech., Vol. 10, No. 1, 25-32, 1961). An approximate solution of the integral expression is obtained for a Landau—Teller temperature dependency of the relaxation time and constant vibrational heat capacity. An expression is given which allows the measurement of the temperature dependence of the relaxation time by density measurements behind the shock front. (This expression should read in the English translation:

$$\rho t = \left\{\rho_o/v_o\right\} [\bar{E}(z) + 7/2\, az - 3z^2 - b]/[6z - 7/2a)z^2\, dz/dx]\}$$

with $z = \rho_o/\rho_i$ $E(z) = (1/vo^2)\, E_k(T)$; $T \equiv (V_o{}^2/R)Z(a-2)$].

4142

Armour Research Foundation, "Theoretical Investigations of Sonic Boom Phenomena," WADC Tech. Rept. No. 57-412, Armour Research Foundation, Chicago, Ill., 231 pp., 1957.
AD-130 883.

A theoretical investigation was made to determine the pressure- and shock-wave characteristics due to a body (i.e., aircraft) in arbitrary motion. In addition, the propagation of these shocks through the atmosphere has been studied, and the effects of many such parameters as Mach number, acceleration, altitude, and slenderness ratio have been determined.

4143

Augenstein, B. W., "The Unsteady Shock Wave," J. Chem. Phys., 17, 429-430, 1949.

Derivation of result given by F. Cap, J. Chem. Phys., 17, 106-7, 1949.

4144

Band, W., and G. E. Duvall, "Physical Nature of Shock Propagation," Am. J. Phys., 29, 780-785, 1961.

Gives an elementary discussion of the basic concepts required for an understanding of shock propagation. Simple derivations are presented of the Rankine-Hugoniot relations, Bethe's stability condition, Earnshaw's relation, and the structure of the shock front or shock profile.

4145

Bernstein, L., "Equilibrium Real-Gas Performance Charts for a Hypersonic Shock-Tube Wind-Tunnel Employing Nitrogen," Rept. No. 23232, Aero. Res. Council, Great Britain, 8 pp., 1961.
AD-273 116.

Presents charts covering a wide range of reflected-shock wind-tunnel operating conditions, using nitrogen as the working gas. A statistical-mechanical model of the gas is assumed which takes account of molecular vibration, electronic excitation, and dissociation. The gas is assumed to be constantly in equilibrium, that is, the reaction rates are taken to be infinitely fast. The equations of motion are solved with the aid of a digital computer, previously reported results for the state of the shock-processed gas in the shock-tube being used.

4146

Bernstein, L., "Tabulated Solutions of the Equilibrium Gas Properties Behind the Incident and Reflected Normal Shock Wave in a Shock-Tube I - Nitrogen, II - Oxygen," Rept. No. 22778, Aero. Res. Council, Great Britain, 69 pp., 1961. AD-270 645.

Tabulated solutions are presented for the equilibrium gas properties behind the incident and reflected normal shock-waves in the shock-tube, for nitrogen and oxygen. They cover the range of shock-wave Mach numbers up to 12 at intervals of 0.2, for selected values of the undisturbed gas pressure between 1 and 2000 mm Hg. The thermodynamic model of the gas used in the calculations is described in some detail, as is the method of solving the equations. The limitations of the assumption of thermodynamic equilibrium are discussed with regard to shock-tube applications, and the estimated accuracy of the tables is indicated.

4147

Bird, G. A., "The Motion of a Shock-Wave Through a Region of Non-Uniform Density," J. Fluid Mech., 11, 180-186, 1961.

The method of characteristics is used to calculate numerical solutions for the one-dimensional motion of a plane shock-wave through a stationary gas which contains a region of nonuniform density. These solutions are compared with those given by the the Chisnell-Whitham approach, which ignores the effects on the shock wave of the disturbances that are generated in the flow behind it, and also with the asymptotic solution given by the simple theory that regards the nonuniform region as a contact-surface discontinuity. It is concluded that the results of the simplified theories must be applied with caution.

4148

Bloch-Dassault, P., "On the Acoustics of Supersonic Motion" (in French), Compt. Rend., 237, 1123-1126, 1953.

Discusses the origin and nature of the detonations produced by aircraft at supersonic speeds, referring particularly to the occurrence of double supersonic bang. The possibility that these two shock waves have their origin in different parts of the airplane is excluded, as it does not agree with observation. The explanation developed in the present paper derives from the classical work of Esclangon (Acoustiques des canons et des projectiles, 1925, and Compt. Rend., 237, 361, 1953; he discusses supersonic flight of projectiles), and is now applied to supersonic flight of aircraft.

The two sound pulses arise from the spherically-spreading sound wave with normal velocity of sound, and from the conical pressure-surface spreading from the nose of the aircraft with a velocity that depends on the Mach number. The time interval between arrival of the two pressure waves at an observer on the ground will depend on the relative positions, etc., of the observer and the aircraft.

4149

Broer, L. J. F., "On the Influence of Acoustic Relaxation on Compressible Flow," Appl. Sci. Res., A2, 447-468, 1951.

The equations of motion for a gas in which relaxation can occur are derived. Some general properties of their exact solutions are discussed. In particular it is shown that the relaxation effects a change in the characteristics of the equations, independent from the magnitude of the relaxation time. The equations for steady one-dimensional flow are solved. It is shown from these equations that shock-waves have a certain minimal total strength and that steady flow whose speed is within the region of possible sound speeds is unstable. Finally some remarks on oblique shocks are made.

4150

Brown, W. F., "The General Consistency Relations for Shock Waves," J. Math. Phys., 29, 252-262, 1951.

Theoretical. Thomas derived a set of relations between the curvatures of the shock and the streamlines behind it, and their derivatives, for the case of a uniform incident stream of ideal gas; the effects of viscosity and thermal conductivity were neglected. In the present paper, the treatment is extended to include nonuniform rotational incident flow. The results are applied to a consideration of the formation and stability of shocks attached to a continuity in curvature. It is shown that if an attached shock exists, it must be normal to the boundary at the point of contact, and that such a shock wave is unstable. The existence in practice of stable normal shocks may be due to attachment of the other extremity of the shock line to a solid boundary with which it is in stable contact, to reflection at the sonic line in transonic flow, or to stabilizing influences in the boundary layer.

4151

Bush, W. B., "The Hypersonic Approximation for the Shock Structure of a Perfect Gas with the Sutherland Viscosity Law," Rept. No. AFOSR-2257, Firestone Flight Sciences Lab., Calif. Inst. of Tech., Pasadena, 24 pp., 1962. AD-275 884.

The classical Navier-Stokes treatment of the shock-wave structure is investigated for a perfect gas with constant specific heats. The viscosity of the gas is prescribed according to the Sutherland law. The Prandtl number is 3/4. The limiting forms of the solution as the upstream flow Mach number approaches infinity, with all other parameters held fixed, are studied. Two distinct asymptotic series are found for the portions of the shock adjacent to the uniform regions upstream and downstream of the shock, and these expansions are matched in an intermediate region of common validity. The leading terms of a uniformly valid expansion are obtained by combining elements from both expansions. Special attention is given to the entropy and the entropy-production rate in the shock wave.

4152

Cabannes, H., "Determination of the Shock Wave Ahead of an Obstacle of Revolution when the Velocity at the Point of the Obstacle if Subsonic" (in French), Compt. Rend., 233, 354-356, 1951.

Theoretical. In a previous paper (Ibid., 232, 481-3, 1951), the paradoxical result was obtained that when the Mach number $M <$ a critical value M_1 the curvature of the attached shock is opposite to that of the obstacle. In the present paper the paradox is removed by the introduction of nonintegral exponents to the power series. It is found that for $M < M_1$ the term $(r/R)^m$, where $0 < m < 1$, predominates over the first order term; when this nonintegral term is taken into account the ratio of the curvatures of the attached shock and the obstacle is positive for all possible values of M, in accordance with experimental observation.

4153

Cabannes, H., "Laws of Shock Reflection in Nonstationary Flow," Document No. ARA-400, Allied Research Associates, Inc., Boston, Mass., 34 pp., 1957.
AD-150 441.

Several results are given without the use of approximations on the problem of the encounter between a plane shock wave and a wedge. In the case of Mach reflection, the regions of uniform flow are delineated. Approximations are used when (1) the wedge angle is infinitely small and the shock is of any strength, and (2) the shock is infinitely weak and the wedge has any angle. Each of these cases can be treated with linearized equations.

4154

Cabannes, H., and C. Stael, "Singularities of Attached Shock Waves in Steady Axially Symmetric Flow," J. Fluid Mech., 10, 289-296, 1961.

An IBM 704 electronic computer was used to integrate the differential equations, which determine the shock singularity, when the velocity after the shock on a body is subsonic. The results are given in twenty-two cases corresponding to three different bodies; the procedure followed was outlined in a previous paper.

4155

Cap, F., "A New Fquation for the Non-Stationary Shock-Wave," J. Chem. Phys., 17, 106-107, 1949.

Attention is directed to the author's paper in Helv. Phys. Acta, from which the more important results are quoted without discussion; and without accuracy, owing to confusion between the symbols μ and u.

4156

Carrus, P. A., P. A. Fox, F. Haas, and Z. Kopal, "The Propagation of Shock Waves in a Stellar Model with Continuous Density Distribution," Astrophys. J., 113, 496-518, 1951.

Aims at investigating the properties of progressing waves that arise if a compressible-gas configuration, in which the density ρ_0 diminishes with increasing distance r from the center, as $\rho_0 \sim r^{-5/2}$ is disturbed from its state of equilibrium by an instantaneous central explosion. It is shown that if this explosion has been sufficiently energetic for the outgoing disturbance to possess the characteristics of a shock wave, the central part of the configuration will be effectively evacuated by the explosion up to a certain distance from the center, depending on the amount of energy liberated by the initial explosion. If the release has been instantaneous (and, in consequence, the total energy of the wave motion is independent of the time t), the inner boundary of the flow (enclosing the empty core) becomes, by definition, a surface of contact discontinuity.

4157

Cassen, B., and J. Stanton, "The Decay of Shock Waves," J. Appl. Phys., 19, 803-807, 1948.

The instantaneous rate of decay or intensification of a shock front in any fluid for which dissipative effects are localized in a shock zone is shown to be directly related to the coexisting pressure gradient in the wake of the wave adjacent to the front. The higher time derivatives of the shock velocity are also explicitly related, although in a more complicated fashion, to the higher spatial derivatives of wake pressure. Thus the experimental observation of the velocity or some related variable of a blast or ballistic shock wave can be used to ascertain properties of the fluid motion in the wake of the shock. Conversely, a knowledge of the wake profile at any instant can be employed to determine the corresponding rate of decay of the shock front. The general theory is applicable to shocks of all strengths where an equation of state can be applied graphically or analytically.

4158

Chang, C. T., "Relaxation Phenomena Behind a Strong Shock in Hydrogen, I. Attainment of the Vibrational Equilibrium State," Riso Rept. No. 35, Danish Atomic Energy Commission, Roskilde, 28 pp., 1962.
AD-276 630.

Reports the estimating of the time required to establish the equilibrium states of translational, rotational, and vibrational degrees of freedom of the gas behind a strong shock in hydrogen. An attempt is made to extrapolate the calculations and to estimate the relaxation times of the various processes in certain temperature ranges.

4159

Chernyi, G. G., "Integral Methods for the Calculation of Gas Flows with Strong Shock Waves," Appl. Math. Mech., 25, 138-147, 1961.

When a strong shock wave propagates through a gas, the density of the gas increases significantly. The region of disturbed motion next to the wave may be considered as a peculiar boundary layer that is in many ways analogous to the boundary layer in a viscous fluid. In the calculations of gas motion in this layer behind the shock wave, integral methods may be used that are basically similar to those used in the theory of boundary layers in a viscous fluid.

4160

Chernyi, G. G., "Unidimensional Transient Flow of a Perfect Gas with Strong Shock Waves" (in Russian), Dokl. Akad. Nauk SSSR, 107, 657-660, 1956.

Previous studies of the problem have been mainly concerned with self-similar flows. The author's approximate calculation method, based on an expansion of the solution in powers of $(\gamma - 1)/(\gamma + 1)$, where γ is the ratio of specific heats, can also be applied to other types of flow. To illustrate the proposed procedure, the author solves the problem of self-similar flow arising from the motion of a piston according to power law.

4161

Ciolkowski, S., "Shock Impingement on a Constriction," Res. Rept. No. RE-150, Grumman Aircraft Engineering Corp., Bethpage, N. Y., 32 pp., 1961.
AD-265 860.

A study of an ideal gas shock impinging on a wall. The flow produced by a shock moving in a tube with a constriction is analyzed, and the analysis is applied to the solution of the shock impingement on a constriction. The state of the gas produced by the interaction of a shock and a constriction is determined for the case where the shock is reflected. Contraction ratios are determined so that the shock is reflected. The interaction of a shock and an interface is studied, and conditions are determined so that a reflected shock is not produced. In the last section, methods are proposed which can be used to analyze the above situations for real gases in thermodynamic equilibrium.

4162

Clarke, J., "Reaction-Resisted Shock Fronts," Rept. No. 150, College of Aeronautics, Cranfield, Great Britain, 12 pp., 1961.
AD-262 507.

It is shown that shock waves whose structure is determined solely by the effects of chemical reactions (reaction-resisted shock fronts) are possible and completely analogous to relaxation-resisted waves. A single dissociation reaction is considered, and numerical results indicate that such waves could be observed experimentally. Bulk viscosities equivalent to reaction effects are possibly 100 or more times shear viscosity values. (Examples are based on Lighthill's ideal dissociating gas.)

4163

Cole, J. D., "Sweepback Theory for Shock Waves at Hypersonic Speeds," Res. Memo. No. RM 1991, Rand Corp., Santa Monica, Calif., 13 pp., 1957.
AD-144 284.

Results are presented of hypersonic small-deflection theory for the pressure coefficient, density, and other characteristics behind the shock wave on a sweptback wedge. The results have application to computation of the pressure on sweptback winds of wedge cross-section outside the region of influence of the tips. They can also be used to estimate the lift of a flat delta wind flying at very high speeds. In addition, the behavior of the shock waves deduced here is the first step in computing nonuniform flow fields behind the shock wave. A comparison with exact theory can be made, an infinite Mach number, to show that the hypersonic small-deflection theory yields very good results out as far as sweepbacks sufficiently large to cause detachment.

4164

Cowling, T. G., "The Influence of Diffusion on the Propagation of Shock Waves," Phil. Mag., 33, 61-67, 1942.

It is shown that, in the propagation of shock waves through a gas-mixture, diffusion produces effects similar to those of viscosity and thermal conduction. If the mol. wts. of the two gases are not very different, the effects are small; when they are as widely different as those of hydrogen and oxygen, the diffusion effects are more important than those of thermal conduction and are comparable with those of viscosity. The velocities of diffusion involved are an appreciable fraction of the velocity of sound in the gas.

4165

Davies, D. R., "Shock Waves in Air at Very High Pressures," Proc. Phys. Soc. (London), 61, 105-118, 1948.

The equations of the shock wave in air at n.t.p. are solved numerically for high pressures up to 1,000 atm. The solution enables all the physical entities, such as temperature, wave velocity, particle velocity, air density, etc., on the shock-wave front to be expressed numerically as a function of the wave pressure. To solve these equations it is necessary to know the internal energy (E) and volume (v) of one gram of air over certain regions of the two-dimensional range $1 < p < 1,000$ atm and $273 < T < 16,000^{\circ}K$. Calculations are carried out to assess the numbers of the various types of molecules, atoms and ions present at any p and T. The only E values needed at high p are those for which T is also high, and the simple gas laws may therefore be assumed for the volume determinations. Statistical mechanics furnishes equations whose solution fixes the composition. This set of equations is difficult to solve to any degree of accuracy if oxides of nitrogen are taken into account.

As a first approximation, the shock wave equations are worked out on the assumption that the species present are N_2, O_2, N, and O. These calculations make full allowance for all quantum states apart from the ionic. They are refined later by taking into consideration the presence of NO and argon (1.3% by weight) and ionization possibilities.

4166

Duff, R. E., "Relaxation Time for Reactions Behind Shock Waves and Shock Wave Profiles," Phys. Fluids, 1, 242-245, 1958.

An expression is developed for the relaxation time for the approach to equilibrium for the dissociation of a diatomic gas behind a shock wave. This expression shows the importance of the variation of temperature behind a shock on the rate of approach to equilibrium. Numerical calculations of the shock-wave profile in O_2 for two different dissociation mechanisms show that the relaxation-time analysis is only appropriate for the description of the dissociation within a few percent of equilibrium. The calculations also show that ozone is not an effective intermediate for the shock dissociation of O_2 and that it is impossible to define a relaxation time for the overall dissociation process, which is inversely proportional to pressure or density.

4167

D'yakov, S. P., "Concerning the Stability of Shock Waves," AFOSR-TN-56-406, Translated by B. B. Cary, Inst. for Fluid Dynamics and Applied Math., Univ. of Maryland, College Park, 14 pp., 1956.
AD-96 214.

A characteristic frequency equation is developed for two-dimensional stationary compression and rarefaction shock waves of any intensity in an arbitrary medium, from which conditions of instability are deduced when disturbances increase exponentially with time. Conditions under which sound is emitted spontaneously by the shock wave are established. The results are applied to several types of Hugoniots and discussed qualitatively.

4168

D'yakov, S. P., "Shock Waves in a Relaxing Medium," Translated by B. B. Cary, Inst. for Fluid Dynamics and Appl. Math., Univ. of Maryland, College Park, Md., 14 pp., 1956.
AD-95 814.

The phenomenon of shock waves in a relaxing medium in which the process of relaxation is accompanied by a decrease in pressure is investigated. A concrete example is given of a medium in which shock waves of this type are possible. An analytical examination is made of weak shocks in a relaxing medium.

4169

Ellinwood, J. W., L. Trilling, and J. F. White, "Shock-Wave Oscillations in Supersonic Flow," Tech. Note No. 57-409, Rept. on Flight Control Technical Requirements, Instrumentation Lab., Mass. Inst. of Tech., Cambridge, 61 pp., 1957.
AD-213 868.

Results are presented of three investigations of oscillating shock waves. "Oscillating Shock Boundary Layer Interaction," by Leon Trilling, is a theoretical study in which a shock wave with a laminar boundary layer is investigated. It is found that for any local Mach number above 1.5, and for any Reynolds number, there is a combination of frequency and shock strength for which shock oscillations are neutrally stable. Stability boundaries are presented.

"Experiments in Oscillating Shock Boundary Layer Interaction," by Joseph Frederick White, describes the design and testing of a mechanism to generate oscillating shock waves in a wind tunnel. Some preliminary measurements obtained with this mechanism are presented, and experimental requirements for a more comprehensive program are suggested.

"Unsteady Lifting Airfoils at High Subsonic Speeds," by John Webster Ellinwood, is a theoretical study of unsteady aerodynamic forces and critical frequencies for airfoils at small angles of attack oscillating in nonviscous flows. A theory based on a simplified mathematical model is derived, and a sample calculation is presented and discussed.

4170

Elliot, L. A., "Shock Fronts in Two-Dimensional Flow," Proc. Roy. Soc. (London), A, 267, 558-565, 1962.

A numerical method of treating shock waves in two-dimensional unsteady hydrodynamic flow is considered. The shock is regarded as a discontinuity in the flow and its motion is determined by a characteristic method from conditions inside its domain of dependence. As an illustration of the method, numerical solutions are obtained for the dynamics of the motion caused by detonating a sphere of explosive over a cap.

4171

Feldman, S., "Hypersonic Conical Shocks for Dissociated Air in Thermodynamic Equilibrium," Res. Rept. No. 12, AVCO Everett Res. Lab., Everett, Mass., 12 pp., 1957.
AD-150 841.

Effort is made to solve the cone problem. The Taylor-Maccoll equation is set up for a dissociating gas in thermodynamic equilibrium. Solution of the conical shock equation is analyzed for an incompressible fluid downstream of the shock. A comparison of the pressure coefficients calculated from the exact solution and the approximate incompressible one shows that they agree very well.

4172

Fletcher, C. H., A. H. Taub, and W. Bleakney, "The Mach Reflection of Shock Waves at Nearly Glancing Incidence," Rev. Mod. Phys., 23, 271-286, 1951.

The interaction of a plane shock wave in air with a plane rigid wall involves (1) a regular reflection in which the incident shock is followed by a reflected shock that joins the incident shock wave at the wall; and (2) Mach reflection in which the reflected shock wave meets the incident shock at a triple point or line at some distance from the wall, and is joined to it by a third shock wave (usually curved) called the Mach shock.

The mathematics of the Mach reflection of shock waves at nearly glancing incidence is here developed by linearizing both the differential equation of wave propagation and the boundary condition. The methods employed by Bargmann, by Lighthill, and by Ting and Ludloff (J. Roy. Aeronaut. Soc., 18, 143, 1951) are discussed, and their results compared with experimental results. Preliminary experiments have shown qualitative agreement with Bargmann's results. Experimental evidence indicates that the observed slip streams are density discontinuities, and occur in the reflection of any shock at suitable angles not in the region of near-glancing incidence. For strong incident shocks, there is agreement between the observed shock configuration and that required by the local three-shock theory.

The slip stream in the case of weak incident shocks, where the configuration violates the local three-shock theory, appears, experimentally, to be a sharp density discontinuity; a calculation similar to that of Ting and Ludloff, but for weak shocks, would show a broad region of changing density. The fundamental problem of Mach reflection of weak shocks has not yet been solved.

4173

Freeman, N. C., "On the Stability of Plane Shock Waves," Rept. No. FM 2476, Aeronautical Research Council, Great Britain, 16 pp., 1956.
AD-203 709.

The decay of small perturbations on a plane shock wave propagating along a two-dimensional channel into a fluid at rest is investigated mathematically. The perturbations arise from small departures of the walls from uniform parallel shape or, physically, by placing small obstacles on the otherwise plane parallel walls. An expression for the pressure on a shock wave entering a uniformly, but slowly, diverging channel already exists as a deduction from the Lighthill linearized small disturbance theory of flow behind nearly plane shock waves. Using this result, an expression for the pressure distribution produced by the obstacles upon the shock wave is built up as an integral of Fourier type. From this, the shock shape, ξ, is deduced, and the decay of the perturbations obtained from an expansion (valid after the disturbances have been reflected many times between the walls) for ξ in descending power of the distance ξ travelled by the shock wave. In particular, the results are derived for the case of symmetrical rooftop obstacles. These predictions are compared with data obtained from experiments with similar obstacles on the walls of a shock tube.

4174

Friedrichs, L. O., and J. B. Keller, "Geometrical Acoustics, II. Diffraction, Reflection, and Refraction of a Weak Spherical or Cylindrical Shock at a Plane Interface," J. Appl. Phys., 26, 961-967, 1955.
See also: Keller, J. Appl. Phys., 25, 938-947, 1954.

The method of Part I is applied to the reflection and refraction of a weak spherical or cylindrical shock wave at a plane interface and by a plane slab. The method is also extended to apply to the diffracted wave that appears in these problems whenever total reflection occurs. From the results are also obtained the leading terms in the asymptotic expansions for high frequency of the fields produced by periodic point or line sources over a plane interface. These terms, which apply to electromagnetic as well as acoustic fields, exactly agree with results previously obtained by much more complicated methods.

4175

Frood, G. H., "Strong Shock Waves in Real Atomic and Molecular Gases," Rept. No. (b) 11/59, Armament Research and Development Establishment, Great Britain, 1959.
AD-217 707.

Using a heat-sink formulation, real gas effects in the equilibrium region behind normal shock waves in pure monatomic and diatomic gases are presented in a form suitable for computation. The gases considered explicitly here are A, Kr, Xe, He, O_2, N_2, Br_2, and I_2. The Mach-number range for which the calculations are intended is $1 \leq M \leq 25$ for an initial gas temperature of 295°K, and initial pressures in the range 10^{-1} to 10^{-6} atmospheres. The problem of the relaxation time for the attainment of equilibrium in strong shocks is discussed in the light of current experimental evidence.

4176

Gadd, G. E., "The Possibility of Normal Shock Waves on a Body with Convex Surfaces in Inviscid Transonic Flow," Rept. No. 20788, Aeronautical Research Council, Great Britain, 9 pp., 1959.
AD-216 968.

It is shown that normal shock waves may possibly occur on a body with convex surfaces in inviscid transonic flow if the flow immediately downstream of the shock has a singularity like that encountered in flow past a boundary with a discontinuity in curvature.

4177

Germain, P., "Burgers' Equation and Its Applications to the Theory of Shock Waves," Cahiers Phys. (France), 14, 285-299, 1961.

In a series of papers designed to throw light on the mechanics of turbulent motion, Burgers investigated solutions of an equation which, although simpler than the equations of fluid motion, still included the essential mathematical features. In this paper the author has used this simplified equation to illustrate how the dissipative effects of viscosity and the nonlinearity of the inertial terms cause deviations from the predictions of the linear theory of sound waves of infinitesimal amplitude.

4178

Glansdorff, P., "Solution of the Boltzmann Equations for Strong Shock Waves by the Two-Fluid Model," Phys. Fluids, 5, 371-379, 1962.

The structure of a plane shock wave is studied by an extension to the gas dynamics of the two-fluid model already introduced in the superfluidity theory. The classical form is used for the linearization of two Boltzmann equations and restricted to the first approximation. This is different from Mott-Smith's solutions, which cannot be derived by linearization from a single Boltzmann equation, and as a result have to be introduced arbitrarily. Six equations of change for conservative quantities (mass, momentum, energy) are obtained, which makes possible the solution of the wave problem without other equations of change.

Calculations are made using the elastic-sphere model. Comparison with observations made on argon gives very satisfactory results. The solutions tend asymptotically to a stationary solution corresponding to a Mach number equal to infinity, and to a shock-wave thickness 11.4 times the mean free path ahead of the shock for all monatomic gases. This establishes the possibility of coexistence of two fluids in nonequilibrium, even thermal, in shock waves with large gradients.

4179

Golitsyn, G. S., and K. P. Staniukovich, "Some Remarks on the Structure of Shock Waves," Soviet Phys. JETP, English Transl., 35, 575-576, 1960.

It is shown that at a maximum of the entropy in a shock wave the fluid velocity relative to the shock equals the local speed of sound. This result is stated to be true also for hydromagnetic and for relativistic shocks and (at two places) for detonation fronts. Simple methods of estimation are used to show that for strong magnetic fields the shock thickness is decreased by an increase of conductivity or of magnetic field.

4180

Greenberg, O., H. Sen, and M. Treve, "Hydrodynamic Model of Diffusion Effects on Shock Structure in a Plasma," Geophysical Res. Papers No. 66, Air Force Cambridge Research Center, Bedford, Mass., 40 pp., 1960.
AD-234 383.

Diffusion effects on the structure of a steady, plane shock in a protonelectron plasma were studied using a simplified, two-fluid, hydrodynamic model in which diffusion is the only shock-broadening mechanism. Charge separations occur inside the shock because of the mass difference between protons and electrons. The shock is shown to have electric field and density oscillations as a functions of distance through the shock. The peak electric fields are large; the peak electric field inside a weak shock of Mach 1.169 reaches 41,700 v/cm for typical quiescent plasma conditions.

4181

Griffith, W. C., and W. Bleakney, "Shock Waves in Gases," Am. J. Phys., 22, 597-612, 1954.

This paper is in part a review but it also contains some original work. It deals with the manner in which shock waves are formed from finite compressions in gases and describes something of the structure of the shock front itself. The principal features of the behavior of shocks in reflection, refraction, and diffraction are discussed with particular attention given to anomalous observations and comparison with simple theories. Some results are given for shocks in real molecular gases showing relaxation effects. Quite a number of illustrations are included from the authors' own observations on the shock tube. The treatment is not exhaustive but covers many points likely to be of interest to teachers of physics.

4182

Gubkin, E. K., "Propagation of Discontinuities in Sound Waves," Prikl. Mat. Meh., 22, 561-564, 1961.

A solution is given for the gas-dynamic equations describing the propagation of small-amplitude shock waves. For spherical and cylindrical propagation, the results agree with those of earlier workers.

4183

Guess, A. W., "Density Compression Ratio Across Relativistic-Strong-Shock Waves," Phys. Fluids, 3, 697-705, 1960.

The relativistic Rankine-Hugoniot shock-wave conditions described by Taub are extended to include radiation pressure and energy density. Specialization to the situation of a nonrelativistic ambient gas gives strong shocks, and solutions are obtained separately for the cases of a pure material gas and a pure radiation gas behind the shock. The material gas is considered to have a constant adiabatic exponent $\nu \leq 2$, or to be itself relativistic, and the value $\nu = 4/3$ gives the radiation gas results. The rest-density compression increases above its nonrelativistic strong shock limit $(\nu + 1)/(\nu - 1)$, by a term proportional to β^2 in the lowest order, where β is the ratio of shock velocity to light velocity. As $\beta \to 1$ (extreme relativistic strong shock) the rest-density compression goes as $1/(1 - \beta^2)^{1/2}$, but there is no setting-in of degeneracy in the shocked gas. In shock coordinates, the flow velocity ratio across the shock (front to back) decreases monotonically from its nonrelativistic limit and approaches the value $1/(\nu - 1)$ as $\beta \to 1$. An expression is also obtained for the velocity of relativistic sound wave propagation in a mixture of a thermally perfect material gas and a radiation gas.

4184

Gustafson, W. A., "On the Boltzmann Equation and the Structure of Shock Waves," Phys. Fluids, 3, 732-734, 1960.

The methods of Mott-Smith and Rosen for the shock-structure problem are correlated. It is found that the application of Rosen's restricted variational technique to the Boltzmann equation yields the transport equation used by Mott-Smith, and in addition determines a transport function. The expression for the average translational temperature profile, as derived by Mott-Smith, is examined for the existence of relative minima or maxima. For a monatomic gas the temperature profiles have no relative extreme inside the shock wave for any Mach number. For a diatomic gas the temperature profiles are smooth for Mach numbers below 1.89, but above that a hump appears.

