ENGINEERING RESEARCH INSTITUTE
UNIVERSITY OF MICHIGAN

ATMOSPHERIC PHENOMENA AT HIGH ALTITUDES

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Submitted for the project by:

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ATMOSPHERIC PHENOMENA AT HIGH ALTITUDES

Department of Aeronautical Engineering

I INTRODUCTION

The previous progress reports on this contract have described a series of high altitude meteorological experiments being undertaken by the Meteorological Branch of the Signal Corps and its contractors, and have covered the progress of the work at the University of Michigan. For this background material, the reader is referred to these previous reports.

II SUMMARY

(1) Shock angle experiment V-2 No. 56.

A report on the results of the shock angle experiment for ambient temperature performed on V-2 No. 56 was issued.

(2) Shock wave curvature investigation.

Data from a wind tunnel investigation at the University of California of shock wave curvature have been received. Results are being calculated.

(3) Shock angle experiment for Aerobees.

Preparation of probe Aerobees SC-15 and SC-19 was continued. Development of the magnetic recorder and the probe amplifiers was completed and construction begun. The mechanical design of the instrumentation including a double screw cone drive and Jato ejected cone was completed and construction begun.

(4) Sampling Aerobees.

Preparation of sampling Aerobees SC-13 and SC-17 was continued. The mechanical design was completed and construction begun. Flight units of the knife openers and cold weld sealers were constructed and tested. Wiring of the rocket circuit was continued. A test of the Jato unit was made.

(5) Helium and neon analysis.

A blend of air with 10 ppm of helium was made and analyzed.

(6) Oxides of nitrogen.

Further investigation of the source of oxides of nitrogen in upper air samples was made.

(7) Sphere method for ambient temperature.

A method of measuring ambient density and hence ambient temperature by measuring the drag of a falling sphere was devised.

III SHOCK ANGLE EXPERIMENT V-2 NO. 56

A technical report An Aerodynamic Method of Measuring The Ambient Temperature of Air At High Altitudes by Bartman, Liu and Schaefer was issued. In abstract: "The measurement of ambient air temperatures at high altitudes by determination of the shape of the shock cone attached to the nose cone of a rocket that moves at high supersonic speeds is described. Data from the trial of the method on V-2 Number 56 are analyzed on the basis of first order conical shock wave theory. On V-2 Number 56 Pirani gage signals were obtained up to 230,000 feet indicating that the method may be applicable up to this altitude. Temperatures calculated for altitudes up to 183,000 feet agree fairly well with what was previously known about temperatures at high altitudes.

"The experimental errors are shown to be negligibly small. The possible existence of large systematic errors and plans for investigating them are discussed.

"The use of this method for measurement of winds at high altitudes is discussed."

IV SHOCK WAVE CURVATURE INVESTIGATION

The wind tunnel investigation of shock wave curvature, described previously, was carried out at the University of California. The following memorandum dated July 28, 1950, was received from the University of California:

"SUBJECT: SHOCK CONTOUR TEST PROGRAM

1.0 OBJECT OF TEST

At the request of Dr. V. C. Liu of the Engineering Research Institute of the University of Michigan, an experimental study of shock wave contours about conical probes was carried out at the Low Pressures Research Laboratory at the University of California in Berkeley. The object of this program was to obtain photographs of the shocks about four different axially symmetric models under several flow conditions using the nitrogen glow technique (Ref.1). Pressure determinations at selected points in the test section were also made for each flow condition.

2.0 DESCRIPTION OF EQUIPMENT

The tests were performed in the No.3 Wind Tunnel (Ref.2) using the No.2 and No.3 nozzles. The No.2 nozzle covers a Mach range from 2.1 to 2.8, while the No.3 nozzle extends this range from 2.8 to 3.5.

All photographs were made using 3 1/4 in. x 4 1/4 in. Defender 428 cut film. A view camera was used to hold the film and was equipped with a 6 in. focal length, f-4.5 maximum aperture lens.

The pressure traverses were made with a source-shaped impact tube (No.14) 0.300 in. dia. and with a hole dia. of 0.060 in. The conical probe (No.15) was used to determine the static pressure. This probe consists of a 5° half-angle cone joined to a 0.300 in. dia. cylinder, with pressure orifices located on the cone surface.

The four models used in this program were all 20° half-angle cones mounted on cylindrical supports. The physical dimensions were as follows:

(1) Cone base dia. 0.700 in., cylindrical support dia. 0.700 in.
(2) Cone base dia. 0.350 in., cylindrical support dia. 0.350 in.
(3) Cone base dia. 0.100 in., cylindrical support dia. 0.100 in.
(4) Cone base dia. 0.700 in., cylindrical support dia. 0.060 in.

A remotely controlled traversing mechanism within the test section of the No.3 Wind Tunnel provided means for mounting and moving models or probes in the test section. Selsyn motors and generators gave position coordinates on standard 5-place counters located outside of the vacuum chamber. The two probes - No.14 and No.15 - were mounted on this mechanism together with a vertical support rod which held the four models. Either of the two probes or any of the four models could be moved into the test section as required without alteration of the air stream.

3.0 PROCEDURE

Two test runs were made - Run 116 using the No.2 nozzle and Run 117 using the No.3 nozzle. During Run 116 photographs of the four models were obtained with N_2 flow rates of 21, 10.3 and 4.1 lbs/hr (Table 1). The exposure times, aperture settings, etc. are listed in Table 3. Pressure measurements were made at 15 points for each flow condition, but with the discharge off. The location of these points is shown on Figs. 1, 2 and 3. These plots also indicate the Mach number at each point as calculated from the probe pressure measurements using the non-viscous theory (Ref.3). Additional pressure measurements were made with the nitrogen glow energized, to determine the possible effect on the flow conditions.

During Run 117, photographs of the four models were obtained at two flow conditions. A third flow condition was attempted, but the nitrogen glow technique would not operate satisfactorily at the highest stagnation pressures encountered with the No.3 nozzle. The same experimental procedure was used in Run 117 as is outlined above for Run 116, and the data are summarized in Tables 2 and 3.

4.0 RESULTS

A total of 20 photographs, one each of four models at five flow conditions, were obtained during Runs 116 and 117. Each photograph is identified by a number which is listed in Table 3. The negatives are enclosed with this memorandum.

The pressure measurements made at 15 points in the test area for each flow condition are listed in Tables 1 and 2. These data have been reduced to give the Mach numbers, Reynolds numbers and static pressures in the test area. The Mach number distribution has been plotted for each flow condition, on Figs. 1, 2 and 3 (for Run 116) and Figs. 4 and 5 (for Run 117).

No attempt has been made to analyze the data, in accordance with the request of the University of Michigan. Attention is drawn to the rows marked with an asterisk in Tables 1 and 2, which indicate pressure measurements obtained with the glow energized. The computed Mach numbers and static pressures differ slightly under these conditions as compared with the measurements made with a "cold" stream. The effect is believed to be due primarily to an observed increase in stagnation pressure and temperature caused by the heating effect of the discharge in the stagnation chamber.

5.0 REFERENCES

1) R.A. Evans and G.J. Maslach - "Status Report on Wind Tunnel Flow Visualization by Glow Method", Univ. of Calif. Eng. Projects Report HE-150-68, May 1950.

2) S.A. Schaaf, D.O. Horning, E.D. Kane - "Design and Initial Operation of a Low Density Supersonic Wind Tunnel", Univ. of Calif. Eng. Projects Report HE-150-62, August 1949.

3) E.D. Kane - "Drag Forces on Spheres in Low Density Supersonic Gas Flow", Univ. of Calif. Eng. Projects Report HE-150-65, February 1950."

For tables and figures see Shock Contour Test Program, Institute of Engineering Research, University of California, Series No. UCB 336.

Several methods of examining the photographs were tried: slide projector, optical projecting comparator, densitometer, (recording and non-recording). The comparator provided too much magnification and the densitometer spots were too large for acceptable resolution. Therefore the negatives were projected by slide projector and the screen images traced on paper. The following significant conclusions may be drawn from an analysis of the tracings:

1) The angle between the axis of the cone and the tangent to the shock wave contour at the station corresponding to the base plane of the

cone approaches the Taylor-Maccoll shock wave angle asymptotically. See Figure 1. This asymptotic value is actually reached with the 0.700 in. dia. cone.

2) The influence of disturbances traveling upstream in the boundary layer appears to be negligible.

Experimental errors in the method are estimated to not cause an error of larger than ± 10% in the Mach numbers and to not affect the above conclusions. The sources of error are:

1) Non-uniformity of Mach number distribution in the wind tunnel section.

2) Error in Mach number calibration for the tunnel.

3) Variation in flow conditions from run to run.

4) Uncertainty about the nitrogen after-glow technique of flow visualization at low densities.

5) Error in making and measuring the tracings.

Figure 2 shows a typical photograph (at M = 3.1, test section static pressure about 50μ) taken by the nitrogen after-glow technique (enlarged).

