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ELECTRONIC SPECIAL RESEARCH DIVISION
ROCKET SONDE RESEARCH SECTION

1 October 1946

UPPER ATMOSPHERE RESEARCH
REPORT NO. I

The report consists of a series of articles by various authors on research connected with the first cycle of V-2 firings.

Report R-2955

Compiled and Edited by

M. A. Garstens, H. E. Newell, Jr., and J. W. Siry

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Approved by:

Dr. E. H. Krause, Head
Rocket Sonde Research Section
Dr. J. M. Miller, Superintendent
Electronic Special Research Division

Commodore H. A. Schade, USN
Director, Naval Research Laboratory

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ABSTRACT

The upper atmosphere research conducted by the Naval Research Laboratory in connection with the first cycle of V-2 firings at the Army's White Sands Proving Ground, is described. A historical review of the V-2 research activities to date is provided. A description of the V-2 is given together with past and future firing schedules. The warhead, the emergency cutoff system, and the telemetering system, all designed, developed, and provided by the Naval Research Laboratory for general use in the firings, are described in detail. The main features of the June 28 flight are listed. Details of the experiments on cosmic rays, on atmospheric temperatures and pressures, on the ionosphere, on solar spectroscopy, and on biology, are presented together with the results which have been obtained. Also the problem of ejection and recovery of instruments is discussed.

UPPER ATMOSPHERE RESEARCH
REPORT NO. I

GENERAL INTRODUCTION

by

E. H. Krause

The Naval Research Laboratory has obtained some data on the upper atmosphere from the first cycle of V-2 firings at the White Sands Proving Ground in New Mexico. In addition much valuable experience has been gained in various new techniques essential to high altitude research by means of rockets. This report sets forth some of the methods employed in adapting rockets to a program of upper atmosphere research, and presents such data as has already been obtained.

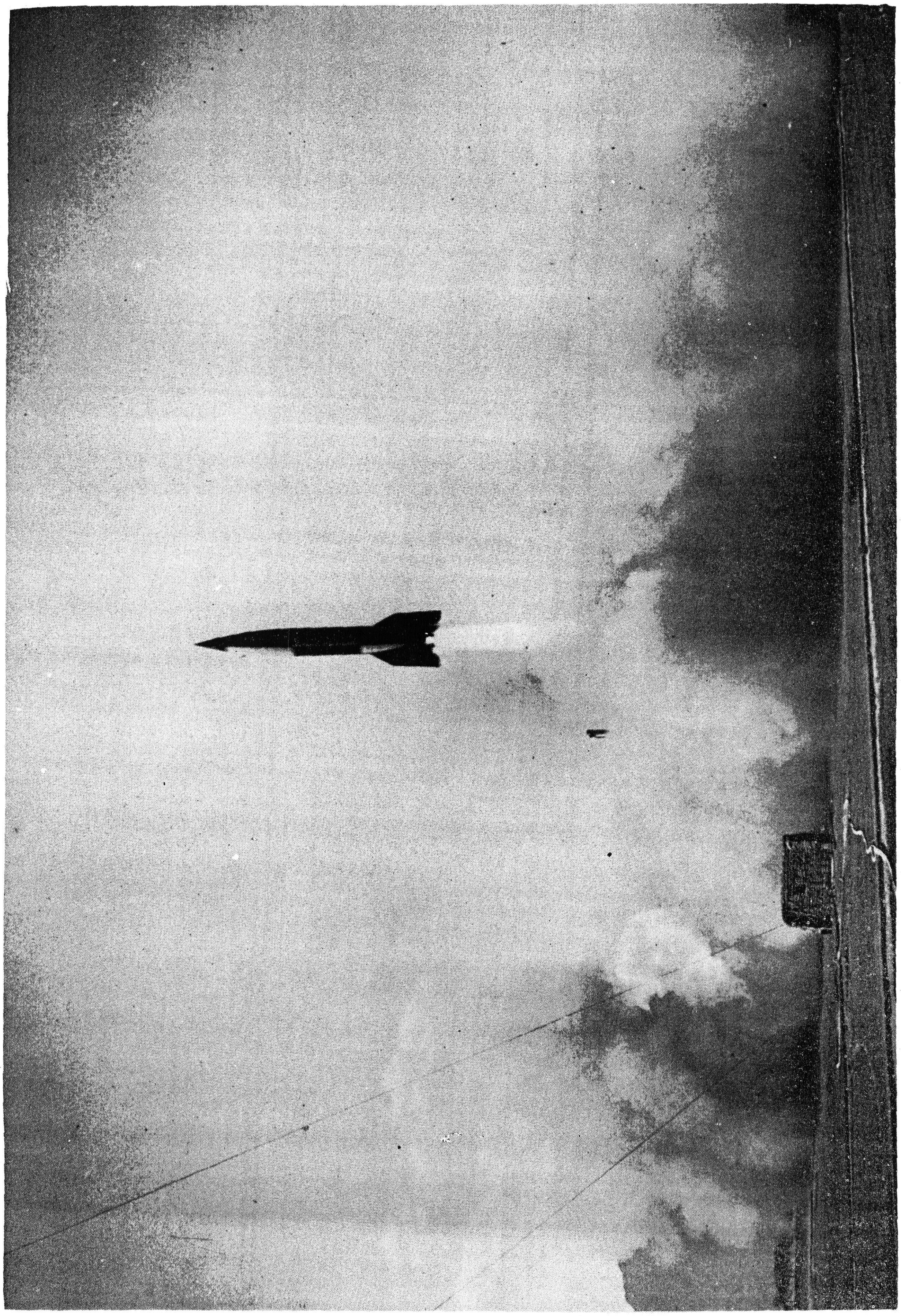
1. History. The Rocket Sonde Research Section was established at the Naval Research Laboratory by Laboratory Order on 17 December 1945 to begin operating on 1 January 1946. Its function was "to investigate the physical phenomena in, and the properties of, the upper atmosphere." To this end, an organization was set up to develop the necessary techniques, instrumentations, and devices required to carry out such a mission. On 7 January 1946 in a conference between representatives of the Rocket Sonde Research Section and Col. J. G. Bain of the Army Ordnance Department, held for the purpose of investigating sources of rockets adaptable to a program of high altitude research, it was brought out by Col. Bain that Army Ordnance had obtained a considerable number of V-2's from Germany and was contemplating firing them in the near future. He went on to explain that the purpose of the firings was threefold:

(1) To gain experience in the military aspects of handling and firing rockets of this size.

(2) To obtain information on the technical characteristics of the rockets as well as optical and radar tracking data.

(3) To obtain data on the upper atmosphere.

The work in the first two catagories was being handled by various Army Agencies, and already a rather definite program was under way. The upper atmosphere research program, however, was still to be



THE V-2 TAKES TO THE AIR FOR THE FIRST TIME IN AMERICA formulated and implemented. Col. Bain extended to the Rocket Sonde Research Section an invitation to join in this part of the program. As a matter of fact, he found it to his satisfaction that there should exist a group already established to carry on upper atmosphere research, and which could be brought into the V-2 program. Inasmuch as the Rocket Sonde Research Section had been anticipating a delay in actual upper atmospheric research of perhaps as much as two years, in awaiting the development and construction of a suitable research vehicle, Col. Bain's invitation was enthusiastically received and accepted.

This was the beginning of a collaborative program between Army Ordnance and the Naval Research Laboratory (later joined by other agencies). The program has progressed exceptionally smoothly, in spite of the hundreds of problems which have arisen. The success so far enjoyed has doubtless been due in large measure to the splendid spirit of cooperation continuously shown by Col. H. N. Toftoy, Lt. Col. J. G. Bain, and Lt. Col. H. R. Turner and their colleagues in the Army Ordnance Department.

2. The V-2 Panel. To further the upper atmosphere research phase of the V-2 program, and to insure the most efficient possible use of the facilities involved, on 16 January 1946 a meeting of interested agencies was convened at the Naval Research Laboratory. About fifty people, representing more than a dozen different agencies and universities attended, and joined in a general discussion of the V-2 upper atmosphere research program. As a result of this discussion a "V-2 Upper Atmosphere Research Panel" was established. It was agreed that the panel membership be restricted to persons actually working in the program. Since that time the membership has undergone numerous changes until today it comprises the following:

Dr. E. H. Krause	Naval Research Laboratory, Chairman
Mr. G. K. Megerian	General Electric, Technical Aide
Mr. J. Brinster	Princeton University
Dr. W. G. Dow	Michigan University
Dr. M. J. E. Golay	Signal Corps Laboratory
Dr. C. F. Green	General Electric
Dr. M. D. O'Day	Watson Laboratories
Dr. Newbern Smith	National Bureau of Standards
Dr. J. A. Van Allen	Applied Physics Laboratory
Dr. F. L. Whipple	Harvard University

The panel meets approximately once every month, and to date has met eight times.

3. The White Sands Proving Ground. Overall responsibility for assembling and firing the V-2's rests with the White Sands Proving Ground of the Army Ordnance Department, the Proving Ground being located near Las Cruces, New Mexico. This Army agency, in collaboration with the

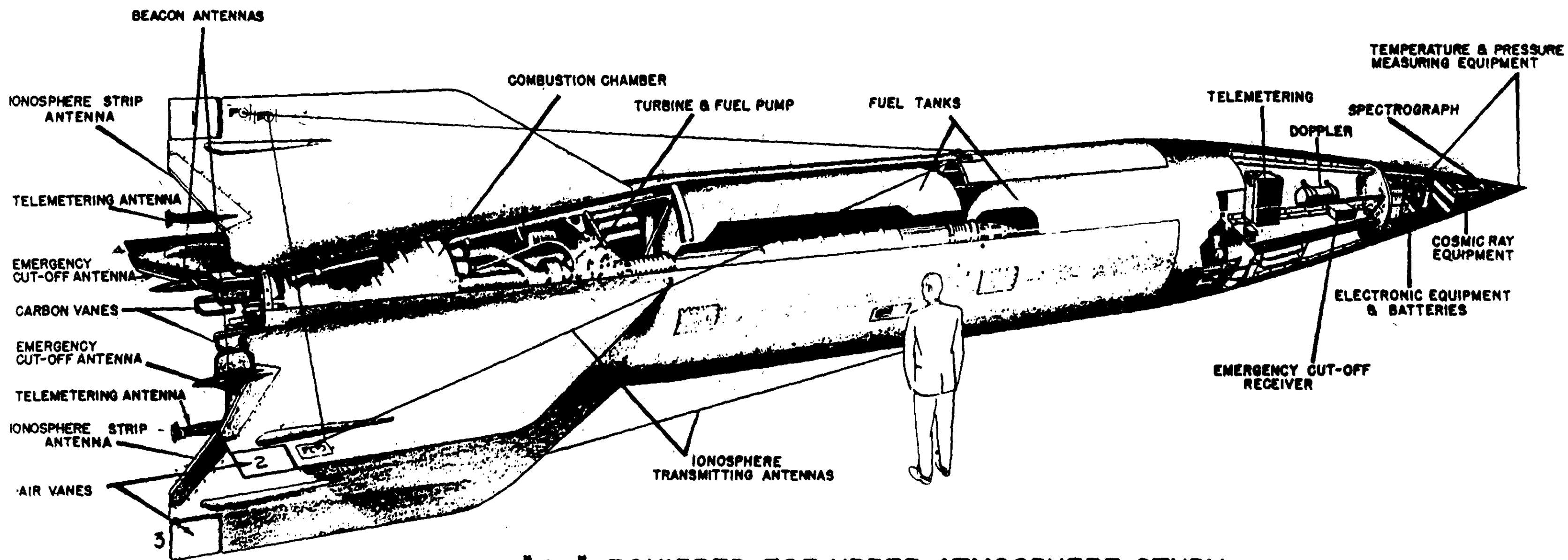
General Electric Company (under Army Ordnance Contract), is responsible for and supervises all installation work in the V-2, including that of equipment for upper atmosphere experiments. The major portion of the instrumentation for high altitude research is located in the warhead, which the Naval Research Laboratory designed specifically for the program. For the June 28 firing the warhead equipment was assembled and installed in the warhead at the Naval Research Laboratory and the entire assembly flown to White Sands Proving Ground. Thus, as far as the warhead was concerned, only certain calibrations, tests, and tie-ins had to be made on location. However, the work in the afterbody, such as antenna installations, was of necessity done at White Sands Proving Ground by Naval Research Laboratory personnel under the supervision of Army and General Electric representatives.

4. The Naval Research Laboratory. Most of the work described herein as done at the Naval Research Laboratory, was accomplished by the Rocket Sonde Research Section. However, the Physical Optics Division, under the direction of Dr. E. O. Hulburt, assumed an active and important role in two phases of the V-2 program: (1) during several of the firings at White Sands Proving Ground they conducted tests on infra-red tracking methods, the results of which will be made known in a separate report; and (2) the Physical Optics Division and the Rocket Sonde Research Section collaborated on the design of the spectrograph used in the June 28 firing. The spectrograph is described in detail in Chapter III, Section H.

In addition there are many persons from various groups and agencies who have entered into the V-2 program through the Naval Research Laboratory's participation by extending to the Rocket Sonde Research Section advice, facilities, etc. The gratitude of the Section is expressed here for all such assistance received.

5. Ballistics Studies of the V-2. Many of the experiments conducted in the V-2 require an accurate knowledge of the position and velocity of the missile throughout its trajectory. The ballistic data and the methods of obtaining it are the responsibility of the Aberdeen Ballistic Laboratory and the Signal Corps. Three principal methods are employed: optical; radar with beacon; and doppler tracking. The data is taken in such a way that critical information, such as fuel burnout time, maximum altitude, range at impact, etc., is available during and immediately after the flight. This is the source of the data listed in Chapter I, Section B, Table II. Detailed trajectory information is recorded but requires considerable time for analysis. To date, such detailed information has been received only for the April 16 and May 29 flights.

6. Report on Naval Research Laboratory Activities. The Naval Research Laboratory has already received many requests for reports on its activities in the V-2 Upper Atmosphere Research Program. It is not surprising that widespread interest in the program should exist. Those



"V-2" EQUIPPED FOR UPPER ATMOSPHERE STUDY agencies doing similar work are naturally interested in all general information on experiences in the new field. Those working to perfect guided missiles which can traverse the upper atmosphere are vitally interested in many of the techniques employed and in much of the experimental data for direct application to their own rapidly expanding field. The research also affords information important in the field of meteorology, as, for example, in weather studies. It is, in fact, apparent from the requests received that many groups are as much interested in the details, methods, and techniques employed in the experiments as they are in the results obtained. Accordingly, this report has been compiled with the feeling that it should be as detailed as possible. As a result, the present volume consists actually of a series of reports on the various phases of the program in which the Naval Research Laboratory is involved. These set forth not only results, where such have been obtained, but also include such details and experiences as might prove of interest to other workers in this or related fields.

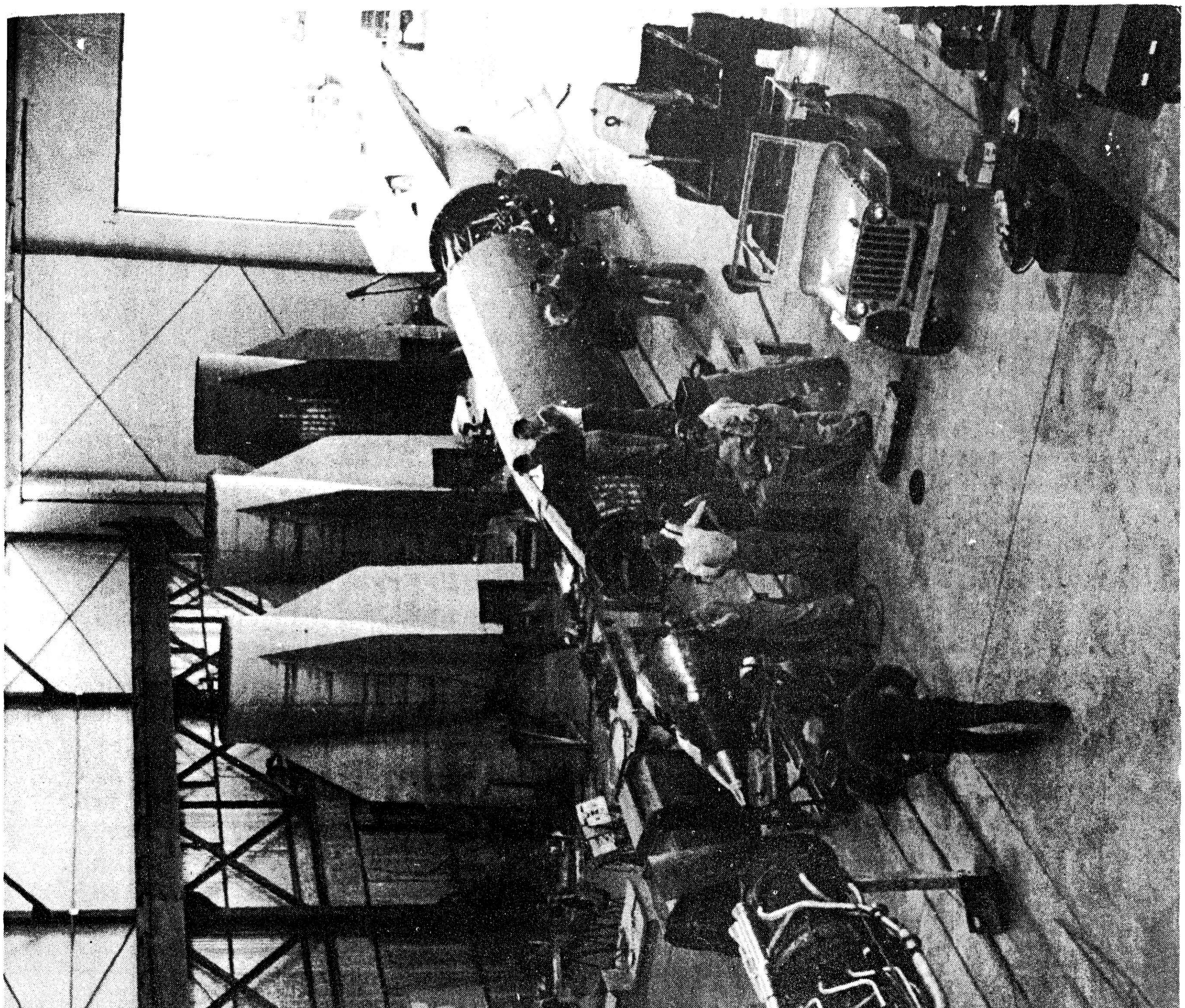
The discussion is divided into three chapters. The first affords a brief description of the V-2 together with an outline of the firing program of the Army Ordnance Department.

