ENGINEERING RESEARCH INSTITUTE
UNIVERSITY OF MICHIGAN

# ATMOSPHERIC PHENOMENA AT HIGH ALTITUDES

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(Meteorological Branch, Signal Corps)

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for the period

September 1, 1950 to December 31, 1951

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Department of Aeronautical Engineering

## 1. INTRODUCTION

This is the fifth and final report in a series on Contract No. DA 36-039 sc-125 describing high altitude meteorological experiments being carried out by the University of Michigan for the Meteorological Branch of the Signal Corps. The program was a continuation of one which was carried out between July 1946 and August 1950 on Contract No. W-36-039 sc-32307. For background material the reader is referred to the Final Report on that contract. The work is continuing on Contract No. DA-36-039 sc-15443, for which a series of quarterly reports will be issued. This report consists of new material and edited excerpts from the project reports listed below. The excerpts are not noted as such. Work reported previously is summarized, whereas work accomplished in the final quarter, which is not covered by a previous report, is described in more detail.

## 2. PURPOSE

The purpose of the research was set forth in a Signal Corps Technical Requirements specification dated 10 August 1951 as follows:

"3.1 This specification covers the research into the necessary techniques for (1) the measurement of ambient air temperatures and densities, (2) the collection and analyses of air samples, all within the region of 30 to 100 km altitude.

3.2 The techniques shall be confirmed by field experiments using Aerobee rockets as vehicles. Emphasis shall be placed on the following four types of experiments:

a) A method for obtaining air samples at the following approximate altitudes: 30-40 kms, 70 kms and 90-100 kms.

b) Analysis of the upper air samples by the gas adsorption system and/or mass spectroscope.

c) The measurement of ambient density, temperature and, if feasible, winds.

d) The determination of ambient temperatures from the measurements of the shock angle of a rocket in flight.

e) The performance of subsidiary experiments related to the major ones, reduce data and calculate results, prepare reports."

## 3. PROGRAM

A series of rocket firings to carry out the program objectives was planned. Attention was shifted to the Aerobee as a research vehicle because the available supply of V-2's was running out. Adaptation of the sampling experiment, which started with SC-1 in December 1948, was further developed under the current contract. Three Aerobees, SC-13, SC-17 and SC-21, which incorporated several important new features, were flown. The analysis of the samples from SC-17 were of very great interest in that, for the first time, unmistakable evidence of gravitational separation of atmospheric gases was found. Considerable effort was expended also on solving the problems of sampling at 100 kilometers which is thought to be about the limit of the present technique. The original plan was to carry the 100 kilometer equipment on an RTV-A-1a high-performance Aerobee. However, through the cooperation of the Ordnance Corps, space was made available on a V-2 to be flown for training purposes. It is now planned to sample throughout the range 50 to 100 kilometers with this rocket to take advantage of the better performance. Also, design of sampling apparatus to be used on balloons was started for a series of flights up to 100,000 feet planned for the fall of 1952.

Adaptation to the Aerobee of the shock wave probe method for measuring ambient temperature was also carried out, and two Aerobee flights were made. In both cases no data were obtained because the missiles failed shortly after take-off. Following these firings (SC-15 and 19) it was learned that a V-2 rocket was available, and it was decided to adapt the Aerobee instrumentation to it to take advantage of the improved stability. This flight, V-2 60, also yielded no results because the moving cone drive failed to operate properly.

Another experiment, that of measuring ambient density and temperature by measuring the acceleration trajectory of a freely falling sphere was conceived and development begun. This work had advanced far enough by summer that a flight was planned. Following the flight of V-2 60 it was decided to shelve temporarily the probe experiment and concentrate on the falling sphere. After the latter has been adequately tried, it is planned to evaluate the two temperature methods to determine whether or not further development of either is desirable.

The major laboratory effort during the contract went into the development and construction of rocket apparatus. Major activities which did not result in flight equipment were as follows:

a) Further development of the selective adsorption gas analyzer.

b) Arranging for air sample analyses at Durham University and Consolidated Engineering Corporation.

c) Arranging for a wind tunnel study of drag of various Aerobee front end configurations at the Aeronautical Research Center, University of Michigan and Jet Propulsion Laboratory, California Institute of Technology.

d) Arranging for the measurement of coefficient of drag of spheres at the Naval Ordnance Laboratory facility at White Oak, Maryland.

A summary of firings accomplished during the contract is given in Table I.

TABLE I

Summary of Rocket Firings by the University of Michigan
in the Interval September 1, 1950 to December 31, 1950

| Rocket No. | Date | Time MST | Peak Altitude MSL Feet | Kilometers | Major Objectives or Apparatus |
|---|---|---|---|---|---|
| Aerobee SC-13 | 10-27-50 | 0620 | 262,000 | 79.9 | Composition by sampling |
| Aerobee SC-15 | 12-11-50 | 1004 | Failed at take-off | | Ambient temperature by probing shock wave |
| Aerobee SC-17 | 12-19-50 | 1151 | 269,000 | 82.0 | Composition by sampling |
| Aerobee SC-19 | 6- 7-51 | 1818 | Failed at take-off | | Ambient temperature by probing shock wave |
| Aerobee SC-21 | 9-26-51 | 1707 | 226,000 | 68.9 | Composition by sampling |
| V-2 60 | 10-29-51 | 1404 | 465,000 | 141.8 | Ambient temperature by probing shock wave |

## 4. REPORTS

4.1 The following Progress Reports were issued:

| Progress Report No. | Type | Period |
|---|---|---|
| 1 | Interim | 9-1-50 to 12-31-50 |
| 2 | Quarterly | 1-1-51 to 3-31-51 |
| 3 | Quarterly | 4-1-51 to 6-30-51 |
| 4 | Quarterly | 7-1-51 to 9-30-51 |
| 5 | Final | 9-1-50 to 12-31-51 |

4.2 A series of one page letter-type progress reports was issued during the course of the work.

4.3 Two Letters to the Editor appeared in the Physical Review:

"Does Diffusive Separation Exist in the Atmosphere Below 55 Kilometers?". Hagelbarger, Loh, Neill, Nichols, Wenzel, Phys. Rev., 82, 107, (1951).

"Diffusive Separation in the Upper Atmosphere". Jones, Loh, Neill, Nichols, Wenzel, Phys. Rev., 84, 846, (1951).

4.4 The following technical memoranda were issued:

No. 1. Preliminary Investigation of Sphere Method of Ambient Temperature Measurement. V. C. Liu, Eng. Res. Inst. Proj. M893 (1950).

No. 2. Upper Atmosphere Ambient Densities and Temperatures as Obtained from the Measurement of Drag Forces upon a Falling Sphere. F. L. Bartman, Eng. Res. Inst. Proj. M893 (1951).

No. 3. On Sphere Method of Ambient Temperature Measurement in the Upper Atmosphere with Wind. V. C. Liu, Eng. Res. Inst. Proj. M893 (1951).

No. 4. Performance Analysis of a Sounding Rocket. V. C. Liu, Eng. Res. Inst. Proj. M893 (1951).

No. 5. Estimation of the Transient Skin Temperature of a Falling Sphere. V. C. Liu, Eng. Res. Inst. Proj. M893 (1951).

## 5. COMPOSITION

The primary objective of the air sampling program at the University of Michigan has been to investigate the phenomenon of gravitational separation. The situation existing at the beginning of this contract was as follows: Forty-six sample bottles had been flown on various V-2's and Aerobees of which 14 bottles yielded samples thought to be characteristic of the sampling altitude. The Aerobee samples ranged up to 58 kilometers and were thought to be quite reliable and free of contamination. The V-2 samples ranged up to 72 kilometers, and it was thought that the amount of contamination from rocket-borne ground air was probably low enough to not invalidate the results. Analyses of nearly all of the samples had been performed by the charcoal adsorption method at the University of Durham and the University of Michigan and had shown, with increasing precision, that no increase in the helium or neon or decrease in the argon ratios to nitrogen over the ground values was present. An increase in the ratio $N^{14}N^{14}/N^{14}N^{15}$ detected by mass spectrometer in samples supplied by Michigan was reported by McQueen,[1] but this result is thought by the Michigan group to be not attributable to gravitational separation.[2]

The start of the contract found the rocket sampling apparatus greatly improved over that used previously. The general objectives for which the improvements had been designed were to confirm the results of early V-2 samples in the vicinity of 70 kilometers so as to eliminate the shadow of contamination and to take advantage of the increased precision of the analyzers. It was also desired to push the sampling technique to higher altitudes to reach the region where measurable separation might exist.

### 5.1 Sampling Aerobees SC-13, SC-17 and SC-21

The sampling apparatus of these rockets differed markedly from anything flown previously. The most important new features were:

a) Placing the intake tubes of the bottles at the most forward part of the rocket during sampling. This was desirable to insure that, as long as the rocket was supersonic and had not too great an angle of attack, gases leaking from spaces or outgassing from surfaces behind the intakes could not enter them. One-inch diameter copper tubes extended straight forward and passed through an airtight bulkhead. The tubes were sealed at the very ends so that there were no hoses or manifolds to be flushed. In operation, the openers removed the entire ends of the tubes leaving wide diameter, straight intakes to the bottles. During the early part of the flight the tubes were covered by a false cone which was removed by a Jato unit just before the intake tubes were opened. On SC-13 and SC-17 the openers were motor-driven knives which cut off the forward end of the tubes. On SC-21 pyrotechnic pistons knocked off the ends of the tubes.

b) The use of new cold-weld sealers to seal the intake tubes. One objective of this design was to eliminate the hot copper surfaces of the previous sealers in the hope that all of the atmospheric oxygen would thereby be available for analysis. However, even with the cold sealers, nearly all of the oxygen appears to be lost by oxidizing the cold copper so that oxygen analysis has not been realized. Another objective of the new sealers was to permit the use of wide diameter, straight tubes without restrictions although this feature is probably not restricted to the cold sealer. The straight tubes were desired not only to increase the "take" at 70 km but also to permit gathering enough air at 100 km for analysis.

c) The lightening of the payload to increase the sampling altitude and to reduce the drop load of the parachute. A typical payload weight was 160 pounds and on SC-17 and SC-21, by lowering only the bottles and the skin around them, the parachute load was reduced to 81 pounds.

The auxiliary apparatus of these flights was similar to that used previously, i.e., cut-off receiver, radar beacon, motor-driven cam timer and $C^{14}O_2$ contaminator.

Fig. 1 is a schematic of the instrumentation and Fig. 2 a photograph of the forward end of SC-21. Fig. 3 shows a schematic of the sealer and Fig. 4 the relative positions of sealers and openers on SC-21.

All three of the rockets were launched without unusual difficulty. The peak altitudes, which are given in Table I, were in each case less than predicted. A general falling off in the altitude performance of Aerobees has been experienced by all agencies using them and is the subject of investigation by these agencies and Aerojet Engineering Corporation. A wind-tunnel investigation of the drag of front-end configurations of University of Michigan Aerobees (including SC-13, 17, and 21) was carried out at Michigan and California Institute of Technology. It showed that increased drag could account for only a little of the loss of peak altitude. See Tech. Memo. No.4.

Parachute recovery was excellent in all three cases. See Fig. 5, which shows the recovery of SC-17. Practically no damage was suffered in any of the drops. Unfortunately, the operation of the sealers and openers was not always perfect. On SC-13, two of the three knives operated correctly, and one stalled half-way through the cut. No samples were obtained, however, because the sealers had not been pressurized, and the black powder failed to ignite at the reduced pressure. On SC-17, one knife cut completely through while two cut half-way through. All of the sealers operated successfully, and in spite of the poor openings, samples were obtained in all three bottles. On SC-21, all of the openers and sealers operated correctly, but the seal on the highest bottle leaked so that samples were obtained from two only. The leak was possibly due to improper cleaning or a speck of dust which caused an imperfect weld.

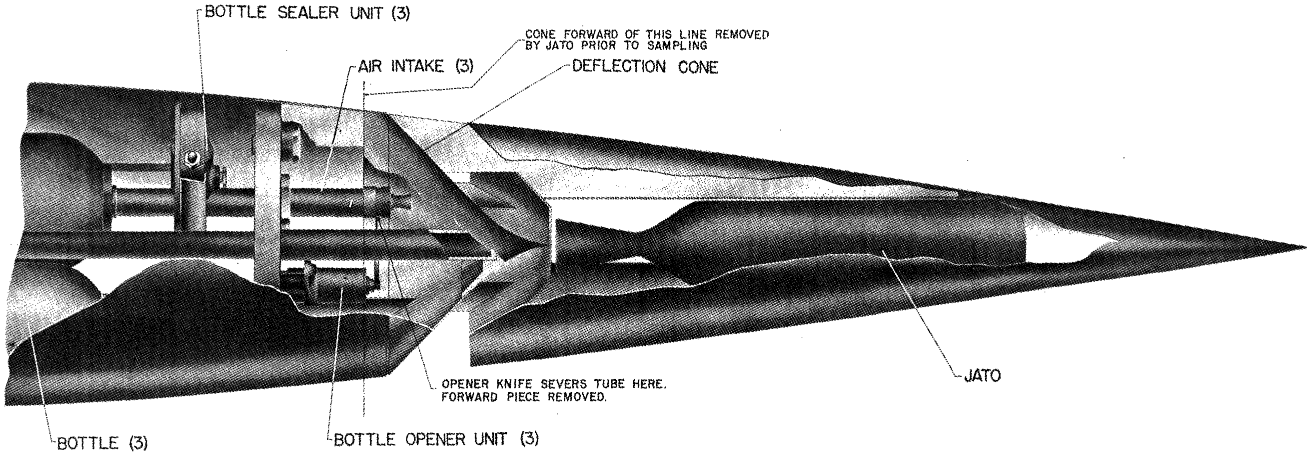



Fig. 1. Schematic of SC-13 and SC-17.

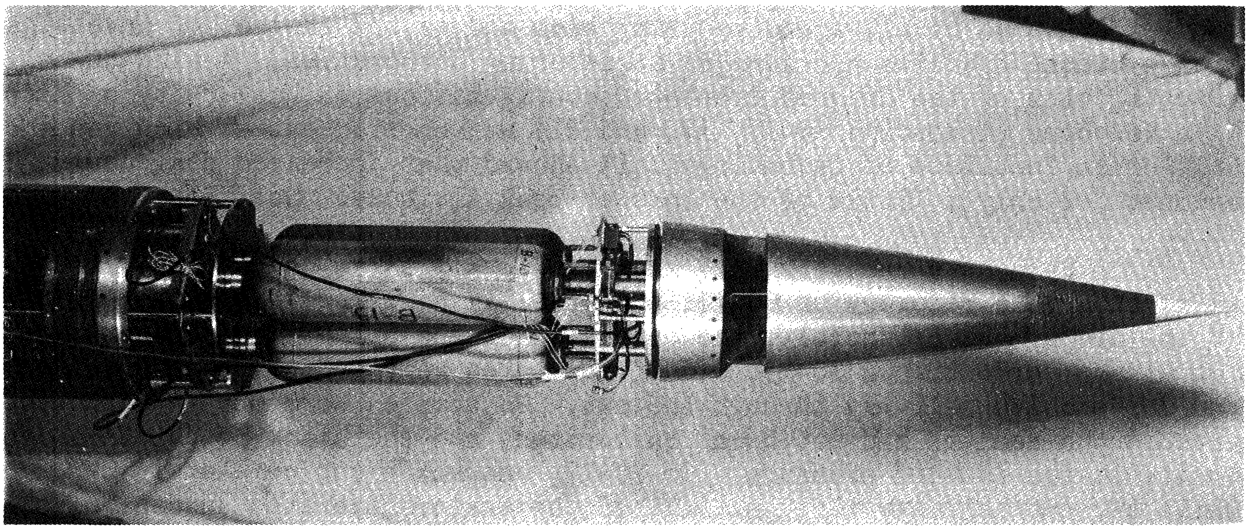


Fig. 2. Front End of SC-21.