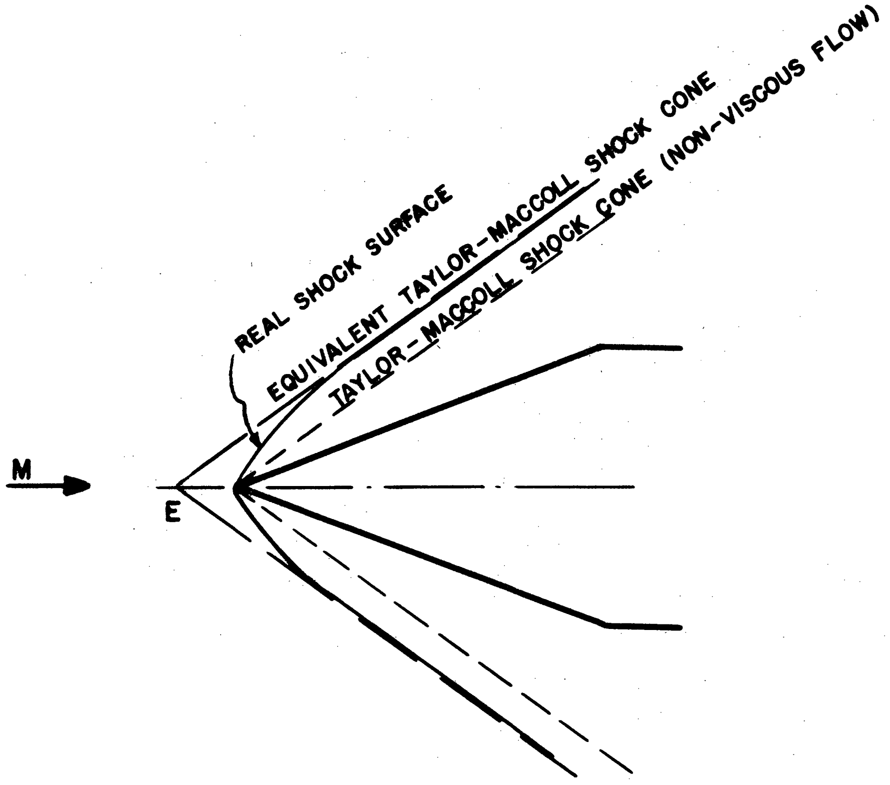


Fig. 1.
Shock Cone Approaches Equivalent Taylor-Maccoll Cone

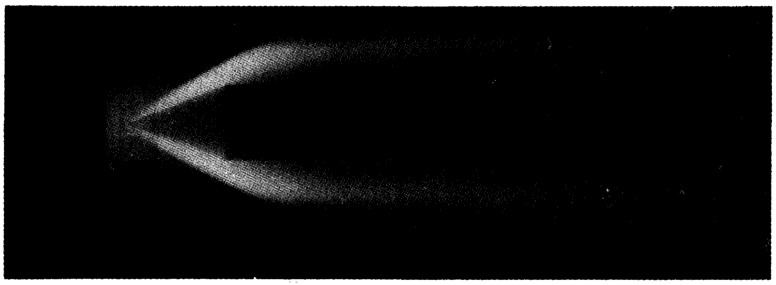


Fig. 2. Shock Wave Photographed by Nitrogen After-Glow Technique (Enlarged)

On the basis of the above conclusions it is suggested that in the evaluation of the free stream Mach number of the supersonic flow around a cone in a slightly viscous fluid through measurements of shock wave surface as in the probe experiment, an equivalent Taylor-Maccoll shock cone vertex be determined by using the two inner probes and the two corresponding outer ones, as in Figure 1. In other words, the conical surface tangent to the real shock surface at large distances from the tip is considered as the equivalent Taylor-Maccoll shock cone in non-viscous flow.

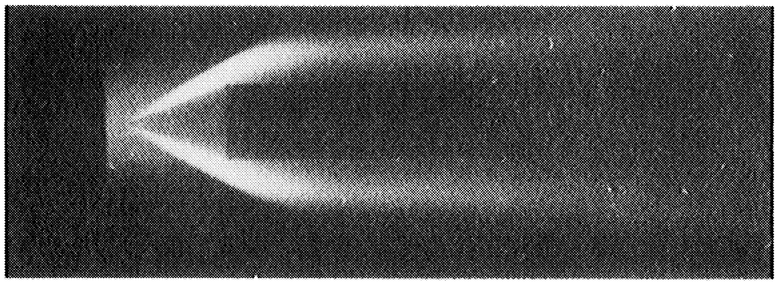
The above suggestion, based on a limited number of wind tunnel runs, is considered to be tentative only due to the possible errors in the wind tunnel technique as mentioned and the limited size of models used.

V SHOCK ANGLE EXPERIMENT FOR AEROBEES

Preparation of Aerobee SC-15 scheduled for firing November 2nd was continued.

Development and construction of the magnetic recorder and associated electronics was completed. The lamination and coil head units were received from the Brush Development Company and assembled according to our design. See Figure 3. The tape puller design was completed. The unit is shown in Figure 4.

Several problems arose in designing the recorder circuits:



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1) Crosstalk of the order of 50% between adjacent channels was experienced. This was indicated to be a playback phenomenon caused by fringing flux on the tape. It was remedied by additional shielding of the heads from each other by means of a sheet of .013" thick transformer steel on top of the heads next to the tape. The shield, shown in Figure 3, reduced crosstalk to 5% at 10 cps, the value diminishing with increasing frequency.

2) Simulated probe signals showed an "anticipation" on playback evidently caused by fringing flux preceding the actual signal on the tape. This difficult problem was finally solved by reducing the tape speed to one inch per second which, in effect, shortens the anticipation to a negligible amount. The slower tape speed also reduced crosstalk to 1% or less at any frequency. Frequency response was, of course, reduced by the slow tape speed. However, response on a square wave input is such that at least 50% of the rise edge occurs in one millisecond. This is adequate for probe signal time measurements. The low frequency response of the system is now a function of the playback amplifiers. Construction of playback amplifiers with suitable low-frequency response was started. By modification of these amplifiers, the playback system could, if necessary, be made to reproduce the entire frequency spectrum of the flight amplifiers and recorder. Figure 5 shows a simulated probe signal run at two tape speeds. Recording and playback are always at the same speed. The 7 1/2"/sec speed shows "anticipation" and the 1"/sec speed shows no anticipation. The final characteristics of the over-all recorder playback system are shown in Figures 6 and 7.

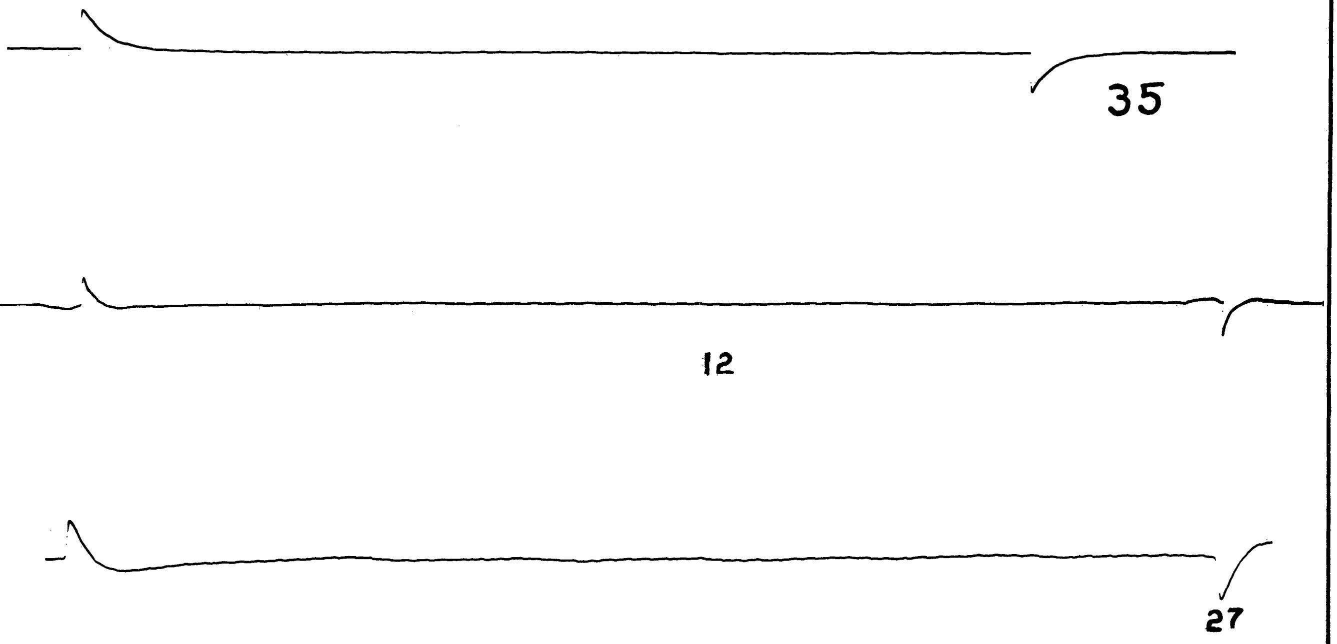

Fig. 5.
Recorded Simulated Probe Signal (top).
Playback at 7 1/5"/sec Showing Anticipation (center).
Playback at 1"/sec Showing No Anticipation (bottom).