The second chapter covers the auxiliary equipment provided by the Naval Research Laboratory for the V-2, which includes the emergency cutoff system, the telemetering, and the warhead. Such equipment has been furnished for all V-2 firings to date.

The third chapter contains a discussion of experiments conducted by the Naval Research Laboratory in various V-2's. The discussion includes reports on cosmic rays, temperature, pressure, the ionosphere, solar spectra, and ejection mechanisms.

In addition, there are four appendices giving reports on various types of data which have been compiled at the Naval Research Laboratory and elsewhere, and which are necessary to the prosecution of the research described in Chapter III. Some of these describe the current state of the art according to judgments based on the best available sources; other reports cover the theoretical solution of problems which have arisen at the Naval Research Laboratory, the results of which should prove of general interest.

7. <u>Future Naval Research Laboratory Activities</u>. Although the success of the firings to date leaves much to be desired, nevertheless this limited experience has proved unquestionably the advantage of the rocket as an aid to upper atmosphere research. It is felt that the new contributions to scientific knowledge which the rocket vehicle has already provided and will continue to provide at an ever increasing rate are well worth the cost involved.



THE V-2 BEING ASSEMBLED

The completion of the first firing cycle has seen the establishment of basic techniques necessary to the taking of physical data aboard a supersonic vehicle and radioing that information to ground stations. In addition, the first step has been taken in perfecting methods for the physical recovery of film, recorders, etc.

The exploitation of these techniques in future flights should furnish much needed information in the fields of cosmic rays, solar spectroscopy, the ionosphere and atmospheric physics.

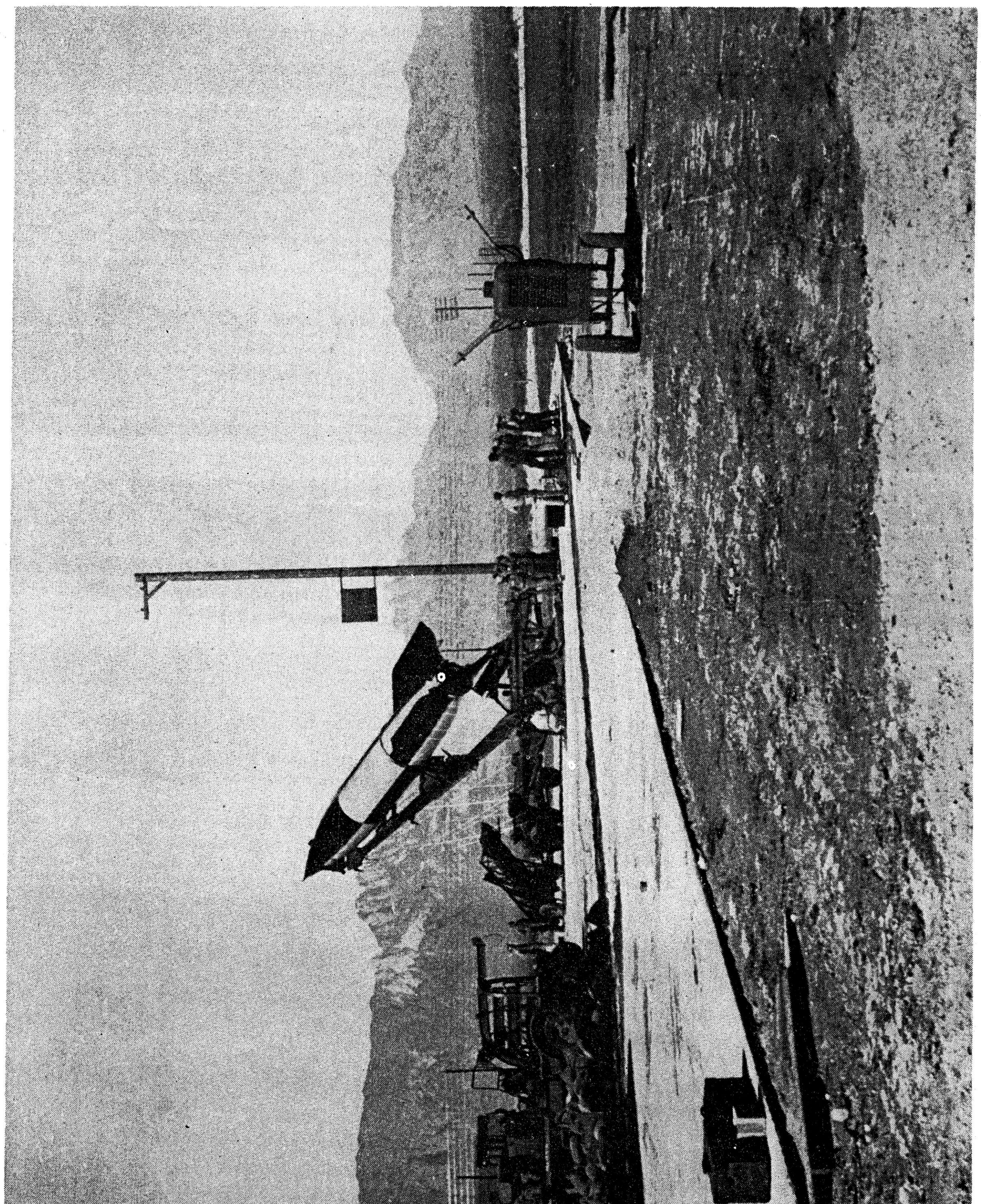
The Office of Naval Research and the Naval Research Laboratory consider the research in this field to be of sufficient importance that a long range program extending through the next 3 years, has been set up to continue the work. Steps have, therefore, been taken to provide a steady flow of sounding rockets after the present supply of V-2's runs out in January, 1948. The Army Ordnance Department and the General Electric Company have agreed that the assembly of captured V-2's after that time would be prohibitive because of the large amount of work that would be required to repair the effects of 3 years deterioration.

A contract has been let jointly by the Bureau of Ordnance, the Office of Naval Research, and the Naval Research Laboratory with Aerojet Engineering Corporation for the development of a high altitude sounding rocket which will carry 150 pounds to an altitude of 265,000 feet. The Naval Research Laboratory is to receive five of these rockets. Delivery of the first rocket is expected to be made sometime in the middle of 1947.

In addition the Office of Naval Research and the Naval Research Laboratory have let a contract with the Glenn L. Martin Company for the design and construction of ten high altitude sounding rockets which can carry a payload of 500 pounds to 500,000 feet or alternatively, 100 pounds to 750,000 feet. Delivery of the first of these is anticipated for the spring of 1948.

More details on the performance and characteristics of the rockets under development will be given in subsequent reports as the work progresses.

It is also planned to expend a great amount of effort in improving the performance of the telemetering system. A considerable increase in radiated power is contemplated. Improved antennas with better pattern and directivity characteristics are under development both for the ground station and for the missile, and the use of circular polarization is contemplated. Fixed, rather than mobile, ground stations are already being installed at the White Sands Proving Grounds. One mobile station will, however, be retained.



THE V-2 BEING RAISED INTO FIRING POSITION

A contract has been let with the New Mexico Agricultural and Mechanic Arts College at Las Cruces. The college is to provide facilities for the processing and analysis of telemetering films. The general intent is that, once film processing machinery is available, the telemetering record will be recorded on film rather than on paper so that copies can be run off for the various interested agencies. Detailed analysis of one of the copies can then be made by personnel at the college.

The various upper atmosphere experiments described in Chapter III of this report will continue along with several additional projects. Research is in progress to devise suitable means of telemetering spectrographic data. A fair amount of success with this program is anticipated for the very near future. The experiments to determine the structure of the upper atmosphere will be extended to add composition analyses to the temperature and pressure measurements already under way. Also an extensive program of antenna design and pattern measurement is to be undertaken to provide suitable radiators for the ionosphere experiments as well as for telemetering.

CHAPTER I

GENERAL DESCRIPTION OF THE V-2 AND THE FIRING PROGRAM OF THE ARMY ORDNANCE DEPARTMENT

by

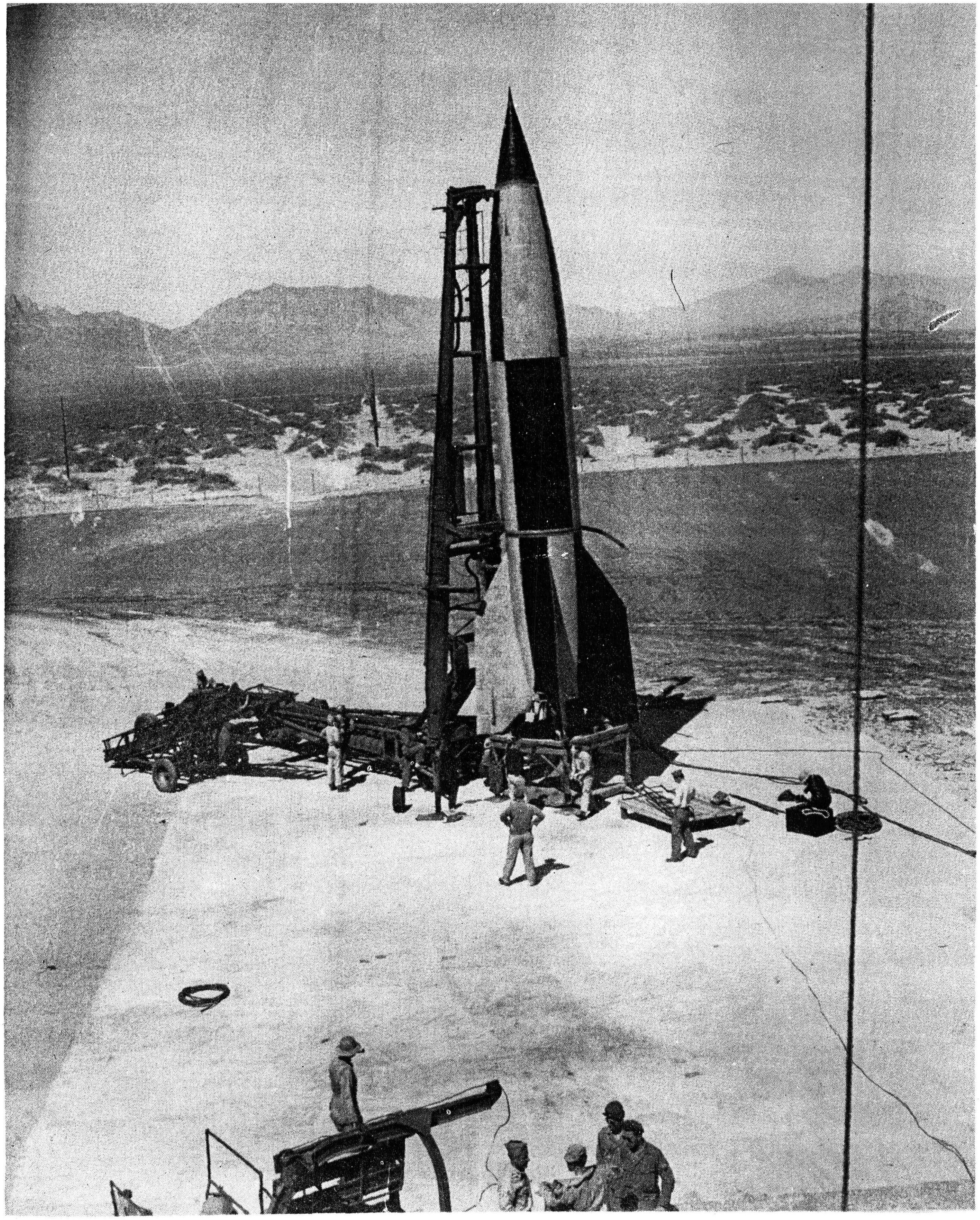
C. H. Smith

A. Description of the V-2

The primary purpose of the present volume is to describe the research and development work done at the Naval Research Laboratory in connection with the V-2 program. The principal interest of the Rocket Sonde Research Section is, of course, in upper atmosphere research and the instrumentation work associated therewith. But in order to evaluate properly the difficulties encountered in carrying on such research and in developing adequate instrumentation, it is essential that pertinent characteristics of the vehicle used be thoroughly understood.

A listing of the more important characteristics of the V-2 is given in Table I. Data concerning the various possible V-2 trajectories are shown in Fig. 3. The trajectories as plotted represent minimum and maximum conditions for different fuel cutoff times. In most of the recent firings the fuel cutoff scheme using accelerometers has been discarded in favor of letting the fuel burn out. The primary purpose of the Germans in using the fuel cutoff in the V-2 was originally that of obtaining accurate fire against a target. A similar motive existed in the early firings at White Sands when fuel cutoff was used for the purpose of making careful trajectory studies. At present, however, one of the main objectives is the attainment of as great an altitude as possible so that the fuel is allowed to burn out completely.

One of the most disturbing features of the V-2 from the point of view of high altitude research, is the slow roll which exists after fuel burnout. This requires special provision in some of the experiments as is brought out below in the discussions on cosmic rays and solar spectroscopy. It has been found that the period of roll varies from missile to missile over the range from 12 to 60 seconds.



THE V-2 ON ITS FIRING PLATFORM

TABLE I

TECHNICAL DESCRIPTION OF THE V-2

Dimensions		
Length of NRL Warhead[1]		7' 6"
Length of Control Compartment		4' 7"
Length of Fuel Tank Section		20' 5"
Length of Tail		14' 5"
Total Length of White Sands V-2[2]		46' 11"
Caliber		5' 5"
Length of Fins		12' 11"
Extreme Diameter of Fins		11' 8"
Weights		
NRL Warhead:[3]		
Shell	1,055 lbs.	
Scientific Equipment Installed for June 28 Firing	1,055 lbs.	
Counterweight added by NRL	200 lbs.	
Total		2,310 lbs.
Control Compartment		1,058 lbs.
Fuel Tank Section:		
Empty	1,636 lbs.	
Fuel, etc.	19,392 lbs.	
Total		21,028 lbs.
Rocket Motor		2,053 lbs.
Tail, etc.		1,885 lbs.
White Sands V-2:[4]		
Empty	8,842 lbs.	
Fuel, etc.	19,393 lbs.	
Total		28,334 lbs.
Fuel Injection Pressure		18 atm.
Combustion Chamber Pressure		14.5 atm.
Combustion Chamber Temperature		2,000°C.
Exit Velocity of Gases		6,560 ft/sec.
Thrust		28.3 tons
Greatest Impact Pressure (Occurs 45 sec. after take-off when the altitude is 7.5 miles and the velocity is 1,450 mph)	approximately	13 lbs/sq in.
Lifting Acceleration		1 g.
Maximum Acceleration		6 g.

