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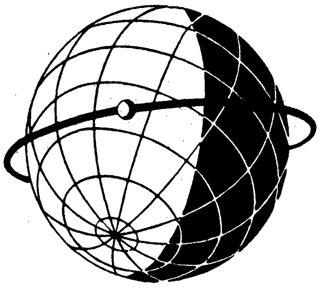
PREFACE

The papers incorporated here were prepared for presentation at the Fifth Assembly of the "Comité Special de l'Anée Géophysique Internationale" held in Moscow, Russia, during the period July 30 - August 9, 1958. The first paper is a summary of Report ES-1 prepared previously on this project.

The second paper constitutes a review of the theoretical basis for measurements carried out by several rocket firings, to evaluate the ambient pressure, temperature, and density of the atmosphere to altitudes of 80-90 km over Fort Churchill, Manitoba, Canada. As of the writing of this report, 8 Nike-Cajun launchings and 2 Aerobee launchings have been carried out, including two prototype Nike-Cajun flights. The paper reprinted herein constitutes a preliminary report on data reduction for these launchings.

U. S. National Committee
for the
International Geophysical Year

A RADIOACTIVE-IONIZATION-GAGE PRESSURE-MEASUREMENT SYSTEM



This report was prepared by N. W. Spencer and R. L. Boggess of The University of Michigan for presentation at the 5th General Assembly of CSAGI, Moscow, July 30-August 9, 1958.

INTRODUCTION

Rocket measurements of upper-atmosphere structural parameters have, in large measure, been based upon the evaluation of the dynamic air pressure at selected points on the surface of the rocket. Various locations have been chosen for these determinations, but, generally speaking, the nose cone has provided the location for most experiments, as this region permits, usually, the most reliable measurements.

Experiments based upon surface-pressure-measurement concepts and aerodynamic considerations are limited in altitude capability to heights less than approximately 90-100 km, since at this level the mean free path of the gas particles becomes long with respect to sensing-device dimensions. Other factors imposing this limit, related to the mean-free-path concept, are growth of the boundary layer of air surrounding the rocket, reduction of the Reynolds number, and atmospheric composition changes, all resulting in breakdown of aerodynamic concepts based upon the gas law and relatively high air density considerations.

Accordingly, instruments appropriate for measurement under continuum conditions are adequate if they can indicate pressures down to 10^{-3} mm Hg, the approximate value encountered in the 90- to 100-km region. Correspondingly, a high pressure limit is likewise generally accepted in the altitude neighborhood of 30 km as balloon-borne pressure- and temperature-measurement experiments are considerably less expensive to carry out up to this level, where the ambient pressure is approximately 10 mm Hg. Rocket-borne equipment, however, at this altitude, can experience much higher (factor of 20 or more) pressures due to the "ram" effect which varies roughly as the square of the Mach number.

Thus instruments suitable in the sense of useful measuring range must be able to measure with the desired precision over the range 100 to 10^{-3} mm Hg, or 5 decades. This large range imposes a severe burden on many instruments, generally being considerably more extensive than their useful range. Some devices, however, do respond adequately throughout this pressure range and have permitted the development of measurement systems which take advantage of their favorable properties.

A radioactive ionization gage is one such instrument which satisfies this requirement. It possesses other desirable characteristics: (a) it is undamaged by exposure to atmospheric pressure; (b) it is physically rugged; (c) it has nearly instantaneous electrical response; and (d) its construction is relatively simple. Correspondingly, it exhibits some drawbacks: (a) it has a very small output current magnitude; (b) the radioactive source constitutes a potential health hazard; and (c) there is some nonlinearity at very high and very low pressures, generally outside the range indicated above.

The purpose of this paper is to describe briefly a unit, developed and used extensively during the IGY program for pressure measurement, that employs a radioactive ionization gage as its basic sensing element.

OUTLINE OF INSTRUMENT

Figure 1 illustrates in block diagram form the system adopted for use with the radioactive ionization chamber. In the arrangement, the small current produced by the chamber is passed through a resistance of sufficient magnitude to cause a voltage drop equivalent to the voltage level desired for presentation to the telemeter. Since large resistances (10^{12} ohms in some cases) are required, and because a telemeter generally imposes relatively low input impedances, a matching circuit in the form of a unity negative feedback amplifier is included. It provides, in effect, current amplification, overcoming one of the drawbacks of a radioactive ion chamber as noted previously.

This circuit arrangement likewise permits realization of the extensive pressure-range characteristic exhibited by the chamber, for it is necessary only to alter the magnitude of the chamber load resistance in some fashion to accomplish a sensitivity change.

In the system which has been used extensively in the IGY program, five different resistances are employed to cover the desired range. Figure 2 illustrates the complete current-output voltage relationships under conditions where the resistance is changed by a factor of six at appropriate currents.

Figure 3 illustrates a composite pressure-current relationship for a typical ion chamber corresponding to the Fig. 2 curves. Figure 4 is a schematic diagram of the amplifier circuit.

AUTOMATIC RESISTANCE CHANGE

To employ fruitfully an arrangement that requires resistance change as a function of current or pressure or their equivalent in telemetered signal necessitates, of course, a device which senses that a change is required and then brings about the correct alteration.

A simple d-c servo circuit has been developed for this function. It employs rotary solenoids for effecting the mechanical shift, and thyratrons for control of the solenoids. The energy for the solenoids is drawn slowly from the system power supply, and is stored in a capacitance as functioning of the system is required only every several seconds.

The thyratrons are controlled by transistors which enable rapid thyratron grid-voltage changes and hence more stable control. The output voltage of the d-c amplifier, which constitutes the pressure signal, is applied to the transistors as well as to the telemeter for this control purpose. Thus the total system is able to maintain an on-scale output signal, by self-induced selection of the proper resistance, throughout the useful range of the device. A schematic diagram of the servo circuit appears in Fig. 5.

POWER SUPPLY

All power necessary for operation of the pressure-measurement system is obtained from a small silver cell battery pack, which supplies approximately 6 volts and has a rated capacity of 1 ampere hour. Conversion for the high voltages required is accomplished by a transistor-oscillator system of conventional design.

The primary cells are adequate for about 1 hour of operation of the system.

PHYSICAL DETAILS AND OTHER CHARACTERISTICS

The entire system has been constructed in a form readily applicable to rocket instrumentations. It is contained (including power) in a cylinder 2-1/4 inches in diameter, 16 inches long, and weighing 3-1/4 pounds. Figure 6 is a photograph of a system with cover removed. The various portions of the equipment are indicated.

Figure 7, which shows the load-resistance changes encountered during a recent rocket application, illustrates the pressure-range selection properties of the system.

Finally, Fig. 8 presents a curve of total head pressure vs. time measured with a typical system. The curve is comprised of "raw" pressure data.

ACKNOWLEDGMENT

Many individuals have contributed ideas and effort to the development of this measurement system. M. A. El-Moslimany participated extensively in the area of chamber development, as did L. R. Brace in circuit development. Many others, including W. G. Kartlick, G. Burdette, J. Horvath, and T. Miller, were greatly involved in other aspects of the system. Much credit is due to all these individuals.

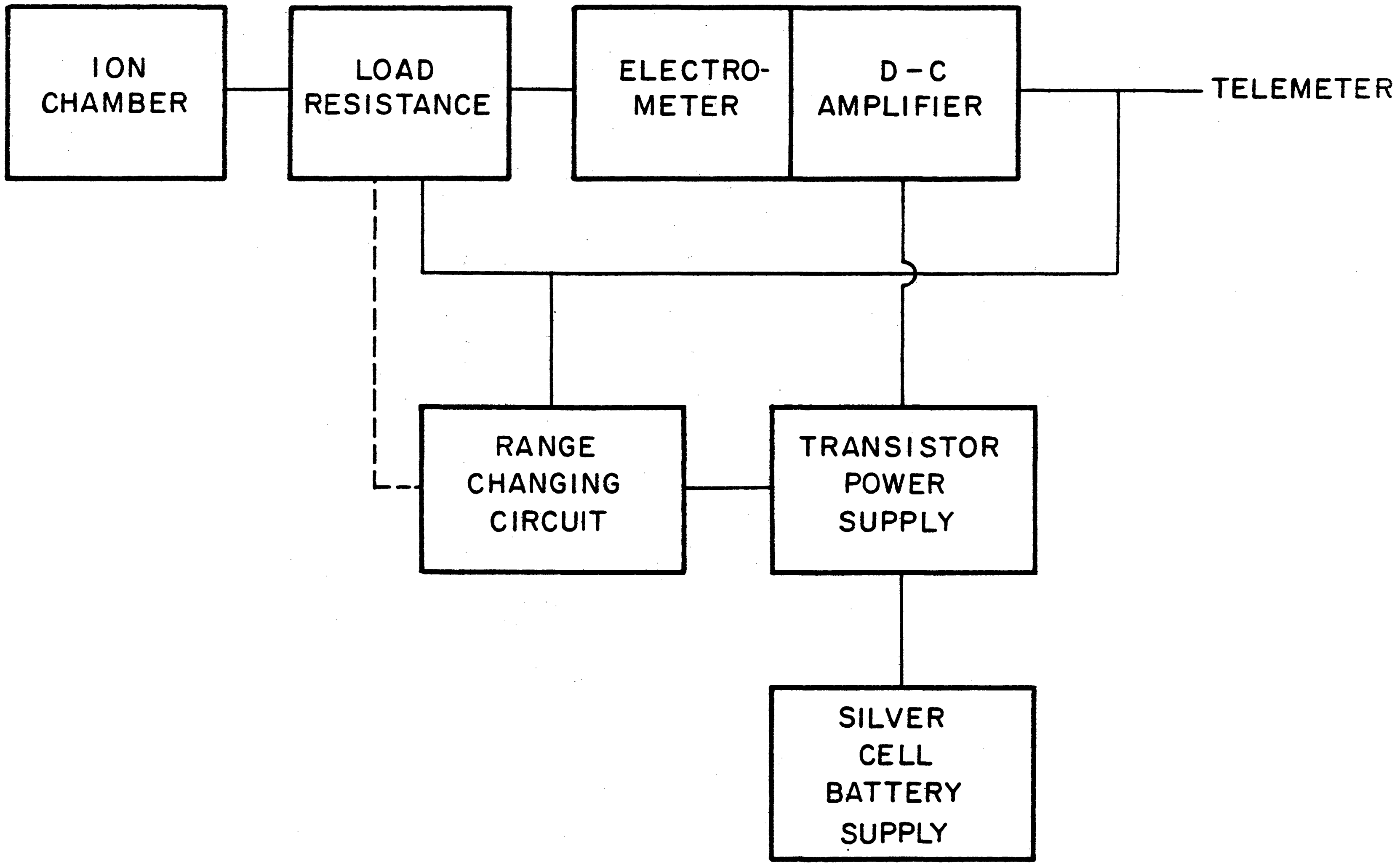


Fig. 1. Block diagram of radioactive pressure-measurement system.