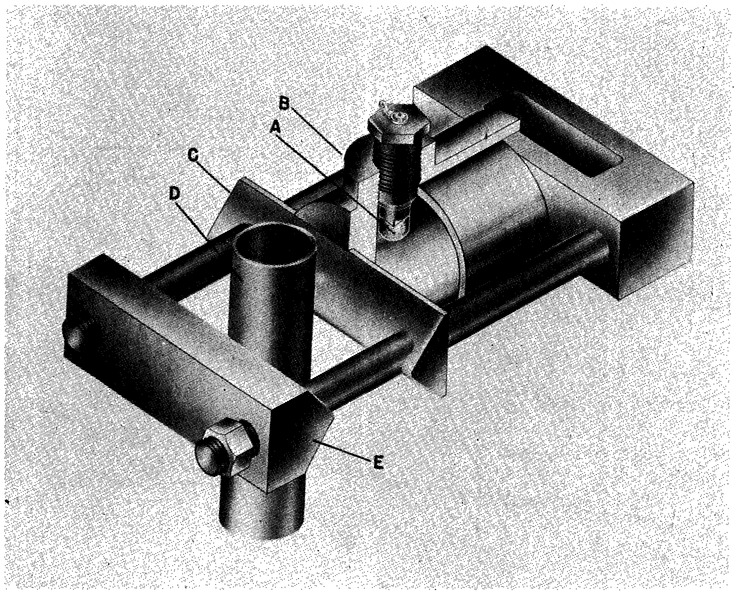



Fig. 3. Schematic of Cold-Weld Sealer.
A. Black Powder, B. Squib Holder, C. and E. Jaws, D. Tube.

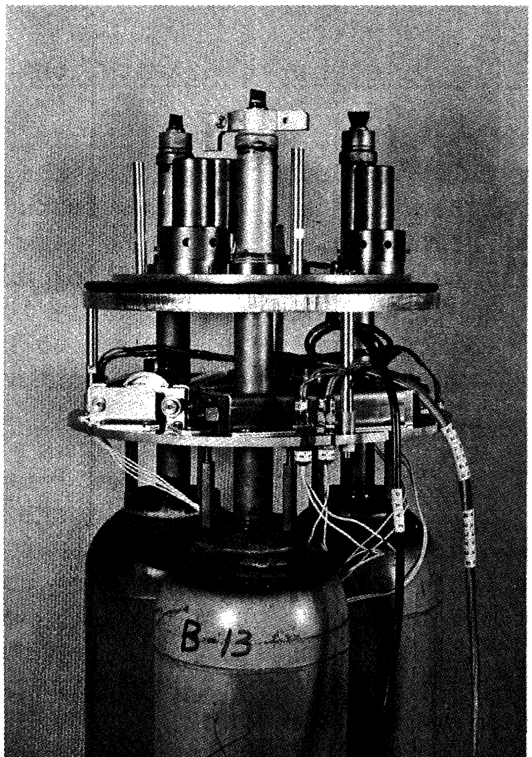



Fig. 4. Openers and Sealers, SC-21.

Fig. 5. Parachute Recovery, SC-17.

## 5.2 Sample Analysis - The Detection of Gravitational Separation

During the course of the work at Michigan, Professor Paneth and his co-workers at the University of Durham completed the construction of a new charcoal adsorption analyzer. It embodies new features which permit faster analyses with increased precision. In order to take advantage of these improvements and to eliminate unnecessary handling of the samples, the steel bottles from SC-17 and SC-21 were shipped directly to Dr. Paneth for attachment to his apparatus. Since these were thought to be the most reliable samples yet obtained, it was felt desirable to achieve a quick and precise analysis.

The analysis results received from Dr. Paneth were of very great interest indeed. For the first time a marked change in atmospheric composition was detected. The magnitudes are not in quantitive agreement with a simple diffusion relation, assuming perfect mixing to a base altitude and separation under quiet conditions above the base. However, they are quite reasonable when it is realized that mixing and separation may take place simultaneously, and they are in the right direction, i.e., helium and neon increasing and argon decreasing. In short, although our knowledge of gravitational separation is very scant, there can be no doubt that it has been detected in these samples in the altitude range 58.2 to 71.7 kilometers.

The results of the measurements are given in Table II. The values shown are:

$$\frac{\text{volume of gas, relative to nitrogen, in sample}}{\text{volume of gas, relative to nitrogen, in ground level air}}$$

TABLE II

University of Durham (Paneth) Charcoal Adsorption Analysis

| Steel Bottle | Glass Vial | Rocket No.[a] | Altitude km MSL | Date of Sampling | Date of First Analysis | Amount of Sample cc NTP | Analysis[b] Oxygen | Helium | Neon | Argon |
|---|---|---|---|---|---|---|---|---|---|---|
| B-9 | -- | SC-17 | 69.5-71.6 | 12-19-50 | 5- 4-51 | .535 | 0.03 | 1.49 | 1.07 | 0.95 |
| B-9 | (corrected for an assumed 400% contamination) | | | | | .107 | | 3.45 | 1.35 | 0.75 |
| B-8 | -- | SC-17 | 67.1-69.5 | 12-19-50 | 6-25-51 | .185 | 0.25 | 2.02 | 1.18 | 0.89 |
| B-6 | -- | SC-17 | 64.0-67.1 | 12-19-50 | 6-12-51 | .388 | 0.07 | 1.44 | 1.08 | 0.93 |
| B-15 | -- | SC-21 | 58.7-60.7 | 9-26-51 | 12- -51 | 4.2 | <0.01 | 1.035±0.003[c] | 1.008±0.001[c] | 0.996±0.002[c] |
| B-13 | -- | SC-21 | 56.1-58.7 | 9-26-51 | 12- -51 | 6. | <0.01 | Same as ground level air | | |
| **Some Previous Samples** | | | | | | | | | | |
| 32 | 1B | V-2 27 | 61.1-72.0 | 10- 9-47 | | | <0.02 | 0.93 | 1.00 | 1.01 |
| 35 | 2B | V-2 35 | 55.4-65.5 | 5-27-48 | | | 0.02 | 1.01 | 1.00 | 1.00 |
| 37 | 3B | V-2 35 | 55.4-65.5 | 5-27-48 | 2- 1-49 | | <0.01 | 0.98 | 0.99 | 1.00 |
| 63 | 19D | SC-4 | 54.7-58.3 | 7-21-49 | 3- 6-51 | | 0.00 | 1.01 | 1.45[d] | 1.01 |
| 61 | 15B | SC-2 | 53.6-57.7 | 6- 2-49 | 7-25-49 | | 0.12 | 1.00 | 1.00 | 1.01 |
| 77 | 25D | SC-3 | 50.4-53.3 | 12- 6-49 | 4-17-51 | | 0.60 | 0.98 | 1.00 | 1.00 |
| 60 | 16A | SC-2 | 49.6-53.6 | 6- 2-49 | 8- 4-49 | | 0.61 | 0.96 | 0.98 | 1.00 |

(a) SC rockets are Aerobees.

(b) Paneth quoted figures to two places of decimals although the mean deviations calculated from individual experimental results are often below 0.005.

(c) Mean deviation.

(d) Unreliable because of contamination by $H_2$ from the sealer. The presence of $H_2$ was confirmed by mass spectrometry.

Results of some earlier samplings are included for comparison with the new ones. The samples are arranged in descending order of the mean of the opening and closing altitudes.

It will be noted that the highest bottle (B-9) contained the largest sample but showed the smallest relative change in composition. A reasonable explanation of this is that the bottle leaked in an amount of ground air equal to about four times the volume of the upper air sample. Assuming such contamination, one can roughly calculate the expected separation at the altitude of bottle B-9. These figures are given in Table II.

Previous analyses by the charcoal adsorption method have revealed no separation in samples taken up to 66.6 kilometers (mean altitude).(3) On the basis of mass spectrometric measurements on samples taken up to 56.5 kilometers, McQueen(1) concluded that appreciable gravitational separation existed at this altitude. That such marked separation was unlikely was pointed out by Hagelbarger et al.(2) Subsequent measurements made on other fractions of the same samples used by McQueen have shown little or no separation. Paneth and Michigan measured the helium to nitrogen ratio using the charcoal adsorption method, and the Consolidated Engineering Corporation of Pasadena measured the nitrogen isotope ratio $N^{28}/N^{29}$. The results are compared with McQueen's in Table III. The nitrogen isotope values shown are:

$$\frac{N^{28}/N^{29} \text{ in sample}}{N^{28}/N^{29} \text{ in ground air}};$$

the helium values, both calculated and measured, are the same as in Table II.

It can be seen that Paneth and the University of Michigan indicate practically no separation in bottles 45, 37, 61, and 42, but that a small amount of separation may be indicated by the Consolidated Engineering measurements. It is possible, however, to reconcile these results within the experimental errors whereas such reconciliation is not possible with McQueen's results for bottles 63, 61, and 42. It has been pointed out(2) that a 3.5% increase in the $N^{28}/N^{29}$ ratio at 56.6 kilometers would correspond to a 134% increase in the ratio $He/(N_2 + A)$ assuming that $T = 280^\circ$ K and that all of the helium enrichment took place in the same altitude interval as the $N_2^{28}$ enrichment. The helium values corresponding to the McQueen and Consolidated measurements were calculated using these assumptions. The values are given in Table III for comparison with the measured values. It is concluded from these data that the separation of helium in any samples previous to B-6, B-8, and B-9 is of the order of 5 $\pm$ 5% or less. The question arises as to why little or no separation was measured in bottles 32 (Table II) and 45 (Table III) which sampled at about the same mean altitude as bottle B-6. The possible explanations which come to mind are: (a) that there are variations due to unknown causes in the level at which separation begins, or (b) that the V-2 samples were contaminated with much ground air.

The two early samples mentioned, 32 and 45, were collected in bottles mounted at the rear and mid-section, respectively, of the V-2 with relatively small protruding intake scoops. It is quite possible that there

## TABLE III

| | | | | Mass Spectrometer Analysis | | | | | | Charcoal Adsorption Analysis | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | U. of Virginia (McQueen)[a] | | | Consolidated Engineering[b] | | | U. of Durham Paneth[c] | | U. of Michigan[d] | |
| Steel Bottle | Rocket No. | Altitude km MSL | Date of Sampling | Glass Vial | Measured Nitrogen Isotopes | Calculated Equivalent Helium | Glass Vial | Measured Nitrogen Isotopes | Calculated Equivalent Helium | Glass Vial | Measured Helium | Glass Vial | Measured Helium |
| 45 | V-2 44 | 60.8-69.5 | 11-18-48 | | | | 12D | 1.004±.005 | 1.10 | | | 12A | 1.05±.05 |
| 37 | V-2 35 | 55.4-65.5 | 5-27-48 | | | | 3D | 1.005±.005 | 1.13 | 3B | .98 | 3A | .98±.05 |
| 63 | SC-4 | 54.7-58.3 | 7-21-49 | 19B | 1.039±.004 | 2.50 | | | | 19D | 1.01 | 19A | 1.01±.05 |
| 61 | SC-2 | 53.6-57.7 | 6- 2-49 | 15C | 1.027±.002 | 1.90 | 15D | 1.007±.005 | 1.18 | 15B | 1.00 | 15A | 1.00±.05 |
| 42 | V-2 40 | 49.0-59.8 | 7-26-48 | 5B | 1.027±.005 | 1.90 | 5D | 1.006±.005 | 1.16 | | | 5A | 1.05±.05 |
| 77 | SC-3 | 50.4-53.3 | 12- 6-49 | 25B | 1.004±.003 | 1.10 | | | | 25D | .98 | | |
| 69 | SC-5 | 45.0-47.8 | 9-20-49 | 20B | 1.000±.003 | 1.21 | | | | | | | |
| 74 | SC-7 | 41.4-44.9 | 12- 6-49 | 28B | less than 1.003 | | | | | | | 28A | 1.00±.03 |

(a) Mean deviations based on at least 4 runs are given. No estimate of the experimental errors is given.

(b) Mean deviations calculated on the basis of 2 to 5 runs are of the order of 0.001, but the estimated experimental error due to background noise and other factors is 0.005. The error due to the presence of $O_2$ in the amount contained by these samples is negligible.

(c) Paneth quoted figures to two places of decimals although the mean deviations calculated from individual experimental results are often below 0.005.

(d) Mean deviations calculated on the basis of 2 to 4 runs are of the order of 0.01, but the estimated experimental errors are 0.05.

was contamination by rocket-borne ground air. Later installations on Aerobees were specifically designed to prevent contamination. Measurements of contamination on Aerobee installations by means of a radioactive tracer technique[4] showed the contamination of the samples by rocket air to be less than 0.002%, and it is reasonable to suppose that Aerobee samples in general were uncontaminated.

The diffusive separation found in the B-6, B-8 and B-9 samples occurred in the 64 to 72 km range. According to recent measurements[5] this is a region of rapidly decreasing temperature. Accordingly, it would seem that the region would be characterized by considerable turbulence and mixing rather than by the quiescence necessary for the amount of diffusive separation measured. This may indicate that for sufficient lengths of time there is a considerable departure from the temperature pattern reported over White Sands, New Mexico, or that air is moved in without mixing from a different latitude or an altitude where the temperature increases with increasing height.

References:

(1) McQueen, J. H., Phys. Rev., 80, 100, (1950).

(2) Hagelbarger, Loh, Neill, Nichols, and Wenzel, Phys. Rev., 82, 107, (1951).

(3) For a discussion of optimum sampling intervals, see Progress Report for the Third Quarter, California Institute of Technology, Signal Corps Contract DA 36-039-sc-34, (Dec. 31, 1950).

(4) Final Progress Report, Engineering Research Institute, University of Michigan, Signal Corps Contract No. W-36-039 sc-32307, (Oct. 31, 1950).

(5) Best, Havens, and LaGow, Phys. Rev., 71, 915, (1947), also Havens, Koll, and LaGow, Pressures and Temperatures in the Earth's Upper Atmosphere, Naval Research Laboratory Report, (March 1950).

## 5.3 100 Kilometer Samples

In Report No. 2 of this series the feasibility of collecting, with present techniques, air samples at an altitude of 100 km was pointed out. This altitude was rather arbitrarily chosen as a target altitude, and the objective of collecting higher samples was set before the measurement of separation at 70 km was made. Work was started on the problem of preparing bottles for 100 km sampling, but upon receipt of the results of SC-17 was shifted to the preparation of SC-21 to sample at 70 km for confirmation. Work was resumed on the problem and a firing of an RTV-A-1a high performance Aerobee was tentatively set for late in the year. It became known soon after that space was available for sampling on V-2 59, and it was decided to instrument this rocket instead since it would provide an excellent opportunity to sample throughout the range 50 to 100 km thus making possible in one flight confirmation of the results at 70 km and the collecting of samples at 100 km.

The instrumentation of V-2 59 posed several problems. Two of these, preparation of bottles with higher vacuums and suitable monitoring gages, and the procuring of high altitude parachutes, had been worked on in connection with the proposed high altitude Aerobee. Two new problems were the mechanical design of the missile instrumentation and the preparation of as many as nine bottles plus spares for a single flight.

### 5.31 100 Kilometer Bottles and Gages

In order to keep contamination to 1% or less, the high altitude bottles should be evacuated to 0.01 $\mu$Hg or better. This had been accomplished many times in previous bottles, but the Pirani gages used to monitor pressure after the bottles were sealed off from the evacuation system were sensitive to only about 1.0 $\mu$Hg. Several ideas involving more sensitive gages or techniques of concentrating the enclosed gas near a gage were considered and worked on with limited success. The Philips gage had several desirable features such as good sensitivity in the desired range and rugged simplicity. Its chief drawbacks were the weight and porosity of the magnet structure. It was thought that the magnet would have to be very rigidly mounted to prevent damage on impact and that a study of the adsorption of sample by the magnet at ordinary temperatures would be necessary. Both of these problems were obviated by the following design: the Philips gage is constructed as an integral part of the forward end of the intake tube. The anode loop is suspended from an insulated feed-through. Steel pole pieces are silver-soldered into the brass end fitting and, in monitoring, an external magnet is slipped in place over the pole pieces. When the opener is operated the piece containing the loop and pole pieces is ejected so that the sealed-off bottle does not contain the gage. Figs. 6 and 7 show the construction and assembly of the device.