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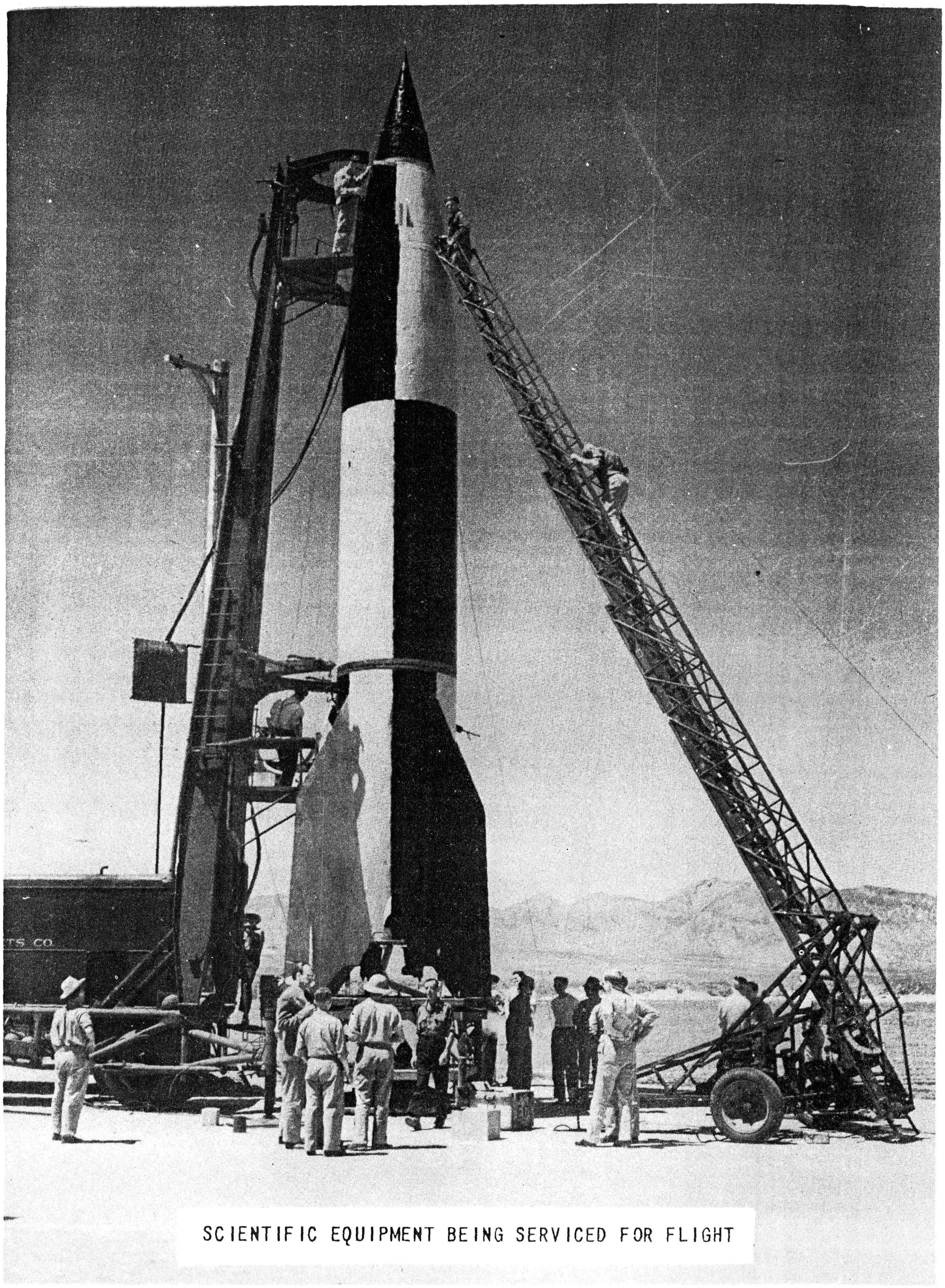
[1]Length of German Warhead 6' 7"
[2]Total Length of German V-2 46'

TABLE I (Cont'd.)

TECHNICAL DESCRIPTION OF THE V-2

[3]Weight of German Warhead:		
Shell	551 lbs.	
Explosive	1,654 lbs.	
Total		2,205 lbs.
[4]Weight of German V-2:		
Empty	8,837 lbs.	
Fuel, etc.	19,392 lbs.	
Total		28,229 lbs.



SCIENTIFIC EQUIPMENT BEING SERVICED FOR FLIGHT

CHAPTER I

GENERAL DESCRIPTION OF THE V-2 AND THE FIRING PROGRAM OF THE ARMY ORDNANCE DEPARTMENT

B. The Firing Schedule at White Sands

Although the V-2 is very satisfactory as a vehicle for a wide range of experimentation, nevertheless the firing schedule set up restricted the type and number of experiments which could be included because of the limited time available for preparation. Such a tight schedule was set for two reasons: (1) in the early firings more importance was attached to the military aspect of the program; and (2) deterioration of the missile set a limit on the time in which the V-2's had to be expended. The schedule was such that the Naval Research Laboratory had only three months to prepare experiments for its first firing. In addition, the Rocket Sonde Research Section was still in the process of organizing itself for such work, much of which was entirely new. It is felt that these facts should be presented here to provide a proper background for evaluating the experiments described in the report.

A tabulation of the schedule to date is given in Table II. The present schedule for the next cycle of V-2 firings appears in Table III.

TABLE II

SUMMARY OF THE FIRST CYCLE OF V-2 FIRINGS
15 MARCH THROUGH 22 AUGUST 1946

Firing	Date	Research Agencies	Altitude# (yards)	Range# (yards)	Remarks
1.	15 March 1946				Static Firing.
2.	16 April 1946	General Electric* Applied Physics Laboratory Naval Research Laboratory	6,000	9,400	Emergency cutoff used. One fin fell off.
3.	10 May 1946	General Electric* Applied Physics Laboratory Naval Research Laboratory	124,800	62,500	Demonstration firing.
4.	29 May 1946	General Electric* Bureau of Standards Applied Physics Laboratory	122,600	66,200	Normal flight. No recovery.
5.	13 June 1946	General Electric* Bureau of Standards Naval Research Laboratory	180,000	70,400	Air burst attempted but not achieved.
6.	28 June 1946	Naval Research Laboratory*	118,000	70,520	Air burst attempted but not achieved.
7.	9 July 1946	General Electric* Naval Research Laboratory	146,060	107,360	4^{o} excess in tilt program.

TABLE II (Cont'd.)

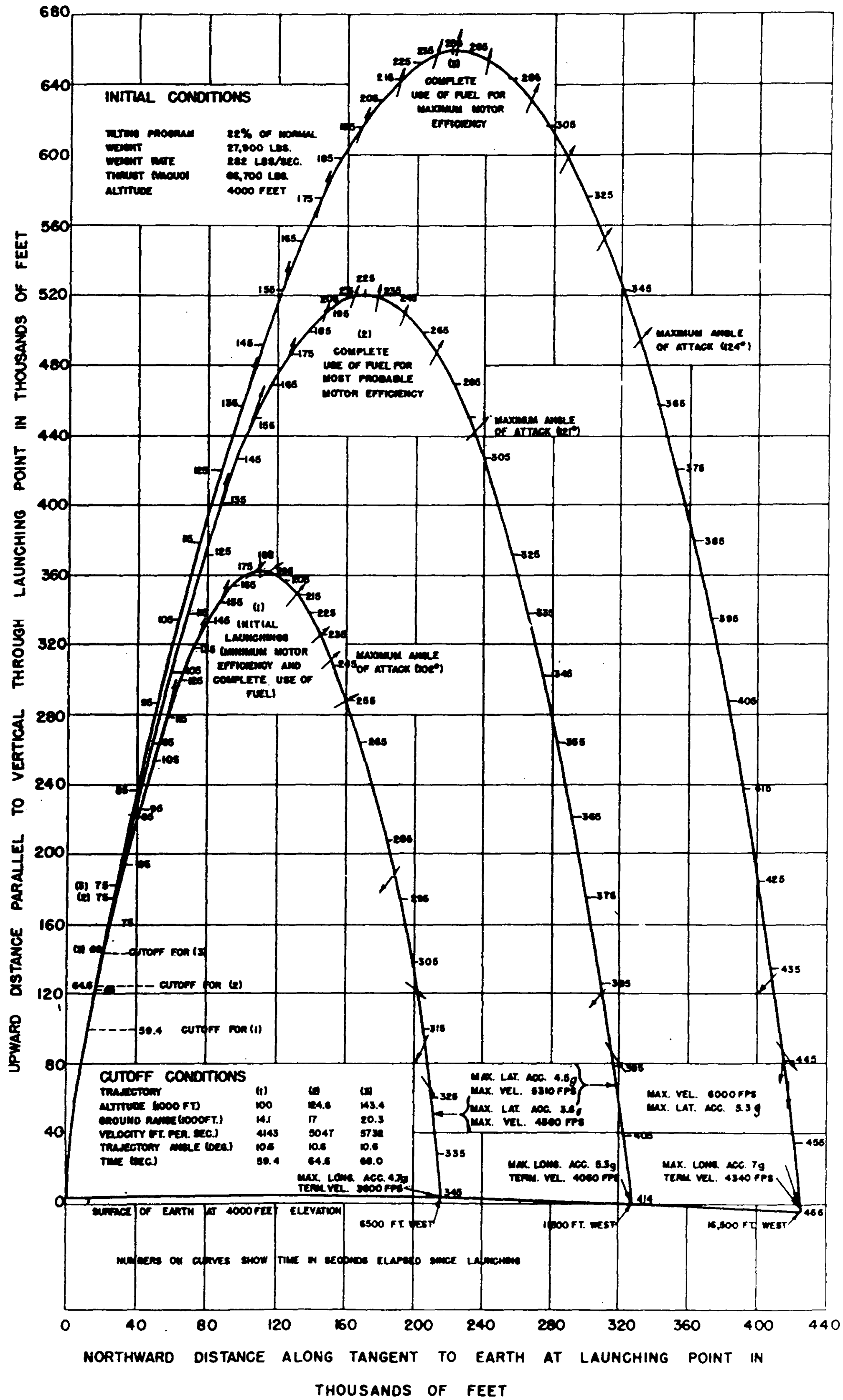
SUMMARY OF THE FIRST CYCLE OF V-2 FIRINGS
15 MARCH THROUGH 22 AUGUST 1946

Firing	Date	Research Agencies	Altitude# (yards)	Range# (yards)	Remarks
8.	19 July 1946	General Electric* Naval Research Laboratory	6,000	2,000	Rocket exploded after 27 sec. due to oxygen pump failure.**
9.	30 July 1946	Applied Physics Laboratory*	183,000	120,000	Air burst achieved but warhead not found. After-body recovered in fairly good shape.
10.	15 Aug. 1946	Princeton University*	7,000 (approx.)	1,300 (approx.)	Emergency cutoff used. Steering control failed. Rocket nosed over and exploded on impact.
11.	22 Aug. 1946	University of Michigan* Watson Laboratories*	110	1,500	Emergency cutoff used. Gyro failure.**

* Primary agency involved.
** Cause of failure assigned by Army Ordnance.
\# Altitude and range data assigned by Army Ordnance.

A-4 MISSILE TRAJECTORY (WHITE SANDS TESTS)

(CALCULATED FROM GERMAN DATA ON G. E. DIFFERENTIAL ANALYZER)



CALCULATED BY J. R. MOORE OF GENERAL ELECTRIC COMPANY, 5 APRIL, 1946
COPY MADE BY ROCKET-SONDE RESEARCH SECTION
NAVAL RESEARCH LABORATORY, 17 APRIL, 1946

TABLE III

PROPOSED SCHEDULE OF THE SECOND CYCLE OF V-2
FIRINGS THROUGH 6 FEBRUARY 1947

Firing	Date	Research Agencies
12	10 October 1946	Naval Research Laboratory
13	24 October 1946	Applied Physics Laboratory
14	7 November 1946	Princeton University
15	21 November 1946	Watson Laboratories University of Michigan
16	5 December 1946	Naval Research Laboratory
17	17 December 1946	Applied Physics Laboratory
18	9 January 1947	Princeton University
19	23 January 1947	General Electric
20	6 February 1947	Watson Laboratories University of Michigan

CHAPTER II

EQUIPMENT DEVELOPED AND PROVIDED BY THE NAVAL RESEARCH LABORATORY FOR GENERAL USE IN THE V-2 FIRINGS

A. The Warhead. General Description of the Naval Research Laboratory Installations

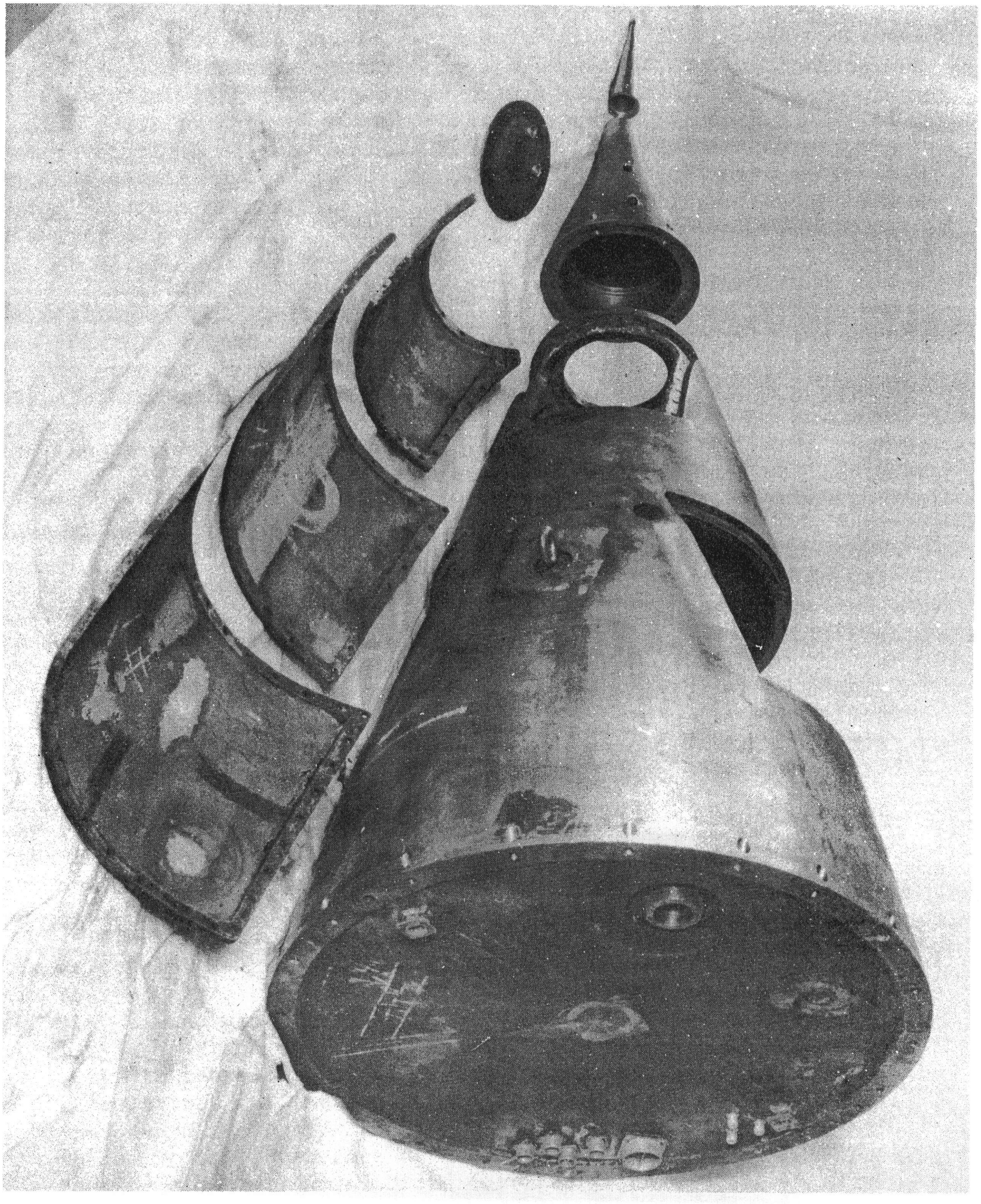
by

J. T. Mengel

The plan to use V-2 missiles as vehicles for atmospheric research gave rise to the need for the design and construction of a special warhead suitable for the experimentation contemplated. Inasmuch as there were available to the Rocket Sonde Research Section the facilities of the Naval Gun Factory in Washington, D. C., the Section undertook this task, not only for itself, but also for the other agencies represented on the V-2 panel. At present, twenty-five such warheads, designed by the Naval Research Laboratory, have been built by the Naval Gun Factory. A photograph of one of the warheads is shown in Fig. 1.

The warhead is made of 3/8 inch cast steel throughout, except for the upper access door, which is 1/8 inch steel or aluminum, as occasion demands. The entire assembly, which comprises three sections: a nose tip, a nose section, and a main body, weighs approximately 1,000 pounds when empty. In the first Naval Research Laboratory flight of June 28, the nose tip which is 12 inches long and has a base diameter of 3 inches, was used for pressure and temperature measurements of the atmosphere during the rocket flight. The nose section, which lies between the tip and the main warhead body and is 22 inches long with base diameters of 3 and 12.37 inches, housed the solar spectrograph. Most of the electronics equipment connected with the experimentation was located in the main warhead body, which was sealed at ground level so as to maintain a pressure of 1 atmosphere, and which also contained batteries, and the ground controls used prior to launching. This main portion of the warhead is 57 inches long and has base diameters of 12.37 and 37.625 inches.