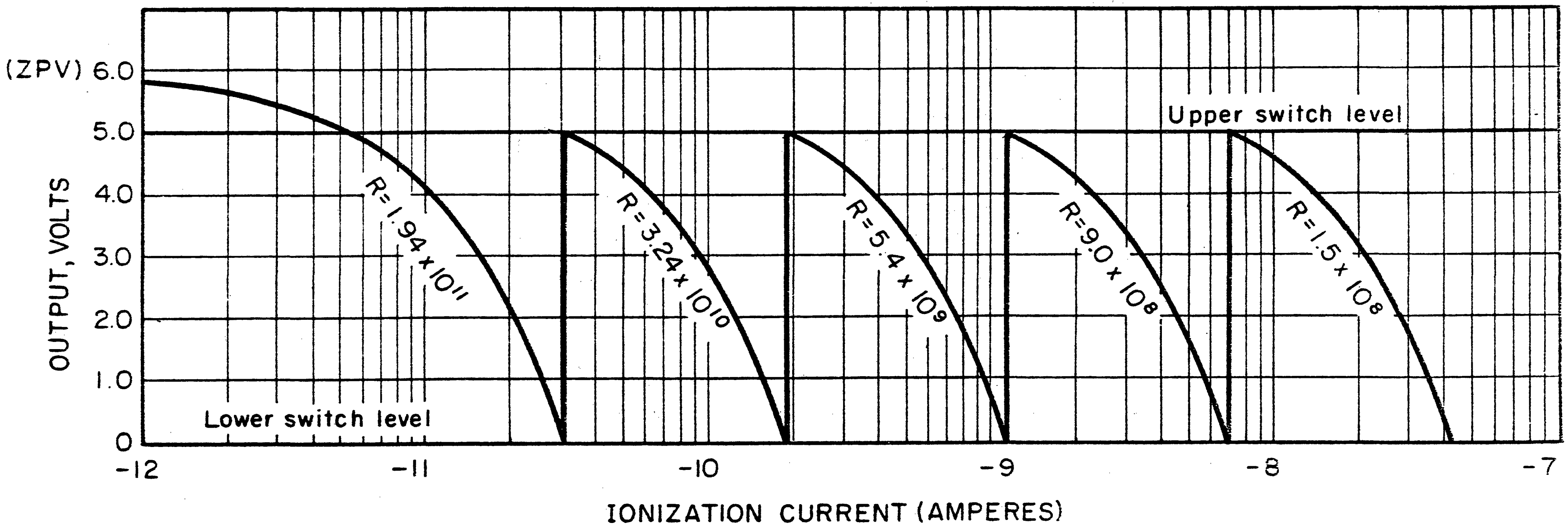


Fig. 2. Output voltage and hi-meg resistor relationships.

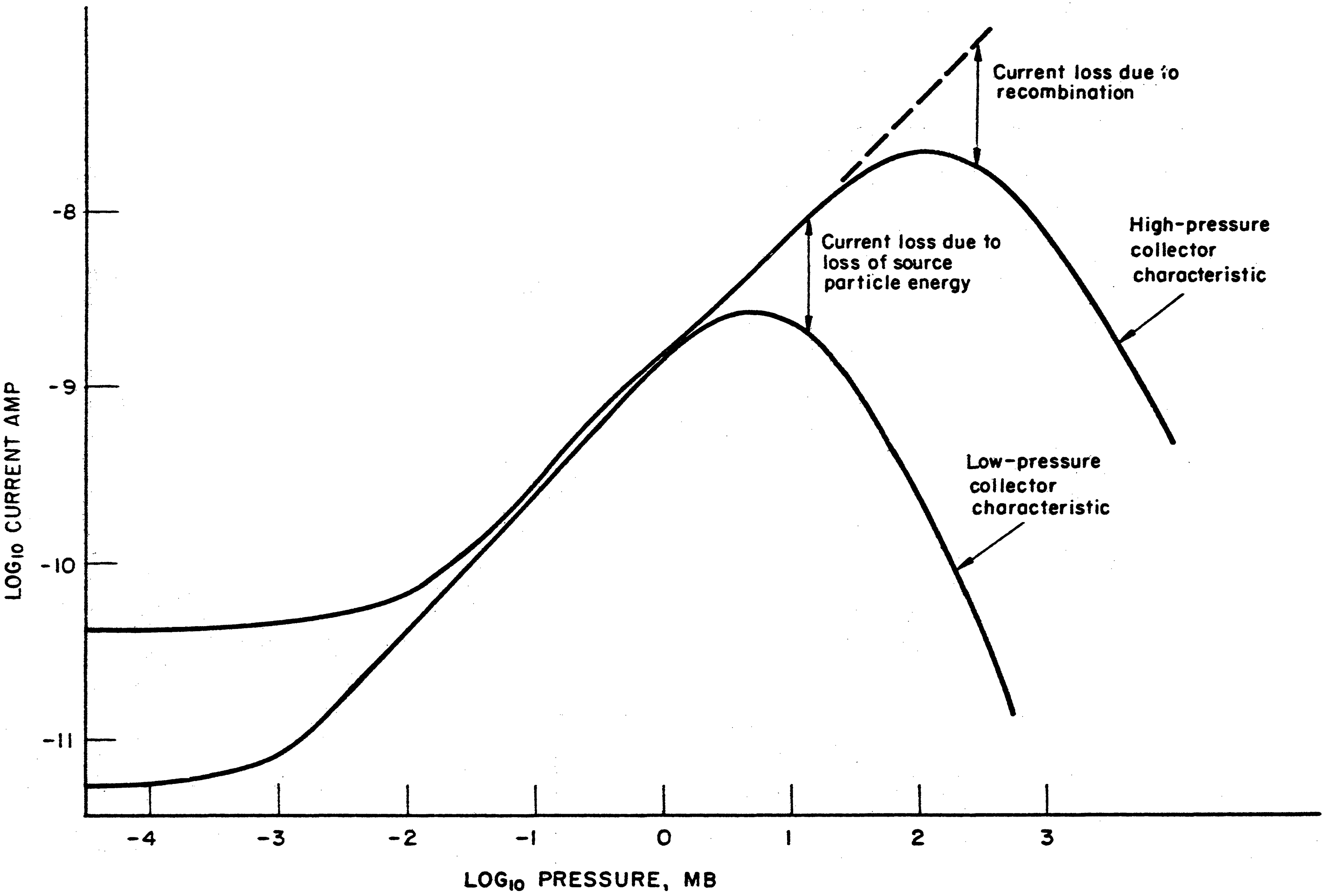


Fig. 3. i-p curve of typical ionization chamber showing low-pressure and high-pressure characteristics.

