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A REVIEW OF NUISANCE AND HAZARDOUS NOISE

S. Steven Kushner
Research Associate

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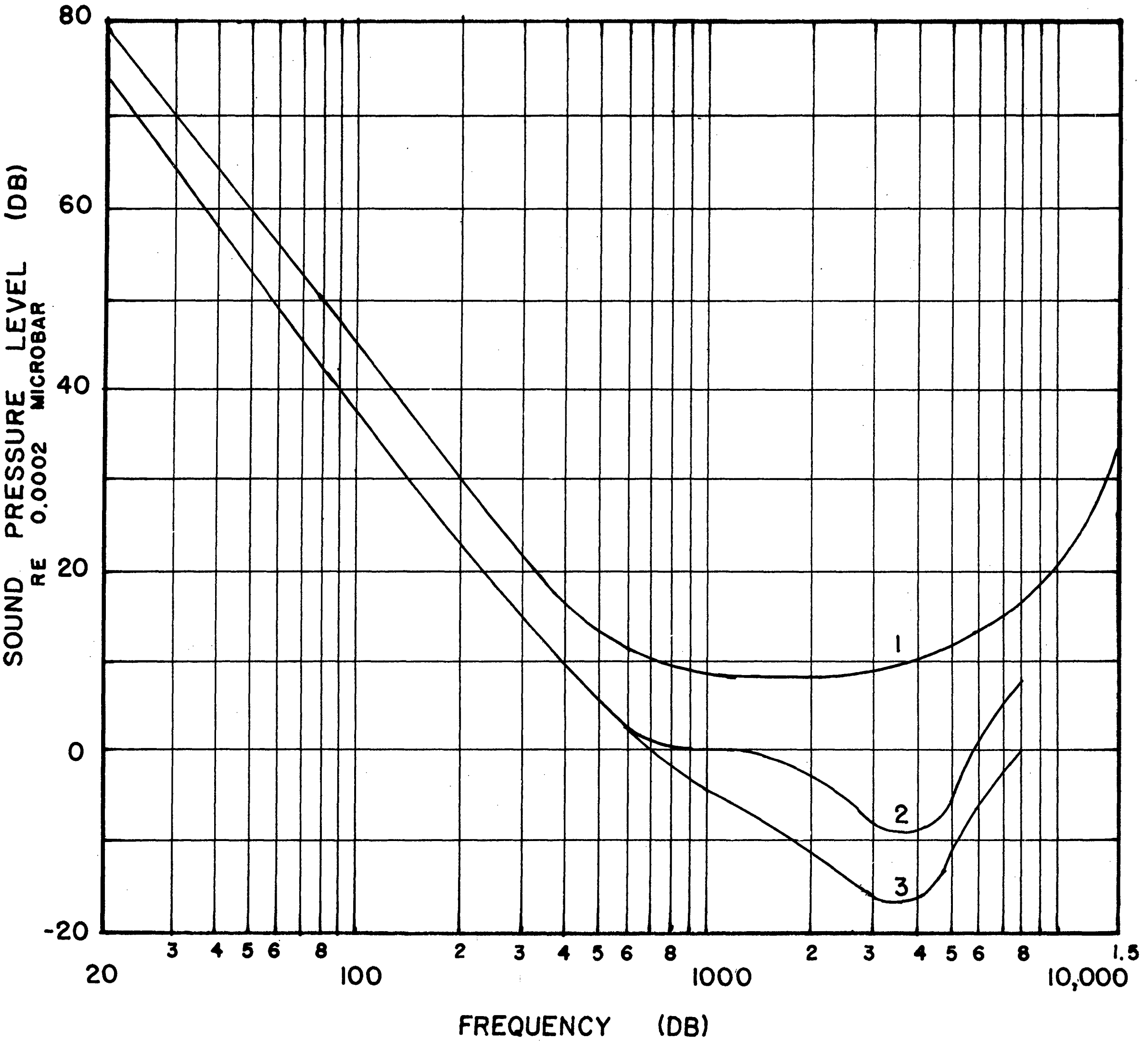
INTRODUCTION

In a literature review pertaining to nuisance and hazardous noise levels, it is first necessary to define what is meant by nuisance noise and what may be categorized as hazardous noise. As may be expected, there is no clear-cut separation between these two terms. Indeed, the transition is a gradual one with parameters of sound-level spectrum, individual acuity, exposure time, and the like.

In a general sense, nuisance noise may be characterized as noise encompassing a spectrum and range of levels which is irritating and inconveniencing but which produces no serious auditory effect over an extended period of time. This is the usual case of noises of 85 db (re 0.0002 dynes/cm^2) and below. On the other hand, hazardous noises are usually of a level greater than 85 db and produce either auditory or nonauditory physiological reactions or both, depending on their character. It should be remembered, however, that the labeling of a sound as merely nuisance noise might be severely questioned by personnel losing a limb due to a masking of the communication channel by a low-level noise. A more quantitative description of a noise relative to hazard and nuisance can be obtained by categorizing the spectrum content and level of the noise with respect to its effect upon the exposed individual. For this reason, this literature review has dealt with the problem of environmental noise and its ensuing effects upon man through a discussion of the following topics: masking effects, temporary and permanent hearing loss (or threshold shift), annoyance, the use of protective devices, and nonauditory levels, and effect of high-level noise on the individual. To provide a basis for better understanding of the subjects which will be discussed, some general basic information on the reaction of the human ear to various sounds follows.

Audible Range--The audible frequency region is usually considered to be from 50 cps to 15,000 cps, although the limits vary from person to person, and, for a particular individual, depend on time and environment. The sensitivity of the ear is remarkable since in the vicinity of 3000 cps it responds to sound pressures as low as 10^{-4} dynes/cm^2 (which is -6 db re 0.0002 dynes/cm^2). On the other hand, a pressure of 300 dynes/cm^2 (or 120 db) corresponds to a noise level which results in only mild discomfort to the listener.

Threshold of Hearing--For practical purposes it would be of interest to investigate the response of the ear to everyday sounds, that is, to sounds which are complex in character. A useful method of specifying the sensitivity of the ear to these sounds is to determine the lowest sound pressure that is detected by the ear, i.e., to determine the threshold of hearing. Although such determinations are complex, simplified measurement methods have resulted in the establishment of threshold-of-audibility curves as shown in Figure 1[1]. The American Standard pure-tone curve shown is obtained by measuring the sound-pressure level in an anechoic chamber at a point in the center of the head position at a specified distance from the sound source with no one in the room. The binaural response of the individual is



1. Monaural curve (Ref. 52)
2. Binaural curve (Ref. 53)
3. Binaural curve (Ref. 54)

Figure 1. Threshold of Audibility Curves

then plotted in db versus frequency. Notice that this curve crosses the 0-db level at 1000 cps and that the most sensitive ear response lies between 1000-6000 cps. Curves obtained by two other threshold detection methods are also shown in Figure 1. Since the speech frequencies are predominant in the middle range of the spectrum, audiometric tests are usually conducted in this range, i.e., between 100-8000 cps.

Threshold of Tolerance--At the other extremity of level response lies the threshold of tolerance. This is a difficult term to define because of the reaction of the ear. Here, as well as at low sound-pressure levels, exposure of the ear to sound tends to elevate the threshold limits under examination. Attempts to set limits of discomfort, tickling sensations, and pain have shown that sound-pressure levels of pure tones adjusted to correspond to these limits and applied through earphones had to be increased as the experiment progressed. Figure 2 shows the results of several experiments along this line.[2] Because of this indefiniteness, the most that can be stated is that for pure tones there exists a threshold for tickling sensations and pain above 140 db while the discomfort threshold varies between 120-130 db. Any attempt to set up a criterion for establishing an overall standard must be tempered by both the physiological and psychological reactions of the human auditory system with respect to body functions, exposure time, sound spectrum, presentation, etc.

Pitch--Pitch may be defined as the response of the ear which differentiates sound as they appear on a musical scale, the unit of

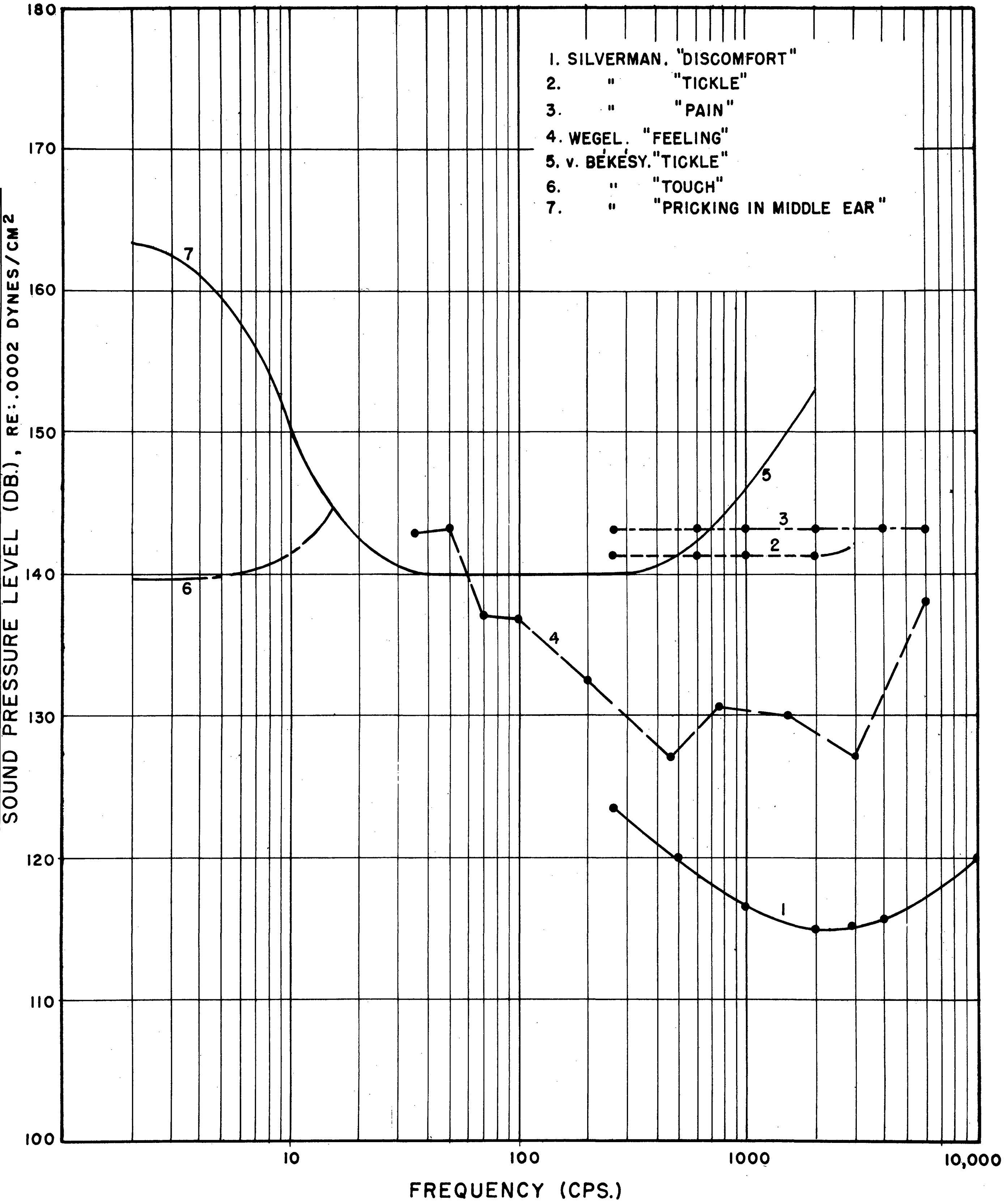


Figure 2. Threshold of Tolerance Curves

pitch being the mel. Pitch is not a simple functional response of the ear, and though related to frequency, pitch is also influenced by the spectrum and amplitude of sounds. That is, sounds of the same frequency composition but of different levels do not have the same pitch. As a result, the following arbitrary standard has been established: a 1000-cps tone of 60 db is said to be 1000 mels. Figure 3 gives the relation between the subjective pitch in mels versus frequency using a tone with a loudness level of 60 phons.[3]

Loudness--Loudness, although primarily a function of sound pressure also depends on spectrum content, and is the auditory sensation attribute which scales a sound from "soft" to "loud". The unit of loudness is the sone, which by definition is the loudness of a 1000-cps pure tone at 40 db above the listener's threshold.[4]

Loudness Level--Loudness level is measured in phons. By definition a phon is the sound-pressure level in db of a 1000-cps tone that seems as loud as the sound under test. Representative equal loudness-level contour curves are shown in Figure 4 for both pure tones and bands of noise. The relationship between loudness in millisones and loudness level in phons is demonstrated graphically in Figure 5.

MASKING

The ability of the ear to hear two sounds at one time is a physiological phenomenon. However, this function, which provides for the discrimination between sounds, is subject to the effect of imposing one sound on another. This causes one of the sounds to become indistinct,

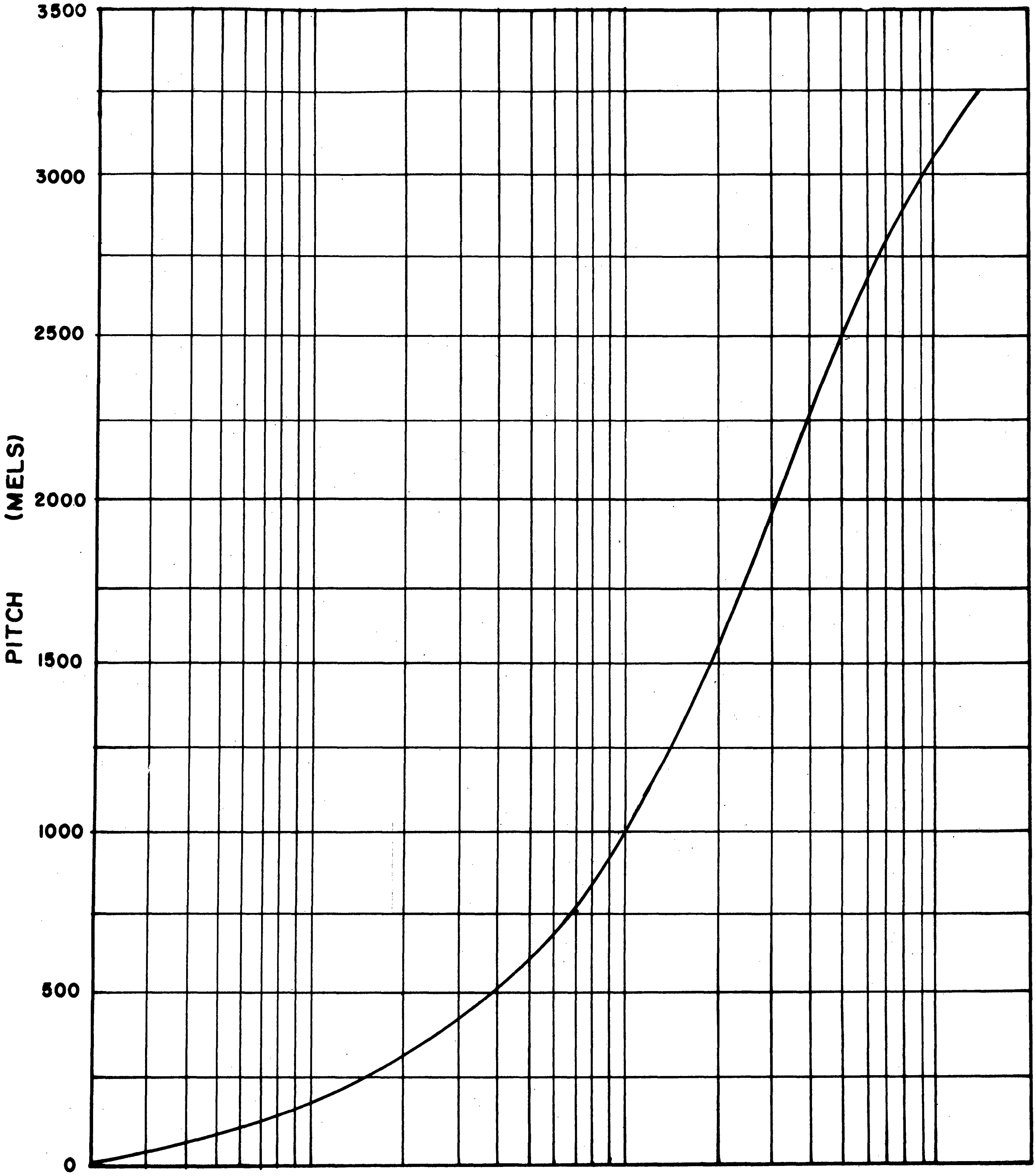


Figure 3. Pitch as a Function of Frequency

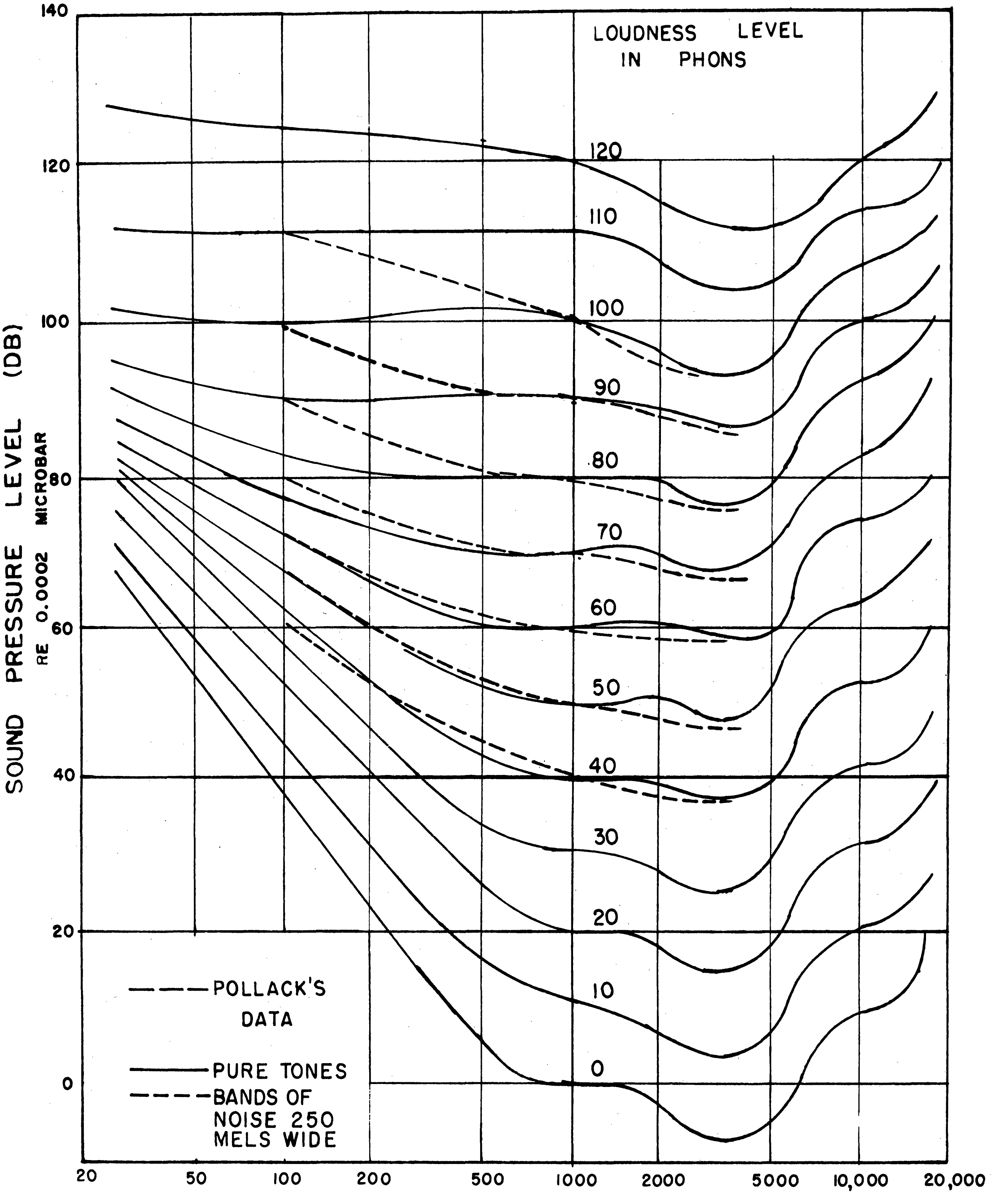


Figure 4. Equal Loudness Level Contours

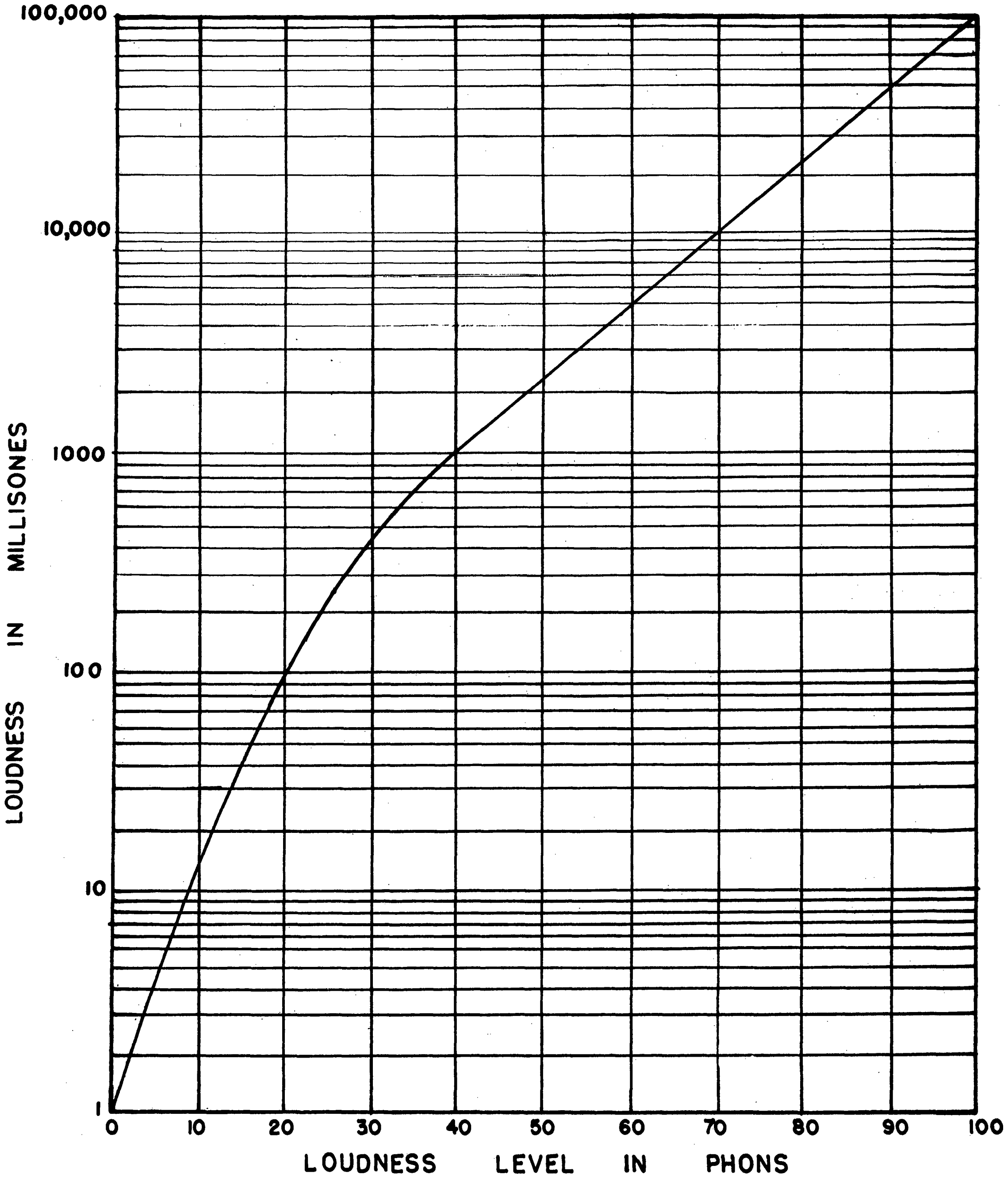


Figure 5. Loudness vs. Loudness Level

or, as it may be said, auditory masking has occurred. Auditory masking is best defined as "the shift of the threshold of audibility of a masked sound due to the presence of a masking sound."[5] For the purposes of this report the masked sound will be limited to speech and the masking sounds will, therefore refer to any other sounds which may interfere with the speech signals from a communications standpoint. In practice the detection and reduction of masking sounds may be undertaken by either of two general methods. The first is one in which an attempt is made to reduce the entire noise spectrum proceeding from the largest single contributor to the overall noise level, until a favorable reduction of the overall noise level has been obtained. The second method of reduction is aimed at those specific masking sounds which perform the masking function with respect to the human speech spectrum.