### 5.32 Parachutes

No solution to the parachute problem for the RTV-A-1a had been reached. A double chute system in which the final chute is not opened until below 100,000 feet was considered briefly but was thought to be complicated and unproven. No design of an ejector suitable for Aerobees was available. A second method using parachutes of silicone rubber coated Fiberglas and the

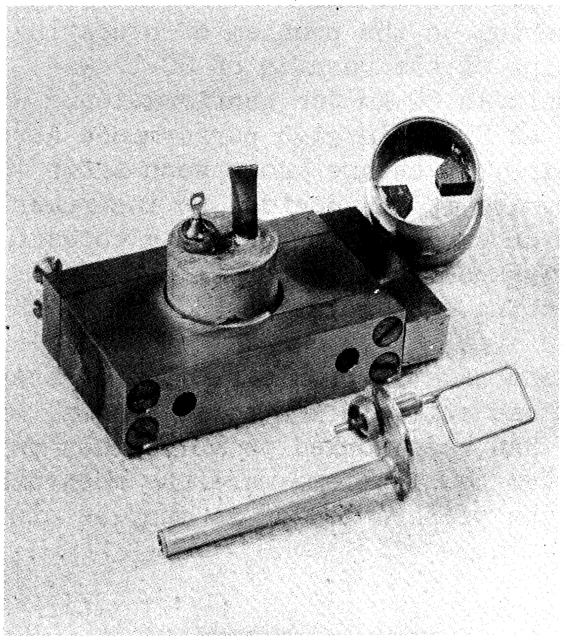


Fig. 6. Details of Philips Gage.

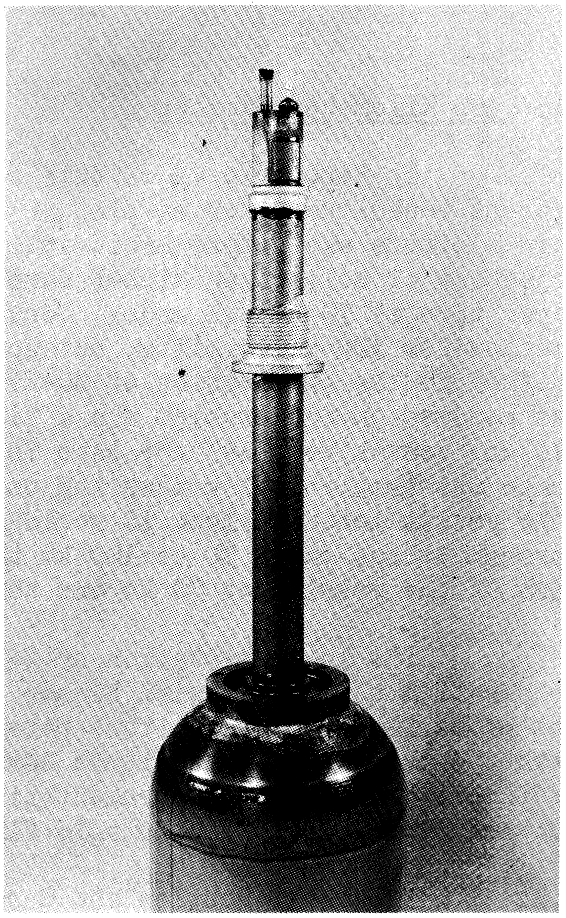


Fig. 7. Philips Gage on Bottle.

Signal Corps ejector appeared feasible, but the added weight of the new parachutes would seriously cut down the peak altitude. When it was decided to fly V-2 59, extra weight no longer presented a problem, and parachutes were ordered from Aerojet Engineering Corporation. Two chutes will have canopies of 1750-pound test Fiberglas with nylon shrouds, and one will have a canopy of 1100-pound test Fiberglas with nylon shrouds. The general construction will be the same as the eight-foot reinforced nylon parachutes used successfully on previous Michigan Aerobees. The lighter parachute will be used on the lower altitude bottles so that its performance may be compared with the heavier ones. The loads dropped will be about the same and from the same altitude for all three parachutes, but less value is attached to the lower bottles.

5.33 <u>Design of the Instrumentation</u>

Sample bottles flown on previous V-2's were usually assigned a disadvantageous position on the rocket either because the contamination problem was not thought to be serious or because, on a particular rocket, other experiments were thought to be more important. On V-2 59 the entire warhead space will be devoted to bottles so that the feature of having the intake tubes forward of everything else can be used. A standard warhead will be cut off near the base, filled with lead, and covered with a steel plate. On this plate will be bolted three bottle instrumentations similar to that of SC-21. They will be 15 inches longer to accommodate the new parachutes and will be surmounted by a single Jato-ejected cone instead of one for each. Vertical separators will be placed between the individual instrumentations to prevent fouling during parachute ejection. The 100 kilometer sample will be collected in a single bottle of 2000 cubic inch capacity instead of three 500 cubic inch bottles to eliminate the rather involved process of combining the contents of three bottles without spoiling good samples with contaminated ones. Fig. 8 shows the instrument configuration of the rocket.

### 5.34 New Evacuation System

In order to make possible the preparation of the many bottles necessary for V-2 59 and to accommodate the large one for 100 km, a second evacuation system with a large oven was built. It is shown manifolded to the original system and the helium leak detector in Fig. 9.

### 5.4 Related Activities

Some air samples containing 10 ppm of helium instead of 5 ppm were prepared and analyzed to calibrate the charcoal analyzer. The analyses showed increased helium only of the right order of magnitude. The error was thought to lie in the calibration of the final Pirani for increased helium and in the preparation of the blends. This experiment has been shelved since Professor Paneth is now in a position to perform all necessary analyses quickly. Work was also started on modifying the analyzer to handle very small samples, but this project too was shelved. However, a new, small volume oxygen cell was installed and calibrated.

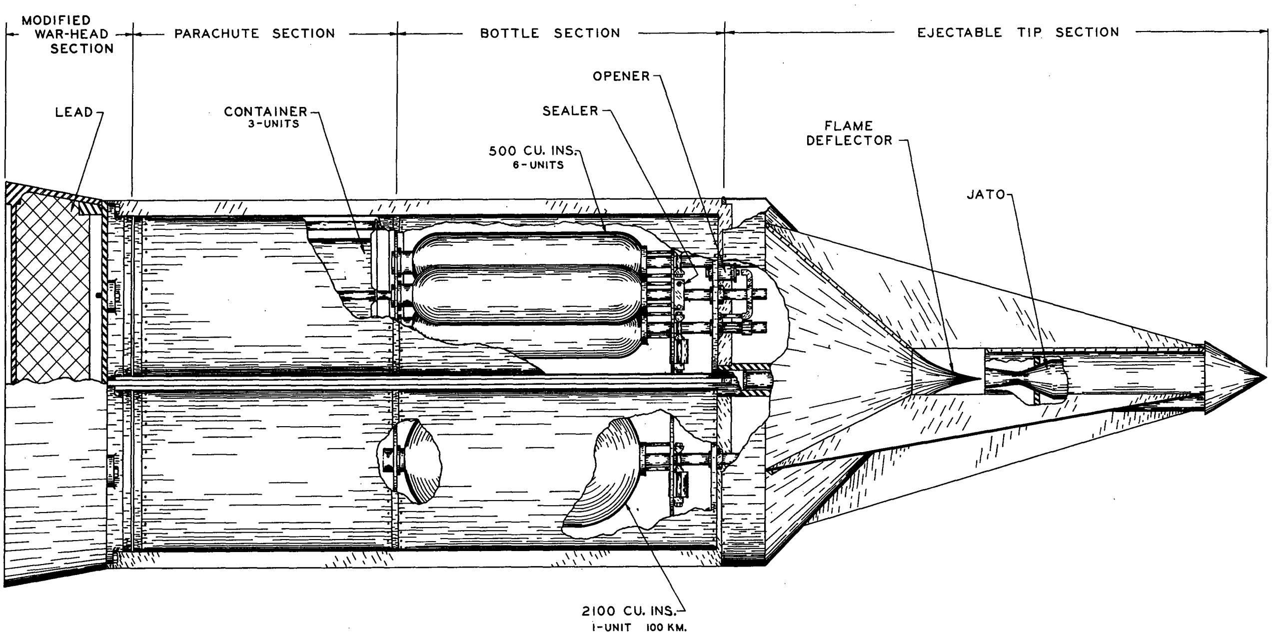



Fig. 8. Bottle Instrumentation, V-2 59.

The toepler pump used to transfer samples from the steel bottles to glass vials was modified for automatic operation. One feature of the modification is to open the valve magnetically to permit very small amounts of gas to pass the pump instead of being compressed into small bubbles and trapped in the mercury. Further development of the vialing system was also shelved in view of the availability of Professor Paneth's new apparatus.

The pyrotechnic opener used successfully on SC-21 was re-designed for lighter weight and to incorporate a new "O" ring arrangement which will be more effective in stopping leakage. The new opener, shown in Fig. 10, also has a detent ball to prevent the piston from moving forward as the pressure falls during the rocket ascent.

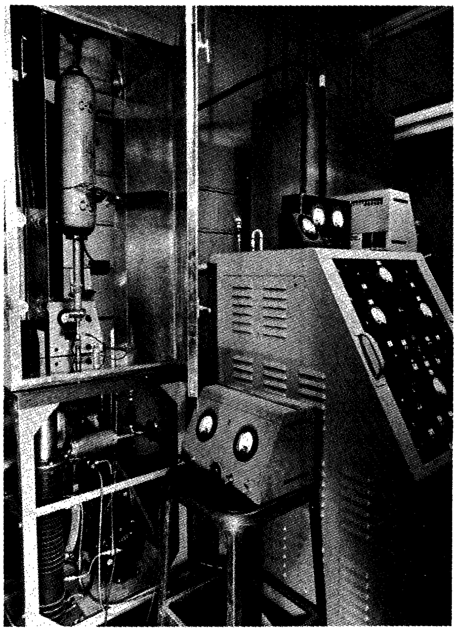


Fig. 9. New Evacuation System.

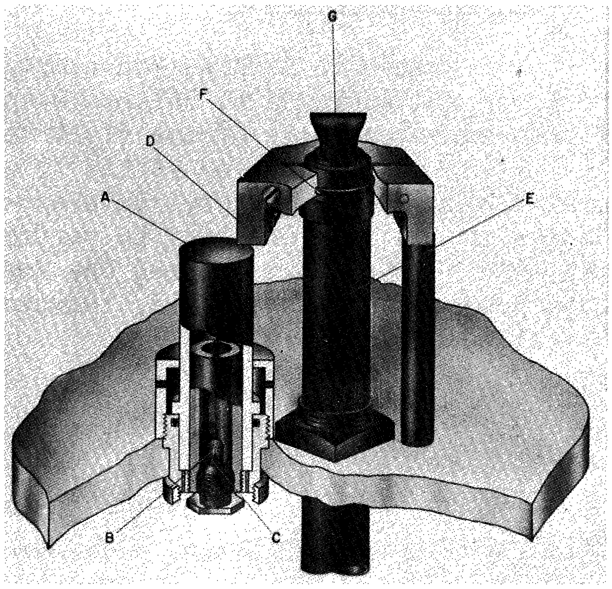



Fig. 10a. Opener Schematic.

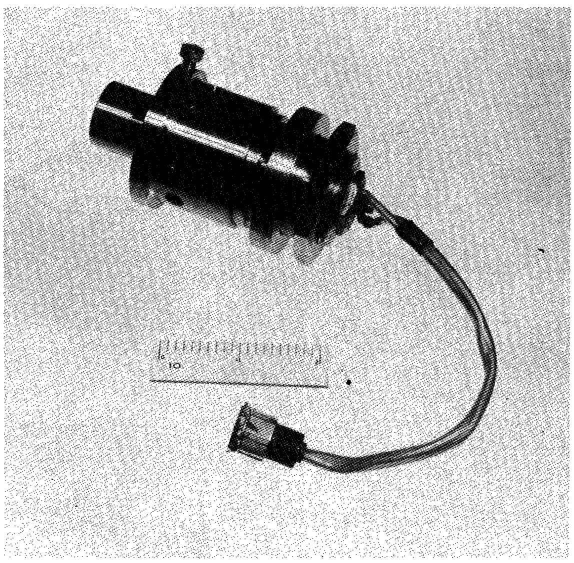


Fig. 10b. New Opener Assembled.

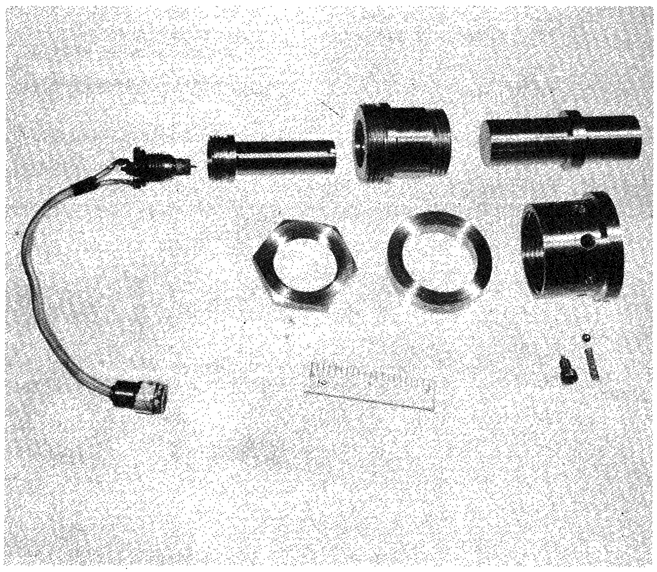


Fig. 10c. New Opener Exploded.

## 6. THE SHOCK WAVE EXPERIMENT FOR TEMPERATURE[1]

Development of the shock wave probe method for ambient temperature was started early in the previous contract. A comprehensive error analysis and three experimental attempts on V-2's 33, 50 and 56 were rewarded with sufficient success to justify continuing the development of the experiment. Certain drawbacks, such as complexity and the necessity for a stable missile, were recognized but were thought to be not worse than in other methods and to be more than compensated for by the fact that in the probe method each point is a measurement of temperature independent of other points. Adaptation of the method to the Aerobee was carried out and had been nearly completed by the beginning of the subject contract.

### 6.1 Probe Aerobees SC-15 and SC-19

The design of the probe experiment for Aerobees has been completely described in previous reports. The main features were a reversible screw drive for moving the cone to scan the shock wave across the probes, a 10-probe array to overdetermine the shock wave and measure shock wave curvature, and a Jato-ejected false cone to protect the probes and cone during the early part of the flight. An important unit of the development was a 13-channel magnetic recorder for data gathering. Fig. 11 shows the over-all assembly and Figs. 12 through 17 the important components.

SC-15 was fired on December 11, 1950, and SC-19 on June 7, 1951. The preflight operations were completed without undue difficulty. Both missiles failed shortly after take-off although in each case booster operation appeared normal. In SC-15 the acid-aniline flame appeared to come from the side of the tail section, while in SC-19 it appeared to come from between the motor and tail section and was intermittent. Both missiles crashed soon after take-off.

The cause of the failures is not known. A study of the wreckage and of films gave no evidence of any failure on the part of the instrumentation. No useful data were obtained from either flight.