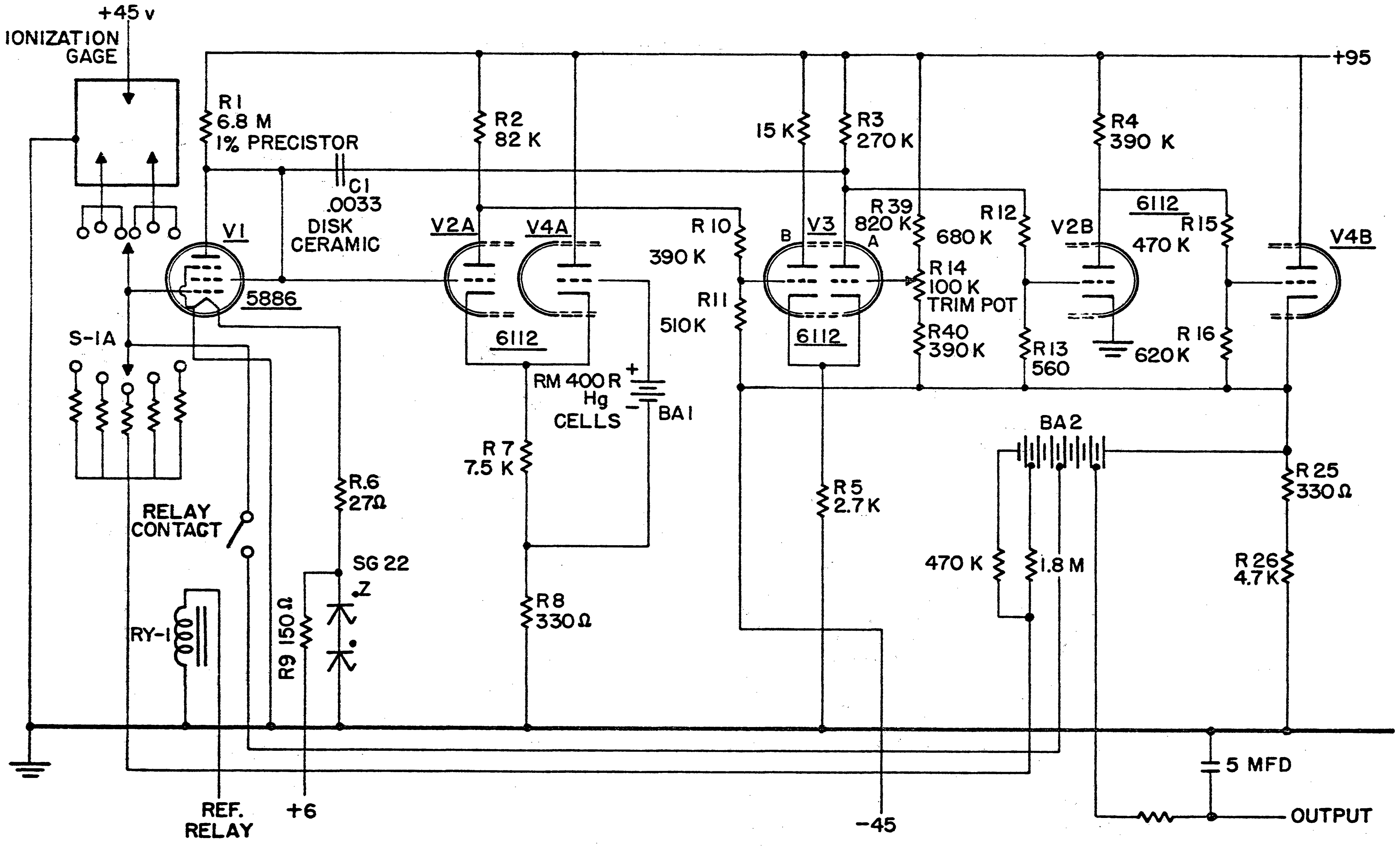


Fig. 4. Amplifier schematic diag

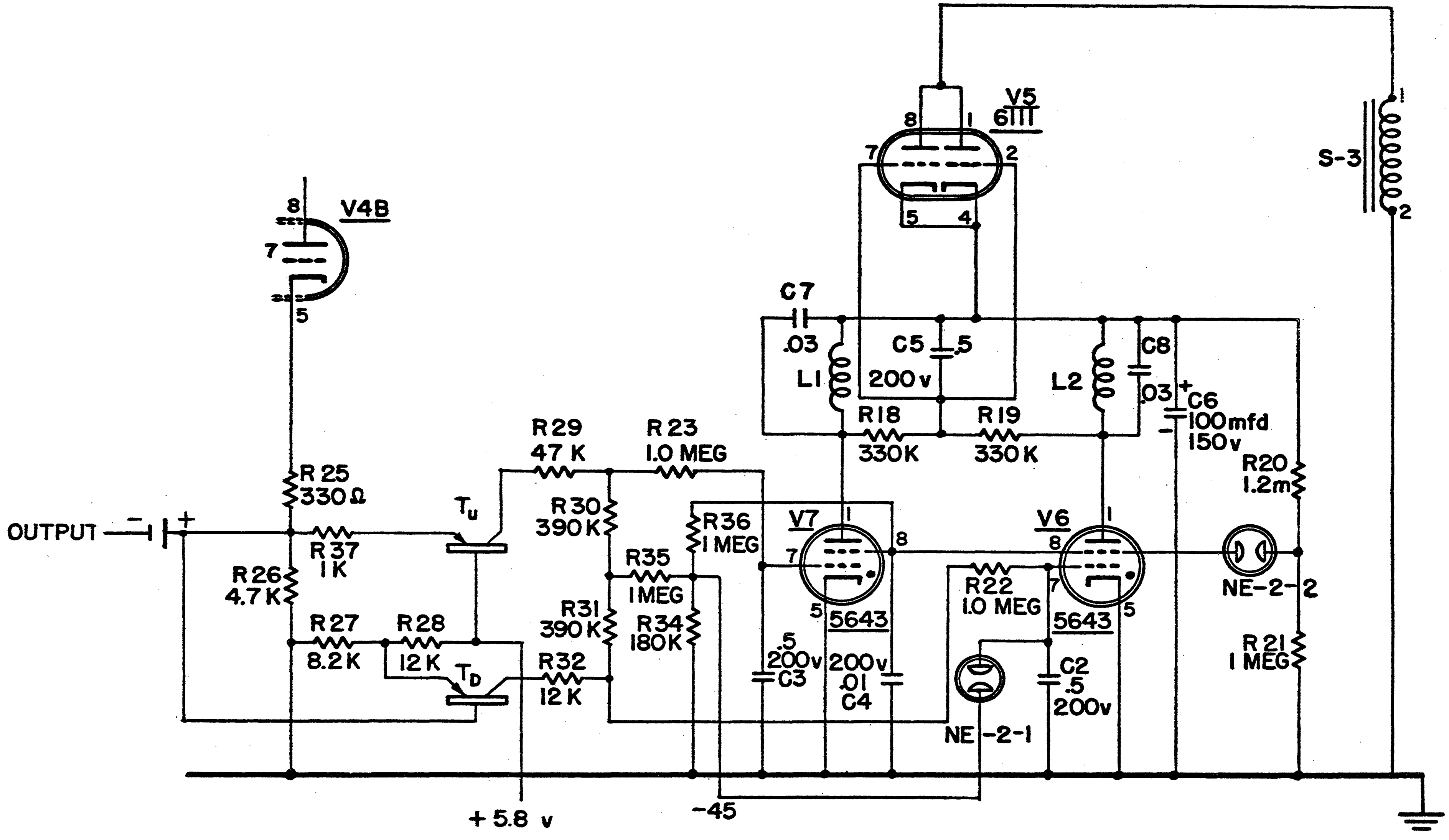


Fig. 5. Range-changing-circuit schematic diagram.

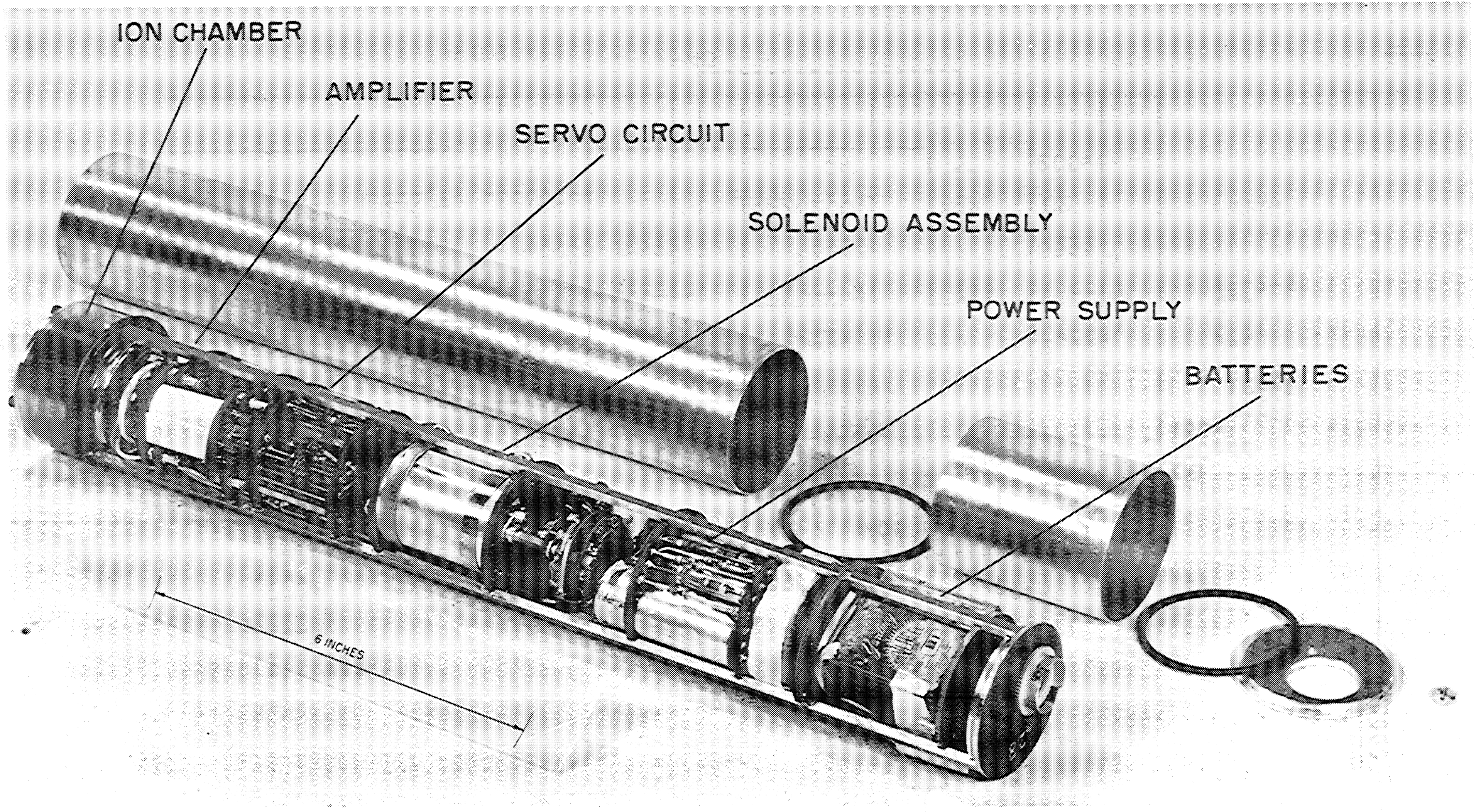


Fig. 6. Complete system out of enclosing tubing.

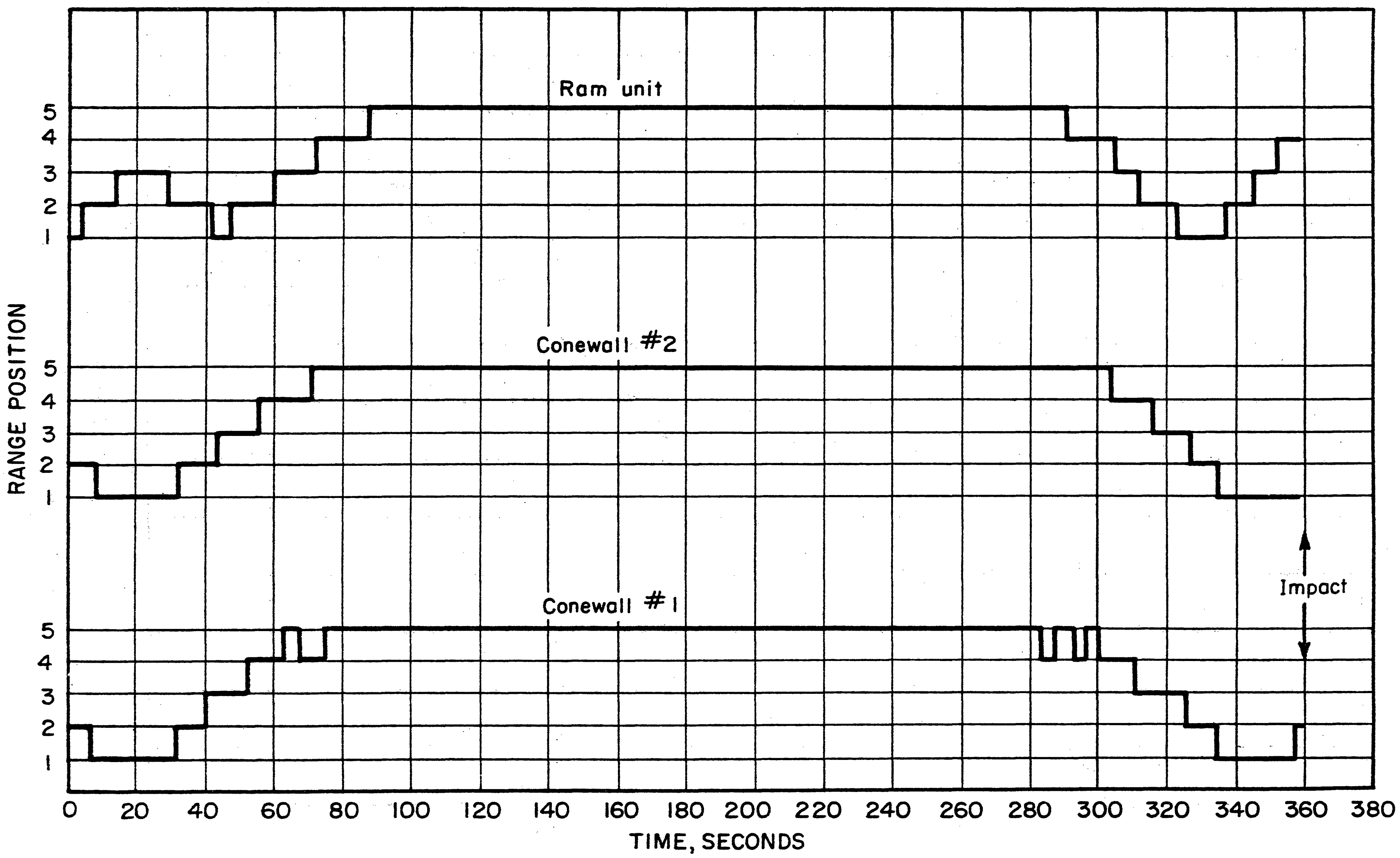


Fig. 7. Range position vs. time for 3 units on Nike-Cajun AM 6.38.