In some cases of noise-reduction problems, treatment of the noise source using each of the two criteria mentioned might well result in two different final noise spectra, the main difference being that the reduction with respect to specific masking sounds would result in a preferential reduction of the sounds below 5000 cps. In this respect, the noise spectrum generated by most Air Force ground-support equipment encompasses that portion of the audible spectrum in which masking is of primary concern, and fortunately, regardless of which procedural reduction method is employed, the end result is a reduction of the masking properties of the source with respect to human speech.

Speech Spectrum--To properly evaluate reduction of a masking sound, the speech spectrum should be studied and the effectiveness of the masking of the intrusive sound should be determined. Many different experiments have been undertaken with respect to the masking of speech, and rather than confuse the problem with the wide variety of experimental evidence available, an attempt will be made to use data of a few representative experiments, leaving to the reader the alternative of reading from supplementary references.

In general, the power distribution in the speech spectrum is concentrated, for the average male, between 100 and 5000 cps with the peak lying at approximately 500 cps. Figure 6 is the long interval speech spectrum of 7 male voices plotted in rms pressure for a bandwidth of 1 cycle.[6] This was obtained by utilizing a condenser microphone pickup located 18 inches in front of the lips and analyzing the resultant voltage with an audio spectrometer. The overall pressure at this point was 76 db with 1-cycle bandwidth variations from 47 to 16 db.

Filtering Function of the Ear--Measurements made by Bekesy indicate that different portions of the basilar membrane produce different amplitudes of vibration when exposed to different frequencies.[7,8] This is effectively a filtering action in the electrical sense of the word and allows the ear-response functions to be described in terms of bandwidth levels and response. Indeed, the critical bandwidths have been defined as those bandwidths in which a pure tone can be detected in the presence of white, random noise. With the availability of data on thresholds of audibility and perceptibility and the knowledge of the bandwidth character of the ear, rather thorough investigations of masking have been undertaken.

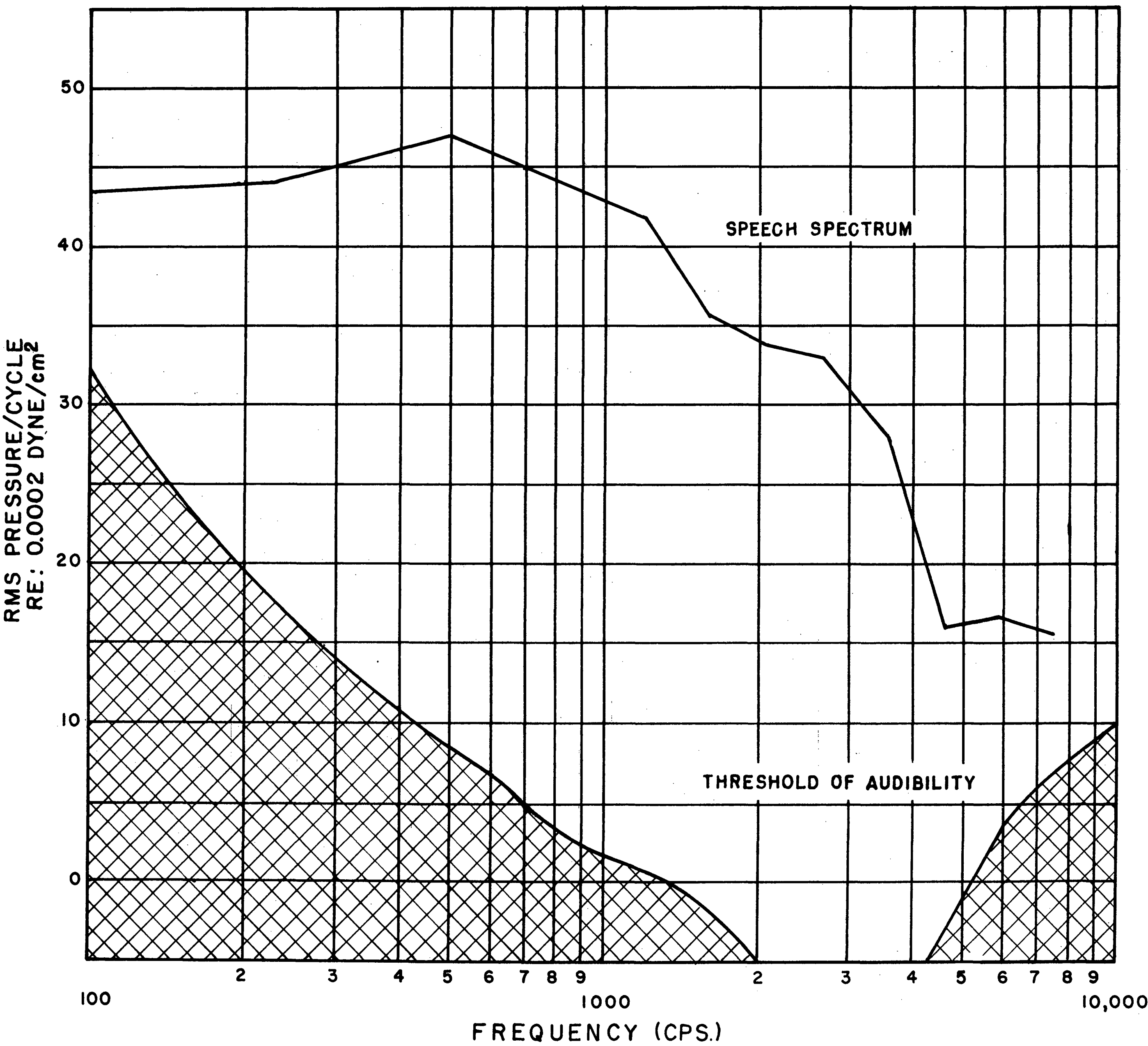


Figure 6. The Long-interval Speech Spectrum for Seven Male Voices

In his investigation of masking,[6,9] Miller, et al., used the threshold of perceptibility as the identifying level. This threshold is the level at which the gist of continuous speech discourse can just be understood. Using this simple criterion, listeners were instructed to determine the threshold of perceptibility for speech when various sounds were used as maskers. Figure 7 shows the masking of speech by pure tones of 300 cps and 1000 cps, and by random noise. Notice that a pure tone of 1000 cps at 100 db raises the threshold 18 db, while a 300-cps tone of 100 db raises the threshold by 42 db, and random noise at 100 db raises the threshold by 68 db.

In an effort to obtain improved accuracy, articulation tests have been used. In this test, a speaker reads a series of words, or a recording of words is run off and the percent of words heard by the listener is called the articulation score, a 50% score being considered as the threshold level.

Masking of Speech by Pure Tones--Pure-tone masking was studied quite thoroughly by Steven, Truscott, and Miller.[9] It was found that the greatest masking occurs around 500 cps by sine waves, but at high intensities the largest masking is encountered at about 300 cps. This is due to the function of the ear which results in the upward spreading effect of maskers on the frequency scale. This has been pointed out to be the effect of distortion by harmonics produced in the ear at high levels and by auditory nerve response characteristics.[10,11,12]

Complex Tones--For practical purposes it is much more valuable to examine the available data on complex tones and noise. By using maskers

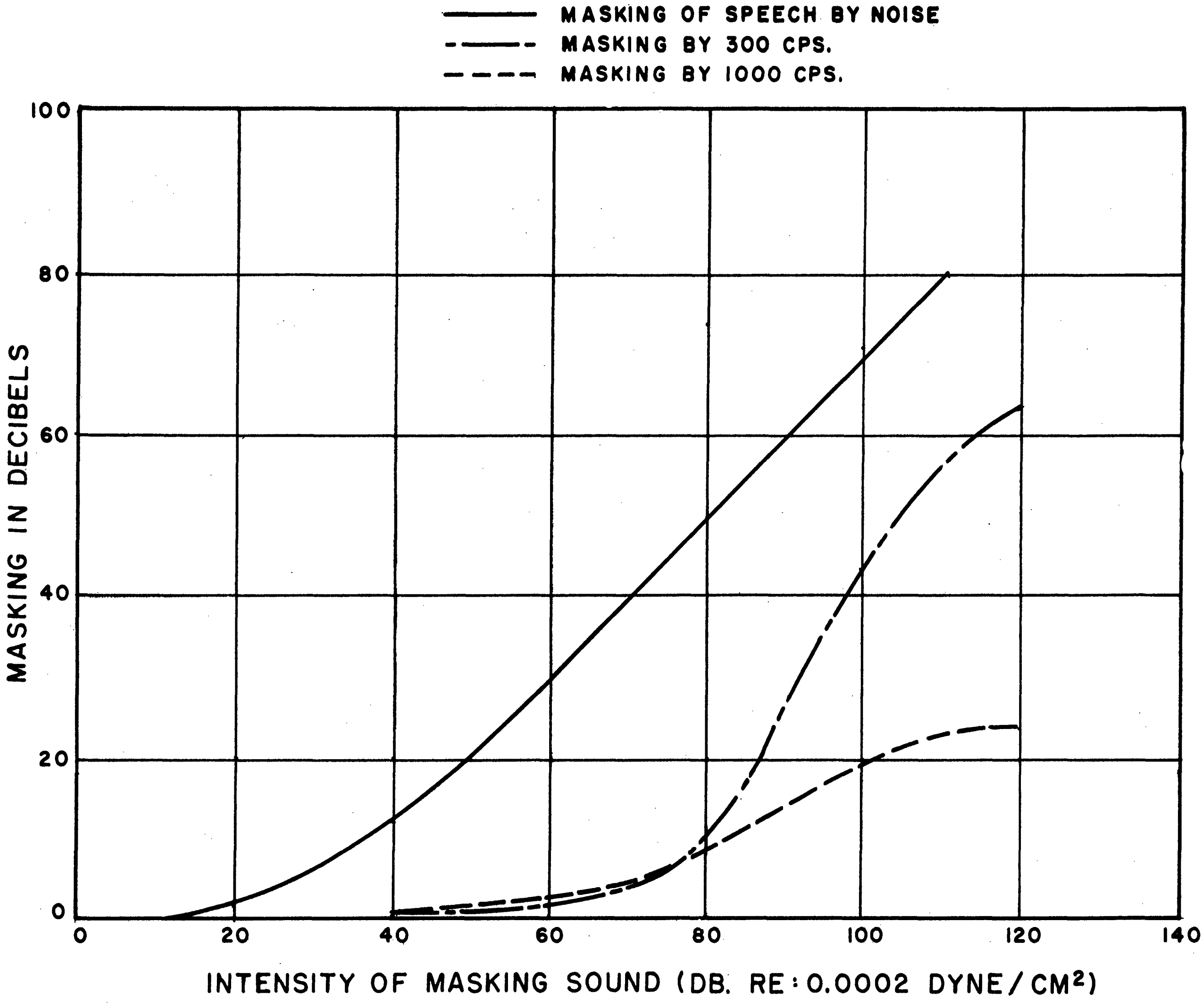


Figure 7. The Shift in the Threshold of Perceptibility for Speech vs. the Intensity of Different Masking Sounds

composed of square waves, it was shown that waves with fundamentals of 80 and 400 cps each have the same approximate masking ability, and are therefore less critical to frequency change then sine waves. Furthermore, there is no apparent optimum masking frequency for square waves as the intensity level of the maskers is increased.

Using 10-microsecond pulses at different repetition-frequency rates, it was found that the greatest masking occurs at approximately 200 pulses per second. Correlation of the above data showed that for equal sound-pressure levels the pulsed masker is the most effective, and is 7 db more effective as a masker for speech than the square wave, which in turn is 7 db more effective than the sine wave.

Further experimentation with complex tones of high harmonic content was carried out, using a warble-tone relaxation oscillator in which the tone rose slowly from the lowest to the highest frequency, and then dropped quickly back. With the speech output maintained at 95 db, the warble tone was raised in 6-db steps under different experimental conditions. Figure 8-a is a plot of warble-tone frequency band versus percent articulation. Notice that the lowest band of 170 to 220 cps is by far the most effective masker, showing 50-percent articulation at approximately 7 db above the speech level, whereas the 550-750 cps band showed 50-percent articulation at a level of 20 db above the speech output.[6]

Figure 8-b shows the masking comparison of three warble tones of the same mid-frequency and the same warble rate, but of different bandwidth. There is little difference between the 400- to 500-cps warble and

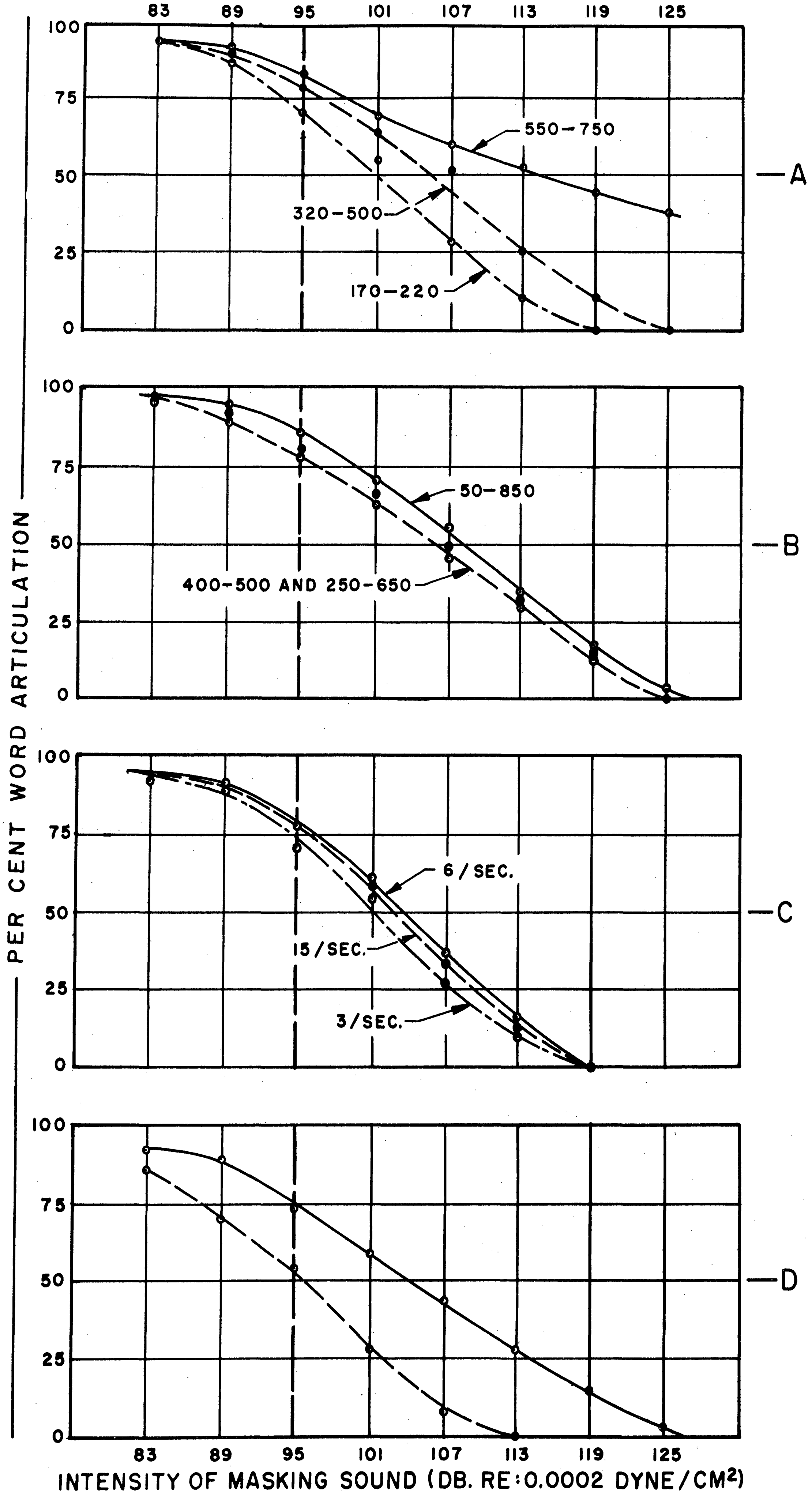


Figure 8. Percent of Words Correctly Heard as a Function of the Intensity of Various Tonal Masking Sounds

the 250- to 650-cps warble, but the 50- to 850-cps warble shows some decrease in masking ability. Obviously, this is due to the warble spread into the higher frequencies of smaller masking ability.

When the warble rate is varied between three and fifteen warbles per second, there is no significant difference in the masking quality of the warble. This is shown in Figure 8-c.

Another experiment was performed in which complex tones ranging in fundamental frequency from 300-600 cps were repeated in an irregular pattern. From Figure 8-d, an increased masking of 10 db can be observed when a complex tone of 200 cps is added.[6]

From the experiments outlined above it may be observed that, for both pure and complex tones, the low tones are more effective in masking speech, since low-frequency sounds tend to mask upward on the frequency scale as their intensity is increased, whereas high-frequency maskers do not effectively mask down scale.

Masking _of_ _Speech_ _by_ _Noise_--As was shown in Figure 7, random noise is a more effective masker than a pure tone of the same sound-pressure level. Figure 9 shows the results of resolving noise into narrow bands and obtaining the masking ability of each band using a 96-db speech-level output. From this plot several facts are evident: (a) a wide band of noise covering the entire speech spectrum masks more effectively than any single noise band within the spectrum; (b) at low noise levels, high-frequency noises are better maskers than low-frequency noises; and (c) at high noise levels, low-frequency noises are better maskers than high-frequency noises. Result (a) is easily

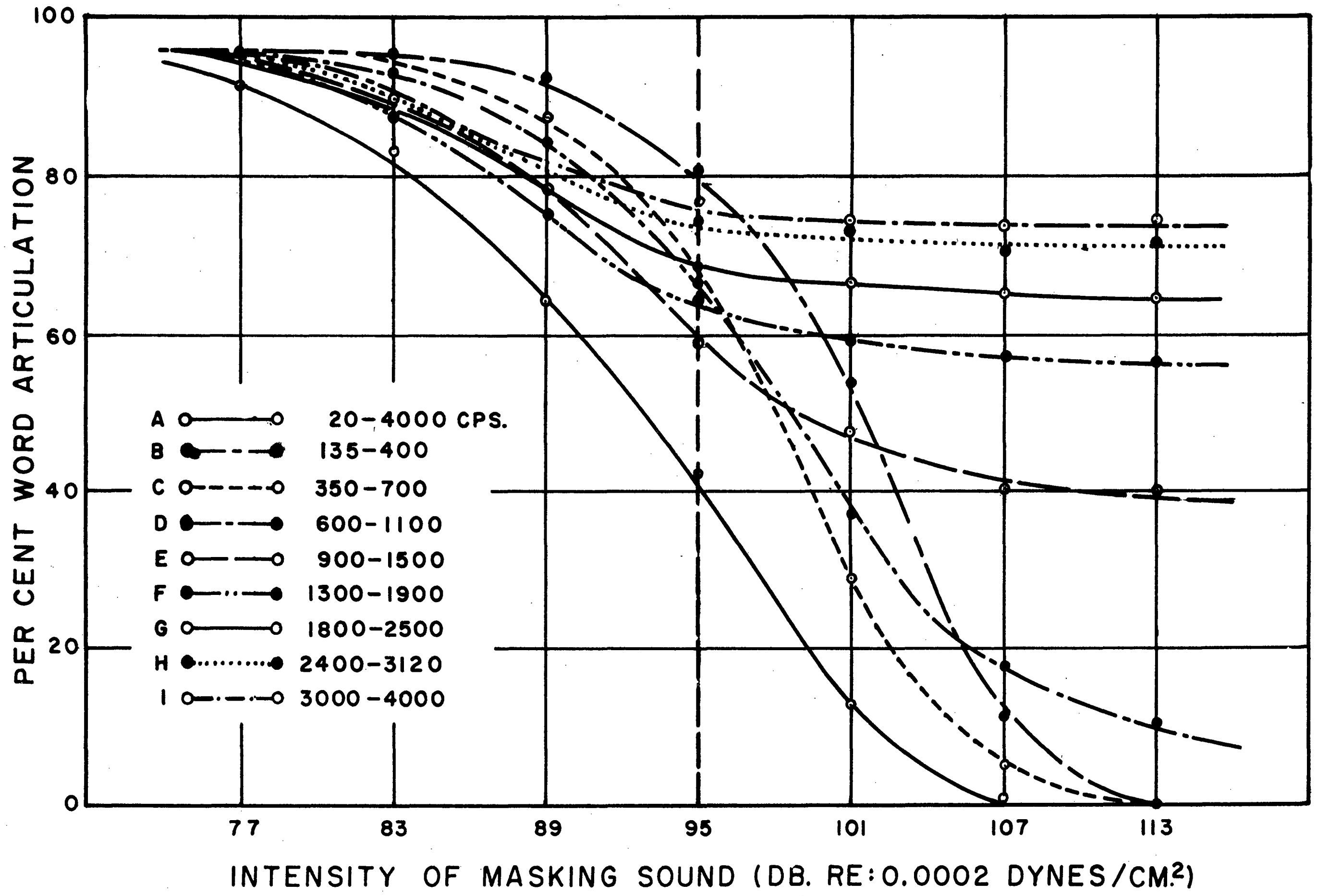


Figure 9. The Articulation Score as a Function of the Intensity of the Masking Noise of Various Bandwidths on a Speech Level of 95 db

understood since it would be expected that the masking of speech would be much more effective by a sound whose frequency range covered the output spectrum of human speech. Results (b) and (c) are explained by two facts which have been previously observed. They are that only low frequencies of high-pressure levels tend to extend their masking into higher frequency ranges, and also that the speech spectrum shows a high output in the low-frequency regions and low output in the high-frequency regions. Thus, for low masking-noise levels, the high-frequency noise masks the upper frequencies of speech, whereas the low-frequency noise is not able to mask effectively the low frequency of speech. However, as the masking-noise intensity increases, the high-frequency noises now not only mask the low speech frequencies but also extend the masking into the higher frequencies.

Some other experiments concerning the masking properties of noise versus noise content include modulating a random noise by switching filters in and out, and by comparison of two noises having identical spectra but different wave forms.[6] In the first case the modulated noise did not change the articulation score obtained, and in the second case little variance in masking ability was noted between identical spectra of random noise and frequency-modulated noise.