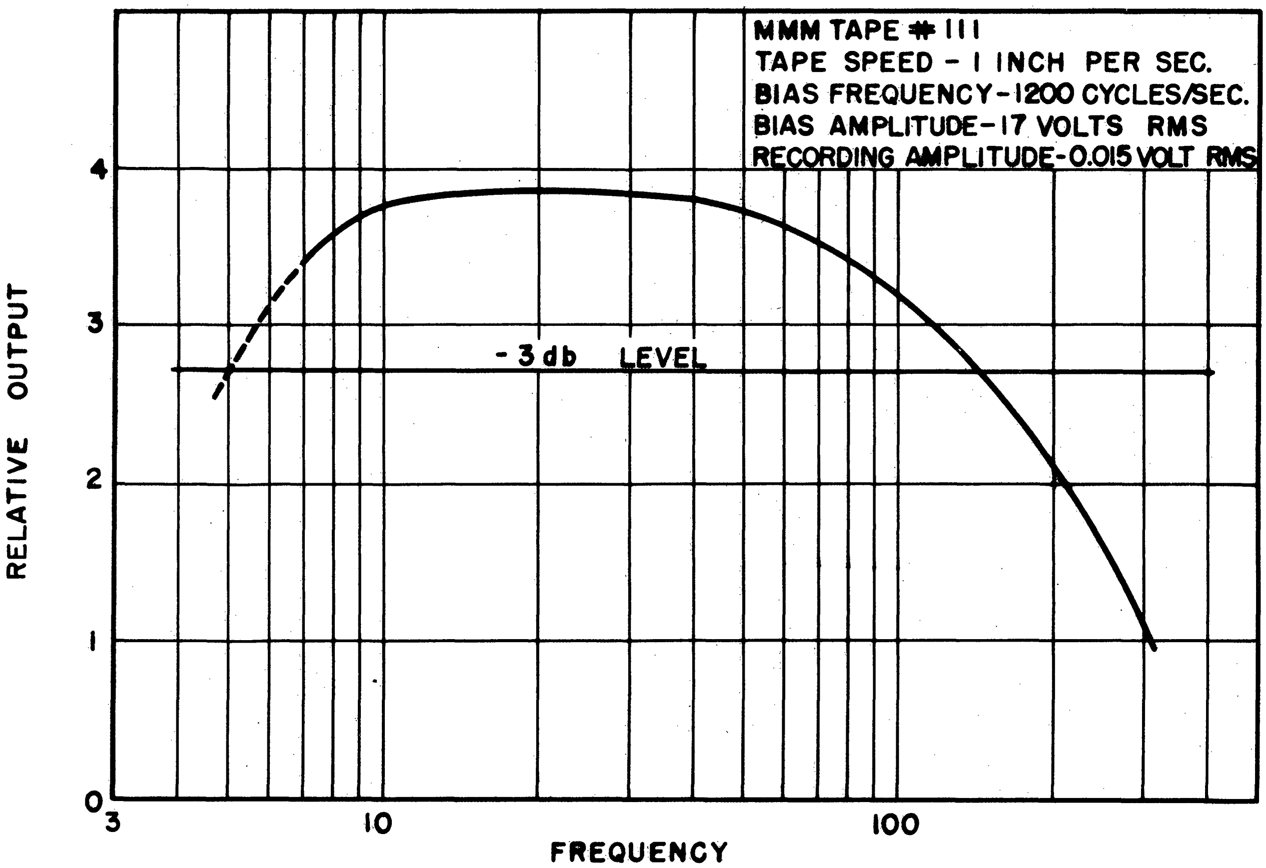

Fig. 6.
Frequency Response Characteristic of Entire Recorder System

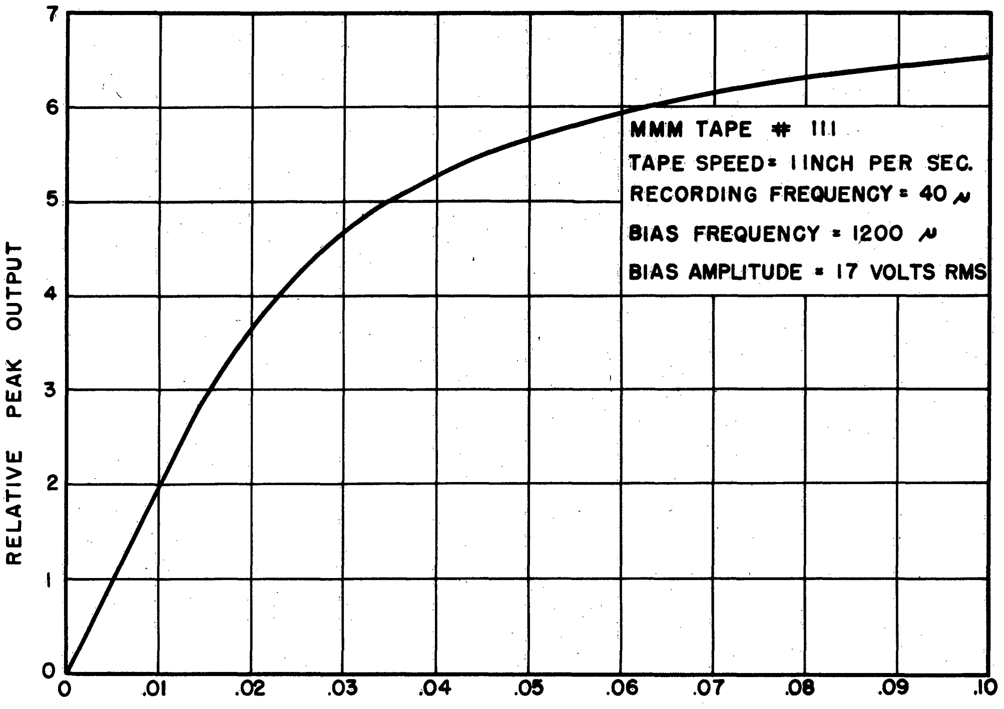

Fig. 7.
Input - Output Characteristic of Entire Recorder System

One of the ten flight probe amplifiers designed for plug-in mounting is shown in Figure 8 and its circuit in Figure 9. Figure 10 shows the frequency response characteristic of the amplifiers. The tape bias and marker oscillators are shown in Figure 11. Their circuits are shown in Figures 12 and 13.

The mechanical design was completed. Tests of the hydraulic cone drive described in the previous Progress Report showed up several difficulties. The unit was quite heavy, pump gear noise was transmitted to the piston and the filling operation was difficult and messy. Therefore, the hydraulic drive was abandoned in favor of a double thread screw running continuously in one direction. The screw was designed, built and tested satisfactorily. The completed unit is shown in Figure 14. The motor obtained for the drive is a 1/5 horsepower Bendix MA63AX, 24 volt DC, compound wound.

The probes and moving magnesium cone will be protected from heating up to 100,000 feet by a forward false cone. This cone will be ejected by a Jato at the desired altitude. The assembly is shown in Figure 15 and the Jato and Jato tests are described in Section VI.