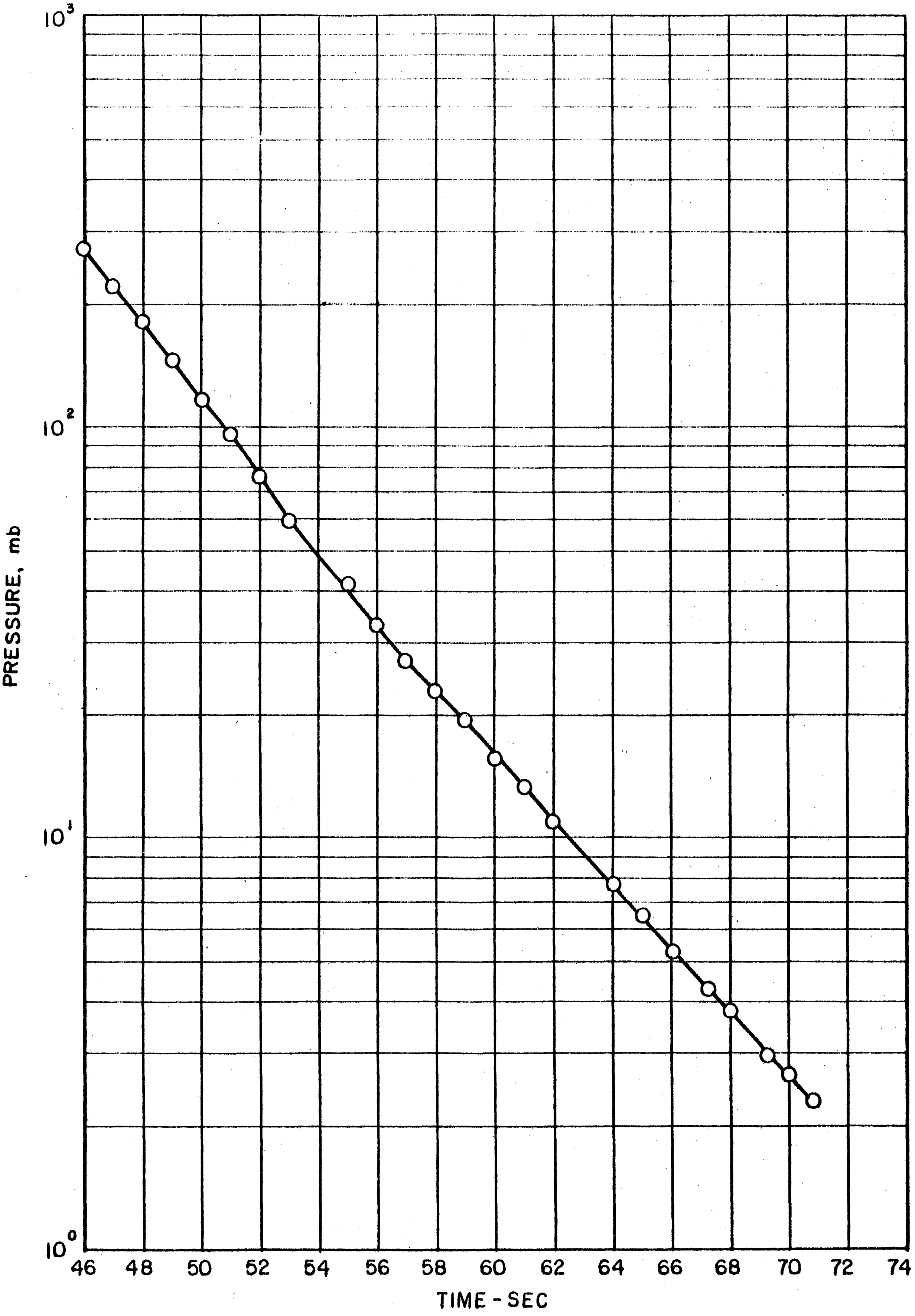


Fig. 8. Ram pressure vs. time.

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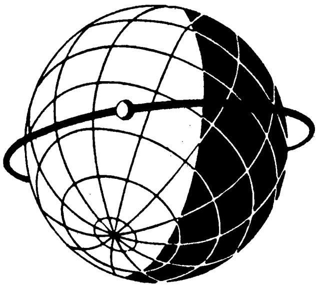
International Geophysical Year

PRESSURE, TEMPERATURE, AND DENSITY TO 90 KM OVER FORT CHURCHILL



This report was prepared by N. W. Spencer, R. L. Boggess, and D. Taeusch of The University of Michigan for presentation at the 5th General Assembly of CSAGI, Moscow, July 30-August 9, 1958.

INTRODUCTION

The measurement of the ambient pressure, temperature, and density of the atmosphere in the region between levels readily attainable by radio-sonde carrying balloons, and about 90 km has occupied upper-air researchers for many years. This approximate 90-km limit is chosen because at this point the mean free path of the gas particles is, in general, short as compared with the dimensions of feasible rocket-borne equipment. Particular emphasis has been placed upon distribution of these quantities during the International Geophysical Year, which presented American researchers with an opportunity to conduct measurements in the near-arctic regions on a scale that was not previously possible. Various devices, including grenades,[1] falling spheres,[2] and pressure-sensing instruments of various types,[3] have been employed by the several groups which have participated in this type of measurement. These devices are used in different ways, enabling a very desirable diversification of attack upon measurement of the structural parameters. Instrumentation employing grenades permits direct determination of the temperature and also winds. The falling-sphere technique enables measurements of the drag on a sphere which can be interpreted straightforwardly in terms of density. Techniques which employ as their primary data pressure measured at various points on a rocket body enable direct interpretation of these data, under some conditions as ambient pressure, under other circumstances as ambient density, and under still different conditions as the free-stream Mach number which is ambient temperature-dependent. Once the primary measurement has been accomplished by any of the techniques, reasonable assumptions make possible the evaluation of the other equation-of-state variables through various computation techniques.

It is the purpose of this paper to describe (a) experiments* that have been carried out employing pressure as the basic data, and (b) the results of some preliminary data reduction that has been accomplished.

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[1] Stroud, W. G., Bandeen, W., Nordberg, W., Bartman, F. L., Otterman, J., and Titus, P., Temperature and Winds in the Arctic as Obtained by the Rocket-Grenade Experiment, paper presented at 5th General Assembly of CSAGI, Moscow, July 30 - August 9, 1958.

[2] Jones, L. M., Fischbach, F. F., and Peterson, J. W., Seasonal and Latitude Variations in Upper-Air Density, paper presented at 5th General Assembly of CSAGI, Moscow, July 30 - August 9, 1958.

[3] Lagow, H. E., Horowitz, R., and Ainsworth, J., Arctic Atmospheric Structure to 250 Kilometers, paper presented at 5th General Assembly of CSAGI, Moscow, July 30 - August 9, 1958.

*Department of Electrical Engineering, The University of Michigan, under sponsorship of Geophysics Research Directorate, Air Force Cambridge Research Center.

THEORETICAL CONSIDERATIONS

Consideration of the aerodynamic properties of a right circular cone moving at small angles of attack with respect to the surrounding medium has resulted in considerable theoretical as well as experimental study by many students of the art and has led to the establishment of sound theories regarding flow properties. One of the more recent of these studies has been reported by Antonio Ferri.[4]

Publication of these theories has made possible evaluation of ambient properties of the stream through measurement of the local parameters. Specifically, considering for the moment the case of zero yaw, consideration of the total head pressure P_i and the cone-wall pressure P_c leads to determination of the "free-stream" Mach number which has primary dependence upon the ambient temperature. This has been shown[5] as follows. Consider the quotient (identity)

$$\frac{P_i}{P_c} = \frac{P_i}{P_a} \times \frac{P_a}{P_w} \times \frac{P_w}{P_s} \times \frac{P_s}{P_c} , \qquad (1)$$

where:

P_i = impact or total head pressure,

P_c = cone-wall pressure,

P_a = ambient pressure,

P_s = stagnation pressure behind shock wave, and

P_w = pressure behind shock wave.

To reduce this expression, one considers the ratio of pressures across a normal shock wave in terms of the Mach number and γ, the ratio of specific heats.

Thus

$$\frac{P_a}{P_c} = \left[\frac{2\gamma M^2 - (\gamma-1)}{\gamma + 1}\right]^{\frac{1}{\gamma-1}} \left[\frac{(\gamma+1)M^2}{2}\right]^{\frac{\gamma}{1-\gamma}} . \qquad (2)$$

The second factor on the right of (1) can be evaluated by reference to Kopal[6] who tabulated values of radial velocity V_w, tangential velocity U_w, and

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[4] Ferri, A., Supersonic Flow Around Circular Cones at Angles of Attack, NACA Report 1045.

[5] Sicinski, H. S., Spencer, N. W., and Dow, W. G., "Rocket Measurements of Upper Atmosphere Ambient Temperature and Pressure in the 30- to 75-Kilometer Region," J. Appl. Phys., 25, 2, 161-168 (Feb., 1954).

[6] Kopal, Z., Massachusetts Institute of Technology Tech. Report No. 1, 1947, Department of Electrical Engineering, Center of Analysis.

the velocity of sound a as functions of the Mach number.

Thus from Kopal,

$$\frac{P_W}{P_a} = \frac{(\gamma^2-1)\ (C^2 - U_W^2 - V_W^2)}{4\gamma V_W^2 - (\gamma-1)^2\ (C^2 - U_W^2 - V_W^2)} \quad . \tag{3}$$

In this expression, C is a velocity attainable only theoretically by considering all heat energy converted into uniform motion, so

$$C = V^2 \left[1 + \frac{2a^2}{V^2(\gamma-1)}\right] \quad , \tag{4}$$

where V is the body velocity relative to ambient air.

The third ratio P_W/P_S can be evaluated from the Bernoulli integral assuming adiabatic flow behind the shock wave. Again using Kopal's velocities,

$$\frac{P_W}{P_S} = \left[1 - \left(\frac{U_W}{C}\right)^2 - \left(\frac{V_W}{C}\right)^2 \frac{\gamma}{\gamma-1}\right] \quad . \tag{5}$$

The fourth ratio, P_S/P_C, is obtained by letting V_W in Eq. (5) be zero, thus completing the establishment of the functional dependence of the measurable pressure ratio upon the Mach number. Computation for Mach numbers up to 5.5 and a cone half-angle of 7.5° has been carried out and tabulated,* assuming constant γ. Figure 1 is a plot of these values, and Fig. 2 is a plot of the dependence of the cone-wall pressure on the ambient pressure and Mach number which also follows from these considerations.