4185

Hafele, W., "Analytical Treatment of Powerful, Plane, Non-Stationary Shock Waves," (in German), Z. Naturforsch., 10a, 1005-1015, 1955.

The work of von Weizsacker, Hain, and von Hoerner relating to shock waves, and based on the work of Taylor and Guderley (Luftfahrt-Forsch., 19, 302, 1942) is extended. It is shown that with the passage of time shock waves having different initial distributions tend increasingly towards a homologous solution. Such plane solutions are studied by means of Guderley's method; a single such solution is derived and discussed for ratios (ρ) of specific heats respectively equal to 1.1, 1.4, 1.66 and 2.8; a simple, explicit, analytical solution for the case $\rho = 1$ is derived. This solution is characterized by a markedly linear velocity distribution, while for the other values of ρ the velocity distribution is approximately linear. The approximation, in the course of time, of the nonhomologous types of shock waves to the homologous types is discussed.

4186

Hafele, W., "The Stability of the Type of Shock Waves Included in the Class of Homologous Solutions" (in German), Z. Naturforsch., 10a, 1016-1020, 1955.

The approximation of nonhomologous types of shock waves to homologous solution is discussed, and it is shown that consideration of stability is dependent upon the phenomenon of reversible edges, which is somewhat clarified. Knowledge of the homologous type of solution is presumed.

4187

Hain, K., "Interaction of Two Powerful One-Dimensional Shock Waves" (in German), Z. Naturforsch., 11a, 329-339, 1956.

The two types of possible interaction between two powerful one-dimensional shock waves, namely, collision and overtaking, are discussed mathematically for the case of waves which have already attained their asymptotic stable form, corresponding to the homologous distribution factor K = 0.39. In the case of collision, for which, up to the present, only an approximate solution has been derived, numerical calculations show that the development of shock waves with time is essentially independent of the initial Mach number, and that all shock waves practically disappear after reaching the same homologous distance, $\xi = -0.7$, from the point of collision. In the case of overtaking waves, calculations show that the stability of the homologous solution corresponding to K = 0.39 is renewed after the waves meet, the whole wave distribution very quickly reverting to this homologous distribution.

4188

Hain, K., and S. V. Hoerner, "Unstationary Strong Shock-Wave Fronts" (in German), Z. Naturforsch., 9a, 993-1004, 1954.

Treats the case of a strong, plane, unstationary shock wave entering a space filled with constant-density gas, for example, and interstellar cloud. A procedure based on the method of characteristics is presented for calculating velocity, density, and pressure distributions behind the front as functions of time, starting with any given initial distributions. With no momentum transfer from the front backwards, all initial distributions are shown to tend with time to von Weizsacker's homologous solution (Z. Naturforsch., 9a, 269-275, 1954), with the parameter $K = 0.39 \pm 0.01$, or better still, to Hafele's singular solution of homologous equations (Z. Naturforsch., 10a, 1016-1020, 1955).

4189

Hasimoto, Z., and S. Morioka, "Local Description of the Flow Behind a Steady, Two-Dimensional, Curved Shock Wave," J. Phys. Soc. Japan, 16, 1616-1624, 1961.

Considers the local properties of the rotational-flow field behind a steady, two-dimensional, curved shock wave, which occurs in the supersonic uniform flow of a perfect gas. The states of the flow field in the vicinity of a point on a shock wave are described as a power series about this point, under the assumption that the shape of the shock wave is regular. The hodograph transformation of such a field becomes singular at the points where the Jacobian relating to the transformation vanishes. The fields in the vicinity of such singular points are discussed in detail.

4190

Herpin, A., "The Kinetic Theory of the Shock Wave" (in French), Rev. Sci., 86, 35-37, 1948.

In an earlier paper (Rev. Sci., 85, 817-826, 1947) the author showed that an extension of the kinetic theory is required for explaining the process of transformation of kinetic energy into heat energy within a shock wave. The present paper constitutes a first attempt in this direction. The theory given leads to Hugoniot's law of compressibility and allows an estimate of the thickness of the transition zone to be made.

4191

Herpin, A., "On the Reflection of Shock Waves" (in French), Compt. Rend., 223, 276-278, 1946.

Formulae are given for the pressure of the gas after the passage of the wave, and for the velocity of propagation of the wave, assumed to be plane and moving in a cylindrical tube. Similar formulae are given for the reflected wave, and some numerical values are given for the ratios of the pressures, densities, and velocities of the wave and its reflection.

4192

Hida, K., "An Approximate Study on the Detached Shock Wave in Front of a Circular Cylinder and a Sphere," J. Phys. Soc. Japan, 8, 740-745, 1953.

Assuming the flow behind the detached shock wave to be similar to the rotational flow of an incompressible fluid, various quantities can be determined relating to the shock in such a way that the shock conditions may be satisfied in the neighborhood of the nose of the shock wave. It is found that the vorticity correction does not alter the nondimensional curvature of the shock at the nose but makes its location further away from the body than in the case without vorticity. The result is compared with experiment, and they are found to agree fairly well.

4193

Hida, K., "Asymptotic Behavior of the Location of a Detached Shock Wave in a Nearly Sonic Flow," J. Phys. Soc. Japan, 10, 882-889, 1955.

Applies the solutions of the Tricomi equation. The distance, b, of a detached shock wave from an obstacle and the curvature of a shock at its nose, 1/R, vary, respectively, as $1/b \propto (M_\infty - 1)^2$, $1/R \propto (M_\infty - 1)^3$, M_∞ being the Mach number at infinity. In axisymmetrical cases, similar results can be obtained by assuming that the flow behind a detached shock wave may be expressed by the asymptotic solution for the sonic flow formulated by Guderley and Barish. The results are $1/b \propto (M_\infty - 1)^{2/3}$, $1/R \propto (M_\infty - 1)^{5/3}$.

4194

Hida, K., "On the Curved Shock Wave Due to an Infinite Wedge Placed in a Supersonic Uniform Flow," J. Phys. Soc. Japan, 9, 853-860, 1954.

With the aid of analysis in the hodograph plane, it is shown that besides the well-known two-shock configurations, two more shock configurations can occur as the result of placing an infinite wedge in a supersonic, uniform flow. These two shocks are both curved waves; one is an attached shock that turns from a weak shock at the vertex of the wedge to a strong one at infinity, while the other is a detached shock that is normal at the nose of the body and becomes strong at infinity. Numerical calculations are carried out for the case when $M_1 = 1.50$ and $\theta_0 = 11^o45'$, where M_1 and θ_0 are respectively the Mach number at infinity upstream and the semivertical angle of the wedge.

4195

Hida, K., "On Some Singular Solutions of the Tricomi Equation Relating to Transonic Flow," J. Phys. Soc. Japan, 10, 869-881, 1955.

Two singular solutions of the Tricomi equation relating to transonic flow are presented, both of which have a singularity corresponding to a uniform flow at infinity upstream—either subsonic or supersonic—and tend toward Guderley's solution when the Mach number at infinity approaches unity. First, the solutions are given formally in integral forms, and then their analytic continuations, which are valid within various portions in the hodograph plane, are studied. Special references are also made to the behavior of the solution in the vicinity of the singular point.

4196

Hochstim, A. R., "Equilibrium Compositions, Thermodynamic and Normal Shock Properties of Air With Additives, Vol. I.," Rept. No. ZPh-122, General Dynamics/Convair, San Diego, Calif., 200 pp., 1961.
AD-274 930.

Equilibrium concentrations, thermodynamic and normal shock properties were tabulated for pure air and air enriched with various amounts of oxygen, nitrogen, carbon dioxide, and graphite. The solutions were obtained numerically by minimizing free energy. The data were tabulated at even intervals of temperature, density, and pressure. The tables include gaseous and solid phases. Sublimation temperatures of carbon as a function of pressure and the concentration of carbon in air were obtained. A graphical method is presented for comparing the properties of air behind normal shocks (or oblique shocks) at a given altitude and shock velocity with the corresponding properties of seeded air.

4197

Hochstim, A. R., "Gas Properties Behind Shocks at Hypersonic Velocities, I. Normal Shocks in Air," Rept. No. ZPh(GP)-002, Convair, San Diego, Calif., 1957.
AD-151 591.

The Hugoniot shock equation is solved by a new, exact method for air in complete equilibrium (dissociation and ionization included). The most recent internal energy and compressibility tables available were used. Solutions are obtained for velocity range of 2 - 18 km/sec, ambient density of 1 to 10^{-7} times sea level density, and ambient temperatures of 220°, 240°, 260°, 273.16°, 280°, 300°, and 350°K. Included are detailed tables and graphs of various relations between pressure, temperature, and density behind a normal shock as a function of ambient temperature, density, and free-stream velocity. The report includes a discussion of a new method for extending the accuracy of the tables, a discussion of the effects of ambient temperature, etc.

4198

Hochstim, A. R., "Gas Properties Behind Shocks at Hypersonic Velocities, II. Introduction to General Thermodynamics of a Real Gas," Rept. No. ZPh-003, Convair, San Diego, Calif., 50 pp., 1957.

Basic thermodynamical relations are derived as a function of compressibility and internal energy. Derived is a list of formulas for velocity of sound, specific heats and reversible adiabatic (isentropic) properties for a real or ideal hot gas in complete equilibrium (which may include dissociation or ionization, or both). It is shown how these general expressions reduce to formulas for cold, ideal gas. Many of the derived quantities are going to be used in computation of various properties of air in equilibrium from 2,000 to 15,000°K.

4199

Hochstim, A. R., and R. J. Arave, "Gas Properties Behind Shocks at Hypersonic Velocities, III. Various Thermodynamical Properties of Air," Rept. No. ZPh-004, Convair, San Diego, Calif., 135 pp., 1957.
AD 152 728

Various equilibrium properties of argon-free air from 2000°K to 15,000°K are computed and tabulated. There are 31 temperatures and 37 densities between $10^{1.6}$ and $10^{-5.6}$ times the sea level density. Calculations are based on a numerical differentiation method. The tables included the velocity of sound, specific heats, various γ's—functions for isentropic (reversible adiabatic) processes and partial derivatives of internal energy and compressibility with respect to density at constant temperature, and with respect to temperature at constant density. It is found that the specific heats have maxima corresponding to the points where compressibility $Z = \frac{Pv}{RT}$ as a function of temperature and density has maximum values of derivatives (at $Z \sim 1.11$, $Z \sim 1.65$ and $Z \sim 3.15$). Specific heats have minima at points corresponding to complete dissociation of oxygen ($Z \sim 1.21$), oxygen and nitrogen ($Z \sim 2.0$) and at points corresponding to completely (singly) ionized oxygen and nitrogen ($Z \sim 4.0$).

It is shown that in isentropic processes the γ's to be used are neither the ratio of specific heats nor enthalpy over internal energy. Three γ's, one for P - p, one for T - P and one for the P - T relation are introduced and tabulated. An extensive appendix on numerical differentiation accompanies this report.

4200

Hollyer, R. N., and O. Laporte, "Parameters Characterizing the Strength of a Shock Wave," Am. J. Phys., 21, 610-613, 1953.

Inspection of the equations of compressible hydro-dynamics in one dimension shows that the steady state may possess a discontinuity in the flow variables u, p, ρ. From this there arises the possibility of constructing a dimensionless parameter characterizing shock strengths. Its relations with other shock parameters are discussed.

4201

Hornig, D. F., "Energy Exchange in Shock and Detonation Waves," Tech. Rept. No. 4, Frick Chemical Lab., Princeton Univ., N. J., 1962.
AD-286 790.

In shock waves with strengths and final temperatures equivalent to those in detonations, translational and rotational equilibrium is reached in the initial compression process, i.e., in 10-20 collisions. Vibrational relaxation was not well studied at the temperatures appropriate to detonation but are certainly much slower, of the order of hundreds or thousands of collisions. On the basis of model calculations, the main part of the heat evolution in hydrogen-oxygen detonations occurs later. All of this supports the ZND model of a gaseous detonation. No signal was observed that could be shown to originate in reflection from the initial compression in $H_2 + 3O_2$ detonations. Rather, the observed signal seemed to be caused by scattering from a zone extending about 2.5 mm back into the detonation wave. This observation is consistent with the observation by White and others of a complex wave structure and, possibly, turbulence in detonations at low pressure. Such structure or turbulence persists up to several atmospheres initial pressure. In that case the properties of detonations may be largely affected by turbulent heat transfer rather than by molecular relaxation processes.

4202

Israel, W., "Relativistic Theory of Shock Waves," Proc. Roy. Soc. A, 259, 129-143, 1960.

The paper is concerned with the relativistic theory of shock phenomena in a simple, nonconducting fluid. Three conditions on the equation of state are exhibited that yield the result (demanded by the principle of causality) that the shock speed shall always be less than the fundamental velocity c. By a consideration of one-dimensional continuous flow, an additional condition, expressing the stability of compressive shocks, is derived. On the basis of these four conditions, it is then proved that, as in the classical theory, entropy rises across a compressive shock, and the transition in the fluid velocity relative to a normally incident shock is from supersonic to subsonic.

4203

Jarre, G., "The Dissociation of a Pure Diatomic Gas Behind a Strong Normal Shock Wave," Tech. Note No. 3, Politecnico di Torina (Italy), 18 pp., 1957.
AD-148 046.

A study of the dissociation of a pure diatomic gas behind a strong normal shock wave included an analytical discourse on the general expression of the dissociation rate, the employment of simplified models of the dissociating gas and of the shock wave, an analysis of heating and compression effects of the shock on the dissociation, and an analysis of the space-constant of relaxation. Results showed that the discontinuous transition through the shock is only controlled by the upstream Mach number, while the continuous relaxation behind the shock is only controlled by the heating effect and the compression effects. The compression effect mainly determines the space constant of relaxation or its asymptotic value.

4204

Johansson, C. H., "Shock Waves in Gases at the Detonation of Brisant Explosives," Arkiv Mat. Astron. Fysik, 33A, Paper 13, 23 pp., 1946.

A paper, mainly theoretical, that deals with the propagation of detonation waves through gases. The detonation of an explosive involves its conversion into a heated mass of gas at high pressure, the temperature and pressure being of the order of 3,000°C and 10^5 atmospheres. At the instant of detonation the boundary surface has a velocity of the order of 10^4 meters per second. The state of the compression layer in the surrounding gas has been calculated on the assumption of an ideal gas—an assumption that appears to lead to correct results. Dissociation of atmospheric air is noticeable when the boundary velocity exceeds about 3,000 meters per second, and because of the energy thus consumed, the temperature increases rather slowly with the velocity, up to 8,000 meters per second, where the dissociation is nearly complete.

Further investigation proves that about half the work conveyed to the compression layer is consumed to give kinetic energy to the gas and the other half to increase the internal energy of the gas. A discussion follows on the velocity of propagation of the shock wave. For a detonation, the normal velocity of sound is a lower limit, to which is added a translational term owing to the expansion of the explosion. The translational term dominates near the origin of the explosion, while at greater distances the normal velocity of sound dominates.

4205

Jones, C. W., "On Gas Flow in One Dimension Following a Normal Shock of Variable Strength," Proc. Roy. Soc. (London), A, 221, 257-267, 1954.

Unsteady nonhomentropic flow of a gas in one dimension is studied by taking a form of the Lagrangian equations of motion. An exact solution representing progressive waves is found, and this is applied to the problem of a shock advancing into a region in which the pressure is constant, but the density (and temperature) varies according to a simple power law. The problem is shown to depend upon a single first-order differential equation of standard type, and it is indicated how numerical solutions could be constructed if desired. For convenience in presentation, however, the discussion is limited to the case of a very strong shock, and only qualitative conclusions are offered at this stage.

4206

Kanwal, R. P., "Existence and Uniqueness of Flows Behind Three-Dimensional Stationary and Pseudo-Stationary Shocks," Tech. Summary Rept. No. 9, Mathematical Res. Center, Univ. of Wisconsin, Madison, 12 pp., 1957.
AD-286 397.

An attempt was made to show that the integration of the various conservation equations is equivalent to the solution of a Cauchy problem with the shock front as surface on which the initial data is given. By Cauchy-Kowaleski theorem it is proved that in a neighborhood of the shock the flow behind the shock exists and is uniquely determined. The paper is divided into two parts. The first part deals with the stationary flows, while the second part deals with the pseudo-stationary flows. The detailed analysis is given only for the stationary flows. Formal methods of tensor analysis are used throughout the paper.

4207

Kanwal, R. P., "Propagation of Curved Shocks in Pseudo-Stationary Three-Dimensional Gas Flows," Tech. Summary Rept. No. 6, Mathematical Res. Center, Univ. of Wisconsin, Madison, 13 pp., 1957.
AD-286 395.

In a previous paper, the curved shocks in three-dimensional steady gas flows were discussed. Formulas were derived that make possible the determination of the derivatives of velocity, density, pressure and entropy behind the shock surface when the flow in front is known. Furthermore, the explicit determination of the vorticity components behind the shock was made, which led to the formulation of a general theorem regarding the characterization of surfaces behind which the flow will remain irrotational. It was found that a plane, a right circular cone, a cylinder, and a developable helicoid are the only such surfaces. The main purpose of this paper is to discuss the same problem in the case of unsteady flows. In the case of plane unsteady flows, Taub has solved the corresponding problem by introducing a dimensional argument indicating that, when viscosity and heat conductivity are neglected, there is no intrinsic length in the problem and the problem may be stated in terms of the independent variables alone.

4208

Kapur, J. N., "On the Existence and Uniqueness of Flows Behind Three-Dimensional Curved Shocks," Proc. Indian Acad. Sci. A, 54, 116-120, 1961.

Kanwal (Bull. of the Amer. Math. Soc., Vol. 9, 201-7, 1958) discussed flows behind three-dimensional stationary and pseudo-stationary shocks. He applied the existence theorem after reducing the basic equations of gas dynamics to the normal form by using the formal methods of tensor analysis. It is shown here that it is simpler to apply Cauchy-Kowaleski theory directly to the equations without first transforming them. The method is used for discussing the conditions for the existence and uniqueness of flows behind unsteady curved shocks as well as flows behind curved shocks in three-dimensional magnetogasdynamics.

4209

Kaufman, L. G., and M. Morduchow, "On the Stability of One-Dimensional Viscous Flows: Sound Waves and Shock Waves," WADC Tech. Rept. No. 59-355, Aeronautical Res. Lab., Wright Air Development Center, Ohio, 44 pp., 1959. AD-229 452.

The solution to the steady one-dimensional Navier-Stokes equations is presented for the case of Prandtl number equal to 3/4 and constant coefficients of specific heats and viscosity. The solution has been shown to be valid for ordinary air flows with free-stream Mach numbers not exceeding about two. The unsteady flow solution is achieved by assuming a small one-dimensional perturbation of the steady flow and then linearizing the equations. Solutions for the disturbance then vary exponentially with time. There are then derived two simultaneous ordinary differential equations for the velocity and temperature disturbances as functions of the space variable, with the complex damping or amplification factor as an eigenvalue depending on the disturbance wave length. Disturbed uniform flows of both inviscid and viscid fluids are solved exactly; the resulting characteristic equations have eigenvalues with negative real parts indicating that the disturbance decreases with time and hence that the uniform flows are stable.

These results can be interpreted as indicating the speed of propagation and the rate of damping of one-dimensional sound waves with viscosity and heat conduction. Approximate methods are applied to obtain the characteristic equation for shock-wave flows. All of the several methods used here, which are essentially applications of the methods of collocation and of averages, yield the exact solution results for the special case of sonic flows, and all tend to predict instability for shock-wave flows. The analysis indicates, in particular, that for shock-wave flows there will always exist sufficiently large disturbance-wave lengths for which the disturbances will tend to amplify with time. The instability is less pronounced, if at all present, for very small disturbance-wave lengths (less than 10^{-4} inches for sea-level atmospheric conditions).

4210

Keller, J. B., "Geometrical Acoustics, I. The Theory of Weak Shock Waves," J. Appl. Phys., 25, 938-947, 1954.

In the first part the discontinuity conditions in an arbitrary continuous material are deduced for a general (i.e., possibly curved) discontinuity surface. It is then shown that only three types of discontinuities are possible—shocks, contact discontinuities, and phase-change fronts. In the second part of the acoustic discontinuity, conditions are deduced and specialized to a perfect fluid without heat conduction. Then a first-order partial differential equation is obtained for the location of an acoustic shock front. This equation can be solved, as in optics, by means of rays. The variation of shock strength along a ray is then determined (this is one main result of this paper). Coefficients of reflection and transmission for an acoustic shock at a contact discontinuity in the basic flow are also obtained. Finally, the results are exemplified by an analysis of the shock tube.

4211

Kelly, P. D., "Conical Flow Parameters for Air and Nitrogen in Vibrational Equilibrium," Rept. No. 1164, Ballistic Research Labs., Aberdeen Proving Ground, Md., 54 pp., 1962. AD-278 178.

The Taylor-Maccoll equation for supersonic flow about cones has been integrated numerically for air and nitrogen in instaneous vibrational equilibrium (chemical reactions are assumed to be frozen). Free-stream Mach numbers from 8 to 20 were used for 300°K free-stream temperature. The values of the flow quantities (i.e., velocity components, polar angle, temperature, pressure and density) are given through the shock layer for different values of free-stream Mach number and flow-deflection angle at the shock. It was found that by nondimensionalizing some of the flow quantities (temperature, pressure, and density) with respect to the changes in their values across the shock layer and by plotting them as functions of the nondimensional shock layer thickness, that the points for different values of free-stream Mach number and cone angle lie along the same curves. This gives an approximate method for obtaining other solutions. As was expected the results presented are shown to lie between those of Kopal (translational and rotational degrees of freedom only) and Romig (dissociation and ionization included).

4212

Kofink, W., "On the Two Flow Fields Behind a Forked Compression Shock" (in German), Ann. Physik, 9, 401-405, 1951.

The mathematical discussion in a previous article (Ann. Physik, 9, 200-12, 1951) is extended to include the flow behind the shock wave. General expressions for the ratio of the velocities, the densities and the cross-sections, and for the entropy difference on either side of the boundary line between the two flows are obtained. A particular mathematical (not physical) case is considered for which the equation of the sixth degree reduces to a quadratic and four linear equations giving values for the roots that may be used as initial values for the solution of the equation in the general case.

4213

Kogure, T., and T. Ôsaki, "Stationary Shock Waves in a Plane Stellar Atmosphere, I. The Structure," Publ. Astron. Soc. Japan, 13, 250-262, 1961.

Considers the effects of radiative flow on the structure of a shock wave propagating outward in a plane stellar atmosphere. The equations of hydrodynamics and of radiative transfer are solved simultaneously, with the assumption that the shock wave is quasistationary and that the local thermodynamic equilibrium is attained everywhere at every instant. The structure of the shock wave is then specified by ρ_0 the surface density, T_0 the surface temperature, D the velocity of the shock front relative to the surface, and τ_f the optical depth of the shock front (τ_f being taken as a parameter). The numerical calculation is carried out for a case of $\rho_0 = 10^{-7}$, $T_0 = 5000°K$, $D = 5c_0$, where c_0 is the sound velocity at the surface. The stationary structures of the shock wave for some values τ_f are constructed.

The main results obtained are as follows: (1) A temperature peak appears just behind the shock front, and the height of the peak is comparatively insensitive to τ_f. Thus the isothermality of shock transition cannot be admitted in the cases considered. (2) The effect of radiative cooling is conspicuous. The final temperature T_* drops remarkably when τ_f is small, compared with that obtained from the classical Hugoniot relations. (3) The rate of compression for the final state exceeds the value of $(\nu + 1)/(\nu - 1)$ considerably.

4214

Kontorovich, V. M., "Stability of Shock Waves in Relativistic Hydrodynamics" (in Russian), Zh. Eksperim. i Teor. Fiz., 34, 186-194, 1958.

Investigates stability against small perturbations of the discontinuity surface for shock waves in an arbitrary medium described by relativistic equations for an ideal fluid.

4215

Kuropatenko, V. F., "A Method of Calculation of the Propagation of Shock Waves," Dokl. Akad. Nauk SSSR, 133, 771-772, 1960.

A set of simultaneous difference equations is substituted for corresponding differential equations of aerodynamics. Procedures for solving the equations are described.

4216

Kusukawa, K., "On the Shock Wave in the Elastic Medium," J. Phys. Soc. Japan, 7, 200-203, 1952.

As the result of the four conservation laws, i.e., those of the conservation of mass, momentum, energy, and the area of the section of the tube of flow, the following conclusions for the shock wave induced in an elastic medium have been obtained:

(1) When the wedge moves with the supersonic speed z, the angle between the shock wave and the direction of undisturbed velocity (denoted by α) is $\alpha = \sin^{-1}(M^{-1}) + \theta$, where

$$\theta = [(3\lambda + 2\mu)/(\lambda + 2\mu)]\left[\left(M^4\alpha^2\beta\delta^2\right)\Big/\left(4C_0(M^2 - 1)^{2/3}\right)\right],$$

and $M = z/a$. a, β, c_0, λ, μ, and δ denote the speed of sound, the coefficient of the linear expansion, the specific heat, Lame's constants of the elastic medium, and the half-vertex angle of the wedge, respectively.

(2) The plane shock wave is reflected by the plane rigid wall, α and α' denoting the angles included between the incident or reflected waves and the wall,

$$x' = \{\eta x(1 + \eta^2x^2) - x(1 - \eta^2)[1 + \eta^2x^2(\eta^2 - 1)]^{1/2}\}/$$
$$\{(1 + \eta^2x^2)[1 + \eta^2x^2(\eta^2 - 1)]^{1/2} + \eta x^2(1 - \eta^2)\},$$

where $x = \tan\alpha$, $x' = \tan\alpha'$, and $(1 - \eta^2)$ represents the strength of shock.

4217

Kusukawa, K., "On the Theory of Shock Waves Produced by a Rigid Cone Moving Through an Elastic Medium with Supersonic Velocities," J. Phys. Soc. Japan, 6, 166-167, 1951.

The field of flow around a slender conical obstacle is calculated by a method similar to that used for a wedge. Values of the strain at the wall of a cone of semi-angle 5^0 are tabulated for Mach number M = 1.06 to M = 2.92.

4218

Kusukawa, K., "On the Theory of Shock Waves Produced by a Rigid Wedge Moving Through an Elastic Medium with Supersonic Velocities," J. Phys. Soc. Japan, 6, 163-165, 1951.

Using linearized equations appropriate to the condition of small strain, formal solutions are found for the field of flow around a wedge moving with supersonic velocity. Two special cases considered: are irrotational flow and flow of a deformable incompressible fluid. It is shown that the formal solution for the first case implies that η, the coefficient of friction between the fluid and the wedge, is defined by

$$\eta = \mu \sin(2\alpha - \gamma)/[\lambda + \mu \cos 2(\alpha - \gamma)]$$

where α is the semi-angle of the shock wave attached to the apex of a wedge of semi-angle γ; λ and μ are Lame's constants. Such a solution is physically possible because $0 < \eta < \mu/(\lambda + \mu) < 1$.

A formal solution is possible in the second case, but as it implies a shearing force acting in the direction of the velocity of flow, it is physical unrealizable. A numerical solution for $\gamma = 5^0$ is given; it is found that in this case the minimum difference in transverse strain across the shock front occurs at Mach number M = 1.36.

4219

Kuznetsov, N. M., "The Structure of a Shock Wave in Air, Taking into Account the Kinetics of Chemical Reactions," Transl. No. MCL-1118, Aerospace Tech. Intelligence Center, Wright-Patterson Air Force Base, Ohio., 12 pp., 1961. AD-262 611.

Practical formulas are given for solving the problem of the distribution of the temperature and concentration of the components of dissociating air in the nonequilibrium zone beyond the steep leading edge of a shock wave in rarefied air. The question of the dissociation of oxygen and nitrogen, and the relationship among the temperature beyond the edge of the wave, the wave velocity, and the gas density are also examined.

(This translation is from Inzhenerno-Fizicheskii Zhurnal, 3, 17-24, 1960; see entry No. 4220.)

4220

Kuznetsov, N. M., "The Structure of a Shock Wave in Air Taking Account of the Kinetics of Chemical Reactions," Memo. RM-2931-PR, Rand Corp., Santa Monica, Calif., 17 pp., 1962. AD-270 126.

Applications are cited for the practical use of a formula for solving the problem of temperature distribution and the concentrations of the components of dissociating air in the nonequilibrium region beyond the steep leading edge of a shock wave in rarefied air. The problems of the dissociation of oxygen and nitrogen, the dependence of the temperature in front of the wave on the velocity of the wave, and the density of the gas are analyzed.

(A translation from the Russian; see entry No. 4219.)

4221

Lamb, L. Y., "The Effects of Driver Temperature Gradient on Shock Tube Flow," Rept. No. TDR-930(2230-11)TN-1, Aerospace Corp., Los Angeles, Calif., 34 pp., 1962. AD-285 537.

Considers the initial condition of a shock tube in which an axially distributed temperature gradient exists within the driver gas. Theoretical analysis of the wave interactions revealed that compression waves originating from the hotter regions of the driver gas overtake the shock wave and reinforce it progressively. This case is compared with the usual uniform-temperature driver case (zero gradient), and a series of tests was conducted to correlate theory with experiment. The results qualitatively verified theoretical predictions that the compression waves reinforce the propagating shock wave. This phenomenon should minimize the effects of attenuation in shock-tube flows.

4222

Latter, R., "Similarity Solution for a Spherical Shock Wave," J. Appl. Phys., 26, 954-961, 1955.

The point-source, spherical shock wave moving into a constant density γ-law gas is considered in the limit of infinite shock strength from the point of view of the Richtmyer-von Neumann viscosity technique. A similarity solution of this problem is shown to exist, and is obtained for various boundary conditions with $\gamma = 1.4$. The solutions are obtained analytically in that part of the flow field not involving viscosity, and numerically in the other parts of the flow field. It is found that whereas all discontinuities of the physical parameters are removed by the viscosity, there remain discontinuities in the slopes of these parameters at the shock front. It is indicated, moreover, that the complete flow field depends upon the form and magnitude of the viscosity.