### 6.2 Probe Experiment on V-2 60

Following the flight of SC-19 it became known that space was available on V-2 60 to be flown by the Ordnance Corps for training purposes. Because of the better stability of V-2's compared to Aerobees and because of the possibility of measuring V-2 angle of attack, it was decided to adapt the instrumentation design of SC-15 and SC-19 to the V-2. The modifications have been described previously. The over-all appearance of the apparatus is shown in Fig. 18. The only additions to the Aerobee installations were an aspect camera installed by APL in the mid-section and the use of the NRL telemeter in addition to the Michigan magnetic recorder. Amplifiers, similar to those on V-2 56, which coupled the probe signals to the telemeter were constructed.

Two trajectory conditions are important for favorable operation of the probe experiment: (a) the velocity should be within certain limits for maximum angle sensitivity to changes in temperature and (b) the angle of attack should be small for good accuracy. Fig. 19 illustrates good conditions

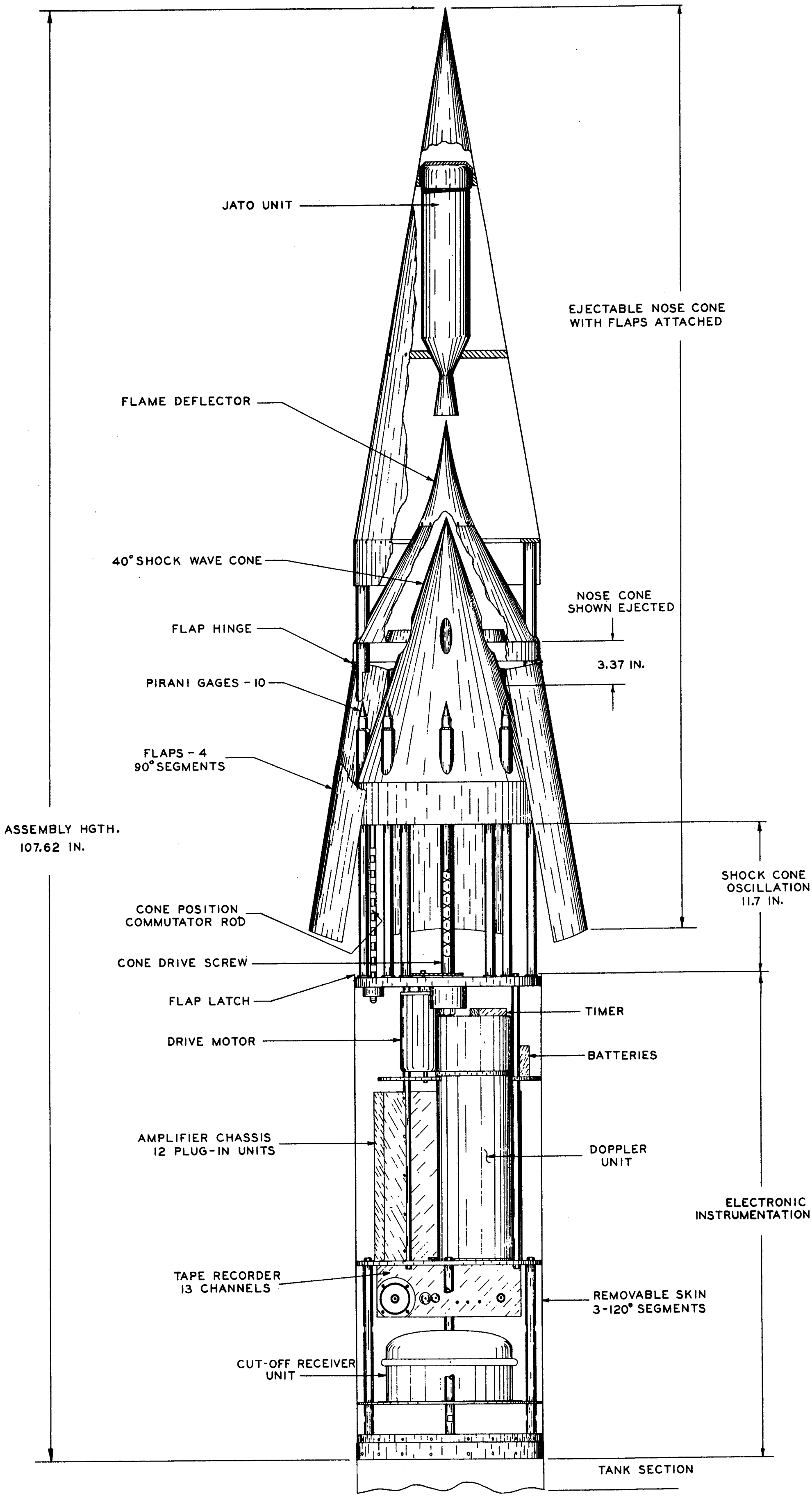



Fig. 11. Probe Aerobee Schematic.

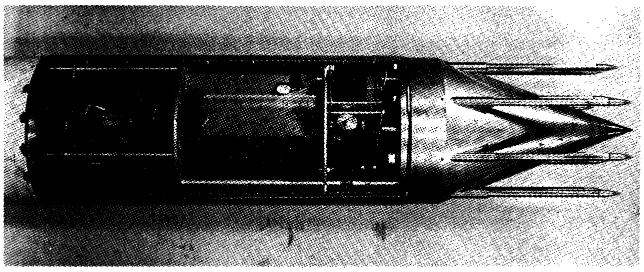


Fig. 12. Probe Aerobee Assembly.

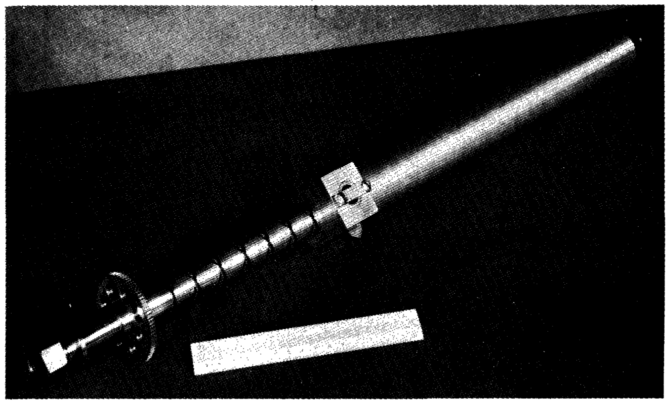


Fig. 13. Reversible Screw Drive.

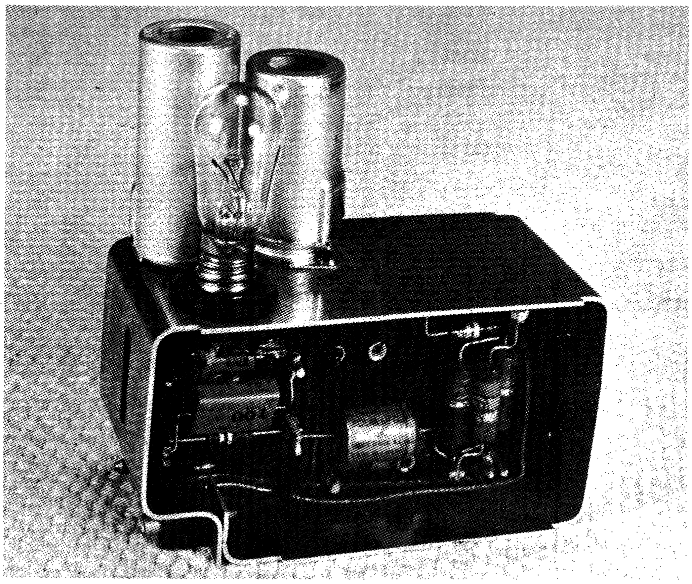


Fig. 14. Bias Oscillator.

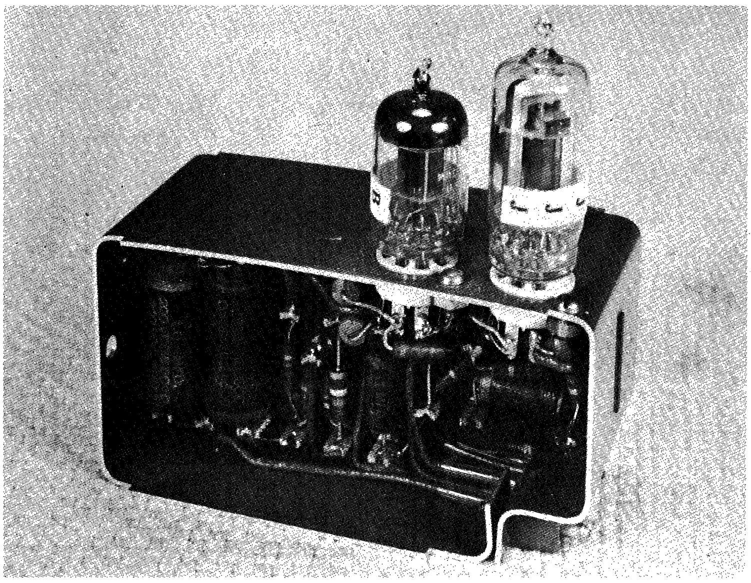


Fig. 15. Probe Pirani Amplifier.

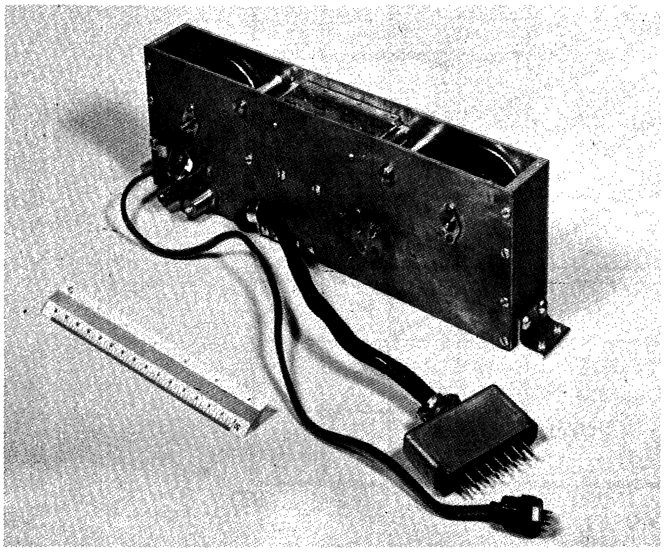


Fig. 16. Magnetic Tape Recorder.

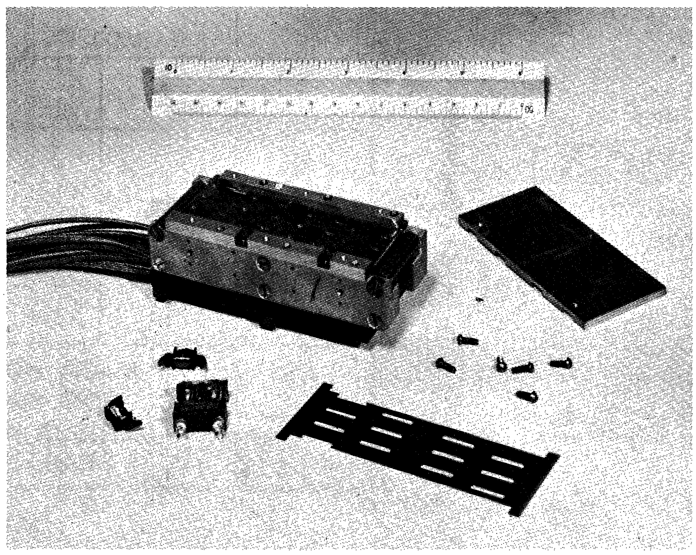


Fig. 17. 13-Channel Head Assembly.

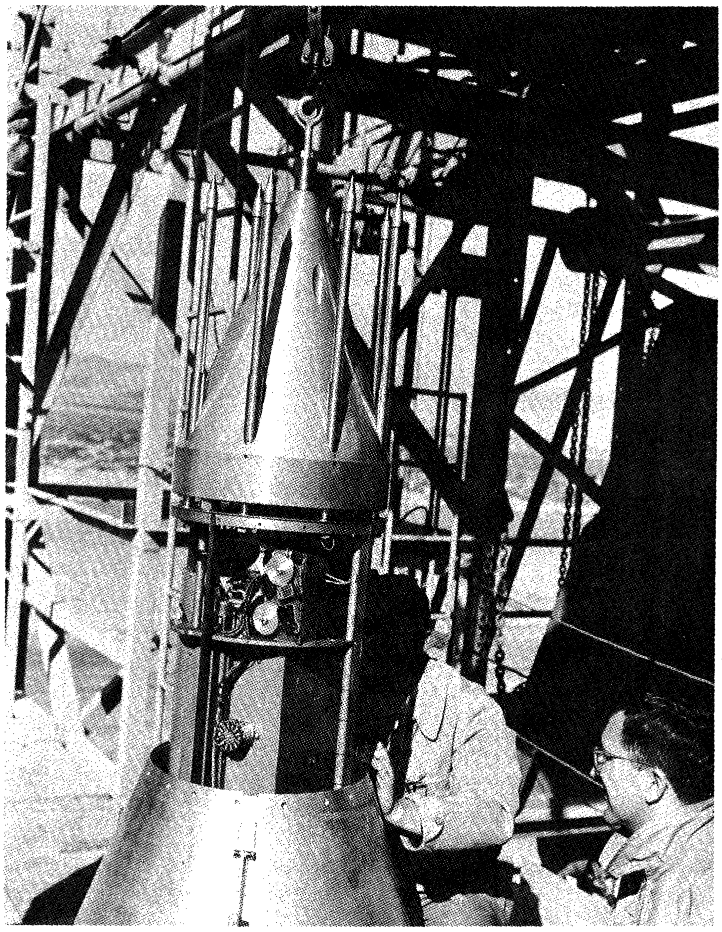


Fig. 18a. Probes, V-2 60.

Fig. 18b. Front End, V-2 60.

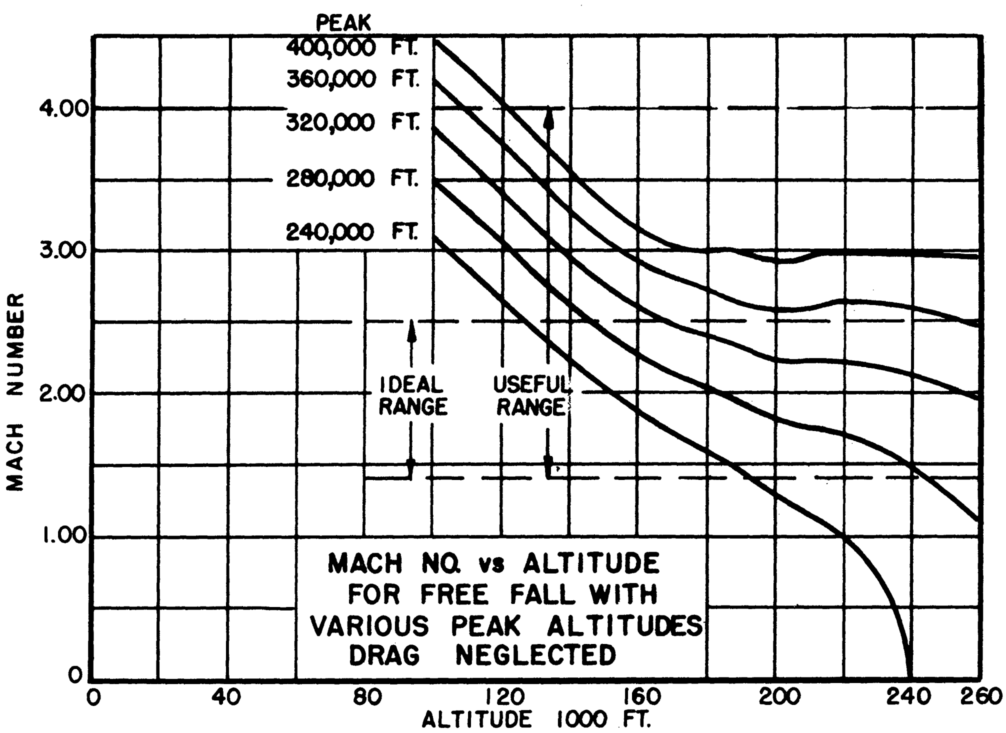



Fig. 19.

for the first criterion. For V-2 60 a peak altitude of 400,000 feet was selected. Since the peak altitude was predicted to be about 450,000 feet on the basis of a 10,500 pound missile dry weight and exhaustion of one propellant, it was decided to cut-off early by command. The cut-off was to be initiated when the reflection radar plot of velocity vs. altitude crossed a precalculated limit curve. See Fig. 20. Cut-off was to be effected in two stages: cut back to 8 ton stage for 2 seconds, then cut-off. There is some evidence to indicate that this procedure results in improved post-burning stability.