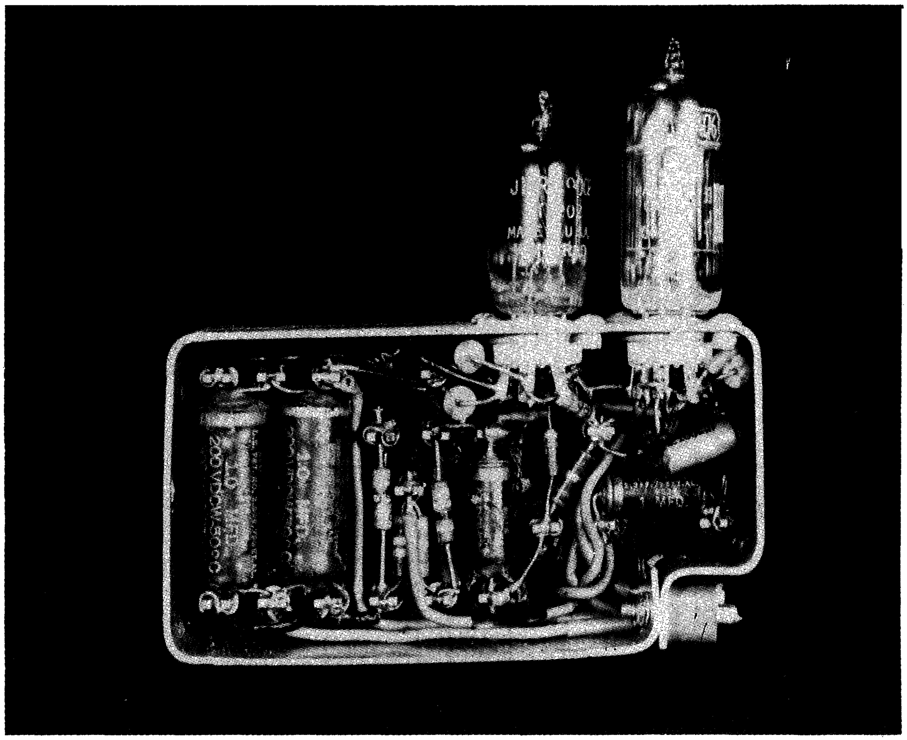

Fig. 8. Flight Probe Amplifier

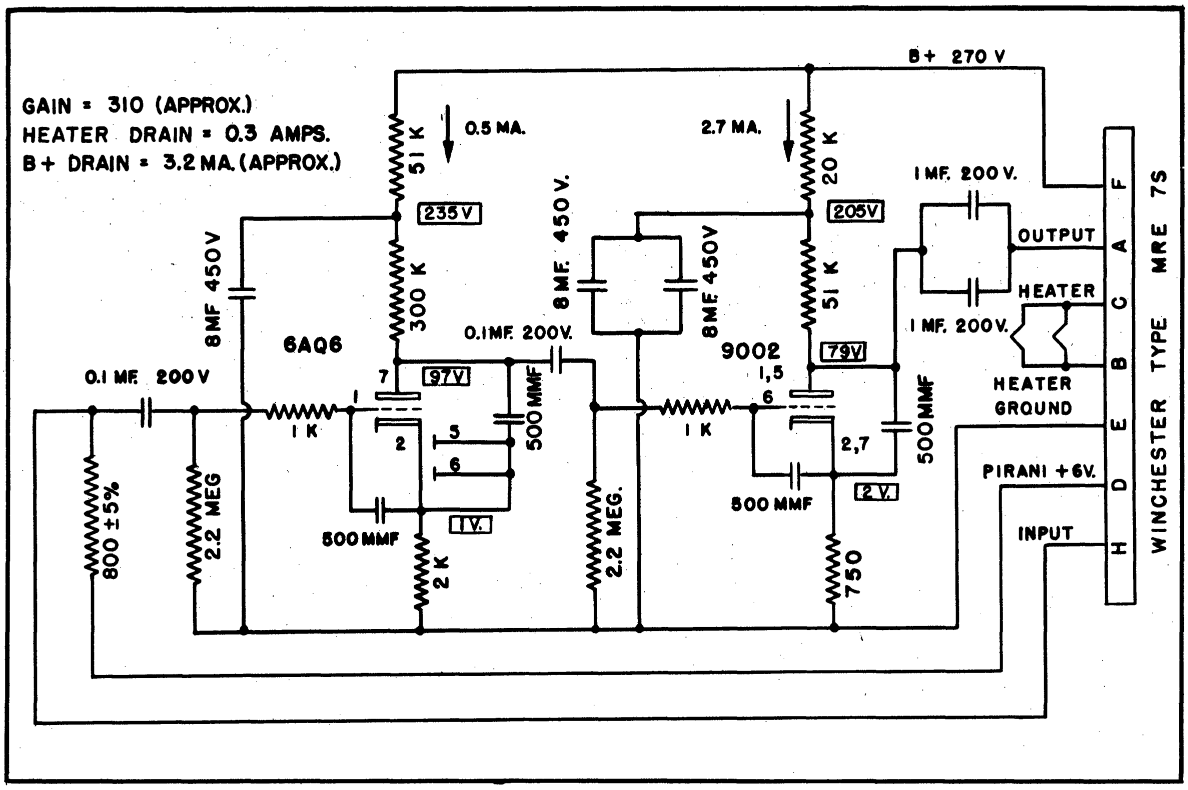

Fig. 9. Circuit of Probe Amplifier

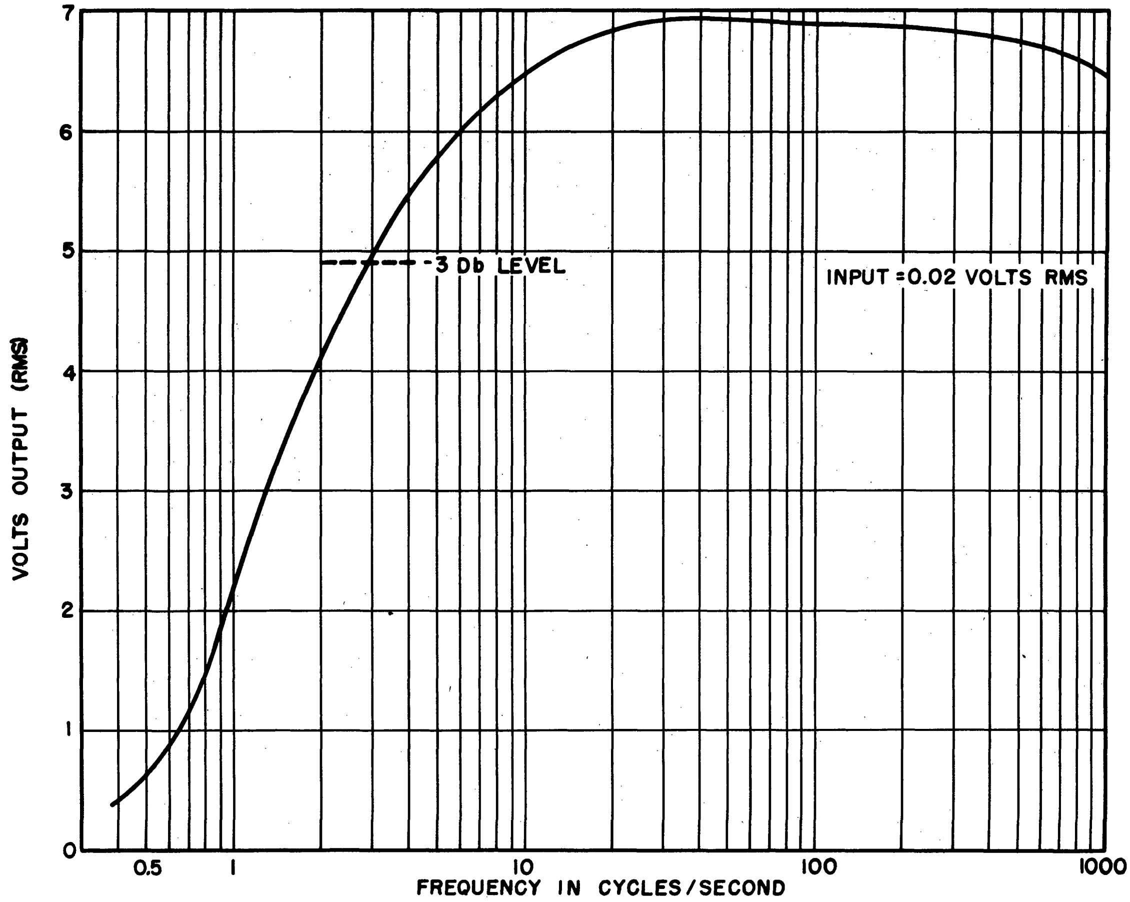

Fig. 10. Frequency Response of Probe Amplifier

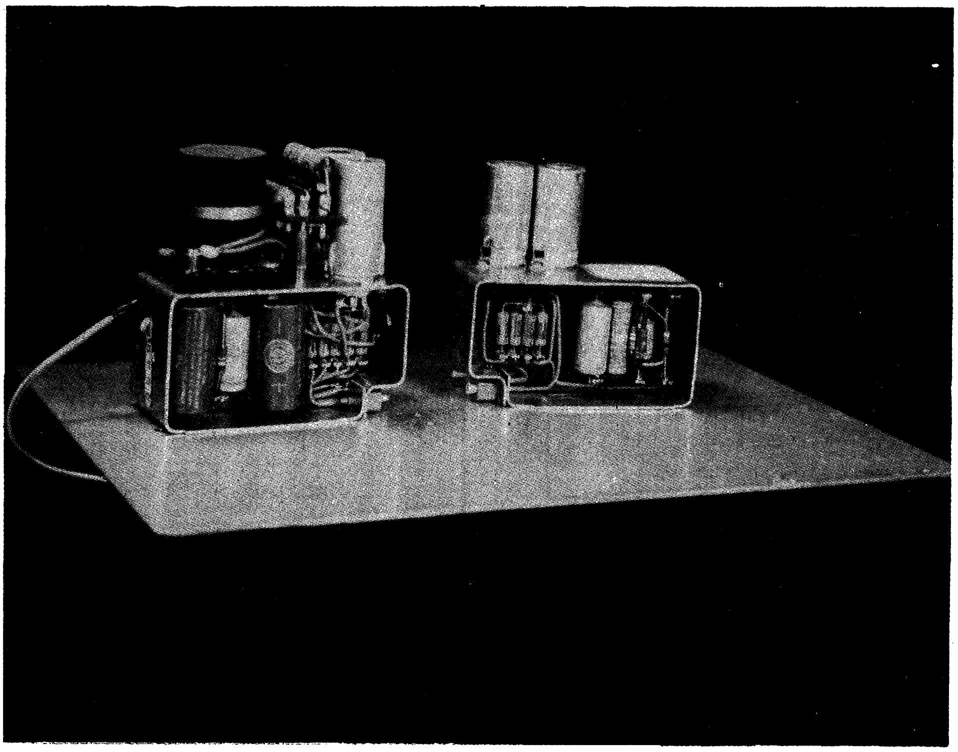

Fig. 11. Bias Oscillator (left). Marker Oscillator (right)