4223

Lemcke, B., "An Investigation of the Stagnation Conditions in the Shock-Compression Heater of a Gun Tunnel," FFA Rept. No. 90, Aeronautical Research Inst. of Sweden, 34 pp., 1962. AD-283 266.

Theories for piston- and shock-wave history, peak pressures, and final temperature in a gun tunnel are presented. The development of pistons for use at pressure ratios of more than 1,000 is described. The theory for the peak pressures is compared with experiments for pressure ratios from 30 to 1,000; they are found to agree well. Temperature estimations from pressure records and running times indicate that stagnation temperatures of the order of $3{,}000^{\circ}K$ have been achieved at the attained pressure ratios without preheating the working gas.

4224

Lighthill, M. J., "The Energy Distribution Behind Decaying Shocks, I. Plane Waves," Phil. Mag., 41, 1101-1128, 1950.

A critical examination of an approximate theory by K. O. Friedrichs (Communs. Pure and Appl. Math., 1, 211-245, 1948). This theory deals with the motion of a perfect gas behind the shock-wave generated by a piston set impulsively in motion and then brought gradually to rest; it is assumed that motion is restricted to the region between the shock wave and a following sound wave (sent out by the piston as it comes to rest), and that the specific entropy of the moving gas is the same as in the undisturbed state. This approximate solution may be termed the simple wave.

In the present paper, Friedrichs' theory is extended to cover a fluid having arbitrary thermodynamic properties, and the total energy of the gas in the simple wave is compared with the work done by the piston; these differ by an amount comparable with the entropy gain of the fluid as it passes through the shockwave, the difference being attributed to the motion of the gas behind the simple wave. A closer examination of the gasflow in this region shows that the pressure distribution is that which would be produced by reflection of the simple wave at the shock front, giving rise to a pressure pulse whose reflection at the piston would cause motion of the gas in the region behind the simple wave.

It is concluded that the errors in Friedrichs' theory are comparable with the changes produced by altering the simple wave in two respects: (a) the specific entropy of the whole wave is altered to its known maximum as a result of passage through the shock front; (b) the velocity distribution is altered (e.g., by altering the piston velocity by an amount whose ratio to the local velocity of sound is of the order of the cube of the shock strength). The Friedrichs theory is further extended to include the case when the piston, set impulsively in motion, is decelerated through zero to a negative velocity, and then brought abruptly to rest, to produce a second shockwave following that set up by the initial motion. It is shown that the accuracy of Friedrichs's theory is maintained so far as the first shock is concerned, but the motion of the second shock at a large distance from the piston is given less accurately.

4225

Lighthill, M. J., "The Flow Behind a Stationary Shock," Phil. Mag., 40, 214-220, 1949.

A linearized equation for steady inviscid adiabatic flow of a gas is derived, and used to analyze the bending of the bow shock on a supersonic aerofoil due to the incidence of waves from the surface. The shock strength is not assumed to be small. The waves are reflected along the characteristics, the reflection coefficient is calculated, and, for a thin supersonic aerofoil, the entropy boundary layer due to inexact leading-edge sharpness are discussed.

4226

Lighthill, M. J., "The Position of the Shock-Wave in Certain Aerodynamic Problem," Quart. J. Mech. Appl. Math., 1, 309-318, 1948.

For the motions caused by the uniform expansion of a cylinder or sphere into still air, and for steady symmetrical supersonic flow past a cone, first approximations are obtained to the strength and position of the shock-wave for small disturbances. The correct approximations to the pressure on the surface are also shown. The work is mathematically rigorous, and provides some justification of approximate methods that have been used, in the general theory of supersonic flow past bodies of revolution, for example.

4227

Lighthill, M. J., "Shockwaves," Mem. Manchester Lit. Phil. Soc., 101, 7-22, 1960.

Ramsden Memorial Lecture. Review (for the nonspecialists) of shock-wave phenomena in gases, liquids, and solids, and in interstellar matter. Analogous phenomena, such as deceleration waves in traffic flow and river flood waves (bores), are considered.

4228

Lilley, G. M., R. Westley, A. H. Yates, and J. R. Busing, "The Supersonic Bang," Nature, 171, 994-996, 1953.

The double (occasionally triple) bang heard when an airplane passes through the sound barrier is explained by consideration of movements of bow and tail waves relative to the plane at different Mach numbers.

4229

Losev, S. A., and A. T. Osipov, "Study of Nonequilibrium Phenomena in Shock Waves," Foreign Tech. Div., A. F. Systems Command, Wright-Patterson AFB, Ohio., 84 pp., 1961. AD-268 874.

A survey is presented of the basic methods and the results of theoretical and experimental study of the various relaxation phenomena in shock waves. A theoretical examination of the equilibrium establishment is discussed according to individual degrees of freedom; the examination is made on the basis of the kinetic theory of gases. The experimental study of the state of the gas in shock waves is then discussed. The method using shock tubes is examined. Only endothermic processes in gases are examined.

4230

Love, E. S., "A Reexamination of the Use of Simple Concepts for Predicting the Shape and Location of Detached Shock Waves," Tech. Note No. TN 4170, Natl. Advisory Comm. for Aeron., Washington, D. C., 53 pp., 1957. AD-149 183.

A re-examination has been made of the use of simple concepts for predicting the shape and location of detached shock waves. The results show that simple concepts and modifications of existing methods can yield good predictions for many nose shapes and for a wide range of Mach numbers.

4231

Lun'kin, Yu. P., "Shock Wave in Real Gases" (in Russian), Zh. Tekhn. Fiz., 29, 272-273; in Soviet Phys. Tech. Phys., English Transl. (New York), 4, 238-239, 1959.

A parameter of the shock wave is related to the pressure, density, and enthalphy of the gas behind the front. It is suggested that the calculation of the variable specific heat of an ideal gas that dissociates and ionizes is analogous to the calculation of the properties of a real gas.

4232

Lun'kin, Yu. P., "The Structure of Shock Waves," Soviet Phys. Tech. Phys., English Transl., 2, 1169-1175, 1957.

A method is proposed for analyzing the nonequilibrium processes that occur in a shock wave. The variation of the gas parameters is evaluated, accounting for the excitation of vibrations and the dissociation of molecules.

4233

Lyubarskii, G. Ya., "The Kinetic Theory of Shock Waves," Soviet Phys. JETP, English Transl., 13, 740-745, 1961.

The structure of a low-intensity shock wave in a monatomic gas is obtained at large distances from the wave front. The calculation is based on a kinetic equation with a simplified collision integral containing a constant collision time. It is shown that in this case various physical quantities approach their limiting values at infinity with a slower rate than in the hydrodynamic theory. Therefore, if the kinetic equation is replaced by a finite system of ordinary differential equations, it is impossible, in principle, to obtain the correct asymptotic solutions of the kinetic equation.

4234

Lyubarskii, G. Ya., "The Structure of Shock Waves," Appl. Math. Mech., 25, 1559-1571, 1961.

A mathematical discussion of the discontinuities at a shock front and the criteria for knowing whether particular algebraic relations do or do not represent a real shock wave.

4235

Mackie, A. G., and D. G. Weir, "The Propagation of Shock Waves of Constant Strength," Proc. Cambridge Phil. Soc., 56, 64-74, 1960.

Reports an examination of conditions under which plane shock waves of constant strength can propagate through a gas in a given homentropic motion. Since the entropy change across the shock is taken to be constant, homentropic flow exists behind the shock also. The motion behind the shock is determined by solving a Cauchy problem with data given about the back of the shock. The theory is illustrated by two examples, one of which generalizes a result obtained by Copson.

4236

Makino, R. C., and R. E. Shear, "Unsteady Spherical Flow Behind a Known Shock Line," Rept. No. 1154, Ballistic Research Labs., Aberdeen Proving Ground, Md., 75 pp., 1961.
AD-273 205.

The hydrodynamical equations of unsteady spherical flow are converted into characteristic form and solved numerically by a difference method. The initial-value curve is the shock line obtained by the least-square fit to some compiled shock-front data on spherical Pentolite, of such form as to approach Kirkwood-Brinkley's theoretical asymptotic shock-front-decay curve. Results are tabulated on positive sound paths, mass particle paths, and lines of constant distance.

4237

McCrea, W. H., "Shock Waves in Steady Radial Motion Under Gravity," Astrophys. J., 124, 461-468, 1956.

In the steady radial flow of a polytropic gas toward a center of gravitational attraction, it is shown that a standing shock wave can, in general, exist within a certain distance of the center. This possibility elucidates certain features of Bondi's investigation of such radial motion and, in particular, helps to resolve an indeterminacy he had noted. Reasons are given for concluding that the phenomenon may have application to accretion by a binary star.

4238

McKowen, P., "The Equilibrium Composition and Flow Variables for Air Dissociated by a Strong Shock Wave," Rept. No. 02-984-040, Bell Aircraft Corp., Buffalo, N. Y., 428 pp., 1957.
AD-142 607.

Equations and tables are presented for shock-flow variables, which include the effects of varying specific heat and dissociation based on a simplified, ideal-mixture model of air. Upstream conditions include the 0- to 300,000-ft altitude range and M2 to 20. Downstream conditions are based on the equilibrium composition found as a function of the downstream temperature and pressure. Simplifying assumptions are given in a derivation of the shock relations. Equations are given that describe the equilibrium composition. Results are computed for 180^{O}R increments; they agree with the more accurate results of Rand Corp. and of the National Bureau of Standards.

4239

Melnik, R. E., and R. A. Scheuing, "Shock Layer Structure and Entropy Layers in Hypersonic Conical Flows," Res. Rept. No. RE-149, Grumman Aircraft Engineering Corp., Bethpage, N. Y., 83 pp., 1961.
AD-267 125.

The problems of obtaining uniformly valid solutions to the nonlinear conical flow equations in the thin-shock-layer limit is presented. The significance and nature of the associated streamline patterns and in particular, of the loci of entering streamlines are discussed at some length. The basic thin-shock-layer theory is shown to be nonuniformly valid on certain crossflow surfaces. The nonuniformities are of the general type referred to as entropy layer.

4240

Meyer, R. E., "On Supersonic Flow Behind a Curved Shock," Quart. Appl. Math., 14, 433-436, 1957.

A solution to the flow problems is presented that accounts approximately for the entropy gradients and vorticity downstream of the shock. The flow downstream is a simple wave in which the entropy and a characteristic parameter, α, of homentropic theory have the values occurring just on the nose in the real flow. The solution is obtained on the approximation that α is constant along streamlines. It predicts the same pressure on the body as is predicted by shock-expansion theory.

4241

Meyer, R. E., and D. V. Ho, "Non-Uniform Shock Propagation in a Stratified Atmosphere," Tech. Rept. No. 20, Div. of Applied Mathematics, Providence, R. I., 32 pp., 1959.
AD-220 292.

To test an hypothesis of Whitham (J. Fluid Mech., 4, 337, 1958) an approximate solution is developed for the gas motion behind a very strong shock travelling into a perfect gas with density varying rapidly in the direction of shock propagation. The approximation is valid for arbitrary density variation for heavy gases with ratio of specific heats sufficiently close to unity, and for air it furnishes reliable (and quite simple) results for density ratios of up to about 3 and down to about 0.2. As far as the evidence collected here supports Whitham, it shows his hypothesis to be small (entropy) variation approximation; but the approximation obtained from the interaction of the shock with a constant discontinuity turns out to be at least as good.

4242

Meyer, R. E., and D. V. Ho, "Note on Shock Propagation in a Stratified Atmosphere," Tech. Rept. No. 35, Brown Univ., Providence R. I., Office of Naval Research, 1960.

A locally exact wave-strength relation is given for the propagation of a very strong plane shock into an atmosphere initially at rest, and some of its implications are discussed. It contributes to the elucidation of Whitham's rule and its background, and furnishes the first-order correction to that rule for the early stages of the motion in those cases where the rule is not initially exact.

4243

Morduchow, M., and P. A. Libby, "On the Distribution of Entropy Within the Structure of a Normal Shock Wave," PIBAL Rept. No. 759, Polytechnic Inst. of Brooklyn, N. Y., 70 pp., 1962. AD-284 699.

A unified mathematical account is given of the available knowledge of the entropy distribution through a normal shock wave, together with additional new results. The most notable feature of this distribution is that as long as heat conductivity is present the entropy will first increase within the shock until it reaches a maximum value at a certain point, and then diminishes to its final value behind the shock. A physical discussion of the results is given, in addition to a review of the phenomena not usually included in the analysis of shock-wave structure. A systematic review of classical shock-wave structure according to the Navier-Stokes equations is included, as is a discussion of the physical validity of these equations. The structure of, and the entropy distribution within, weak shock waves in general, and shock waves of arbitrary strength with Prandtl numbers of 0, 3/4, and infinity are analyzed in detail, together with qualitative results for shock waves in general.

4244

Morgenroth, H., "The Question of Non-Stationary Plane Shock Waves with a Total Energy Which Varies with Time," Ann. Phys. (Germany), 9, 212-216, 1962.

It is shown that the equation of motion for the shock-wave front given in a paper by Morgentroth, et. al., cannot correspond to the homology case if the total energy can vary arbitrarily. One can only derive this equation under strongly simplifying assumptions.

4245

Morrow, C. T., "Shock Spectrum as a Criterion of Severity of Shock Impulses," J. Acoust., Soc. Am., 29, 596-602, 1957.

Shock impulses have not as yet yielded to any practical method of spectral analysis that would permit convenient, exact calculation of all the peak internal responses of hardware subject to such accelerations, or comparison of shock severities by inspection. The shock spectrum, with a few supplementary techniques, provides adequate insight into the responses of a one-degree-of-freedom resonator. As an indication of the responses of a system with several coupled degrees of freedom, a second-order shock spectrum is defined. An oscillatory constituent of the spectrum is also defined in such a way as to be applicable to any order of spectrum. Investigation of these two concepts leads to the conclusion that if the first-order shock-spectrum technique is to be used as a basis for measuring the severity of a laboratory test shock with that of a service shock, spectra should be plotted for both positive and negative directions. Moreover, when feasible, such spectra should ordinarily be plotted as distinct curves for the intervals during and after the test shock, and the oscillatory constituent for the interval during the shock should be estimated.

4246

Morse, T. F., "Electromagnetic Acceleration of a Shock Wave in a Constant-Area Duct," Phys. Fluids, 5, 596-603, 1962.

When a rapid-current discharge occurs in a gas between two electrodes, a current sheet forms that accelerates into the gas and produces a shock wave, much as does a piston in conventional gas dynamics. Due to the high velocities it reaches, the shock wave ionizes the gas, and a plasma is formed in the region between the current-carrying contact front and the shock wave. Nonsteady electromagnetic acceleration of a one-dimensional shock wave was studied for the case of an arbitrary but constant specific-heat ratio of the plasma. Approximate closed-form solutions for the velocity of the contact surface and shock wave were obtained, illustrating both the weak dependence of the contact front's velocity on ν, and the relation between the fluid mechanical and "snowplow" models of the shock acceleration. It was also shown, for the case under consideration, that the contact surface and shock positions are initially parabolic, and finally hyperbolic, functions of time, and the pressure may be approximated by a linear function of the Lagrangian variable.

4247

Mott-Smith, H. M., "The Solution of the Boltzmann Equation for a Shock Wave," Phys. Rev., 82, 885-892, 1951.

It is pointed out that the distribution of molecular velocities in a strong shock wave in a gas is bimodal. Assuming the distribution function to consist of a sum of two Maxwellian terms with temperatures and mean velocities corresponding to the subsonic and supersonic streams, the space distribution, as determined by the solution of a transport equation, is appropriate to describe a shock wave. Comparison of the solutions of two different transport equations shows that the assumed distribution changes relatively slowly with time and so is an approximate stationary solution of the Boltzmann equation for strong shocks. The shock thickness is considerably greater than that given by previous theories. The nominal thermal conduction coefficient is negative in the afterpart of the shock.

4248

Novikov, I. I., "On the Existence of Shock Waves of Rarefaction" (in Russian), Dokl. Akad. Nauk SSSR, 59, 1545-1546, 1948.

Shock waves of rarefaction cannot occur when the adiabatic compressibility $(\partial V/\partial p)_S$ increases with increasing pressure. In certain special cases $(\partial^2 V/\partial p^2)_S$ is negative and shock waves of rarefaction can exist, in principle. An example, given by Zeldovich (J. Exptl. Theoret. Phys., 4, 363, 1946) is a van der Waals gas with a large specific heat at constant volume. Another example, wet steam in the neighborhood of the critical pressure (approx. 210-225 atm), is noted in the present paper.

4249

Oguchi, H., "On the Attached Curved Shock in Front of an Open-Nosed Axially Symmetrical Body," J. Phys. Soc. Japan, 9, 861-866, 1954.

Considers the flow near the nose over an open-nosed axially symmetrical body placed in a uniform flow of sufficiently high Mach number. The equation valid near the nose is derived by a method of perturbation. From the solution of this equation, the flow near the nose can be determined, and further, a formula relating the initial curvature K_W of the shock to the curvature K_S of the body surface in a meridian plane is derived. Finally, the conical shock and the attached shock of a sharp-nosed body are discussed on the basis of this formula. In the axially symmetrical case it is pointed out that the curvature of the shock exhibits a singular behavior at the Crocco point, as in the two-dimensional case.

4250

Ohyama, N., "Propagation of Shock Waves in Inhomogeneous Medium, IV. Second Order Approximation," Progr. Theoret. Phys., Japan, 26, 251-262, 1961.

Ono, Sakashita, and Yamazaki derived a first-order approximation formula for the propagation of shock waves in an inhomogeneous medium by extending Chisnell's method. In this paper, corrections to their formula are obtained by taking into account the effects of the second-order reflected waves. The calculation is restricted to the case of the strong shock limit, and it is shown that the rate of growth of the shock strength obtained by the first approximation is little influenced, so far as the strong shock limit is concerned, by taking the effects of the second-order waves into consideration.

4251

Ono, Y., "Propagation of Shock Waves in Inhomogeneous Gases, III. Spherical Shock Waves," Progr. Theoret. Phys., Japan, 24, 825-829, 1960.

The propagation of spherical shock waves in the stellar interior is considered, extending the method developed in Parts I and II. A differential equation of the shock strength is derived, which can be applied to any stellar models. It is found that the spherical damping effect is pronounced near the center of stars, and this guarantees the stability of the stellar core in general. In the envelope, this effect becomes negligible, and it is justified to treat the shock waves near the stellar surface as plane.

4252

Ono, Y., S. Sakashita, and H. Yamazaki, "Propagation of Shock Waves in Inhomogeneous Gases, I," Progr. Theoret. Phys., Japan, 23, 294-304, 1961.

Chisnell's method of shock propagation is generalized for the case of inhomogeneous gravitating gases. The relation between shock strength and initial pressure is derived to the first approximation, using a polytropic index as parameter. The strength of a shock wave, which is generated near the center and progresses outwards, increases rapidly, being proportional to some inverse power of pressure near the surface. Applying the results to the Eddington model, some speculation concerning the origin of nova explosions is made.

4253

Pastori, M., "Wave Propagation in an Isotropic Continua and Corresponding Principal Directions" (in Italian), Nuovo Cimento, 6, 187-193, 1949.

At any point within an isotropic medium in which shock waves propagate, there exist at least three directions, so that, for the wave surfaces to which these directions are normal, the sum of the squares of the three velocities of propagation is stationary.

4254

Penney, W. G., and H. H. Pike, "Shock Waves and the Propagation of Finite Pulses in Fluids," Repts Progr. Phys., 13, 46-82, 1950.

This paper is a review of theoretical work, much of it unpublished and contained in several Ministry of Home Security reports. Shockwave relationships are considered, and the refraction, reflection, and diffraction of plane shock waves are discussed.

4255

Petschek, H. E., "Aerodynamic Dissipation," Res. Rept. No. 23, AVCO Everett Res. Lab., Everett, Mass., 1957. AD-201 438.

An attempt is made to re-examine the derivation of the basic aerodynamic flow equations in order to discuss dissipation in a completely ionized gas in the presence of a magnetic field, and to demonstrate that the basic microscopic dissipation mechanism is appreciably different. An expansion of a Maxwell-Boltzmann equation is used to describe the history of the individual particle motions in the gas. Two Boltzmann equations, one for the electrons and one for the ions, coupled with four Maxwell equations that describe the electromagnetic field, are used. The magnitudes of various terms in the Boltzmann equation are examined for the classification of regions in terms of the gas state.

The steepening of a pressure pulse into a shock wave is used to illustrate some of the differences to be expected in an M region, the region with lower temperatures and higher densities. With an exception of shock velocities at the speed of sound, the shock wave steepens until its thickness is comparable to an ion Larmor radius, or possibly to a smaller dimension.

There is a discussion of magnetic storms on the earth that result from a shock wave caused by a disturbance on the sun.

A method for computing the final steady-state shock structure is attempted; it consists of computing corrections to the zero-order distribution function from the Boltzmann equation.

4256

Polachek, H., and R. J. Seeger, "On Shock-Wave Phenomena; Refraction of Shock Waves at a Gaseous Interface," Phys. Rev., 84, 922-928, 1951.

Treats the problem of the refraction of a shock wave at a gaseous interface. The governing equations are formulated and analyzed. Continuous families of solutions are obtained numerically for a number of gas combinations at varying angles of incidence on a plane interface between ideal gases (characterized by a certain range of parameters). It is believed that these solutions, which represent a three-wave configuration at the interface with a reflected shock wave or with a reflected rarefaction wave, are physically real inasmuch as they tie in with the two known limiting solutions of an infinitesimal shock at any angle of incidence and of any finite shock at normal incidence.

Two of the significant features of the present solutions are: (1) regular refraction (three-wave configuration at the interface) does not occur at glancing incidence and (2) in the region of regular refraction there is no total reflection of finite shock waves.

4257

Raizer, Yu. P., "On the Structure of the Front of Strong Shock Waves in Gases" (in Russian), Zh. Eksperim. i Teor. Fiz., 32, 1528-1535, 1957.

The internal structure of the front of shock waves, which takes radiation into account, is investigated. Approximate solutions to the equations are found. The profiles of the hydrodynamical quantities, density, and radiation flux are constructed.

4258

Richtmyer, R. D., "Detached-Shock Calculations by Power Series, I," NYO-7973, Inst. Math. Sci., Univ. of New York, 49 pp., 1957.
AD-150 033.

A method is described for calculating the flow of an inviscid, ideal gas between a blunt body moving at high Mach number and the detached shock that precedes it. The method is based on power-series expansion in two space variables about a point on the shock. Special Univac routines for formal calculation with power series have been developed; they include an interpretive routine of such a nature that the partial differential equations that determine the coefficients of the power series can be transcribed directly into a pseudocode. An important feature of the method is the use of special floating-decimal subroutines in which the possible loss of significant digits by cancellation is continually monitored. Test calculations that have been made with the method are reported. The results appear to indicate that the method has considerable promise for fluid-dynamical problems of this kind, but further development in certain directions is indicated.

4259

Robbertse, W. P., and J. M. Burgers, "Solutions of the Equations for the Non-Uniform Propagation of a Very Strong Shock-Wave, I.," Proc. Koninkl. Ned. Akad. Wet, enschap. 52, 958-965, 1949.

If the position x at time t of a gas element specified by the parameter s is given by $x = \phi(s, t)$, the gas-velocity immediately behind the shockwave can be expressed in terms of $\partial\phi/\partial t$ or, independently, in terms of ds/dt along the shockpath in the x-t plane. The equality of these two expressions furnishes a condition defining ϕ; a formal solution for is possible when $\partial\phi/\partial s = f_1(s)/f_2(t)$, where f_1 and f_2 are certain special functions of s and t: in effect, specifying f_1 and f_2 defines the initial gas-density distribution.

An example given concerns propagation of a shock-wave at a velocity > that of sound, in a perfect monatomic gas; a constant gravitational force g is assumed to act in a direction opposite to that of propagation. A solution for ϕ is possible for a particular variation of initial density ρ_0. When g = 0, ρ_0 is approx. $\propto x^{-1.75}$; this corresponds to a shock wave whose velocity increases with time as $t^{1/3}$.

4260

Robbertse, W. P., and J. M. Burgers, "Solutions of the Equations for the Non-Uniform Propagation of a Very Strong Shock Wave, II.," Proc. Koninkl. Ned. Akad. Wet, enschap. 52, 1067-1074, 1949.

Special solutions to the propagation equations obtained in a previous paper are compared with those obtained earlier by the first author (Thesis, Delft, 1948) for the case of no gravitational force (g = 0) and constant initial gas density (ρ_0 = constant). The present solutions require a variable gas-density, but it is possible to arrange that $\partial\rho_0/\partial s = 0$ and $\partial^2\rho_0/\partial s^2 = 0$ at s = 0 (s being a parameter specifying a certain gas element), and it is found that in this case the earlier treatment and the present one agree well.

A numerical example is given by way of illustration of the theory, which, it is suggested, may have astrophysical applications.

4261

Rosen, P., "The Solution of the Boltzmann Equation for a Shock Wave Using a Restricted Variational Principle," J. Chem. Phys., 22, 1045-1049, 1954.

Using a variational method and the Mott-Smith velocity-distribution function, the thickness of a plane shock wave is calculated for various Mach numbers. The results compare fairly well with those obtained by Mott-Smith. It is also shown that the Mott-Smith distribution function becomes a better choice as the Mach number increases.

4262

Rott, N., "An 'Almost' Linear Approximate Method for Determination of the Flow Field Behind a Strong Shock," Rept. No. GM-TN-66, Guided Missile Res. Div., Ramo-Wooldridge Corp., Inglewood, Calif., 1957.
AD-221 090.

It is known that the Newtonian or modified Newtonian pressure distribution is a good approximation to the pressure field near the nose of a blunt body; for strong shocks, the pressure change normal to the body, between body and shock, appears not to be too important. It is proposed to assume a Newtonian pressure field (a known function of position) for the sole purpose of calculating the density. Under this assumption, the density will depend on the stream function, i.e., on the entropy given by the initial state behind the shock; and on the position relative to the shock, i.e., on spatial coordinates. If the density were calculated exactly from the energy equation, its dependence on the velocity magnitude would introduce nonlinear terms, while the density calculation in a spatially known pressure field leads to linear terms with spatially varying coefficients.

4263

Roy, M., "The Structure of Shock and Combustion Waves" (in French), Compt. Rend., 234, 168-170, 1952.

An earlier paper (Ibid, 218, 813, 1944) dealing with the structure of a one-dimensional pure shock wave in a compressible, viscous, and thermally conducting fluid is extended to take account of chemical reaction initiated by the shock. The specific heat, Prandtl number, viscosity, and thermal conductivity are assumed constant, the chemical reaction is supposed continuous, and the effect of thermal radiation is neglected. It is shown that if the space-coordinate (x) transverse to the shock front is transformed to the dimensionless variable ξ (where $\xi = 3\rho_1 u_1 x/4\eta$, ρ_1 and u_1 being the gas density and velocity at $x = -\infty$ ahead of the shock, and η the viscosity), the pressure p, temperature θ, density ρ and stagnation temperature D at any point in the shock may be expressed (in terms of their values at $x = -\infty$) as functions of ξ, independent of the viscosity and conductivity of the medium.

Two distinct types of wave can arise: When the Mach number M of the wave propagation velocity is low, p is almost constant, and ρ varies approximately as θ^{-1}; when M is large, ρ is approximately constant in the preshock zone, while p varies approximately as θ. Waves of the first type are identified with deflagration flames; those of the second type, with quasi-detonation waves. It is found that the temp. distribution $[\theta(\xi)]$ alters very little over the range M = 0.01 to M = 9. The scale of the reduced variable ξ does, however, change appreciably and is so small at M = 9 that the pressure increases several times within a distance of one mean free path. This result gives rise to doubt about the validity of assuming macroscopic continuity.

4264

Ryazanov, E. V., "Examples of Exact Solutions of Problems of Propagation of Shock Waves in a Gravitating Gas for Zero Temperature Gradient" (in Russian), Doklady Akad. Nauk SSSR, 126, 955-957, 1959.

A spherical shock wave expands into a gas. The undisturbed gas in front is at rest in gravitational equilibrium and has density $Ar^{-\omega}$ (a and ω are constants). Behind the shock wave the velocity is 2r/3t and the density is constant/t^2. The heat conductivity is taken as energy conservation. Assuming a perfect gas, there are three possibilities: (1) $\omega = 5/2$ and γ (specific heat ratio) = 4/3, in which case the energy is constant, except at t = 0, when a finite amount of energy appears at the center; (2) $30/13 < \omega < 5/2$ and $\gamma = 2(8\omega - 15)/3\omega$, in which case energy is constant throughout; (3) $\omega = 2.65$, $\gamma = 1.55$, in which case energy is also constant. These are suggested as models for certain stellar phenomena.

4265

Sachs, R. G., "Some Properties of Very Intense Shock Waves," Phys. Rev., 69, 514-522, 1946.

Conditions have been obtained for the existence of a steady shock wave of such an intensity that radiation pressure plays a role in determining the properties of the shock. These conditions are completely analogous to the Rankine-Hugoniot equations for ordinary shocks; they are obtained by consideration of the conservation of mass, momentum and energy. The results are applied to hydrogen and other very light gases. The application to other media requires a much more complicated discussion of the equation of state and sp ht under extremely high pressures and temperatures. In the light gases, the thickness of the shock front is extremely large because the radiation free path, which is determined by Comptom scattering, is also large. The velocity of sound in a medium under very high pressures and temperatures is also discussed, and it is found that this velocity continues to increase with increasing pressure, a condition that is necessary for the shock to be stable.

4266

Sakurai, A., "On the Theory of Cylindrical Shock Wave," J. Phys. Soc. Japan, 4, 199-202, 1949.

An investigation of the two-dimensional flow of a compressible fluid that moves outward from a circular source. Viscosity and thermal conductivity are taken into account in deriving the equations of flow, but in the numerical solution of these equations, a particular combination of values of viscosity and conductivity is chosen, in order to simplify the computation. If the source is of finite dimensions the gas velocity is sonic. Three types of flow may be distinguished: (a) the velocity rises monotonically to a maximum, while the pressure falls to zero; (b) the velocity falls continuously to zero, while the pressures rises to a maximum; (c) the velocity becomes at first supersonic, then falls gradually to zero, the pressure reaching a constant value different from the maximum attained in type b. It is claimed that the type-c flows bear a close resemblance to those in which a shock wave occurs.