The missile was erected on October 22 and was to have been fired on October 25. Extra time for gantry checks was allowed because of the difficulty on previous Michigan V-2's with interference between Dovap and NRL telemeter. In this case, interference with telemeter by Dovap was again experienced but was removed by filtering the telemeter power supply leads. The difficulty was not cleared until too late on the firing day, however, so that the launching was postponed. The weather caused further postponements until October 29 on which date the firing took place at 1404 hours. The only serious preflight difficulty occurred at X-3 minutes when the magnetic tape recorder monitor indicated that the recorder had stopped running. However, inasmuch as telemeter was operating well, and because the missile was fueled and less than an hour of suitable light conditions for the aspect camera remained, it was decided to go ahead. It was subsequently learned that the recorder tape had broken for an unknown reason. The recorder had been operated many times previously without breaking the tape although some significance was attached to the fact that the only other instance of breakage occurred on the one previous occasion that the pressure tight recorder case was pressurized.

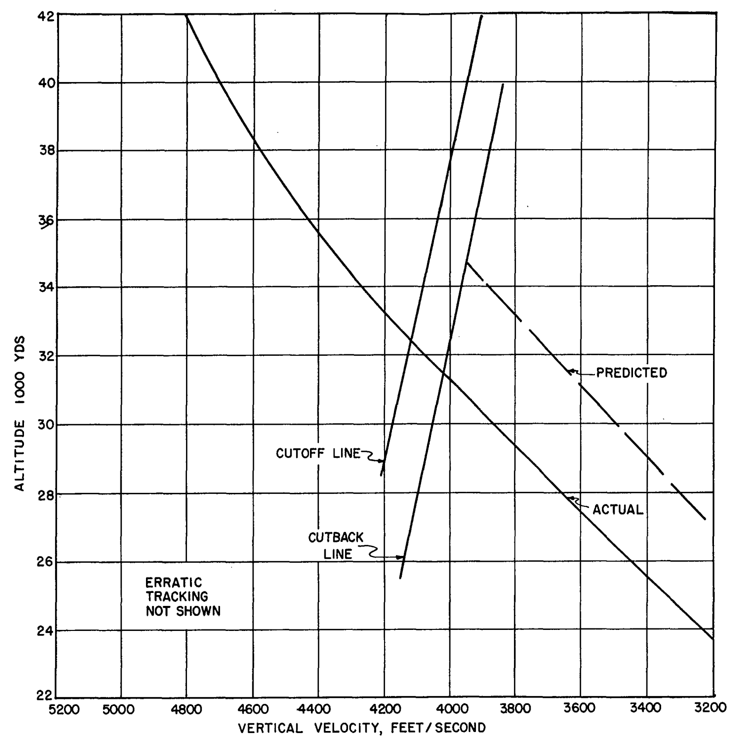



Fig. 20. Velocity vs. Altitude Limit Curve, V-2 60.

The following information is extracted from the Preliminary Ballistic Instrumentation Report issued by BRL on 5 November 1951:

| | |
|---|---|
| Zero time | $14^h\ 04^m\ 1.97^s$, MST (Blockhouse timing) |
| Nose cone ejection | about 67.1 seconds (Telescopes) |
| Missile burnout | about 70.5 seconds (Telescopes) |
| Maximum vertical velocity | about 4600 feet per second (Impact Computer) |
| Position at burnout (from Army Blockhouse) | Altitude about 131,700 feet<br>North about 15,000 feet<br>East about 1,400 feet (Askanias) |
| Time to peak | about 220.0 seconds (Radar) |
| Maximum altitude | about 87.6 miles (Radar) (462,000 feet) |
| Time to warhead detonation | about 382.3 seconds (Telescopes) |
| Position at 382.7 seconds (from Army Blockhouse) | Altitude about 57,200 feet<br>North about 213,500 feet<br>East about 3,000 feet (Askanias) |

(See Fig. 21 for Askania trajectory.)

Visual observations, which were confirmed by examination of the aspect camera pictures, indicated that the missile was very stable and had little roll. At about 23 seconds some portions of fin coverings were observed to fall off.

The planned cut-back was not carried out because the reflection radar plot was erratic so that the time of crossing the limit line was uncertain. Burning continued until exhaustion of one propellant, resulting in the higher than desired altitude. Warhead detonation was planned for 100,000 feet in the hope of getting probe signals on the down leg. It actually occurred at 60,000 feet. This resulted in very great damage on impact although the recorder, which was to have been the prime item of recovery, was little damaged. See Figs. 22 and 23.

The auxiliary instrumentation operated fairly well. Dovap operated and gave good signals until 290 seconds. The APL aspect camera operated until the film was exhausted at 291 seconds. Good telemeter records were obtained from take-off to 163 seconds and from 225 seconds to warhead blow-off.

Practically no data, however, were received from the primary experiment. For some unknown reason the scanning probe cone failed to operate until somewhere in the vicinity of peak. The cone was not moving when telemeter went out at 163 seconds but was operating when telemeter resumed at 225 seconds. By this time all but one of the probe Pirani gages had failed so that the only data points are from one probe between 222,000 feet and 136,000 feet on the downward leg. Laboratory experience showed that most of the Pirani gages could be expected to burn out above 260,000 feet. The reasons for the early failures of four of the gages are not known although two of these occurred within a half second of Jato operation. The burnout times were as follows:

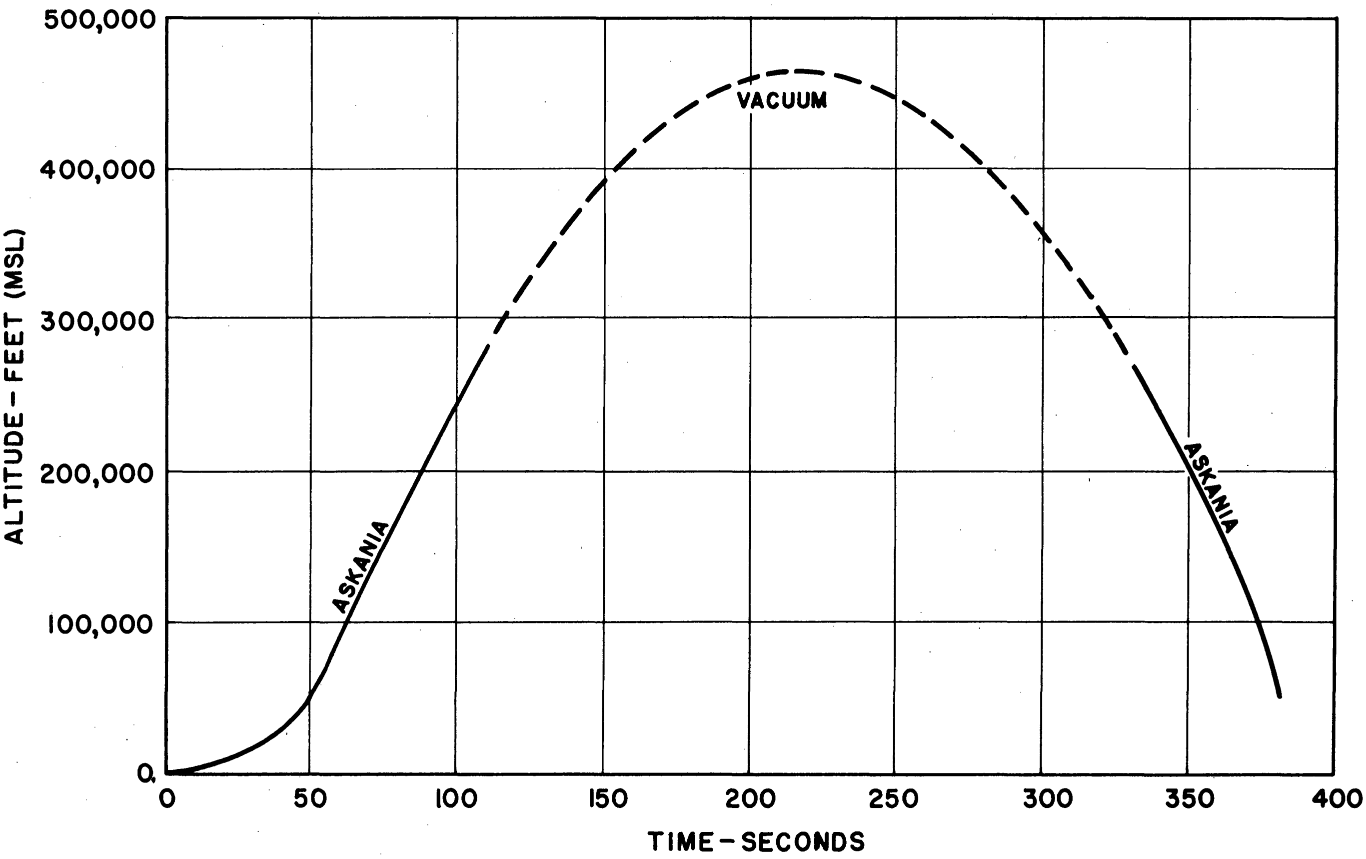
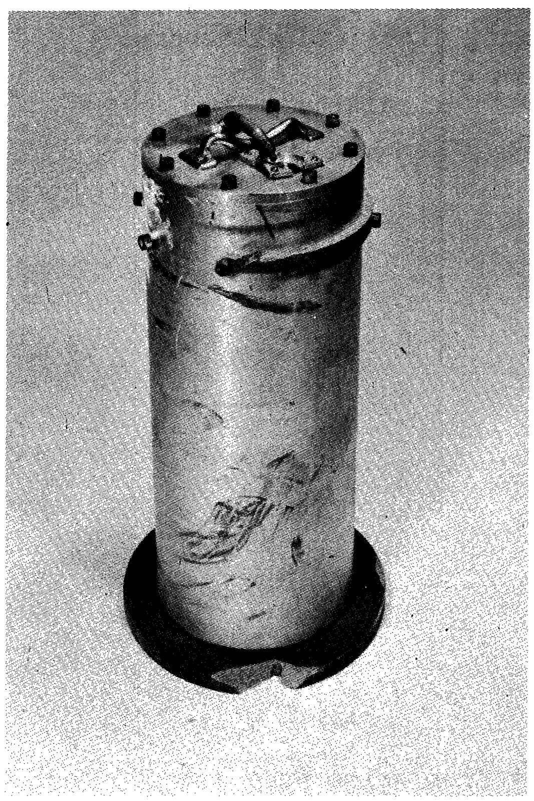



Fig. 21. Altitude vs. Time, V-2 60.



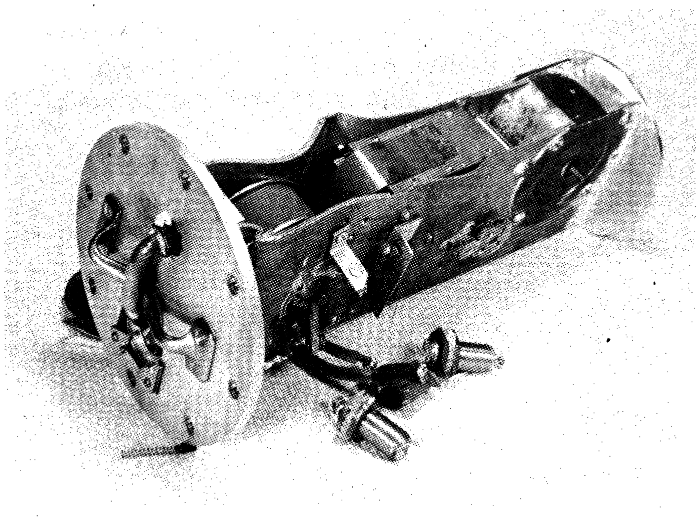


Fig. 23. Recorder, V-2 60.

Fig. 22. Recorder Case, V-2 60.

| Probe | Time (sec.) | Altitude (ft.) Askania |
|---|---|---|
| 1 | 120.4 | 317,000 |
| 2 | 67.0---(Jato ejection 67.0) | 112,000 |
| 3 | 67.5 | 114,000 |
| 4 | 116.5 | 304,000 |
| 5 | 115.6 | 302,000 |
| 6 | 73.8 | 143,000 |
| 7 | unknown | |
| 8 | 73.6 | 142,000 |
| 9 | 104.6 | 264,000 |
| 10 | at warhead separation | 60,000 (down leg) |

An exhaustive examination of the evidence failed to reveal the cause of the failure of the cone to run. Several possibilities such as timer failure, starting relay failure, jamming of the cone drive, and high drag were considered. However, there was not enough information to place the blame on any one of these possibilities. It should be noted that the timer-controlled nose cone ejection occurred correctly 3 seconds before the moving cone should have started. Also, when the moving cone did operate, it operated steadily at the correct speed and did not stop until the drag force became large.

In all, 10 signals attributable to the shock wave were received from probe No. 10. The telemeter record with these signals is shown in Fig. 24. The signals occurred at the following times and altitudes:

| Signal | Probe Direction | Time | Altitude-ft. Askania |
|---|---|---|---|
| 1 | ↓ | 343.9 | 222,000 |
| 2 | ↑ | 345.1 | |
| 3 | ↓ | 345.7 | |
| 4 | ↑ | 347.0 | |
| 5 | ↑ | 349.4 | |
| 6 | ↓ | 354.1 | 182,000 |
| 7 | ↓ | 358.3 | |
| 8 | ↑ | 361.9 | |
| 9 | ↓ | 362.6 | |
| 10 | ↑ | 364.1 | |
| 11 | ↓ | 364.8 | 136,000 |

The signals were indistinguishable from noise from 136,000 feet to 60,000 feet.

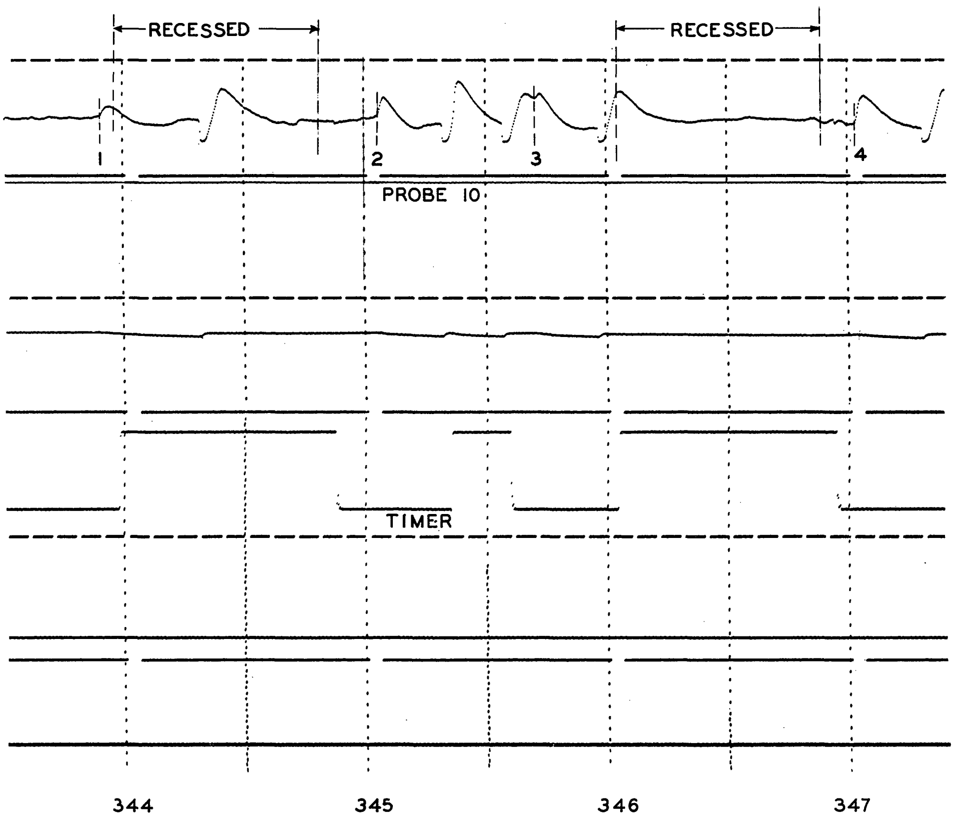



Fig. 24. Telemeter Record Showing Probe Signals, V-2 60.