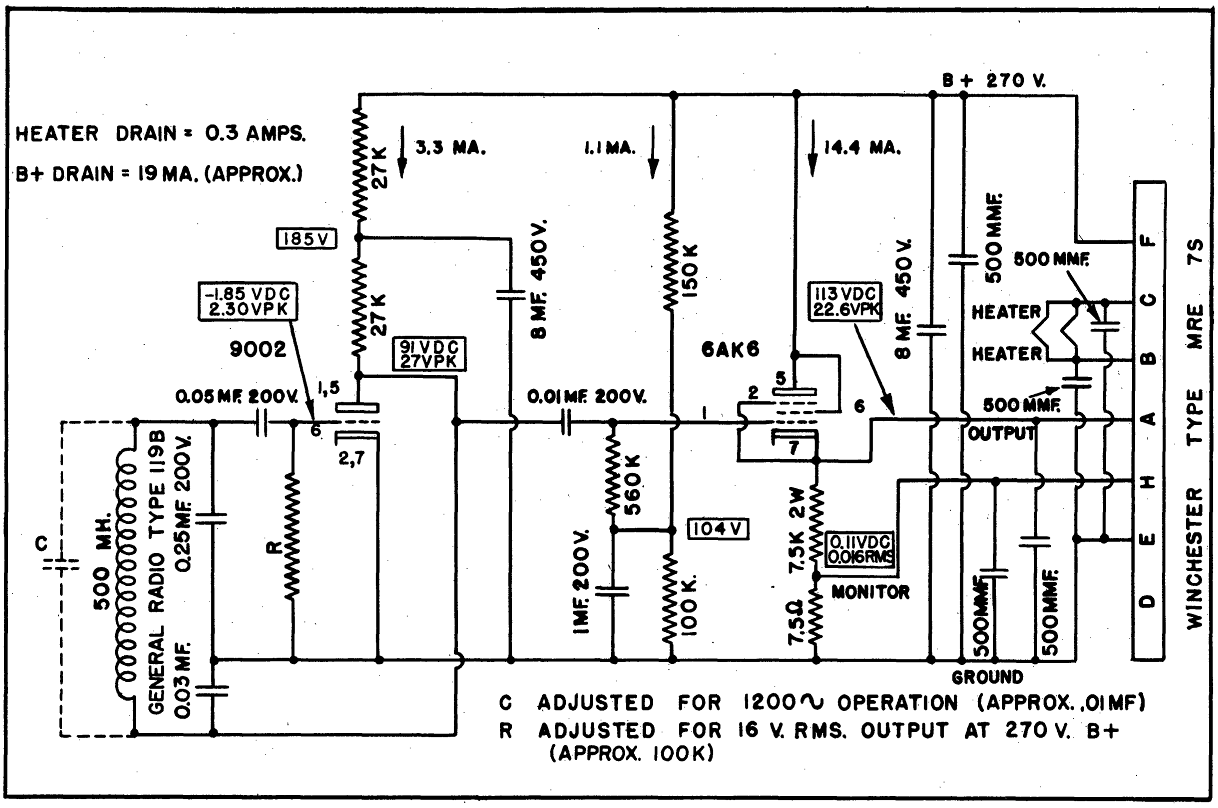

Fig. 12. Circuit of Bias Oscillator

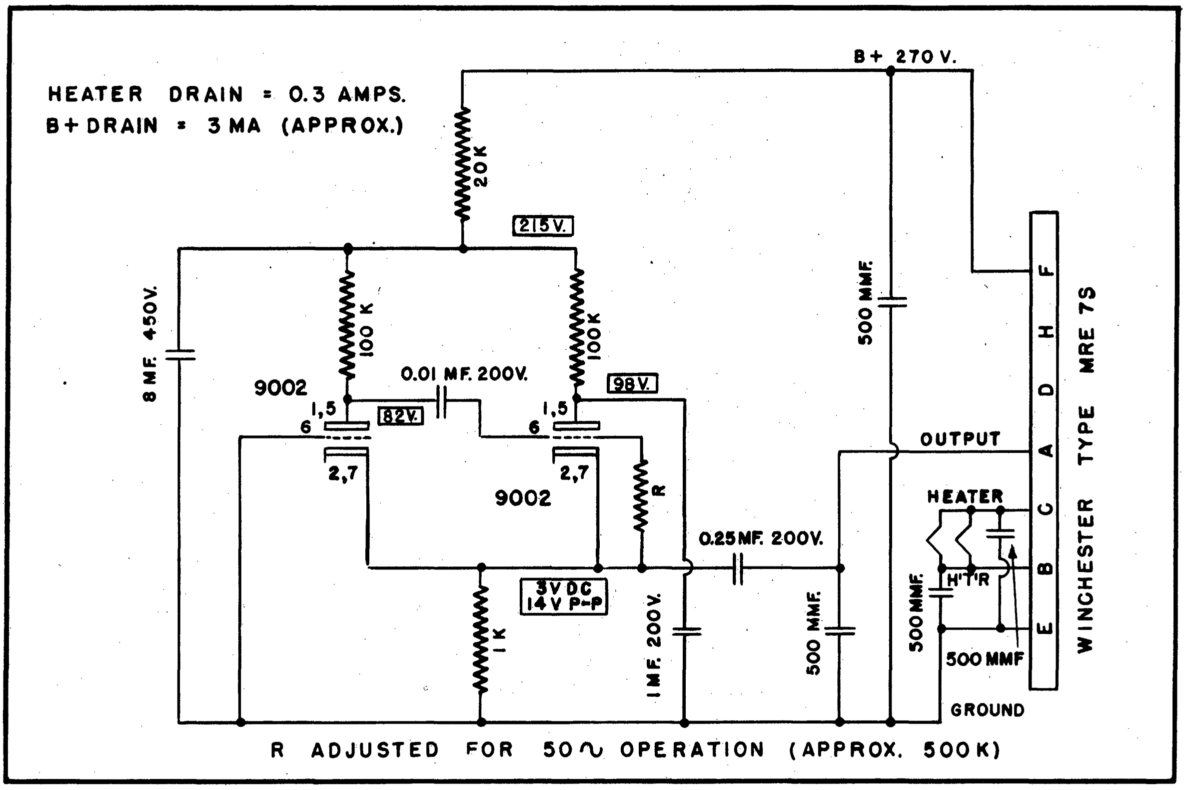

Fig. 13. Circuit of Marker Oscillator

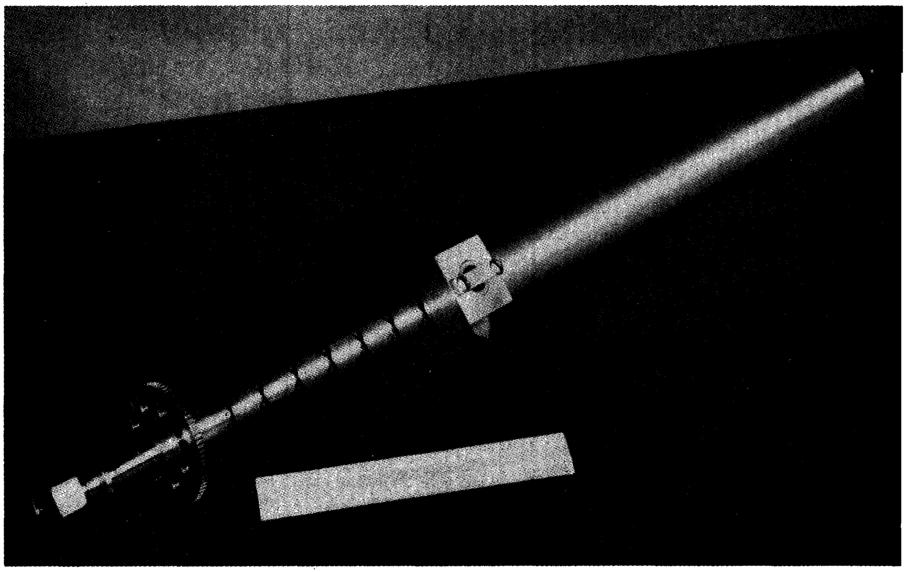

Fig. 14. Continuous Reversing Drive Screw Mechanism

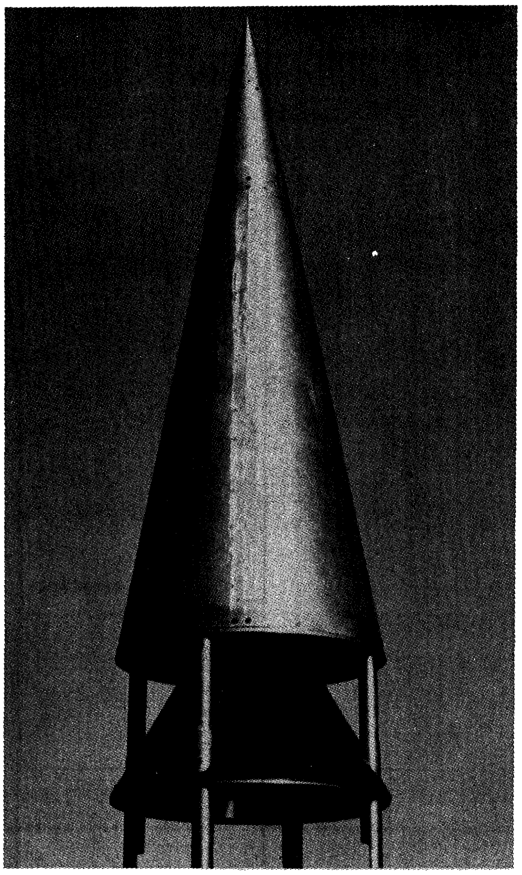

Fig. 15. Ejectable Cone Assembly Probe Aerobee

VI SAMPLING AEROBEES

Aerobee SC-11, described in previous Progress Reports, was designed in an attempt to increase the amount of air sample taken by enlarging the bottle intake orifices and exposing them more directly to the free stream flow in order to realize a larger fraction of ram pressure. The objective was to obtain usable amounts of air at 70 km. The new sealers did have large orifices but were complicated and, like the previous hot solder sealers still removed the oxygen from the sample. The cold welding of copper tubing described in Progress Report No. 17 showed promise of eliminating the major difficulties of the previous sealers. Therefore, the development of flight cold sealers and a new opening technique to be used on Aerobees SC-13 and SC-17 was rushed.