The batteries were standard Navy non-spilling storage batteries for the 6.3 volt and 24 volt supplies, together with specially constructed high voltage batteries of minimum size capable of giving .300 amperes at 750 volts for about 30 minutes, and a 1500 volt battery for low current drain.



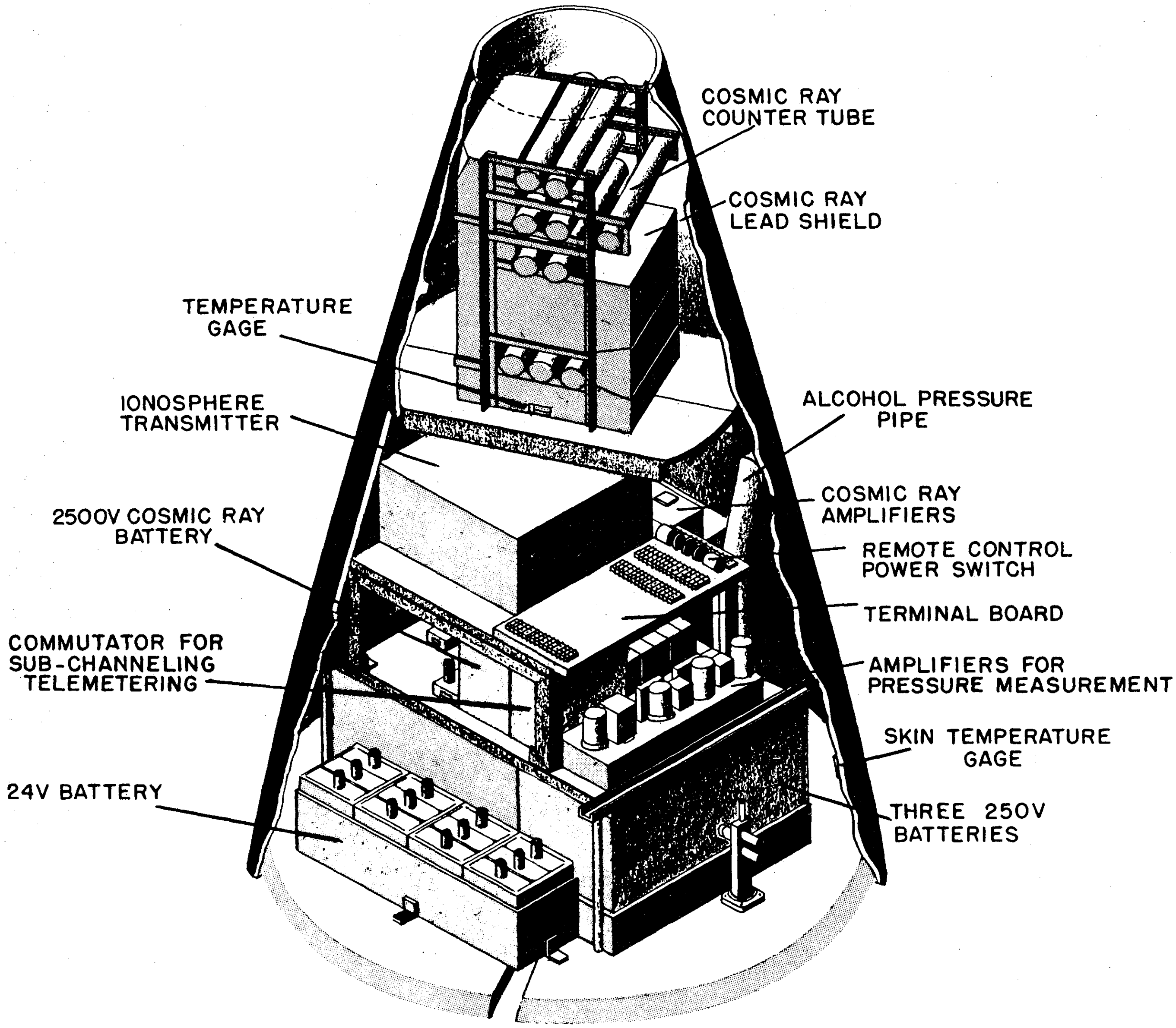
V-2 WARHEAD SHELL WITH ACCESS DOORS REMOVED

The electronics installations included a three channel ionosphere transmitter, the cosmic ray counter electronics, amplifiers for temperature and pressure measuring units, and also smaller special purpose transmitters and receivers. There were in addition a special 17 point power switch, commutators for conversion of two channels of telemetering into 28 sub-channels for conveying pressure and temperature data, the cosmic ray counters with 500 pounds of lead shielding, and a terminal board. Drawings of the main warhead shell with its instrumentation are shown in Figs. 2 and 3.

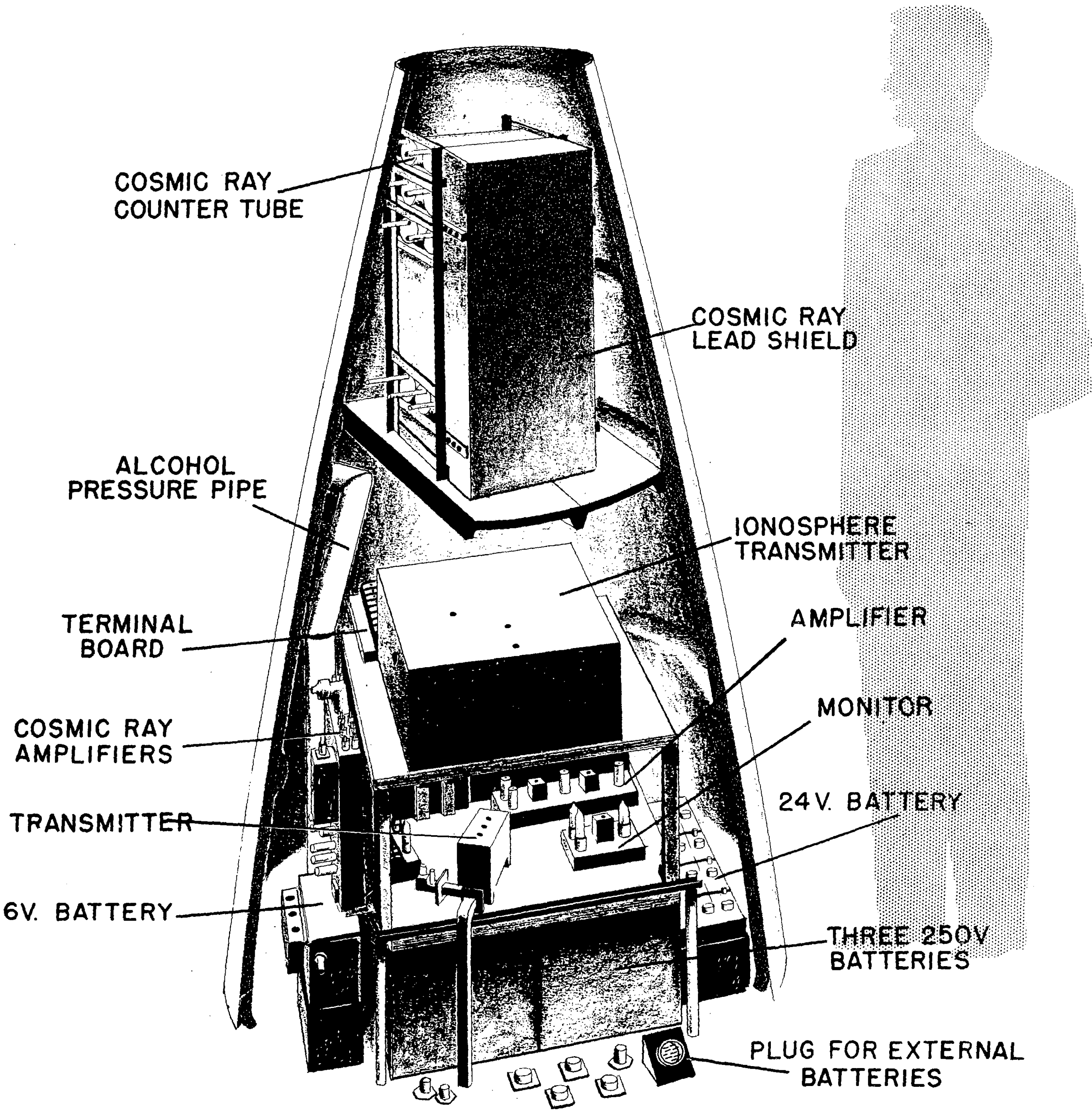
All equipment must be mounted so as to withstand an upward acceleration of 6g. This is accomplished by using heavy channel sections securely welded to internal ribs which were cast into the warhead for this purpose. In addition, for each flight the entire shell consisting of the main warhead body, the nose section, and the nose tip, together with all installations, must be carefully balanced prior to final assembly of the rocket, in order to locate the center of gravity for proper operation of the rocket while in flight. This was done for the June 28 Naval Research Laboratory flight on a specially designed balancing cradle.

Although most of the power supply and instrumentation for research goes into the warhead, considerations of space and convenience make it advisable to locate such equipment as is common to all flights in the portion of the missile immediately behind the warhead. This portion is known as the control chamber, and is divided into longitudinal quadrants. Quadrant I contains the telemetering transmitter, emergency cutoff receiver, doppler tracking unit, and batteries for cutoff receiver, as shown in Fig. 4. Quadrant II houses the electrical ground control pullaway plug which is released at the instant full power is applied to the rocket motor at launching. Quadrant III encloses the gyro control equipment for the rocket, and in Quadrant IV there are pressure tanks and extra control batteries.

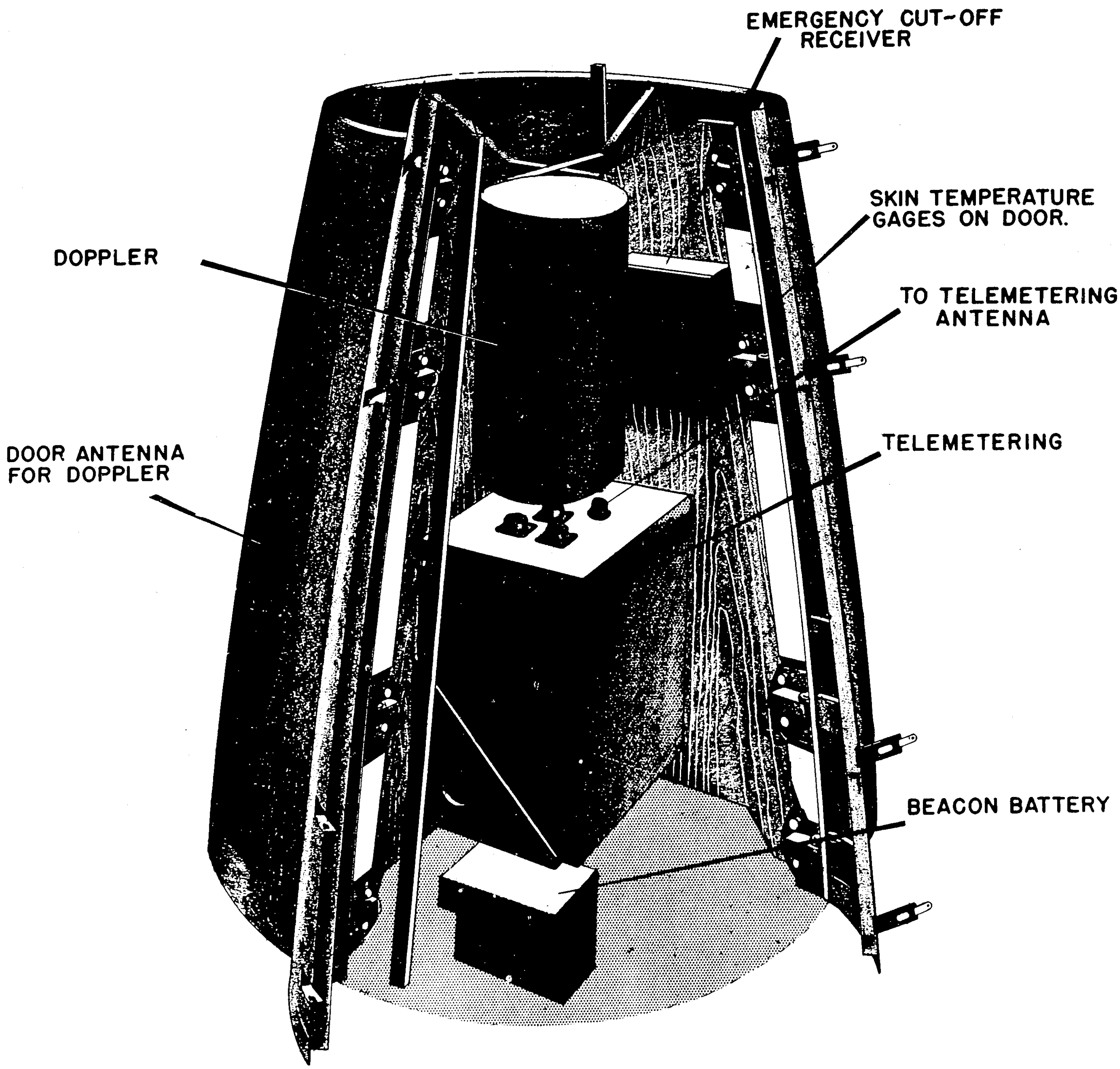
In the June 28 Naval Research Laboratory flight an attempt was made to separate the warhead from the afterbody of the missile just prior to reentering the atmosphere on the downward flight. To accomplish this, explosives were attached to the stringers supporting the warhead. In addition weight was added to the base of the warhead to make it tumble base downward after separation, and thereby to increase its air resistance and improve generally the chances of recovery. The weight was added in the form of circular laminas of 1/2 inch boiler plate welded to the lower face of the warhead base. Eight such plates, of decreasing diameter, were welded together to form essentially an inverted cone having a total weight of 490 pounds. This made the total weight of the final warhead assembly exactly 2800 pounds.



WARHEAD INSTRUMENTATION (VIEW I)



WARHEAD INSTRUMENTATION (VIEW 2)



CONTROL CHAMBER INSTRUMENTATION

CHAPTER II

EQUIPMENT DEVELOPED AND PROVIDED BY THE NAVAL RESEARCH LABORATORY FOR GENERAL USE IN THE V-2 FIRINGS

B. The Emergency Cutoff System

by

W. V. Foley and H. C. Hanks

The launching of a V-2 rocket is always accompanied by some uncertainty. Should something happen to the missile very early in its flight, it could depart considerably from its prescribed course and perhaps land outside the firing range. To provide for such a contingency the Naval Research Laboratory modified an existing radio control system to provide for manual cutoff of the fuel at any time by an operator on the ground. To date such emergency equipment has been installed in ten missiles and used in three flights, as shown in Table II.

The frequency modulated radio control system developed during the war for drone and missile control was most readily adapted for the purpose. The transmitter used is the ARW-3, 10-channel equipment with an output of 50 watts which can be raised to a total of 250 watts by means of the AM-10/ARW-3 amplifier. This amplifier has been used in all flights except that of April 16, in which case a tube had burned out just prior to the firing. In spite of this the 50 watt output from the ARW-3 proved satisfactory to initiate cutoff.

The receiver used in the missile is the ARW-17, 5-channel radio control receiver. This receiver was developed by the Naval Research Laboratory during the war and used in the Azon and Razon. The receiver has the dimensions 4-5/8 x 9-1/8 x 8-1/8 inches, and an approximate weight of 17 pounds. It is shown installed in quadrant I of the control chamber in Fig. 2. A pressurized case has been included for the receiver in all missiles since the July 28 firing. This pressurized installation for the July 28 V-2 is shown in Fig. 1.

Three of the control channels are used for emergency cutoff purposes. By interconnecting output relays on the receiver, the emergency cutoff signal is effective only if all three channels are received simultaneously. This type of operation minimizes the effect of interference from the many other radio frequencies involved in the flight. For those firings in which the warhead blow-off is obtained by a radio signal, channels 4 and 5 of the ten are used.

The equipment is capable of operation throughout the frequency band from 30 to 42 megacycles. In all operations thus far, the frequency used has been 40.54 megacycles.