4267

Sakurai, A., "On the Thickness of Plane (Shock) Waves in a Gas in Turbulent Motion," J. Phys. Soc. Japan, 5, 114-117, 1950.

In the absence of thermal conduction, radiation and viscosity, the region of transition of pressure, density, and velocity in a plane shock is infinitely thin, but if the effects of such processes of energy-transfer and dissipation are allowed for, the transitional region becomes finite in thickness. It is shown that turbulence provides a mechanism for energy-transfer and dissipation whereby a plane disturbance of finite thickness and of a permanent type (as regards its mean properties) can be propagated in a compressible fluid. The thickness of the transitional zone is $LmM/(M^2 - 1)$ where L is the mixing length and m, M are the Mach numbers of the velocity perturbations and of the main flow.

4268

Scala, S. M., L. Talbot, and B. B. Cary, "High Altitude Shock Wave Structure, Part I. Shock Wave Structure with Rotational and Vibrational Relaxation; Part II. A Shock Tube Study of the Thermal Dissociation of Nitrogen," TIS Rept. No. R62SD32, Space Sciences Lab., General Electric Co., Philadelphia, Pa., 130 pp., 1962. AD-285 619.

A theoretical model is developed for the structure of a shock wave in a diatomic gas that includes rotational and vibrational relaxation phenomena. The experiments were carried out in a combustion-driven shock tube, and data for vibrational relaxation times and dissociation rates were obtained for nitrogen. This report includes estimates of the distribution of translational temperature through a normal shock wave; they neglect relaxation phenomena. Realistic values of the thickness of the shock transition also were obtained. Coupling between the internal degrees of freedom was investigated. Combustion-generated shock was used for shock-structure studies; the relative efficiency of nitrogen atoms and molecules was determined. The data indicate that at temperatures to 6000°K in pure nitrogen, vibrational relaxation and dissociation may be treated in an uncoupled manner. The data were compared with those obtained by earlier investigators.

4269

Seigel, A. E., "Theoretical Study of the Effect of the Non-Ideality of a Dense Shocktube Driver Gas with Special Reference to Non-Uniform Shocktubes," Ballistics Res. Rept. No. 5, Naval Ordnance Lab., White Oak, Md., 1957. AD-162 932.

It is shown that the performance of a dense driver gas in a shocktube may be considerably different from an ideal driver gas as a result of the attractive and repulsive forces that exist between the gas molecules. An amazing result of the density effect is that at moderately high densities the nonideality may decrease the driving efficiency in a uniform shocktube, while in a nonuniform shocktube it increases the driving efficiency.

4270

Selivanov, V. V., and I. Ya. Shlyapintokh, "The Thermodynamic Properties of Air on Thermal Ionisation and the Shock Wave," JSRP Control No. 590944, Royal Aircraft Establishment, Great Britain, 13 pp., 1958. AD-225 148.

Presents the results from calculating the thermodynamic properties of air over the temperature range 2.10^4 to 5.10^{5} °K and at densities from 10ρ to $10^{-3}\rho_0$, where ρ_0 is the initial density at 0°C and 1 atm pressure. The parameters of a strong shock wave in air were determined, taking account of its ionisation at the wave front. The method described is applicable to the calculation of the thermodynamic state of any ideal gas obeying the Boltzmann statistics.

4271

Sidorkina, S. I., "Some Aerosol Motions" (in Russian), Dokl. Akad. Nauk SSSR, 112, 398-399, 1957.

Discusses the effect of particles in the air on hydrodynamic processes. The modified general adiabatic equation is presented. Such phenomena as shock waves, intense explosions of different geometry, frontal jumps, and supersonic motion are mentioned in this short treatment.

4272

Sidorov, A. F., "Shock Waves in the Flow of a Polytropic Gas Having Straight-Line Characteristics," Appl. Math. Mech., Great Britain, 25, 558-565, 1961.

The methods of Sidorov and Yanenko (Dokl. Akad. Nauk. SSSR, 123, 5, 832, 1958) are applied to find the flow of gas behind shock waves of constant strength but of general shape, when the flow behind the shock has straight characteristics in the isothermal and adiabatic cases.

4273

Skripkin, V. A., "Conditions for Shock Waves According to the General Theory of Relativity" (in Russian), Doklady Akad. Nauk SSSR, 123, 799-802, 1958.

Conditions for excitation of shock waves in an ideal, compressible medium are formulated in terms of the general theory of relativity. It is shown that for a centrally symmetrical field, the components of metric tensor of a four-dimensional space remain continuous during the passage of a shock wave, while their derivatives are discontinuous. The conditions for first and second derivatives of the components of metric tensor are deduced for the shock wave.

4274

Smith, W. R., "Four-Shock Configuration," Phys. Fluids, 5, 593-596, 1961.

The two-dimensional stationary flow configuration of four plane shock waves intersecting at a point was calculated for a perfect gas of specific-heat ratio $\nu = 1.4$. The configuration represents the mutual reflection of an initial pair of shock waves of arbitrary strengths. The ratio of the stronger initial shock strength to the weaker ranged from 1 to 100 in terms of the pressure ratios across the shock waves, with the strength of the weaker wave ranging from 1.1 to 10. Calculations were made at 10° intervals over the entire range of angles of incidence for which the four-shock configuration was possible. The ordinary weak solution was entirely machine-calculated, along with its extreme angle. The sonic angles were calculated by graphical interpolation from calculated flow Mach numbers. The sonic and extreme angles were found not to differ by more than 1.1° in the range of shock strengths used. A new family of solutions that exists for unequal shock strengths was discovered graphically by plotting the machine-calculated shock polars.

4275

Spence, D. A., "Unsteady Shock Propagation in a Relaxing Gas," Proc. Roy. Soc. (London) A, 264, 221-234, 1961.

A study is made of the motion of the shock wave produced when a piston is impulsively set in motion with constant velocity into a diatomic gas at rest, conditions being such that behind the shock there is a zone of vibrational or dissociational relaxation. The dissociation case is treated by the method of linearized characteristics, using Freeman's formulation for the rate equation, while the vibrational case is included in a discussion in which the third-order equation for acoustic disturbances, derived by Chu, is applied to the flow behind the shock. It is shown that in either case the initial speed of the shock is that corresponding to frozen flow between it and the piston, but that the lower speed calculated from equilibrium thermodynamics is approached at large times. Distributions of pressure and velocity between the piston and the shock are found: at long times after the start of the motion these are precisely those given by the Bethe-Teller theory for partly dispersed shock waves. Some applications to other shock motions are discussed.

4276

Staniukovich, K. P., "Unsteady Motion of Continuous Media," Pergamon, New York, 745 pp., 1960.

This translation of a Russian work treats the unsteady flow of inviscid fluids under isentropic conditions. The problems treated involve shock-type phenomena and are necessarily limited to situations involving one spatial variable.

The book begins with the development of the basic equations governing fluid motion. Both the Eulerian and Lagrangian forms are presented, and the equations are given in the cylindrical and spherical coordinate systems as well as in Cartesian form. Following this, a systematic process of development is followed from plane to cylindrical to spherical processes, always with the restriction of one space variable. After an extensive treatment of these problems, the author proceeds to consider topics of a more general nature: propulsion, gravitational fields, rarified and dense media, and relativistic effects.

4277

Steverding, B., and L. Werner, "Thermodynamic Relaxation of Atmospheric Gases in Shock Waves," Planetary Space Sci. (Great Britain), 3, 113-117, 1961.

Applies the thermodynamic theory of relaxation to shock waves. Soft shock waves, which are nearly adiabatic, show a simple exponential relaxation mechanism, which agrees with results obtained from the kinetic gas theory. For strong shock waves, deviations occur that increase as the disturbance of the thermal equilibrium increases.

4278

Stocker, P. M., "A Second Approximation in Shock-Expansion Theory," Rept. No. (B)17/58, Armament Research and Development Establishment (Great Britain), 6 pp., 1958. AD-201 578.

Shock-expansion theory can be justified mathematically only for weak-shock waves but it is now well known that it is accurate over a wide range of shock-wave strengths. In this note a method for finding the flowfield produced by a moving piston is derived in a manner that makes some allowance for entropy variations and for the reflexion of waves from the shock. It is then possible to deduce a second approximation for the pressure at the piston, which improves the accuracy of shock-expansion theory.

4279

Stollery, J. L., "Real Gas Effects on Shock-Tube Performance at High Shock Strengths," Tech. Note No. Aero. 2413, Royal Aircraft Establishment (Great Britain), 24 pp., 1957. AD-157 381.

Calculations have been made to find the flow conditions behind shock waves in argon-free air of strengths $M_s = U/a_1$ up to about 35. The tables used are based on the currently accepted value for the dissociational energy of nitrogen of 9.758 e.v. per molecule, and are for equilibrium conditions. Two cases only have been considered, namely:

$$P_1 = \frac{1}{10}\,\text{atm}, \rightarrow T_1 = 290^{\circ}\text{K}$$

and

$$P_1 = \frac{1}{100}\,\text{atm}, \rightarrow T_1 = 290^{\circ}\text{K}.$$

The driving conditions needed to produce such strong shocks have been calculated assuming "ideal" hydrogen ($\nu = 1.41$) to be the driving gas. In conclusion, the test conditions available through expanding the flow behind the shock are presented for an expansion ratio of 225 and the question of flight simulation is discussed.

4280

Talbot, L., "A Survey of the Shock Structure Problem," Rept. No. R62SD46, Space Sci. Lab., General Electric, Philadelphia, Pa., 31 pp., 1962. AD-278 048.

A survey is made of recent theoretical and experimental investigations on the structure of shock waves. Included are discussions of shock structure in monatomic gases, relaxation and diffusion phenomena in shock waves, some brief comments on detonation waves, and some remarks on the interaction between the shock wave and the shock layer in low-density hypersonic flow over a blunt body.

4281

Taylor, A. B., and D. Phil, "An Approximate Solution of the Equations of Transonic Flow, I. Aerofoils with Attached Shock Waves," Rept. No. 23388, Aeron. Res. Council (Great Britain), 19 pp., 1962.
AD-278 363.

An approximate nonlinear solution to the equations of steady, compressible, potential flow past an aerofoil is given. The solution contains a shock of finite length attached normally to both the upper and lower aerofoil surfaces at high subsonic free-stream Mach numbers. By an iteration the approximate solution is improved, and results for pressure distributions compare favorably with other theoretical methods, giving all the correct physical phenomena.

4282

Taylor, G., "The Air Wave Surrounding an Expanding Sphere," Proc. Roy. Soc. (London), A, 186, 273-292, 1946.

The radial outward flow produced by a uniformly expanding sphere is examined mathematically. The differential equations governing the flow are solved numerically, and the distributions of velocity and pressure are calculated for a range of rates of expansion. The region of expanding air is bounded by a shock wave outside which the air is undisturbed. As the radial velocity of the sphere increases the thickness of the layer of disturbed air decreases till at infinite rate of expansion it is only 6% of the radius of the sphere.

4283

Teare, J. D., and G. J. Dreiss, "Theory of the Shock Front, III. Sensitivity to Rate Constants," Res. Note No. 176, AVCO Everett Res. Lab., Everett, Mass., 17 pp., 1959.
AD-234 032.

Computer programs for the calculation of relaxation phenomena were used in a study of the sensitivity of the features of the nonequilibrium shock front to certain of the pertinent rate constants. A summary is presented of the results of the survey with respect to the effect on some re-entry observables. Calculations are made at three Mach numbers (12, 17, and 20.8) for normal shock waves incident to air at a pressure P_1 = 0.02 mm Hg (50-mi altitude). The features discussed are the NO concentration profile, with particular attention to the magnitude and location of the peak; the electron density profile; and the radiation profile for a typical molecular-band system.

4284

Teare, J. D., P. Hammerling, and B. Kivel, "Theory of the Shock Front, II. High Temperature Reaction Rates," Res. Note No. 133, AVCO Everett Res. Lab., Everett, Mass., 13 pp., 1959.
AD-227 864.

A re-examination was made of the mechanism leading to O_2 Schumann-Runge radiation. A previous calculation predicted an overshoot above the equilibrium intensity in pure oxygen, for contradiction to experiments. A revised theory takes into account the de-excitation of the radiating state by collision. This mechanism, in conjunction with a small ($\approx 10^{-20}$ cm^2) cross section for vibrational de-excitation, leads to predictions that do not overshoot. The rate constants for dissociation of nitric oxide and for the exchange reactions are discussed, and some conclusions are reached regarding their bounds. It is shown that the magnitude of the peak in NO concentration depends on many reactions, while the tail is sensitive only to the rate of NO dissociation. The ionization rate in air is shown to be sensitive to only one rate constant, which has been measured by Lin.

4285

Theordoriedes, P., "The Shock Wave in a Non-Monatomic Fluid," Inst. for Fluid Dynamics and Appl. Math., Univ. of Maryland, College Park, 20 pp., 1958.
AD-152 182.

With atomic vibration representing the intramolecular processes of nonmonatomic fluids, the structure of a normal shock wave is analyzed. Conservation equations of mass, momentum, and energy are set on trimerous viscosity, and specialized for an uni-axial steady flow taken initially as supersonic under stratospheric conditions ($T_1 = 218^{o}K$, p_1 = 0.1 atm). As to normal shock of varied strength, boundary conditions are calculated for variable enthalpy. Temperature dependency for all physical parameters is based on NBS-Tables (1955), thus including, for enthalpy, the anharmonicity and interaction of periodic modes. Results of numerical integration are communicated for molecular nitrogen. Comparison of these results and Becker's classical figures for air of constant Prandtl number shows that temperature effects would make about tenfold his shock-thickness in the velocity profile, and an added broadening, by an average of about 43%, is found, because of bulk viscosity, working from ultrasonic measurements of Zmuda (J. Acoust. Soc. Am., 23, 472-477, 1951).

4286

Thomas, L. H., "Note on Becker's Theory of the Shock Front," J. Chem. Phys., 12, 449-457, 1944.

Becker concludes, inter alia, that violent shocks have a small thickness compared with a free path, and that the relevant Boltzmann equation is not applicable. It is shown that this last conclusion rests on an oversight; the thickness of a shock front is always at least of the order of magnitude of a free path, and it is to be expected that the Boltzmann equation can be applied even for the most violent shocks.

4287

Thomas, T. Y., "Calculation of the Curvatures of Attached Shock-Waves," J. Math. Phys., 27, 279-297, 1949.

The angle of inclination α of the shock-wave near the apex (total angle 2ω) of a pointed cylindrical obstruction in a plane supersonic gas stream of Mach number M is calculated. A formula is quoted relating the curvature k of the shockwave to the curvature K of the streamline immediately behind it. Near the apex K is specified by the geometry of the obstacle. Tables are given (based on a ratio of specific heats $\gamma = 1.405$) for k/K and ω in terms of α; the pressure- and density-ratios across the shock-wave are also tabulated. Values of M range from 1.05 to 4.45; the corresponding Mach angles cover the range 73^{o} to 15^{o} in approximately uniform 5^{o} steps. The tabular data are also presented.

4288

Thompson, L., and N. Riffolt, "Propagation of Shock Waves in Air. Part I"; Thompson, L., "____, Part II," J. Acoust. Soc. Am., 11, 233-254, 1938-1939.

From a consideration of conditions at the boundary of a source of shock in air, and of conditions at great distances, a formula of the Riemann type has been derived for the velocity of propagation of a finite pulse. The formula includes an additional constant, which provides the necessary flexibility to represent data obtained throughout the fields of sources consisting of detonating charges of explosives, and of other sources. The observations of wave displacements have been summarized in terms of an integral for reduced times, from which the constants of the function for velocity are immediately available. All distances are defined with reference to an equilavent dimension of the source, and the characteristics throughout the velocity field are obtainable from the characteristics of the source.

A table is given for the velocity of a condensation pulse, for representative boundary velocities, at various distances from the source out to points at which the velocity has decreased approximately to its asymptotic value (the normal velocity of sound). Results obtained by Wolff and Burlot for very large sources are shown for comparison on a plot of reduced times. Preliminary results, obtained with piezogauges, of experiments to determine relative pressures at the head of the wave are given in comparison with theoretical gauge pressures.

In Part II, using the Rankine-Hugoniot equations, formulae are obtained for density and pressure at the head of a shock wave; they are referred to the velocity of the wave as a parameter. Gauge pressures are defined in a form considered to represent the observations of pressure obtained in Part I. The function is used to calibrate the gauge, and a comparison of results by Rayleigh's pressure function is included. A discussion is given of the appropriate ratio of specific heats for condensation cycles as extremely short in duration as those of intense shock waves, with references to the literature bearing on the subject of the accumulation of molecular excitational energies in short intervals of time.

4289

Treanor, C. E., and P. V. Marrone, "The Effect of Dissociation on the Rate of Vibrational Relaxation," Rept. No. QM-1626-A-4, Cornell Aeronaut. Lab., Inc., Buffalo, N. Y., 13 pp., 1962. AD-273 103.

The rate of dissociation behind strong waves in N_2 and O_2 is calculated, using a revised model for the coupling of vibration and dissociation. In previous calculations a model that coupled the rate of dissociation to the degree of vibration excitation (CVD model) was used. The present model adds to the CVD model the fact that the rate of vibrational excitation is in part determined by the rate of dissociation. Since the average energy of dissociated molecules is greater than the average energy of the remaining molecules, this coupling results in a drain on the average vibrational energy. It is shown that this coupling reduces the strong overshoot in vibrational energy that was previously obtained, and decreases the rate of dissociation behind strong shocks.

4290

von Weizsacker, C. F., "Approximate Representation of Intense Non-Stationary Shock Waves by Homologons Solutions" (in German), Z. Naturforsch., 9a, 269-275, 1954.

The equations of continuum, momentum, and entropy are invariable with respect to changes of the units of length, time, and density, and therefore possess symmetrical (homologous) solutions invariable with respect to the same group of units. For the case of a strong, nonstationary, plane shock wave, these equations are reduced to a system of ordinary differential equations by suitable substitutions and then solved numerically.

4291

Wetzel, L., "Precursor Effects and Electron Diffusion from a Shock Front," Phys. Fluids, 5, 824-830, 1962.

Experiments disclosed electrical effects well ahead of an advancing shock front. Some of these were attributed to the diffusion of electrons through the shock front from the ionized region behind it. The diffusion hypothesis is examined in terms of a simple heuristic model, in which the diffusion is assumed to take place from a plane electron source moving with the shock velocity. According to this model, there is no true electron "front," as was suggested by some experiments with ionizing shocks. However, a transient in the electron distribution may give rise to a virtual front in certain experimental situations. Under reasonable assumptions, the existing observations of precursor fronts by Weymann are found to be consistent with the predictions of the model.

4292

Wittliff, C. E., and J. T. Curtis, "Normal Shock Wave Parameters in Equilibrium Air," Rept. No. CAL-111, Cornell Aeron. Lab., Inc., Buffalo, N. Y., 94 pp., 1961. AD-270 202.

Gives tables and graphs of normal shock wave parameters for equilibrium air. The composition of the air behind the shock is also tabulated. The results cover the range of velocities from 2000 to 26,000 fps in increments of 1000 fps and altitudes from sea level to 300,000 ft at 10,000-ft intervals. The 1959 ARDC model atmosphere was used to specify ambient conditions ahead of the shock. An effective specific heat ratio was tabulated that permits solution of oblique shock waves.

4293

Wood, W. W., and F. R. Parker, "Structure of a Centered Rarefaction Wave in a Relaxing Gas," Phys. Fluids, 1, 230-241, 1958.

The structure of a centered rarefaction wave in a relaxing ideal gas is studied theoretically, both analytically and numerically, with neglect of the Navier-Stokes terms (viscosity, etc.) in the hydrodynamic equations. The role of the frozen sound speed is clarified, in that it is shown that there is a transition from frozen flow at short times to equilibrium flow at long times.

4294

Wood, W. W., and J. G. Kirkwood, "Hydrodynamics of a Reacting and Relaxing Fluid," J. Appl. Phys., 28, 395-388, 1957.

Reports formulation of general equations governing the hydrodynamic behavior of an ideal compressible fluid in which chemical reactions and internal relaxations proceed. For one-dimensional flow the equations are transformed to characteristic form, in which the "frozen" or high-frequency sound velocity plays a role analogous to the unambiguous sound velocity in the nonreactive case.

4295

Wu, T. Y. T., "Two-dimensional Sink Flow of a Viscous, Heat-conducting, Compressible Fluid; Cylindrical Shock Waves," Quart. Appl. Math., 13, 393-413, 1956.

The Navier-Stokes equations are given for the cylindrical sink flow of a viscous, heat-conducting, perfect gas, and the qualitative properties of the solutions together with a detailed calculation are discussed for the case of a flow of large Reynolds number. Solutions belonging to the supersonic branch all contain cylindrical shock-type flow in the transonic region of flow; these solutions gradually deviate from the inviscid supersonic branch, reach a minimum and then approach asymptotically the viscous subsonic branch. The results for shock strength and shock thickness are quite different from those of plane normal shock. Entropy variation of the fluid and the effect due to variation of viscosity coefficients are discussed.

4296

Wuest, W., "Theory of the Bifurcated Compression Shock Wave" (in German), Z. Angew. Math. Mech., 28, 73-80, 1948.

A simplified graphic determination is given. The method fails when one of the waves degenerates into a Mach wave, and an analytical method is developed for that case. The conditions for the occurrence of bifurcated shock waves are discussed. A comparison of the theory and experiments is included.

4297

Zababakhin, E. I., and M. N. Nechaev, "Field Shock Waves and Their Cumulation" (in Russian), Zh. Eksperim. i. Teor. Fiz., 33, 442-450, 1957.

For electromagnetic waves with a narrow transitional region between initial and final states, a cylindrical converging wave is considered. It is found that as the wave converges its amplitude infinitely increases and a qualitatively new cumulation phenomenon emerges—the appearance of infinitely strong fields in the front of a wave that is reflected from the axis of the wave cylinder, at finite distances from that axis. This phenomenon is not specific for electromagnetism but is inherent in the (cylindrical) geometry of the waves. Acoustic waves possess the same property, but in their case the solution is valid only for weak waves, whereas this restriction does not apply to electromagnetic waves.

4298

Zadoff, L. N., "Axisymmetric Shocks in the Newtonian Limit for Nonrigid Boundaries," Phys. Fluids, 5, 831-839, 1962.

The natural generalization of the snowplow equation in two-dimensional axisymmetric or Cartesian geometries is a Newtonian approximation in which the possibility of surface deformation is admitted. Such a general Newtonian approximation was derived from the Lagrangian fluid equations, using an ideal-gas model in the limit of strong-shock and high-density ratio across the shock front. In one dimension the result reduces properly to the snowplow equation. In two dimensions, if the surface is constrained and the motion steady, the result consists of the Newtonian plus Busemann terms. The general result contains in addition a Coriolis term. The theory is applied to the evaluation of the pressure on the surface of a conical plasma whose vortex angle is decreasing uniformly with time. Although the results are derived for an ideal-gas model, they are applicable whenever dissociation and ionization are taking place behind a strong shock front.

4299

Zel'dovich, Ia. B., "Cylindrical Self-Similar (Automodel'nye) Acoustic Waves" (in Russian), Zh. Eksperim. i Teor. Fiz., 33, 700-705, 1957.

A family of exact solutions is obtained for cylindrical motion in the acoustic approximation which depends on a single parameter. It is obtained by superposition of plane waves and can be expressed in an elementary form by quadratures. In the course of time these solutions transform retaining similitude (automodel solutions). Results were obtained for motion involving a finite pressure discontinuity on the front of the converging cylindrical wave. It is confirmed that the pressure in the reflected wave is infinite at finite distance from the center. The maximal pressure is estimated by taking into account deviations from the acoustical approximation at large wave amplitudes.

4300

Zel'dovich, Ia. B., "Motion of a Gas Due to a Pressure of Short Duration (Shock)," Soviet Phys. Acoust., English Transl., 2, 25-35, 1956.

The paper considers the propagation of a plane shock wave and the motion behind the wave front arising in the gas during the action of a strong, momentary, external pressure. The law of attenuation of the wave and the distribution of pressure, density, and velocity that must occur after the action of the pressure ceases, are found to be asymptotic over a time large in comparison with the duration of the external pressure. The solution shows an exponential dependence upon wave amplitude, time, and distance traversed by the wave. The author also examines difficulties with the equations of conservation of momentum and energy in the asymptotic solution, and also the problem of practical realization of such motion.

4301

Zel'dovich, Ia. B., "Shock Waves of Large Amplitude in Air" (in Russian), Zh. Eksperim. i Teor. Fiz., 32, 1126-1135, 1957.

The state of air compressed by a strong shock wave is examined by taking into account disassociation and ionization. Approximate expressions for the density and temperature in this region are given. The radiation from the front of the shock wave is considered. With increasing amplitude of the shock wave, the visible temperature of the wave exhibits a maximum, due to the formation of an opaque layer of air in front of the wave, preheated by radiation. The structure of the shock wave is studied with radiative heat exchange taken into account. A rigorous proof of the impossibility of a continuous solution and of the necessity of discontinuities in the velocity, density, and temperature in a strong shock wave is presented. The wave structure in a strongly ionized gas is investigated, taking into account slow energy-transfer between ions and electrons.

4302

Zeldovich, J., "The Possibility of the Rarefraction Shock Waves," J. Phys. (USSR), 10, 325-326, 1946.

It is shown that for the gases with a large molar heat capacity C_V (> ~ 20 cal/deg. mole) there exists a region where rarefaction waves must propagate in the form of shock waves, and compression waves must be blurred in the course of propagation.

4303

Zhukov, A. I., and Ya. M. Kazhdan, "Motion of a Gas Due to the Effect of a Brief Impulse," Soviet Phys. Acoust., English Transl., 2, 375-381, 1956.

Interpretation of the equations concerned with the passage of a shock wave through a cold gas. Results are given for the motion of a gas under the action of a finite pulse of short-duration.

4304

Zoller, K. "On the Structure of the Compression Shock" (in German), Z. Physik, 130, 1-38, 1951.

In a previous treatment by Becker (Z. Physik, 8, 321 (1922)) the contributions of viscosity and thermal conductivity to the equations of conservation of mass, momentum, and energy through a stable plane shock wave were expressed in terms of only the first derivatives of the velocity and temperature of the gas-flow. In the present treatment, the viscosity and thermal conductivity are derived from the kinetic theory of a gas consisting of point-masses having an inverse-fifth-power law of repulsion; this is equivalent to expressing the viscosity and thermal conduction terms in the conservation equations as an infinite series of derivatives and their cross-products. The effects of 2nd-order derivatives and the cross-products of 1st-order derivatives have been taken into account in numerical solutions carried out for pressure-ratios p_1/p_0 = 1.5, 4.0 and 6.5 (where p_1 is the pressure behind the shock and p_0 the pressure before the shock). These calculations show that the thickness of the shock-front for p_1/p_0 = 4.0-6.5 is 2-3 times as large as would be expected on Becker's theory. It is pointed out, however, that for p_1/p_0 = 6.5, and to a lesser extent for p_1/p_0 = 4.0, the results are somewhat unreliable, because in these cases the effects of higher-order derivatives may not be negligible; but the computational labor involved in dealing with derivatives higher than second-order becomes prohibitive.

4305

Zubkov, A. I. and L. I. Sorkin, "The Effect of Viscosity on the Flow in the Region of a Straight Compression Shock," Trans. No. FTD-TT-62-172, Foreign Tech. Div., Air Force Systems Command, Wright-Patterson AFB, Ohio., 14 pp., 1962. AD-276 874.

Investigations were conducted on the physical picture of the flow in the region of a straight compression shock and the localization of the spearation that occurs as a result of the interaction between a straight compression shock and the boundary layer.

Wave Propagation, Shock, Theory — See also Wave Propagation, Blast, Detonation
See Also — 17, 28, 73, 218, 226, 255, 256, 261, 441, 475, 495, 496, 518, 522, 527, 561, 573, 686, 696, 797, 871, 896, 910, 913, 914, 927, 947, 955, 1143, 1203, 1239, 1345, 1368, 1408, 1737, 1795, 1806, 1908, 1956, 1961, 1963, 1970, 1971, 1995, 1999, 2006, 2019, 2023, 2025, 2052, 2071, 2072, 2278, 2306, 2340, 2613, 2820, 2909, 2984, 2988, 2989, 2993, 2999, 3006, 3182, 3206, 3347, 3361, 3430, 3431, 3436, 3451, 3468, 3503, 3520, 3544, 3552, 3560, 3563, 3566, 3580, 3590, 3591, 3600, 3602, 3609, 3618, 3653, 3657, 3663, 3672, 3752, 3754, 3760, 3762, 3766, 3767, 3768, 3775, 3776, 3777, 3779, 3791, 3807, 3810, 3811, 3817, 3826, 3835, 3842, 3849, 3854, 3856, 3862, 3870, 3874, 3927, 3945, 3946, 3961, 3962, 3964, 4014, 4042, 4063, 4075, 4083, 4097, 4116, 4121, 4125

WAVE PROPAGATION, SOUND, THEORY

4306

Barakat, R. G., "Propagation of Acoustic Pulses from a Circular Cylinder," J. Acoust., Soc. Am., 33, 1759-1764, 1961.

In two-dimensional linear acoustic theory Huygens' principle fails; the failure of Huygens' principle being manifested by the existence of a tail to the acoustic pulse. A two-dimensional problem of importance is the radiation of acoustic pulses of various shapes by an infinitely long circular cylinder. The problem is attacked directly via the use of the Laplace transform. In the inversion of the Laplace transform, a relatively new function, called the Nielsen W_0 function, is encountered. Exponential, sine, and rectangular pulses are studied, and their shape is determined at various distances from the cylinder. Finally the passage to the steady state of a semi-infinite sine-wave train is outlined.