These points have been reduced to shock angle, Mach number, and temperature assuming zero angle of attack. The results, however, are useless because the corrections for pitch, yaw and roll, which have yet to be applied are usually large. When these data are received the temperatures will be recalculated. The final results will probably also have large errors, because, since the aspect camera film was exhausted at 291 seconds, the only available pitch, yaw and roll data are from ground tracking, and these are known to be spotty for this missile. Velocities, also, are available only from tracking as doppler signals ceased at 290 seconds.

As noted above, the probe experiment has the large advantage over other current methods for ambient temperature that each point is instantaneous and independent of others. There are no averaging processes in the method. The results from the flight of V-2 56 indicated that the method was workable and reliable. The chief drawbacks are dependence on angle of attack and complexity. The latter point was emphasized by the loss on Aerobees SC-15 and SC-19 and V-2 60 of very expensive instrumentation from which no results were obtained. In looking about for a technique to circumvent these difficulties, the falling sphere method described in the next section was conceived. Since it showed promise of measuring temperatures with useful precision to greater altitudes than the probe method and with simpler apparatus, the decision was made to suspend temporarily work on the latter method. After the sphere method has been adequately tried, a re-evaluation of the two experiments will be made.

References:

(1) Bartman, F. L., Liu, V. C., and Schaefer, E. J., An Aerodynamic Method of Measuring the Ambient Temperature of Air at High Altitudes. Eng. Res. Inst. Technical Report, July 1950.

## 7. FALLING SPHERE EXPERIMENT FOR AMBIENT DENSITY AND TEMPERATURE

The method of measuring ambient density and temperature by measuring the acceleration trajectory of a freely falling sphere was proposed late in the previous contract although all of the development work has been performed on the subject contract. The method was suggested as a means of circumventing the experimental difficulties of the probe method. It showed promise of being relatively simple to construct and operate and, since the measurements are made after the apparatus has left the rocket, to be independent of rocket performance factors except altitude. The first phase, an error analysis and a quantitive estimate of the errors based on existing data and techniques;[1,2] indicated that the method could measure density and temperature to above 300,000 feet with relatively good precision. Although a differentiation of velocity data to get acceleration is required, the altitude interval over which a slope may be taken with good precision was found to be much less than 10,000 feet. The effect of winds and the possibility of measuring them was investigated.[3] Following the theoretical investigation, the engineering development was started. It proceeded well enough so that a flight in December 1951 appeared feasible, but this schedule has not been possible and the first flight is scheduled for early in 1952.

### 7.1 The Method

A flexible, inelastic, fabric sphere 4.5 feet in diameter is packed in a deflated condition in the forward end on an Aerobee. The sphere contains an inner wooden cylinder supported on a diameter by two access doors. The cylinder contains a miniaturized doppler unit and its antennas. The sphere, which contains sufficient air under pressure to inflate it to 2.5 psia at altitude, is restrained in the rocket by a split cylindrical section. One half-cylinder is bolted to the tank section, the other is removable. The two halves are held together by a winding of Fiberglas cord. At peak, the cord is severed by detonating a lengthwise piece of Primacord thus permitting the sphere to be ejected. It falls freely and is tracked by the Dovap system, the sphere unit of which has been operating since take-off. Fig. 25 is a schematic of the apparatus.

### 7.2 Theory and Estimated Errors

The equation of motion of the falling sphere, solved for density, is:

$$\rho = \frac{2}{AV^2C_D} M\left(g - \frac{dV}{dt}\right) \qquad (1)$$

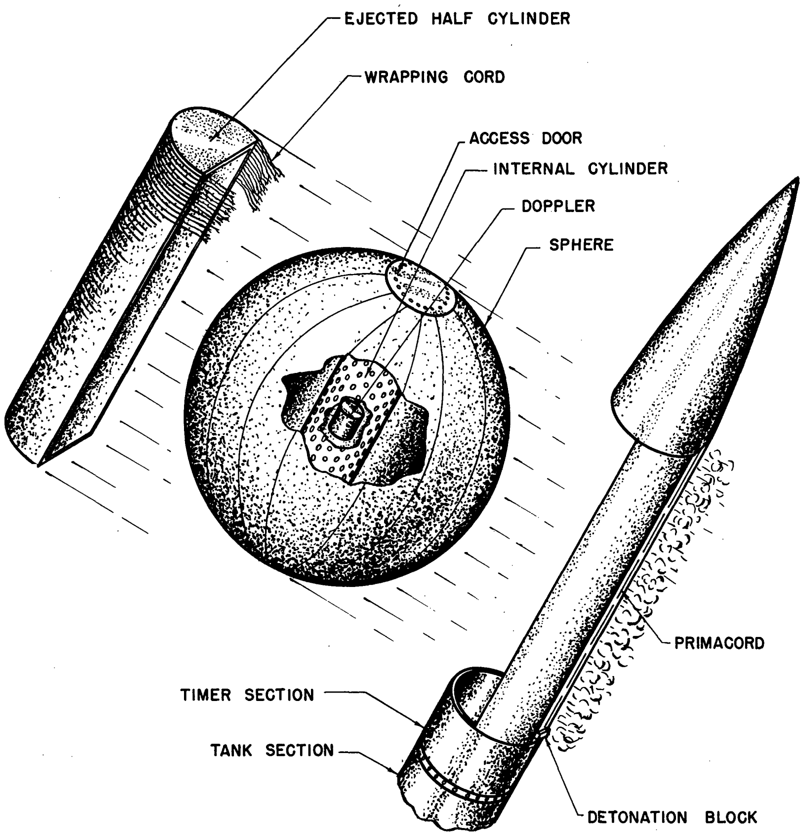



Fig. 25. Sphere Ejection Schematic.

where

$\rho$ = density

M = mass of sphere

g = acc. of gravity

$\frac{dV}{dt}$ = acc. of sphere

$C_D$ = coef. of drag

A = area of sphere

V = velocity of sphere

By integrating the hydrostatic equation and substituting the equation of state for a gas, we get:

$$T_h = \frac{1}{\rho_h R} \int_h^{h_1} \rho g \, dh + \frac{p_1}{\rho_h R} \qquad (2)$$

where

T = abs. temp.

h = altitude

R = gas constant

Combining (1) and (2) and applying the rules for propagating errors, we have:

$$\left(\frac{\sigma_{T_h}}{T_h}\right) = \sqrt{\frac{\sigma_{I_h}^2 + \sigma_{p_1}^2}{p_h^2} + \left(\frac{\sigma_M}{M}\right)^2 + \frac{\sigma_g^2 + \sigma_a^2}{(g - a)^2} + \left(\frac{\sigma_A}{A}\right)^2 + 4\left(\frac{\sigma_V}{V}\right)^2 + \left(\frac{\sigma_{C_D}}{C_D}\right)^2} \quad (3)$$

The terms in this equation with their estimated maximum probable errors are as follows:

| Term | Max. Prob. Error |
|---|---|
| $I_h = \int_h^{h_1} \rho g \, dh$ | $<1\%$ |
| $p_1$ = pressure at $h_1$ | $<1\%$ (provided the first calculated temperature point at h is at a distance of at least 50,000 ft. below the first data point at $h_1$) |
| M = mass of sphere | negligible |
| g = acc. of gravity | negligible |
| $a = \frac{dV}{dt}$ of sphere | 3% (see Sec. 7.21) |
| A = cross-sectional area of sphere | negligible |
| V = sphere velocity | negligible |
| $C_D$ = sphere drag coeff. | 5% (see Sec. 7.22) |

From (3) it can be seen that it is necessary to know the pressure $p_1$ at the reference altitude $h_1$. However, it can be shown that the error in T due to an error in $p_1$ diminishes rapidly as $h_1 - h$ increases and that a useful curve of T is obtained even if it is assumed that $p_1 = 0$.

Since the principal errors in T are contributed by errors in the doppler measurement of acceleration and the errors in $C_D$, an investigation of these quantities was made. See below and ref. (2).

An investigation(3) was made of the effect of winds on the experiment. It was shown that, in general, the ambient density and the velocity vector of the wind cannot be determined simultaneously. However, an investigation of special cases showed that:

a) If the wind direction is given, density and wind velocity may be determined.

b) If the vertical velocity gradient of the wind is small compared to that of the sphere, density and the wind vector may be determined.

c) If the velocity of the wind is small compared to that of the sphere, density may be determined with little error by neglecting wind.

d) If two spheres having different M/A ratios are dropped and it is assumed that the wind velocity is constant during the time interval between the passage of the two spheres through a given altitude, density and the complete wind vector may be determined.

Other investigations included:

a) The prediction of trajectories under various assumptions. These curves are necessary for determining the range of parameters for which $C_D$ must be known for calculating doppler errors, for calculating heating, etc. Two curves of interest for a 4.5-foot, 50-pound sphere are shown in Fig. 26 and 27. The first shows

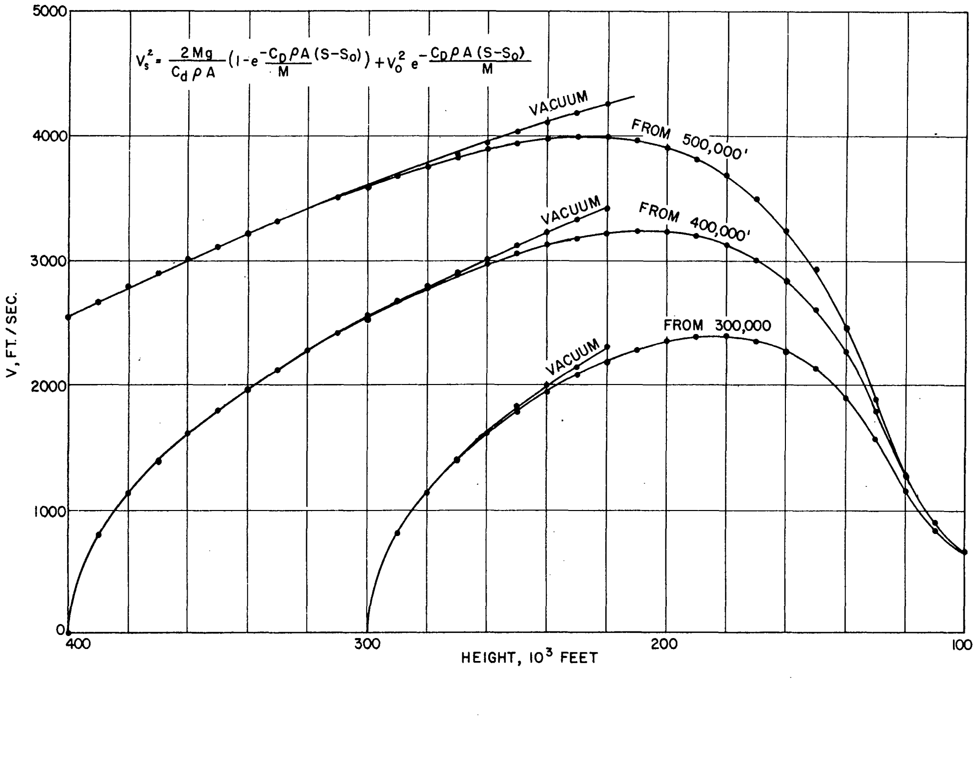



Fig. 26. Velocity vs. Altitude for 4.5-ft., 50-lb. Sphere.

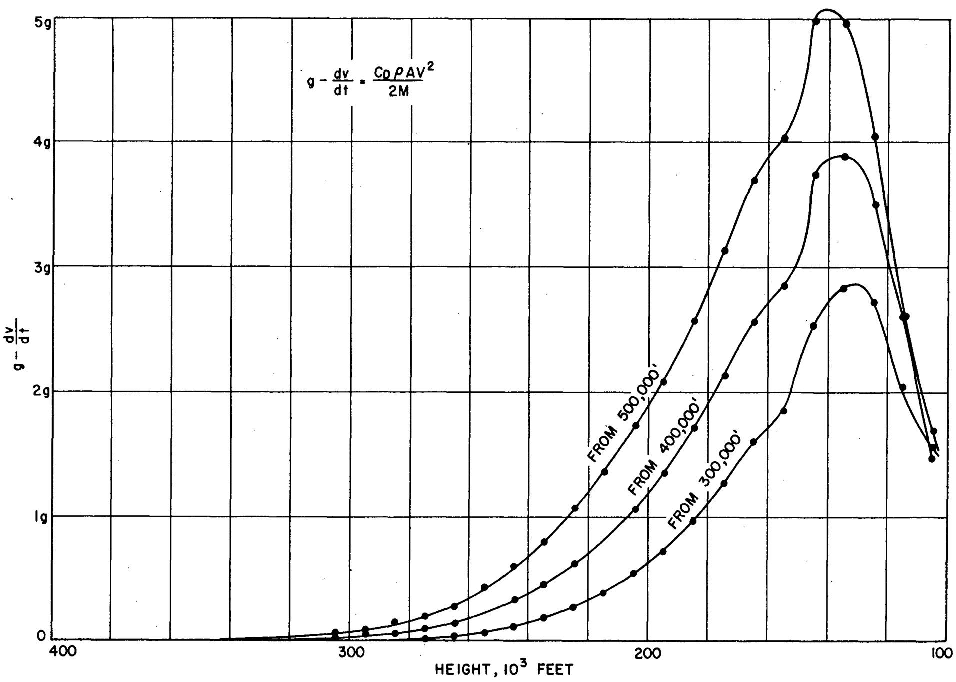



Fig. 27. $g - \frac{dV}{dt}$ for 4.5-ft., 50-lb. Sphere.

velocity trajectories for different starting altitudes. In this curve $(S-S_o)$ is a constant incremental distance chosen as 10,000 feet for calculating the curve. The second is a plot of the differential acceleration $g - \frac{dV}{dt}$ for different starting altitudes.

b) Heating of the sphere during fall.(4) A graphical solution to a semi-empirical equation for total heat flow was obtained. The result is plotted in Fig. 28.

c) The possibility of using a "constant drag" trajectory for density measurements. It was shown that in the lower portion of the trajectory where the drag force is approximately equal to the weight, a first approximation to the density may be calculated from velocity alone.

d) Deformation of the sphere under loading. It was shown that to maintain sphericity, the internal pressure should be equal to or larger than the net force transmitted by the end plate to the fabric.