Evaluation of the Mach number and its subsequent interpretation based upon the adiabatic sonic velocity expression enable explicit statement of the ambient temperature as

$$T = \left(\frac{V}{M}\right)^2 (R\gamma)^{-1} \quad ,$$

where R is the gas constant and V is the cone velocity defined for Eq. (4).

The above discussion assumes that the angle between the subject cone and the stream is zero. Although for many rockets with suitably high stability and high velocity during passage through the 90-km level this condition is sufficiently well met, many other rockets do not maintain negligibly small angles of attack with the air stream.

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*Forthcoming report.

Correction of the yawed cone pressure to a nonyawed pressure is feasible provided, of course, that knowledge of the angle of attack and rotational position of the cone-surface measurement point is at hand. These corrections may be made by reference to the work of A. H. Stone,[7] which has been shown to permit the following expression:

$$P_{cy} = P_c \left\{ 1 + \epsilon \cos \Phi \left(\frac{\eta}{P_c}\right) + \epsilon^2 \cos 2\Phi \left[\frac{P_2}{P_c} + \frac{\gamma}{2}\left(\frac{U_s}{a}\right)^2\right] + \epsilon^2 \left[\frac{P_o}{P_c} + \frac{\gamma}{2}\left(\frac{U_s}{a}\right)^2\right] \ldots \right\}, \qquad (6)$$

where:

P_{cy} = yawed cone surface pressure under rotational angle Φ and yaw angle E,

P_h = perturbation coefficients (Kopal),

P_c, U_s, γ have been previously defined,

Φ = rotational angle, and

ϵ = yaw angle.

Once P_c has been obtained, consideration as a nonyawing case can be adopted, for the total head or "impact" pressure does not, under readily realized conditions, suffer from relatively large yaw angles.

Thus, using the approach discussed, one may evaluate ambient pressure and temperature directly from measurement of pressure quantities on a rocket nose cone. The density, of course, follows directly.

An alternative means enables the determination of ambient density from only total head pressure measurements. The method involves the Rayleigh supersonic Pitot-tube formula and has been well described by Newell.[8] The Rayleigh equation is

$$\frac{P_i}{P_a} = \left(\frac{\gamma+1}{2}\right)^{\frac{\gamma+1}{\gamma-1}} \gamma^{-\frac{1}{\gamma-1}} M^2 \left[1 - \frac{(\gamma-1)}{2\gamma M^2}\right]^{-\frac{1}{\gamma-1}} . \qquad (7)$$

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[7] Stone, A. H., J. Math. Phys., 30, 200 (1952).

[8] Newell, H. E., Jr., High Altitude Rocket Research, Academic Press, Inc., New York, 1953, pp. 122-123.

By substituting

$$M^2 = \frac{V^2}{a^2} ,$$

and

$$\frac{\gamma P_a}{\rho} = a^2 ,$$

and

$$\gamma = 1.4 \text{ (diatomic gas) } ,$$

$$P_i = 0.92\rho V^2 + 0.46\rho + \ldots . \qquad (8)$$

For $M > 3$, approximately, all terms except the first become negligibly small. Thus, rearranging and expressing in MKS units,

$$\rho = 1.166 \times 10^3 \frac{P}{V^2} \text{ kg/m}^3 . \qquad 9)$$

INSTRUMENTATION

Experiments utilizing ram and cone-wall pressures have been carried out during the IGY using Aerobee and Nike-Cajun rockets.

The Aerobee rocket instrumentation has included the following major items:

1 impact pressure-measurement system,
4 cone-wall pressure-measurement systems,
1 gyroscope,
1 telemeter, and
1 doppler beacon.

Cone-wall pressures were measured at a point approximately 0.8 cone length from the tip, the pressure ports being spaced 90° on the 7.5° half-angle cone. The instruments employed were radioactive-ionization-gage systems,* one at each of the five locations. The systems are capable of measurements between atmospheric and 10^{-3} mm Hg with a precision of approximately 1 part in 50 and are completely independent from each other.

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*Described in companion paper.

The gyroscope employed exhibits freedom about two axes and permits determination of roll angle and the angle between the rocket axis at launch and the axis at subsequent times. This information considered with trajectory tangents permits angle-of-attack evaluation, as utilized in data reduction as noted previously.

The telemeter employed is a proven DKT-7 model which has 15-channel capacity. It is a pulse-time system and operates at a frequency of 227 mc.

The doppler beacon operates at a receiver frequency of approximately 36 mc and consequently a transmission frequency of 72 mc. It enables the evaluation of the rocket trajectory with considerable precision.

Thus the Aerobee is instrumented to enable a complete reduction in the event of yaw during the information-gathering period.

One additional instrument not previously mentioned in this paper has been included in Aerobee instrumentation. It is considered in the development stage and performance during IGY flights has not been studied. The experiment involves the measurement of the angle of flow of the stream over the nose-cone surface during yaw. Small, low-mass "vanes" drive capacitor transducers, permitting angle determination. Knowledge of the angle at two points and of rocket velocity permits an independent evaluation of the free-stream Mach number, and consequently an independent measure of temperature. A photograph of the Aerobee instrumentation appears as Fig. 3.

A simplified version of the Aerobee-borne experiment is carried by the Nike-Cajun and includes the following major units:

1	impact pressure-measurement system,
2	cone-wall pressure-measurement systems, and
1	doppler beacon including a single telemeter channel.

The installation of these items is similar to that of the more extensive Aerobee experiment. A 7.5° half-angle cone is employed, the two cone-wall pressure ports being located about 0.8 times the cone length from the tip. Again, in accordance with minimizing data reduction the cone-wall pressure ports are located at points diametrically opposite.

A doppler beacon identical to that noted previously is employed in this instrumentation. A single telemeter channel incorporated in the system is utilized for data transmission. A photograph of the Nike-Cajun instrumentation appears as Fig. 4.

PRELIMINARY DATA REDUCTION

The U. S. IGY program has included, at the time of preparation of this paper, two Aerobee and six Nike-Cajun rockets instrumented as indicated above for surface-pressure measurement. Many data have been obtained from these flights, most of which are clearly satisfactory. On the other hand, some data are of questionable clarity and accordingly require considerable attention.

In general the data-reduction policy adopted has been to reduce all data by as many alternative methods as possible. One of the simplest computations, and one generally carried out first after tabulation and study of the raw data, is that employing the total head pressure to evaluate density, using Eq. (9). This has been done for most of the satisfactory flights, and preliminary curves obtained are presented in Fig. 5.

Reduction of data from flight number AM 2.21 (Aerobee) has received more attention than reduction of the data from the other flights. Accordingly, greater confidence can be expressed in this curve. All data presented, however, must be considered tentative and subject to revision in whole or in part.

Figure 6 presents two curves of ambient pressure vs. altitude also derived from flight AM 2.21. It can be noted that one curve has been derived through conversion of cone-wall pressure by the Mach number method discussed earlier in this report. The second curve has been derived by integration of the density curve shown in Fig. 5. The total head pressure employed is common to the two computations. A check point from balloon data taken at nearly the same time as the flight was in progress has been shown on both Figs. 5 and 6 for comparison. At the time of preparation of this paper, the authors expected to include some preliminary temperature data. However, some possible errors were detected which will have a bearing on possible fine structure, and accordingly it was decided to withhold the data for further study. Aside from the fine structure, however, the temperatures are generally 20°-30°C lower than present standards. Figure 7 is a curve of ambient pressure vs. altitude for AM 6.36 (Cajun) again derived from the density data given for that rocket in Fig. 5.

It will be noted that except for a portion of the data presented from AM 2.21, the curves given in this paper have resulted from reduction of total head pressures. The present data-reduction effort is being applied largely to application of the Mach number method to existing data; it is felt that, except possibly for the region in the neighborhood of 90 km, temperature and pressure data of much greater precision will result.

The derivation of temperature and pressure by use of the hydrostatic equation imposes a severe burden on the precision of the raw data, whereas the Mach number method provides a more attractive path to evaluation of these parameters. A greater data-reduction effort is naturally a consequence of this choice.

In all cases, however, reduction employing all techniques will be carried out. Figure 6 illustrates a favorable situation wherein reasonable agreement is achieved. Greater confidence must be expressed in the data obtained by the Mach number method. Generally speaking, the two Aerobee rocket flights have given data for which yaw correction has been unnecessary. On the other hand, the Cajuns have imposed this burden on the reduction. However, many rockets, although experimenting modest yaw, the order of the cone angle, likewise experience roll rates which are sufficiently great to enable adequate evaluation of nonyaw cone-surface pressure from the yaw-produced varying pressure function. When the plane of yaw is nearly normal to the local trajectory plane, the measured surface pressure is equivalent to the unyawed pressure. This condition obtains twice per roll period, and thus, for roll rates of 1-2 per second, occurs repetitively for modest changes in ambient pressure during rocket ascent. Figure 8 illustrates the situation for a recent rocket flight in which the two pressures were measured at the ends of a nose-cone diameter. The crossing points permit evaluation of the nonyaw pressure in the absence of yaw information.

By a similar technique which in effect "averages" the pressure as it varies with rotational angle, the nonyaw pressure may likewise be obtained. In this procedure the maxima under rotation are considered; it is assumed that the yaw angle is constant or changes only negligibly during the half roll.

These procedures presumably introduce greater errors into the reduction than does the analysis noted previously, wherein the yawed pressure is corrected to unyawed pressure Eq. (6). However, in the case of the Cajun, a considerably simplified experiment is made possible, as well as a much less tedious and time-consuming data-reduction task. Experimentally, angle measurement by gyroscope or other means becomes unnecessary.

An additional benefit results from this "averaging" procedure. When one considers the velocity environment of the nose cone, it is customary and convenient to think in terms of the stream rather than the cone as possessing the vector velocity. Thus any winds or vertical air motions become perturbations on the horizontal or vertical velocity components, as the case may be. Changes in horizontal component then appear only as changes in angle of attack and are only in this manner distinguishable. The averaging process referred to above thus includes the effect of winds, in contrast to the "correction" method which necessarily assumes that winds are zero.

Vertical air motion too appears as a perturbation, but only in the vertical component. It is not distinguishable except as a perturbation in total head pressure. Generally one can ignore the effect here, as the vertical velocity component during the useful measuring period is much larger than expected vertical air motion.

By means of data reduction as indicated above, it will be possible, in the relatively near future, to report ambient pressures and temperatures for those flights for which preliminary density has been presented, and for other flights which have not been reduced.