Among other masking experiments of note, but which do not bear as directly upon the ground-support noise problems, are interaural phase variations in binaural perception of sounds and the interaural phase relations between speech and masking noise at the ear.[13,14]

Time Variation of Noise in the Masking of Speech--Investigation of the tempral continuity of masking noise has revealed two interesting facts, that the masking function of the noise is related both to the amount of time the noise is present, and to the actual interruption rate of the noise. Figure 10 shows that a steady noise is a more effective masker than the same noise present at only a percentage of the steady-state condition. A noise which is on for 65 percent of the time must have a level of better than 120 db to reduce the articulation score to 50 percent with a 95-db speech level, whereas a continuous noise of only 95 db results in the same articulation score.[6]

The interruption rate of noise has also been studied; it has been determined that for noise interrupted at a rate of 1-100 times per second the masking effectiveness is substantially reduced from that obtained using a continuous masker, whereas interrupted noise at rates of 200 times per second and above shows a masking essentially equivalent to that of continuous noise.[15]

Speech Interference Levels--Since articulation tests are a tedious undertaking and vary with sentence or word presentations, it was found possible to correlate the contribution of the speech spectrum by bands taking into account the speech-to-noise ratio in the band, and using weighting factors to give an articulation index.[16] This presents a computation problem and in itself is a significant task. Indeed, the problems of incorporating narrow band noise and repetitive sounds are yet to be evolved accurately. In lieu of the articulation index a more

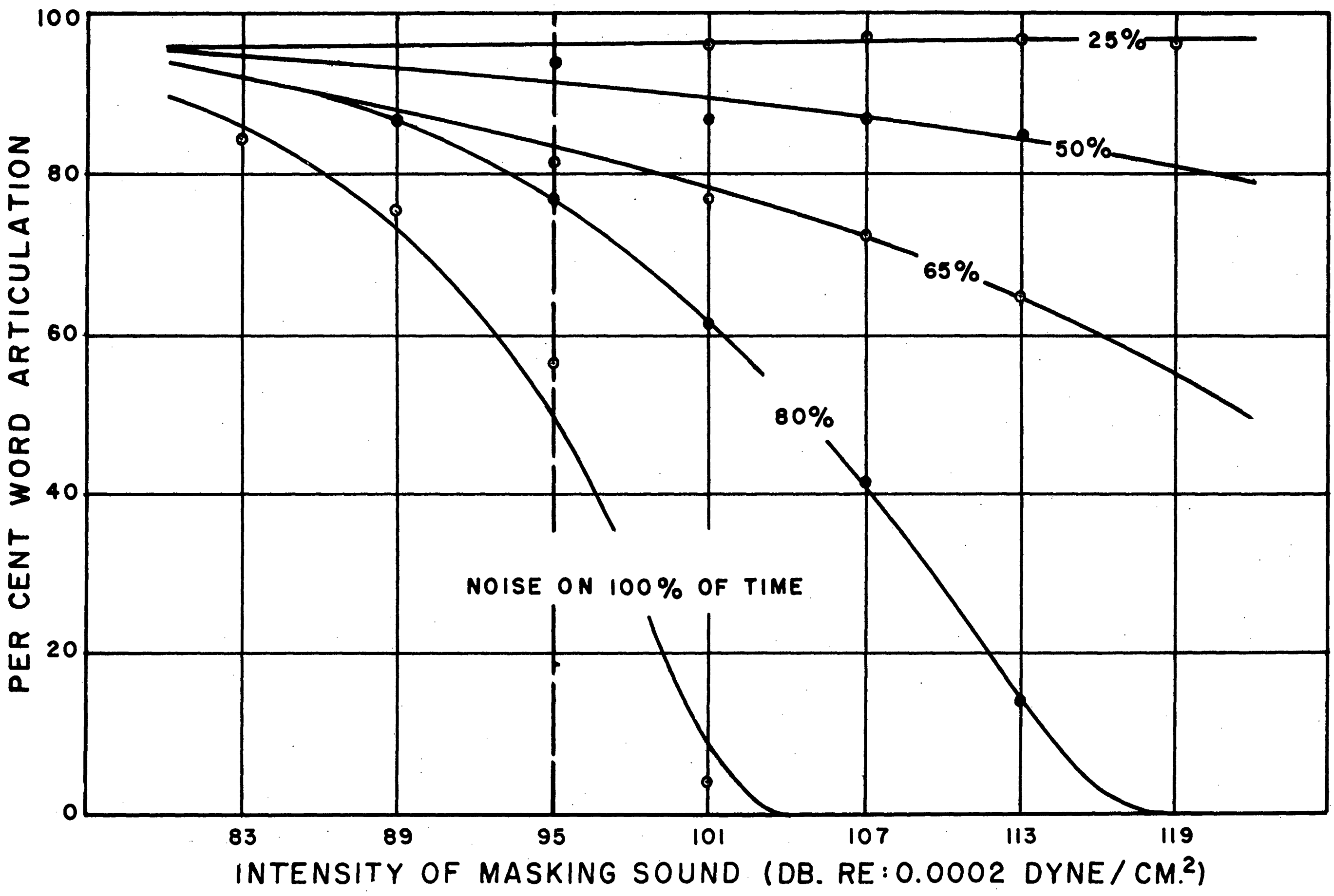


Figure 10. The Articulation Score as a Function of the Intensity of Interrupted Masking Noises and Percent Time of Masking for a Speech Level of 95 db

simplified standard has been suggested. This is the speech interference level. Since approximately 80 percent of the most important range of speech frequencies is covered in the range of 600 to 4800 cps, this range has been divided into three octave bands of 600-1200, 1200-2400, and 2400-4800 cps, the speech interference level of a masking noise being defined as the arithmetic average of the sound-pressure levels in these three bands.[17,18,19] Since sound-pressure levels are often measured in octave bands for a rapid and first approximation of the pervailing noise level, the use of speech interference levels may be practical.

From Figure 11 it can be seen how readily the speech interference bands mentioned above cover the speech spectrum.[19,20] By obtaining the masking noise levels in the three bands, it is possible to obtain the articulation index with a fair degree of accuracy. It may also be noted from Figure 11 that if the audible speech spectrum lies in a shaded portion above the threshold of hearing and the ambient noise, but is below the overload area, then the articulation index will be 100 percent. However, if the masking noise covers some of the shaded region, falls below the threshold of hearing, or is above the overload line, then the articulation index will be less than 100 percent. Thus, its rating would be 43 db, and then for a speech level as shown of approximately 69 db, there would be no effect on the intelligibility of the speech.

By taking into account (1) the speech interference level of the masking noise, (2) the level of the speaker's voice, (3) the distance from the speaker's mouth to the listener's ear, and (4) the type of vocabulary used, Table I was tabulated for speech interference levels which

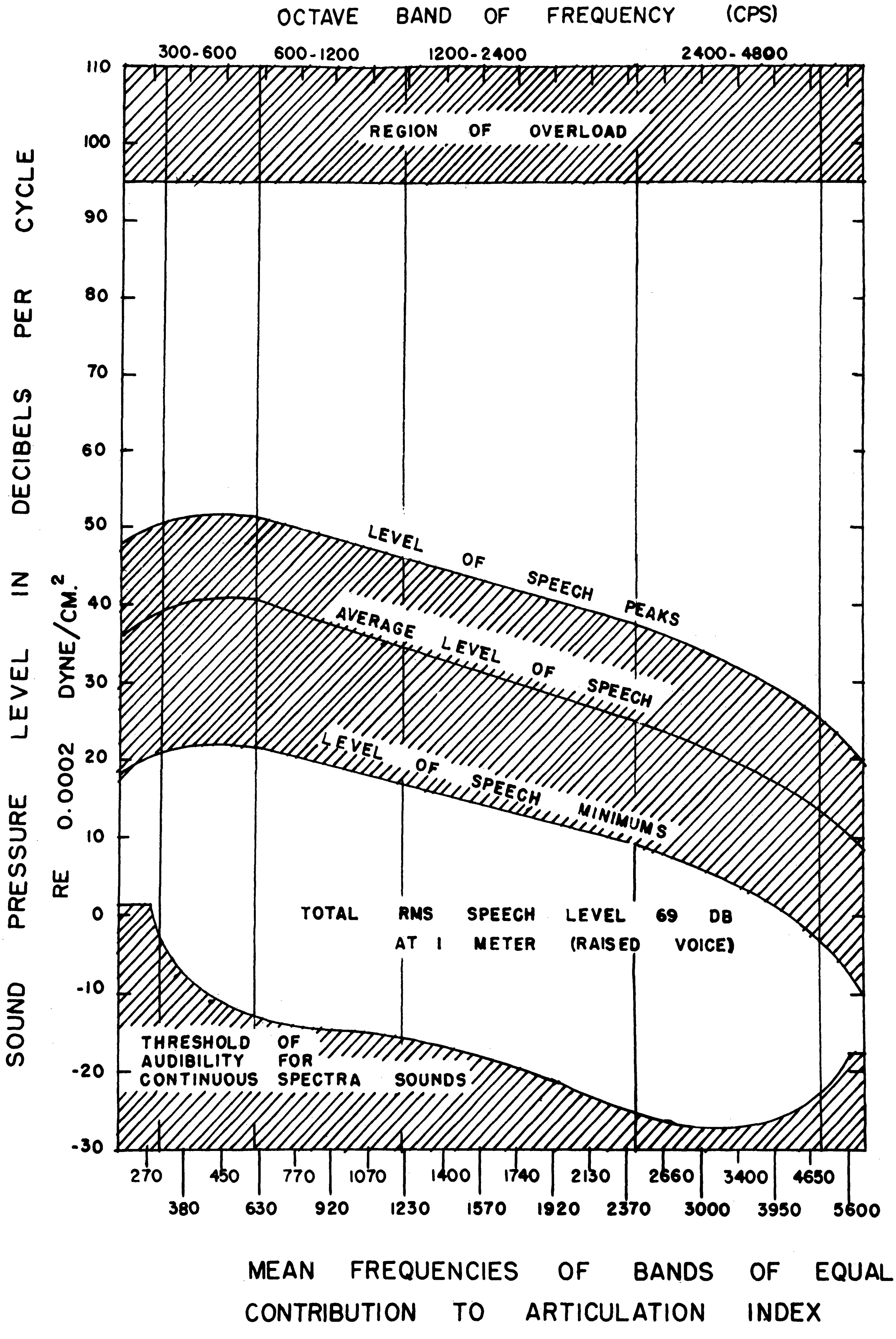


Figure 11. Chart for Computing Articulation Index for Speech

TABLE I. SPEECH COMMUNICATION CRITERIA[2]

Relation between SC criteria expressed by speech interference levels (SIL) and the communication conditions for a degree of intelligibility that is marginal with conventional vocabulary and good with selected vocabulary.

SIL in Decibels	Voice Level and Distance	Nature of Possible Communication	Type of Working Area
45	Normal at 10 ft	Relaxed conversation	Private offices, conference rooms
55	Normal at 3 ft	Continuous in work areas	Business, secretarial, control rooms of test cells, etc.
	Raised at 6 ft		
	Very loud at 12 ft		
65	Raised at 2 ft	Intermittent	
	Very loud at 4 ft		
	Shouting at 8 ft		
75	Very loud at 1 ft	Minimal (danger signals; restricted prearranged vocabulary desirable)	
	Shouting at 2-3 ft		

barely permit reliable conversation at the distances and voice levels noted.[2,19,21] It must be remembered that the lower frequencies, that is, those below 600 cps, are not taken into consideration and, as has been demonstrated, low-frequency high-intensity sounds are excellent maskers. It must also be noted that attempts to employ speech interference levels will be in error if the masking sound is repetitive, pure tone, or shows some peculiar spectrum. To take low-frequency masking components into account, speech communication criterion (SC) curves have been formulated and extrapolated to low frequencies. Figure 12 is an SC plot of sound-pressure levels in bands versus frequency. To illustrate the use of the information presented, the SC 45 curve designates the octave-band level permissible if a condition of sound interference level of 45 is to be obtained. From the foregoing discussion one may observe that it is possible to categorize certain sounds as effective maskers. Therefore, information such as given by SC curves has a definite value to the noise-reduction engineer when he is confronted with a particular noise-masking problem.

TEMPORARY AND PERMANENT HEARING LOSS

In the discussion of masking, the interference effect of a sound during its presence was systematically investigated. If the temporal aspect of the measurement procedure was to be changed so that the auditory response was to be measured following the termination of the interfering sound, the problem under investigation would now be the post exposure response of the auditory system. As such, the measuring procedure becomes somewhat more complex. Since the prime objectives of post exposure auditory measurements are to assay both temporary and permanent hearing losses, the complexity of the measurements is greatly increased, especially with respect to testing for permanent hearing loss, because of the accompanying continuous pathological changes in the auditory system as well as possible psychological changes.

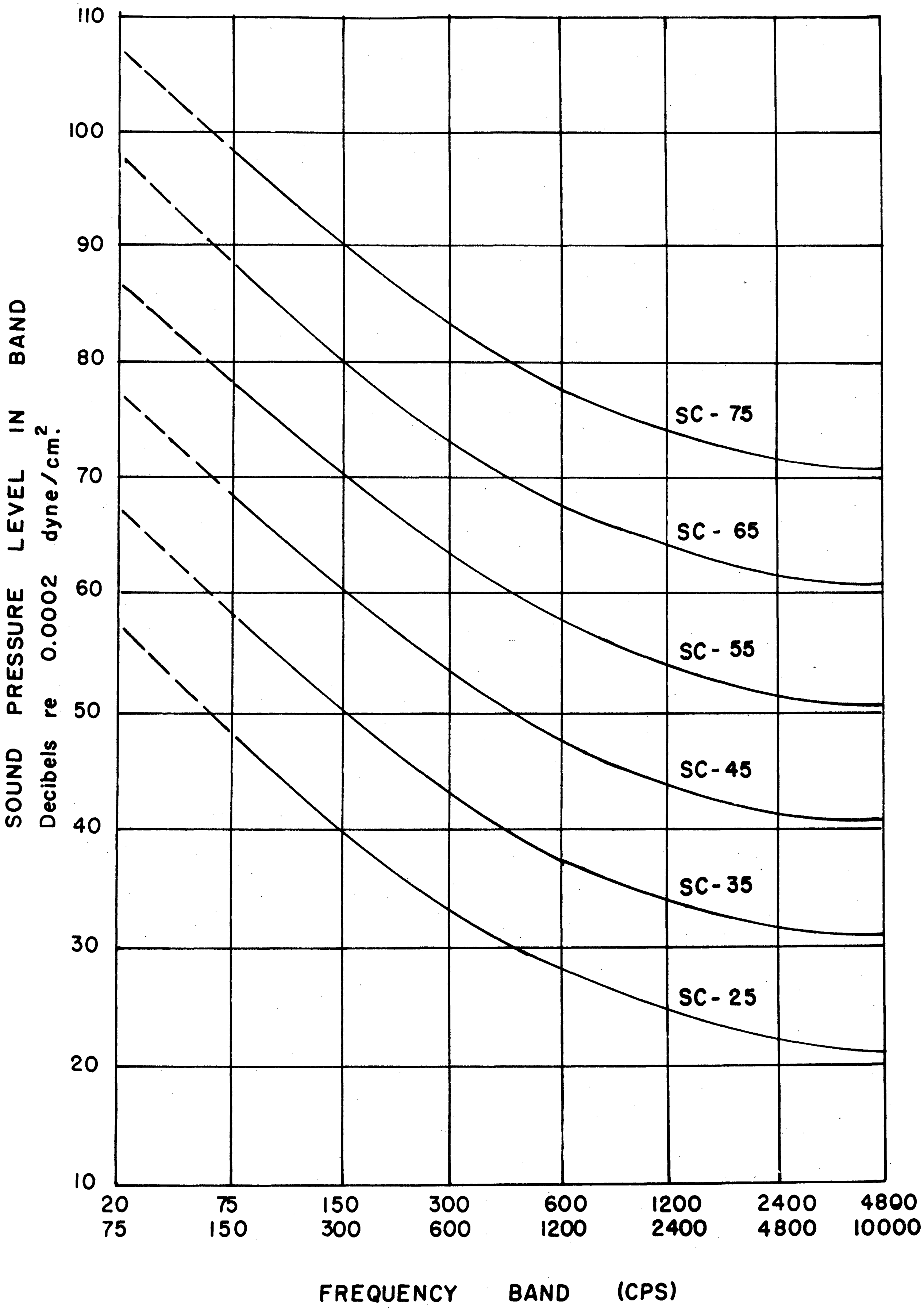


Figure 12. Curves for Speech Communication Criteria

Thus far, there is no absolute time limit accepted as valid for measurement of either temporary or permanent hearing loss. However, many experiments have been carried out and considering the number of variables involved, a certain pattern in information concerning post exposure hearing loss has become apparent. The general statement can be made that both temporary and permanent hearing loss are linked to the intensity and frequency of the noise as well as the duration of exposure. It has been proposed that the minimum sound-pressure level of noise below which no hearing loss occurs is approximately 85 db.[22] This does not mean that any noise above this level is certain to produce a hearing loss. Indeed, the consequences of exposure to noise varies not only with the individual but also with respect to each ear of the individual. Another factor involved in the specification of hearing loss is that of adaptation, meaning here that property of the auditory system which decreases the auditory response in the presence of continuous high-level noise (from an initial peak value). However, adaptation ought not to be accepted as beneficial for ear protection, even though the auditory response is reduced, since it does not necessarily offer any measure of physical protection for the auditory system.

Keeping in mind the diverse number of parameters involved, and the literally hundreds of experiments which have been undertaken, it is to be realized that this survey of hearing loss will attempt only to summarize the results of past efforts and to incorporate the data of more recent reports. Hearing loss and its permanency has been a chief concern of the American Academy of Ophthamology and Otolaryngology. The guide which it has set up as a conservation-of-hearing tool in the industrial field is applicable in many other fields.[23] A recent ASA publication presents an excellent reference to the relationship between high-intensity noise and man.[24]

Temporary Hearing Loss--Hearing loss may be a reversible phenomenon. If a person is exposed for a time to high-intensity noise, he may suffer a hearing loss; if he is then removed to quiet surroundings, his hearing may return to normal after a period of time. The man has experienced a temporary hearing loss or temporary threshold shift. The same experiment may be repeated and the same results obtained. However, if the conditions are varied so that the man is returned to the noise environment before recovery, an added increment of hearing loss will be incurred, and this loss plus the loss which remained upon reexposure demands an even longer quiescent recovery period. Upon continuation of these conditions a point of no return is reached and the subject has suffered a permanent threshold shift. It has been suggested that such a shift be considered permanent if the hearing loss is apparent after removal of the subject from the noise environment for a period of six months.[23]

The initial temporary threshold shift usually occurs in the higher range of frequencies (that is, above those frequencies most useful for speech perception), and gradually moves into the lower frequencies. However, the spectrum and the level of the noise to which the subject is exposed has a determining factor on the threshold shift. For instance, Figure 13 gives the temporary hearing loss for a

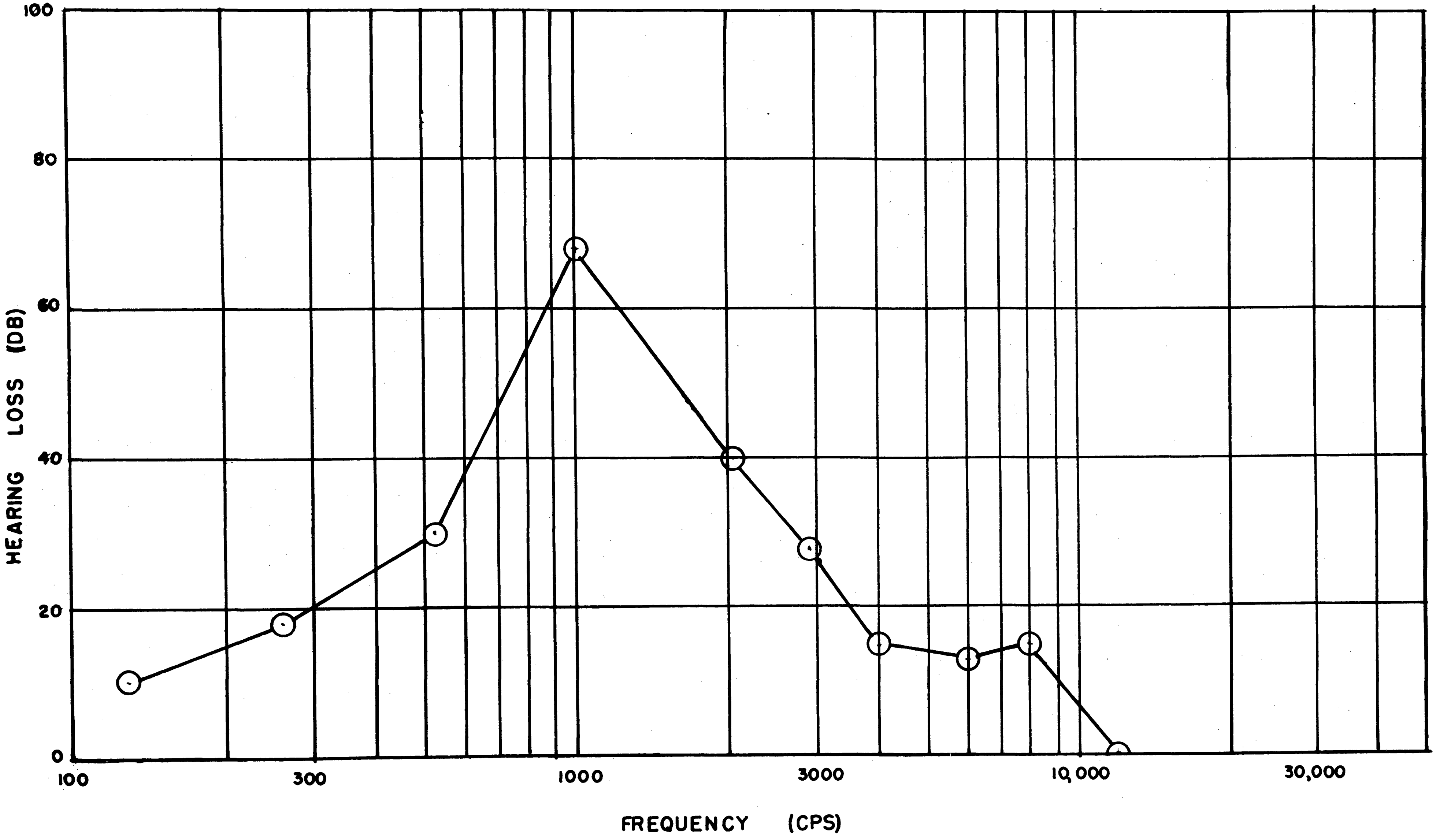
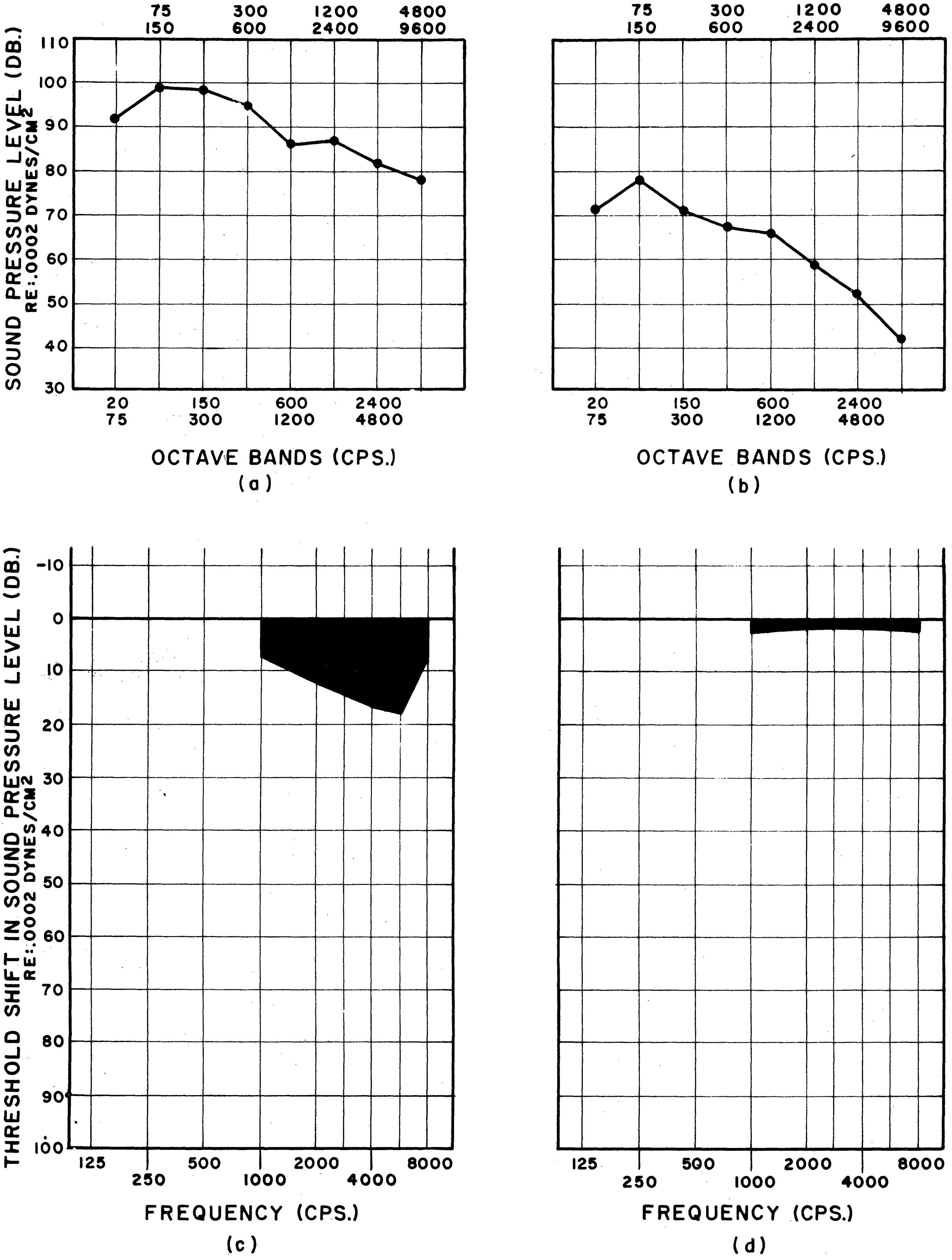


Figure 13. Temporary Hearing Loss After a 10-minute Exposure to a 146 db Jet Engine Noise Source

subject exposed for ten minutes to an intense jet-engine noise source of 146 db.[25] Notice that the peak loss, some 68 db, occurs at 1000 cps with the major overall loss apparent between 300 and 3500 cps. Thus the frequency components present in the intense jet noise are capable of producing temporary shifts at speech perception frequencies.