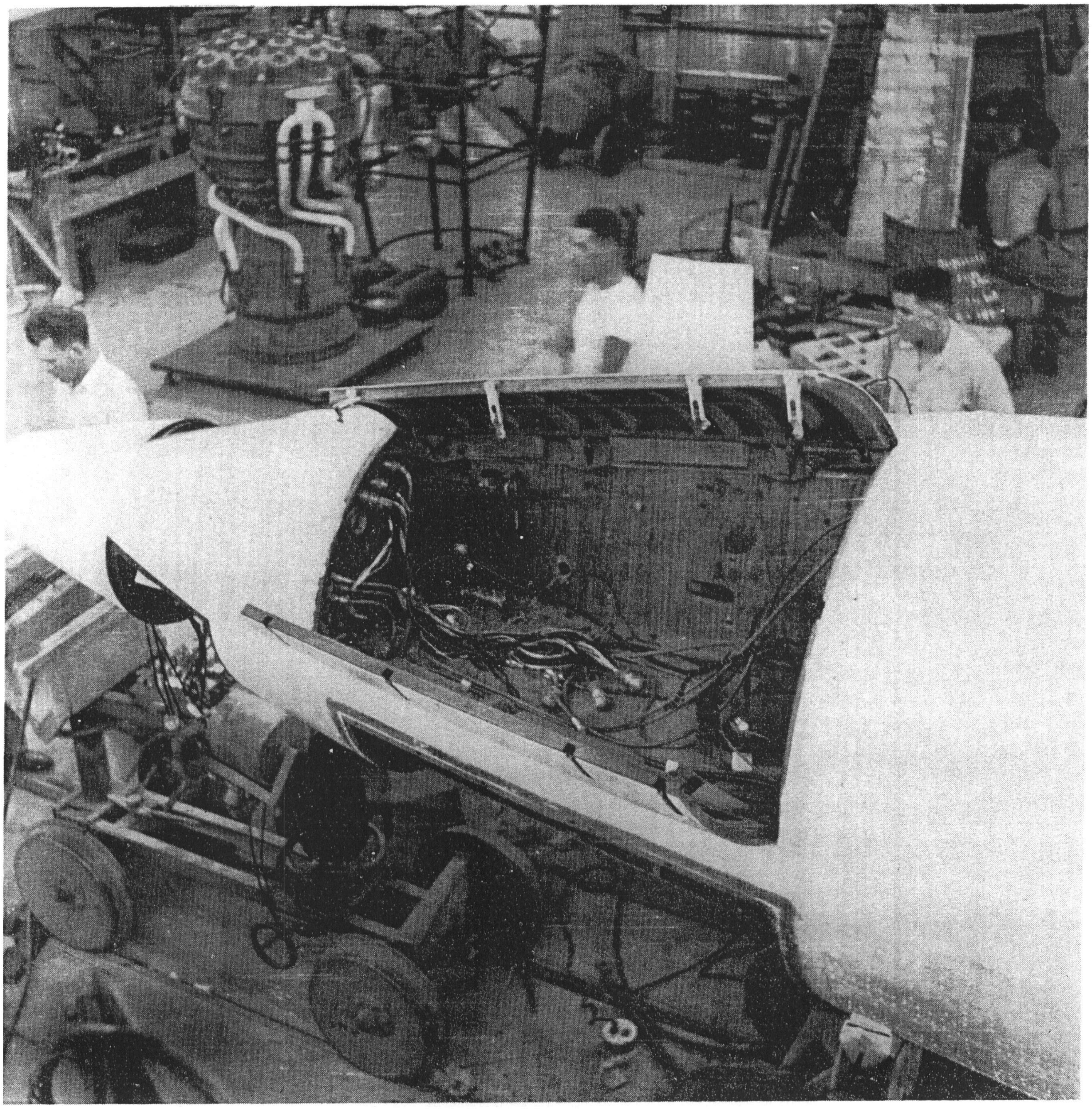
Both the transmitter and receiver are crystal controlled.

The ground installation for emergency cutoff is usually placed at a point approximately 1 mile south of the launching stand. The equipment is mounted in a jeep for mobility. A picture of the installation is shown in Fig. 3.

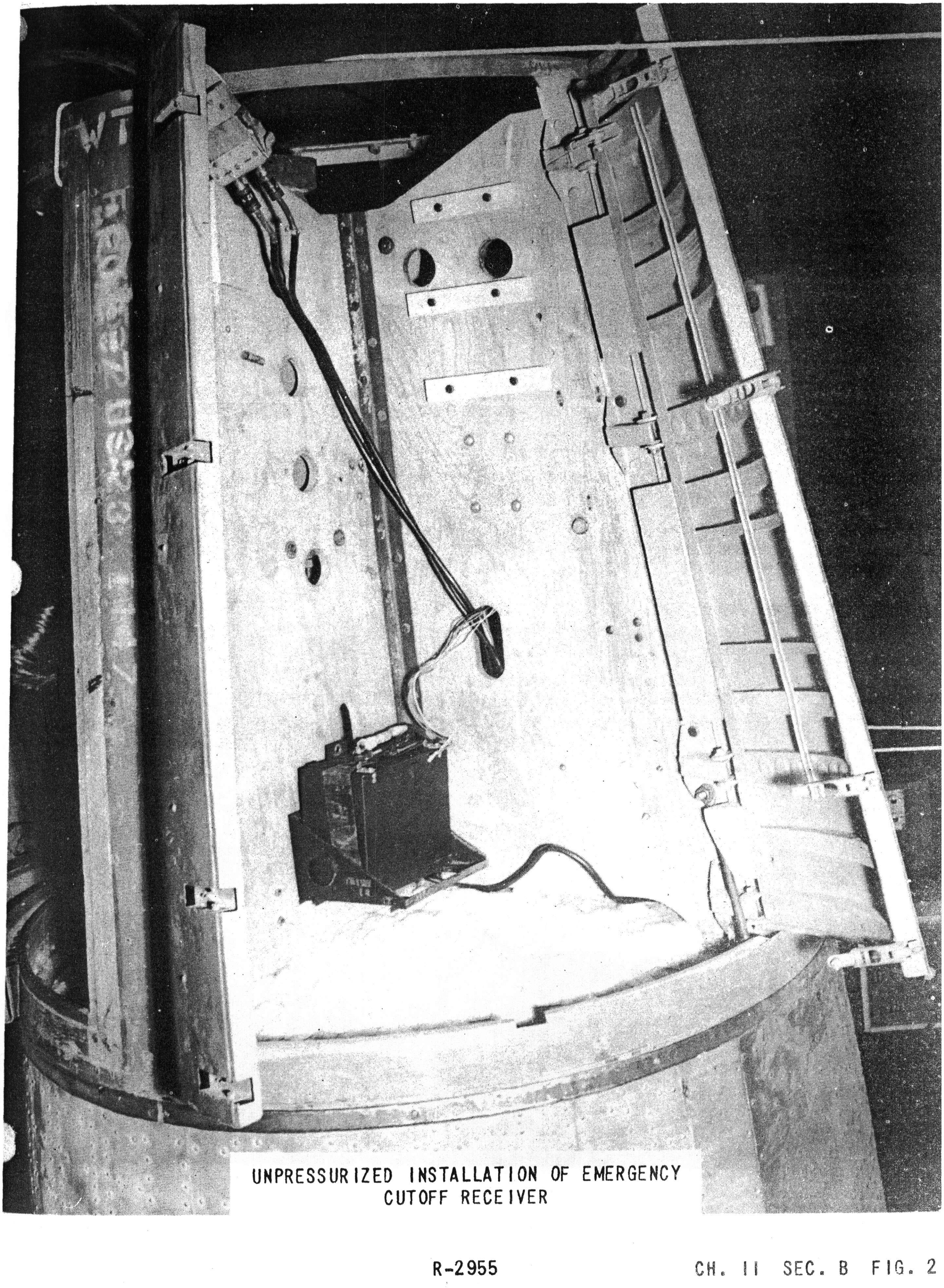
The receiver in the V-2 utilizes one of the German strip antennas, as shown in Fig. 2 of the General Introduction. The strip antenna is a dipole, half on one fin and half on another. The results of the April 16 firing proved that this was not the best choice for an emergency cutoff antenna, since during the flight one of the fins carrying the emergency cutoff antenna fell off very early in the flight. Also, in coming off, it tore loose the other half of the dipole, with the result that the antenna through which emergency cutoff was successfully effected, consisted of merely a small piece of wire which was still attached to the feed line.

In the June 28 firing, the emergency cutoff receiver was also used for blowing off the warhead. To accomplish this, another ground station was located within approximately 5 miles of the calculated impact point. Communications with the launching site were provided at this point. As mentioned previously, channels 4 and 5 of the receiver were used for warhead blow-off. A decelerometer which was hurriedly constructed, was set to close at 1 g deceleration, but to increase the reliability of the setup, a radio blow-off circuit was connected in parallel with the decelerometer. Fig. 4 shows this circuit.

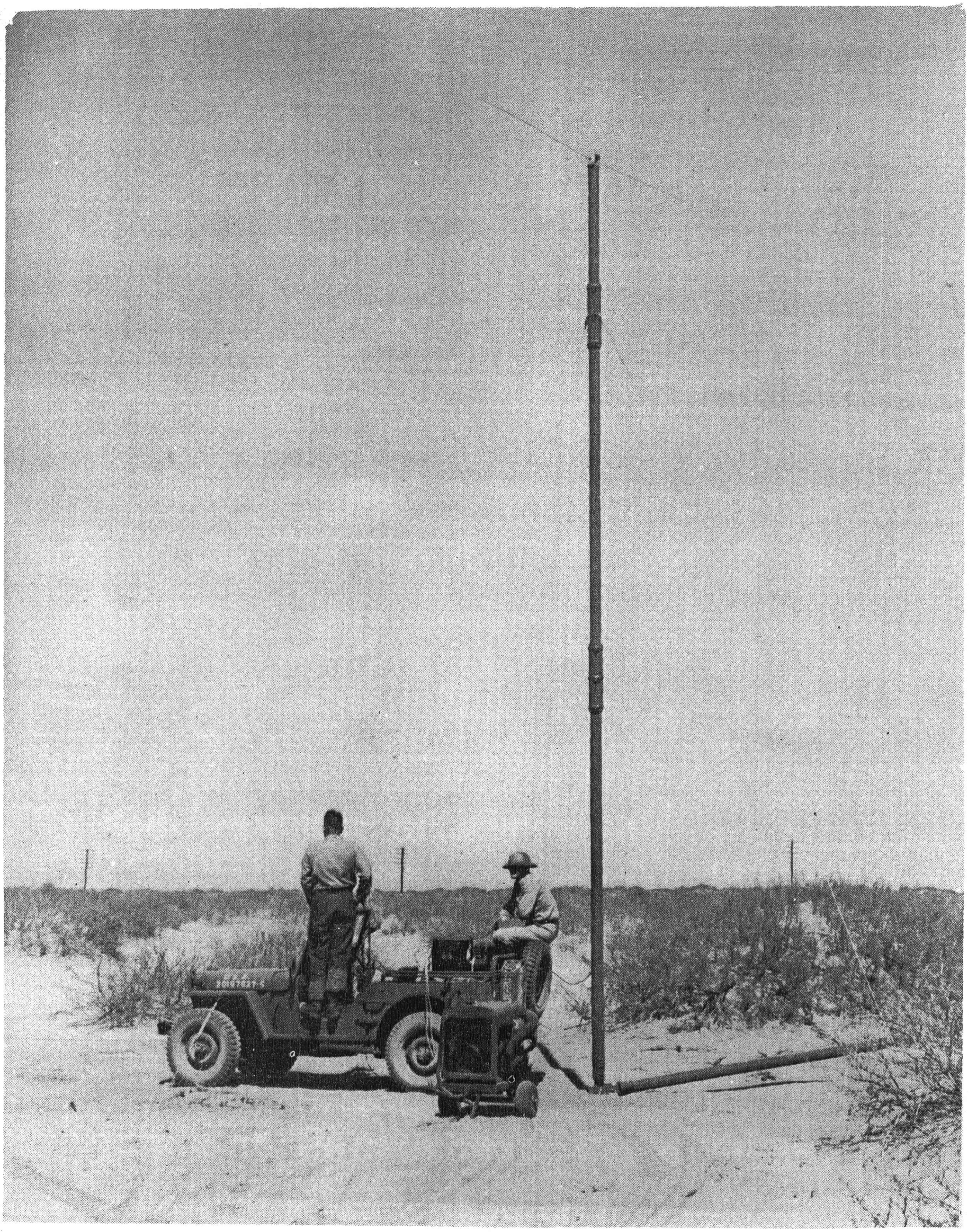
The signal for blow-off on the radio channel was given at 320 seconds, which was slightly before operation of the decelerometer was expected. Numerous independent observers saw that the two pounds of explosive in the top of the instrument chamber did detonate. This was also shown to be true by film records. However, as far as could be seen from the various optical stations, the missile remained intact. These observations, the size of the crater formed upon impact, and the complete destruction of the missile wrought by the impact, seem to be conclusive evidence that separation of the warhead and after-body did not take place.



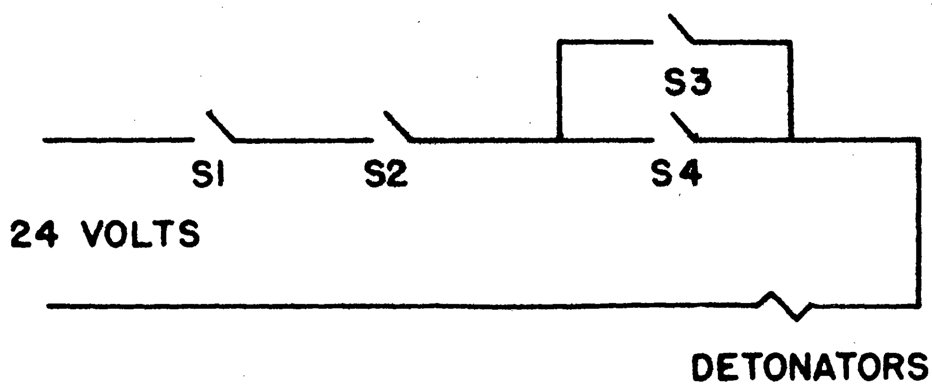
EMERGENCY CUTOFF RECEIVER INSTALLED IN
PRESSURIZED CONTROL EQUIPMENT



UNPRESSURIZED INSTALLATION OF EMERGENCY
CUTOFF RECEIVER



EMERGENCY CUTOFF GROUND STATION



S1-MANUAL ARMING SWITCH

S2-V-2 PROGRAM SWITCH
(CLOSED AT 260 SECONDS
AFTER TAKE OFF)

S3-ACCELERATION SWITCH

S4-RADIO CONTROLLED
SWITCH

ARMING AND FIRING CIRCUIT

CHAPTER II

EQUIPMENT DEVELOPED AND PROVIDED BY THE NAVAL RESEARCH LABORATORY FOR GENERAL USE IN THE V-2 FIRINGS

C. Telemetering from the V-2

by

V. L. Heeren, C. H. Hoeppner,
J. R. Kauke, S. W. Lichtman, and P. R. Shifflett

1. Introduction. One of the most important problems which must be solved in connection with the use of a rocket as a vehicle for upper atmosphere research is that of making available to the observer information obtained at the rocket during flight. Actual recovery of a record either by ejection during the rocket flight or from the wreckage after the missile has crashed to earth again, presents tremendous problems which have as yet been solved only partially. On the other hand, the techniques of radio telemetry have progressed in the past few years to the point where they can be used to radio a wide variety of measurements from the upper atmosphere. At present, although methods of recovery are under development, telemetering techniques appear to furnish the most satisfactory means for high altitude research in rockets.

Radio telemetering equipment designed by the Rocket Sonde Research Section has been employed for this purpose during all of the V-2 firings at White Sands. The service furnished is basic both to the upper atmosphere research program and to concurrent studies made of the technical and military characteristics of the rockets themselves. Typical of the basic research data telemetered by the system are: temperatures and pressures in the upper atmosphere; various characteristics of the primary cosmic radiation; and properties of the ionosphere. For studies of rocket performance, data are telemetered on such quantities as speed, rocket acceleration and attitude, skin temperatures at various critical points, and motion of the control fins.

The general problem of telemetering is taken to include not only the making of measurements at a distance, but also the relaying of the data so obtained to a specified station, where they may be recorded. A complete telemetering system includes the functions of measuring, of transmitting, of receiving and of recording. What is referred to in this discussion as the Naval Research Laboratory "telemetering system" actually is a system for performing only the last three of these functions. The design and construction of apparatus for performing the first of the functions is generally included in the instrumentation of the experiment concerned. The data from the experimental instruments are presented to the telemetering system in the form of characteristic voltages of fixed sign. In the pages to follow, these voltages will be referred to as "data voltages".

The system used at White Sands was designed to telemeter, by means of independent time channels, as many as twenty three separate quantities by successively sampling a corresponding number of data voltages. The sampled voltages are then converted by the system to a form suitable for radio transmission. They are then radioed to a ground station, reconverted to their original form, and recorded.

To obtain reliable telemetering over ranges in excess of 100 miles with limited allowances for size and weight of the rocket borne equipment, a time modulated pulse system was chosen. The pulse system delivers a higher peak power with a lower average power consumption and occupies less space than a comparable continuous carrier system. The system used in the V-2 operates at about 1000 megacycles, a frequency which is high enough to penetrate the ionosphere, and which at the same time is clear of other frequencies used in the flights.