The configuration of SC-13 and SC-17 (scheduled for October 26 and November 7) is identical to that of SC-11 from the forward part of the bottles rearward. From this point forward the design is new as follows: a) New cold weld sealers will be used, b) New, motor operated, knife openers will be used, c) The entire forward cone will be ejected by Jato. These changes permit a straight tube intake 12 inches long and 1 inch in diameter. The forward end of the tubes will be the most forward part of the rocket if the angle of attack is suitable. Thus no volume of air, sealed or otherwise, is carried forward of the intake orifices. The seals, being cold, will permit recovery of the oxygen component.

Figures 16 and 17 show the construction of a flight sealer. The charge is 6 grams of black powder which is ignited by a double hot wire squib. The travel is 1 1/8 inches and the total force developed is about 8000 pounds. Two factors have been found to be important in achieving

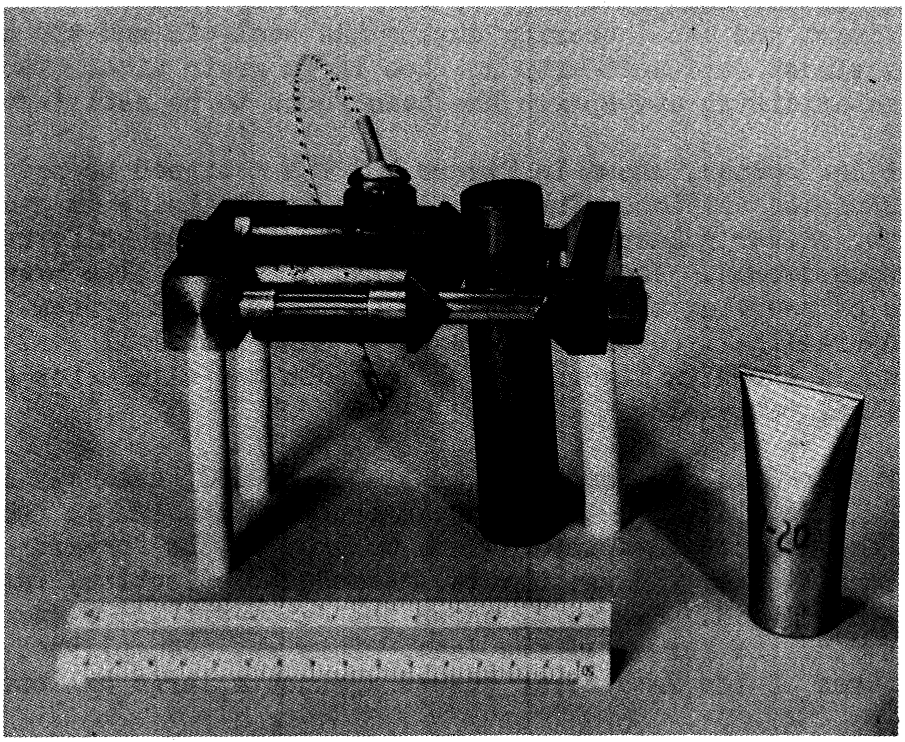

Fig. 16. Flight Cold-weld Sealer

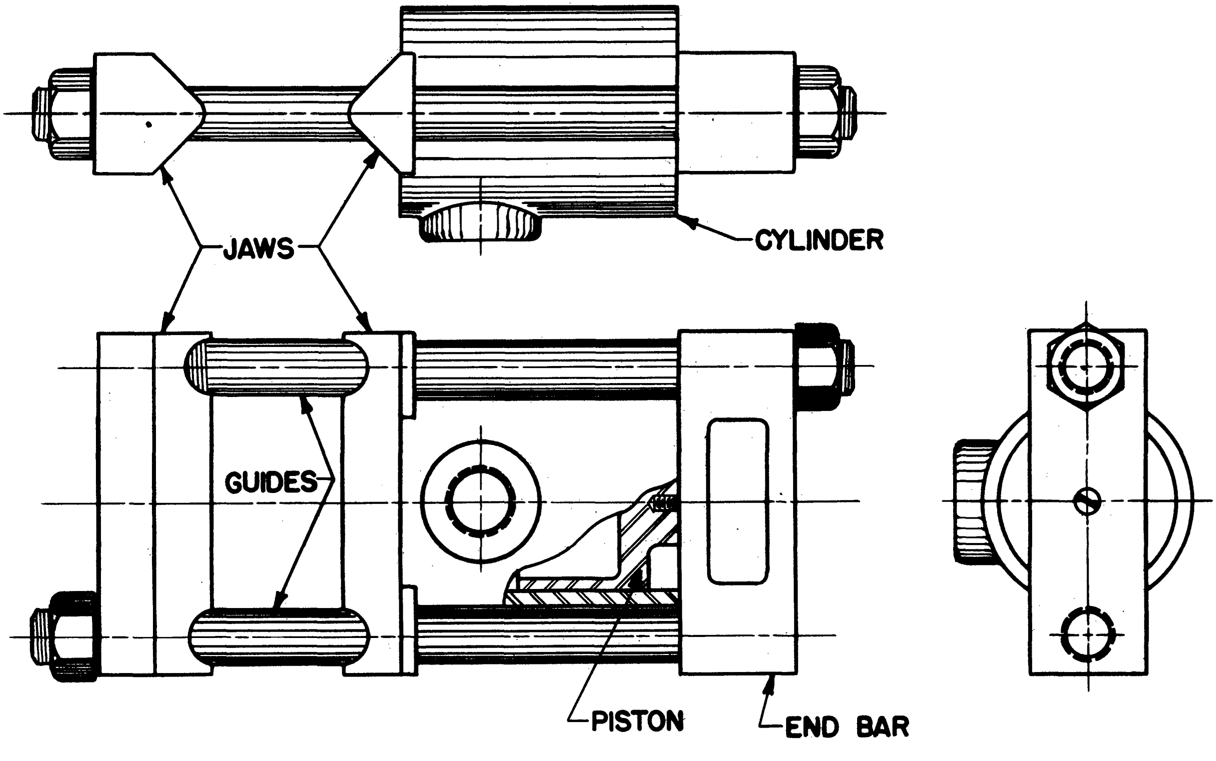

Fig. 17. Flight Cold-weld Sealer

vacuum-tight seals: the tubes must be very tightly clamped to prevent excessive movement and hence tearing during the seal-off and the copper must be annealed almost dead-soft with not too large grain size. Two hours at 1200°F in an oxidizing atmosphere has been found to be satisfactory.

A new opener, shown in Figure 18, was designed to provide a clean-edged unrestricted orifice. The section cut by the knife is steel .002 inches thick, silver soldered to the copper tubes. The knife rotates 90 degrees in one second. The cold-sealing technique has also been applied to the process of removing the bottles from the evacuation system. Figure 19 shows the hydraulically operated jaws which make the small seal on the bottle assembly shown in Figure 20. This technique eliminates any heating after the final outgassing.

The forward cone and Jato (T-31-0.9-ES-800) assembly is shown in Figure 21. It is slid over the lower instrumentation and is not held by clamps. A test of the Jato thrust in a mock-up of the forward cone was made under NTP conditions. The net thrust, after jet deflection, was about 545 pounds for one second. Figure 22 shows the Jato unit and Figure 23 the set-up for measuring the thrust of the Jato. This was accomplished by taking Fastax pictures of the Jato as it pushed against a large calibrated spring.