Observation of subjects exposed to noise of lower intensities is also of interest.[23,26] Temporary threshold shift studies were conducted on 31 subjects at their normal industrial occupation. Of these subjects 16 were classified as normal, 15 as having impaired hearing. Four other subjects were used as a control group and were not exposed. Thresholds were measured before the daily exposure, during the day, and immediately after the daily exposure. Actually, the noise environment could be classified as two different spectral distribution categories at two different plant locations. The noise source consisted of nine supercharged diesel engines of 1700 horsepower producing an overall noise level of 105 db on the work floor. This can be compared to a level of approximately 20 db less in the control room and switchboard. By comparison of the two noise levels and the resulting temporary threshold shift of personnel occupying the respective environments, several facts are evident. Figure 14 shows a comparison of the noise environment (see Figure 14-a) tends to increase with frequency, showing a maximum loss of approximately 18 db at 6000 cps (see Figure 14-c). On the other hand, the lower noise level, as shown in Figure 14-b produces approximately a 2-3 db loss and is for all purposes constant over the frequency range tested. By separating the response curves of those



igure 14. Hearing Loss as a Function of Frequency for Two Different Noise Environments

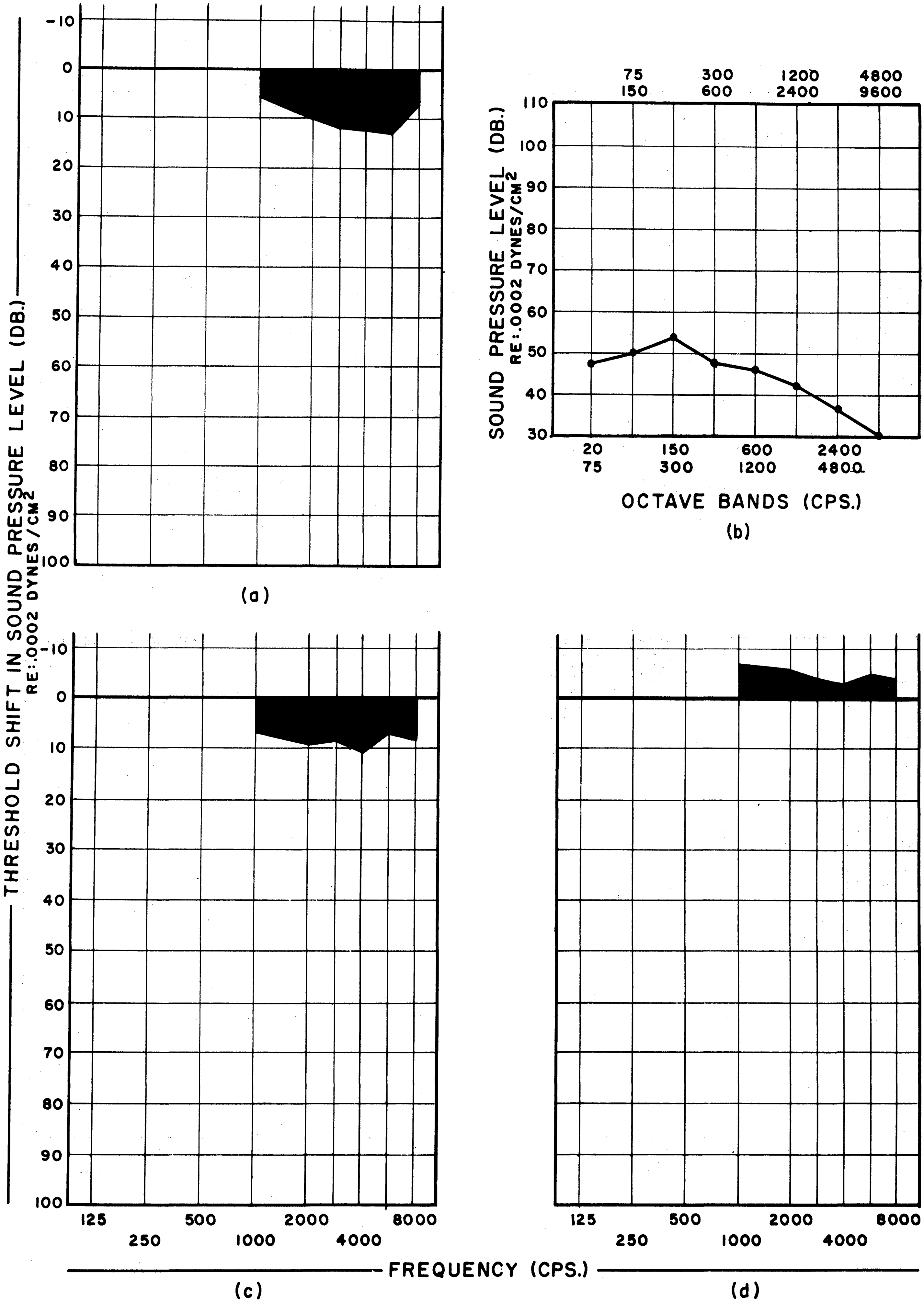


Figure 15. Comparison of Temporary Hearing Losses Suffered by Normal (a,c) and Impaired (b,d) Auditory Systems

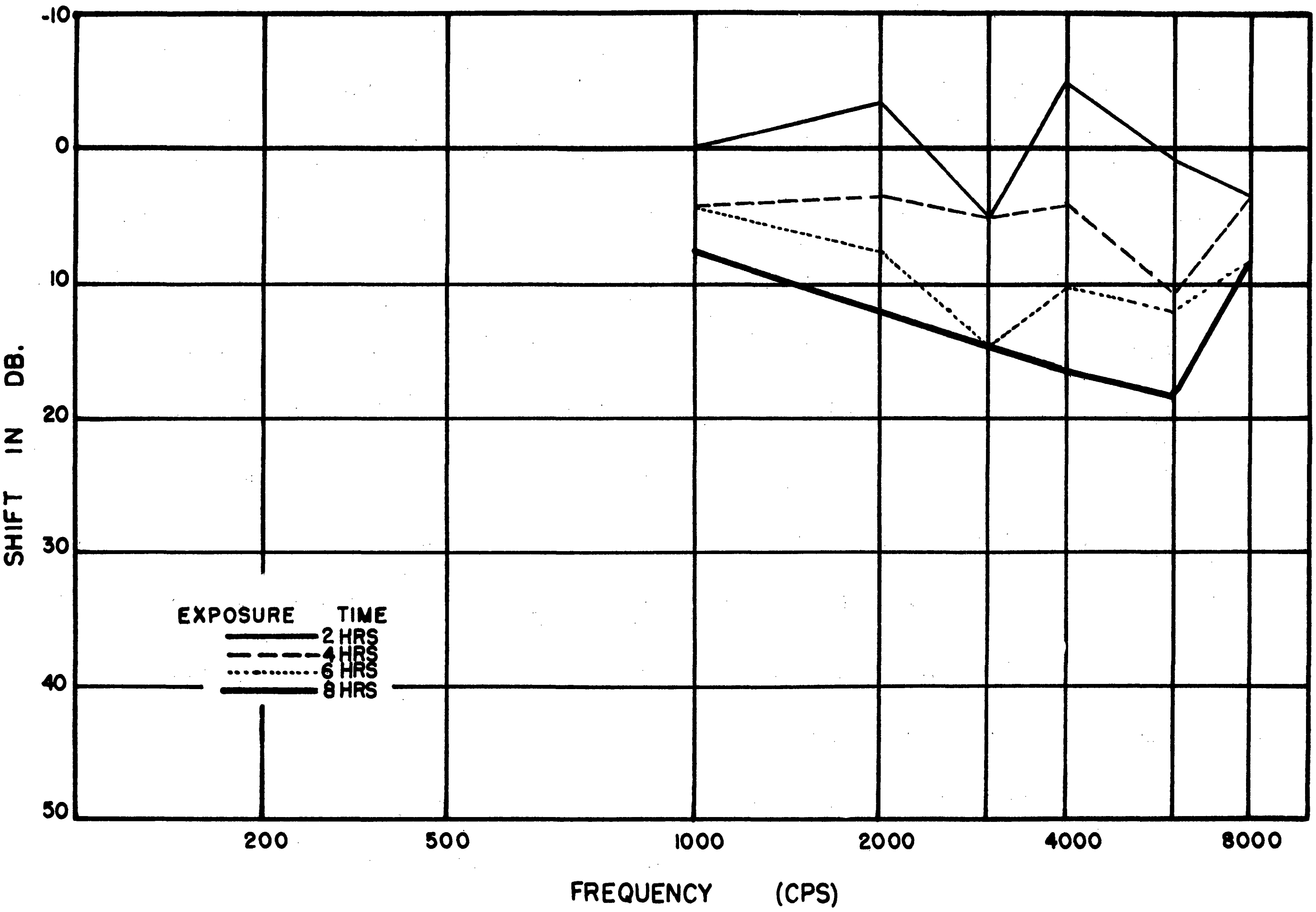


Figure 16. Hearing Loss as a Function of Frequency for Exposure Times of 2, 4, 6, and 8 hours

exposed to high level, as shown in Figure 14-a, into temporary shifts for the normal group and for the impaired group, it can be seen from Figures 15-a and 15-c that the overall threshold shift for the normal group is several db greater than that of the impaired group. Notice, however, that the control group subjected to a "quiet" noise environment of approximately 50-60 db (Figure 15-b) exhibits a negative threshold shift as shown in Figure 15-d, that is, a lowering of the hearing thresholds of approximately 2-4 db. Another important factor is apparent from Figure 16, which is a series of two-hour plots of hearing loss during exposure to the spectrum of Figure 14-a. Notice that the maximum shift occurs during the first two hours of exposure, with lesser shifts apparent at the end of four, six, and eight hours, respectively.

These data are interesting from the standpoint of ground-equipment noise-reduction effort when one considers the remarkable similarity between the relative octave-band plots of the C-26, MA-1, etc., and that of the data under consideration. The value of such information lies in the fact that here are data on temporary hearing loss which have been scientifically gathered and evaluated, utilizing the ideal laboratory condition of the actual complex noise environment.

Hearing Losses Caused by Exposure to Pure Tones--Experimentation which has been carried on in the field of threshold shifts, using a pure tone either as the exposure stimulus and/or the recovery testing stimulus, has yielded some significant results. As in the case with pure-tone masking stimuli, a low-level exposure stimulus tends to raise the threshold in a more or less symmetrical manner about the exposure frequency regardless of exposure time. As this level is raised, not only does threshold shift become distributed more to frequencies above the exposure stimulus, but also the recovery period is shorter for lower than for higher frequencies. There is some doubt as to whether the use of pure-tone sounds gives an accurate accounting of threshold shift. Indeed, some evidence has been found that a 5000-cps tone and noise used in pulse tests do not measure the same responses of the hearing mechanism.[27] Nevertheless much useful information using pure tones has been obtained. Figure 17 shows the exposure-time effect of a 500-cps tone relative to a 1000-cps test stimulus tone of 30 milliseconds' duration.[2] Notice that there is no noticeable threshold shift with duration of 500-cps exposure tone until the sensation level reaches 70 db. In other words, for low-level exposure tones, the threshold shift is not a function of the duration of the exposure stimulus. Notice also that these data are for relatively short time exposures (i.e., 0.1-4 seconds). For a longer exposure time of one minute, threshold shifts increase at a rapid rate for a sensation level of approximately 90 db. This is apparent from Figure 18-a where both the one-minute exposure stimulus and the test stimulus are a 2048-cps tone.[2] Using the same frequency for both exposure and test stimuli, the threshold shift of four different subjects was examined. In Figure 18-b the change of threshold shift is shown for subjects who were exposed to the 2048-cps tone at a sensation level of 100 db for a period up to five minutes.

Hearing Losses Caused by Exposure to Complex Noises--As indicated by results from measurements of engine noise, the most valuable

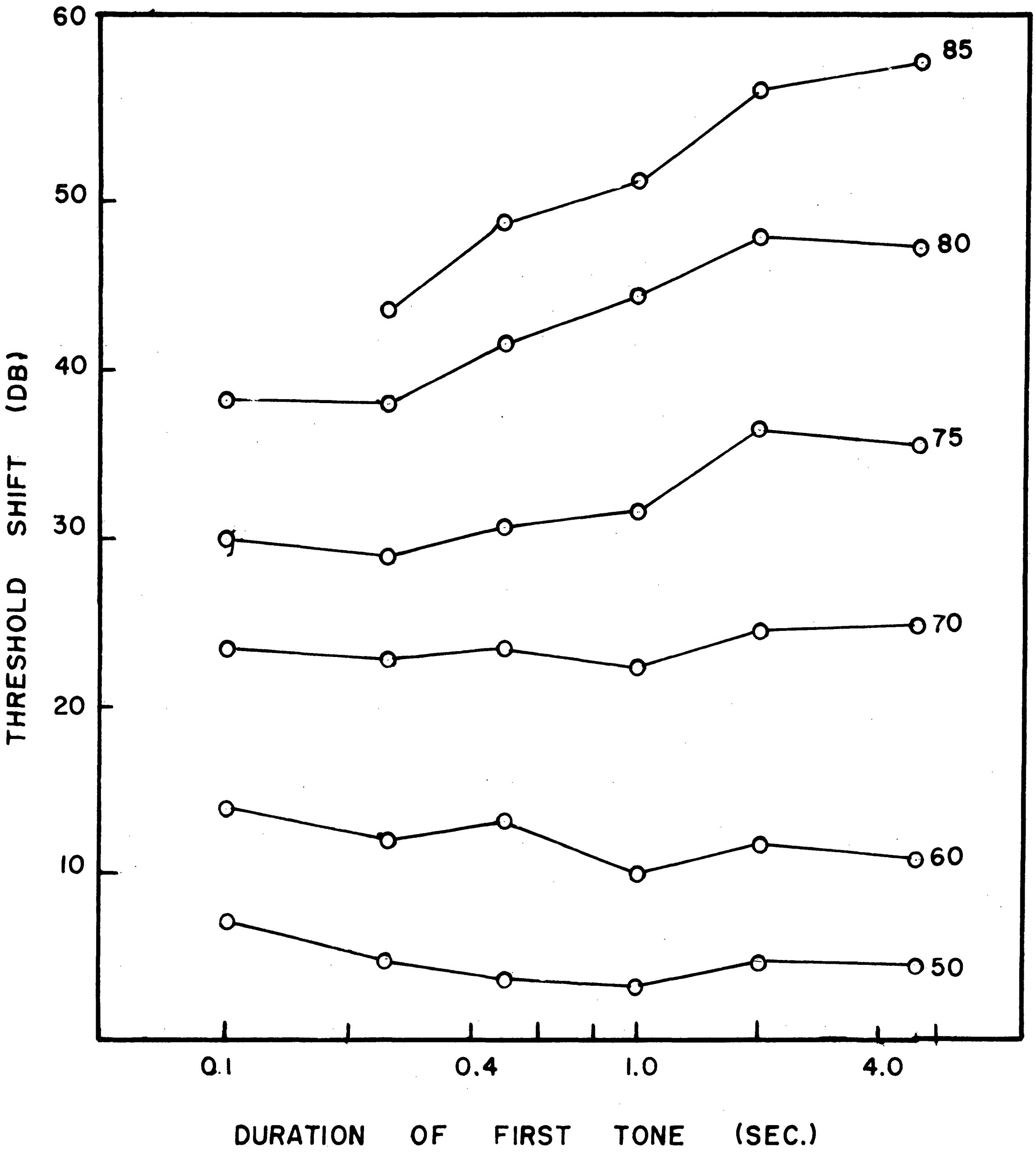


Figure 17. Effect of Duration of Exposure Tone of 500 cps on Threshold Shift of a 1000 cps Tone of 30 Milliseconds Duration

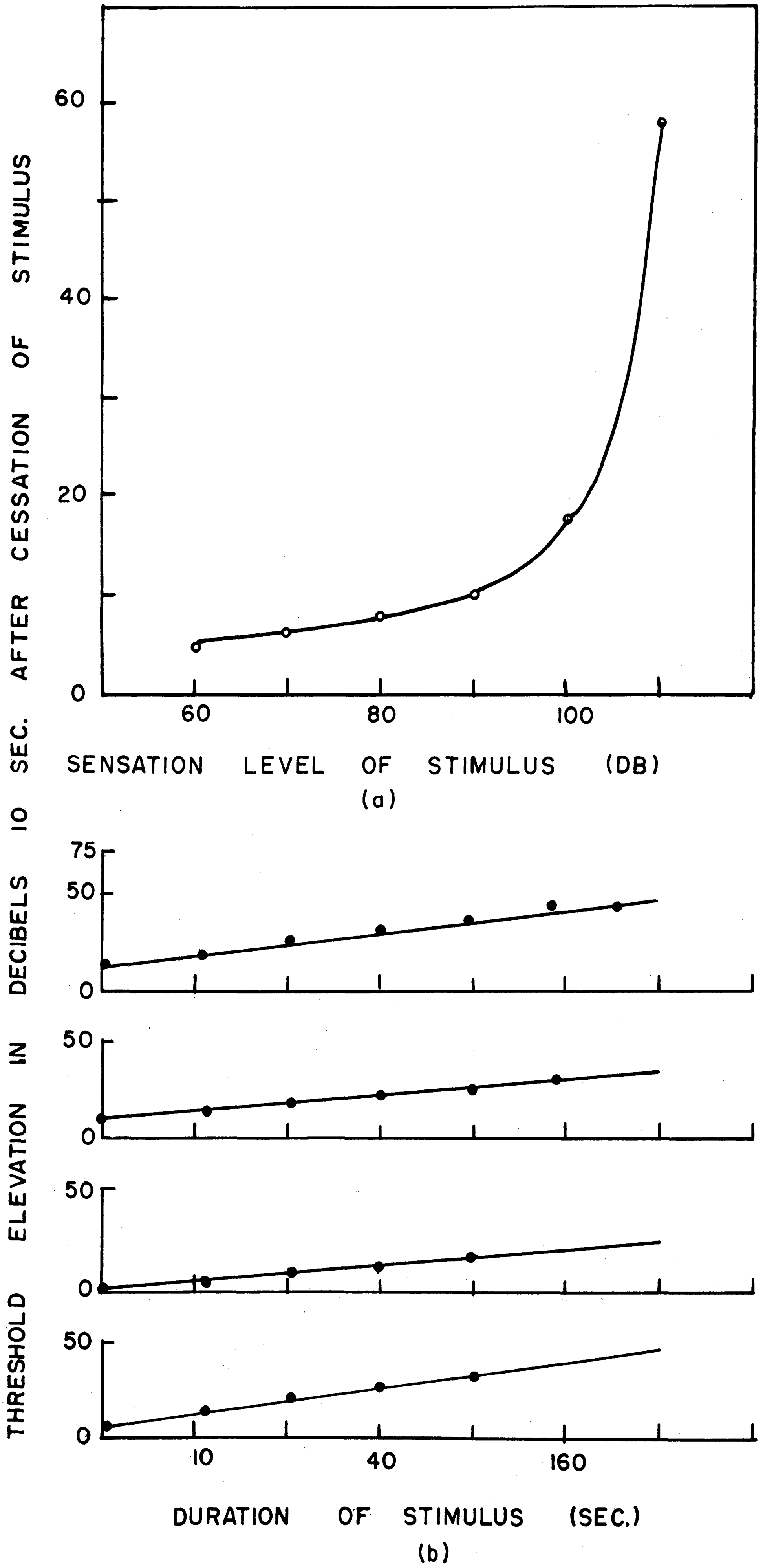


Figure 18. Threshold Shifts as a Function of Stimulus Intensity and Duration of Exposure

data on temporary threshold shifts should be those obtained for complex sounds used as the exposure stimuli. The usual types of noise spectra used as stimuli are octave-band spectra, although one-half octave-band noise and controlled shape spectra have also been used. As is the case with pure tones, the reactions to complex sounds used as exposure stimuli are influenced by spectrum content, intensity, and duration. Recent pulse-type tests, using both shaped noise and octave-band noise as exposure stimuli for levels up to 115 db, showed little change in fatiguing effects except over a two-hour exposure period. Even that exposure period produced a shift of only 4-5 db.[28]

It is obvious that high-intensity exposure stimuli must necessarily be used in the laboratory if actual conditions are to be approximated. Figure 19 shows the temporary hearing loss incurred by several subjects when exposed to band spectra of 130-db overall level for a period of 32 minutes.[22] It can be observed that the average threshold shift has increased in the frequency bands tested up to approximately 4000 cps, above which there is a decrease in threshold shift. It may also be noted that the greatest losses occur in the speech reception range. Intensities over 150 db have also been utilized for determining temporary threshold shifts. In this case the acoustic level has been obtained by using either a jet engine or a siren as the source. Even at this level threshold-shift levels returned to normal after a maximum of 7 days, although the initial threshold shift occurring within the exposure time of 3-10 minutes was about 60 db. Various other noticeable effects on threshold shift have been observed from high-

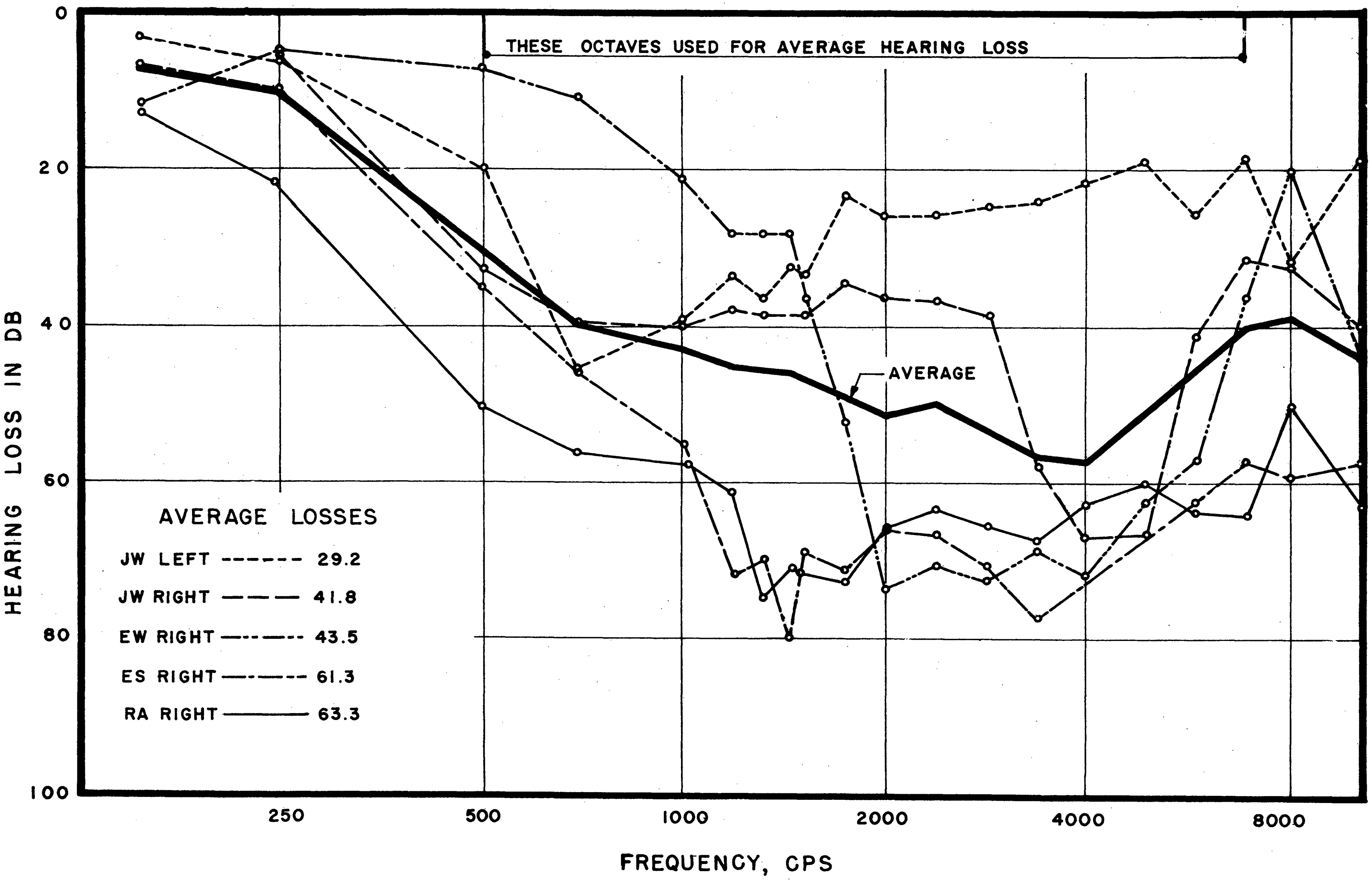
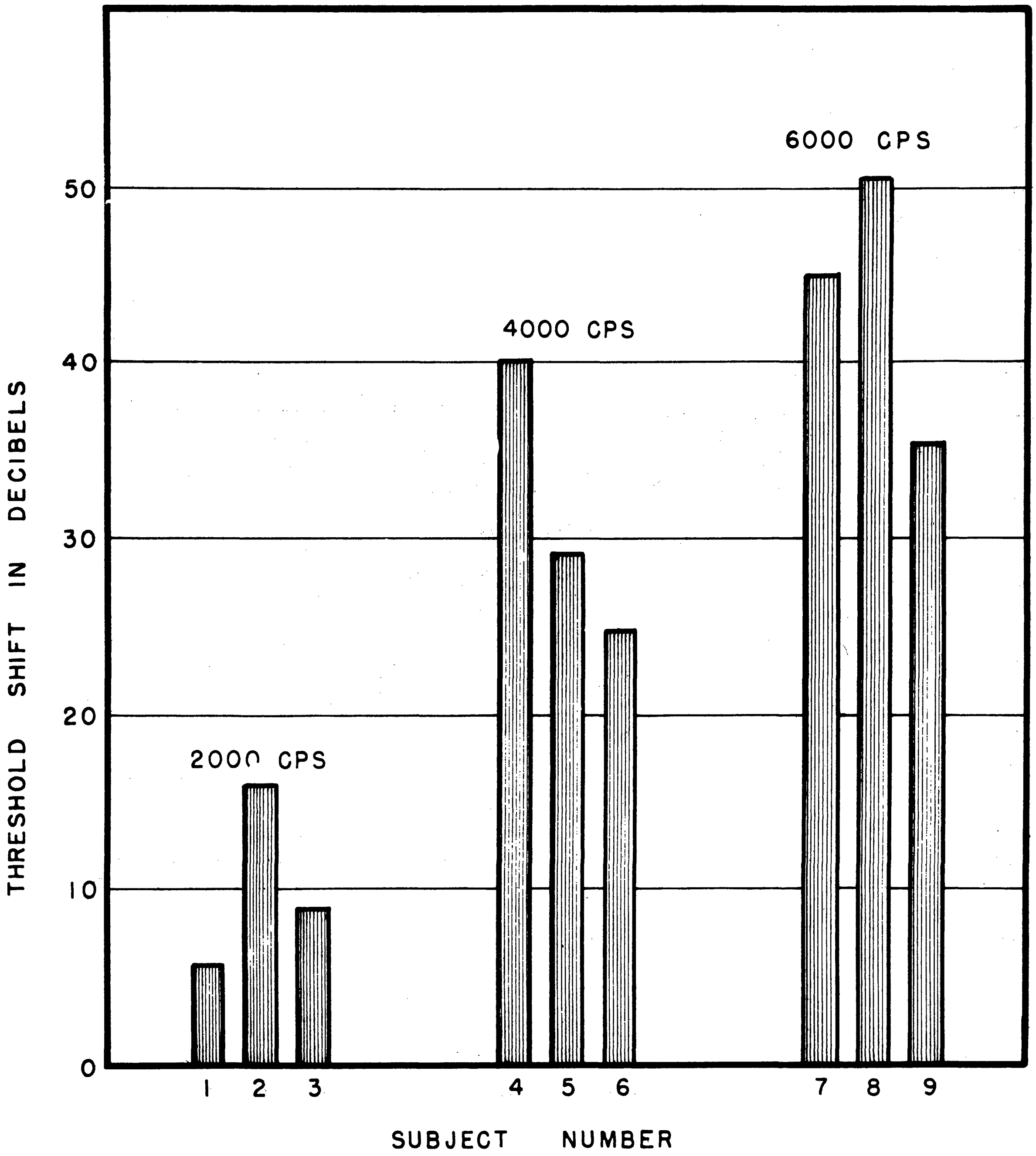