ACKNOWLEDGMENT

A research program of the magnitude indicated in this paper is possible only with the support and cooperation of many individuals and organizations. This is particularly true of the U. S. IGY rocket program which is in every sense a joint effort of many organizations. Thus we are indebted to (a) Col. L. G. Smith, who represents the launching facility, and to whom much credit is due for the overall success of the IGY effort; (b) Mr. W. W. Berning and H. Zancanata of the Ballistics Research Laboratory for the excellent doppler trajectory facilities; (c) personnel of the White Sands Agency for many range services; (d) the Naval Research Laboratory and New Mexico College of Agriculture and the Mechanic Arts for telemetering functions; (e) Major Mark Holmes, representing the Canadian Army at Fort Churchill; and (f) Mr. Raymond Petracek of the Aerojet-General Corp., for his particularly helpful services.

The University of Michigan work has been carried out under sponsorship of, and with extensive cooperation and assistance from, the Geophysics Research Directorate of the Air Force Cambridge Research Center. We are particularly indebted to Mr. John Downing of that organization for instrumentation items necessary to the experiments, and to Mr. Raymond Minzner and Mr. Peter Wyckoff for technical and administrative advice and assistance in establishing and carrying out the program. The program is a totally joint effort of The University of Michigan and the Geophysics Research Directorate.

The U. S. National Committee also contributed substantial support to the investigation in sponsoring a portion of the scientific instrumentation development task.

Finally, the authors wish to acknowledge the aid of the many individuals of the University group who have and are contributing the many ideas and the effort necessary to carry out the program.

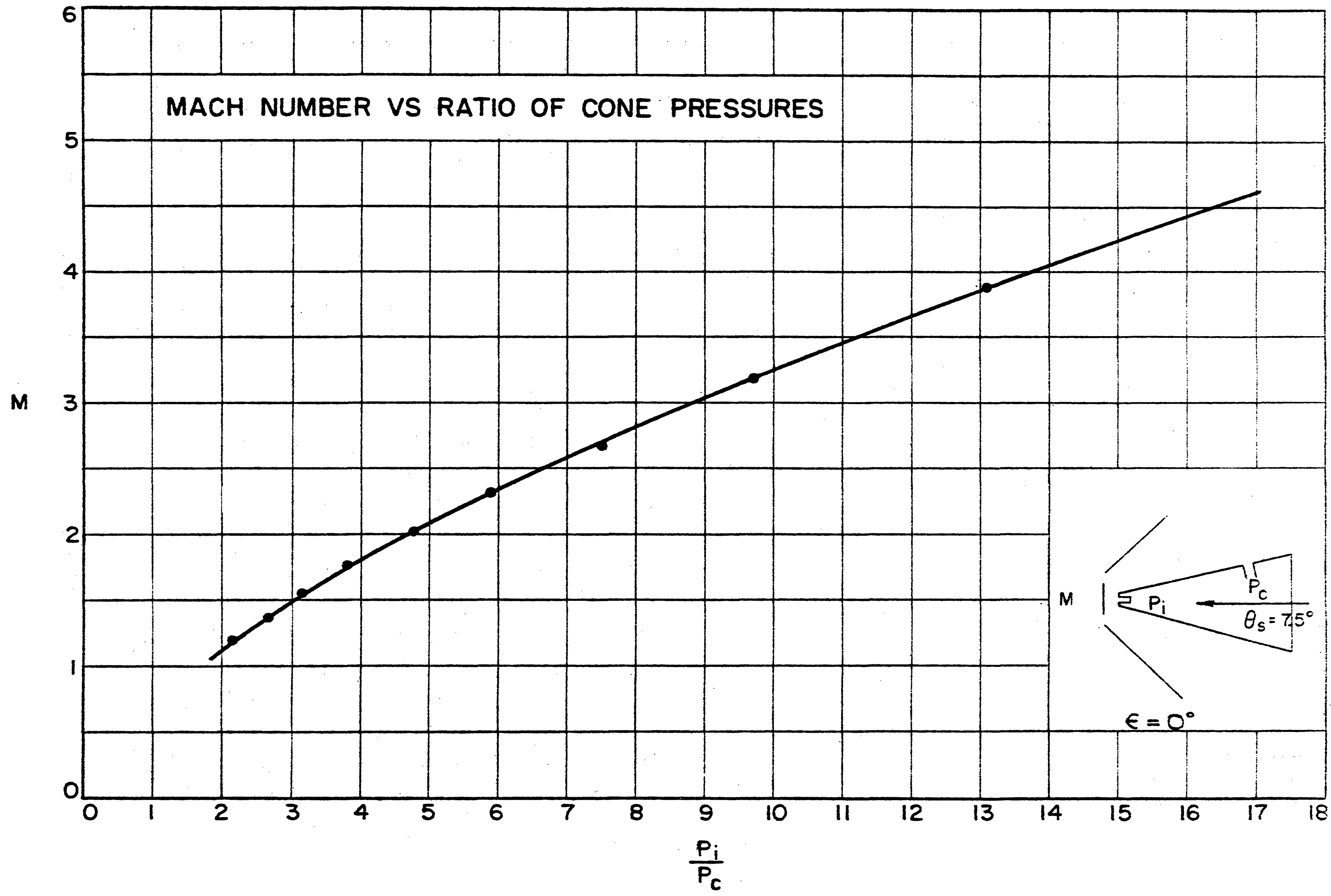

Fig. 1. Mach number vs. quotient of cone pressures for nonyaw case of a 7.5° half-angle, supersonic cone.

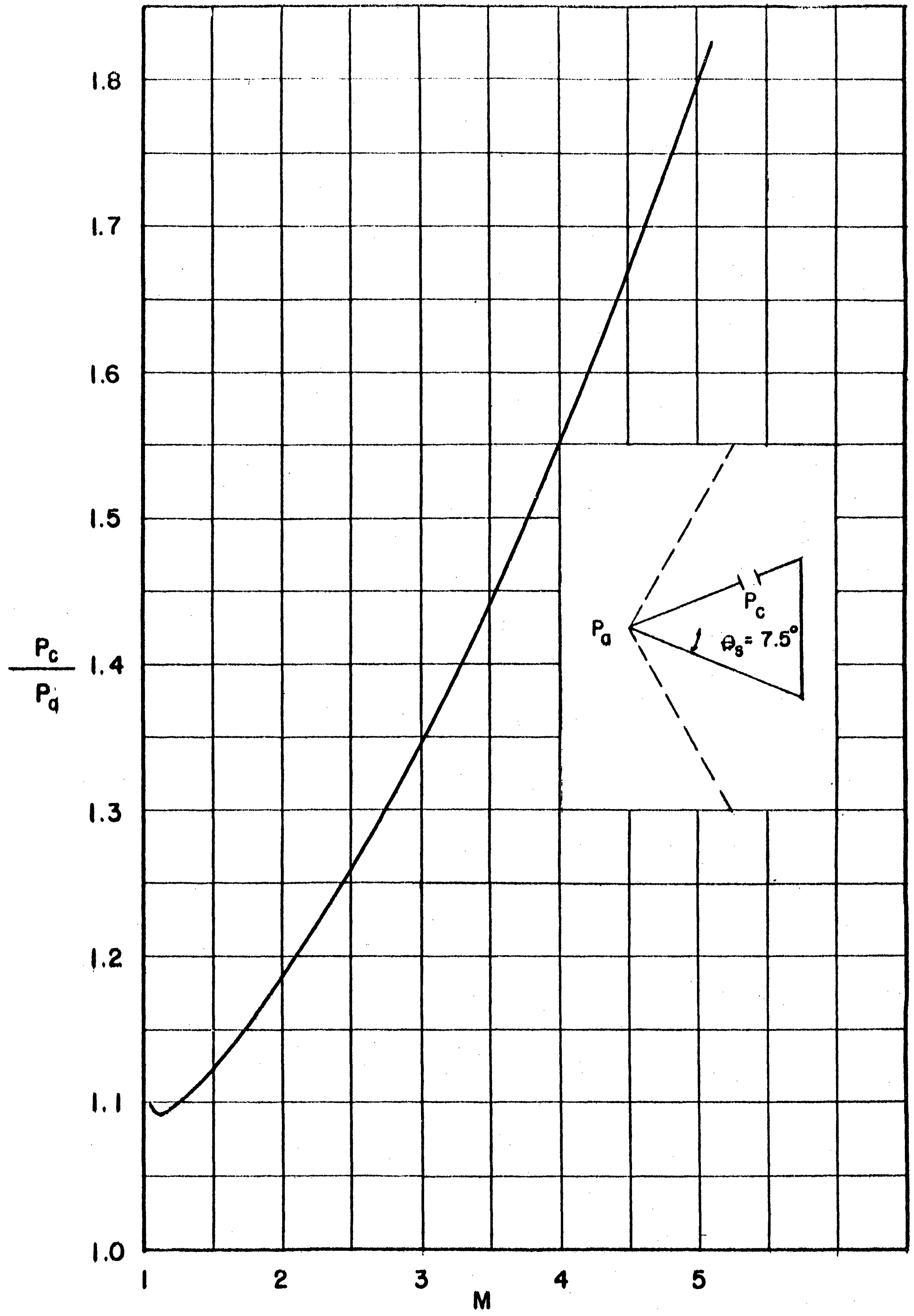

Fig. 2. The relationship between the unyawed surface pressure and the ambient pressure as a function of the free-stream Mach number for a nonyawing, 7.5° half-angle supersonic cone.