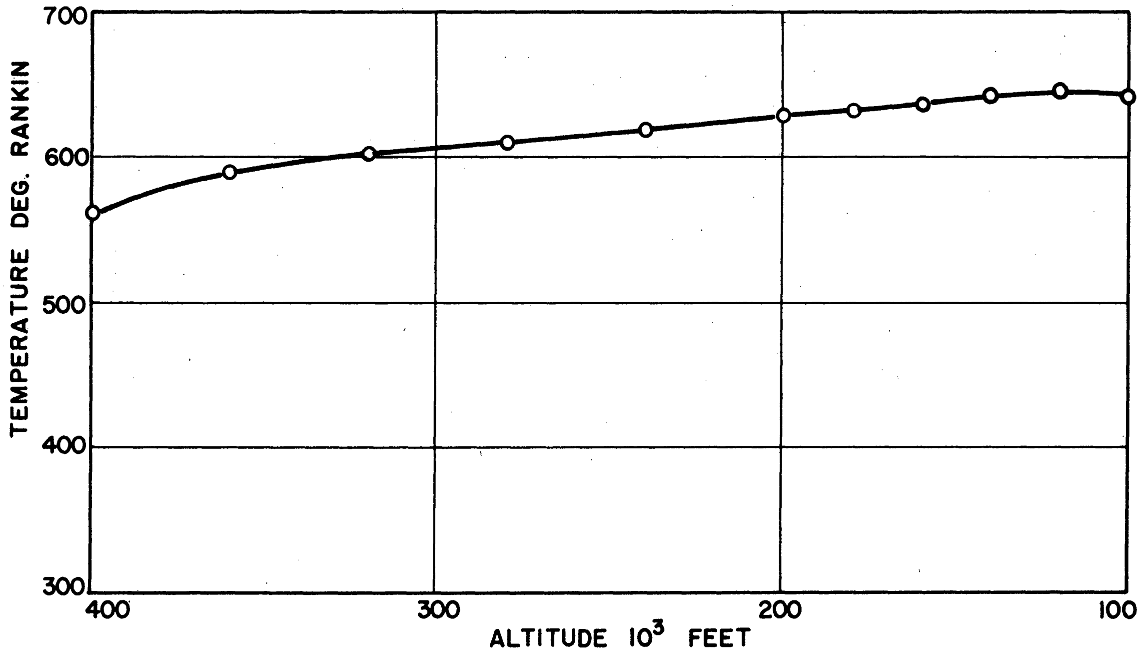



Fig. 28. Sphere Skin Temperature.

## 7.21 Error Due to Doppler Errors

On the basis of conversations with personnel at BRL and a report(5) issued by them a re-evaluation of the error in the measurement of sphere acceleration was made. The fundamental assumptions are:

a) That the spin rate will be low enough to be analyzed out of the doppler record. No estimate of spin rate has been made. However, it appears reasonable to assume that the sphere spin will be of the same order as missile spin, and missile spin rates can be handled in the doppler reduction.

b) That doppler cycles can be counted to within 0.1 cycle. This is based on experience in reducing typical good doppler records on missiles at WSPG.

Based on these assumptions the curves of Fig. 29 for a 4.5-foot, 50-pound sphere dropping from 400,000 feet were plotted. They show (against altitude) the altitude interval over which velocity must be differentiated to give a 1% error in differential acceleration g - dV/dt, and the error in g - dV/dt for a constant altitude interval of 10,000 feet.

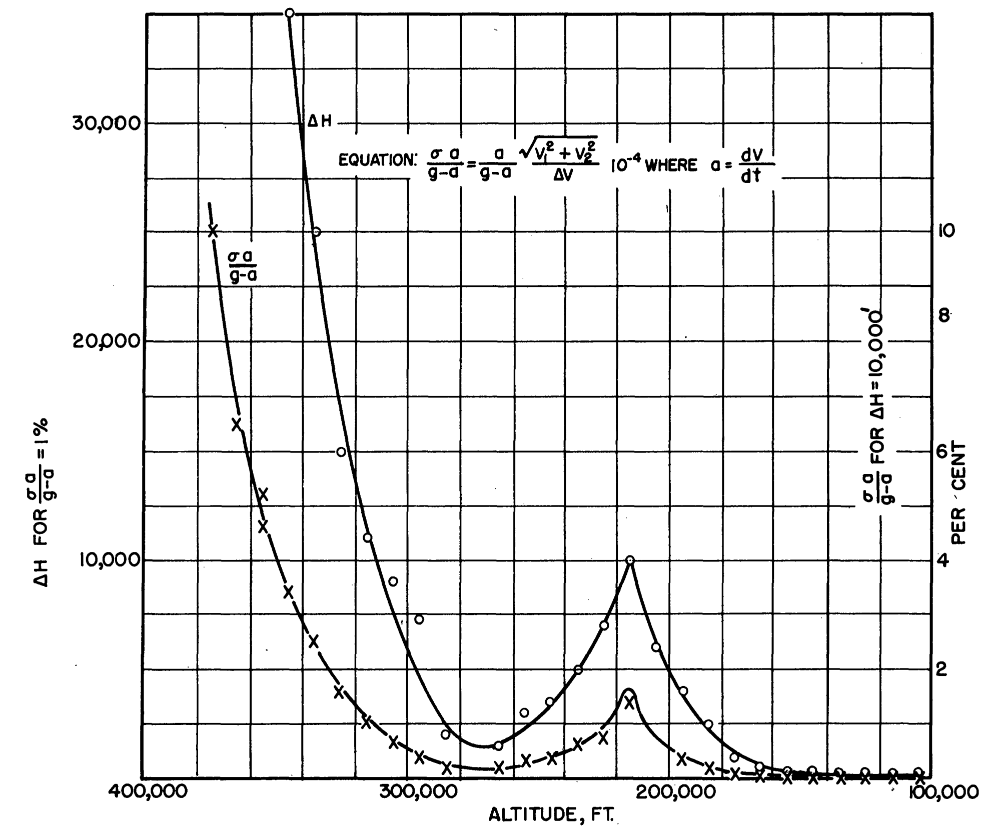



Fig. 29. Error in $g - \frac{dV}{dt}$

7.22 Coefficient of Drag Data

A survey of available $C_D$ data was made in the literature and by discussion with people who have made sphere drag measurements. The results of this survey are shown in Fig. 29 where the available data is shown on a Mach number vs. Reynolds number plot. The sphere trajectory is also plotted, and it may be seen that few data existed in the region of the experiment. A three-dimensional plot of $C_D$ against M and Re was also made. See Fig. 30. This was done to see if there are any regular trends in the data. It appears that in the region of the sphere experiment $C_D$ may not vary greatly with either M or Re.

In view of the lack of data in the desired region, a query was directed to the Naval Ordnance Laboratory at White Oak, Maryland, to see whether or not measurements could be made in the Pressurized Ballistic Range. In reply it was stated that NOL would be pleased to cooperate if a formal request were made, and this step was taken.

The first results obtained from runs made in calibrating the range and the results from the main test are listed in Table IV.

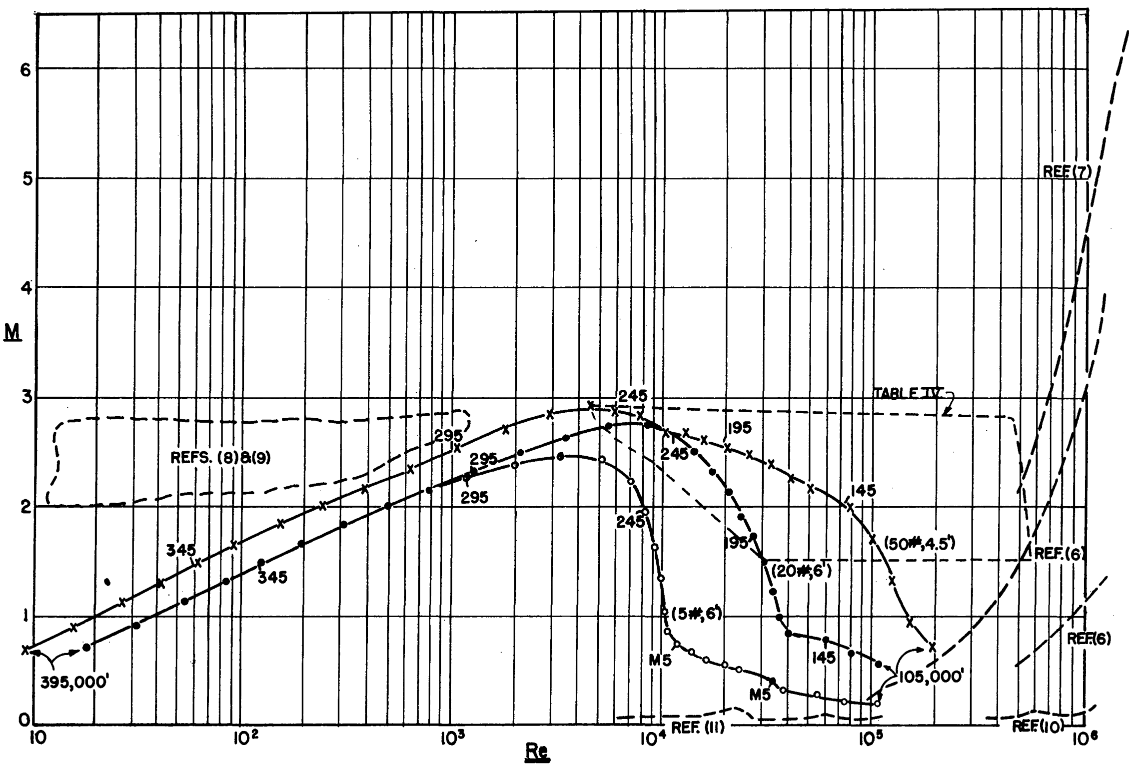



Fig. 30. Existing $C_D$ Data vs. M and Re.

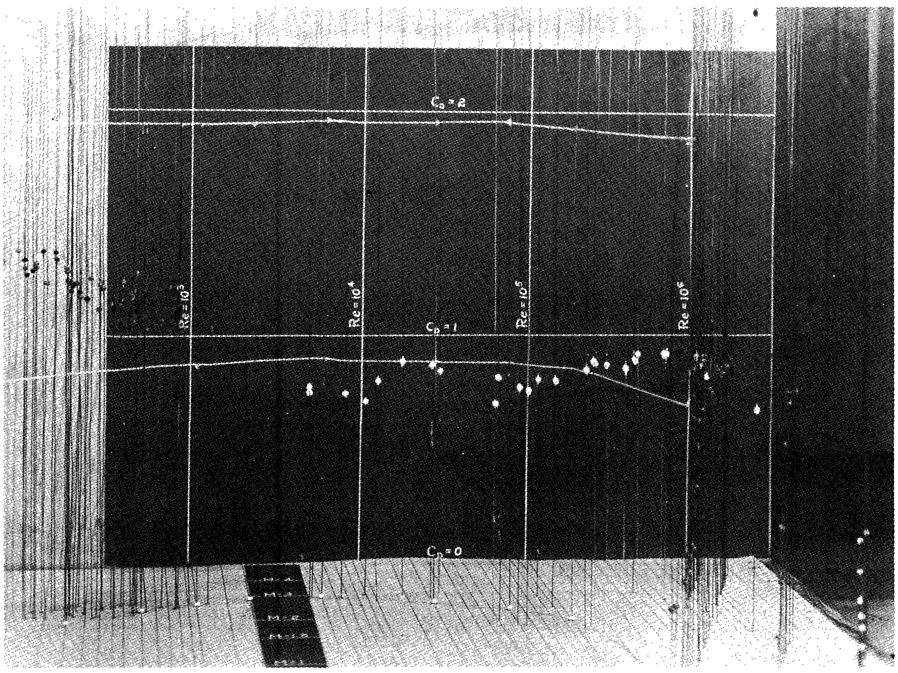



Fig. 31. 3-Dimensional Plot of $C_D$ vs. M and Re.

TABLE IV

Supersonic Drag Coefficients For Spheres*

| Shot | $C_D$ | M | Re x $10^4$ | Dia. (in.) |
|---|---|---|---|---|
| | | Calibrating Runs | | |
| 283A | .855 | 2.88 | 0.638 | .375 |
| 283B | .877 | 2.85 | 0.42 | .25 |
| 284A | .832 | 3.02 | 0.8912 | .50 |
| 284B | .859 | 2.97 | 0.4377 | .25 |
| 286 | .881 | 1.45 | 82.1 | .50 |
| 287 | .973 | 2.08 | 59.17 | .50 |
| | | Main Tests | | |
| 363D | 0.9984 | 1.778 | 18.572 | 0.750 |
| 362D | 1.0022 | 1.90 | 46.926 | " |
| 362C | 1.0122 | 1.938 | 31.202 | " |
| 358D | 0.9599 | 2.7723 | 26.639 | " |
| 360D | 0.9622 | 2.6216 | 18.311 | " |
| 364C | 0.9568 | 2.714 | 16.256 | " |
| 361D | 0.9694 | 2.62 | 39.851 | " |
| 364D | 0.9636 | 2.66 | 27.097 | " |
| 360A | 0.9455 | 1.661 | 4.6486 | 0.500 |
| 361C | 1.0256 | 1.414 | 9.8266 | " |
| 358C | 0.9581 | 2.154 | 8.2547 | " |
| 360C | 0.9309 | 2.620 | 7.5030 | " |
| 367B | 0.9450 | 1.660 | 5.0497 | 0.28125 |
| 367A | 0.9592 | 1.788 | 3.8257 | " |
| 362A | 0.9511 | 2.838 | 2.1743 | " |
| 365A | 0.9004 | 2.530 | 0.9206 | " |
| 366A | 0.9689 | 2.804 | 1.3083 | " |
| 366B | 0.9511 | 2.670 | 1.9185 | " |
| 361B | 0.9200 | 1.455 | 3.1855 | 0.25000 |
| 363C | 1.0350 | 1.597 | 10.937 | 0.750 |

Experimental errors are estimated to be about ±5 percent. The figures in the table are given as received.

* These data were obtained in the NOL Pressurized Ballistic Range for the University of Michigan (ARR-157).

## 7.3 Engineering Design

The engineering design of the sphere experiment was started as soon as the preliminary investigations had shown that the method was theoretically feasible. The four major components of the apparatus are: (a) the sphere and its internal structure, (b) the ejection system, which includes the external configuration of the forward end of the rocket, (c) the doppler unit, and (d) the auxiliary circuit. Several systems of instrumenting the method were considered. The fact that the sphere would be inflated was determined when calculations showed that a 15-inch sphere (which would fit in an Aerobee) would not contain suitable doppler antennas and would have little drag in the altitude region of interest. A 4.5-foot sphere appeared to be about as large as could be contained in the Aerobee and was large enough to contain the doppler antennas. The inner cylinder combined the functions of supporting the doppler and cutting down the expansion rate of the sphere. The wooden outer cylinders were chosen so that the doppler could operate throughout the flight. Several mechanical latches for the outer cylinders were considered but were abandoned in favor of the wrapping cord, Primacord combination which has the advantages of simplicity, great strength and being nonconducting.

Upon completion of the entire apparatus a trial ejection will be made in a high altitude chamber at the Aero Medical Laboratory, Wright-Patterson Air Force Base.

### 7.31 The Sphere

Several manufacturers were approached with the problem of fabricating the sphere. A favorable response was received from the Goodyear Tire and Rubber Company, Akron, Ohio, and tentative specifications were agreed upon. Two spheres were fabricated of neoprene impregnated nylon fabric .020 inch thick. An inner sphere was assembled of orange-peel gore sections with cemented butt-seams. A second outer sphere was cemented over the first. The butt-seams were placed half-way between the seams of the inner sphere. Two 12-inch diameter holes at opposite ends of a diameter were left for access doors. In the first sphere these were temporarily covered with rubber discs to permit inflation. Since the first sphere was not spherical enough for flight, it was used for leakage, strength and ejection tests. The second sphere, which met the sphericity specification, was fitted with Micarta rings cemented to the fabric. Aluminum access doors were fitted to the rings with gaskets between them. The spheres were designed to be inflated to 5 psig but were found to be sufficiently hard at 2.5 psig.