Figure 19. Audiograms for 5 Subjects Following 32-minute Exposure to 130 db Band Spectrum

intensity exposure on diplacusis.[29]

Permanent Hearing Loss--Experiments to determine the contributing factors to permanent hearing loss have not been extensive for obvious reasons. Instead, attempts have been made to determine hearing-loss criteria to be used in the prevention as well as the detection of such loss.[23,24] Some of these criteria are apparent from the temporary threshold shift data already presented. Preliminary predictive tests have been carried out with varying results. Figure 20 shows the threshold shift obtained using a noise exposure stimulus of 105 db for a 30-minute period. Note that the average shift increases with frequency from 2000 cps to 4000 cps and 6000 cps. This suggests a displacement upwards of the effect in magnitude of the exposure noise. Figure 21 shows the recovery time at these three frequencies, emphasizing that the recovery time is also a function of initial threshold shift as well as frequency and intensity. To correlate predictive information for prevention of permanent hearing loss a damage-risk (DR) criterion has been proposed.[2] This has been based on numerous field studies and is divided into criteria for both long-term and short-term exposures. Figure 22 shows the proposed lifetime and steady-noise DR criterion curves of wide-band noise as well as pure-tone and critical bands of noise which have modified the proposed criterion referred to previously.[22] On examination of the DR curves presented in this figure, it may be noted that long-term exposure to levels lying above these curves is inadvisable. The absolute value for a DR criterion for short-term exposure to very high noise levels has not been determined, and it has been suggested that although some individuals have been exposed to 150-db levels of noise without apparent results, there should



EACH BAR REPRESENTS THE
MEAN OF THREE EXPOSURES
FOR A DIFFERENT SUBJECT

EXPOSUE: 30 MIN. AT 105 DB

Figure 20. Initial Threshold Shifts at Different Frequencies

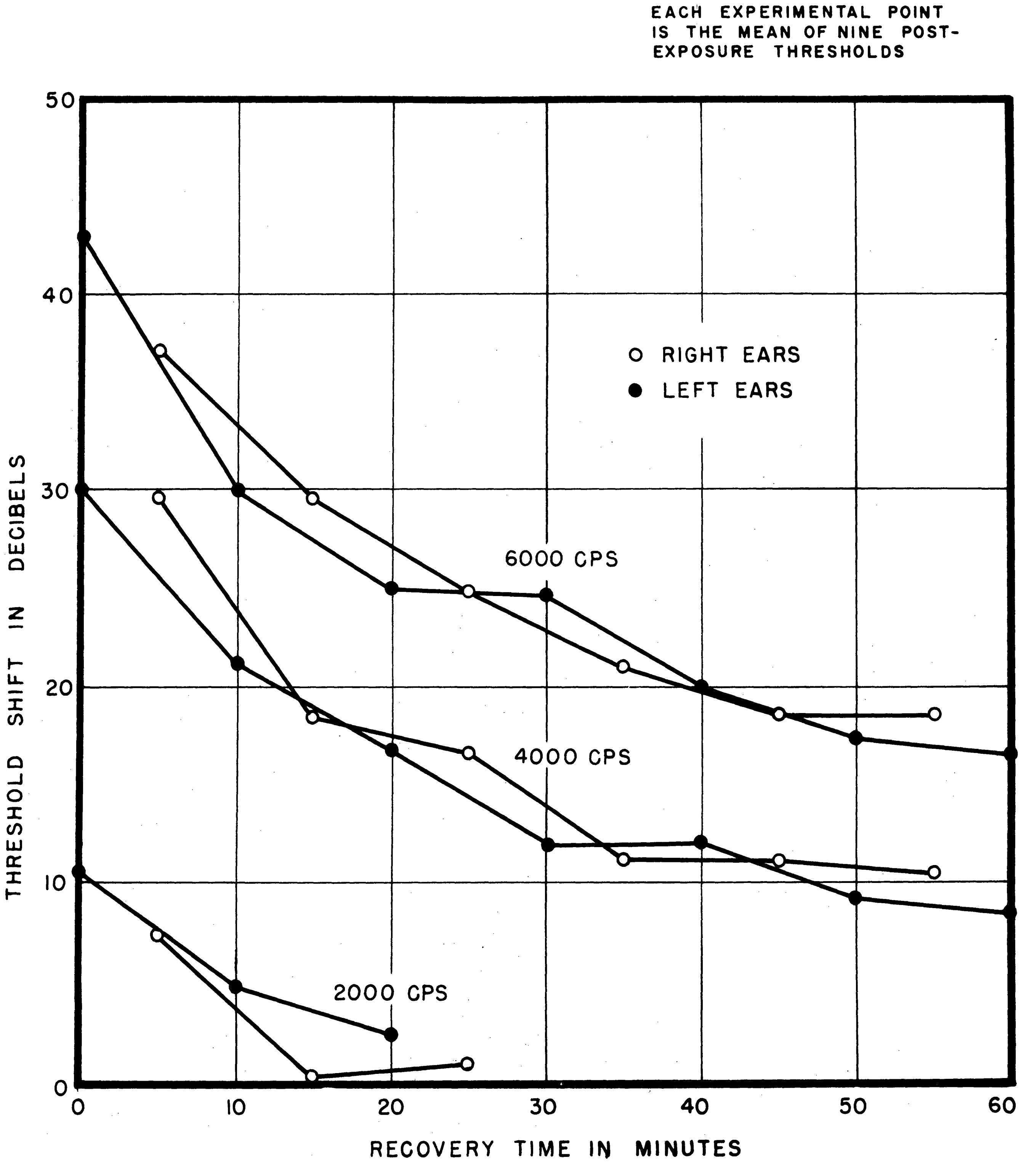


Figure 21. Recovery Curves for Nine Subjects-Three at Each Frequency

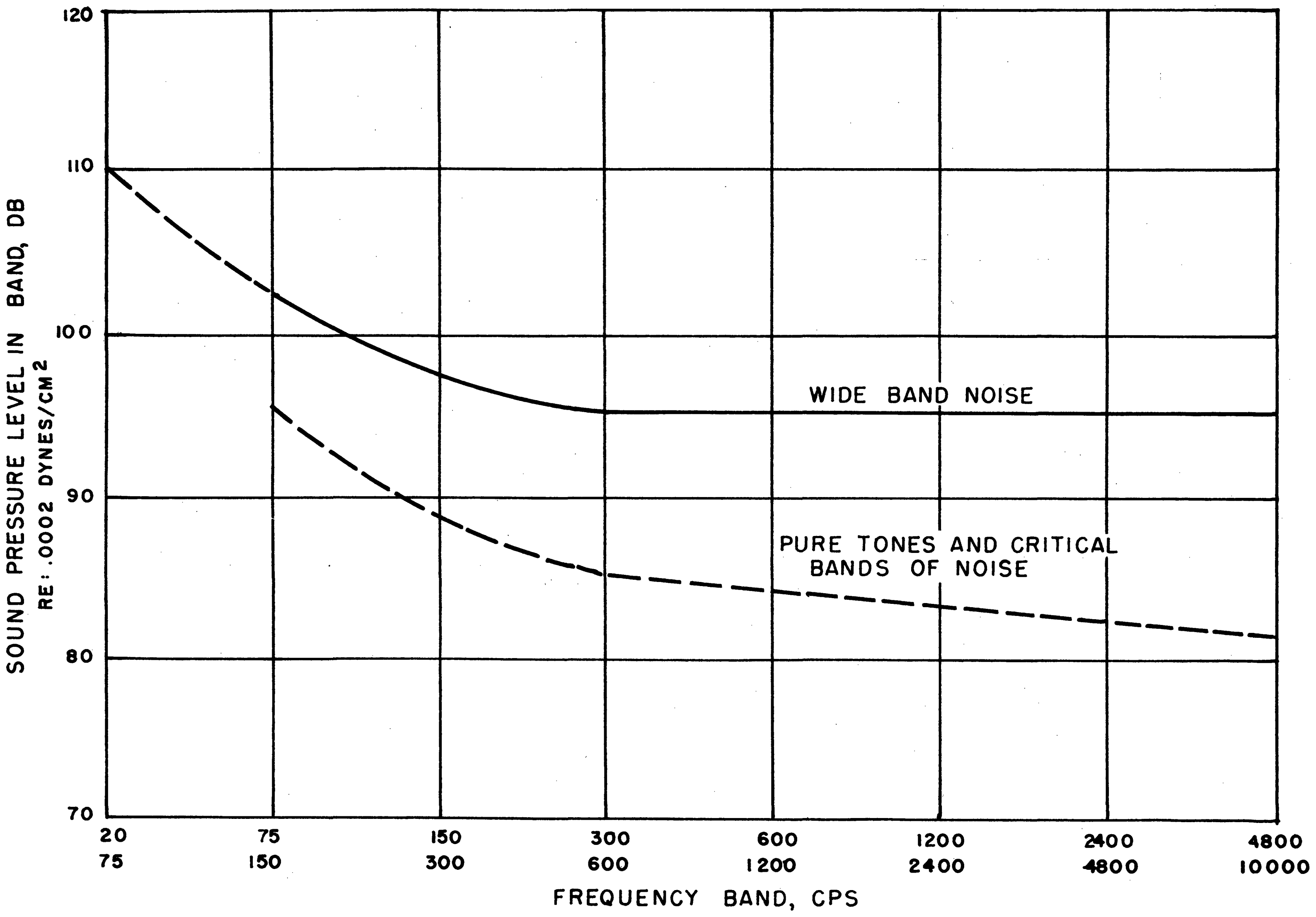


Figure 22. Damage risk (DR) Criterion for Steady Noise and for Lifetime Exposures

be no exposure to levels of 145-150 db or more for a time greater than one minute.

ANNOYANCE

In the field of acoustics, most parameters such as loudness, pitch, etc., involved in both physical and psycho-acoustic measurements can be described in at least a quasi-quantitative quantity either by straightforward instrument measurement or by jury analysis. Unfortunately, the annoyance factor has thus far resisted so simple a treatment. Everyone with normal hearing has had an occasion to be in an area of annoying sound and it seems that if one is annoyed by sound, it should be simple to define this sound. However, the factors which make a sound annoying are variable, and the annoying aspects of sound change not only with its physical characteristics but also with the environment and attitude of the individual. It is well known that many persons are sensitive to personal and environment factors which affect their physical or mental well-being, and by proper "needling" a desired reaction can be obtained. Thus, if a large group of people were to be subjected to certain particular stimuli, certain general reactions could be expected. This is true also of annoying sounds, and as a result some general annoying properties of sounds may be tabulated. However, a single comprehensive annoyance number has, as yet, not been formulated and accpeted as a rigid laboratory standard.

Contributing Factors to Annoyance--A number of annoyance factors have received considerable attention with respect to their relative contributions to a total annoyance value. These major contributors are intensity, frequency, intermittency, unexpectedness, and inappropriateness.[25] One experiment consisted of presenting to groups of 10 to 20 subjects a pair of sounds with instructions to decide which was more annoying, taking into account the probable annoyance involved if a long-term exposure were involved. In one instance, a stepped pattern of tones was utilized with results obtained for eight contributing annoyance factors. The results are quoted below:[6]

1. The higher the pitch of the component tones, the greater the annoyance-value. The range of frequencies tested was from 200-1500 cycles.

2. A wide range of frequencies between the highest and lowest steps is more annoying than a restricted range. Listeners reported that the wide range of component frequencies tended to be perceived alternately, first as a complete pattern and then as two patterns, one of high and one of low pitch. This effect is very similar to figure-ground reversals in visual perception.

3. The addition of continuous tones to the stepped pattern of tones produces complex effects dependent upon the frequency-relation between the tones. Beats give the sound a rough pulsing irregularity which the listeners disliked.

4. Listeners asked to compare continuous sounds of different wave-shapes found the complex sounds especially brief pulses, more annoying. In general, the sine wave was found to produce little annoyance.

5. Patterns of 3, 4, 6, and 12 tones were compared but the number of different steps in the complete pattern had little effect on the judgments of annoyance.

6. If one of the steps of a pattern is slightly longer in duration from the others, a rhythmic quality is added which the listeners judged to be more annoying than tones of equal duration. Even more annoying, however, is the pattern in which all the tonal durations are randomly varying.

7. A slow rate of repetition for a pattern of tones is considered slightly more annoying than a rapid rate.

8. Up to a certain limit, the annoyance-value is increased if silent intervals are introduced between the successive steps.

Practically all surveys of annoyance factors agree that intensity is the most important contributor. This is quite important with respect to ground-support-equipment personnel who, even when not exposed to painful noise, may be irritated by the annoyance contribution of a moderately high-level noise. This level seems to be somewhat in excess of 80 to 90 db. Several experiments have been carried out in which subjects have been exposed to aircraft-type noise. In one instance several subjects were exposed to aircraft noise of 90 db and 115 db (overall).[30] Exposure to the lower level showed no particular annoyance response, whereas continued exposure to the higher (115 db) level tended to produce irritation and tiredness.

Several experimental attempts have been made to correlate frequency and loudness to annoyance. Figure 23 shows such an attempt.[4]

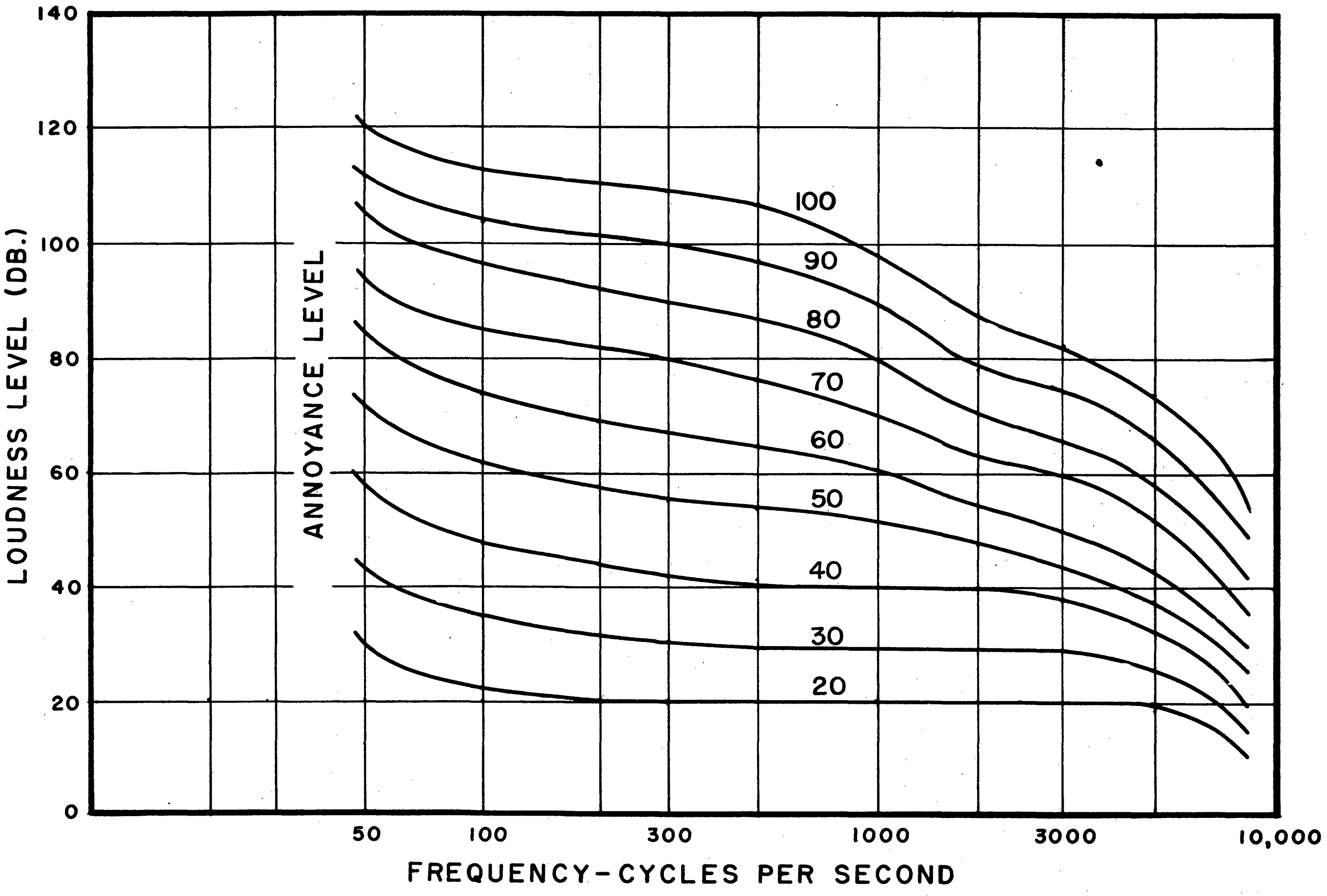


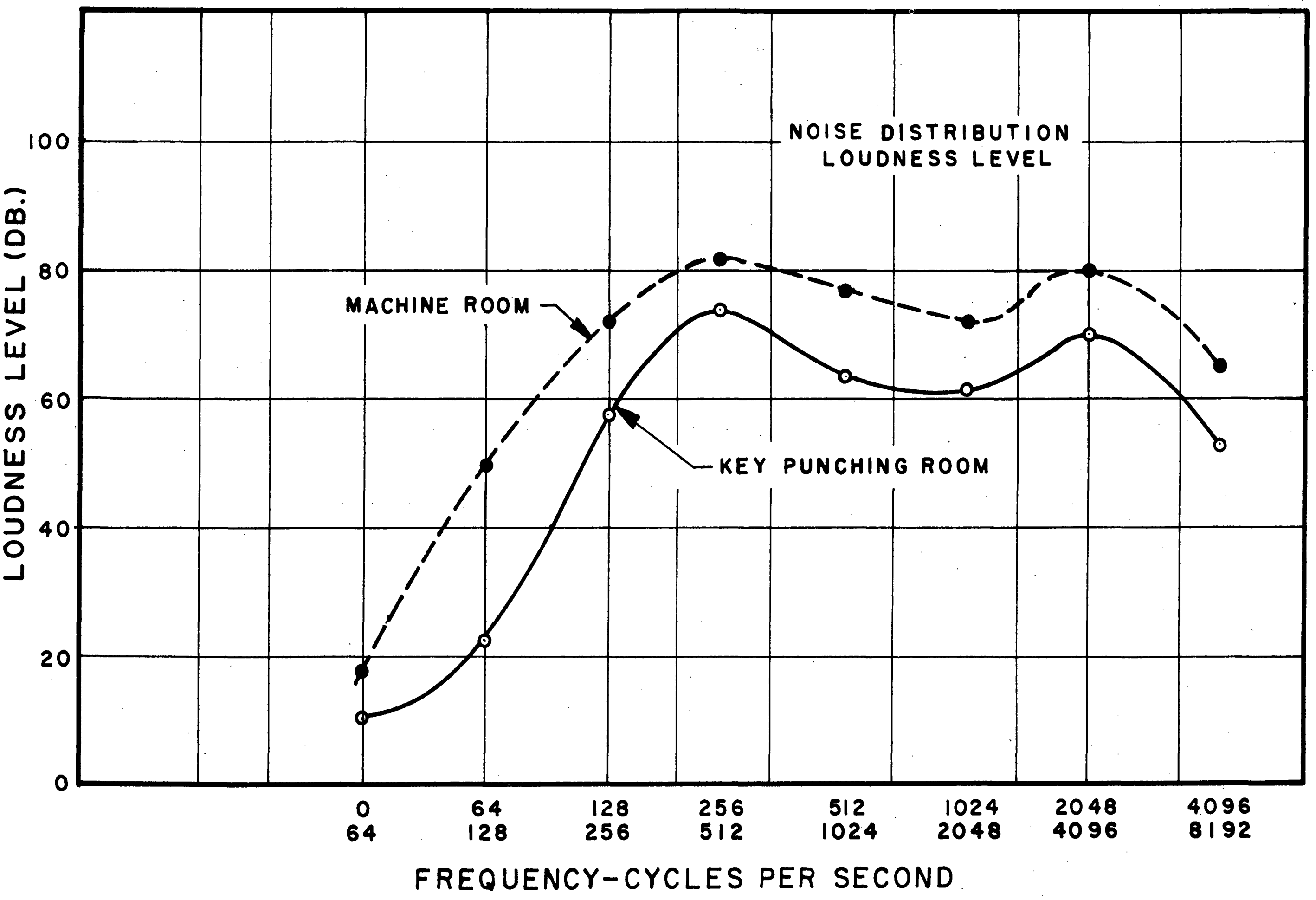
Figure 23. Annoyance Levels as a Function of Frequency

Here the equal loudness curves have been converted into equal annoyance curves. The annoyance contours follow the equal loudness contours at the lower frequencies but digress at the higher frequencies. Application of these curves can be demonstrated by examination of the following figures. Note that Figure 24-a is a plot of the loudness levels of two office-machine rooms.[4] By application of the annoyance-level curves, Figure 24-b shows a marked increase of annoyance at the high-frequency sector of the plot.[31]

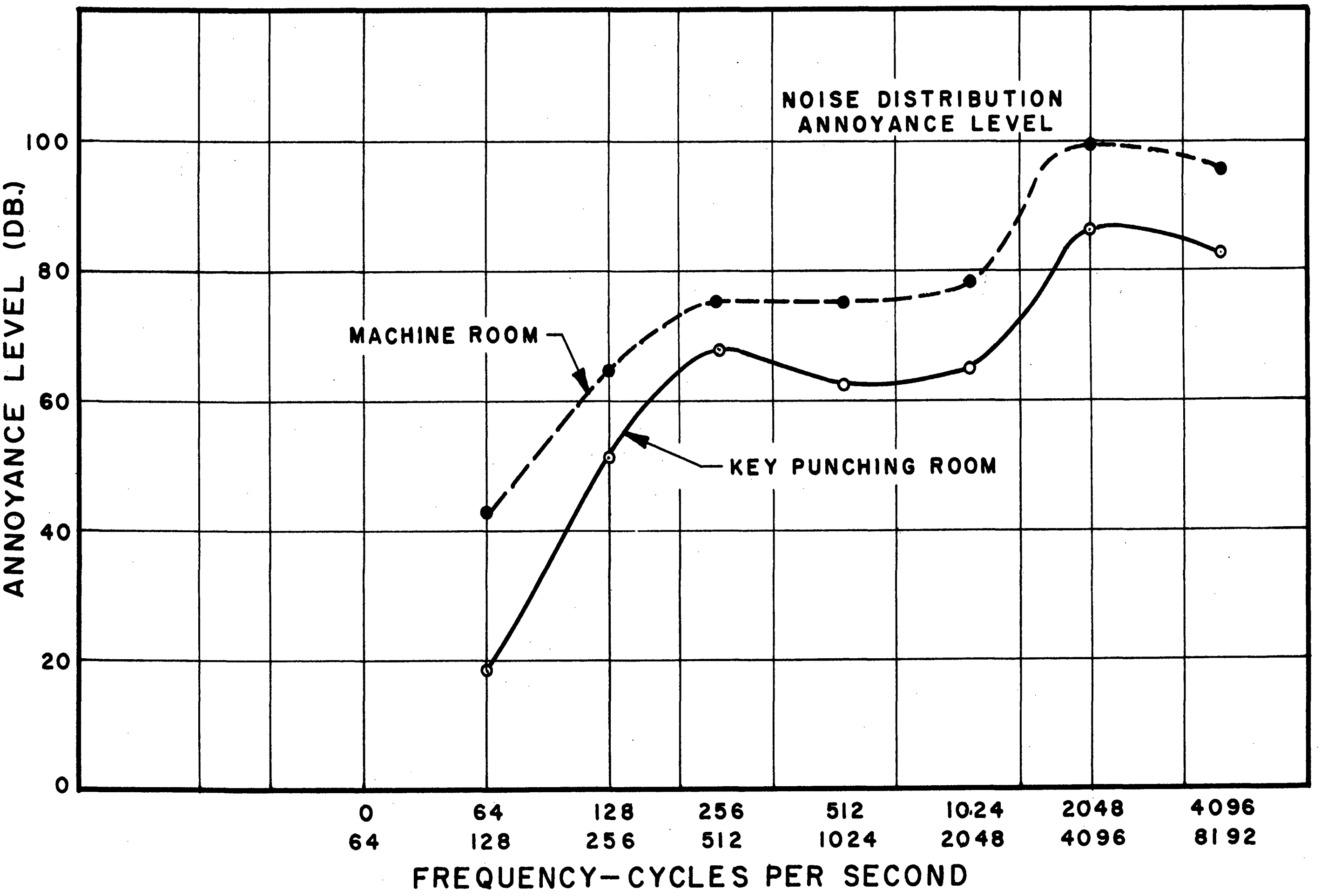
Another experiment consisted of utilizing bands of noise for evaluation according to annoyance value. A band of noise of 1900 to 2450 cps was chosen as a standard, and other bands were treated for equal loudness and then for equal annoyance to this band. Figure 25 shows comparisons with the level or the standard band varying from 94 db to 64 db.[22] In each case, the annoyance contribution shows an increase with frequency. This is significant at the lower intensity levels since this points out the definite effect of frequency where intensity is no longer a major consideration.