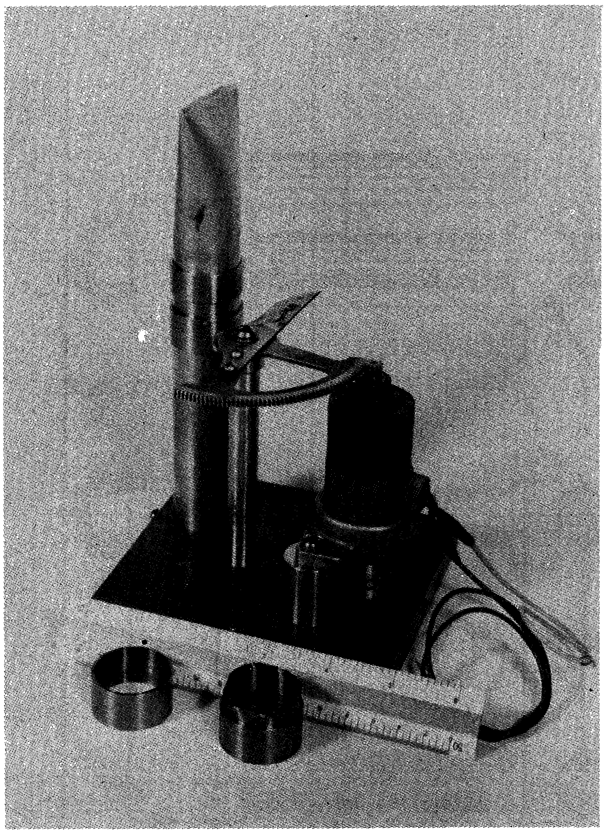

Fig. 18. Flight Opener

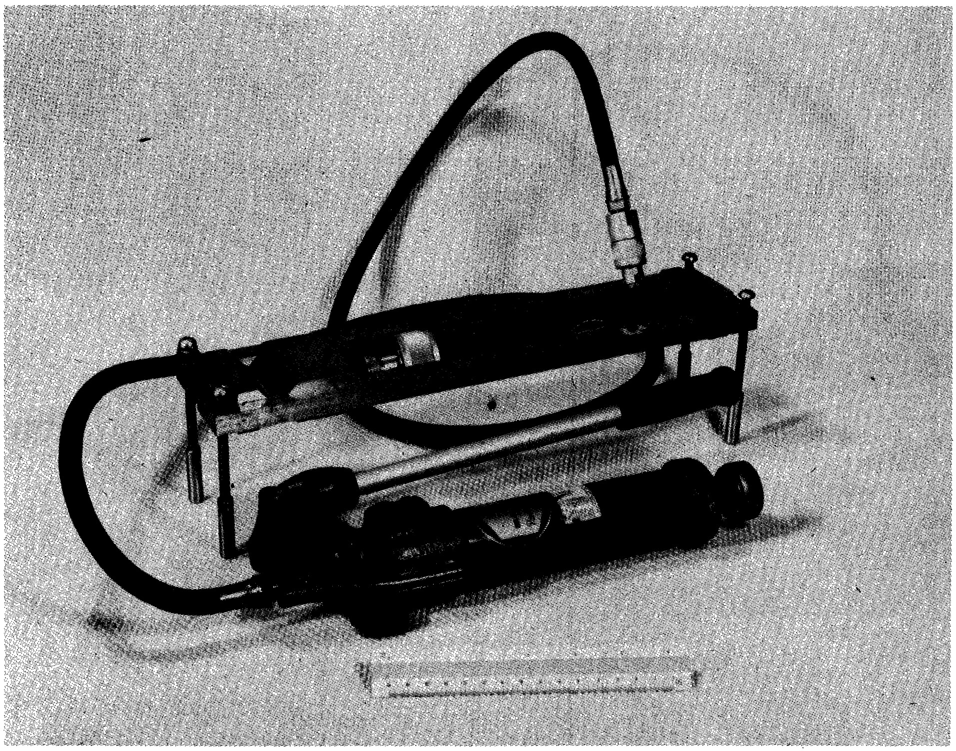

Fig. 19. Hydraulic Laboratory Seal-off Mechanism

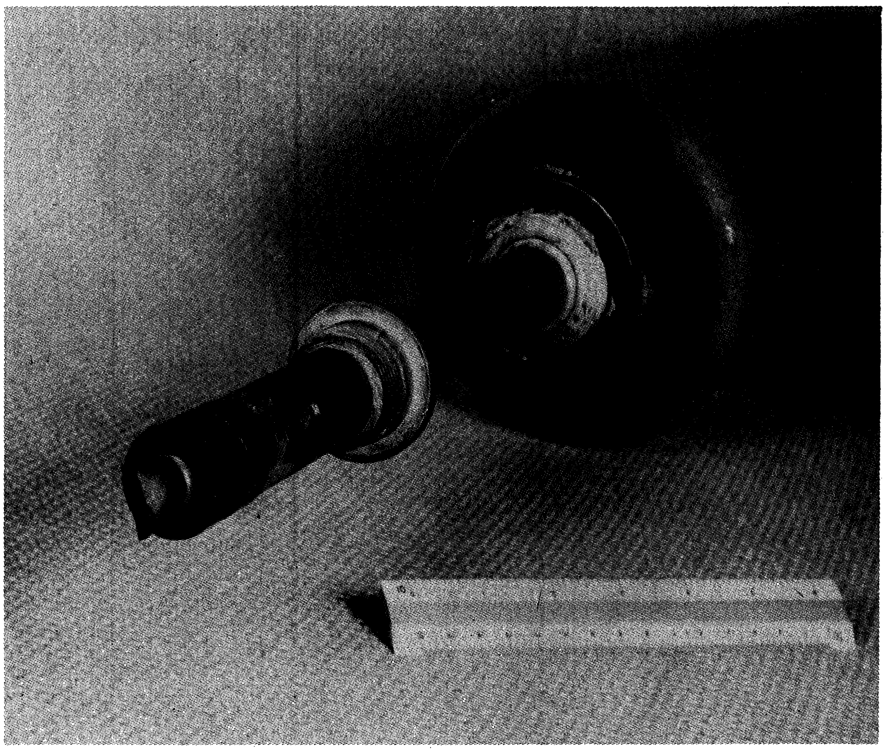

Fig. 20. Bottle Assembly

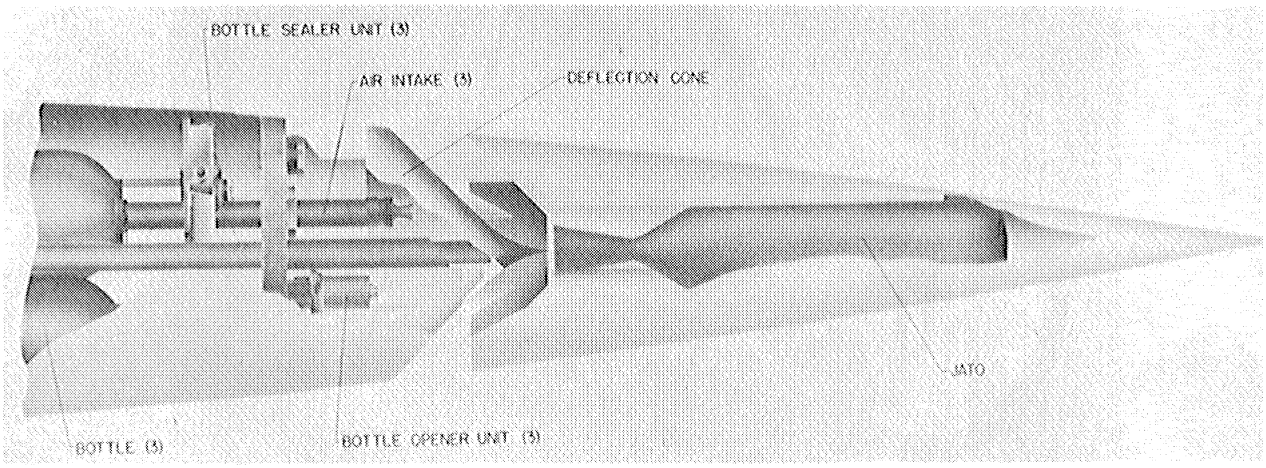

Fig. 21. Forward Cone and Jato Assembly

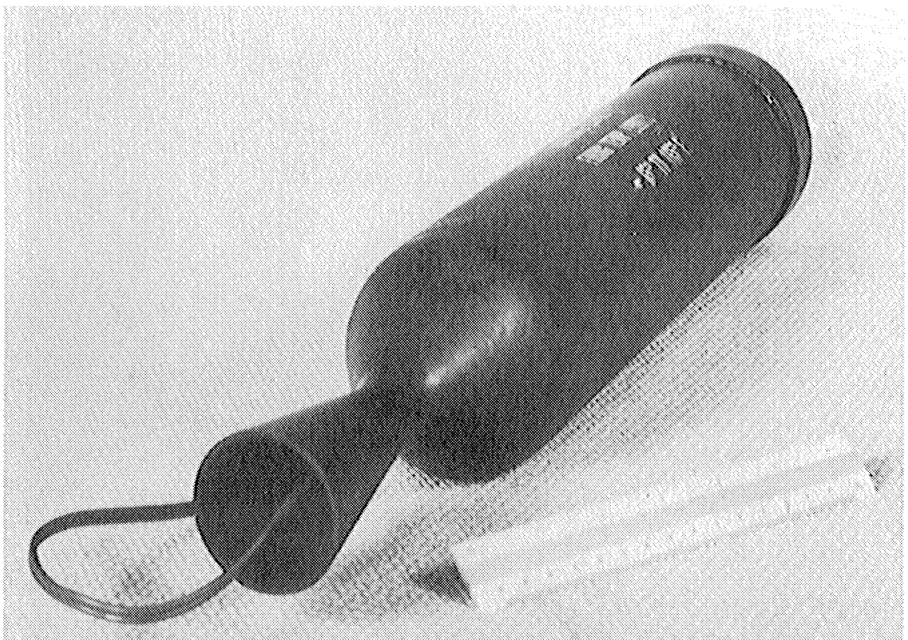

Fig. 22. Jato

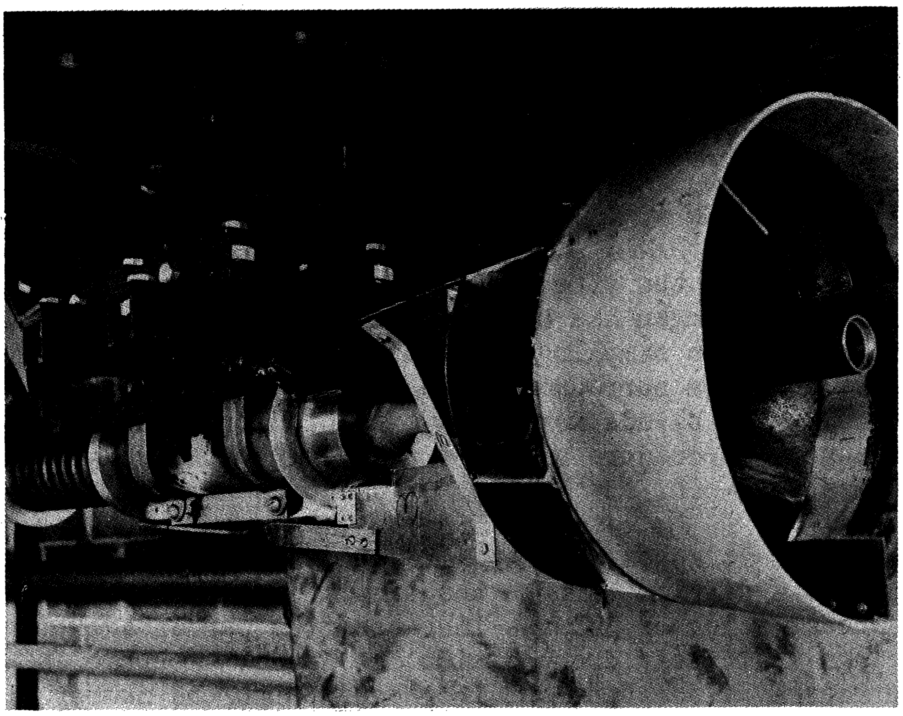

Fig. 23. Jato Thrust Test Set-up

VII HELIUM AND NEON ANALYSIS

Two analyses of roof air and four of upper air sample 28-A were made on the selective adsorption analyzer. Sample 28-A was taken on Aerobee SC-7 on December 6, 1949 at 41.0 - 44.9 km (msl). The results follow:

Sample	Run	O_2[1]	He[2]	Ne[2]
Roof	1	19.7	+ 3.5	- 4.5
	2	19.8	+ 3.1	- 5.6
28A	1	18.4	+ 3.5	- 3.4
	2	18.1	+ 3.0	- 3.1
	3	18.4	+ 2.8	- 3.4
	4	18.3	+ 2.6	- 2.7

[1] Percent by volume.

[2] Percent deviation from Paneth's value for ground air.

These results confirm the systematic errors previously shown for He and Ne. When these errors are allowed for, practically no change in He or Ne from ground air is shown which also confirms previous results.

A blend of air containing 10 ppm of He was made and analyzed. The analysis showed a much larger concentration of He than 10 ppm. A quantitative result was not obtained because the indicated He concentration was larger than could be read on the calibration curve of the Pirani gage. It is thought that an error was made in preparation of the blend. This important check will be repeated with new blends at the first opportunity.

VIII OXIDES OF NITROGEN

The study of the effect of the sampling techniques upon the gaseous oxides of nitrogen has been completed. This was accomplished by simulating the complete sampling procedure by flowing the prepared blends into the brass housings surrounding the opener diaphragm from the glass blending system. The blends were then extracted from the metal sampling bottle by the usual procedure and were sealed into the soda glass vials using the flame seal-off.

At first it appeared that a large percent (about 20%) of the original NO_2 blend carried through the sampling procedure. However, when the blend concentration of NO_2 was increased the percentage of NO_2 that carried through definitely dropped with the actual amount of NO_2 in the vials being roughly a constant but increasing with the number of hot glass seal-offs. This suggested that there was a generation of the oxides of nitrogen at the glass seal-off. This was verified by carrying through the same procedure using atmospheric air without any oxides of nitrogen added. The effect of glass seal off alone was then studied by eliminating the metal bottle and running atmospheric air directly into the glass vials after being outgassed under vacuum. Both types of experiments definitely gave the test for NO_2. The amounts of NO_2 present were orders of magnitude larger than the effect obtained for atmospheric air when the air was admitted through glass stopcocks and the glass seal off omitted.

A thorough search through the literature revealed no report on the release of gaseous oxides of nitrogen from hot glass. The analytical techniques used generally made use of vapor pressure - temperature measurements. The principal gases evolved from hot glass or water vapor and carbon dioxide with the residue, not analyzed, generally attributed to nitrogen. Inquiries made to C. H. Hahner, Chief of the Glass Section of the National Bureau of Standards, and R. H. Dalton of the Research Department of the Corning Glass Works, Corning, New York, revealed that there has never been any evidence of any significant quantities of oxides of nitrogen dissolved in the glass. It appears more likely that the oxides of nitrogen found resulted from the contact of air with the hot glass since small quantities of nitrates and nitrites are found in ampoules of soda lime glass that have been sealed off in air.