2. <u>General Description</u>: <u>Basic Telemetering Theory</u>. The basic method of data transmission in the Naval Research Laboratory pulse-time modulated telemetering system is to convert the data voltages into time intervals. These intervals, defined by voltage pulses, correspond in length to the magnitude of the data voltages. The data voltages are sampled in a specific order and are used to generate a series of pulses, the time intervals between which measure the sampled data voltages. The intervals maintain the same time sequence as the sampled voltages, the pulse marking the end of one interval serving as the initial pulse of the succeeding interval. A complete sampling of all data voltages is used to form such a group of time intervals periodically. A master keyer initiates the sampling process at a uniform rate. The distinction between different groups is made possible by allowing for a sufficiently long time between the initial pulses of each group. In this manner, the interval between the last pulse of one group and the first of the next is made to be very much longer than any of the measurement intervals.

<u>The Airborne Unit</u>. The diagram in Fig. 1 is a schematic, in block form, of the airborne unit which converts data voltages into appropriate form and transmits a corresponding radio frequency signal. A master keyer, which is a freely running multivibrator of constant period, generates the first pulse of each group. This pulse is fed to a channel collector, a circuit common to the outputs of each time channel, and at the same time is used to trigger time channel multivibrator No. 1. The

multivibrator for each channel is of the self returning type, the recovery time of which is determined by the corresponding data voltage. The first, upon recovery, delivers a pulse both to the channel collector and to channel No. 2. The multivibrator of No. 2, in turn, triggers that of the next channel and delivers an output pulse to the collector. The process is repeated in appropriate sequence until all time channels have operated, after which the circuit is quiescent until the master keyer again initiates the sequence. The output pulses delivered to the channel collector by the various multivibrators are then fed to a power modulator which in turn pulses the VHF power oscillator, feeding the antenna.

The Ground Station. Fig. 2 is a block diagram of the ground station, which receives, decodes and records the data. The antenna is trained to follow the airborne radiator by both optical and signal maximizing techniques. The detected output of the receiver, suitably amplified, is fed into a decoder unit, the purpose of which is to recover the original voltage forms from the time modulated signals. The original data is then separated into the various channels, displayed on meters, and recorded by various methods.

The use of several different methods of recording safeguards against the possibility that the whole record be lost due to the failure of any one method. The principal record is made on a moving strip of photographic paper by means of Hathaway magnetic string oscillographs. A sample recording appears in Fig. 4. Auxiliary records are obtained by photographing the meter panel with a 35 mm movie camera. An oscillographic record is made of the output of the video amplifier with a continuous film camera. The same signal is recorded on a magnetic wire recorder from which the data can be recovered later in the event of decoder failure. Timing signals are impressed on all of the recording media from a time signal receiver.

The Decoder. A block diagram of the decoder unit appears in Fig. 3. Output from the telemetering receiver is fed to the pulse discriminator which may be adjusted to reject pulses of other than a specified duration. The discriminator output is fed to both the synchronizing pulse generator and to the input of each channel separator via the pulse inverter. The synchronizing generator output consists of one pulse at the start of every group of received pulses, which goes to channel No. 1 separator, triggering a multivibrator. This multivibrator is returned to its original state by the second pulse of the pulse group now arriving from the inverter. When separator No. 1 is returned, it delivers a pulse which triggers No. 2 separator. The return of No. 2 separator is effected by the third pulse of the incoming series relayed by the pulse inverter. This action continues, each channel separator triggering the following channel while being itself returned by the incoming signal.

During the conduction period for any channel separator, the corresponding metering circuit is fed a constant voltage, the same for all channels, for a length of time equal to the interval representing the corresponding data voltage. A capacitor is charged thereby to a potential which depends upon the duration of the voltage applied. By suitable circuits, this potential is measured with a vacuum tube voltmeter, the magnitude being a linear function of the original data voltage.

3. Auxiliary Systems: The Calibrator. Calibrator units are placed in the transmitting station to determine any shift in the absolute response of the system. The calibrator periodically breaks the connection from the data voltage source to the pulse time modulator channel, and connects in its stead, first a ground or zero voltage and then a stable reference potential of 3.5 volts. Two such calibrating units are built into each transmitter. A schematic diagram of the calibration circuits appears in Fig. 5. Fig. 4 shows the calibration on several channels of an oscillograph recording.

The Commutator. A large number of slowly varying quantities such as temperature and pressure may be measured through a single telemetering channel by mechanical commutation. When used, such mechanical commutators are provided as part of the instrumentation of the experiment concerned.

For the June 28 firing, temperature and pressure measurements utilized 16 commutated sub-channels compressed into two telemetering channels. Two 10 contact commutators were driven by a common shaft rotating at 2 r.p.s., the data voltages being connected to the fixed contacts of the commutator, the movable arm selecting each in sequence. Each commutator consisted of ten equally spaced contact segments, cyclically arranged about a central shaft carrying the moving contact. By this means, each of eight data voltages was in its turn connected to the input of one or the other of the two sub-commutated telemetering channels. The remaining two contacts were used to supply reference voltagesand to identify the end of each commutator cycle. The oscillogram of Fig. 6 shows a record obtained by subcommutating.

These commutators proved to be reliable and supplied the data in a convenient form for analysis. Improvements have been incorporated into the latest commutators, where the number of contacts has been increased to 14 and the speed reduced to 1 r.p.s. A photograph of the latest model is given in Fig. 7. In order to facilitate the checking of individual subchannels, a switch for stopping the driving motor and a knob for turning the commutator by hand are included. The manual drive is normally held disengaged from the motor shaft by means of a spring as shown by the photograph.

The definite advantages of commutation have been recognized by other groups utilizing the telemetering channels and the use of commutators will undoubtedly be expanded in future tests.

The Timing System. The data taken by telemetering is correlated with radar tracking plots, optical data, and photographic records of the missile's trajectory by means of a master timing signal. Thus, the telemetered information may be plotted as a function of the altitude of the rocket.

The timing signals originate at a special installation provided by a group from the Army's Aberdeen Proving Ground. They consist of a timing pulse every half second above a 100 cycle background, beginning at the time of the rocket takeoff, with every twentieth pulse after takeoff omitted. These signals are made available to all groups engaged in the V-2 firing operations.

At the telemetering ground station, the time signals are fed to one of the Hathaway oscillograph recording channels to make a permanent time reference along with the telemetered data. One edge of Fig. 6 shows the recorded time signal. The time signal also triggers time marking devices used with the movie camera, wire recorder, and continuous film camera.

4. Physical Layout: The Airborne Unit. Obvious limitations in size and weight are imposed at the outset on any rocket borne equipment. The airborne unit of the telemetering system is therefore compressed into as small a space as possible. The dimensions are 14 x 14 x 20 inches and the total weight, including the pressure sealed case, is 150 pounds. A view of the unit in its case is shown in Fig. 8, while Fig. 9 shows two groups of pulse time modulator circuits and the high voltage supply battery. Sample pulse time modulator units illustrating the subminiature tube construction are shown removed from their sockets. The two motors seen in the upper corners of the view drive the calibrator unit for each section of the pulse time modulator. Fig. 10 shows the location of the oscillator cavity, the power modulator, and the filament battery in the transmitter assembly. Fig. 1 of Chapter II, Section B shows the instrument compartment of a V-2 rocket before installation of the airborne unit.

Fig. 11 shows the 1000 megacycle dipole antenna mounted on one of the V-2 rocket fins. The bakelite covering over the antenna, which is intended to prevent corona loss and also to facilitate pressurizing, must be rigid enough to withstand an aerodynamic drag of 150 pounds. The 45 foot RG-17/U transmission cable from transmitter to antenna is pressure sealed to prevent ionization losses in cable connectors at high altitudes.

The Ground Station. The telemetering ground station is not limited in size and weight as is the telemetering transmitter, but may be constructed as elaborately as desired, consistent with mobility. Fig. 12 shows the trailer in which the equipment is housed, and a truck which contains a 25 kilowatt power generator. The trailer carries a 1000 megacycle receiver, a decoder, recording equipment, monitoring and test equipment, communication receivers and transmitters, and timing mechanisms. The interior of the trailer is shown in Fig. 13. On the table from right to left are the timer unit, antenna servo control unit, a monitoring scope, and a video amplifier. The upright instrument near the middle of the view is the decoder. The instrument on the table in the lower left corner of the view is a standard 12 channel Hathaway magnetic string oscillograph. The meters on the panel between the decoder and oscillograph read individual channel output voltages and are photographed by a 35 millimeter Bell and Howell movie camera, not shown in the figure. The decoder circuits, aside from the power supply, are completely constructed of subassemblies, an example of which is shown in Fig. 14. These subassemblies, plug into sockets as shown in Fig. 15 and permit quick removal for replacement and repair. Fig. 16 gives a front view of the decoder.

The ground station antenna located at the center of the trailer roof is shown in Fig. 17. The antenna can be directed either by an observer on the roof or by an operator inside the trailer. For the most part all operations work automatically during a telemetering run except for directing the antenna which is done both optically and by listening to the signal and maximizing the output.

More than one ground station is used to lessen the chance of a break in the telemetering service. In all of the firings to date, there have been two mobile stations in operation similar to the one described above, and at present a fixed station is under construction.

5. Procedure for Calibration and Data Recovery. The overall response of the telemetering system is very nearly linear. A careful determination of the departure from complete linearity is made for each channel prior to each rocket flight. The procedure is to apply known voltages to the input of each channel in the airborne unit. The corresponding outputs at the ground station may then be plotted against the known input voltages to obtain a calibration curve. This is usually done by first converting the output voltages to percentages relative to the output corresponding to the maximum input. An example of such a calibration curve appears in Fig. 18.

During actual flight operation of the telemetering system, two known voltages are periodically and alternately applied at the input of each channel requiring specific calibration. This provides two known points on the calibration curve. It is assumed that even though there may be a drift in the magnitude of the output for a given input, nevertheless the form of the calibration curve remains unchanged. This would not, of course, be true for a calibration in terms of actual, rather than relative, output values.

The records provided by the Hathaway oscillographs are plots of the voltage outputs of the decoder versus time. Such recorded output voltages may be used with the calibration curves described above to determine the actual voltages applied to the inputs of the airborne unit. A sample oscillogram is shown in Fig. 4. Both at the top and at the bottom of the strip there are recorded auxiliary markings. One is a time scale indicating half second intervals from takeoff. Such a time scale provides a means of relating data to rocket behavior. The other is a reference base line provided to indicate sidewise motion of the paper as it moves through the recorder. The base line may be used in the final reduction of data, for eliminating the effect of such a shift.

Ordinarily the calibration of the data voltage source is independent of the telemetering system. The effect of the telemetering input on high impedance sources, however, must be determined. Fig. 19 is a typical calibration of an accelerometer which was telemetered in a V-2 flight by means of the channel calibrated in Fig. 18.

The difficulty of recovering data from a record varies with the type of information required. The procedure outlined above applies to the making of quantitative measurements. Fig. 20 shows data recovered from a quantitative record of the accelerometer discussed in connection with the calibration curves of Figs. 18 and 19. If subcommutation of a telemetering channel is employed, it is necessary to add to the record a means for determining a specific phase in the commutation cycle. This may be done by reference to a periodically recurring deflection pattern introduced into the record specifically for this purpose. The pattern incidentally furnishes additional calibration for the subcommutated channel. To recover data represented by an on-off signal, it is necessary merely to be able to distinguish between zero and non zero voltages; there is plainly no need for calibration.

6. Detailed Circuit Description: Pulse Time Modulator. The pulse time modulator is designed to generate a time interval over the range of from 50 microseconds for a zero voltage input to 200 microseconds for a + 5 volt input signal. These times are measured from the leading edges of the two pulses defining a time interval.

To maintain satisfactory differentiation between groups, it is necessary that there be a spacing of at least 600 microseconds between the last pulse of one group and the first pulse of the next. Furthermore, the full 200 microsecond period, corresponding to a + 5 volt input, might conceivably be required for all channels in one sampling cycle. Thus, the time required for the formation of a single group of telemetering pulses may be as long as 5,200 microseconds for a 23 channel system. In such a case, the maximum allowable repetition rate is 192 cycles a second. With such an arrangement data voltages fed into the telemetering channels are sampled 192 times a second. There is, however, no reason why the pulse group repetition rate must be this rapid. The system is adaptable to any rate of less than 192 cycles a second.

The circuit diagram of the airborne unit appears in Fig. 21; the corresponding wave forms are shown in Fig. 22. All electronic circuit functions are initiated by a master keyer, which is simply a freely running multivibrator. The period of the multivibrator of the master keyer is the pulse group repetition period, and is set by adjusting R-4. The output from the master keyer, Fig. 22:A, consists of square waves which are coupled through short time constant circuits to both channel No. 1 and the channel collector. The positive surge from the keyer does not affect either channel No. 1 or the channel collector. The surge does not affect V-4 because the grid is already at full conduction potential. It does not pass to the channel collector because it is blocked by the diode crystal, X-1. At time t_1, the negative surge from the keyer acting upon the blocked multivibrator of channel No. 1, triggers it from its normal state to a temporary state, i.e., from a state in which V-4 is conducting to a state in which V-3 is conducting. As a result of the negative surge impressed upon the grid of V-4 the potential of the common cathodes drops until V-3 begins to conduct. Conduction of V-3 produces a negative surge at its anode which is coupled to the grid of V-4 to drive that grid still further negative. Channel No. 1 now remains in its temporary state until the charge impressed upon this grid, leaks off through resistors R-13 and R-14.

During the temporary state of channel No. 1, the grid potential of V-4 rises at an exponential rate determined by C-5, R-13 and R-14. At time t_2, after the grid of V-4 has returned sufficiently positive, conduction in V-4 again begins; the cathode potential rises, a positive surge is generated at the anode of V-3 which is coupled to the grid of V-4, and the circuit returns to its steady state condition. Upon its return to the steady state condition, however, a negative surge is generated at point D. This surge, coupled through short time constant circuits to channel No. 2, initiates in channel No. 2 an action similar to that which took place in channel No. 1. Such action continues from one channel to the next, the return of a channel to its stable state triggering the succeeding channel to its temporary state, and simultaneously delivering a pulse to the channel collector circuit. When the last channel is reached the action stops and does not repeat until a pulse from the master keyer once more triggers channel No. 1.

The length of time during which each channel remains in its temporary state, is determined by the voltage input to that channel. Each channel is calibrated so that with 0 volts applied to the input, the temporary state is of 50 microseconds duration, and with 5 volts applied to the channel the temporary state is of 200 microseconds duration. The calibration procedure, as illustrated in connection with channel No. 1, consists of first setting the input voltage to zero and adjusting R-13 until the temporary state duration is 50 microseconds. Then with a positive voltage of 5 volts applied to the input, R-9 is adjusted until the temporary state duration is 200 microseconds. Fixed resistances matching the values of R-9 and R-13 are then mounted in place of the temporary variable resistances. The applied voltage is effective both upon the triggering and the return of each channel. A positive voltage on the grid of V-3, Fig. 21, produces a much heavier conduction in that tube when the channel is triggered. Hence, a larger negative signal is impressed on the grid of V-4 and therefore takes a longer time to leak off through resistors R-13 and R-14. Furthermore, the level to which the voltage must leak, before conduction in V-4 begins, is raised. As a consequence the voltage which is effective in determining the temporary state duration is the input voltage which is applied during the temporary state. With this system of pulse time modulation the duration of the temporary state of each channel can be made a linear function of the input voltage.

Upon the return of each channel to its normal state a negative pulse is transmitted to the channel collector, Fig. 22:G. Each pulse is transmitted through a small crystal diode to the common line G. The purpose of the crystal diodes is to prevent interference between channels and to allow a pulse of sufficient amplitude to reach the amplifier of the channel collector. Furthermore, only the negative pulse on the return of each channel to its normal state is transmitted through the diode to common line G. Thus, for 23 channels, 24 pulses in each group are transmitted to the grid of the amplifier tube, V-7, where they are amplified and inverted in phase to trigger the blocked multivibrator of the channel collector. The channel collector is similar in action to the channels themselves, except that its temporary state is made very short. The pulse generated by the return of each channel, triggers the channel collector to produce an output pulse Fig. 22:I, which is of constant duration and amplitude, regardless of the variation in the signal received from each channel. The periods between collector trigger pulses, therefore, occur simultaneously with the periods at which the respective channel multivibrators are in their temporary states. The information has thus been converted from a voltage to a pulse spacing.

Positive pulses from point I of the channel collector, Fig. 21, first pass through a cathode follower, V-10, and trigger and blocking oscillator, V-11A, which in turn generates sharp pulses of one microsecond duration. Since the blocking oscillator is of a type commonly used in television synchronization circuits, its operation will not be described here. The one microsecond pulse from the blocking oscillator is fed through the cathode follower, V-11B, and hence at low impedance to the grid of the 3E29 modulator tube, both halves of which are connected in parallel. The grids of the modulator tube are driven highly positive to cause full conduction of the tube. A pulse transformer steps up the output pulse from the modulator tube and applies it to the radio frequency oscillator.