The contributions of intermittent, unexpected, and inappropriate noise to annoyance may well be explained by the following: " . . . Accordingly, we apparently find it difficult to ignore any noise or sound unless we can attach some meaning to it and understand the reasons for its presence. This is presumably highly distracting, keeping one forever alerted when unanticipated, novel, unusual, sudden sounds or noises are received."[4]

Thus it can be observed that annoyance in ground-crew environment is something of a predicament as regards noise reduction. Whereas


NOISE DISTRIBUTION
LOUDNESS LEVEL
LOUDNESS LEVEL (DB.)
100
80
60
40
20
0
MACHINE ROOM
KEY PUNCHING ROOM
0 64
64 128
128 256
256 512
512 1024
1024 2048
2048 4096
4096 8192
FREQUENCY-CYCLES PER SECOND

(a)


NOISE DISTRIBUTION
ANNOYANCE LEVEL
ANNOYANCE LEVEL (DB.)
100
80
60
40
20
0
MACHINE ROOM
KEY PUNCHING ROOM
0 64
64 128
128 256
256 512
512 1024
1024 2048
2048 4096
4096 8192
FREQUENCY-CYCLES PER SECOND

(b)

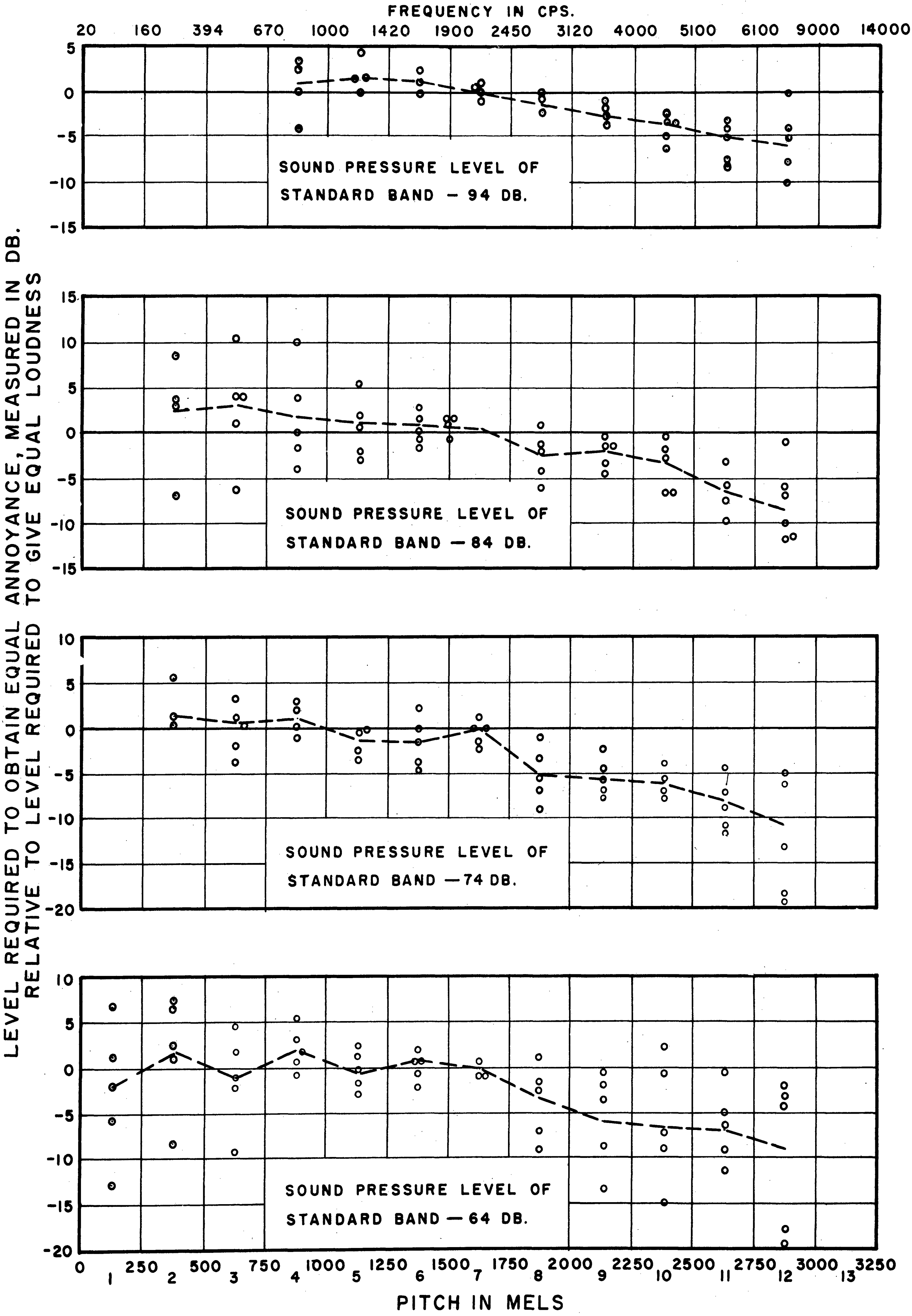


Figure 25. Equal Annoyance Contours for Bands of Noise 250 mels Wide; Band No. 7 Taken as Standard

attempts may be made to reduce high-intensity pain-producing noise levels, low-frequency masking-noise levels, and annoyance due to high-frequency spectrum content, it is nearly impossible to remove the factors of intermittency, unexpectedness, and inappropriateness where these must by the nature of the situation become an integral part of the acoustical environment.

<u>Airport Environment Annoyance Problems</u>--However, certain aspects of annoyance outside the acoustical confines of ground-support operational environment have been investigated. These are the aspects of annoyance with which "outsiders" -- that is, the residents of neighborhood areas -- are primarily concerned. Indeed, a whole set of criteria has been compiled on the basis of investigation of community reactions to noise problems. From these criteria one may ascertain what the reaction of a particular community will be when confronted with a particular type of intrusive noise. The results of the investigations have led to a single noise-evaluation number designated as the composite noise rating (CNR).[32] This number, as is implied, is of a composite nature taking into account such factors as the intensity of the noise, its loudness, spectrum, repetitive character, duration, and seasonal appearance as well as other factors including the background noise and the previous exposure to noise of a community. From proper evaluation of the above factors and correlation with noted community response, a set of curves can be formulated as is shown in Figure 26, in which community response is noted on the ordinate and the composite noise rating in upper case letters is plotted on the abscissa. Thus,

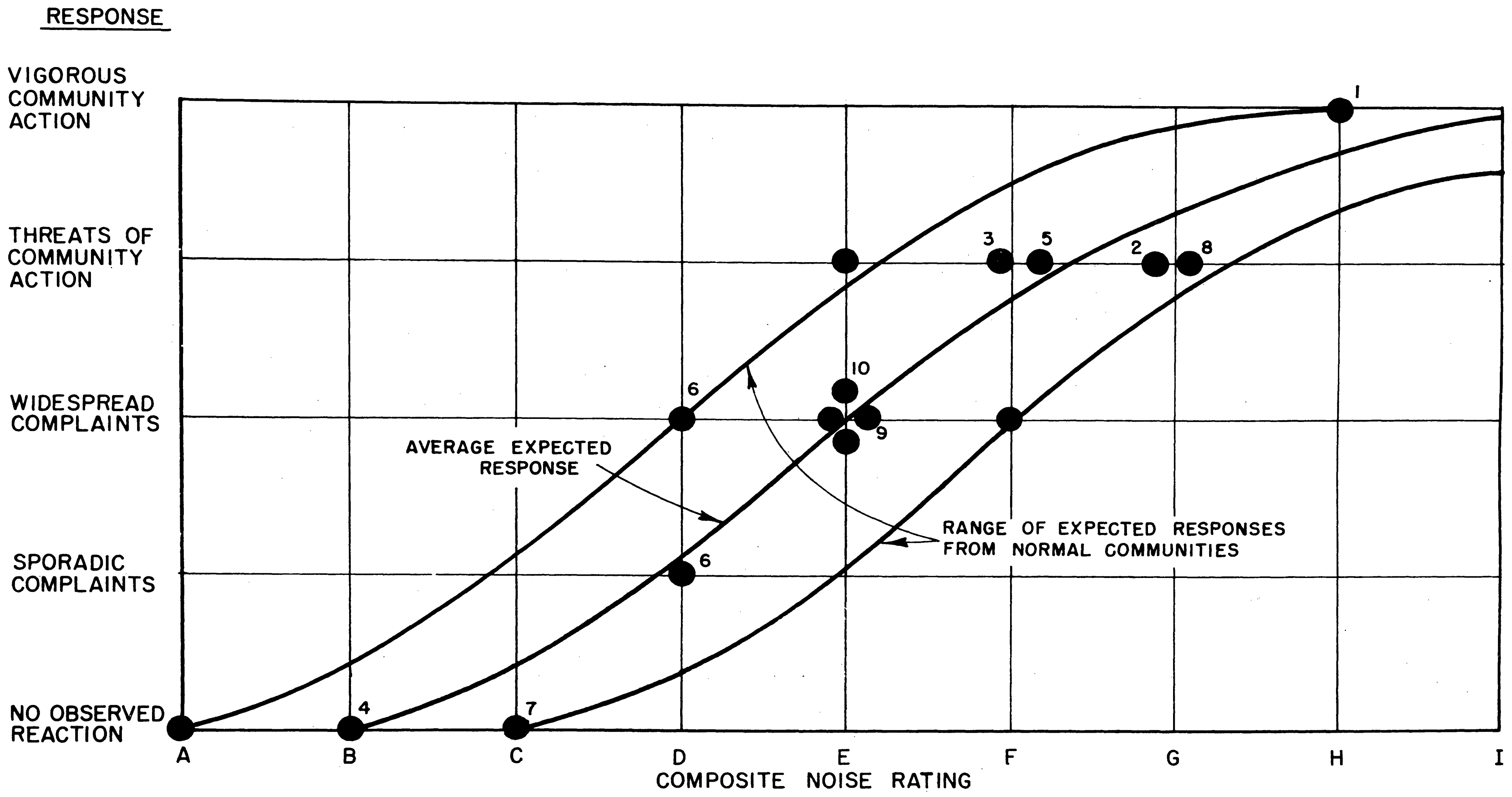


Figure 26. Community Response vs. Noise Severity

when the composite noise rating is ascertained by proper evaluation of the factors noted above, the range of expected reaction of a community may be obtained from the plot of Figure 26. Thus, a CNR of value E may be expected to result most generally in widespread complaints, though variations may occur ranging from reactions of sporadic complaints to threats of community action.

However, assaying community response to annoying noises is only the first step in solving an annoyance problem. That is, the intruding noise has been identified and its consequent reaction on a community has been determined; the problem now is how to lessen the noise. This is a major problem at airport installations since the noise contributors are not only units of ground-support equipment but also engine test stands and operations aircraft.

Ground-support equipment and engine test stands offer less of a problem than do operational aircraft with respect to controlling the noise emitted from each of these units. Ground-support equipment, though mobile, contains power plants of lesser horsepower and accordingly produces less acoustic energy than do aircraft. Furthermore, ground-support equipment is more amenable to noise-reduction treatments than are aircraft since maximum engine efficiency, weight, and contour design which may be affected in the course of treatment are not nearly as critical on ground-support equipment as they are on aircraft.

Engine test blocks, although sources of large acoustic power output, have the advantage over aircraft in that they are stationary, and therefore acoustic treatment, though costly, can be designed into the permanent installation of the test stand.

On the other hand, operational aircraft must, for economic and military reasons, operate at peak efficiency. Thus the possibility of applying palliative noise-reduction treatments, since these treatments usually result in added bulk or interfere with the original airflow design, is greatly reduced compared to ground equipment. However, this is not of much concern to communities adjacent to airport facilities. To such neighborhoods, a noise which interferes with their normal routine is annoying and this annoyance must somehow be alleviated. The question now arises -- what can be done in a situation where operational aircraft are a disturbing influence on communities bordering an airport installation? Eventually, this problem is placed in the lap of the airport management, which may institute one or more of the following corrective measures:[33]

1. Prohibit use of the airport to aircraft which cannot be operated below maximum noise limits.

2. Elimination of unnecessary flights -- especially during evening hours.

3. Designate the use of preferential runways so that both take-offs and landings occur at areas which are at a maximum distance and/or downwind from the neighboring community. This also applies to engine run-up areas.

4. It has also been suggested to lengthen the runways sufficiently to provide for a longer take-off run and thus reduce the necessity for full power application before the aircraft is airborne without reducing any safety factor in take-off.

5. Exmpasize proper flying technique to aircraft operators to reduce instances of full engine-power application caused by such factors as unfamiliarity with the airport, selection of propeller pitch, flap positions, etc., during landing procedure.

6. Locate future buildings so that they act as an acoustic barrier between the aircraft and the community.

7. Plant thick foliage on airport perimeters and construct earth barriers between the airport and the community either to absorb or reflect some of the acoustic energy, and also to shield aircraft operations from the sight of the community; this latter effect presumably would have some psychological value.

8. Encourage neighboring communities to zone areas adjacent to the airport for industrial use only.

9. Finally, institute a policy of good public relations with surrounding communities to provide for better understanding by both airport officials and residents of their mutual problems.

In summary, it should be noted that annoyance due to ground-support equipment is an important factor of special concern to all persons including those who are not directly operating such equipment.

EAR PROTECTION DEVICES

The advent of high-energy noise sources and the realization of the severe damage which these sources can work upon the human body has given great emphasis toward design of protection devices. The experimental work has resulted in the development of at least four "receiver" noise attenuation devices or ear defenders: (1) the ear plug, (2) the cushion, (3) the helmet, and (4) the acoustic barrier. The reasons for such a variety of devices are obvious. In the first place, a combination of two or more of these devices can decrease the noise levels to the sensitive structure of the ear more than each used individually, and secondly, the body must be protected in extreme intensity noise environments since exposure produces extra auditory effects, i,e., nausea from chest-cavity resonances.

In a general consideration of the why and wherefore of ear protectors it must be realized that the air conduction path, though normally the most sensitive path, is not the sole available means of exciting the hearing nerves. Indeed, if total air conduction were eliminated, the hearing level would only be reduced by 45 db.[34] This is due to cranial excitation by the airborne sound energy. If both these means of sound conduction are sufficiently shielded, the sound energy may reach the hearing mechanism by means of the chest in which case the level is reduced by 60 db, and by shielding the entire body above the abdominal cavity from airborne sound one may expect a reduction of 80 db. It seems rather startling that a person using such drastic acoustic shielding should still be hearing a sound of 75-db level in the acoustic environment produced by some types of jet engines.

For practical reasons the ear plug and the ear cushion have been used much more extensively than either acoustic helmets or acoustic barriers. The latter is most practical where groups of co-workers must enjoy reasonable communication, i.e., jet test sites or flight-deck islands.

Since the initial recommendations in 1890 of the ear plugs, and in 1925 of the ear cushion, much progress has been made with respect to the design of these noise attenuation devices.[35] Whereas the initial progress in formulating a workable attenuator consisted mainly of trial-and-error techniques, recent work has produced quite exacting and realistic analyses in the presentation of attenuator properties.[36,37] For example, the human ear, using both insert and cushion types of noise attenuators, can be analyzed as its electrical analog, with factors of skin compliance, transmission through the attenuator, leakage path, and bone conduction being appropriately defined.

Testing of Ear Defenders--The actual testing of ear defenders may be accomplished by either of two major methods, (1) the psychophysical method in which the reaction of the individual is an inherent factor in the analysis, or (2) the physical method in which the individual is merely the holder for the attenuator, the measurements being taken across the device to determine its transmission loss. A variation of the latter method is the artificial method in which a mock head is used as the holder. The most popular method is the psychophysical method since human reaction is desired when various ear protection devices are to be tested. With the general psychophysical method two types of measurements are used: the absolute-threshold-shift method, and the adjustment or loudness-balance method. The absolute-threshold-shift method consists of comparing the hearing threshold of the open ear with that of the defender-protected ear. Many variations are apparent, including earphone testing versus free field tests, monaural versus binaural testing, etc. Errors are likely to be incurred for several reasons.[34] The noise environment may be of a level sufficiently high to confuse the low-level threshold value; there is an apparent increase in physiological noise when the ear opening is blocked; and there is a difference between levels required to give equal apparent response between open and partially covered ears. The loudness-balance method uses levels well above absolute threshold, and is usually only subject to the error incurred by measuring levels between partially covered and open ears. The sound to be identified may be presented by earphones, by a loud speaker, or by utilizing one of each. Obvious problems of leakage, time, etc., are to be expected.

Actually, the results of various attenuation methods using a particular ear defender were not as large as might be expected. Comparison of a binaural free-field threshold shift and monaural psychophysical test, using six different ear defenders of the cushion type, yielded similar results. Figure 27 is a typical comparison in which the general attenuation curve varies by a maximum of approximately 5 db.[35] Other experiments show that careful control of the involved experimental parameters provides good reproducibility of results from different attenuation tests.[34]

Attenuation Values of Various Defenders and Combinations Thereof--The value of an ear defender depends primarily upon its noise-attenuation properties, although other factors such as comfort, fit, hygiene, durability, etc., deserve some consideration when a choice is to be made. The attenuation characteristics of various plugs, cushions, and helmets have been measured by many investigators with