4307

Bechert, K., "Propagation of Cylindrical and Spherical Waves in Frictionless Gases and Liquids" (in German), Ann. Physik, 39, 169-202, 1941.

In this mathematical work solutions are given for the problem of the propagation of cylindrical and spherical waves in frictionless gases and liquids in polytropic change of state, neglecting heat conduction and gravity and regarding pressure as dependent solely on density. The subject is dealt with as follows: Part I: Introduction. Results. Part II: Cylindrical and spherical waves for which ρ depends only on u. Sec. 1. Reduction of the problem to the integration of an ordinary differential equation of the first order (Eq. 16). Sec. 2. General properties of the motion. The singular integrals of Eq. 16. Sec. 3. Integration of Eq. 16. The case n = -1 (liquids). Sec. 4. A special cylindrical wave in liquids. Part III. More general cylindrical and spherical waves. Sec. 5. A more general expression for cylindrical and spherical waves; reduction to the integration of an ordinary differential equation of the 1st order (Eq. 51). Sec. 6. General properties of the motion. The case a = -1. The singular integrals of Eq. 51. Sec. 7. Discussion of Eq. 51. Part IV. Sec. 8. The problem of the general solution for cylindrical and spherical waves. Appendix: Derivation of the general integral from the complete integral (Eq. 52).

4308

Biot, M. A., and I. Tolstoy, "Formulation of Wave Propagation in Infinite Media by Normal Coordinates with an Application to Diffraction," J. Acoust., Soc. Am., 29, 381-391, 1957.

In the theories of acoustical and electromagnetic vibrations of enclosures, as well as in field theory and electrodynamics, one quite commonly uses normal modes as generalized coordinates in Hilbert space. Here the method is extended to unlimited or partially limited mechanical media, essentially by first solving the problem for an enclosure and going to a limit while expanding all or some of the boundaries to infinity. This leads to a very useful technique of somewhat more generality than analogous procedures used in field theory. Thus it is applicable to all nondissipative mechanical continua, for any boundary conditions, irrespective of the order or number of differential operators describing the continua and regardless of whether the coordinate systems are separable or not. A general orthonormality condition valid in all such cases and the necessary rules for dealing with divergent normalizing coefficients are easily obtained by limiting procedures.

An equally general formulation for arbitrary sources is obtained from the principle of virtual work. The method is illustrated by simple examples, for the case of a point source representing the instantaneous injection of a unit volume, i.e., an idealized, infinitely rapid explosion. It is shown that in the problem of diffraction by a rigid wedge or corner, one is led very quickly to an explicit solution in closed form, involving elementary functions only. Some physical implications of this solution are mentioned briefly. The advantages of the normal coordinates method are discussed when thus used in propagation or diffraction problems in unlimited or partially limited mechanical continua. Obvious advantages are its generality, its flexibility in dealing with arbitrary sources, and the fact that it leads directly to the progressive transient solutions.

4309

Boillet, P., "On the Interpretation of Huygens' Principle: The Case of Acoustic, Elastic and Electromagnetic Waves" (in French), Cahiers Phys., 11, 59-87, 1957.

This paper deals only with acoustic waves. It is a part of the author's dissertation presented in Paris in 1955. It is shown that the intuitive ideas in Huygens' Principle are justified by the mathematical theory. The latter, which occupies the bulk of the paper, is concerned with properties of the solutions of the equations of wave propagation. The work will be completed in subsequent papers.

4310

Bourgin, D. G., "Propagation of Sound in Gases," Phil. Mag., 7, 821-841, 1929.

A mathematical attempt to link up explicitly the kinetics of sound with the internal constitution of the entities composing the gas. Abello's empirical conclusion was that the logarithm of the ratio of transmissions is a linear function of the concentrations. This can hardly be true in general, and even in the most favorable case we ordinarily should expect the ratio of two quadratics in the concentrations. Abello's relation holds in this extreme case only when degrees of freedom of the component gases are the same.

4311

Bourgin, D. G., "Sound Propagation in Gas Mixtures," Phys. Rev., 34, 521-526, 1929.

An earlier treatment of the propagation of sound in mixtures of two gases is generalized and somewhat simplified. The essential point of the theory is the consideration of the internal energy variations by the assignment of fictitious internal state temperatures which, in the simplest case assumed here, are taken to be constant for each of the component gases. The long-wavelength velocity expression is directly interpretable as a Laplace formula for a gas of mean reciprocal mass and averaged specific heat. From a more general point of view, the velocity of propagation of infinitesimal waves is always given by the Laplace result, provided that a frequency variation of specific heats is recognized. Explicit mention is made of the detailed effect of viscosity and the two conductivities. Experimental data support the theory.

4312

Bouthillon, L., "Coordination of the Different Types of Oscillations," Bull. Soc. Franc. Electriciens, 6, 151-182, 1936.

A résumé is given of the main points of a general theory of mechanical, acoustical, optical, and electrical oscillations. After reviewing the linear equations for classical mechanical systems and for electrical networks, the oscillations of electromechanical systems are considered. This is followed by a review of nonlinear mechanics. Finally, a group of studies on acoustic, mechanical, electric and optical oscillations of continous media is presented. The way in which the wave equation enters into these fields is recalled and among the applications are considered stationary and progressive waves, interference, reflection, refraction, and diffraction. The fundamentals and the general results of a comprehensive study of the wave equation are thus demonstrated.

4313

Bouwkamp, C. J., "A Contribution to the Theory of Acoustic Radiation," Phillips Res. Rept., 1, 251-277, 1946.

The field of radiation in an ideal medium produced by a harmonically oscillating membrane with arbitrary amplitude distribution in a closely fitting aperture of an infinite rigid plane is studied mathematically. The problem is stated by means of the velocity potential in the form of a boundary value problem in connection with the wave equation. A new argument is given as to why the time-factor exponent ($-i\omega t$) is preferred. The general formulae are applied to a circular membrane, and King's theory is very much extended.

4314

Carrier, G. F., "The Propagation of Waves in Orthotropic Media," Quart. Appl. Math., 4, 160-165, 1946.

An extension of a previous paper (1945). The displacements are written in terms of the potential, ϕ, and the differential equations governing the stress and expressing equilibrium are obtained. These are transformed into wave equations, the solutions of which are discussed. The final result is an expression for ϕ in the familiar form of a retarded potential.

4315

Chertock, G., "General Reciprocity Relation," J. Acoust. Soc. Am., 34, 989, 1962.

A reciprocity relation is derived between the radiation field of a surface vibrating in an arbitrary mode with arbitrary time dependence, and the generalized force exerted on the surface in the same mode by an external source with the same time dependence.

4316

Cunningham, W. J., "Application of Vector Analysis to the Wave Equation," J. Acoust., Soc. Am., 22, 61, 1950.

The author criticizes the duplication of efforts to derive separate sets of differential equations for the propagation of sound waves in the various systems of coordinates, such as rectangular, spherical, cylindrical, etc. He then derives an acoustic-wave equation using vector notation, valid in any coordinate system. In application to a particular coordinate system the vector operators could be written in the special form of that system to produce a more familiar form of the wave equation.

4317

Frankl', F. I., "Isentropic Relativistic Gas Flow" (in Russian), Zh. Eksperim. i Teor. Fiz., 31, 490-492, 1956.

General baroclinic isentropic relativistic gas flows are considered. The vortex equations and the nonlinear equation for the propagation of sound are derived. A relativistic generalization of Thomson's theorem is derived for the case of barotropic flow.

4318

Gibson, W. E., and F. K. Moore, "Acoustic Propagation in a Diatomic Gas Subject to Thermal or Chemical Relaxation," Cornell Aeronaut. Lab., Inc., Buffalo, N. Y., 1958. AD-206 988.

A theory of acoustical propagation in a gas subject to relaxation phenomena is presented. An acoustical equation is obtained for small disturbances from an equilibrium state of rest; this equation applies equally well to unsteady one-dimensional waves or to steady two-dimensional disturbances. The problem of a two-dimensional airfoil in a supersonic flow of a relaxing gas is considered. From the acoustic equation, the law of decay of shock waves and the values of the flow properties on the surface of the airfoil are derived. The asymptotic behavior of the flow field is obtained far from the airfoil so that the formation of an equilibrium wave is described. The acoustical equation involves the two-wave operators, which can be defined on the basis of the frozen and equilibrium sound speeds. The closeness of the sound speeds allows a simplification of the full equation to a variant of the telegraph equation. This approximate equation is uniquely determined by the requirements that the shock-decay law and the exact value of the equilibrium sound speed be preserved. An explicit solution for the flow field is presented and proved to closely agree with the exact solution on the surface of the airfoil and in the asymptotic range.

4319

Hunt, F. V., "Notes on the Exact Equations Governing the Propagation of Sound in Fluids," J. Acoust. Soc. Am., 27, 1019-1039, 1955.

The assumption underlying the exact equations of motion for thermoviscous fluid are reviewed, and the complete equations are given, for reference convenience, in both tensor and vector form. The first- and second-order acoustic equations are then exhibited and used to obtain the source terms that account for the generation of vorticity and streaming. In order to preserve a broad base from which to make the approximations appropriate under various circumstances, all terms are retained explicitly, including those arising from any functional dependence of the viscosity and thermal coefficients on the state variables. The distinction between spatial and material coordinate systems is carefully drawn and conversion transforms are derived rigorously and their use illustrated. The general properties of finite-amplitude waves are demonstrated by including the second-order terms in a plane-wave solution of the exact wave equation in material coordinates, with special concern for the effects of large amplitude on speed of propagation and on wave-form distortion. Sound absorption and dispersion measures for a viscous conducting fluid are analyzed in terms of Truesdell's recent exact solution of the first-order secular equation. These differ characteristically from the corresponding measures predicted for pure relaxation in a two-fluid mixture. It is concluded that a complete and adequate theory of sound absorption and dispersion will need to take into account both relaxation and viscothermal phenomena as well as their interaction, and that until such a general theory is available, the exact theory of viscothermal effects — rather than the crude linear approximation commonly, but inappropriately, called "classical" — should be used in computing the "excess" absorption and dispersion to be accounted for by relaxation processes. The exact solutions of the secular equation permit a new evaluation, in series form, of the characteristic acoustic impedance for a thermoviscous medium. The notes conclude with a revised account of the spectral character of thermal noise in the acoustic medium based on the quantum hypothesis and a merger of the concepts of architectural acoustics and specific-heat theory.

4320

Junger, M. C., "The Physical Interpretation of the Expression for an Outgoing Wave in Cylindrical Coordinates," J. Acoust. Soc. Am., 25, 40-47, 1953.

The sound field generated by a vibrating cylinder of infinite length, whose dynamic configuration is periodic in ϕ and z, is expressed in terms of acoustical impedance ratios. It is noted that symmetrical modes of vibration are suppressed at certain frequencies because the corresponding reactive impedance is infinite, and that all z-dependent modes become nonradiating below certain cut-off frequencies, the corresponding impedance being purely reactive. Graphs are presented for the impedance ratios corresponding to certain modes.

For modes independent of z, the sound field is in the form of concentric cylindrical waves. For z-dependent modes, as the length of the plane wave increases from zero to a certain critical cut-off value, the sound field changes from a set of concentric cylindrical waves to two sets of conical waves of decreasing vertex angle; at and beyond the cut-off point, the conical waves have degenerated into a set of plane standing waves normal to the z axis. Simultaneously, the sound field has ceased being periodic in the radial direction.

Practical applications of these phenomena are suggested.

4321

Kappler, E., "Physics of Liquids and Gases" (in German), FIAT Rev. Ger. Sci. (1939-1946), 348 pp., 1948.

The section on physics of liquids contains a discussion of work on: the X-ray analysis of molecular structure; dielectrical and optical phenomena, including dielectrical relaxation; interactional and associational phenomena (due to intermolecular forces), including the structure of soap-and-water solutions; systems with long-chain molecules; anisotropic or crystalline liquids; thermodynamics and statistical mechanics of liquids; thermodynamics of liquid mixtures and solutions; transport phenomena; heat conduction, viscosity, and convection; the propagation of sound in liquids; electrical conduction in liquids and electrolytes. The section on physics of gases has sections on: thermodynamics and the kinetic theory of gases, including transport phenomena; sound propagation; dielectric and optical properties; electrical discharges in gases. For the sections on unsteady phenomena and colloid physics, see FIAT Rev. Ger. Sci., 261-266, 1948, and Muller and Erbring, Ibid., 267-330, 1948, respectively.

4322

Kaspar'iants, A. A., "On the Propagation of Sound Waves in a Viscous Gas in the Presence of Heat Conduction" (in Russian), Prikl. Mat. Meh., 18, 729-734, 1954.
See Also: Translation available from M. D. Friedman, 2 Pine Street, West Concord, Mass.

General solutions are obtained of linearized equations for viscous, thermally conducting perfect gases, assuming the velocity, condensation, etc., are proportional to $e^{i\sigma t}$, where σ is a constant.

4323

Kaspar'iants, A. A., "The Problem of Sound Wave Propagation in 'Van Der Waals' Gases and Liquids," Soviet Phys. Acoust., English Transl., 4, 336-343, 1959.

It is assumed that the medium in which sound waves are propagated obeys van der Waals' equation of state. Navier-Stokes' linear equations are applied to such a medium. The velocity of sound and the absorption coefficient are derived in a form convenient for further calculations. The differential equations of acoustic wave propagation may be used to find the spatial distribution of the acoustic field, allowing for the viscosity and thermal conductivity of the medium.

4324

Kleiman, Ia. Z., "Certain Peculiarities in the Motion of Mixtures," Soviet Phys. Acoust., English Transl., 5, 158-166, 1959.

Compression and rarefaction waves in a multicomponent medium are discussed in the acoustic approximation. Separation of components may occur behind the wave front, because of their different velocities. It is shown that, under certain conditions, a group of waves may appear in a mixture, the number of waves being equal to the number of components. The first wave (compression or rarefaction) in such a group is similar to a wave in a single-component medium. The other waves are characteristic of mixtures.

4325

Kozina, O. G., and G. I. Makarov, "Transient Processes in the Acoustic Fields Generated by a Piston Membrane of Arbitrary Shape," Soviet Phys. Acoust., English Transl., 7, 39-43, 1961.

The authors consider transient processes in acoustic fields created by plane piston membranes in a rigid wall with a fairly arbitrary contour. It is assumed that this contour is convex. If, in addition, the membrane has an axis of symmetry in the plane of the wall and its contour is described by an analytic function, the field for all forms of membranes in the vincinity of the wave fronts will be described by certain standard functions.

4326

Marx, H., "On the Theory of the Cylindrical and Spherical Waves in Frictionless Gases and Liquids," Ann. Physik, 41, 61-88, 1942.

An examination of those solutions given by Bechert for the hydrodynamic equations for cylindrical and spherical waves in frictionless gases and liquids in which the density ρ depends solely on the flow velocity and the equation of state $p = p_0 + (a^2 s^n)/n$ holds (p = pressure, p_0, a, and n are constants), together with a determination of their physical utility.

4327

Matschinski, M., "The Propagation of Waves in an Imperfect Elastic Medium" (in French), Compt. Rend., 238, 203-205, 1954.

An approximate method is given for determining the change in waveform and the absorption due to the imperfect elasticity of the medium (plasticity is excluded).

4328

Nyborg, W. L., "Acoustic Streaming Due to Attenuated Plane Waves," J. Acoust. Soc. Am., 25, 68-75, 1953.

Theories for calculating steady-streaming associated with sound fields are reviewed, comparing the methods and approximations of various authors. Two illustrative problems are worked out, both for rectilinear flow due to irrotational sound fields. The first deals with a single attenuated plane wave traveling down a tube, as in Cady's quartz wind experiments. In the second, a pair of crossed plane waves is treated, giving rise to a quite different kind of streaming. In obtaining solutions, attention is given to boundary conditions; here, gradients of the excess static pressure, another second-order quantity, come into consideration. Significantly, streaming speeds depend critically upon α, the attenuation constant, where α may be due to any common cause, such as heat conduction, scattering, thermal relaxation, etc. From these results it appears that streaming measurements cannot be used to distinguish between absorption mechanisms. Numerical values are given for a few cases; high speeds of flow may be expected in a bubbly medium.

4329

Nyborg, W. L., "Acoustic Streaming near a Boundary," J. Acoust. Soc. Am., 30, 329-339, 1958.

An approximate solution is developed for sonically-induced steady flow near a fluid-solid interface. The result is valid, subject to stated conditions, for the flow near any portion of surface in the vicinity of which the irrotational oscillatory velocity distribution U_α is known. The principal condition on the validity is that the acoustic boundary layer parameter $(\nu/\omega)^{1/2}$ (where ω is the angular frequency and ν is the kinematic viscosity coefficient for the fluid) should be small compared to the scale of U_α. Applications of the general result are made to special situations, one case of particular interest being that of a small source near a rigid plane. The conclusion is reached that small compressible bodies, and especially resonant gas bubbles, resting on boundaries are likely sites of pronounced microstreaming in a sound field.

4330

Offerhaus, M. J., "On Sound Propagation in a Monatomic Gas," Univ. of Wisconsin, Madison, 37 pp., 1962.
AD-285 204.

Two methods for a theoretical discussion of sound propagation in a monatomic gas are discussed; they both aim at finding periodic solutions, one of the hydrodynamical equations, the other of the Boltzmann equation; and we refer to them as the hydrodynamical and the kinetic method. Both lead to solutions on successive levels of approximation, the first by gradually including, in the hydrodynamical equations, terms with gradients of higher order; the second by gradually increasing the number of functions from which to build a velocity distribution. The main result reached by either method is a law of attenuation (dispersion and absorption) of the sound; the forms which this law takes, in both treatments, in consecutive approximations are discussed and compared. The treatment holds for a gas with a Maxwellian intermolecular potential, but the results can, in good approximation, be taken over to a real monatomic gas. A comparison is finally made with experiments in monatomic gases done by Greenspan, who has extended his measurements into the region where the sound frequency becomes comparable to the collision frequency by decreasing the latter. It is shown that in this region the available approximation schemes prove necessarily inadequate.

4331

Ott, H., "The Saddle Point Method in the Vicinity of a Pole with Wave Optics and Acoustics Applications" (in German), Ann. Physik, 43, 393-403, 1943.

Generalizes a method by Pauli; the solution leads to a generalized Fresnel integrals. The field of a Hertz dipole in a plane of given conductance is calculated by the method. The occurrence of Zenneck surface waves is investigated. An application to the propagation of sound above water is included.

4332

Pekeris, C. L., "Propagation of Sound in a Rarefied Maxwellian Gas," Inst. of Geophysics, Univ. of Calif., Los Angeles, 7 pp., 1953.
AD-23 611.

A study was made of the dispersion and attenuation of sound in a monoatomic gas with a density for which the mean free path is comparable to or exceeds the wave length of sound. The data on the propagation of sound in He at pressures of 1 mm and less required the solution of Boltzmann's complete transfer equation. Secular determinants of order 5, 8, 12, and 20 were evaluated in an effort to determine the phase velocity and attenuation coefficient. For each determinant order, the propagation constants were solved from the polynomial of the same degree representing the determinant; the polynomial roots were determined numerically. The results appeared to show that with a determinant of order 20, the computed values for the propagation constants is reliable for R greater than about three, where R is proportional to λ/L, the ratio of the wave length of sound to the mean free path. Graphical results are included for the determinant of order eight. Calculations are in progress for the determinant of order 30.

4333

Pekeris, C. L., Z. Alterman, and L. Finkelstein, "Solution of the Boltzmann Hilbert Integral Equation Propagation of Sound in a Rarefied Gas," Tech. Note No. 1, Weizmann Inst. (Isreal), 10 pp., 1961.
AD-268 193.

The Boltzmann-Hilbert integral equation is solved for the problem of propagation of sound in rarefied Maxwell gas, using the eigenfunction method (Uhlenbeck and Wang Chang). Determinants up to order 483 have been solved, and the results converge to wavelengths equal to the mean free path. The results agree with Greenspan's measurements of the propagation of sound in rarefied Helium.

4334

Pinney, E., "A Theorem of Use in Wave Theory," J. Math. Phys., 30, 1-10, 1951.

The theorem relates to the evaluation of a double integral (one being a contour integral). It is of value in numerical calculations in the theory of elastic waves, and is applicable to other problems involving solutions of the wave equation. It can be applied to regions in which one or more wave velocities appear, and it may have applications in the theory of crystal optics.

4335

Rocard, Y., "Propagation of Sound in a Homogeneous Atmosphere," Rev. Sci., 78, 209-211, 1940.

The author deduces an expression for compression in terms of altitude, from which it follows that there is a frequency below which the whole atmosphere vibrates vertically in phase, and that the amplitude varies exponentially with altitude. It appears that with increasing altitude the amplitude of sonic-density variation diminishes absolutely but increases relatively.

4336

Rosemann, J., and V. Agosta, "Propagation of Sound in a Reacting Gas Mixture near Equilibrium," Rept. No. PRL-61-12, Polytech. Inst. of Brooklyn, N. Y., 32 pp., 1961. AD-259 695.

The significant results obtained in research are summarized. A generalized differential equation for the propagation of a pressure pulse is obtained; it is good for all values of the reaction rate. The physical significance of the two sound speed, equilibrium (ae) and frozen (af), is explained on the basis of this equation. For an instantaneous reaction, the state and composition variables are shown to be representable both physically and as solutions of the characteristic differential equations, as step functions; and the reaction rate, as an impulse function. Explicit expressions are obtained for ae and af.

4337

Saxton, H. L., "Propagation of Sound in Gases," J. Chem. Phys., 6, 30-36, 1938.

The propagation of sound and supersonic waves in gases has been attacked by Kneser, Richards and Reid, Rose, and others, without taking viscosity and heat conduction into account. Bourgin neglects viscosity. Herzfeld and Rice have taken heat conduction and viscosity into account along with the effect of internal temperature lag of one state. In the present paper, these effects are considered together with the effect of many internal-energy states. The general equation is derived for wave propagation in a pure gas of any number of energy states. The probability constants involved are functions of temperature and gas composition only. This equation is first solved for the case of a single two-state gas. The solution is then extended to mixtures of gases, including air.

4338

Schoch, A., "Reflection, Refraction and Diffraction of Sound," Trans. by F. J. Berry, Ministry of Supply, Armament Research Establishment, 77 pp., 1953. AD-116 801.

The present state of theory and experiment on the reflection, refraction, and diffraction of sound is very thoroughly presented in this book-length paper. After a brief introduction, the work begins with a comprehensive review of fundamentals including the dynamics of sound waves in homogeneous media, Huygens' Principle, boundary conditions, and uniqueness of solutions. The various situations involving reflection and refraction are then treated, including plane waves at a plane interface, free boundary layer waves along a plane interface, nonplanar waves at a plane interface, plates, and laminated media. Finally, diffraction is treated as phenomena resulting from the presence of curved boundaries. The diffracting properties of cylindrical, spherical, and more complex obstacle shapes are investigated. An extensive bibliography containing 144 references is included.

4339

Siegel, K. M., "Exact Solution for Plane Waves of Sound in Air," Rept. No. EMB-64, Willow Run Labs., Univ. of Mich., 1950. AD-124 747.

The equation describing the motion of sound waves in air ($\gamma = 1.4$) is

$$\frac{\partial^2 \xi}{\partial t^2} = \frac{c^2 \dfrac{\partial^2 \xi}{\partial x^2}}{\left(1 + \dfrac{\partial \xi}{\partial x}\right)^{\gamma + 1}} \tag{1}$$

The substitution

$$\xi = T(t)\, X(x) - x \tag{2}$$

allows us to separate the nonlinear partial-differential equation into two nonlinear ordinary differential equations. Exact solutions to these nonlinear equations are found, and substituting these solutions into (2) yields an exact solution to the nonlinear partial-differential equation (1).

Application of the solution to a certain boundary value problem is discussed.

4340

Sirovich, L., "The Initial Value Problem, Sound Propagation, and Modeling in Kinetic Theory," Rept. No. MF-17, Inst. Math. Sci., Univ. of New York, 91 pp., 1961. AD-264 889.

The one-dimensional initial-value problem of a monatomic, single-component gas is considered. Using the linearized Boltzmann equation, the dispersion relation is studied. In addition to the usual dynamic sound waves one finds an infinity of decaying propagating waves. The phenomenon naturally exhibits itself as a sequence of epochs, the last stage of which is hydrodynamic. With reference to the same problem, macroscopic equations such as Euler, Navier-Stokes, Burnett, Grad's moments equations, etc., are considered. In addition, the recently considered kinetic models of Gross (Phys. Fluids 2, 432, 1959) are applied to the problem. These various formulations are critically analyzed and compared with each other and with the Boltzmann analysis. Lastly, several alternate molecular and macroscopic equations are offered that remedy some of the shortcomings that appear in the above-mentioned approximate theories.

4341

Sretenskii, L. N., "Propagation of Sound in an Isothermal Atmosphere" (in Russian), Izvest. Akad. Nauk SSSR, Ser. Geofiz., 134-142, 1954.

A theoretical analysis of the acoustic field of a point source of sound-propagating waves of constant frequency in an isothermal atmosphere. The potential of the acoustic field is obtained with the aid of the Fourier-Bessel Integral. Asymptotic expressions suitable for large distance from the source are derived for this potential field. These formulae are:

$$\phi \; \frac{-Q}{\pi} \, \frac{\alpha \cos\theta}{1 - \alpha\cos\theta} \, \frac{\exp\left[-\dfrac{\xi}{2c^2}(\alpha - \cos\theta)\sqrt{r^2 + z^2}\right]}{\sqrt{r^2 + z^2}}$$

and

$$\phi = \frac{Q}{4\pi} \, \frac{\beta\cos\theta}{1 + \beta^2\cos^2\theta} \, \frac{\exp\left(\dfrac{\xi}{2c^2}\sqrt{r^2 + z^2}\cos\theta\right)}{\sqrt{r^2 + z^2}} \exp\left[i\left(\sigma t - \frac{\xi B}{2c^2}\sqrt{r^2 + z^2} - \delta\right)\right].$$

4342

Tahsin, S. I., "Propagation of a Sound Pulse in a Medium with a Complex Elastic Modulus," Proc. Iraqi Sci. Soc., 1, 1-9, 1957.

A complex propagation constant is assumed with properties leading to relaxation phenomena. Two approximate methods are used to evaluate the integrals in the regions of no anomaly. The manner of the pulse buildup is established. It is found that a sonic pulse in a relaxing medium builds up exponentially at first and later assumes its oscillatory property.

4343

Trendelenburg, F., "Introduction to Acoustics" (in German), 2nd ed., Springer-Verlag, Berlin, 378 pp., 1950.

A modern and highly technical text on acoustics, with great emphasis on the theory of wave propagation in various media. Chapter II discusses variations of wave form and speed with changes in temperature and pressure. Chapter IV, Par. 22, deals with the influence of atmospheric temperature and wind lapse rate or discontinuities on propagation and refraction of sound waves, anomalous zones of audibility, and stratospheric reflection. The text is amply illustrated with schematic diagrams, graphs, and photographs.

4344

Trott, J. W., "Reciprocity Parameters Derived from Radiated Power," J. Acoust., Soc. Am., 34, 989, 1962.

The radiated sound power in the near and far fields of transducers are equated to obtain the plane-wave and cylindrical-wave reciprocity parameters from the spherical-wave reciprocity parameter.

4345

Tsien, H., and R. Schamberg, "Propagation of Plane Sound Waves in Rarefied Gases," J. Acoust., Soc. Am., 18, 334-341, 1946.

If the density of gas is very small, the conventional Navier-Stokes equations are not sufficiently accurate. The present investigation includes the effect of the so-called third approximations to the solution of the Boltzmann-Maxwell equation, and the results show that, even under extreme conditions, the velocity of propagation deviates from its usual value by only 2%.

4346

Wang Chang, C. S., and G. E. Uhlenbeck, "On the Propagation of Sound in Monatomic Gases," Eng. Res. Inst., Univ. of Mich., Ann Arbor, 52 pp., 1952.
AD-9294.

The Boltzmann equation for a monatomic gas with no external force is stated for a small disturbance h from equilibrium in terms of a collision operator J. From this equation an exact dispersion law is derived for gases. Partial lists of eigenfunctions and eigenvalues are obtained for the collision operator for Maxwell molecules (molecules repelling with a Kr^{-5} force law). A successive approximation method gives the dispersion law as a series in λ/λ, the ratio of mean free path to the wavelength of sound. The extension to molecular models other than Maxwell's is discussed.

4347

Zanotelli, G., "Behavior of a Sound Wave When Passing Through a Cloud Layer" (in Italian), Ann. Geofis. 3, 289-301, 1950.

Discusses sound propagation through air that contains uniformly distributed droplets of equal radius, taking into account the viscosity of the air and the motion of the droplets. Small droplets vibrate with low frequencies, but the larger droplets remain stationary with high frequencies. In the first case the greatest values of the extinction coefficient are obtained; in the second, the refraction index is the greater.

Wave Propagation, Sound, Theory
See Also—53, 69, 95, 245, 441, 550, 553, 554, 574, 575, 586, 591, 879, 904, 922, 1007, 1027, 1151, 1530, 1552, 1557, 1809, 2061, 2570, 2592, 2593, 2709, 2861, 3073, 3212, 3340, 3342, 3547, 3570, 3619, 3622, 3638, 3671, 3674, 3974, 3999, 4000, 4209, 4381

WAVE PROPAGATION, STANDING

4348

Bies, D. A., and O. B. Wilson, Jr., "Acoustic Impedance of a Helmholtz Resonator at Very High Amplitude," J. Acoust. Soc. Am., 29, 711-714, 1957.

The acoustic impedance of a Helmholtz resonator terminating a 10-inch-diameter tube has been investigated for sound pressure levels in the resonator of from 100 db to 170 db and for a range of particle velocities in the neck of from 1.3 cm/sec to 1.2×10^4 cm/sec (rms). Two different mounting orientations showed the same general rise in acoustic resistance and rise in resonant frequency with increasing sound pressure level but gave quite different results in detail.