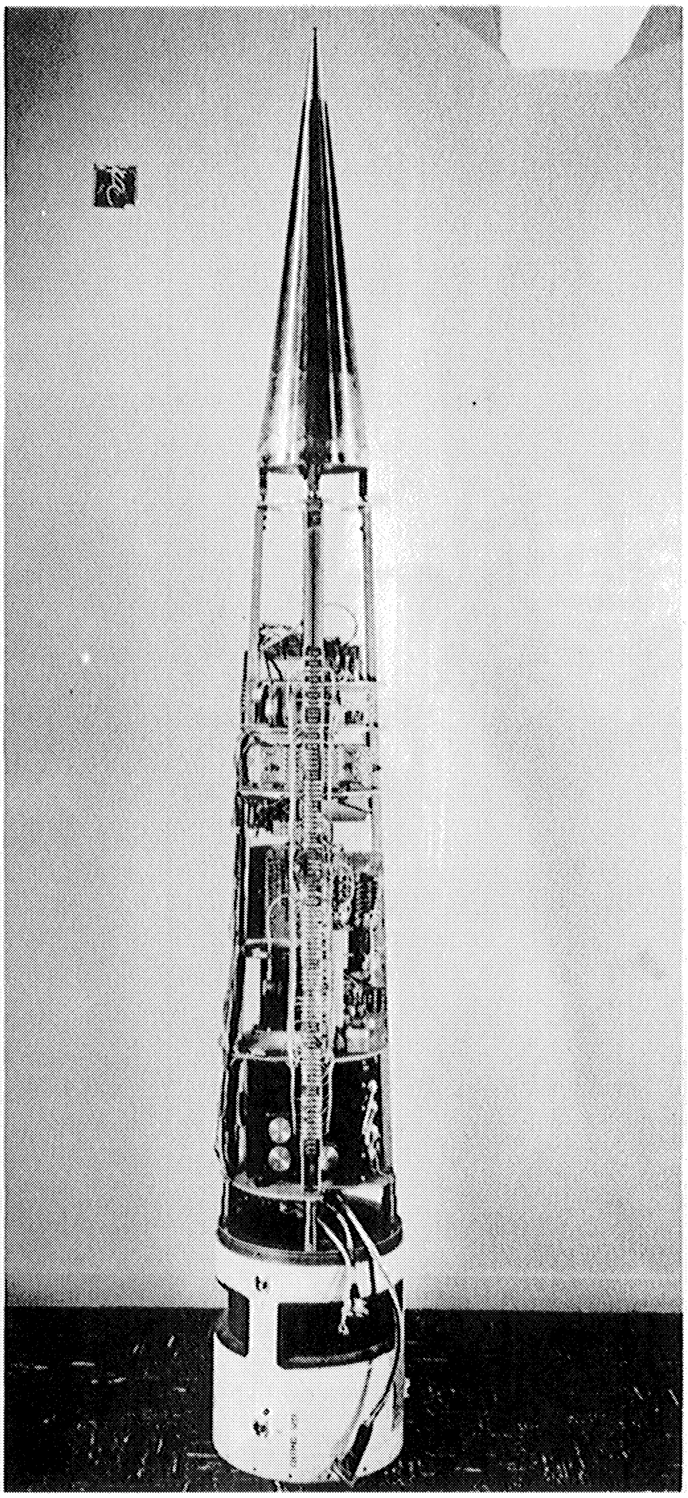

Fig. 3. Photograph of AM2.21 instrumentation without nose skin and pressure-measurement systems.

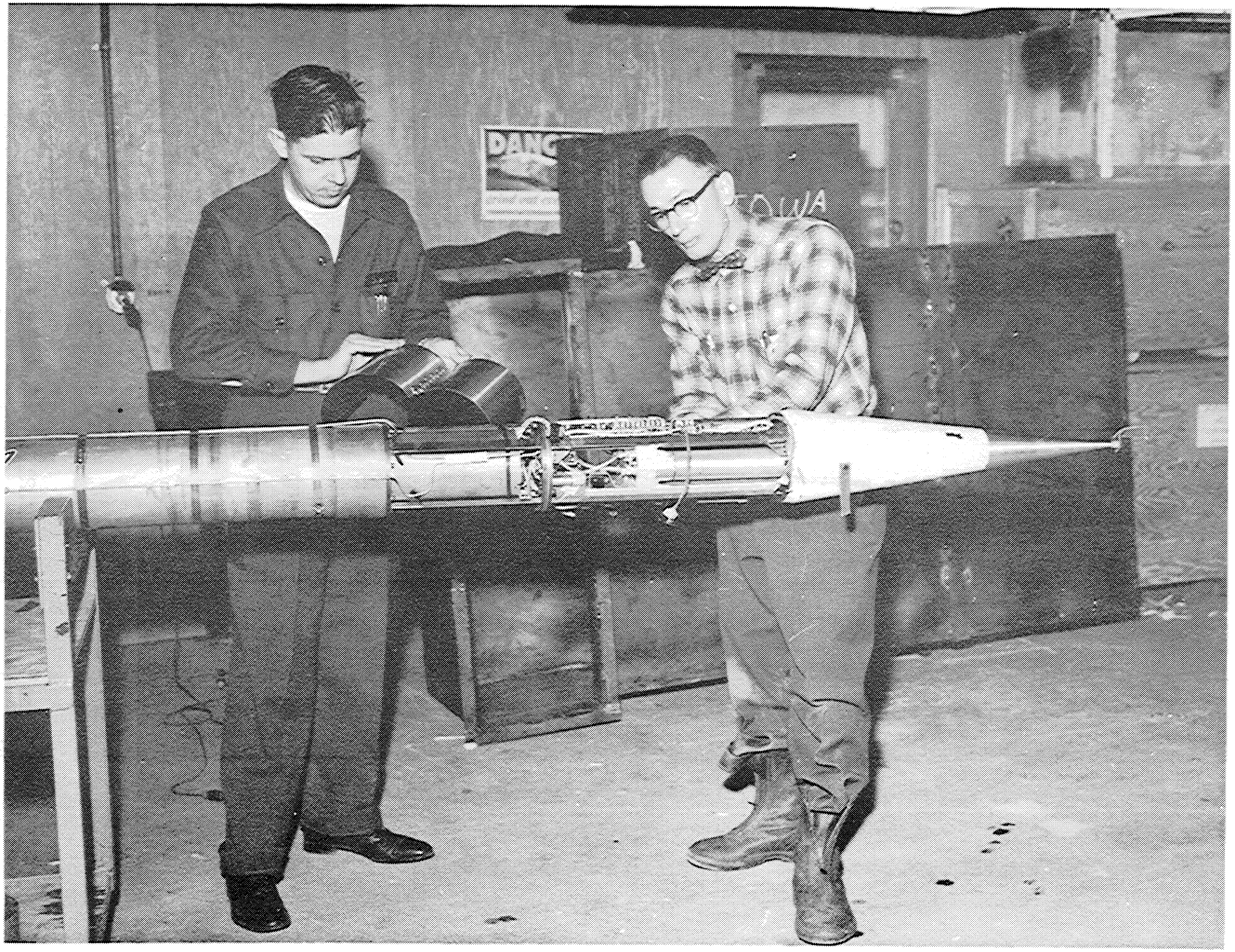

Fig. 4. Photograph of Cajun instrumentation a short time prior to launching.

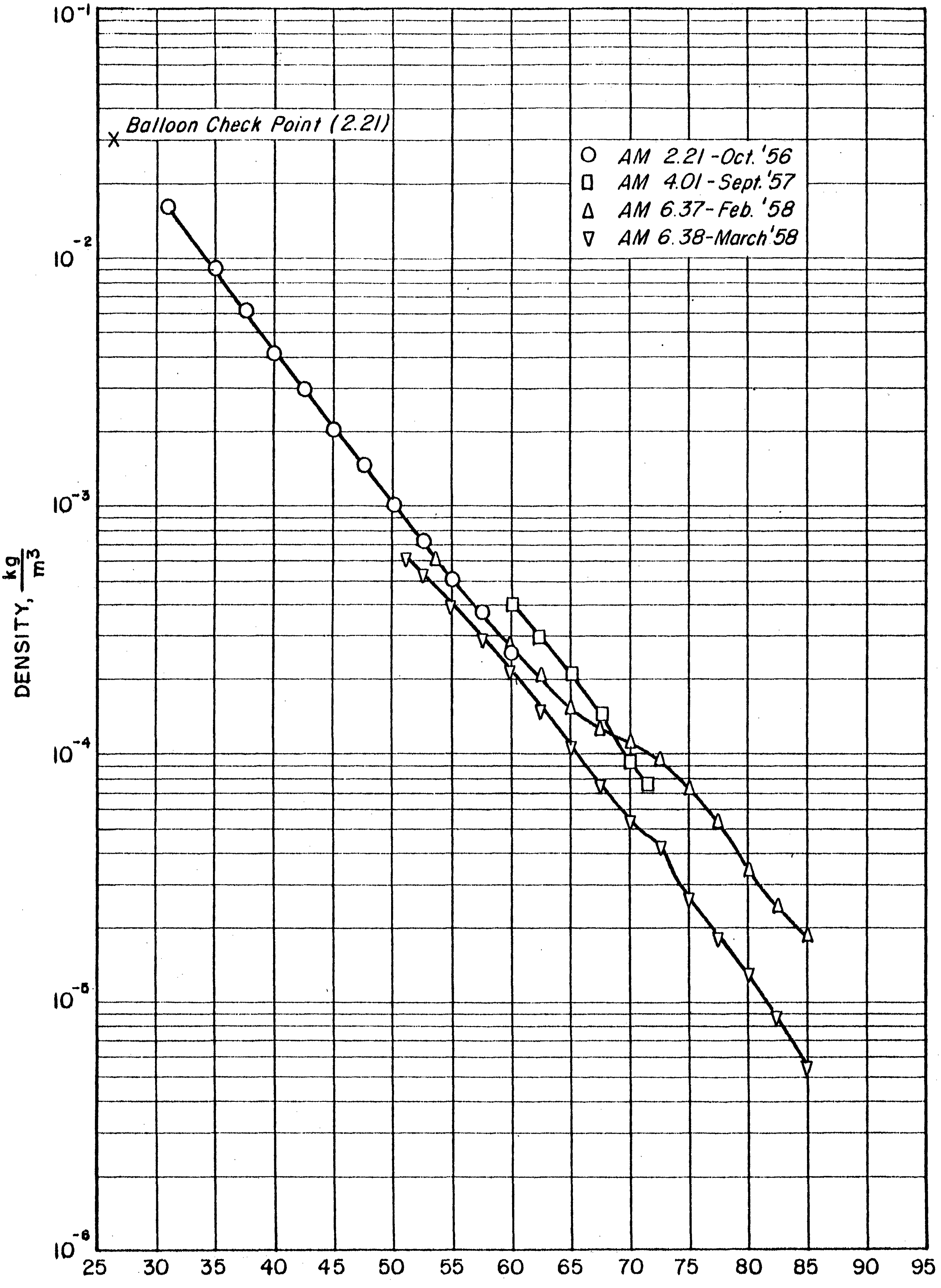

Fig. 5. Density vs. altitude.