The antenna feeder line is capacitively coupled to the oscillator cavity. A peak pulse power output of approximately 750 watts is obtained at 1000 mc, with a pulse width of approximately 0.8 microsecond at the half power level.

Although the telemetering transmitter is not fused, there are some protective devices incorporated in it. A series resistor such as R-8, and crystal diodes such as X-2 and X-3, are connected to the input of each channel to limit the input voltage from 0 to +6 volts. This precaution is taken in order to ensure the proper functioning of the telemetering equipment, even though incorrect voltages are applied to the inputs. Without protection the application of voltages greater or less than those prescribed causes malfunctioning of the entire transmitter. A voltage applied that is too high will cause a channel to oscillate, sending out a series of equally spaced pulses, while a voltage that is too low will completely stop the action of the multivibrator and prevent triggering of all subsequent channels.

Pulse Width Discriminator. The pulses transmitted from the airborne unit are received by the ground station antenna, amplified by the receiver, and are passed on to the decoder units for separating the channels and presenting the channel information for analysis. The signal, as received, may contain signals other than those transmitted by the airborne unit, such as spurious noise peaks, radar interference, etc. Therefore, the signal, upon entering the decoder, first passes into a pulse discriminator, which limits receiver noise and distinguishes the proper pulses on the basis of their duration. Pulses of a duration greater or less than 0.8 microsecond, are automatically eliminated at this point. Only pulses of the proper duration, whose amplitudes are considerably above the average noise level are allowed to pass.

The signal from the receiver is illustrated in Fig. 24:A. It contains pulses of the proper duration as represented by pulse No. 2; pulses of insufficient duration as represented by pulse No. 1; pulses of excessive duration as represented by 3; and receiver noise. During operation, R-3, Fig. 23, is adjusted so that the bias on the grid of V-1 is low enough to limit the average receiver noise and yet allow the pulses to cause V-1 to conduct. The inverted signal, Fig. 24:B, appears on the anode of V-1 and is coupled to the grids of two normally conducting triodes, V-2A and V-2B. When V-2A conducts, its anode is at a negative potential with respect to ground, keeping V-3 cut off. A negative pulse on point B renders V-2A non conducting for the pulse duration, but the rate of potential rise of its anode is limited by the charging rate of the shunt capacitance, C-A, through R-6 and R-7, as illustrated in Fig. 24:C. Only pulses with the proper duration or greater, allow point C to rise high enough to cause V-3 to conduct. The negative pulse developed on the anode of V-3 is coupled to the coincidence tube, V-4, through a short time constant circuit. Only the positive surge generated at point E can have any effect on V-4 because point E is normally at cutoff potential. The effect on V-4 also depends upon the coincidence signal on point G.

A negative pulse at point B, Fig. 23, renders V-2B non conducting as it did V-2A, and the rate of potential rise at point F is also limited; but because the anode of V-2B is normally at a lower potential than that of V-2A by virtue of the difference in cathode potentials, it takes a pulse of greater duration to allow V-5A to conduct than it does to allow V-3 to conduct. The limits have been designed so that only pulses of excessive duration cause V-5A to conduct, and cause a negative pulse at point G. Thus for input pulses of excessive duration, the positive surge on point E at time t_6 has no effect on the anode of V-4, because of the coincident negative surge at point G.

Input pulses of the proper duration produce a positive surge at point E without the blocking negative surge at point G; but the resulting signal at point H is not in as stable a form as desired. Tubes V-5B and V-6 are added to convert the positive surge at point E to a stable, uniform pulse to be passed to subsequent decoder circuits. When a pulse of proper duration is received, the positive surge at point E causes a negative surge to appear at point H which is coupled to the grid of the normally conducting tube, V-6, and cuts it off. A positive surge appears at point K and the common cathode bias, developed by current through R-16, drops until V-5B conducts, causing an additional negative surge at H to hold the grid of V-6 below cutoff. V-5B continues to conduct after V-4 ceases conduction, and point H is held down. The potential on the grid of V-6 immediately begins to rise according to the exponential charging rate of C-6 with current flowing through R-17. When the potential at this point reaches the control region of the grid, V-6 conducts; common cathode bias is produced; V-5B is cutoff; a positive surge appears at point H, driving V-6 to full conduction and causing a negative surge to appear at point K. The values of C-6 and R-17 have been designed so that the duration of the positive pulse at K is from 7 to 10 microseconds. This pulse is passed to subsequent decoder channels.

The range of discrimination can be controlled from the pulse discriminator panel by adjusting the resistors R-6 and R-10, Fig. 23. The values of these resistances control the charging rate of C-A and C-B, and therefore, control the pulse durations required to cause V-3 and V-5A to conduct (Fig. 24:G and Fig. 24:F). R-6 is the control for the minimum limit of the duration of the acceptance band, which can be set from 3/4 to 10 microseconds. R-10, the maximum control, can be set to pass from 0.8 to 12 microsecond pulses. The two limits can be set so that the discrimination will be as close as ± 0.1 microsecond. C-A and C-B represent the shunt capacity of the leads and of the tube elements, but actual condensers of the proper size can be added to shift the useful range to cover pulses of a greater duration.

The Decoder. The Synchronizing Generator. The video signal from the pulse width discriminator to the decoder is very similar to the form of the signal as it left the pulse time modulator in the airborne unit, and the sequence of operations in the decoder is very closely the reverse of what occurs in the pulse time modulator. The first decoder operation is that of generating a synchronizing pulse marking the beginning of each sampling group. This provides a means of directing each channel to its proper output. The relatively long period between pulse groups offers the means of generating the synchronizing pulse.

During the period in the sequence just before a pulse group (Fig. 25:A) is received, tube V-2 is non conducting but its anode is held to ground potential because of current flowing to the grid of tube V-3A. At time t_1, Fig. 26, the first pulse in the ensuing pulse group causes V-2 to conduct fully during the pulse; and because of the high resistance of R-5, the anode potential drops to very close to the cathode potential, discharging C-4 in the process. The grid of V-3A, now far below its cutoff potential, begins to rise slowly as C-4 becomes charged with current through R-5. However, the time necessary to charge C-4 through R-5 is long enough to assure that the grid of tube V-3A does not reach the conducting region before pulse No. 2 occurs, at which time tube V-2 again discharges C-4. This sequence is repeated until the last pulse in the group is reached, tube V-3A remaining non conducting all the while. The interval from the last pulse of one group to the first pulse of the next is long enough to allow the potential at point C to rise until tube V-3A conducts. Conduction begins at time t_x, as shown in Fig. 26. The values of C-4 and R-5 are chosen to make the start of conduction occur approximately 400 microseconds after the last pulse of a group arrives. Conduction then continues until the first pulse of the next group arrives and the cycle is repeated. Signals D and E are therefore generated on the anodes of V-3A and V-3B. Signal D, Fig 26, occurs at very nearly the same position in the cycle as signal A, Fig 22. Signal D serves the same purpose in the decoder that signal A does in the airborne pulse time modulator.

Channel Separators. Signal D is coupled to the channel No. 1 separator, Fig. 25, which is designed to generate a positive pulse, Fig. 25:H, beginning at time t_1 and ending at time t_2 for every pulse group. The positive surge of signal D occurring at t_1 initiates this action, but the only signal from which t_2 can be obtained is signal A, which must first be inverted by tube V-1 before being coupled to the separator. The channel No. 1 separator is a blocked multivibrator consisting of V-4A, V-5A, and V-5B. V-5B normally conducts fully, causing a positive cathode bias on V-5A. The grid of V-5A is returned to ground through R-3 keeping V-5A cut off. The negative pulses on point B do not affect the conduction of V-5A because of the positive cathode bias. Signal D is coupled to V-4A through a small time constant circuit and appears at point F in the form shown in Fig. 26:F. The positive surge causes V-4A to conduct, producing a negative surge at point G and at the grid of V-5B. V-5B is cut off, causing a positive surge at H and removing the positive bias on the cathode of V-5A. At the same time this happens, a negative pulse occurs at B which would prevent the complete triggering of the multivibrator were it not for the fact that the positive pulse at point F is of greater duration than the negative pulse at B. At the termination of the negative pulse at B, the cathode bias has not yet been restored; therefore, V-5A becomes conducting as V-4A becomes non conducting. The low potential at the anode of V-5A and the grid of V-5B is therefore retained, keeping tube V-5B cut off. The multivibrator remains in this temporary condition until negative pulse No. 2 occurs at point B at time t_2. Current in tube V-5A is then cut off; a positive surge occurs at point G causing the grid of V-5B to rise, V-5B conducts; and a negative surge occurs at point H. The cathode bias returns and V-5A stays cut off; further negative pulses at B having no more effect until the cycle is repeated. This process generates the signals at G and H on the anodes of V-5A and V-5B. Since the time t_2-t_1 is the measurement interval of channel No. 1, the signal at H contains channel No. 1 data entirely separated from the data of other channels.

Channel No. 2 separator, Fig. 25, functions exactly like channel No. 1 separator with signal G initiating the action at time t_2 in the same manner that signal D initiated action in channel No. 1 separator at time t_1. The output of channel No. 2 separator, signal M, contains successive measurements from channel No. 2 entirely separated from the other channels. Subsequent channels operate in the same manner, using a signal from each preceding channel to initiate the action, and using signal B to stop the action. The cycle continues until the last channel separator action is completed. The system remains quiet until the next pulse group is received.

Metering Circuits. The function of metering circuits is to convert the information as it appears at point H, M, etc., Fig. 26, to voltages, the values of which are the same as those originally transmitted. Converting the duration of the positive pulse at H to a voltage requires the use of a capacitor which charges at an approximately linear rate for the duration of the pulse. In the channel No. 1 metering circuit, Fig. 25, C-9 is charged in such a manner, with current passing through V-4B, which is normally cut off except for the duration of the positive pulse H. Capacitor C-9 begins to charge from the same reference potential on each cycle. Just before C-9 begins to charge, point I is brought down to the reference level by tubes V-6A, V-6B, and V-7A. Tube V-7A, which is normally cut off, conducts from time t_x until t_1', Fig. 26, because of the positive signal E at that time, and condenser C-9 is thereby discharged to the reference level determined by V-6B. The cathode potential of this tube is supplied from a low impendance; therefore, when the potential of point I falls to the cathode potential, the diode V-6A immediately clamps point I at the reference potential. Point I remains in this condition until time t_1' when V-7A is cut off and V-5B begins conducting. The potential of point I rises according to the charging time of C-9 with R-17, R-18, and the V-4B tube resistance. At time t_2' V-5B is cut off and point I becomes isolated at the final potential to which it reached during charging. This potential is held until t_x', when the next positive pulse at E occurs and point I is again discharged, repeating the cycle.

The signal which appears at point I is shown in Fig. 26:I. The intelligence of channel No. 1 has been reconverted to a steady voltage at this point except for the discontinuity from time t_x until t_2'. This discontinuity is removed by action of V-7B and V-8, Fig. 25. V-7B acts as a cathode follower and V-8, which normally conducts, acts as the cathode resistor of V-7B. Point J follows any level set at point I except during the discontinuity. Point J cannot follow the potential at I during its drop to the reference level since the cathode resistor, tube V-8, is rendered non conducting during that interval. Signal D on one of the control grids keeps V-8 cut off from time t_x until t_1', and then signal G keeps it cut off from time t_1' until t_2'. Thus the voltage at J remains at a constant value until a new level have been reached at point I. The voltage at J without the discontinuity is much more preferable for recording than the voltage at I. It is, therefore, the voltage J which is passed through cathode follower V-9 to the various recording instruments. The metering circuits for the succeeding circuits operate in the same manner, except that where signals D and E operate in channel No. 1, signals G and H will operate in channel No. 2, signals L and M will operate in channel No. 3, and signals of the same sequence operate from channel to channel for all succeeding channels. The output circuits are capable of supplying currents up to 10 milliamperes for the recording insturments. Fig. 26:J illustrates the manner in which the output completely follows signals which change rapidly from cycle to cycle, while Fig. 26:P illustrates the manner in which the output remains constant when the signals are unchanged from cycle to cycle.

To align the telemetering system, adjustments are provided in each metering circuit. Two potentiometers, available from the front panel, are located near each meter. One of these provides the zero adjustment and the other the full scale adjustment. The potentiometer on the left, R-21, is adjusted so that the meter reads zero when the channel input leads to the airborne transmitter are grounded and the potentiometer on the right, R-17, is adjusted to give full scale deflection of the meter when 5 volts is applied. After these adjustments are made, a curve of output versus input is run with points at half volt intervals. This curve is then referred to the calibrating voltage and a complete record of alignment is then preserved.

7. Response and Accuracy. The response of the system to change in data voltage is limited by the telemetering sampling rate. It is still possible, however, to obtain data from voltages varying at a rate higher than the sampling rate. The telemetering link responds fully in any period to the instantaneous data voltages at the moment of sampling. The string galvanometers of the recorder respond to frequencies up to 1000 cycles per second. Of course, specific attention must also be given to the response characteristics of the instrumentation for the various experiments.

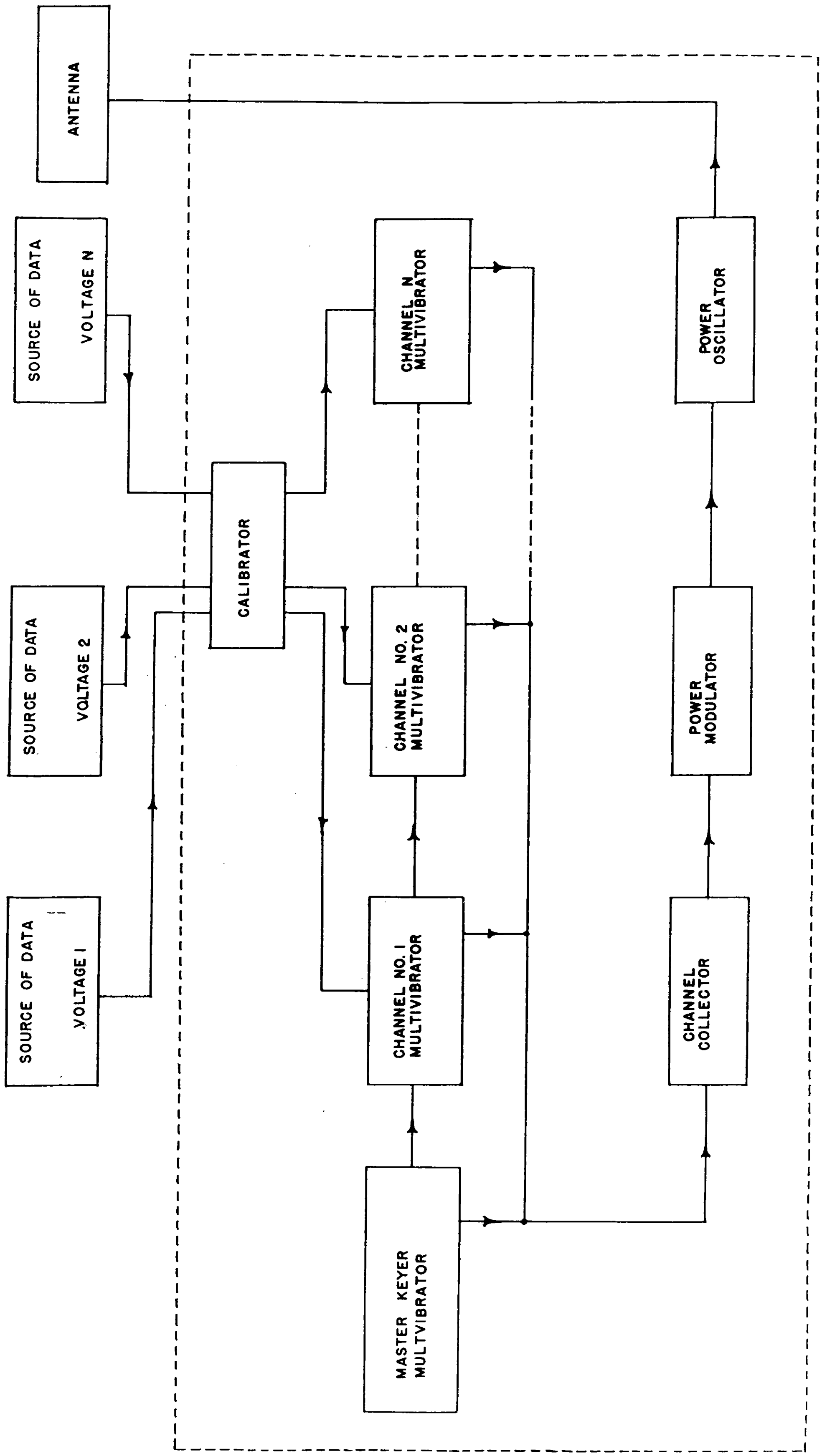
In the discussion of the calibration procedure, it was shown how calibration voltages could be used to eliminate errors due to change in the overall response of the system. The use of such calibration voltages accordingly replaces a relatively indeterminate error by one which is easily estimated. The use of a voltage regulator tube in conjunction with a resistance divider makes it possible to maintain the calibration voltage constant to within ±1%.