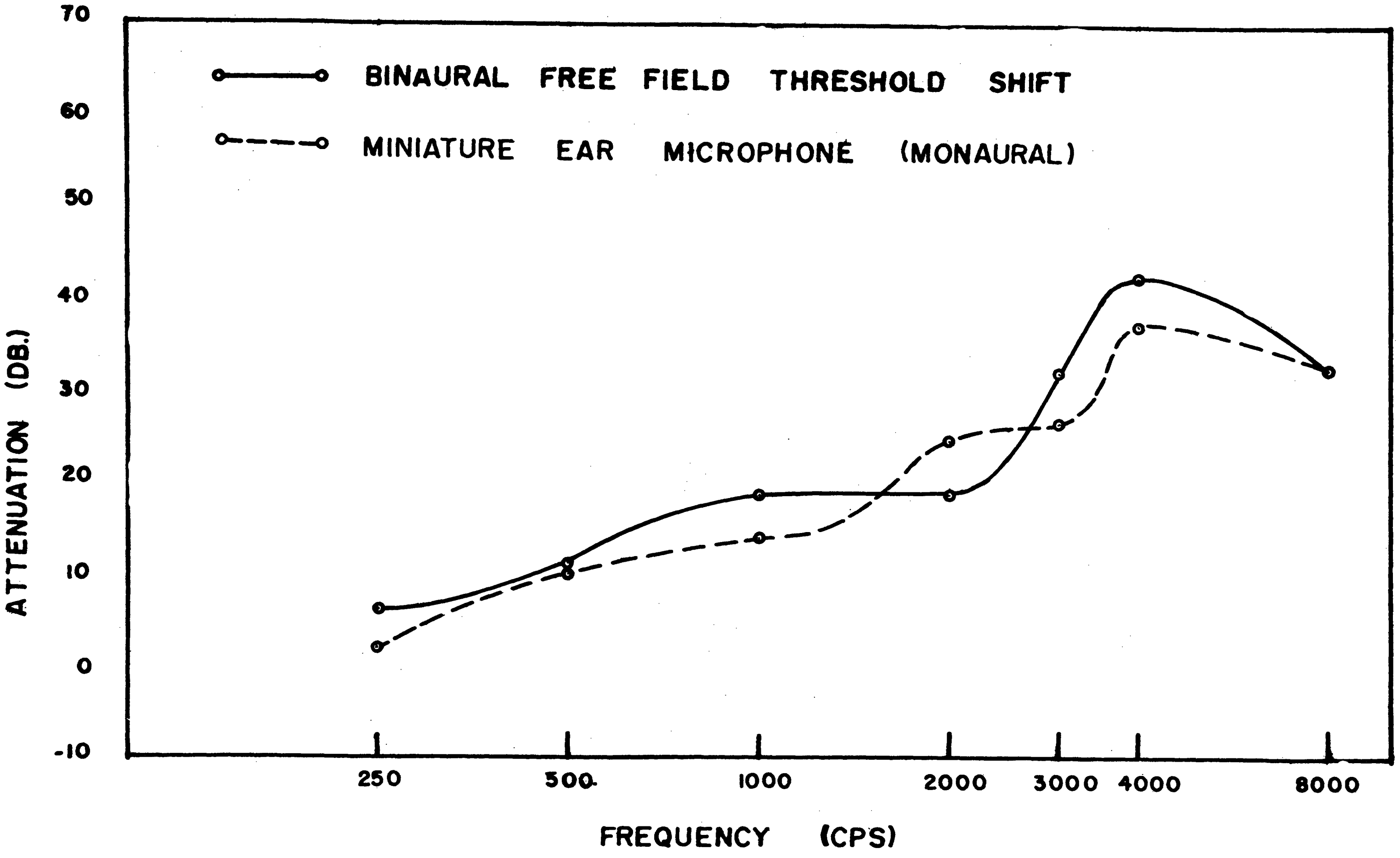
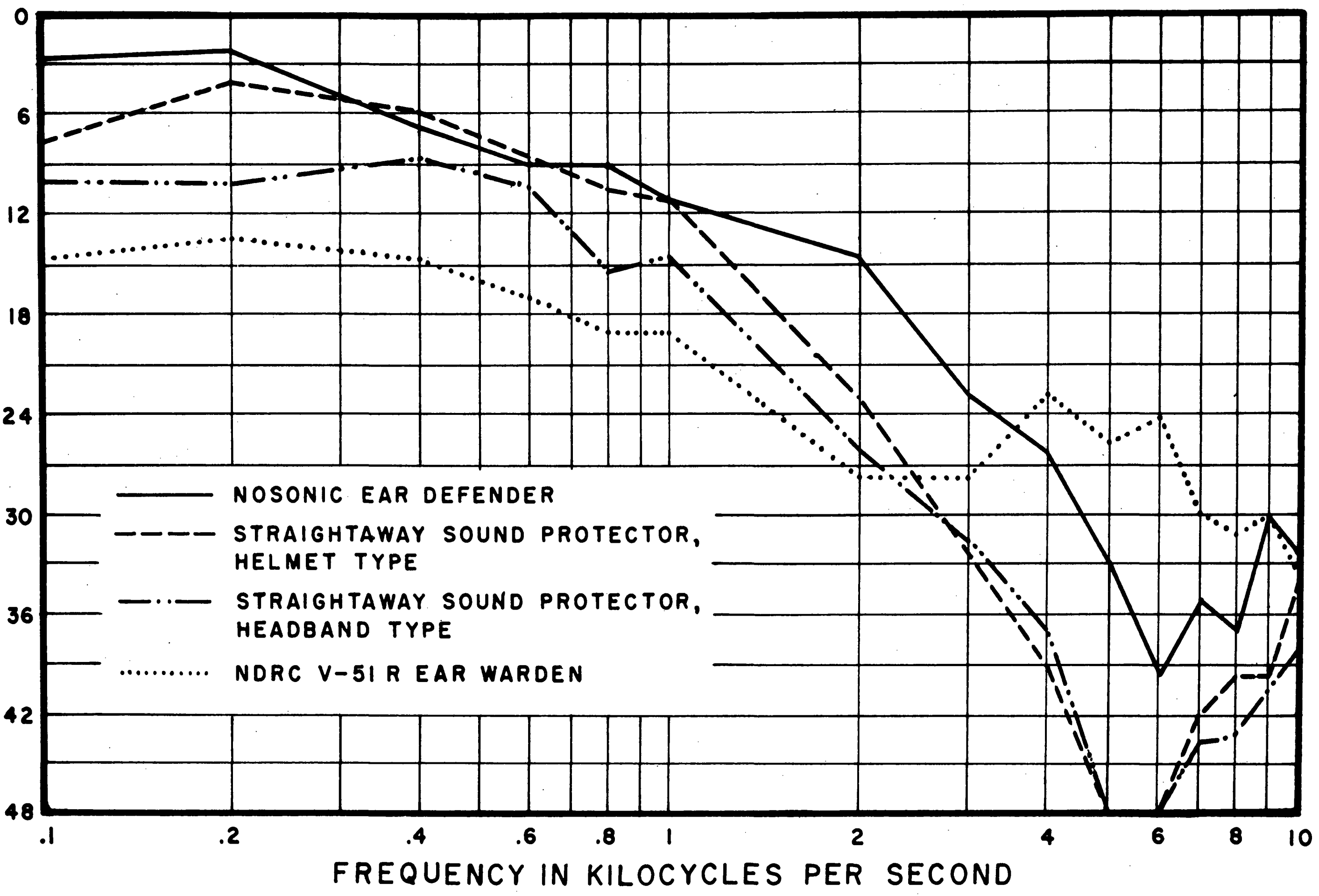
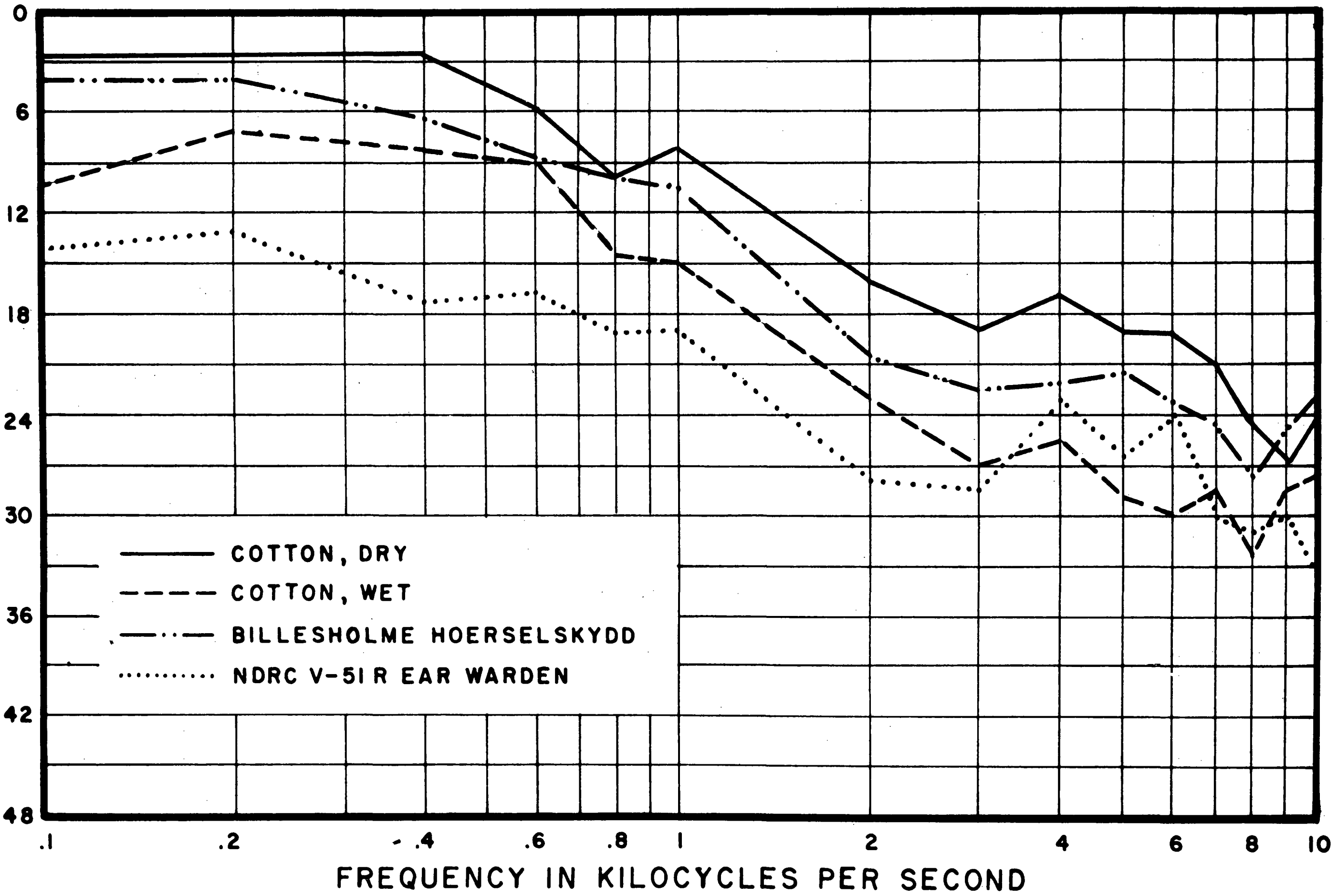


Figure 27. Royal Air Force Type 'F' Flying Helmet Attenuation Curves

favorable agreement.[34,35,38] Typical attenuation curves are shown plotted on Figure 28. An interesting variation is the attenuation curve for a particular experimental plug filled with either mercury or viscous material as shown in Figure 29.[39] As may be seen from the above presentations, there is general increase in attenuation of ear plugs with frequency, ranging from approximately 10 db at 100 cps to approximately 24 to 50 db at 6000-8000 cps. When one considers the acoustic energy output of ground-support equipment in the low-frequency end of the spectrum, the importance of using ear defenders properly to obtain maximum protection is apparent. One method of assuring such protection is by utilizing a combination of ear-defender devices. Such a combination gives added protection should one device become dislodged while the wearer is in a high-level noise environment. This can be shown by comparison of Figures 30-a and 30-b. Figure 30-b portrays the attenuation curve of each device used singly, while Figure 30-a gives the attenuation of several combinations.[35,36,38] It should be noticed that the maximum limits of attenuation for combinations are limited. For instance, used singly, the Mk VI cushion shows an attenuation of approximately 10 db, more than the Mk I cushion. However, the combination of each with the NDRC V51R plug. One might assume the same result with the SMR plug and Mk I defender; that is, a combination of the SMR and Mk VI would give the same attenuation as the SMR and Mk I combination. An interesting fact with respect to communication by wearers of the NDRC V51R ear plug may be obtained from examination of Figure 31.[22] Here percent word articulation was measured with an increasing speech



SOUND ATTENUATION, VARIOUS TYPES OF NOISE PROTECTION DEVICES



SOUND ATTENUATION, VARIOUS TYPES OF NOISE PROTECTION DEVICES

Figure 28. Acoustic Properties of Various Headgear

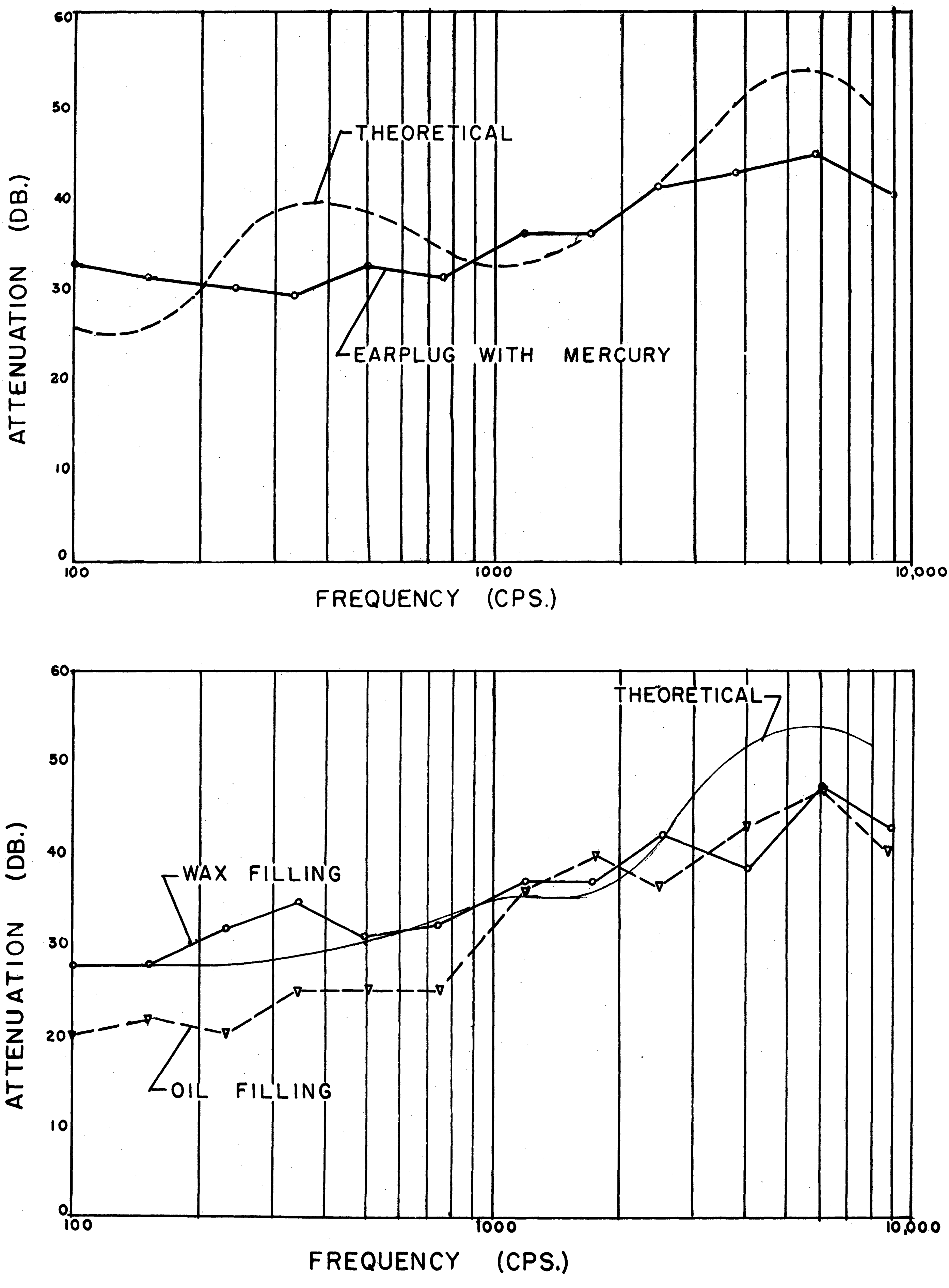
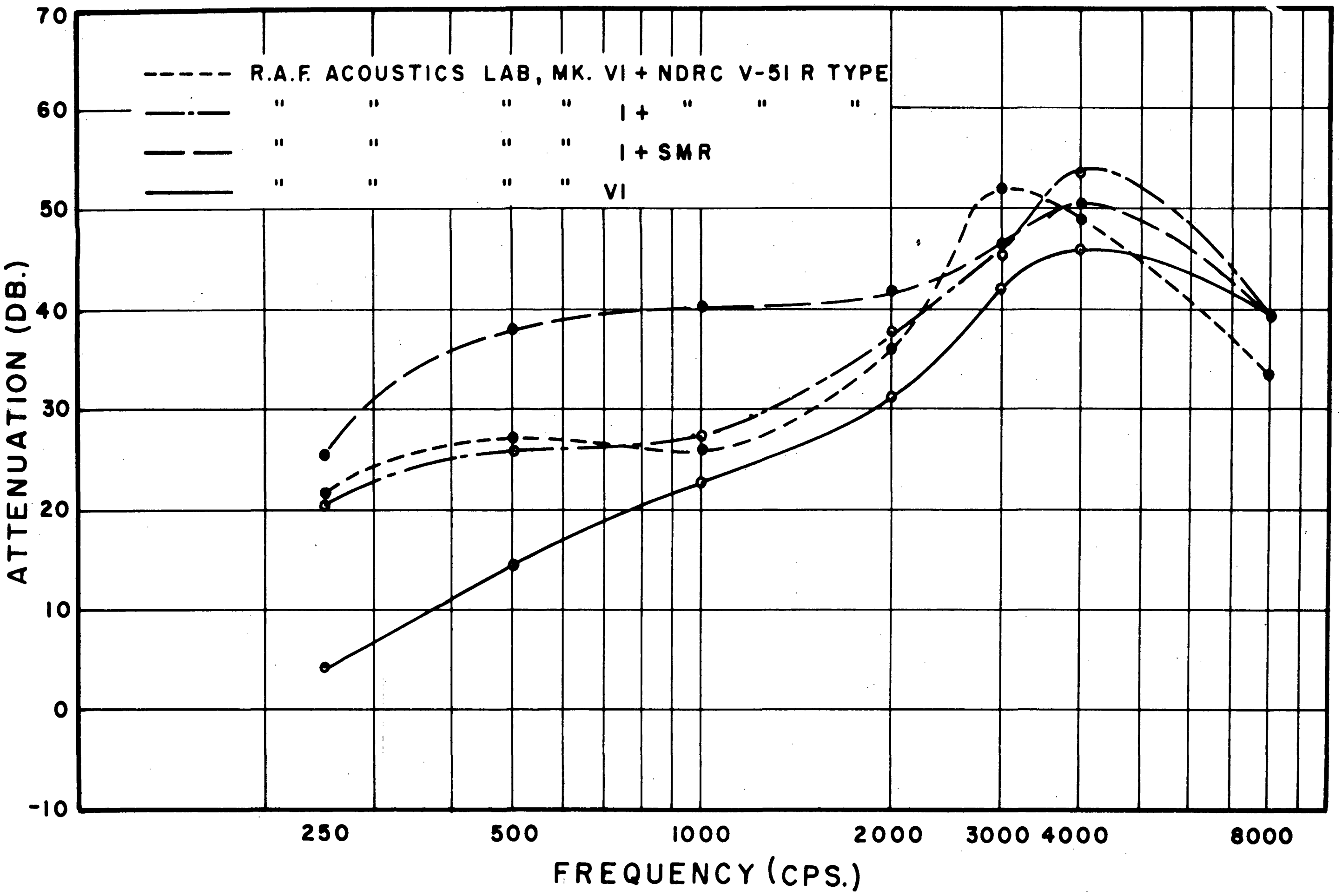
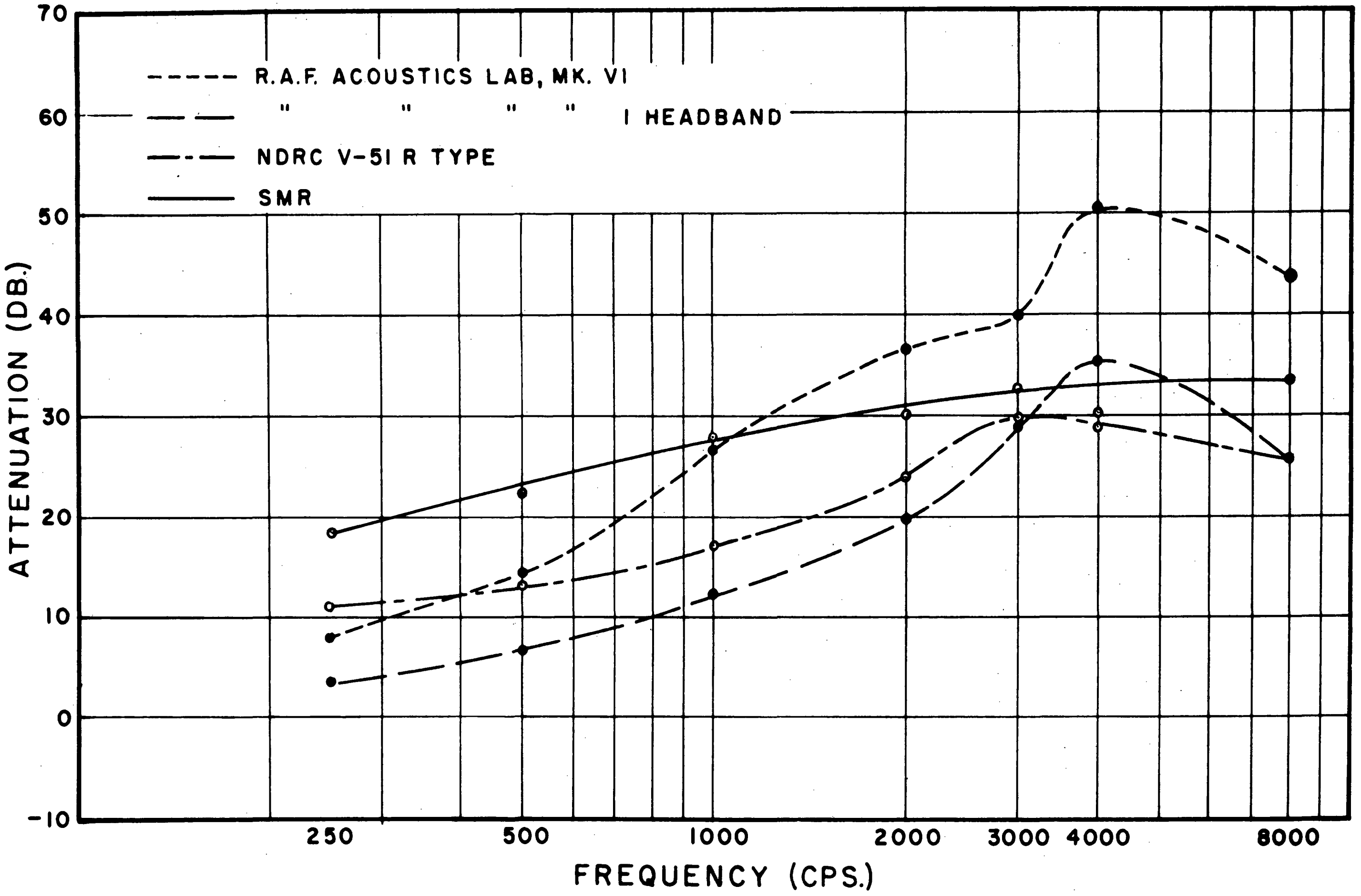


Figure 29. Attenuation Curves Obtained on a Trained Listener for Various Earplugs



(a) ATTENUATION CURVES OF EAR DEFENDER COMBINATIONS



(b) ATTENUATION CURVES AS DETERMINED BY BINAURAL FREE FIELD PURE TONE AUDIOMETRY

Figure 30. Attenuation Curves of Various Ear Defenders Singly and in Combination

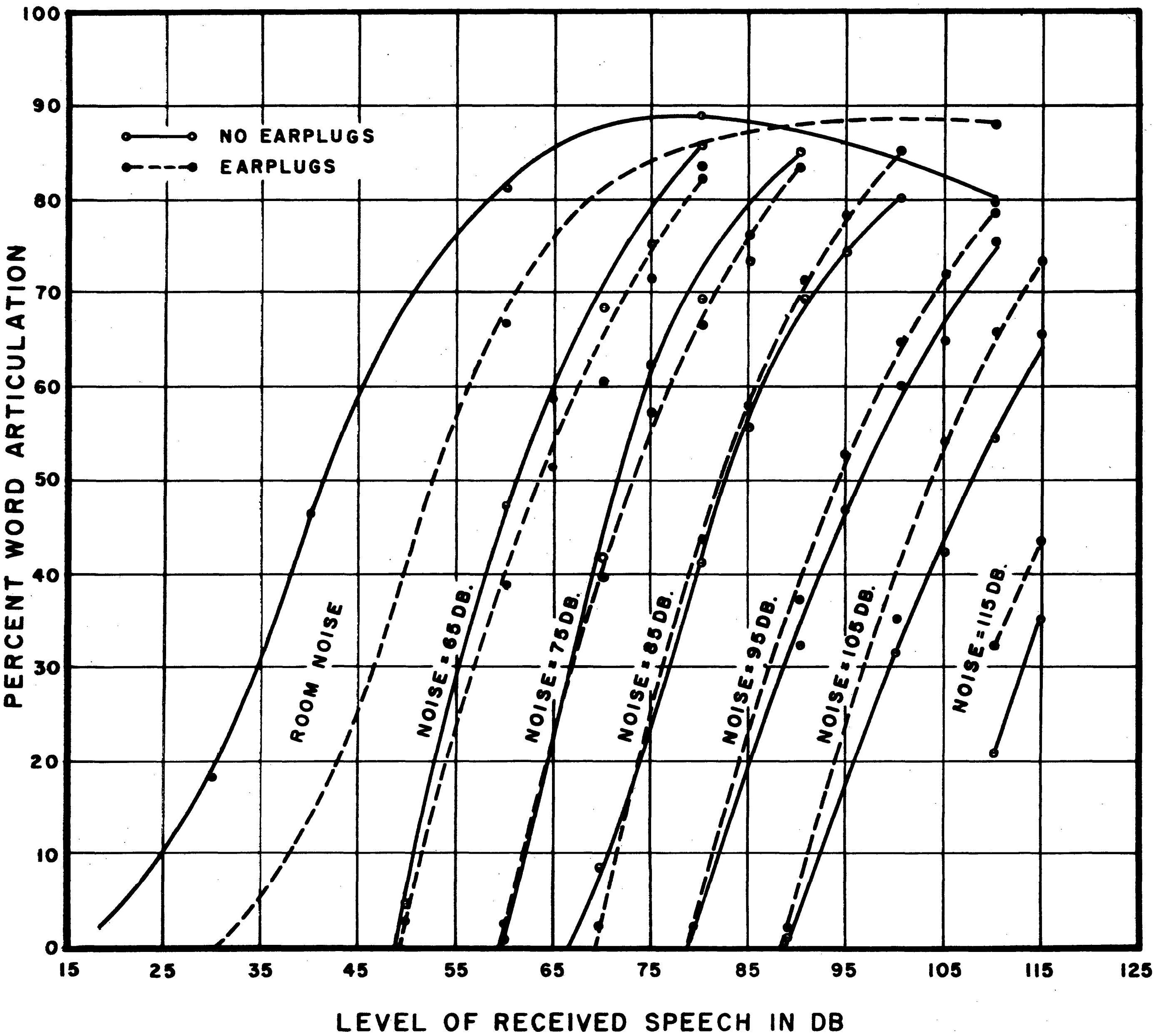


Figure 31. The Relation between Articulation and Speech Level with Noise Level-with and without earplugs

level and at an increasing background-noise level. Notice that as the noise level increases over 75 db the percent word articulation becomes greater for the wearer of ear plugs than for the open ear. In other words, such plugs as the NDRC V51R type may well serve not only as ear protection at high noise levels but also as a means of increasing communication.