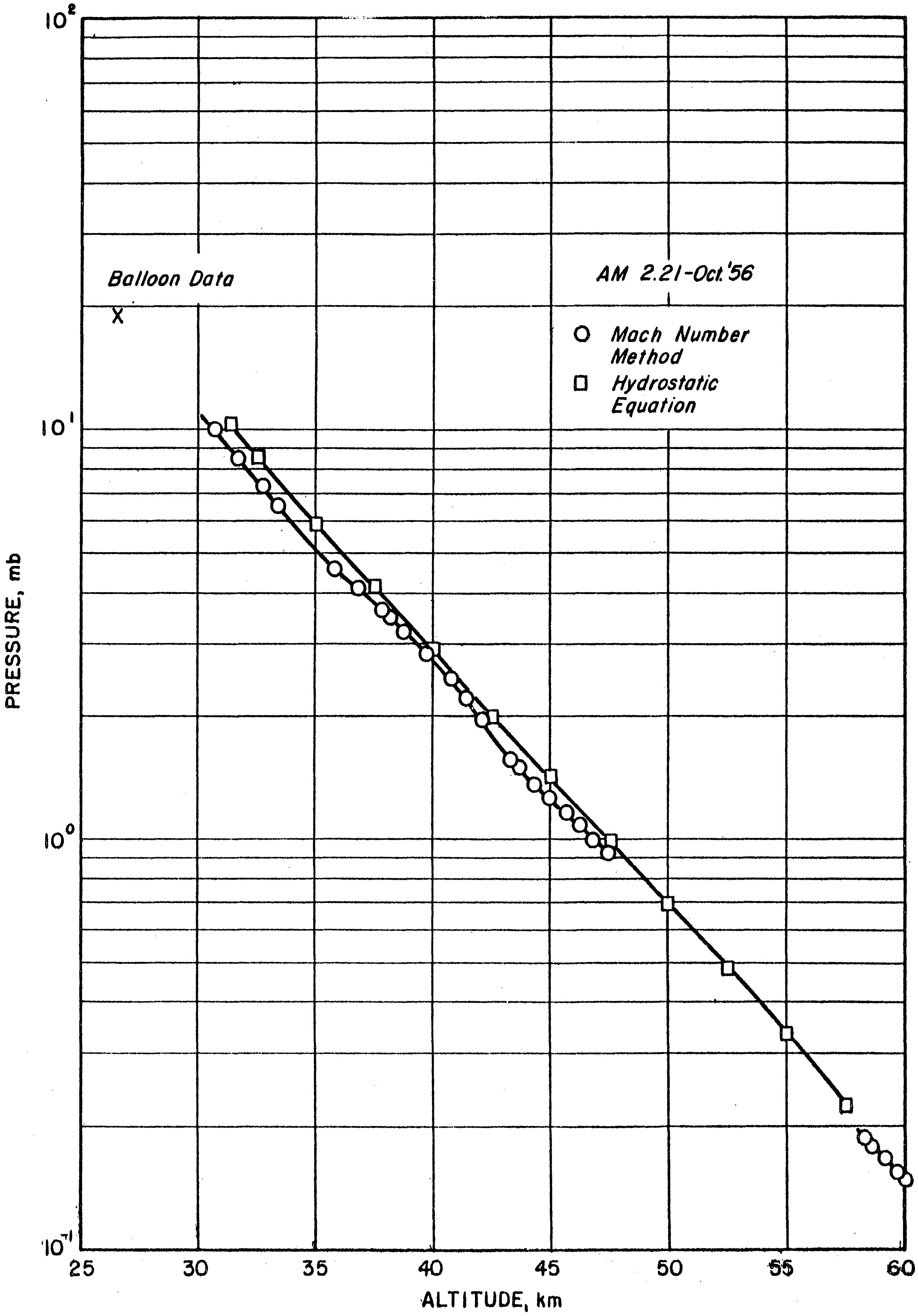

Fig. 6. Ambient pressure vs. altitude, AM 2.21, October, 1956.

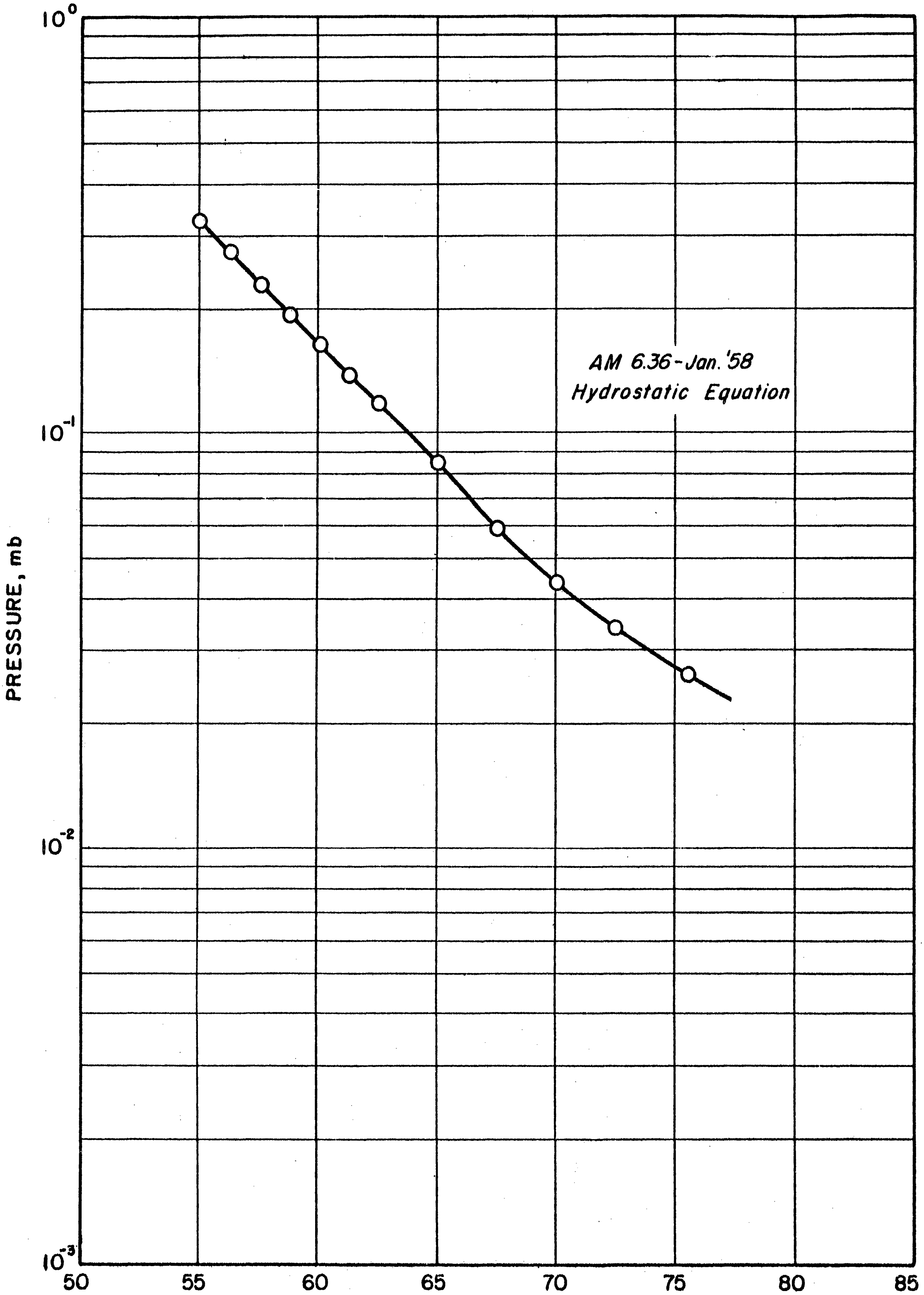

Fig. 7. Ambient pressure vs. altitude, AM 6.36, January, 1958.

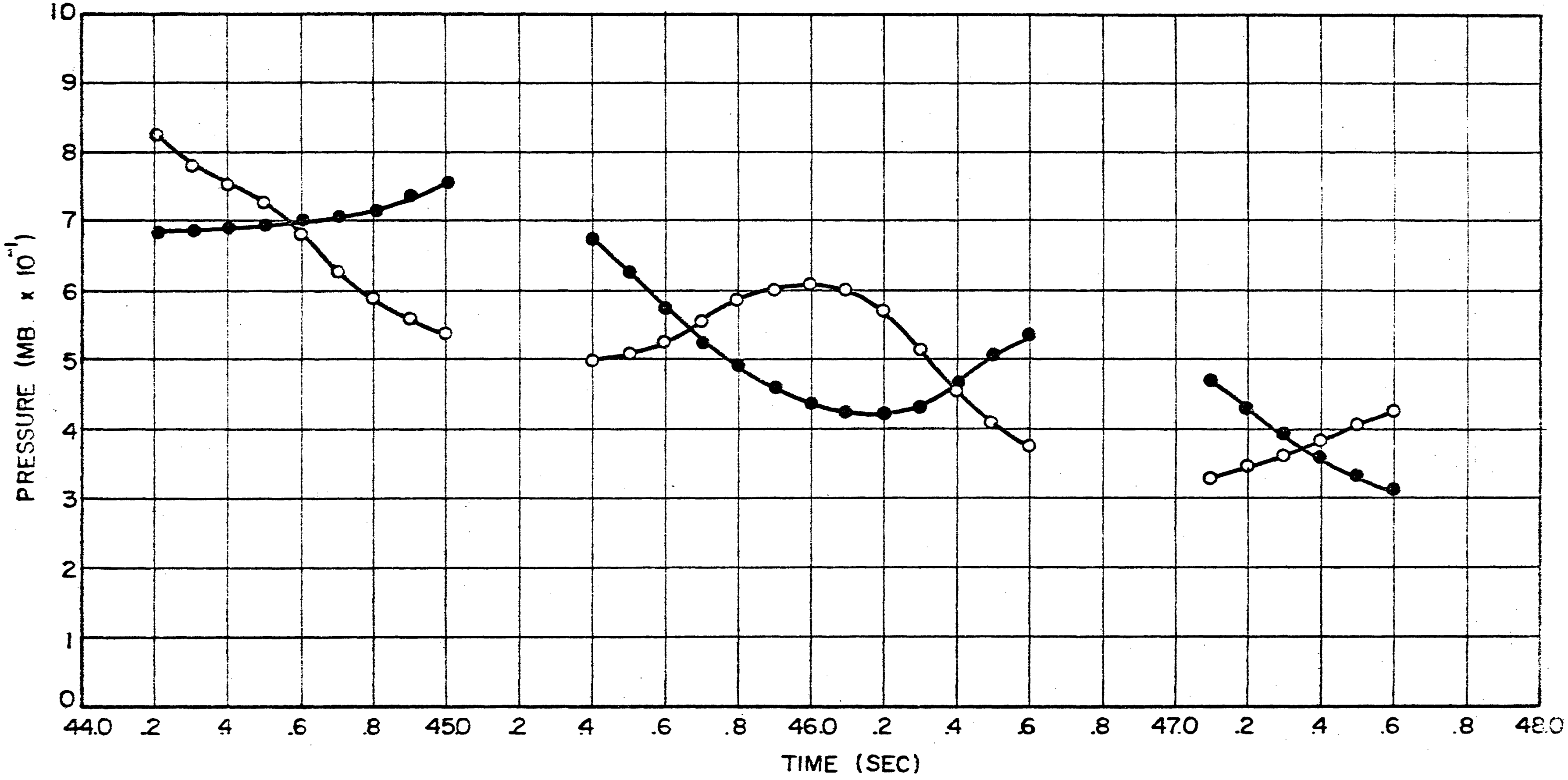

Fig. 8. Cone-wall pressure vs. time for AM6.37 in the interval 44 to 48 sec (opposing gages).