4349

Borisov, Yu. Ya., and N. M. Gynkina, "On Acoustic Drying in a Standing Sound Wave," Soviet Phys. Acoust., English transl., 8, 95-96, 1962.

An investigation is carried out to determine the effect of sound intensity on the drying rate of porous capillary material.

4350

Bourgin, D. G., "Quasi-Standing Waves in a Dispersive Gas," J. Acoust. Soc. Am., 4, 108-111, 1932.

A theoretical investigation into the positions of the nodes in a semistationary wave formed in an absorbing gas by a high-frequency source.

4351

Boyarsky, L. L., "The Calculation of the Thermal Noise in Air," J. Acoust. Soc. Am., 23, 716, 1951.

The basis for the calculation is to consider a cavity containing gas molecules as an acoustic blackbody in which standing waves of sound are set up because of the Brownian movement of the molecules of air.

4352

Buchholz, H., "Integral and Series Representations for the Different Types of Waves of Mathematical Physics in Axial-Parabolic Coordinates" (in German), Z. Physik, 124, 196-218, 1948.

Representations of the required form are found for standing waves and for outgoing waves of any harmonic type when the source is at the focus of the parabola. Plane waves and cylindrical waves are included as special cases. Representations are also obtained for an arbitrary position of the source.

4353

Carman, R. A., "Kundt Tube Dust Striations," Am. J. Phys., 23, 505-507, 1955.

An interesting anomaly in the familiar Kundt tube experiment and the eighty-year search for an interpretation are reviewed for teachers of physics. Unfortunately the correct explanation of this phenomenon, although available, is rarely cited and known to very few. The work and explanation of Andrade are presented and expanded in hopes of remedying this situation.

4354

Fand, R. M., and J. Kaye, "A Hot-Wire Method for Visualizing Intense Stationary Sound Waves," WADC Tech. Note No. 59-74, Heat Transfer Lab., Mass. Inst. of Tech., Cambridge, 6 pp., 1959.
AD-214 148.
See Also: J. Acoust. Soc. Am., 31, 810-811.

A simple method was developed for visualizing intense stationary sound waves, using a thin, electrically heated wire stretched in the direction of sound propagation. The nodes and antinodes of the sound waves appear as a series of alternate incandescent and dark areas on the wire. Photographs of the hot wire indicate the presence of hitherto unreported thermo-acoustic phenomena.

4355

Hayashi, T., "Periodic Variation of Temperature Caused by Sound Waves," Electrotech. J., 3, 103-106, 1939.

Two experimental arrangements are described, one for the purpose of indicating the temperature variations due to the adiabatic changes in sound waves sent along a tube by a loudspeaker. The equipment contains a twelve-couple thermopile, the output of which is passed through amplifiers, attenuator and band-pass filter to a valve voltmeter. In the second set a hot wire is in contact with the sound. The hot wire registers the temperature changes which occur at the antinode of the stationary wave. The amplifying and other equipment is similar to that used in the first experiment.

4356

Ishii, C., "Supersonic Velocity in Dry and Humid Air," Sci. Papers, Inst. Phys. Chem. Research (Tokyo), 201-208, 1935.

The theoretical and experimental formulae for the supersonic velocity in humid air, as found previously, were further tested by measurements of nodal strata formed by stationary waves in dry air and in air with definite humidity. Known values of humidity were obtained by using saturated aqueous solutions of Na and K salts. For frequencies from 288 kcs to 2892 kcs, the wavelength increases with the vapor pressure, e. The velocity V_h in humid air is, in terms of the velocity V_1 in dry air, $V_h = V_1(1 + Ae)$. The coefficient A decreases as the frequency increases, and since the velocity in dry air increases with the frequency, it is concluded that the effect of humidity diminishes with increase of frequency. It is thought that dispersion of velocity occurs with frequencies below 1000 kcs.

4357

Kastner, L. J., "Propagation of Pressure Fluctuations of Large Amplitude in Air Columns," Phil. Mag., 32, 206-224, 1941.

A test of the accuracy of the Helmholtz-Kirchhoff equation for waves in which the average peak amplitude was about 5 in. of Hg above the mean pressure in the pipe. An oscillating piston in a cylinder supplied the pressure pulse to a tube in which the vibrations were built up. The results, using tubes of different diameter and length and different piston speeds, are discussed. The velocity of propagation of pressure waves in air produced in a pipe excited by a piston is independent of frequencies between 20 and 150 cps and appears to diminish at a greater rate with decrease of pipe diameter than for cases when the amplitude is very small. The waves are attenuated as they travel along the pipe and when they are reflected at the ends. The open-end and closed-end reflection coefficients are the more important of these, and their product does not vary greatly with changes of pipe diameter.

4358

Keller, J. B., "Finite Amplitude Sound Waves," J. Acoust. Soc. Am., 25, 212-216, 1953.

Exact solutions of the one-dimensional gas dynamic equations, representing periodic sound waves of finite amplitude, are obtained for a particular medium. The progressive wave from a vibrating piston and the standing wave in a closed tube are examined in detail. Limits on tne amplitude of the sound wave are found in order to avoid shocks or cavitation.

4359

Klein, S., "Strong Demodulation in Air of Two Ultrasounds of Different Frequencies" (in French), Ann. Telecommun., 9, 21-23, 1954.

Two ultrasonic sound sources are situated 10 cm apart and facing each other. The frequency of audible sound is exactly the difference betwen the two ultrasonic frequencies. The intervening space is analyzed and it is shown that the audible sound arises at the nodes and antinodes of pressure of the ultrasonic stationary wave system. To obtain reproduction of music and speech two systems are indicated, one utilizing frequency and amplitude modulation, and the other, only frequency modulation. Circuit diagrams are given.

4360

Lehmann, K. O., "Damping of Large Amplitude Sound Waves," Ann. Physik, 20, 533-552, 1934.

Stationary waves of large amplitude are excited in air of normal density in a tube of 6.7-cm diameter, pressures of 75,000 μbars being obtained at the pressure antinodes. The damping of the vibrations is investigated. The damping constant shows scarcely any change up to pressure amplitudes of 30,000 μbars, but shows increases at greater amplitudes caused by the onset of turbulence. Measurements carried out at pressures up to two atm. show that the damping varies inversely as the square root of the gas pressure for small amplitudes, in agreement with the theory of Helmholtz and Kirchhoff, although the absolute magnitude of the damping constant differs considerably from the theoretical value.

4361

Lippert, W. K. R., "Method of Measuring and Analyzing Wave Motion," Acustica, 12, 125-139, 1962.

The method of determining the propagation parameters of wave motion in an acoustical medium was tested by taking as a model a sample consisting of numerous cylindrical tubes in parallel. Standing and progressive waves before and behind the sample in a duct system with a nonreflecting terminal were measured at many frequencies, whence a complete set of propagation parameters was derived. A refinement of the method was suggested, which serves to eliminate unwanted losses outside the sample, and the achievable improvement in determining the attenuation constant of wave motion in the tube sample is demonstrated and discussed in detail.

The theory of a variant form of the general method is derived, which permits a complete set of propagation parameters to be found from resonance curves of the magnitudes of the characteristic factors only. Experimental results of this novel resonance method and of the extended general method agree well with the corresponding propagation parameters computed by the classical theory.

4362

Matta, K., and M. Mokhtar, "The Velocity of Sound in Vapors," J. Acoust. Soc. Am., 16, 120-122, 1944.

A form of Kundt's tube is employed in which a hot wire records the amplitude in the stationary-wave system. It is calibrated by the use of dry air and of oxygen. The results agree with those determined by other methods.

4363

McCrea, W. H., "Shock Waves in Steady Radial Motion Under Gravity," Astrophys. J., 124, 461-468, 1956.

In the steady radial flow of a polytropic gas toward a center of gravitational attraction, it is shown that a standing shock wave can, in general, exist within a certain distance of the center. This possibility elucidates certain features of Bondi's investigation of such radial motion and, in particular, helps to resolve an indeterminacy he had noted. Reasons are given for concluding that the phenomenon may have application to accretion by a binary star.

4364

Morse, P. M., and R. H. Bolt, "Sound Waves in Rooms," Revs. Mod. Phys., 16, 69-150, 1944.

This is a critical discourse and survey on the present position of room acoustics. It begins with Sabine's pioneer work, gives an account of progress, and points out where further research is required. It discusses the general principles of wave acoustics and shows how they clarify and supplement the geometrical results of earlier workers. It examines the importance of the reverberation time T, background noise, loudness of source, and shape of room, as they affect the recognizability of speech. The value of T given by Knudsen includes the absorptive effect of the air, for above 4000 cps this absorption may be several times the total absorption at the boundaries of the room. Methods of measuring room acoustics reveal the inadequacies of the geometrical theory. The general aspects of wave acoustics studied are the nature of the reaction between the sound wave and the walls of the room and the natures of the steady-state and transient response to a source of sound. The first of these involves a knowledge of the acoustic impedance of the surface; in the second and third the reverberant sound has the characteristic frequencies of the normal modes of vibration of the room and not necessarily the frequency of the source. In a simple rectangular room, a number of different decay rates exist; thus the decay curve cannot be a straight line, and rooms having smooth, regularly-shaped walls show the greatest divergence of decay rates for different standing waves. In general, wave acoustics will have to be used for small regularly shaped rooms, and geometrical acoustics will be sufficient for the analysis of most large auditoriums. The report ends with a very full bibliography.

4365

Muller, H., and E. Waetzmann, "Absolute Velocity Measurements with Hot Wires in Stationary Sound Waves," Z. Physik, 62, 167-179, 1930.

The constant cooling effect that a hot wire experiences through the air vibrations in a sound wave were again investigated according to the method of Goldbaum and Waetzmann. The discrepancy between the results obtained by the above-named workers and other observers was stated and discussed. Absolute measurements were made of the periodic cooling effect, and it was established that for the absolute measurement in sound waves of both the constant and periodic cooling effects on a heated wire, this can only be done successfully by taking special precautionary measures and for certain thicknesses of the wire. Full experimental and theoretical details are given.

4366

Oberst, H., "Method for Generating Extremely Strong Stationary Sound Waves in Air" (in German), Akust. Zh., 5, 27-38, 1940.

A method is described for producing by resonance an acoustic pressure of about 0.1 atm. with purely sinusoidal shape of the pressure/time curve at the antinode formed at the closed end of a thin pipe connected to a pipe of larger diameter. The theory of the system and its experimental examination are discussed, and some hints for its application are given.

4367

Pachner, J., "Investigation of Scalar Wave Fields by Means of Instantaneous Directivity Patterns," J. Acoust. Soc. Am., 28, 90-92, 1956.

A method is presented for determining the traveling and standing components of an arbitrary scalar wave field from the measured instantaneous values of the field on the surface of two spheres surrounding the emitter.

4368

Pimonow, L., "Modulation of Stationary Ultrasonic Waves in Air" (in French), Ann. Telecommun., 9, 24-28, 1954.

Deals first with the general question of modulation. It points out that superposition of vibrations (electrical or mechanical) signifies an addition of amplitudes, whereas modulation corresponds to a multiplication of amplitudes. Part two deals with the modulation of stationary waves of ultrasound, and in part three an outline is given of a so-called "gaseous microphone." This consists of a 30-kc quartz source which sets up a system of stationary waves between its emitting surface and a rigid reflector a short distance away. The progressive waves from a source of audio-frequency sound cross the track of these stationary waves and produce a modulation which is received by a small Rochelle-salt microphone suitably placed near the stationary wave system. In a particular case mentioned in the paper, the depth of modulation is about 3%. Part four discusses the theory of modulation of stationary waves.

4369

Schilling, H. K., and W. Whitson, "Study of Interference Through Acoustics," Am. Phys. Teacher, 4, 27-31, 1936.

The usual approach to the study of interference, in elementary courses, is mainly by way of optics, a procedure that has certain serious drawbacks; to the beginner, it might seem less natural and interesting than the approach through acoustics. This paper describes simple acoustical apparatus for laboratory and demonstration, and the following fundamental experiments on interference of sound waves: double slit; thin films; standing waves; Lloyd's mirror; Fresnel's mirror; effect of plane reflector near point source.

4370

Shaw, E. A. G., "The Acoustic Wave Guide, I., An Apparatus for the Measurement of Acoustic Impedance Using Plane Waves and Higher Order Mode Waves in Tubes," J. Acoust. Soc. Am., 25, 224-230, 1953.

The (1 0) and (2 0) modes of acoustic waves in rectangular wave guides have been excited to the virtual exclusion of plane waves. The experimental techniques depend on the use of acoustic sources equivalent to two or more pistons with appropriate relative phases and amplitudes, precise adjustment of which is accomplished with the aid of an accurately located probe microphone. The standing wave pattern which arises when the wave guide is terminated by a partially absorbing surface may be used to determine the specific normal impedance of the surface, the value of which is characteristic of waves having a particular oblique angle of incidence and may be compared with normal incidence values obtained from plane-wave measurements in the same wave guide and at the same frequency; the angle of oblique incidence may be varied by changing the frequency. The apparatus operates in the 1- 3-kc/sec frequency region, and the accuracy of impedance measurement with (1 0) and (2 0) waves is comparable to that attainable with the usual plane-wave tube techniques. Equivalent angles of incidence at the absorbing surface of up to 84° have been used. The principles underlying the design of the apparatus and some of the distinctive problems which arise with higher order mode waves are discussed.

4371

Slavik, J. B., and J. Tichy, "An Evluation of the Sound Absorption Coefficients Measured by the Standing-Wave Method and by the Reverberation Method" (in Czech), Slaboproudy Obzor, 18, 545-548, 1957.

Previously reported experimental results (Tichy, Slaboproudy Obzor, 17, 197-202, 1956; Faiman, 322-324; and Kolmer, ibid., 500-507) are quoted and compared, together with some supplementary data. Great discrepancies are found between the values obtained by the two methods. It is therefore thought necessary to employ both types of measurement until the value of the reverberation method is definitely established.

4372

Trimmer, J. D., "Sound Waves in a Moving Medium," J. Acoust. Soc. Am., 9, 162-164, 1936-1937.

A theoretical approach is made to the problem of the behavior of sound waves in a pipe through which the medium is moving in a unidirectional flow with uniform velocity V. Calculation indicates the resonances of pipes to be affected by the steady flow, so that the resonance peaks are flattened, while the separation between nodal points is reduced by the factor $1 - (C/c)^2$.

4373

Vajnshtejn, L. A., "The Theory of Sound Waves in Open Tubes," in Translations by J. Shmoys, "Propagation in Semi-Infinite Waveguides," Rept. EM-63, Inst. of Math. Sci., New York Univ., Chap. IV, 29 pp., 1954.
AD-36 349(d).

A rigorous solution is given for the problem of radiation, from the open end of a pipe, of a symmetric sound wave propagated in the tube, toward the end. The reflection coefficients of various modes from the open end are calculated as well as the conversion coefficients from one mode to another. Graphs of absolute values, and phases of these coefficients, and also of the end correction for the dominant piston-like mode, are presented. The radiation characteristics of the open-ended tube are investigated. The theory is generalized to asymmetric modes. Excitation of waves in open tubes is considered. The resonance curve of a cylindrical resonator of finite length, open at one end, is calculated, and the theoretical results are compared with experimental data.

4374

Warner, G. W., "Frequency and Temperature Effect on the Velocity of Supersonic Waves in Gases," J. Acoust. Soc. Am., 9, 30-36, 1937.

An experimental study in which a modified Kundt's tube with movable reflector is used for producing standing waves. As the reflector is moved it passes through nodes and loops and the varying amount of energy reabsorbed by the electrical circuit is used to determine the wavelength by the reaction of a rf milliammeter in the energising circuit. In CO_2, N_2O, and SO_2, the velocity increases with increasing frequency but the increase is greater in CO_2 than in the other two gases. The velocity at any frequency is practically constant at all temperatures in N_2O and SO_2, but in CO_2 the curve is flat for the lower temperatures, rapidly decreases from 6-10 meters per second in the temperature range between 50° and 130°C, and again becomes constant at the higher temperatures.

4375

Wilson, O. B., Jr., and D. A. Bies, "Studies of High Amplitude Sound. A. Measurements of the Acoustic Impedance of a Resonator at Large Amplitudes. B. Measurements of the Attenuation of Repeated Shock Waves. C. A. Logarithmic Amplifiers," Tech. Rept. No. 79, Soundrive Engine Co., Los Angeles, Calif., 21 pp., 1954.
AD-52 274.

The experimental investigation of the acoustic impedance of a Helmholtz-type resonator at very high amplitudes of excitation is presented. Sound levels up to 180 db and particle velocity amplitudes in the neck of the resonator up to 1.5×10^4 cm/sec were used. The results at lower levels are compared with those of previous investigators whose work has been confined to levels below 140 db and particle velocity amplitudes in the resonator neck below 4×10^3 cm/sec. Experimental work on the rate of attenuation of repeated shock waves in a five-inch tube is reported. Qualitative agreement with theory is found but there is at present no adequate explanation of quantitative discrepancies. The design and construction of a logarithmic amplifier is discussed.

4376

Wilson, O. B., Jr., and D. A. Bies, "Studies of Very High Amplitude Sound," Tech. Rept. No. 82, Soundrive Engine Co., Los Angeles, Calif., 22 pp., 1955.
AD-72 433.

A standing wave technique was used to investigate the acoustic impedance of a resonator over a wide range of sound levels. At large sound pressure levels, above 150 db, the sound waves propagating down the impedance tube became essentially repeated shock waves, so that it was necessary to use a filter in the monitoring system and to consider only the behavior of the fundamental component in the repeated shock wave. In this way a range of sound pressure levels in the resonator from 100 to 170 db was investigated. Two different methods of mounting the resonator were considered. In one case the resonator was mounted on the side of the impedance tube next to a solid end plate terminating the tube; in the other case, the resonator was mounted on the solid end plate coaxially with the impedance tube. At the higher levels of excitation a rise in resonant frequency and in accoustic resistance was noted in both cases, but the details of the effects in the cases were quite different. With the resonator mounted on the side, the rise in the acoustic resistance followed Sivian's formula (J. Acoust. Soc. Am., 7, 94, 1935) while the mass end correction decreased only at very high sound pressure levels. With the resonator mounted on the end, the rise in acoustic resistance was at first more rapid, then less rapid than Sivian's formula would predict. The decrease in mass end correction with increasing sound pressure level began at a lower level and was more pronounced than in the former case.

Wave Propagation, Standing
See Also—38, 61, 105, 123, 372, 766, 908, 934, 982, 992, 1387, 1879, 1894, 1991, 2004, 2269, 2782, 2929, 3584, 3631, 3773, 3792, 3903, 3974, 4312

WAVE PROPAGATION, ULTRASONIC

4377

Biquard, P., "Ultrasonic Waves," Rev. Acoust. 1, 93-109, 1932.

A mathematical account of plane wave motion deriving from first principles expressions for the energy transmission associated with a sound wave and the decay of amplitude with distance due to viscosity and heat conduction. At 10°C and at a frequency of 160,000 cps, the effect of conduction on damping is, for water, 7000 times less than the effect of viscosity; whereas for air it is only three times less. The paper concludes with Langevin's deduction of the fact that the pressure exerted by sound radiation is equal to the energy density of that radiation.

4378

Bocker, P., "Measurements on High Intensity Ultrasonic Fields in Air," Acustica, 11, 31-38, 1961.

By means of a resonance oscillator, a sinusoidal ultrasonic field was produced in air at a frequency of 30 kcs and having an intensity up to 0.25 w/cm^2. At this intensity and frequency the equation of state is no longer linear, and the wave front within a propagation distance of 30 cm becomes completely steepened. This steepness was analyzed, and the radiation pressure in the steep-fronted wave was compared with that of a harmonic wave.

4379

Bourgin, D. G., "Quasi-Standing Waves in a Dispersive Gas," J. Acoust. Soc. Am., 4, 108-111, 1932.

A theoretical investigation into the positions of the nodes in a semistationary wave formed in an absorbing gas by a high-frequency source.

4380

Dubois, M., "The Absorption of Sound and Ultrasonics in Gases" (in French), J. Phys. Radium, 12, 876-884, 1951.

This article reviews the general problem of the attenuation, of a plane wave during propagation, due to the properties of the medium and the local modifications produced by the passage of the wave. Viscosity, conductivity rise and fall of temperature, and the variations in the translational and vibrational energy of the molecules are considered. Theoretical and experimental results are compared, and an extensive bibliography is given.

4381

Green, H. S., "Propagation of Disturbance at High Frequencies in Gases, Liquids, and Plasmas," Phys. Fluids, 2, 31-39, 1959.

A method is developed for investigating the propagation of disturbances at small amplitude in fluids from the molecular or ionic standpoint. Adopting as variables the displacements of the particles from a configuration of thermal equilibrium, the equations of motion are derived, in statistical form, for both classical and quantum mechanics. It is shown how to apply this theory in the high-frequency region by neglecting the correlation between the displacements of neighboring particles. Relaxation frequencies are defined, and it is shown that anomalous absorption and dispersion will be found in their neighborhood. Beyond the relaxation frequency, the medium will show elastic or dispersive properties, according to whether the thermal velocities are below or exceed the velocity of propagation. A completely ionized system will have no relaxation frequencies.

4382

Hopwood, F. L., "High-Frequency Sound Waves," J. Sci. Instr., 6, 34-40, 1929.

High-frequency air waves are produced by Langevin's method, putting a massive electrode of lead and a light electrode of copper foil in contact with the two faces of a quartz disc and applying an alternating potential difference of 20,000 volts. The quartz disc dilates and contracts. A beam of air waves is formed at right angles to the disc. If this is horizontal, the formation of stationary wave-striae can be observed in coke-dust laid on glass in the path of the beam. Interference patterns, diffraction effects, attenuation, and the pressure of sound radiation are also demonstrated. These waves kill fish, as Langevin showed. They also break up red blood corpuscles, inhibit the electrical stimulation of a muscle-nerve preparation, and destroy the structure of fresh-water vegetation. If the beam is directed upwards in oil, a mound of oil is raised on the surface; this is in strong vibration, and this vibration can be communicated to liquids in test-tubes. The air dissolved in these liquids is liberated in bubbles. Calorific effects are easy to obtain.

4383

Hubbard, J. C., J. A. Fitzpatrick, B. T. Kankovsky, and W. J. Thaler, "Distortion of Progressive Ultrasonic Waves," Rev., 74, 107-108, 1948.

Spark shadow photographs have been taken of one-millimeter sound waves in air, and a microphotometer trace is used to show the change in waveform. Preliminary results obtained with waves in water, glycerine, and CCl_4 may account for the discrepancy in measured values of ultrasonic absorption.

4384

Kittel, C., "Ultrasonic Research and the Properties of Matter," Repts. Progr. Phys., 11, 205-247, 1946-1947.

The theoretical treatment of the propagation of sound waves in gases, liquids, and solids is given and the expressions for the velocity of sound are derived. The theory of absorption in gases and liquids due to heat conduction, viscosity, and thermal relaxation is given. Reference is also made to absorption in solids caused by thermoelastic relaxation, scattering, plastic flow, thermal conductivity, structural relaxation, anharmonic coupling, and magnetic effects. A comprehensive review of the present status of measurements made on gases, liquids, and solids is given. The development of electronic pulsed-circuit techniques in the 1-30 mcs range is described, and the possibilities of extending the upper frequency limit are discussed. The use of ultrasonics in conjunction with radar is mentioned, together with recent industrial applications. A section on propagation in liquid He is included. Over 200 references are quoted.

4385

Kuntze, A., "Modulated Supersonic Waves," Ann. Physik, 26, 349-371, 1936.

The propagation of unmodulated and modulated supersonic waves in air and in metallic conductors is studied by means of a piezoelectric emitter and detector, modulated being applied to the electrodes of the emitting quartz. The absorption in air of unmodulated waves is independent of pressure in the range 380-1520 mm, and an absorption coefficient 9.4×10^{-4} cm^{-1} is obtained. The modulation coefficient of the 33 kc carrier wave, which is modulated by frequencies of 50-3300 ~, is determined, and some discrepancy between the theoretical and calculated values is attributed to anharmonic vibrations of the quartz. In the case of transmission through metallic conductors, the agreement between the theoretical and calculated values of the modulation coefficient is more satisfactory, owing to the damping of the quartz by contact with the conductor.

4386

Metz, A., "The Total Reflection of Waves in Moving Media," Compt. Rend. Acad. Sci. (Paris), 250, 3796-3804, 1960.

Previous papers have shown that sound waves or ultrasonic waves propagated in media undergo refraction and total reflection not only when they pass from one medium to another where the speed of propagation is different, but also when the media are moving relative to one another. General formulae relating to these phenomena were given previously and the present paper derives a more exact formula relating to the propagation of waves under such conditions. Formulae derived in previous papers are used without detailed explanation.

4387

Mokhtar, M., and M. Shehata, "Scattering of Ultrasonic Waves in Gases," J. Acoust. Soc. Am., 22, 16-19, 1950.

Ultrasonic beams of frequencies in the range of 80 to 1000 kcs emerge from a rectangular slit of known adjustable width into air, O, or CO_2. The disposition of the field in front of the slit is studied with the aid of a hot-wire anemometer, which gives the angle of divergence of the beam and the intensity distribution across the main and the diffracted beams. The results obtained indicate that the laws of diffraction are valid so long as the gas is far removed from its anomalous dispersion region. CO_2 in the range between 100 and 200 kcs shows a high degree of scattering, with the result that the emergent beam loses its definition completely and becomes very diffused.

4388

Pennsylvania State University, "Atmospheric Physics and Sound," Final Rept., Dept. of Physics, Acoustics Lab., University Park, 288 pp., 1950.

This voluminous report contains a detailed account of the instrumentation developed, methods used, and results achieved at Pennsylvania State University in a five-year study aimed at investigating the production and propagation of sound, both sonic and ultrasonic, in the lower atmosphere, through the ground, and in other media. Chapter 7 "Micrometeorology and Atmospheric Acoustics," is a summary of results of temperature and wind velocity measurements (mostly with hot wire thermometers and aneomometers) made up to 50 feet from the ground in conjunction with sound intensity measurements. A definite correlation is found between sound signal fluctuations and inhomogeneities of temperature, but not of wind. Likewise no effect of snow cover on sound propagation was noted.

4389

Pierce, G. W., and A. Noyes, Jr., "Transmission of Sound over Reflecting Surfaces," J. Acoust. Soc. Am., 9, 193-204, 1937.

The paper presents an experimental and theoretical discussion of acoustic signalling between a sending station and a receiving station near a plane reflecting surface, and is applicable to foghorn and submarine signalling. The experiments were made with a small-scale apparatus employing supersonic waves of a frequency of 67.5 kcs. It is shown that at grazing incidence the direct and reflected waves cancel, or partially cancel, as predicted by theory. The cancellation for propagation in air near a water surface, or near another surface of high sound velocity and high density, is found to be restricted to angles very near to grazing incidence.

On the other hand, theory predicts cancellation for much larger departures from grazing incidence if the reflecting surface has high density but low velocity; experimental curves for transmission over beach sand and certain other substances resemble such theoretical results very closely. Acoustic mirages caused by temperature gradients were studied experimentally, and their effects are shown to be of striking importance in modifying the above results.

4390

Pimonow, L., "Modulation of Stationary Ultrasonic Waves in Air" (in French), Ann. Telecommun., 9, 24-28, 1954.

Deals first with the general question of modulation. It points out that superposition of vibrations (electrical or mechanical) signifies an addition of amplitudes, whereas modulation corresponds to a multiplication of amplitudes. Part two deals with the modulation of stationary waves of ultrasound, and in part three an outline is given of a so-called "gaseous microphone." This consists of a 30-kc quartz source which sets up a system of stationary waves between its emitting surface and a rigid reflector a short distance away. The progressive waves from a source of audio-frequency sound cross the track of these stationary waves and produce a modulation which is received by a small Rochelle-salt microphone suitably placed near the stationary wave system. In a particular case mentioned in the paper, the depth of modulation is about 3%. Part four discusses the theory of modulation of stationary waves.

4391

Powell, A., "The Noise of Choked Jets," J. Acoust. Soc. Am., 25, 385-389, 1953.

The noise of a jet changes character after the pressure ratio exceeds the critical value appropriate to sonic exit velocity, the general roar being dominated by a loud "whistling" or "screeching." Schlieren photographs show that sound waves of ultrasonic frequency are caused by the transition of the initially laminary boundary layer to turbulence and also be interaction of this turbulence and the shock waves of the flow. Larger disturbances have also been noted, involving both the jet stream and some of the air external to the jet, and these also give rise to sound waves that have been photographed: it is these that are held responsible for the audible effects. A two-dimensional study has shown the latter phenomenon to be enhanced, and it is shown how the system of disturbances is self-maintained by virtue of sound waves creating initially small disturbances at the jet exit. The directionality of the soundfield has been predicted and found to agree with experiment, and the dimensions of the motion are compatible with the suggested mechanism. The relation to edgetones is pointed out, and the mechanism indicated; a photograph of this phenomenon is shown. Finally, mention is made of how the characteristic noise of jets working above the critical pressure might be reduced, the suggested methods having been found successful in practice.

4392

Riabouchinsky, D., "Supersonic Waves in Gases," Compt. Rend., 205, 1115-1117, 1937.

It is shown that the results previously obtained for the motion of supersonic waves can be derived without the introduction of a complex variable.

4393

Richardson, E. G., "Supersonic Dispersion in Gases," Proc. Roy. Soc. (London) A, 146, 56-71, 1934.

The propagation through various gases of supersonic radiation emitted by piezoelectrically maintained quartz crystals is examined experimentally. New methods involving the change of resistance of an electrically heated wire exposed to the radiation are developed, enabling the wavelength and amplitude of the gaseous vibration to be measured. The method of calibrating the apparatus is also described, and the results are compared with those obtained by older methods. The anomalous dispersion and absorption shown by certain gases is critically examined, and suggestions put forward to account for it. Evidence is adduced to show that some of the radiation "absorbed" is scattered by the gas.

4394

Saby, J. S., and W. L. Nyborg, "Ray Computation for Non-Uniform Fields," J. Acoust. Soc. Am., 18, 316-322, 1946.