Ear Protection Criteria--Application of ear-defender attenuation data has been applied to various noise criteria.[34,40] Figure 32-b presents a simplified attenuation plot of NDRC V51R ear plug, a cushion, and the combination of both. By reference to the Bolt, Beranek and Newman Damange Risk Criterion, and to the Western Electro-Acoustic Laboratory Risk Criterion, the resulting environmental acoustic level for no serious ear damage to the wearer is shown in Figure 32-a. It must be remembered that these risk criteria are based on so-called lifetime exposure. A proposal for a short-term criterion has been brought forward for utilization by ground-support personnel.[40] Here a sound-pressure-level time factor has been developed so that the hearing mechanism is exposed to no greater sound energy for protected ears than for unprotected ears. The basic noise is assumed to be jet noise with a peak output between 75 and 600 cps. Figure 33 presents the various curves based on the "no protection" curve which allows exposures up to approximately 10 seconds for 135-db levels with a continuous drop of 3 db for every doubling of exposure time up to an 8-hour day. Thus by knowing the sound-pressure-level plot surrounding a particular aircraft, and the time required to remain in such a level, the proper protection may be chosen to avoid ear damage. It may be

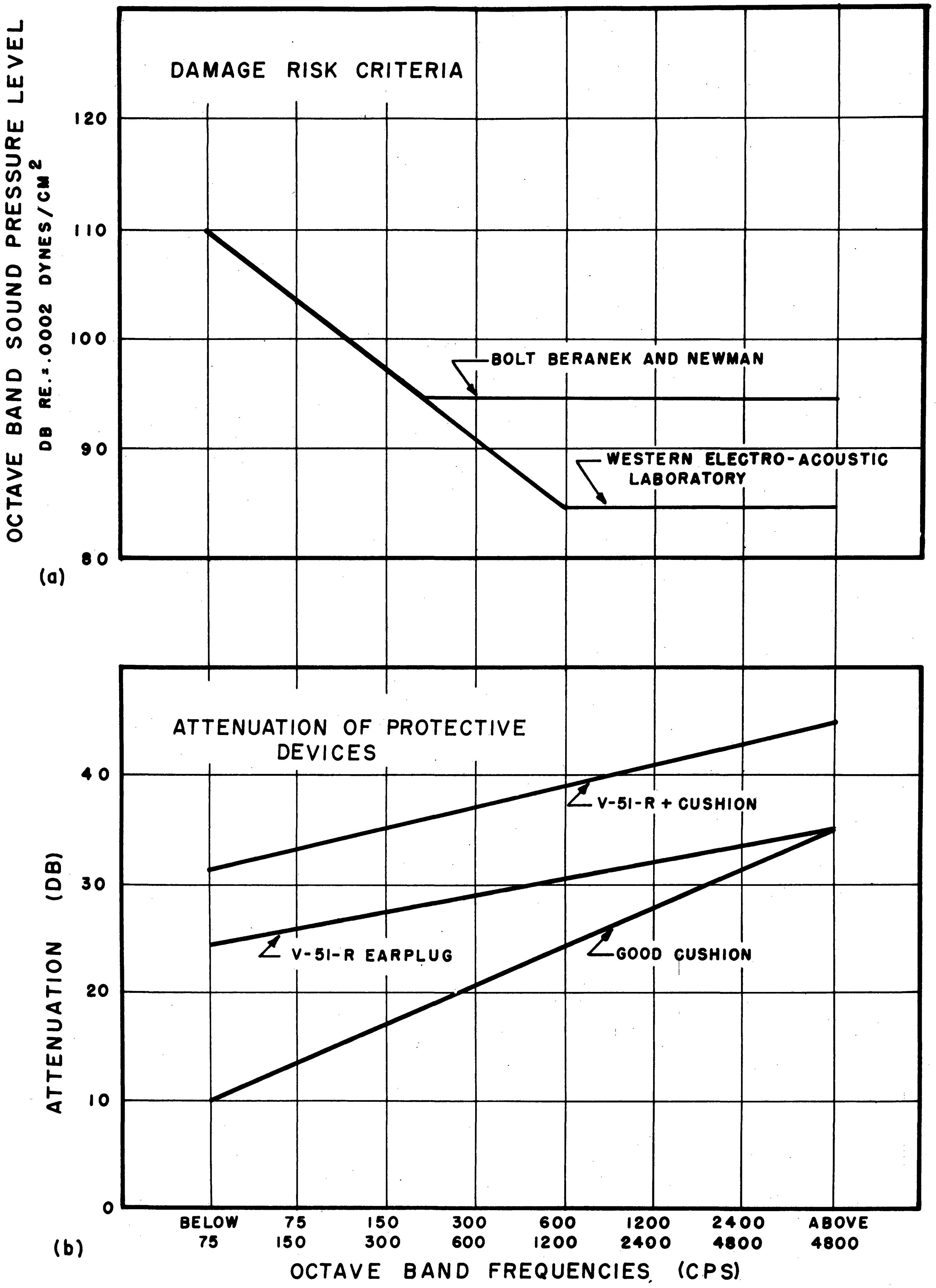


Figure 32. Attenuation Available with Some Protective Devices and Proposed Aural Damage Risk Criteria

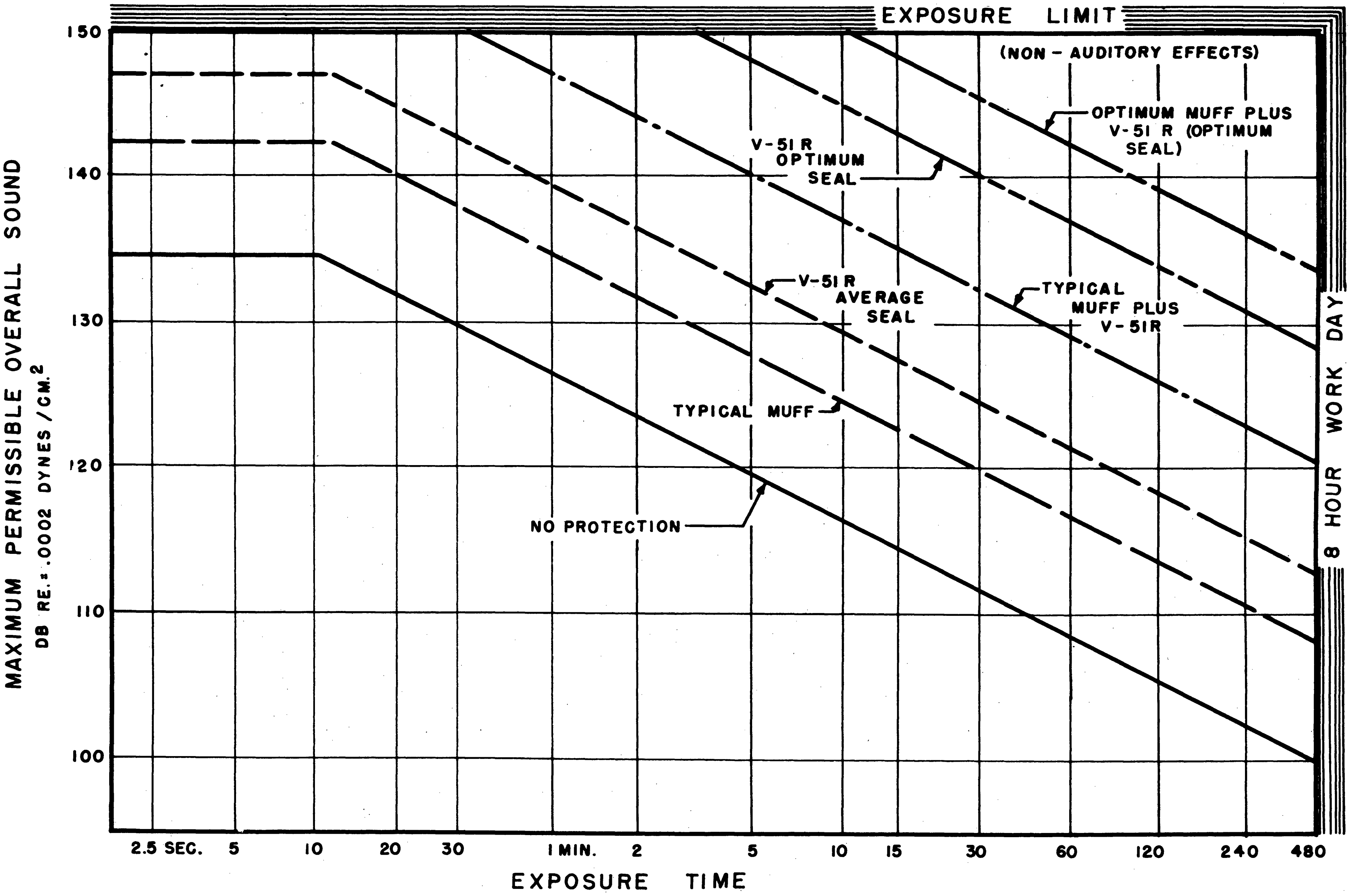


Figure 33. Short Time Exposure Criteria for Jet Type Noise. The Maximum Permissible Overall Sound Pressure Level of Jet Exhaust Noise is Given as a Function of the Average Exposure Time for the Protected and Unprotected Ear

noticed that no criterion is proposed for 150-db levels and up, since exposure to these levels without protection produces permanent hearing loss and nonauditory effects.

NONAUDITORY EFFECTS OF HIGH-LEVEL NOISE AND VIBRATION

One aspect of the nonauditory effects of sound has been discussed in the section on annoyance. However, there are other nonauditory effects which sould be mentioned to complete the discussion. In many respects the field of nonauditory effects has been adequately summarized quite thoroughly elsewhere.[2,22] For the purposes of their relation to ground-support personnel as hazards, these effects will be lightly reviewed with the addition of some relevant data, especially with respect to whole-body vibration. As has been the case in the preceding discussion of the physiological and psychological effects of noise on humans, the main parameters here are the frequency and the sound-pressure level of the acoustic source.

High-Level Noise Sources--The sound-pressure level in which ground-support personel normally operate is usually above 90 or 100 db. Therefore, the physiological effects of acoustic stimulus below this level will not be considered. Indeed, a summary of results concerning such physiological reactions at low acoustic levels points out that man adapts quite well to such stimuli and, in some cases, may even exhibit somewhat greater efficiency due to his increased effort under influence of stress.[22] The deleterious effects of supersonic energy radiated by jet engines is also questionable. Though some disagreement exists, it is generally agreed that the supersonic power output of present-day jet noise is well below dangerous levels.[39,40,41,42] However, the general trend in noise reduction of jet engines places an emphasis on shifting the energy in the spectrum from the audible into the supersonic regions. Should such practices become both widely employed and more efficient, a re-evaluation of potential physiological damage by supersonic noise environments may be necessitated.

Nonauditory Effects of Airborne Sound--Reliable information on the physiological reactions of human beings from acoustic energy in the sonic region at sound-pressure levels above 100 db is based on the reports of Finkle and Poppen,[41,43] and H. O. Parrack.[44] In the first experiment, the subjects were exposed to noise levels of 120 db from a jet source for periods of one hour for ten days and then for two hours each day for five days. Very thorough physiological checks were made of bodily functions such as basal metabolism and clotting time. Also, x-ray, electrocardiograph, and other examinations were made. No significant abnormalities were found prior, during, or after the experiments. The Parrack experiment was carried out in an acoustic environment of 150 db in which the subjects experienced such effects as cranial vibration, blurred vision, and an adverse effect on the proprioceptive reflex mechanism resulting in a "weakness in the knees." The cranial vibration was noted within the range of 700-1500 cps. Other experiments have shown this frequency to be about 800 cps.[45,46] Visual tests performed under auditory stimulus have shown little, if any, significant results.[47,48,49] As a result, it might be assumed that the blurred vision occurring in the Parrack experiment was the result of gross eyeball vibration.

Nonauditory Effects of Vibration--Generally, when the acoustic environment of ground-support personnel is considered, only the airborne energy is considered. This may not be the only source of vibrational energy reaching the subject. In some types of ground-support equipment, such as the Consolidated MA-1, there is a place for an occupant in the equipment, and therefore he may be exposed to vibrational energy transferred from the chassis to his body. This type of nonauditory reaction experiment was carried out using a seat mounted on a platform which was vibrated at frequencies of 5-40 cps in a sinusoidal manner with peak-to-peak amplitudes varying up to one-half inch.[50,51] Certain levels of "annoyance" and "tolerance" were determined on thirteen subjects at 15, 25, and 35 cps. For the whole-body vibration study, eighteen subjects were tested, six each at 15, 25, and 35 cps, using both light and heavy vibrations. The light-vibration levels for each frequency were set at the mean of annoyance levels, while the heavy-vibration levels were set at the mean of the tolerance levels. To separate the nonauditory effects due to the whole-body vibration and those resulting from the accompanying airborne noise, each subject was also exposed to 115-db noise level and a control condition. Each subject was tested for visual acuity, tremor in a supported hand, and aiming tremor. Figure 34 shows the effects of whole-body vibration on visual acuity. Notice that there is little decrease of acuity under noise conditions and the decrease of acuity is consistent with both an increase in vibration and a decrease in frequency. Figure 35 illustrates the results of the manual tremor experiment. The signicant differences from the normal control condition appear at both 15 and 25 cps under both conditions of vibration, with startling loss of control

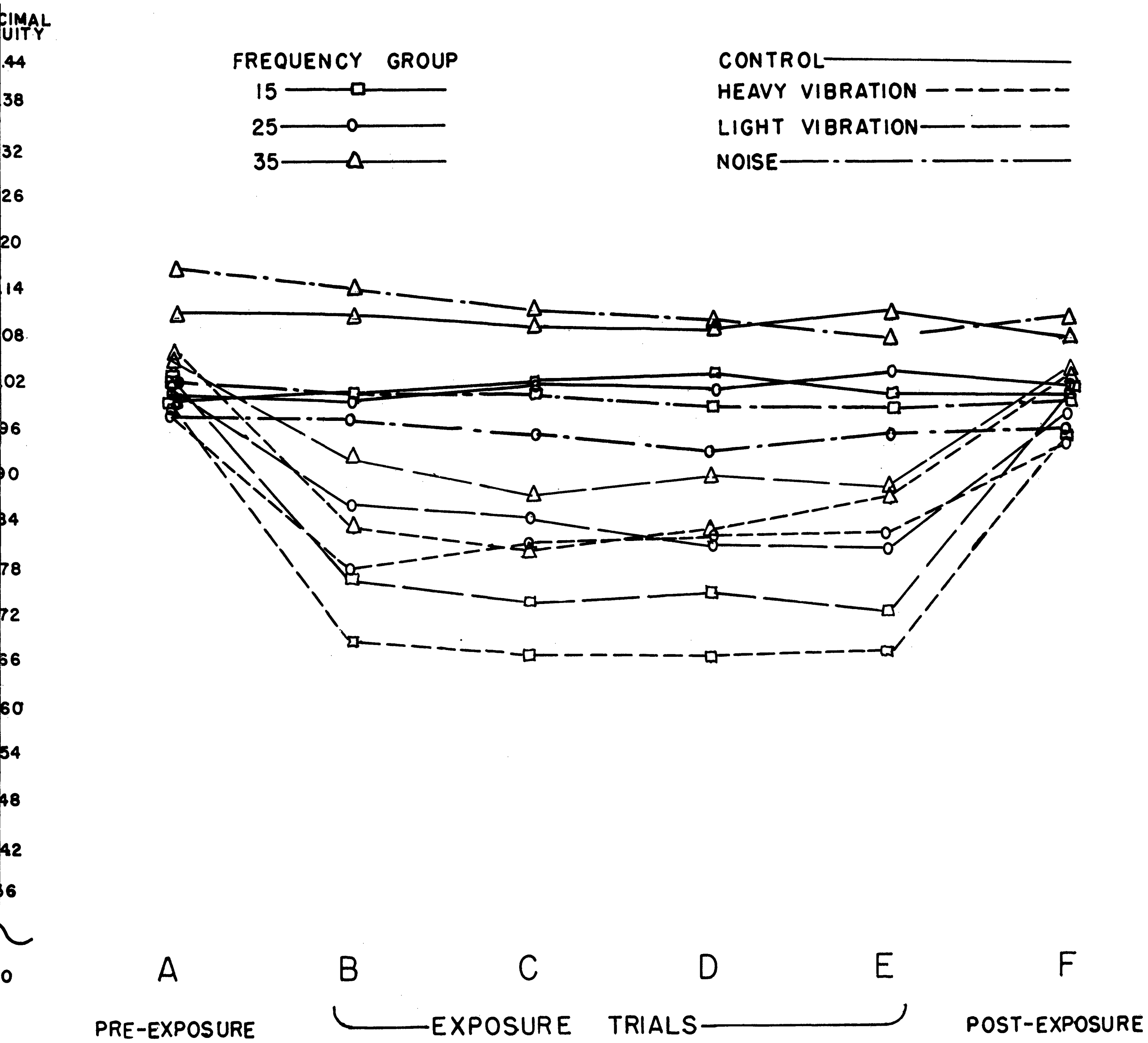


Figure 34. Effects of Noise and Vibration on Visual Acuity

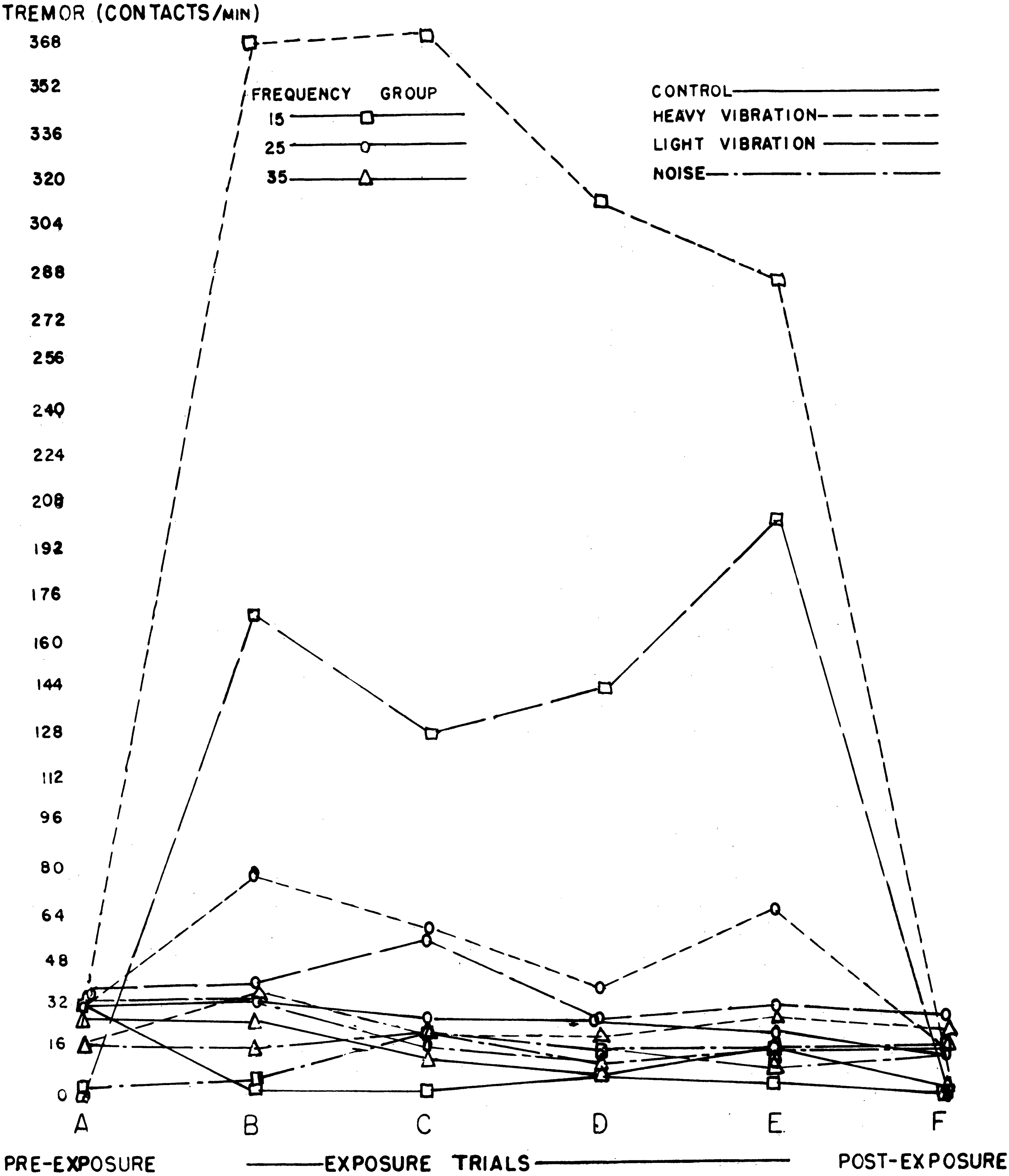


Figure 35. Effects of Noise and Vibration on Manual Tremors

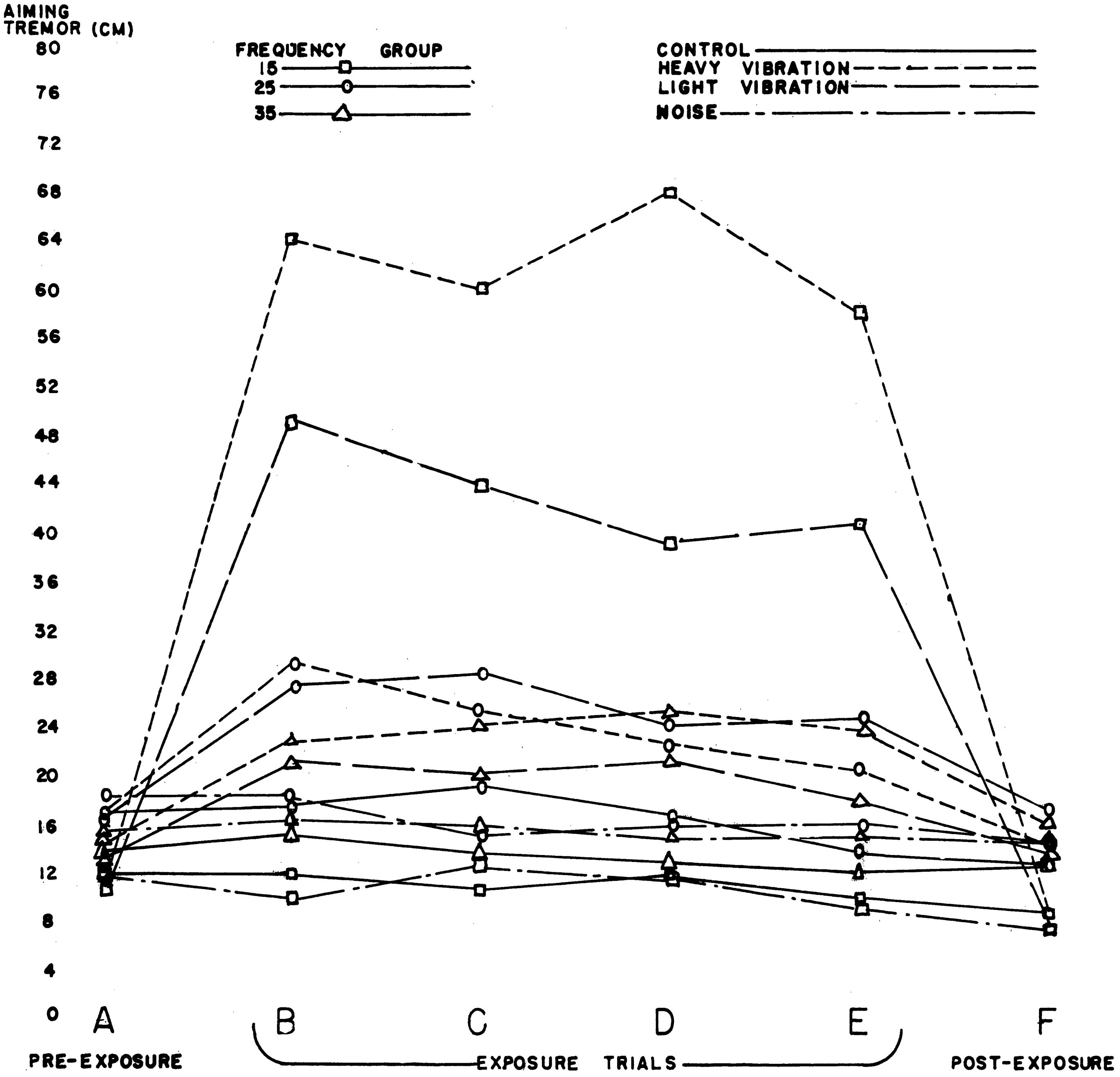


Figure 36. Effects of Noise and Vibration on Downward Aiming Tremor

apparent at the lower frequency, especially during the heavy-vibration condition. Figure 36 depicts the loss of aiming control, with the results again pointing toward greater effect at lower frequencies and heavy vibration.

It may be siad that the major contibutors of energy which tend to produce nonauditory effects beyond the annoyance stage are sources which emit both high-level sonic and subsonic energy. Should the trend toward increasing supersonic energy output of jet engines continue, these frequencies may also prove injurious.

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