Fig. 32 shows the sphere inflated, the inner plywood cylinder and one access door with the pull-away buttons for carrying circuits into the sphere. In the rocket this door is at the bottom next to the instrumentation section. The upper door, which contains the filling valve, is removed to service the doppler.

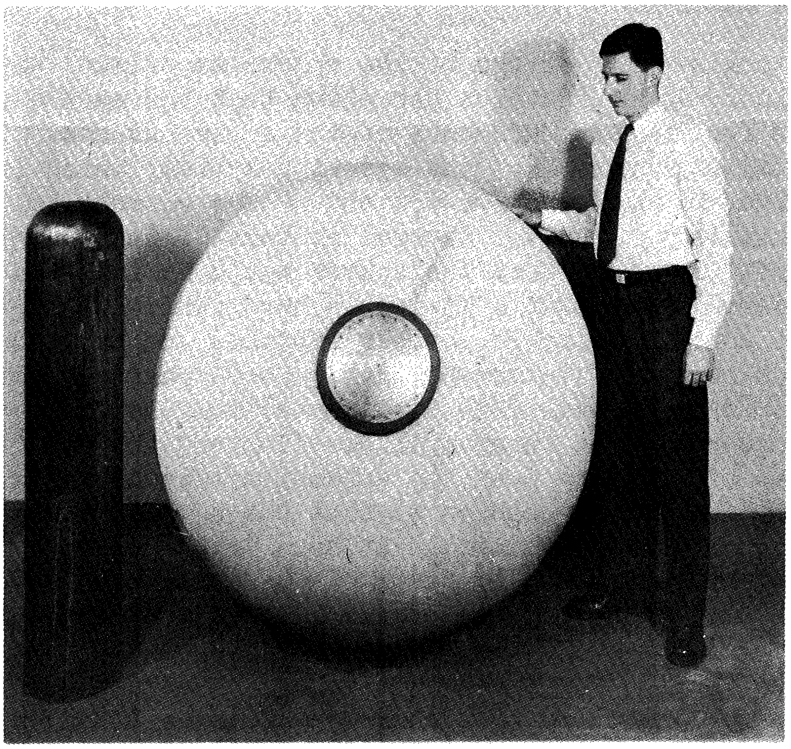


Fig. 32. Sphere and Inner Cylinder.

7.32 The Ejection System

The principal problem in the design of the ejection system and instrumentation exterior was that of strength. The wooden half-cylinders must withstand the expansion force of the compressed sphere, the inertia and drag forces of the rocket in yaw and the blast of the Primacord. Plywood cylinders were designed and purchased from U. S. Molded Shapes, Inc., Grand Rapids, Michigan. The bulkheads at the ends of the cylinders were machined from Micarta. The nose cone was also constructed of molded plywood and is fastened to the forward bulkhead.

Several tests were performed to determine the best pad to protect the fixed half-cylinder from the Primacord blast. The most successful consisted of a sandwich of two sheets of 1/16-inch soft rubber with 1/4-inch of tightly packed sand between them. With this arrangement, no damage to the wood resulted.

Fig. 33 shows the assembly of the cylinders, bulkheads and nose cone. Fig. 34 is a photograph of the cylindrical sections and the nose cone.

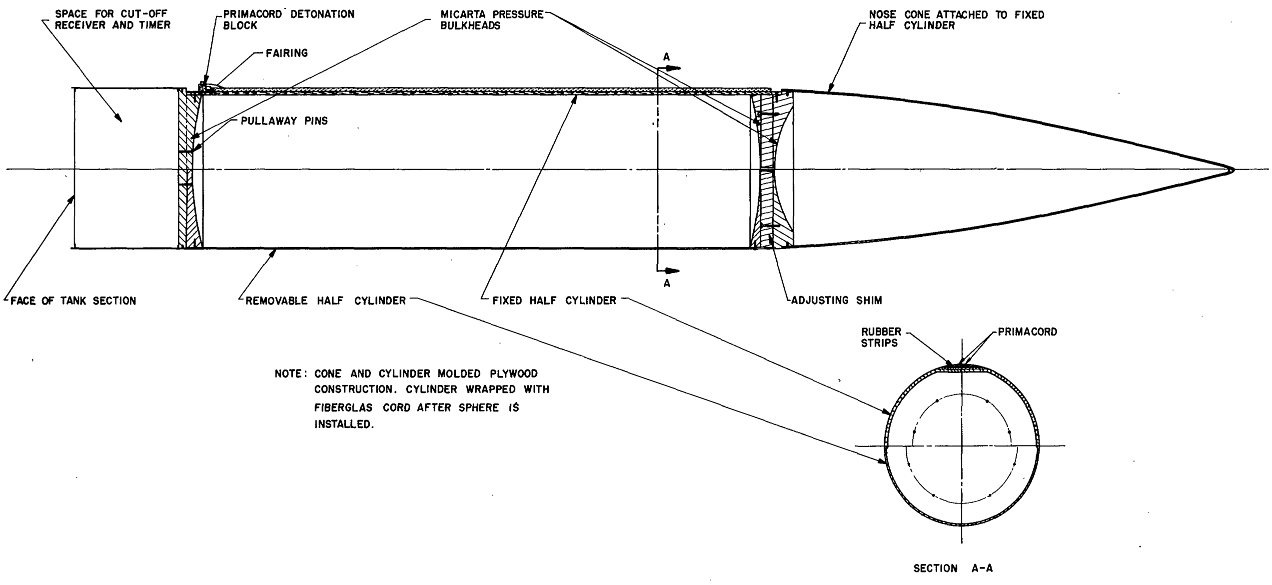



Fig. 33. Sphere Aerobee Front-End Assembly.

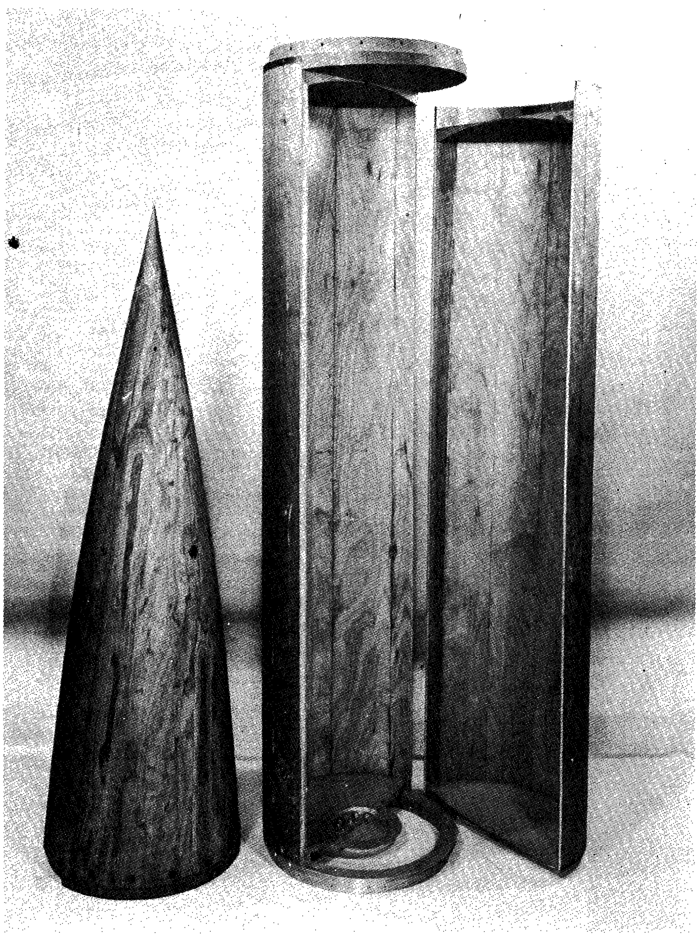


Fig. 34. Outer Half-Cylinders and Nose Cone.

## 7.33 Doppler Unit

A discussion was held with personnel at BRL to determine the configuration of the doppler unit and antennas. It appeared that a convenient arrangement would be to mount the antennas on opposite ends of a Fiberglas board with the electronics between them. The board is as wide as the inside diameter of the internal cylinder and the same length as the cylinder. The connections are carried through an aluminum tube to a plug at one end of the board. The plug mates with a socket when the doppler unit is slid into place on a pair of tracks fastened to the cylinder.

The first doppler unit, shown in Fig. 35, was received from BRL. It was fitted with a Giannini 0-30 psia pressure gage which is used to monitor the sphere pressure. The gage modulates the single doppler telemeter channel. Upon receipt of the doppler unit a series of tests was begun. The unit works satisfactorily, and successful operation of the telemeter and sphere ejection command circuit was carried out. The doppler is powered with a 6-volt NT-6 storage battery which provides about 20 minutes of operating time.

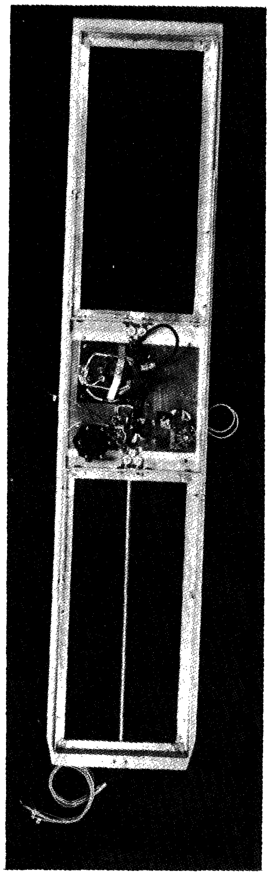


Fig. 35a. Complete Doppler Unit.

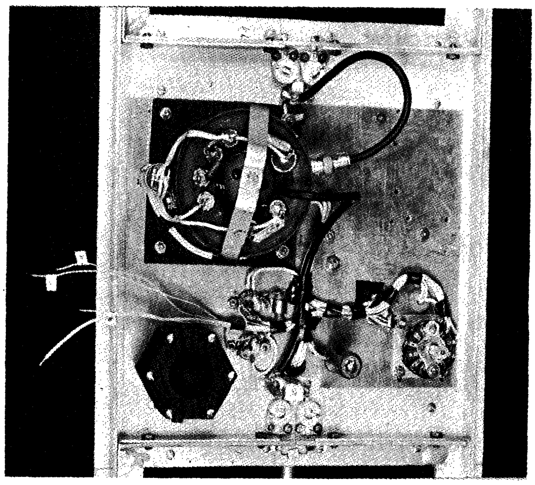


Fig. 35b. Doppler and Pressure Gage.

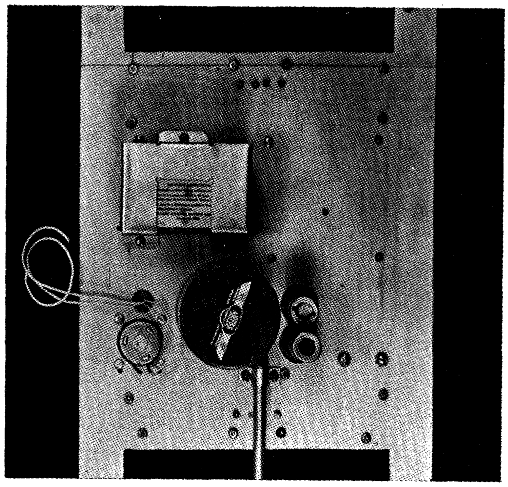


Fig. 35c. Power Supply and Battery.

### 7.34 Auxiliary Circuit

The auxiliary circuit for the rocket which includes timer, batteries and cut-off receiver, is mounted in a 15-inch high section between the wooden cylinders and the rocket tank section. It is similar to those used on sampling Aerobees. The timer provides a time gate which prevents premature ejection of the sphere by the doppler but which gives the ejection signal at a maximum time if the doppler command fails. The auxiliary circuit section of the rocket is shown in Fig. 36.

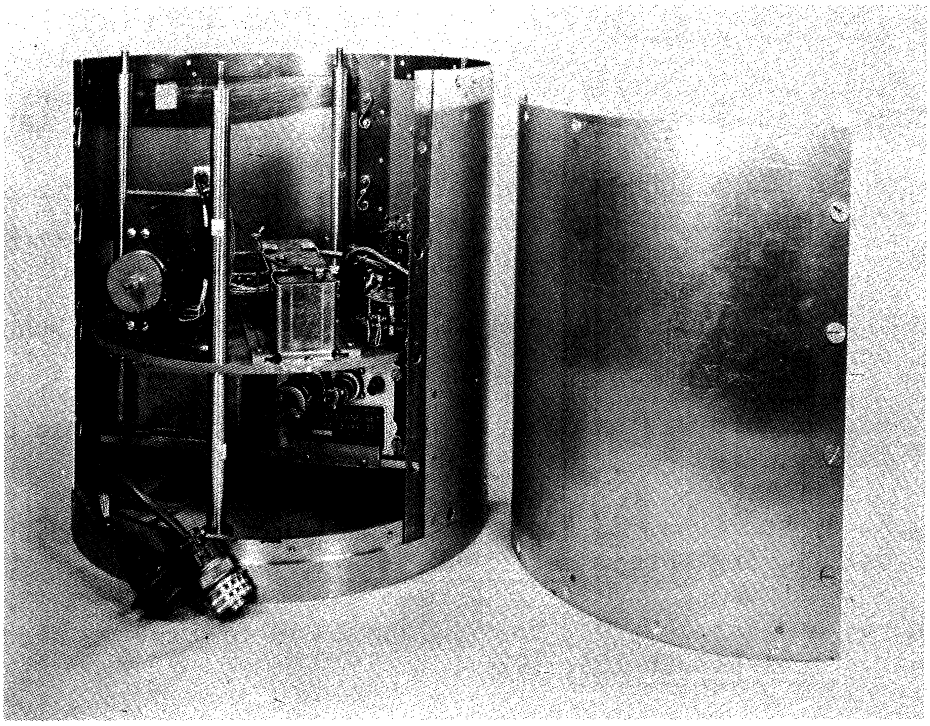


Fig. 36. Circuit Section Sphere Aerobee.

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## 8. RECOMMENDATIONS

### 8.1 Composition

The detection of considerable gravitational separation of the constituents of the atmosphere in the vicinity of 70 kilometers is of very great interest. The important first steps in establishing the pattern of this phenomenon are to obtain information on the following:

a) Altitude dependence,

b) Diurnal variation,

c) Seasonal variation.

Eventually it would be desirable also to make measurements at other geographical locations than WSPG.

8.2 Pressure, Density, Temperature

The sphere experiment for density and temperature should be completely tested and should be evaluated with respect to other methods such as the probe method after a successful trial.

## 9. ACKNOWLEDGMENT

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Personnel at White Sands, both civilian and military, were very generous with aid in field operations. We are particularly indebted to personnel of the following groups: 1st Guided Missiles Battalion, 1st Ordnance Guided Missiles Support Ballalion, in charge of launching Aerobees and V-2's respectively; Ballistics Research Laboratory for providing tracking facilities and data; Signal Corps Engineering Laboratories Field Station No. 1 for providing radar tracking and sound ranging; the Ordnance Corps for supplying V-2 60, the Naval Unit at White Sands for providing laboratory and Aerobee launching facilities; Naval Research Laboratory for providing telemetering on V-2 60; Applied Physics Laboratory for the aspect camera in V-2 60; and White Sands Proving Ground for quarters, food, recreation, search and recovery facilities and many other services. Thanks are due Holloman Air Force Base for aid in installing Aerobee parachutes.

We are particularly grateful to Dr. F. A. Paneth and his colleagues at Durham University for analyzing the upper air samples. We were fortunate in being visited by Dr. Paneth in October, 1951, at which time many phases of upper atmosphere research were discussed.

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Thanks are also due to Ballistics Research Laboratories for cooperation in providing the doppler unit for the sphere experiment and to Naval Ordnance Laboratory for measuring the coefficient of drag of spheres.

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