A formula is derived which simplifies computation. A field is first assumed to be equivalent to an array of horizontally homogeneous strata, each with a uniform gradient of the speed of sound, and the range of the ray through the whole array can be computed in one step, to an adequate degree of approximation. Special problems encountered in applying the formula under certain types of conditions are discussed. The method is particularly useful in the study of the propagation of ultrasonic waves through the atmosphere near the ground, where micrometeorological conditions often produce rather complicated gradient conditions.

4395

Saxton, H. L., "Propagation of Sound in Gases," J. Chem. Phys., 6, 30-36, 1938.

The propagation of sound and supersonic waves in gases has been attacked by Kneser, Richards and Reid, Rose, and others, without taking viscosity and heat conduction into account. Bourgin neglects viscosity. Herzfeld and Rice have taken heat conduction and viscosity into account along with the effect of internal temperature lag of one state. In the present paper, these effects are considered together with the effect of many internal-energy states. The general equation is derived for wave propagation in a pure gas of any number of energy states. The probability constants involved are functions of temperature and gas composition only. This equation is first solved for the case of a single two-state gas. The solution is then extended to mixtures of gases, including air.

4396

Schilling, H. K., M. P. Givens, W. L. Nyborg, W. A. Pielemeier, and H. A. Thorpe, "Ultrasonic Propagation in Open Air," J. Acoust. Soc. Am., 19, 222-234, 1947.

Data and conclusions of practical interest in regard to ultrasonic signalling are presented. Fundamental ultrasonic phenomena of propagation are investigated, and their causes isolated through correlations with simultaneously observed micrometeorological phenomena. Results are presented with two viewpoints: propagation in a nonscattering atmosphere, and propagation in a scattering medium; it was found that sometimes the open air is a scattering, as well as an absorbing, medium. Values of absorption coefficients are presented for frequencies up to 30 kc.

4397

Seki, H., A. Granato, and R. Truell, "Diffraction Effects in the Ultrasonic Field of a Piston Source and Their Importance in the Accurate Measurement of Attenuation," J. Acoust., Soc. Am., 28, 230-238, 1956.

A study is made of the ultrasonic field produced by a circular-quartz crystal transducer and the integrated response of a quartz-crystal receiver with the same dimensions as the transducer. The transducer and receiver are taken to be coaxial, and it is assumed that the transducer behaves as a piston source while the integrated response is proportional to the average pressure over the receiver area. Computations are made for cases of interest in the megacycle frequency range (ka = 50 to 1000; a = piston radius; λ = wavelength; $k = 2\pi/\lambda$). The results contain features of use in identifying and correcting for diffraction errors. These features, which apparently have been missed in previous investigations, are compared with available experimental data. Finally, correction formulae to account for diffraction effects in the accurate measurement of attenuation are discussed. It is shown that the order of magnitude of the diffraction attenuation is given by one decibel per a^2/λ.

4398

Tartakovskii, B. D., "The Phase Jump at the Focus of Spherical Beams of Sound," Soviet Phys. Acoust., English Transl., 7, 179-184, 1961.

Considers the acoustic-pressure amplitude and phase distribution along the axis of a spherical wide-angle beam with an axially symmetric amplitude distribution over the wave front. It is found that, regardless of the specific form of the amplitude-distribution function over the wave surface, along the principal axis of the beam there occurs a phase jump, which becomes gradually restricted by phase oscillations that decay with distance from the focus. It is shown that the structure of the phase jump is determined primarily by the nonuniformity of the amplitude distribution over the wave front.

The theory of the phase jump at the focus of optical focusing systems, although suggested as early as 1909 by Reiche and later given general recognition (see, e.g., Born, Optics), fails to encompass the main feature of the effect of spherical wave-focusing, in that real optical and acoustical beams always by nature possess a small uniformity in the amplitude distribution over the wave front. Some numerical calculations of the amplitude and phase distribution along the axis of sound beams are given to illustrate the expanded theory.

4399

Tartakovskii, B. D., "Sound Field in the Focal Plane of Spherically Converging Beams," Soviet Phys. Acoust.,English Transl., 6, 92-96, 1960.

Considers the amplitude distribution of the acoustic-particle velocity and acoustic pressure in the focal plane of beams of spherical sound waves with a finite flare angle, where the beams are characterized by a nonuniform amplitude distribution over the wave front. Here it is assumed that a sizable variation in amplitude over the wave front, of the same order of magnitude as the amplitude itself, occurs at distances greater than λ/π. Just as in the analysis of the amplification factor, the amplitude-distribution function over the front is expressed by a polynomial, the integration of which permits the solution to be presented in the form of special functions.

4400

Vick, G. L., "On the Propagation of Acoustic Waves in Gases at High Temperatures and Reduced Pressures," LMSD-49762, Lockheed Missiles & Space Div., Calif., 1959. AD-228 429.

Thermodynamic theory, as it applies to the propagation of acoustic waves in gases at elevated temperatures and reduced densities, is reviewed. The results of this study establish the applicability of acoustic methods to the measurement of gas temperature and to research on vibrational relaxation, dissociative relaxation, and viscosity phenomena under high-temperature, low density conditions. It is concluded that acoustic waves will be propagated with a dispersion of less than $a/a_0 = 1.1$ at frequencies below 1 mc at a temperature of 5000°K. Viscosity effects become predominant above 1 mc, resulting in greatly increased dispersion. Two absorption peaks occur at frequencies lower than 0.1 mc corresponding to vibrational and dissociative relaxation.

This study of dispersion and absorption indicates that the velocity of acoustic waves may be reliably used as a measure of gas temperature at frequencies below 1 mc; this could have wide application for shock-tube instrumentation. Measurements of acoustic attenuation below 0.1 mc would yield information concerning vibrational and dissociative relaxation. Viscosity effects may be studied from acoustic wave velocity data at frequencies above 1 mc; such acoustic wave measurements will be a powerful tool for research in the field of gas dynamics.

4401

Williams, A. O., Jr., "Acoustic Wave Fronts from a 'Piston' Source," J. Acoust., Soc. Am., 19, 156-161, 1947.

Some properties are deduced from an approximate expression for the velocity potential. The calculations are limited to frequencies and dimensions of interest in ultrasonics. The results comprise, for plane pistons, a determination of the place where the wave fronts reverse their curvature from converging to diverging shape, a calculation of the radius of curvature of the fronts at moderately large distances from the source, and an approximate theoretical equation for their shape.

4402

Williams, A. O., Jr., "The Piston Source at High Frequencies," J. Acoust. Soc. Am., 23, 1-6, 1951.

For a circular plane piston of radius a, producing an ultrasonic beam with propagation constant k (or $2\pi/\lambda$), an expression is derived for the velocity potential or the acoustic pressure, averaged with respect to magnitude and phase over a "measurement circle" equal in area to the piston and centered in the beam. The expression should be highly accurate for $ka \geq 100$, at distances z from the source governed by $(z/a)^3 \geq ka$. It agrees well with results computed, in another way, by Huntington, Emslie, and Hughes. The assumption that relatively near the source there is a collimated beam of plane waves is shown to be not very accurate; the averaged pressure falls off monotonically over all distances considered. The velocity potential at the rim of the "measurement circle" is also computed, and compared with the plane-wave assumption.

Wave Propagation, Ultrasonic
See Also—16, 270, 296, 470, 590, 760, 828, 920, 1329, 1398, 2181, 2185, 2275, 2432, 2702, 2821, 2944, 2955, 2957, 2969, 2970, 3146

WIND SCREENS

4403

Army Field Forces, Board No. 1, "Test of Noise Reducing Microphone Shelter," Fort Bragg, N. C., 25 pp., 1953.

Tests were conducted to determine whether the Army Field Forces required a noise shelter and whether the requirement is met by the noise-reducing microphone shelter or by an improvised shelter. A noise shelter was found necessary. Satisfactory sheltering was accomplished by an improvised shelter. The noise-reducing microphone shelter proved unsuitable. Further studies are recommended to determine methods for sheltering applicable to various types of terrain and to formulate instructions for manuals.

4404

Badmaieff, A., and E. S. Seeley, "Development of a Large Area Microphone," Quart. Prog. Rept. No. 1, Altec Lansing Corp., Anaheim, Calif., 17 pp., 1961. AD-270 158.

Work was initiated on a large-area microphone system. The microphone is to have an active area of approximately 570 sq ft. It is to be broken up into 96 individual microphone modules, each 2 × 3 ft. in area. Each module is to be a microphone in itself, complete for individual operation. The module is a condenser-type microphone consisting of back and side enclosure, dielectric, guard circuit, back-plate electrode, and diaphragm electrode.

Details and techniques of construction were established by tests of samples of the backplate-dielectric-guardplate assembly. An experimental module was then built for use in preliminary measurements. Facilities were designed and constructed for testing the modules, consisting of a large piston-phone driven by special cone-type speakers, and an infrasonic power amplifier to drive the speakers. The preliminary measurements established the gain requirement for meeting the sensitivity specifications, and indicated the need for special provisions in the electronic circuits to meet the objectives of S/N.

4405

Bleazey, J. C., "Experimental Determination of the Effectiveness of Microphone Wind Screens," J. Audio Eng. Soc., 9, 48-54, 1961.

The main objective in wind screening of microphones is to provide a reduction in wind response without affecting the signal response of the microphone. Measurements have been carried out indoors employing a wind generator; these have been correlated with outdoor measurements under natural conditions of moderate wind velocities. Experimental data have been obtained relating the wind noise to the volume of the wind screen, the type of material used in covering the wind screen, and the number of layers of material used in covering the wind screen.

4406

Bruel, P. V., "Aerodynamically Induced Noise of Microphones and Windscreens," Bruel & Kjaer Tech. Rev., No. 2, 28 pp., 1960.

A newly designed windscreen with airfoil form and two new nose cones to protect condenser microphones against wind turbulence are investigated over a large wind-speed range. Measurements are made both indoors, on a rotating arm, and outdoors, on a car and a light aeroplane. The results are compared with the limited information given in the literature. Also the influence on the frequency response both from the windscreen and from the nose cones is measured for different angles of incidence, and it is shown how the nose cone converts a free-field single-direction microphone into an omnidirectional microphone over a large frequency range.

4407

Carrell, R. M., "A Method for the Quantitative Measurement of Wind-Noise Sensitivity in Microphones," J. Audio Eng. Soc., 3, 102-105, 1955.

A spring-hinge pendulum may be used to carry a microphone noiselessly through the still air of an anechoic chamber. The noise generated by the flow of air past the microphone is easily measured and analyzed. Velocities of the order of 15-20 mph are obtainable with the pendulum, whose period is about 3 sec.

The output of the microphone may be recorded with a high-speed recorder. With the addition of a variable bandpass filter at the input to the recorder, a noise spectroanalysis may be accomplished. Wind-noise spectra of an RCA 77D in three-directional characteristic settings are presented and commented upon.

4408

Daniels, F. B., "Noise-Reducing Line Microphone for Frequencies Below 1 CPS," J. Acoust. Soc. Am., 31, 529-531, 1959.

Describes a novel line microphone that utilizes a distributed input primarily for the purpose of improving signal-to-wind-noise ratio. The input to the transducer takes place through a tapered pipe that is coupled to the atmosphere by means of acoustical resistances uniformly spaced along the length of the pipe. The relationship between the resistances of the openings and the longitudinal variation in the characteristic impedance of the pipe is so adjusted as to make the system nonreflecting. Microphones of this type have been constructed for use in the frequency range below 1 cps for the purpose of studying atmospheric pressure oscillations in this range. A prototype, 1980 ft long with 100 openings, which gives an improvement in the signal-to-noise ratio of as much as 20 db under severe wind conditions, is described.

4409

Hawley, M. E., "Noise Shield for Microphones Used in Noisy Locations," J. Acoust. Soc. Am., 30, 188-190, 1958.

A rubber noise shield was developed which significantly improves the speech-to-noise ratio at a military microphone. The construction and evaluation techniques are described, and the advantage of introducing acoustic damping material is affirmed.

4410

Hayes, J. R. M., and A. L. Cudworth, "A Windscreen for the Ear," J. Acoust., Soc. Am., 26, 254-255, 1954.

Whenever human beings must hear faint sounds in windy places, the masking effect of the noise caused by air turbulence in the ear canal can be a serious problem. We have measured the masking effect at several frequencies, wind velocities, and wind directions. We have also measured to what extent this masking is reduced by a windscreen for the ear.

4411

Kennedy, W. B., et al., "Study of Meteorological and Terrain Factors Which Affect Sound Ranging," Denver Research Inst., Univ. of Denver, Colo., 1954-1957.

Qrtrly. Prog. Rept. 1, March-May 1954, AD-38 446
" " " 2, June-August 1954, AD-43 297
" " " 3, September-November 1954, AD-54 480
" " " 4, December 1954-February 1955, AD-61 530
" " " 5, March-May 1955, AD-70 078
" " " 6, June-August 1955, AD-74 855
" " " 7, September-November 1955, AD-95 798
" " " 8, December 1955-February 1956, AD-95 799
Final Report, March 1954-April 1956, AD-139 326
Qrtrly. Prog. Rept. 1, May-July 1956, AD-140 087
" " " 2, August-October 1956, AD-140 088
" " " 3, November 1956-January 1957, AD-140 090
Interim Prog. Rept., February-August 1957, AD-160 696

This series of reports covers four years of intensive theoretical and applied research and development on sound-ranging as influenced by meteorological and terrain factors. The general problem of increasing the accuracy of sound-ranging by means of corrections based on meteorological and topographical conditions is discussed. Equations are presented for applying wind and temperature corrections to reduce error in observed sound-source azimuths. Problems encountered in setting up the field operation to provide data for a study of meteorological and terrain corrections for the whole sound path are analyzed. Proposed methods for time measurement of sound arrivals, temperature measurement, control of field operations, and power distribution are presented in detail.

The firing-recording arrays are described. The results and the methods of reducing data are given. Special investigations include: an analysis of the problem of acoustic ray-tracing in the atmosphere; determinations of the sonic data obtainable with various geometries of detecting arrays; an analysis for determining the velocity of sound; studies of errors generated within the Short-Range Whole-Path Firing-Recording Array by elevation differences, angular errors in placing the sensing microphones, and errors due to the assumption that the wave front is plane; a study determining the effect of oscillogram-reading errors on calculated sound-wave-arrival azimuths; a discussion of methods of removing data from oscillograms; and tests to determine the calibration requirements of the T-23 microphones. Other discussions include microphone-wind-shield development, the surveying program, and the general field operational problem.

The application of a drift correction to the primary sound-ranging information provided results superior to those obtained by standard artillery methods. For these calculations, data were used from an array of 14 microphones arranged in an isosceles-trapezoidal configuration. The arrival azimuth obtained by using this configuration is more representative of the direction of arrival of the acoustic wave front than that obtained by standard methods. The corrections which were applied for the refraction of the wave front along its path do not appear to be greatly significant from a study of the small sample presented.

4412

Seeley, E. S., and A. Badmaieff, "Development of a Large Area Microphone," Third Quart. Prog. Rept. No. 3, ALTEC Lansing Corp., 1962.
AD-276 701.

Microphone-diaphragm mounting problems were solved by employing a rigid module frame built from the extruded channel, and by developing an improved method for mounting the Mylar diaphragm, prestretched in two dimensions. The range of the attenuator was increased by adding five steps, to provide a total of 60 db. The field junction box circuits were redesigned to a reduced power output and an increased load impedance. The changes reduced the heat generation of the circuits by 70%, and resulted in a temperature rise of only 50°F. A complete microphone system, consisting of two modules, a field junction box, and a station rack completely implemented with cables and power equipment, was constructed.

4413

Spandock, F., "Noise of the Wind and the Carry of Sound in the Free Atmosphere" (in German), Z. Angew. Phys. 3, 228-231, 1951.

It is considered that wind noise arises from turbulence and has a falling-off spectrum for both low and high frequencies. From measurements of screening of wind noise and of its influence on the amplitude, the distribution of sound in consequence of the sheltering effect has been calculated. On the basis of the fact that the frequency change of wind noise and the excitation of waves in the ear are similar, the possibility is discussed that the ear adapts itself to the conditions in the free atmosphere.

4414

van Niekerk, C. G., "Measurement of the Noise of Ducted Fans," J. Acoust. Soc. Am., 28, 681-687, 1956.

A proposed technique for measuring the noise of a ducted fan by means of a microphone placed inside the duct was evaluated by comparing results so obtained with those obtained by measuring the total sound energy radiated from the duct into a reverberation chamber. A suitable microphone windscreen was developed and was used to reduce the aerodynamic self-noise generated by the microphone to a negligible minimum. Good correlation was obtained, and, by studying transverse resonance conditions in a duct, an attempt was made to discover how suitable microphone stations could be found to eliminate measuring errors caused by the existence of standing waves.

Wind Screens
See Also—603, 1122, 1291, 1354, 1379, 1859, 2736

ZONES OF AUDIBILITY AND SILENCE

4415

Angenheister, G., "The Propagation Time of Sound for Long Distances, Part II (in German), Z. Geophysik, 2, 88-101, 1926.

Further comments and registrations of sound waves on the subject. The explosion at Wiener-Neustadt shows the form of the normal and abnormal zone of audibility developed from the presented theory.

4416

Arabadzhi, V. I., "On Anomalous Zones of Audibility" (in Russian), Meteorol. i Gidrol., 5, 21-31, 1946.

Presents thorough theoretical and empirical work leading to the following conclusions: the reception of acoustical waves from the stratosphere occurs because of inversion in refracted waves from the upper part of the inclined wave front with significant vertical extension; the seasonal change in radius of zones of anomalous audibility might explain the formation, during explosions in winter, of acoustical waves of higher frequency than in summer; the "east-west effect" might be explained by the influence of the wind regime on waves of different frequency. Strong skepticism about Wipple's theory of warm stratospheric temperatures as explanation of anomalous propagation is expressed. Sound speed through the ozone layer, about 21 km above the earth, would decrease because ozone is triatomic.

4417

Berlage, H. P., "Audibility of the Detonations of a Semi-Volcanic Steam Explosion in Sumatra," Beitr. Geophys., 40, 369-370, 1933.

On June 24, 1933, at 21h. 54m. 35s. G. M. T., a violent earthquake took place in South Sumatra. In consequence the activity of a certain fumarole field was heightened; and this action culminated in a series of very violent explosions, especially at daybreak on July 10. The detonations of July 10 were heard at great distances; a map shows the stations from which the explosions were reported as having been heard. These extend 660 km, to Keboeman in Java, on one side, and 550 km, to Kuala Tungkal in Sumatra. A window pane was smashed in Batavia (305 km) in a zone of good audibility. An inner zone of radius 170 km round the center of explosion was marked by very poor audibility, and at places beyond this zone the sound appeared to come down to the observers.

4418

Christy, M., "The Audibility of the Gunfire on the Continent at Chignal, Near Chelmsford, During 1917," Quart. J. Roy. Meteorol. Soc., 44, 281-284, 1918.

A diary of acoustic observations made by the author notes that gunfire on the continent near Chelmsford is audible in southeastern England from about May through August each year. This is an untechnical article and the author makes no attempt to explain the seasonal, acoustical phenomenon. Explanations and comments are offered in the very next article of the same journal volume by Whipple as an essential complement to Christy's report. See F. J. W. Whipple, Ibid., 285-289.

4419

Cox, E. F., "Abnormal Audibility Zones in Long Distance Propagation Through the Atmosphere," J. Acoust. Soc. Am., 21, 6-16, 1949.

Five thousand tons of high explosives detonated on Helgoland, April 18, 1947, created air pressure perturbations recorded on microbarographs between 66 and 1000 km SSE from the blast. Instruments responded to frequencies 0.05-5 cps. Arrival times of abnormal signals at six stations more distant than 220 km, supplemented by high altitude meteorological data and the assumption of negligible winds above 30 km, permit calculations of upper-atmosphere temperature. Temperatures agree with NACA values up to 42 km, but show a reduced gradient above that altitude, and a maximum value 294°K in the temperature hump between 30 and 70 km. This temperature maximum establishes a critical ray that is refracted to infinity. A new explanation for observed outer boundaries of abnormal zones is therefore proposed, and substantiated by recorded evidence of dispersion near the temperature maximum. In the signal received near the abnormal zone's outer boundary, high-frequency content predominates.

4420

Cox, E. F., "Errata: Abnormal Audibility Zones in Long Distance Propagation Through the Atmosphere," J. Acoust., Soc. Am., 21, 501, 1949.

(See Ibid., 6, 16, 1949.) This article points out that Schrodinger's dispersion theory deals specifically with vertically traveling waves, hence it cannot be applied near the apex of abnormal signal paths. The original paper must therefore be regarded as presenting experimental evidence of dispersion, unexplained by theory.

4421

Cox, E. F., J. V. Atanasoff, B. L. Snavely, D. W. Beecher, and J. Brown, "Upper-Atmosphere Temperatures from Helgoland Big Bang," J. Meteorol., 6, 300-311, 1949.

Microbarographs situated 66 to 1000 km SSE from Helgoland recorded disturbances initiated by the 5000-ton TNT explosion on that island, April 18, 1947. Special balloons at four meteorological stations obtained weather data to 29.5 km altitude at blast time. Wind velocities are considered negligible up to balloon summits. Assuming negligible winds at higher altitudes, interval velocities of abnormal microbarometric signals permit calculations of upper-atmosphere temperatures. Temperature rises steeply from 221°K at 32 km to 285°K at 42.5 km, then more slowly to 294°K at 55 km, Very long period waves recorded beyond 400 km are believed to have returned from the second high-temperature region of the upper atmosphere. Arrival times are best matched by assuming a cold layer between 55 and 86 km, with lowest temperature 170°K extending from 64 to 79 km. A steep rise to 296°K at 86 km precedes a smaller gradient to 399°K at 172 km.

The authors do not have much confidence in findings for altitudes exceeding 100 km.

4422

Davison, C., "The Sound of a Great Explosion," Quart. Revs. (London), 452, 51-60, 1917.

The first recognition of abnormal behavior of sound waves was in 1901, when noise from guns at Queen Victoria's funeral in London was heard at long distances but not near London. The first explanation of zone of silence attributed to an upward refraction of sound waves through the troposphere, followed by downward bending of the waves by increasing wind velocity at higher altitudes. A figure shows areas of sound.

4423

Davison, C., "The Sound-Waves and Other Air-Waves of the East London Explosion of January 19, 1917," Proc. Roy. Soc., Edinburgh, 38, 115-129, 1918.

A highly detailed report on the areas of audibility and zones of silence associated with an enormous explosion that occurred in East London, England. The report is in narrative style, essentially nontechnical, and presents the results from 725 queries made in 533 places to distances of as much as 150 miles from London. The nature of the sound in various locations and some of its side effects are described. Correlation of the silent zones and areas of audibility with wind and temperature profiles is only casual due to insufficient meteorological data.

4424

de Quervain, A., "Explosion at Oppau on September 21, 1921" (in German), Schweizerische Meteorologische Zentralanstalt, Annalen, 1921.

Discussion, records, synoptic charts, and zones of audibility are given for the Oppau explosion, 21 September 1921.

4425

de Quervain, A., "The Meteor Explosion Waves on July 28, 1915" (in German), Jahresbericht des Schweizerischen Erdbebendienstes, Zurich, 13 pp., 1916.

Observations collected on this occasion indicate the existence of an outer zone of audibility.

4426

Door, J. N., "The Long Range Effects of the Explosion at Wiener-Neustadt on June 7, 1912" (in German), Akad. Wiss. Wien, Kl. 122, 1683-1732, 1913.

Inner and outer audibility zones and zones of silence are distinguished. These are good, thorough, early observations of such acoustical phenomena.

4427

Duckert, P., "Results of Acoustical Observations from Explosions at Oldebroek, December 15, 1932" (in German), Z. Geophysik, 10, 119, 1934.

A detailed discussion of explosion and subsequent sound records. Figure shows zones of audibility and where explosion waves were recorded.

4428

Galbrun, H., "Propagation of a Sound Wave in the Atmosphere and the Theory of Zones of Silence" (in French), Gauthier-Villars et Cie, Paris, 352 pp., 1931.

A detailed theoretical work studying the effects of wind on sound propagation. The first part considers discontinuity in the movement of a fluid in relation to propagation of sound. Physics of sound waves and rays are discussed at length. The second part considers zones of silence, giving a detailed analysis and physical and geometrical aspects.

4429

Gutenberg, B., "The Formation of Abnormal Zones of Sound from Explosions" (in German), Z. Geophysik, 2, 260-266, 1926.

Discussion of the Lindemann-Dobson discovery of warm temperatures above 35 km, particularly considering implications for anomalous propagation of sound.

4430

Gutenberg, B., "Sound Propagation in the Atmosphere," in T. F. Malone, ed., Compendium Meteorol. Am. Meteorol. Soc., Boston, 366-375, 1951.

This is a detailed study of the theory of sound waves in gases, the equations for velocity of sound in quiet and in moving air, and the energy of sound waves in the atmosphere. Microbarographs and their limitations are discussed. Observations and records from microbarographs of sound propagation through the troposphere and the stratosphere, and abnormal audibility zones are also treated. Numerous illustrations show types of records, areas of abnormal audibility from explosions (Germany, 1925, and Vergiate, Italy, November, 1920), and travel time curves. Cross sections showing typical paths of sound waves, and temperature and sound velocity profiles from V-2 flights and other sound propagation data are included.

4431

Gutenberg, B., "On the Propagation of Sound in the Atmosphere" (in German), Naturwissenschaften, 14, 338-342, 1926.

The zone of silence after the Oppau explosion is illustrated. There is a brief discussion of von dem Borne's, Wegener's, Angenheister's, etc., theories of anomalous sound propagation. A figure shows paths of sound waves and speeds at different heights in the atmosphere. The theory of high upper air temperature is treated briefly.

4432

Haurwitz, B., "Physical State of the Upper Atmosphere," J. Roy. Astron. Soc. Can., 31, 19-42 & 76-92, 1937.

This continues previous work. The author first discusses atmospheric ozone, its power to absorb solar radiation, its total amount, its annual variation, and its geographical and vertical distributions. Its great absorbing power is seen to determine to a large extent the temperature of the upper atmosphere; the theory of its origin mainly considered is that of Chapman.

In his second section, the author deals with the anomalous propagation of sound, accounting for the varying directions of audibility in summer and winter. The greater velocity of sound in the upper atmosphere, affording an explanation of the zones of audibility, in all probability arises because of the high temperatures of the upper atmosphere. In dealing with the composition of the atmosphere the author points out that this is constant owing to mixing up to heights of about 20 km. Above this, mixing continues to a certain extent and diffusion equilibrium is not to be expected on theoretical grounds below 100 km.

4433

Haurwitz, B., "Propagation of Sound Through the Atmosphere," J. Aeron. Sci., 9, 35-43, 1941.

Discusses the geometrical laws of sound propagation in a calm atmosphere, considering wind and temperature effects. The region of audibility around a source of sound is asymmetrical according to the wind. Zones of anomalous audibility around an explosion are explained by high temperatures in upper air.

4434

Hubbard, B. R., "Influence of Atmospheric Conditions upon the Audibility of Sound Signals," J. Acoust. Soc. Am., 3, 111-125, 1931.

Summarizes the causes of the irregularity noticed in the audibility of fog signals. The observations and theories of various writers are quoted and the results of the test of fog-horns at Boston, carried out in Sept., 1930, are given. Striking instances are given of the unreliability of loudness observations for ascertaining distance; e.g., a fog signal that is audible for eight miles under favorable conditions may be just audible under other atmospheric conditions at a mile or less. The effect of "silent zones," due to the bending of the sound waves when temperature decreases normally upwards, is considered.

There are now few phenomena of fog signalling that cannot be explained in accord with generally recognized principles. The atmosphere is seldom homogeneous and aberrations in audibility may be due to any or all of three causes—wind, temperature, and humidity. The work of all investigators points to the first of these causes as the most important in causing inefficiency. The observed effects are illustrated by diagrams and tables summarizing the results obtained.

4435

Krakatoa Committee, Royal Society of London, "On the Air Waves and Sounds Caused by the Eruption of Krakatoa in August, 1883, Part II. The Eruption of Krakatoa and Subsequent Phenomena," Trubner & Co., London, 57-88, 1888.

Lists the stations from which barometrical or other observations were received, with descriptions of recording instruments. Times of passage of air waves over each station are recorded and the velocities of air waves calculated. A section on sounds states the detonations were heard over nearly one-thirteenth of the earth's surface. A list of places at which the sounds were heard is given, including Rodriguez, nearly 3000 miles from Krakatoa. Detailed data are included.

4436

Massey, H. S. W., and R. L. F. Boyd, "The Upper Atmosphere," Philosophical Library, New York, 333 pp., 1959.

Of particular interest to acousticians is the chapter on sound transmission in the upper atmosphere. The propagation of explosive sounds originating on the ground, with anomalous transmission and zones of silence, is examined for what it reveals on the variation of temperature with height. Explosions in the upper air itself have been made possible with the use of rockets, and these explosions have been used to chart the distribution of wind and temperature. However, it seems that even more effective use of sound propagation (e.g., sound attenuation studies) could be made.

4437

Maurain, C., "Propagation of Air Waves from the Experiments at La Courtine" (in French), Compt. Rend., 179, 1334-1337, 1924.

Zones of audibility for sound waves from this explosion are briefly described and explained. Figures illustrate the zones of audibility.

4438

Meisser, O., "Sound Propagation in the Atmosphere After Artificial Explosions" (in German), Physik. Z., 30, 170-175, 1929.

A partial review of a series of explosions to investigate acoustical phenomena and theories about the audibility regions of the atmosphere.

4439

Murgatroyd, R. J., "Wind and Temperature to 50 KM over England, Anomalous Sound Propagation Experiments, 1944-1945," Geophys. Mem. Meteorol. Off. (London), 30 pp., 1955.