The conclusion that has been reached is that the small percentage $NO-NO_2$ detected in the glass vials arises from either the hot glass itself at the time of the vial seal off or from a hot glass-air interaction. Since the metal sampling bottles have a strong affinity for NO_2 due to its free valency, all of the NO_2 in the prepared blend must be lost to the walls of the sample bottles. Thus it appeared at first that some of the oxides of nitrogen would carry through the sampling procedure, but more thorough checks preclude such a conclusion. This means that the technique of air sampling by the use of metal sampling bottles is not applicable for the detection and measurements of small concentrations of the gaseous oxides of nitrogen, except possibly nitrous oxide N_2O.

IX SPHERE METHOD FOR AMBIENT TEMPERATURE

The preliminary operation and theory of a method for measuring ambient density and hence temperature up to 300,000 feet altitude by measuring the drag of a falling sphere was worked out. It was shown that an inflated sphere six feet in diameter weighing 20 pounds and dropped from a rocket at 400,000 feet would have an acceleration, at 300,000 feet and below, measurably less than that due to gravity. The differential acceleration would be measured by doppler, the sphere carrying a miniaturized doppler transponder. At 300,000 feet the error in temperature due to doppler error in acceleration was shown to be of the order of one percent and less at lower altitudes. Figure 24 shows the estimated drag vs. altitude curve for the above sphere.

The method, which may be applicable to the measurement of winds, would have some advantages such as simplicity and the elimination of angle of attack problems. However, supplementary data on the coefficient of drag of spheres under the conditions to be encountered would have to be obtained.

A new calculation of the expected accuracy based on information requested from BRL about doppler accuracy will be made. Two manufacturers have indicated that the spheres can be fabricated.

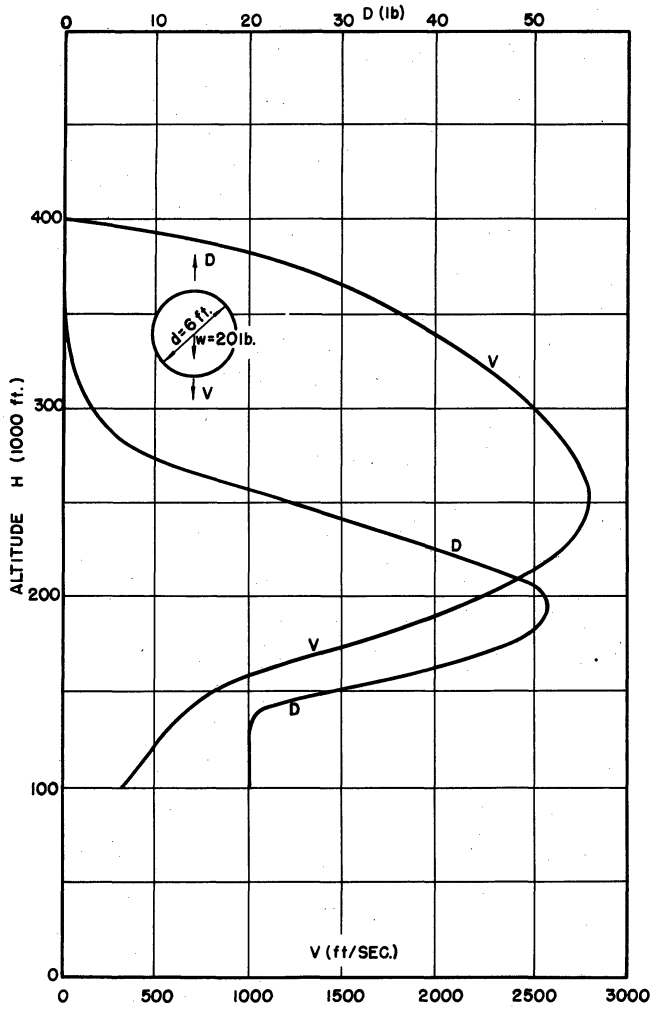

Fig. 24. Sphere Drag and Velocity vs Altitude

X REPORTS ISSUED AND LABORATORIES VISITED

An Aerodynamic Method of Measuring the Ambient Temperature of Air at High Altitudes was issued. See Section III. The following places were visited in the course of the work.

Pennsylvania State College
University of California
Brush Development Company
General Electric Company

XI FUTURE PROGRAM

Sampling Aerobees SC-13 and SC-17 with cold weld sealers will be fired in October. Probe Aerobees SC-15 and SC-19 will be fired in November and December. An attempt will be made to extend conical shock wave theory to the viscous case. A new blend of air containing 10 ppm of He will be prepared and analyzed.

XII ACKNOWLEDGMENT

Thanks are due the White Sands Proving Ground and the Meteorological Branch of the Signal Corps for their cooperation and support. We are indebted to Messrs. Folsom, Kane, Maslach and Schaaf at the University of California for their cooperation in the study of shock wave curvature. Figure 2 is a University of California photograph.