The geometry of zones of audibility is set out. In sixteen experiments explosions at seven to ten points in England were recorded on lattices of microphones. Audibility (up to 387 km) and time of travel are tabulated. The experiments gave, with certain assumptions, the vertical distribution of temperature and winds of 18-50 km. Temperature at 50 km varied from 310^{O}K in July and August to 264^{O}K in January. Wind at 30-45 km changed from westerly 40-80 meters per sec. in winter to easterly < 20 meters per sec. in summer. Radiosonde measurements up to 18 km are given for comparison.

4440

Poisson, R. P., "Audibility of Thunder at Tananarive" (in French, English and Spanish summaries), Meteorol., 4th Ser., 19-25, 1951.

The methods for measuring the audibility of thunder and their reliability are discussed. Instances are cited in which thunder was heard at distance of 39 to 57 km from the point where lightning occurred.

4441

Regula, H., "Investigation of the High Stratosphere by Explosion Waves" (in German), Meteorol. Rundschau, 2, 263-267, 1949.

Zones of silence and abnormal audibility of explosions point to a strong inversion at 35 to 40 km. This is confirmed by V-2 ascents. The location of zones audibility exceeding 150 km, mainly to west in summer and east in winter, agrees with summer and winter winds, according to Scherhag (1948), from topography of 41 mb surface (ca. 22 km). These winds are considered, therefore, to represent the whole layer from 20-45 km. Further experiments should bring temperatures and winds up to 45 km into discussion of synoptic problems.

4442

Rothwell, P., "Sound Propagation in the Lower Atmosphere," J. Acoust. Soc. Am., 28, 656-665, 1956.

An account is given of experiments carried out in the lower troposphere to compare observations of the audible range and of the angle of sound descent from shell bursts at various heights (up to 10,000 feet) with calculations made from elaborately measured temperatures and winds. In stable conditions they agree satisfactorily.

Several cases were observed of anomalous propagation in which sound rays starting upward from the source are bent back to the earth. These showed the phenomena associated with larger-scale anomalous propagation, namely, inner and outer audibility zones, "zone of silence," and double or multiple reception of the single pulse from the source. From the experience gained in these experiments suggestions are made for (1) observation of the time interval between components of the usual double or multiple bangs from a single pulse-source, and for (2) observation of the sound from explosions in the air as well as on the ground to obtain more information than has been obtained hitherto from sound propagation about temperature and wind in the high atmosphere. Rocket explosions might be used for the latter purpose.

4443

Sakai, T., "Anomalous Propagation of Sound Waves at a Short Distance," Proc. Phys. Math.Soc., Japan, 17, 240-273, 1935.

J. Kolzer has observed two cases of anomalous propagation of sound through the atmosphere; viz., when the velocity of the sound increases linearly with the height and then reaches a constant value, a wave can be observed that arrives before the wave that travelled along the earth's surface; and when the velocity decreases linearly with height and then reaches a constant value, there is a zone of silence succeeded by a region of audibility. Taking the case of two atmospheric strata and a cylindrical wave, the author shows that a wave in the upper medium is accompanied by another wave in the lower medium travelling along the surface of separation with the same speed. This wave is identified as the anomalous wave observed by Kolzer, and should only appear when the distance between the source and the observer is greater than a certain critical value. By substituting probable values in the formulae, results are obtained that agree with those observed by Kolzer. A phenomenon termed "multiple reflection shooting" is also predicted.

4444

Schaffers, V., "The Sound of Distant Gunfire," Nature, 107, 44-45, 1921.

The anomalies opposing a correlation of wind and temperature data with the seasonal variations in zones of audibility from distant gunfire of World War I are reviewed in this short report. The author suggests that refraction can account for only the upward bending of rays and subsequent zones of silence. He advocates diffraction near the earth's surface as the only satisfactory explanation for downward ray bending and secondary zones of audibility. It must be remembered that there was very little known about temperature and wind gradients at high altitudes in 1921.

4445

Scheid, G., "Investigations of Sound Propagation over Short Distances" (in German), Deut. Wetterdienst, Ber., 4, 16 pp., 1956.

The first part of this study is a review of the most important studies of anomalous sound propagation over short distances, beginning with the investigations by R. Landenburg and F. Von Angerer, in 1913, on sound propagation in the free atmosphere. In Part 2, the author extends the characteristic sound propagation curves of Kolzer to heights of 1500 meters. It is shown that the resumption of the increase in sound velocity above the values at ground level is characteristic of anomalous sounds. The partial and complete return of the echo produced by the maximum velocity of the sound aloft is used to provide an explanation of the zone of anomalous audibility, in good agreement with the recordings. The increase in amplitude observed in the inner zone of second audibility is explained.

4446

Takesada, Y., "On Sound Channel in Stratosphere," J. Geomagn. Geoelect. (Japan), 12, 171-174, 1961.

The sound channel is formed in accordance with the wind current and temperature distribution. When the sound ray has the same direction of propagation as the jet stream, the velocity minimum in the vertical distribution of the sound velocity exists to about 23 km in height. If the sound ray radiates from the ground, it is refracted at about 13 km in height, and comes back to the ground. When the sound ray has the opposite direction from the wind stream, the velocity minimum of the vertical sound velocity distribution occurs at the altitude of 12 km.

4447

van Everdingen, E., "The Propagation of Sound in the Atmosphere," Proc. Acad. Sci. Amsterdam, 18, 933-960, 1915.

This paper, of historical interest, was written in 1915, and reviews the various theoretical and experimental approaches of that day on the anomalous propagation of sound in air. The theory of refraction of sound waves due to wind and temperature gradients is presented. Lack of temperature and wind data at high altitudes prevented accurate use of this theory in 1915. Other theories (now defunct), postulating a change in composition of the atmosphere with altitude, are reviewed. One of these predicted the existence of a gas, "geocoronium," five times lighter than hydrogen. Copious data on acoustic observations of various large explosions and volcanic eruptions is given in narrative and graphic form to demonstrate the existence of shadow zones and secondary areas of audibility.

4448

Visser, S. W., and J. Veldkamp, "Dutch Observations on the Helgoland Explosion" (in Dutch), Hemel en Dampkring, 45, 150-158, 1947.

An earlier reporting article covers the seismological effects; this covers the meteorological and acoustical observations made in Holland, including abnormal sound data originating from the Helgoland blast. It is indicated that southwest from Helgoland the inner boundary of the abnormal audibility zone may have been as close as 176 km.

4449

Visser, S. W., and J. Veldkamp, "Dutch Observations on the Helgoland Explosion" (in Dutch), Hemel en Dampkring, 45, 150-158, 1947.

An earlier reporting article covers the seismological effects; this covers the meteorological and acoustical observations made in Holland, including abnormal sound data originating from the Helgoland blast. It is indicated that southwest from Helgoland the inner boundary of the abnormal audibility zone may have been as close as 176 km.

4450

Wegener, A., "The Detonated Meteor of April 3, 1916, 3 1/2 Hours After Noon in Kurhessen" (in German), Gesellschaft zur Beforderung der gesammten Naturwissenschaften, Marburg, 14, 1-83, 1917.

Reports detailed observations made of the incident at various points, including physical phenomena, the trail, etc., and the sound. Zones of silence observed after this occurrence between Narburg and Cassel. Two earlier instances cited, supporting the hypothesis of the occurrence of an outer zone of audibility.

4451

Wegener, A., "The Outer Audibility Zone" (in German), Z. Geophys., 1, 297-314, 1925.

A very complete account of outer audibility zones after cannonading, explosions, volcanic eruptions, meteor explosions, etc, with critical discussion of various explanations of this phenomenon. It is found that in central Europe the distance of the maximum sound intensity from the source varies between 120 km in February and about 240 km in August.

4452

Wegener, A., "The Outer Audibility Zone and Its Periodical Annual Variations" (in German), Z. Meteorol., 42, 261-266, 1925.

Compares distances at which sounds from explosions at Lyon (1918), Vergiate (1920), and Witten-Annen (1906) were audible by anomalous propagation in different seasons. Various explanations are offered.

4453

Whipple, F. J. W., "Audibility of Explosions and the Constitution of the Upper Atmosphere," Nature, 118, 309-313, 1926.

The results of hundreds of acoustic observations made on a series of four scheduled, experimental explosions are described and presented in map form to show zones of silence and primary and secondary zones of audibility. Corresponding wind and temperature data in the lower atmosphere were taken, but winds and temperatures at higher altitudes were a subject for speculation. Whipple assumes a negative temperature gradient from 0 to 12 km, an isothermal layer from 12 to about 32 km, and an increasing temperature from 32 km upwards. From this he calculates and shows in graph form a set of sound-ray paths that return to earth at distances comparable to the experimental results. The effects of winds on ray paths are described but not calculated.

4454

Whipple, F. J. W., "The Detonating Meteor of September 6, 1926; An Instance of an Outer Zone of Audibility," Monthly Notices Roy. Astron. Soc, Geophys. Supplement, 2, 89-96, 1928.

Offers evidence of an outer zone of audibility in the case of this detonating meteor. Observations are analyzed to derive information with regard to the velocity of sound in the upper atmosphere. No final conclusions are drawn, but the observations for areas in which there were audible detonations are valuable. Figures show hypothetical sound rays from sources 32 and 40 km above ground. Zones of silence and of normal and abnormal audibility are discussed, and further evidence is provided for the existence of high temperatures in a certain region of the upper atmosphere.

4455

Whipple, F. J. W., "The High Temperature of the Upper Atmosphere as an Explanation of Zones of Audibility," Nature, 111, 187, 1923.

The author proposes that increased temperature in the stratosphere, as discovered by Lindemann and Dobson, might well explain zones of silence and of abnormal audibility.

4456

Whipple, F. J. W., "The Propagation of Sound to Great Distances," Quart. J. Roy. Meteorol. Soc., 61, 285-308, 1935.

Inner and outer zones of audibility are differentiated. Maps are given illustrating the audibility of explosions that occurred at various places: Boden, Sweden, January 11, 1933; and others in India and England. Reproductions of instrumental records of sound and explosion waves are analyzed. A discussion follows of how angles of descent are estimated. Methods are outlined for calculating times of passage of air waves, velocities of the waves, and heights of the trajectories. The Oldebroek explosions of December, 1932, are discussed as examples of conditions in winter. Diagrams show the velocity of waves according to temperature, etc., and trajectories of waves toward the east. Monsoon winds in the upper air are considered, as well as distribution of temperature over the globe; the passage of waves through rarefied

4457

Wiechert, E., "On Sound Propagation in the Atmosphere" (in German), Meteorol. Z., 43, 81-91, 1926.

Inner and outer audibility zones are described, along with normal and abnormal sound waves. Examples of anomalous sound-propagation observation are given for different observers after eight large explosions; distance and speed of travel of waves are considered. The theory is explained, with references and equations. Effect of wind considered, and examples are cited that show the influence of wind on audibility after different explosions.

4458

Wiechert, E., "Remarks on the Abnormal Propagation of Sound in the Air, Part I" (in German), Nachr. Ges. Wiss. Gottingen, Math.-Physik. Kl., 49-69, 1925.

Discusses refraction and differences in speed of sound waves in layers of stratosphere and gives an explanation of abnormal audibility zones depending on actual layers of the stratosphere and wind conditions. Temperature is considered important in view of the new Lindemann-Dobson theory of warm upper-air conditions.

4459

Wiechert, E., "Remarks on the Abnormal Propagation of Sound in the Air, Part II," Nachr. Ges. Wiss. Gottingen, Math.-Physik. Kl., 93-103; "Part III," Ibid., 201-211, 1926.

See preceding abstract.

4460

Witkiewicz, W. J., "On the Zones of Audibility from Explosion Waves" (in German), Meteorol. Z., 43, 91-96, 1926.

Explosions in Moscow (May, 1920) are discussed. Barograph records and zones of audibility are shown. Theories and equations are offered concerning various meteorological influences on the acoustic phenomena.

4461

Witkiewicz, W. J., "Scientific Studies of the Atmosphere" (in French), Editions de l'Observatoire Aerologique de Moscou, 2, 14-42, 1925.

An analysis of explosions at Moscow, May 9, 1920, showing symmetrical formation of outer audibility zones.

Zones of Audibility and Silence
See Also—430, 478, 527, 539, 588, 803, 1168, 1405, 1458, 1477, 1486, 1490, 1513, 1515, 1534, 1540, 1560, 1565, 1566, 1806, 2061, 2363, 2488, 2497, 3080, 3224, 3236, 3237, 3249, 3254, 3258, 3264, 3270, 3291, 3314, 3337, 3358, 3364

INDEX OF SUBJECTS

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Standard Abbreviation	Full Title
Abhandl. Braunschweig. Wiss. Ges.	Abhandlungen der Braunschweigischen Wissenschaftlichen Gesellschaft
Acta Phys. Austriaca	Acta Physica Austriaca
Acta Phys. Polon.	Acta Physica Polonica
Acta Polytech.	Acta Polytechnica
Acta Sci. Sinica	Acta Scientia Sinica (name changed to Sci. Sinica (Peking) Scientia Sinica, Sept. 1954)
Acustica	Acustica
Advan. Sci.	Advancement of Science, The
Aero/Space Eng.	Aero/Space Engineering
Akad. Wiss. Wien	Akademie der Wissenschaften in Wien
Akust. Zh.	Akustische Zeitschrift
Alta Frequenza	Alta Frequenza
Am. J. Phys.	American Journal of Physics
Am. Phys. Teacher	American Physics Teacher
Ann. i Geofis. (Rome)	Annali di Geofiscia (Rome)
Ann. Geophys.	Annales de geophysique
Ann. Phys.	Annales de physique
Ann. Physik	Annalen der Physik
Ann. Telecommun.	Annales de Telecommunication
Appl. Sci. Res.	Applied Scientific Research
Arbok Univ. Bergen, Mat.-Naturv. Ser.	Arbok for Universitetet i Bergen, Mat.-Naturv. Serie
Arch. Elektrotech.	Archiv fur Electrotechnik

*Abbreviations in accordance with Style Manual, American Institute of Physics, 1959, and Chemical Abstracts List of Periodicals, 1956.

Standard Abbreviation	Full Title
Arch. Math. Naturvidenskab	Archiv for Mathematik og Naturvidenskab
Arch. Tech. Messen	Archiv fuer technisches Messen
Arkiv Mat. Astron. Fysik	Arkiv for Matematik, Astronomi och Fysik
Astron. Zh.	Astronomicheskii Zhurnal
Astrophys. J.	Astrophysical Journal
At. Energy Res. Estab. (Gr. Brit.), transl.	Atomic Energy Research Establishment (Great Britain)

Atti Accad. Nazl. i Lincei	Atti della accademia nazionale dei Lincei
Australian J. Sci. Research, A	Australian Journal of Scientific Research, Series A (changed to Australian J. Phys.)
Bull. Acad. Sci. USSR, Phys. Ser.	Bulletin of the Academy of Science of the USSR, Physical Series (English translation of Izvestiya Akademii Nauk SSSR, Seriya Fizicheskaya)
Bull. Am. Meteorol. Soc.	Bulletin of the American Meteorological Society
Bull. Inst. Phys. Chem. Research (Tokyo)	Bulletin of the Institute of Physical and Chemical Research (Tokyo)
Bull. Patna Sci. Coll. Phil. Soc.	Bulletin of the Patna Science College Philosophical Society
Bull. Res. Council Israel	Bulletin of the Research Council of Israel
Bull. Seism. Soc. Am.	Bulletin of the Seismological Society of America
Bull. soc. belge electriciens	Bulletin societe belge des electriciens
Bull. soc. franc. electriciens	Bulletin de la societe francaise des electriciens
Bur. Standards J. Research	Bureau of Standards Journal of Research
Cahiers Phys.	Cahiers de physique
Can. J. Phys.	Canadian Journal of Physics
Can. J. Research	Canadian J. of Research (continuation of Canadian Journal of Research, Section A)
Carl Zeiss Jena Nachricht (German)	Carl Zeiss Jena Nachrieht (German)
Cas. Pest. Mat. Fis.	Casopis pro Pestovani Matematiky a Fisiky
Ciel Terre	Ciel et terre
Communs. Kamerlingh Onnes Lab. Univ. Leiden	Communications from the Kamerlingh Onnes Laboratory of the University of Leiden
Communs. Phys. Lab. Univ. Leiden	Communications from the Physical Laboratory of the University of Leiden (name changed to above with Commun. No. 217)
Compt. Rend.	Comptes rendus hebdomadaires des seances de l'academie des sciences
Compt. Rend. Acad. Sci. URSS	Comptes rendus de l'academie des sciences de l'URSS
Deutscher Wetterdiens & Berichte	
Dokl. Adak. Nauk SSSR	Doklady Akademii Nauk SSSR
Electron. Eng.	Electronic Engineering
Electronics	Electronics

Electrotech. J.	Electrotechnical Journal
Elek. Nachr.-Tech.	Elektrische Nachrichten-Technik
FIAT Rev. Ger. Sci.	FIAT Review of German Science
Geofis. Pura Appl.	Geofisica pura e applicata
Geofys. Publikasjoner	Geofysiske Publikasjoner
Geophysica (Helsinki)	Geophysica (Helsinki)
Geophysics	Geophysics
Geophys. Mag. (Tokyo)	Geophysical Magazine (Tokyo)
Geophys. Mem. Meteorol. Off. (London)	Geophysical Memoirs, Meteorological Office (Air Ministry), London
Gerlands Beitr. Geophys.	Gerlands Beitrage zur Geophysik
Helv. Phys. Acta	Helvetica Physica Acta
Hemel en Dampkring	Hemel en Dampkring
Hochfrequenztech. u. ElektAkust.	Hochfrequenztechnik und Elektroakustik
Imp. Marine Obs., Kobe, Japan, Mem.	Memoirs of the Imperial Marine Observatory, Kobe, Japan
Ind. Eng. Chem.	Industrial and Engineering Chemistry
Indian J. Meteorol. Geophys.	Indian Journal of Meteorology and Geophysics
Indian J. Phys.	Indian Journal of Physics
Ingenioervidenskab. Skrifter	Ingenioervidenskabelige Skrifter
Instr. Exp. Tech.	Instruments and Experimental Techniques (USSR) English translation of Pribory i Technika Eksperimenta
Instr. Pract.	Instrument Practice
IRE Inst. Radio Engrs., Trans. Audio	Institute of Radio Engineers Transactions on Audio
Izvest. Akad. Nauk SSSR, Ser. Fiz.	Izvestiya Akademii Nauk SSSR, Seriya Fizicheskaya
Izvest. Akad. Nauk SSSR, Ser. Geograf. i Geofiz.; Ser. Geofiz.	Izvestiya Akademii Nauk SSSR, Seriya Geograficheskaya i Geofizicheskaya (superseded by Seriya Geofizicheskaya)
J. Acoust. Soc. Am.	Journal of the Acoustical Society of America, The
J. Aeron. Sci. (changed to Aerospace Sci. with Vol. 25, 1958)	Journal of the Aeronautical Sciences (name changed with Vol. 25, 1958, to J. Aerospace Sci.)
J. Appl. Mech.	Journal of Applied Mechanics
J. Appl. Phys.	Journal of Applied Physics
J. Atmospheric Terrest. Phys.	Journal of Atmospheric and Terrestrial Physics

J. Chem. Phys.	Journal of Chemical Physics, The
J. Exptl. Theoret. Phys. (USSR)	Journal of Experimental and Theoretical Physics (USSR)
J. Fluid Mech.	Journal of Fluid Mechanics
J. Franklin Inst.	Journal of the Franklin Institute
J. Geophys. Res.	Journal of Geophysical Research
J. Indian Inst. Sci.	Journal of the Indian Institute of Science
J. Math and Mech	Journal of Mathematics and Mechanics
J. Math. Phys.	Journal of Mathematical Physics
J. Meteorol.	Journal of Meteorology
J. Opt. Soc. Am.	Journal of the Optical Society of America
J. Phys. Radium	Journal de physique et Le radium
J. Phys. Soc. Japan	Journal of the Physical Society of Japan (this is a continuation of Proc. Phys.-Math. Soc. Japan)
J. Phys. (USSR)	Journal of Physics (USSR)
J. Roy. Astron. Soc. Can.	Journal of the Royal Astronomical Society of Canada, The
J. Roy. Meteorolog. Soc.	Journal of the Royal Meteorological Society
J. Sci. Ind. Res. (India)	Journal of Scientific and Industrial Research (India)
J. Sci. Instr.	Journal of Scientific Instruments
J. Soc. Motion Picture Engrs.	Journal of the Society of Motion Picture Engineers (now called J. Soc. Motion Picture Television Engrs.)
J. Tech. Phys. (USSR)	Journal of Technical Physics (USSR)
J. Wash. Acad. Sci.	Journal of the Washington Academy of Sciences
Kgl. Norske Videnskab. Selskabs, Forh.	Kongelige Norske Videnskabers Selskabs, Det, Forhandlinger
Kgl. Tek. Hogskol. Handl.	Kungliga Tekniska Hogskolans Handlingar (same as, Transactions of the Royal Institute of Technology, Stockholm)
Luftfahrt-Forsch.	Luftfahrt-Forschung
Mach. Design	Machine Design
Mem. artillerie franc.	Memorial de l'artillerie francaise
Mem. Inst. Sci. Ind. Res., Osaka Univ.	Memoirs of the Institute of Science and Industrial Research, Osaka University
Mem. Res. Inst. Acoust. Sci., Osaka Univ.	Memoirs of the Research Institute of Acoustical Science, Osaka University (changed to above, 1952)

Meteorol. i Gidrol.	Meteorologia i Gidrologia
Meteorol. Mag.	Meteorological Magazine, The
Meteorologie	Meteorologie, La
Meteorol. Rundschau	Meteorologische Rundschau
Meteorol. Z.	Meteorologische Zeitschrift
Mirovedenie	Mirovedenie
Mitt. Inst. Aerodyn., E. T. H., Zurich	Mitteilungen aus dem Institut fur Aerodynamik, Eidgenossische Technische Hochschule, Zurich
Monthly Notices Roy. Astron. Soc.	Monthly Notices of the Royal Astronomical Society
Nachr. Ges. Wiss. Gottingen, Math.-Physik. Kl.	Nachrichten von der Gesselschaft der Wissenschaften zu Gottingen, Mathematisch-Physikalische Klasse
NASA (Natl. Aeron. Space Admin.)	National Aeronautics and Space Administration
Natl. Advisory Comm. Aeron., Tech. Notes	National Advisory Committee for Aeronautics, Technical Notes now NASA (Natl. Aeron. Space Admin.)
Natl. Bur. Standards (U. S.), Appl. Math. Ser.	National Bureau of Standards (U. S.), Applied Mathematics Series
Nature	Nature
Naturwissenschaften	Naturwissenschaften
Ned. Tijdschr. Natuurk.	Nederlandsch Tijdschrift voor Natuurkunde
Nuovo Cimento	Nuovo Cimento
Organ	Organ, Musical Opinion
Periodica polytech., Elect. Engng.	Periodica polytechnica (Electrical Engineering)
Philips Res. Repts.	Philips Research Reports
Phil. Mag.	Philosophical Magazine and Journal of Science
Phil. Trans. Roy. Soc. London	Philosophical Transactions of the Royal Society of London
Phys. Fluids	Physics of Fluids, The
Physica	Physica
Physics	Physics (name changed to Journal of Applied Physics, 1937)
Physik. Z.	Physikalische Zeitschrift
Physik. Z. Sowjetunion	Physikalische Zeitschrift der Sowjetunion
Phys. in Ind.	Physics in Industry
Phys. Rev.	Physical Review, The
Planetary Space Sci.	Planetary and Space Science

Pontif. Acad. Sci., Acta	Pontificia Academia Scientiarum, Acta
Portugaliae Phys.	Portugaliae Physica
Prikl. Mat. Meh.	Prikladnaya Matematika i Mehanika
Priroda	Priroda
Proc. Acad. Sci. Amsterdam	Proceedings of the Royal Academy of Sciences of Amsterdam (changed to, Proceedings Koniklijke Nederlandsch Akademie van Wetenschappen)
Proc. Cambridge Phil. Soc.	Proceedings of the Cambridge Philosophical Society
Proc. Imp. Acad. (Tokyo)	Proceedings of the Imperial Academy (Tokyo), name changed to Proceedings of the Japan Academy with Vol. 21, 1945)
Proc. I. R. E. (Inst. Radio Engrs.)	Proceedings of the Institute of Radio Engineers
Proc. Iraqi Sci. Soc.	Proceedings of the Iraqi Scientific Societies
Proc. Koninkl. Acad. Wetenschap.	Proceedings of the Koninklijke Akademie van Wetenschappen te Amsterdam (name changed to below)
Proc. Koninkl. Ned. Adad. Wetenschap.	Proceedings Koninklijke Nederlandsch Akademie van Wetenschappen
Proc. Math. Phys. Soc. Egypt	Proceedings of the Mathematical and Physical Society of Egypt
Proc. Natl. Acad. Sci. U. S.	Proceedings of the National Academy of Sciences, U. S.
Proc. Natl. Inst. Sci. India	Proceedings of the National Institute of Sciences of India
Proc. Phys.-Math. Soc. Japan	Proceedings of the Physico-Mathematical Society of Japan
Proc. Phys. Soc. (London) A	Proceedings of the Physical Society (London), Series A
Proc. Phys. Soc. (London) B	Proceedings of the Physical Society (London), Series B
Proc. Roy. Soc. Edinburgh A	Proceedings of the Royal Society of Edinburgh, Section A, Mathematics and Physical Sciences
Proc. Roy. Soc. (London) A	Proceedings of the Royal Society (London), Series A, Mathematical and Physical Sciences
Proc. Roy. Soc. (London) B	Proceedings of the Royal Society (London), Series B, Biological Sciences
Publ. Astron. Soc. Pacific	Publications of the Astronomical Society of the Pacific

Quart. Appl. Math.	Quarterly of Applied Mathematics
Quart. J. Mech. Appl. Math.	Quarterly Journal of Mechanics and Applied Mathematics
Quart. J. Roy. Meteorol. Soc.	Quarterly Journal of the Royal Meteorological Society
Quart. Rev. (London)	Quarterly Reviews (London)
R C A Rev.	R C A Review
Rech. Aeron.	Recherche aeronautique, La
Rept. Aeronaut. Research Inst., Tokyo Imp. Univ.	Report of the Aeronautical Research Institute, Tokyo Imperial University
Rept. Progr. Phys.	Reports on Progress in Physics
Research (London)	Research (London)
Rev. acoust.	Revue d'acoustique
Rev. Fac. Sci. Univ. Istanbul	Revue de la faculte des sciences de l'universite d'Istanbul (Istanbul Universitesi Fen Fakultesi Mecmuasi)
Rev. Gen. Elec.	Revue generale de l'electricite
Rev. Sci.	Revue scientifique, La
Rev. Sci. Instr.	Review of Scientific Instruments, The
Rev. Mod. Phys.	Reviews of Modern Physics
Ric. Sci. e Ricostruz.	Ricerca scientifica e ricostruzione (name changed to Ric. Sci., 1948)
SB Osterr. Akad. Wiss. Mat.-nat. Kl. Abt. II	Sitzungsberichte. Österreichische Akademie der Wissenschaften. Mathematisch-naturwissenschaftliche Klasse. Abteilung II (Austria)
Schweiz. Arch. Angew. Wiss. Tech.	Schweizer Archiv fur angewandte Wissenschaft und Technik
Sci. Cult. (Calcutta)	Science and Culture (Calcutta)
Science	Science
Sci. Papers Inst. Phys. Chem. Res. (Tokyo)	Science Papers of the Institute of Physical and Chemical Research (Tokyo)
Sci. Progr. (London)	Science Progress (London)
Sci. Rept. Res. Inst., Tohoku Univ.	Science Reports of the Research Institutes, The, Tohoku University
Sci. Rept., Tohoku Univ., Fifth Ser. (Geophys.)	Science Reports of the Tohoku University, Fifth Series (Geophysics)
Sci. Sinica (Peking)	Scientia Sinica (Peking)
Slaboproudy Obzor	Slaboproudy obzor

Soviet Phys. Acoust. English Transl. Soviet Phys. "Doklady"	Soviet Physics Acoustics English translation of the "Physics Section" of Doklady Akadamiya Nauk SSSR
Soviet Phys. Tech. Phys. English Transl.	Soviet Physics-Technical Physics
Tellus	Tellus
Terrestrial Magnetism and Atm. Elec.	Terrestrial Magnetism and Atmospheric Electricity (changed to Journal of Geophysical Research, Vol. 54, 1949)
Trans. Am. Geophys. Union	Transactions of the American Geophysical Union
Uchenye Zapiski, Lenigrad. Gosudarst. Pedagog, Inst.	Uchenye Zapiski, Leningradskii Gosudarstevennyi Pedagogicheskii Institut
Uspekhi Fiz. Nauk	Uspekhi Fizicheskikh Nauk
Verslag Gewone Vergader. Afdel. Natuurk., Koninkl, Ned. Akad. Wetenschap	Verslag van de Gewone Vergadering der Afdeeling Natuurkunde, Nederlandsche Akademie van Wetenschappen
Vestn. Mosk. Univ.	Vestnik Moskovskogo Universiteta
Weather	Weather
Weatherwise	Weatherwise
Z. angew. Math. Mech.	Zeitschrift fur angewandte Mathematik und Mechanik
Z. Angew. Math. Phys.	Zeitschrift fur angewandte Mathematik und Physik (same as ZAMP)
Z. angew. Phys.	Zeitschrift fur angewandte Physik
Z. Geophysik	Zeitschrift fur Geophysik
Zh. Eksperim. i Teor. Fiz	Zhurnal Eksperimental'noi i Teoreticheskoi Fiziki
Zhur. Tekhn. Fiz.	Zhurnal Tekhnicheskoi Fiziki
Z. Meteorol.	Zeitschrift fur Meteorologie
Z. Naturforsch.	Zeitschrift fur Naturforschung
Z. Physik	Zeitschrift fur Physik
Z. Physik. Chem.	Zeitschrift fur physikalische Chemie
Z. tech. Phys.	Zeitschrift fur technische Physik
Z. Ver. deut. Ing. (VDI)	Zeitschrift des Vereines deutscher Ingenieure