It is not a simple matter to estimate the magnitude of error introduced into recovered data by the difficulties involved in reading the photographic record. The magnitude is plainly a function of the reader, the clarity of the record, the focus of the recording spot, and the magnitude of the maximum deflection. Combining data recovery errors with calibration errors, it appears that a calibrated accuracy of roughly ± 5% may be expected of the telemetering system. Future refinements in technique and equipment are expected to reduce the overall error to about ± 2%.

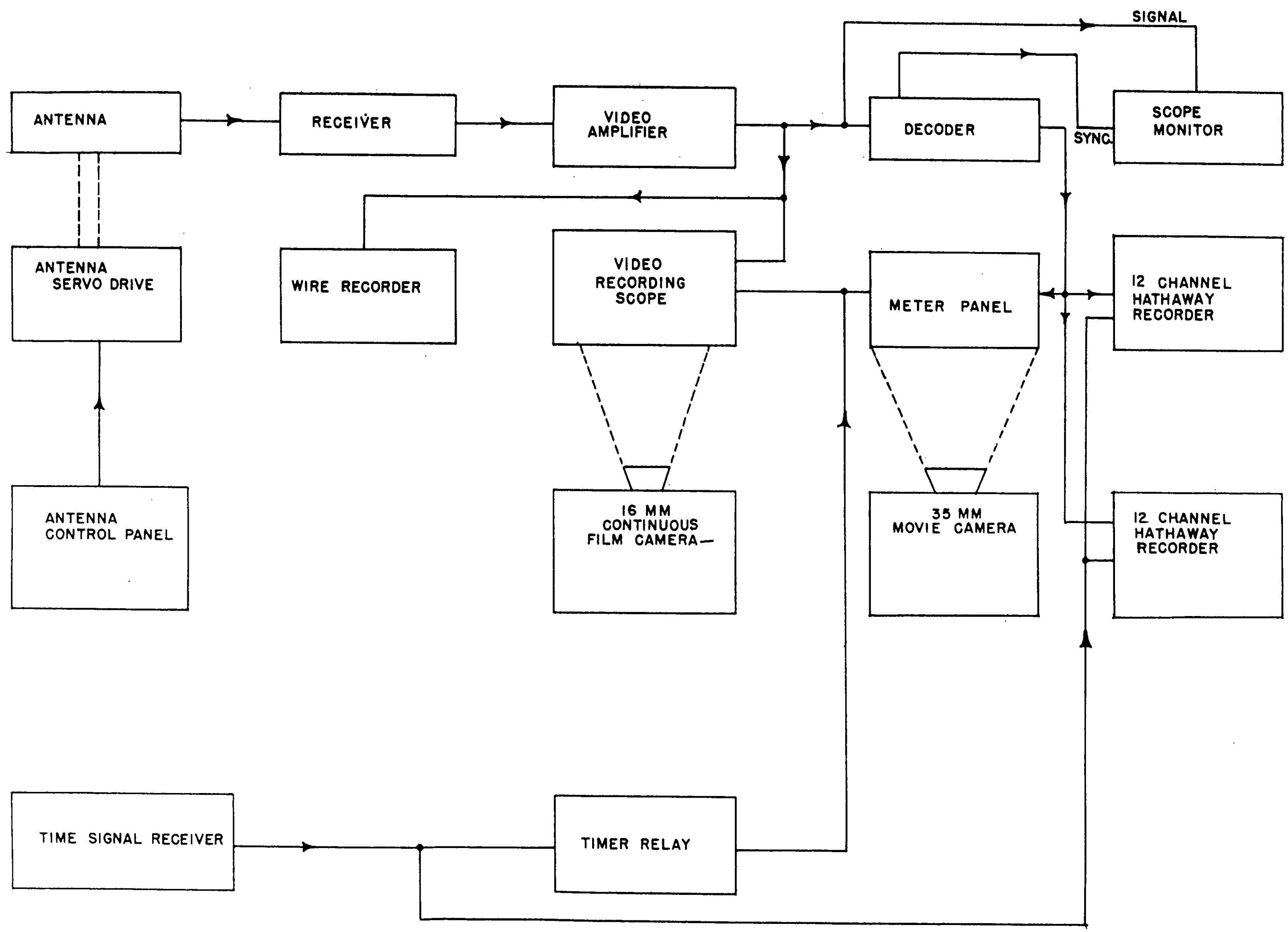
Finally, to the system errors there must be added those introduced by the instrumentation of the various experiments.

8. Acknowledgments. The members of the Rocket Sonde Research Section wish to express appreciation for the excellent cooperation of the Raytheon Manufacturing Company in providing the telemetering airborne units within a very limited time, and in immediately following up all

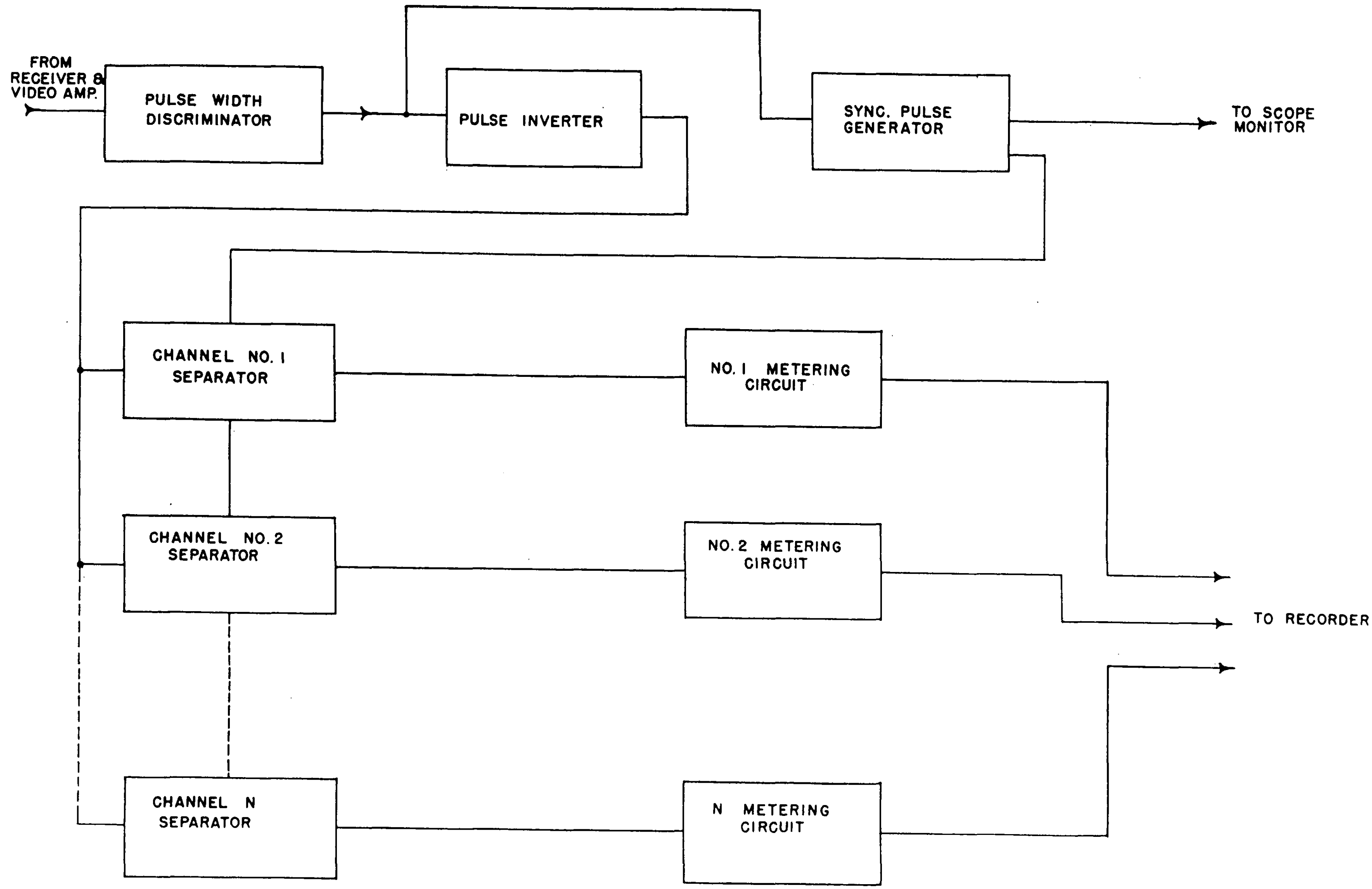
recommended modifications. It is also desired to express appreciation for the services and materials provided by the Applied Physics Laboratory and for the services of the Bureau of Standards and Watson Laboratories.



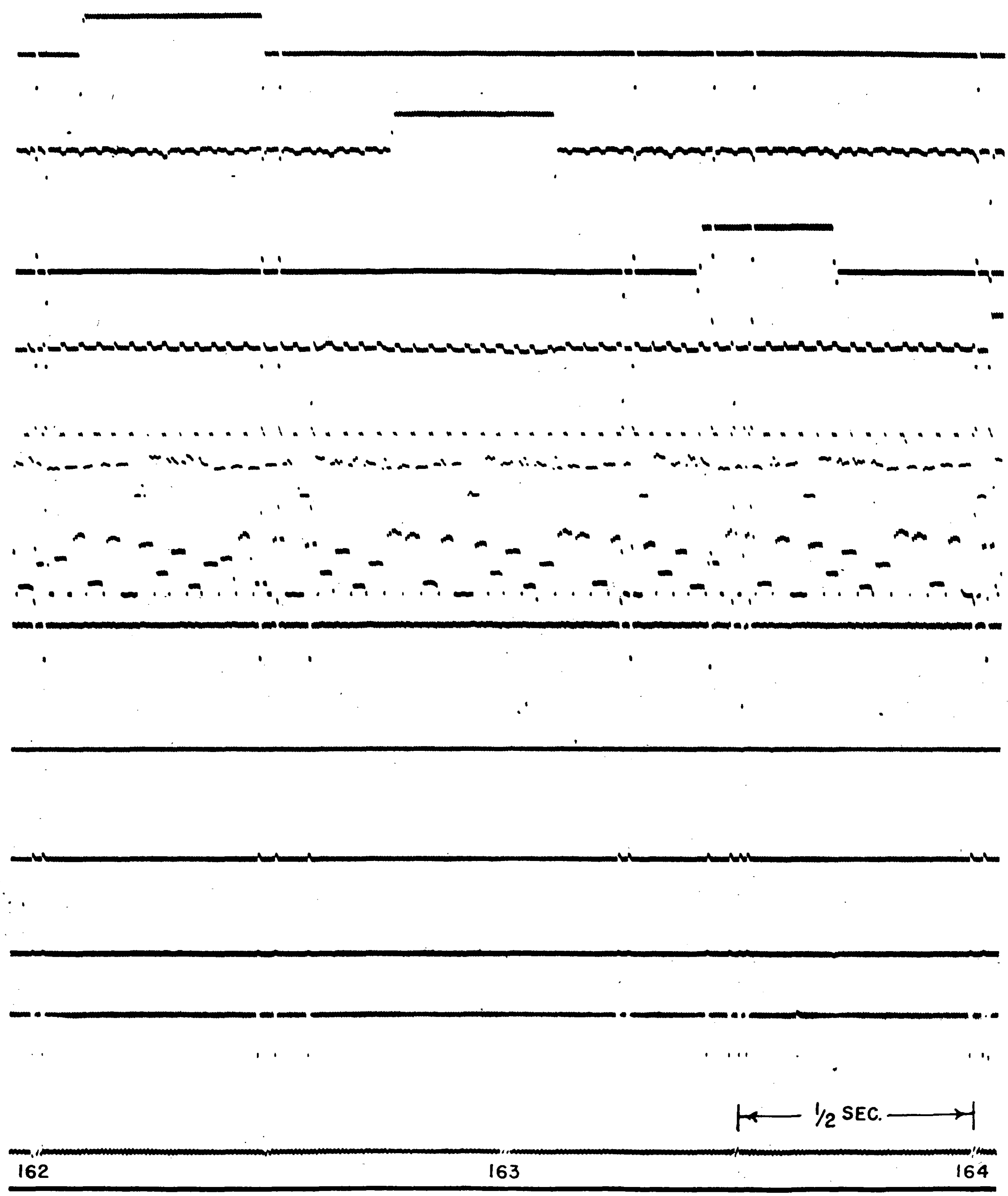
BLOCK DIAGRAM OF AIRBORNE UNIT



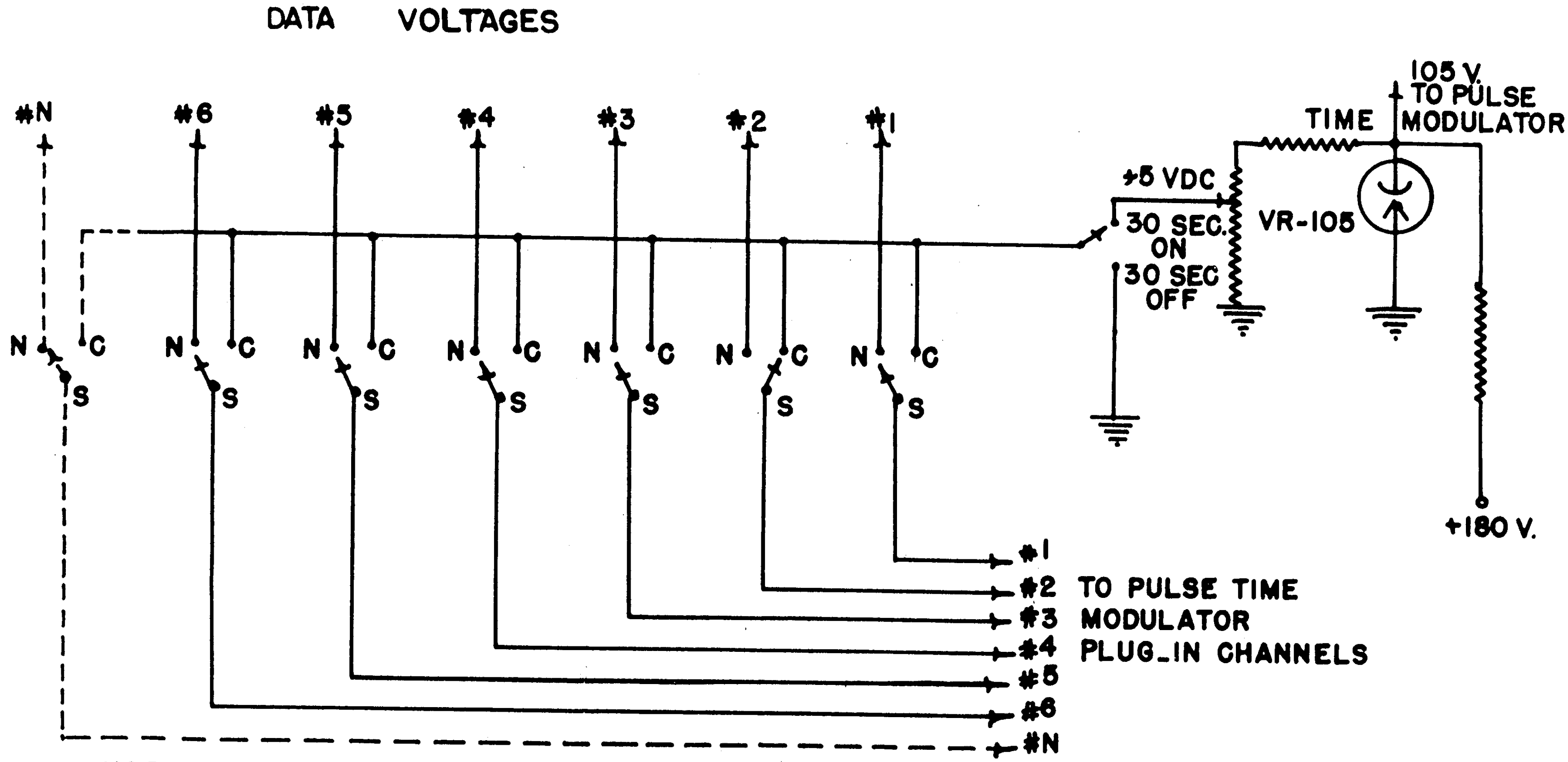
BLOCK DIAGRAM OF GROUND STATION



BLOCK DIAGRAM OF DECODER FOR GROUND STATION



A SECTION OF THE TELEMETERING RECORD. THE HALF SECOND INTERVAL BETWEEN TWO SUCESSIVE TIME REFERENCE PULSES IS LABELED. NUMBER INDICATING ELAPSED TIME IN SECONDS SINCE TAKEOFF HAVE BEEN ADDED.



NOTE:

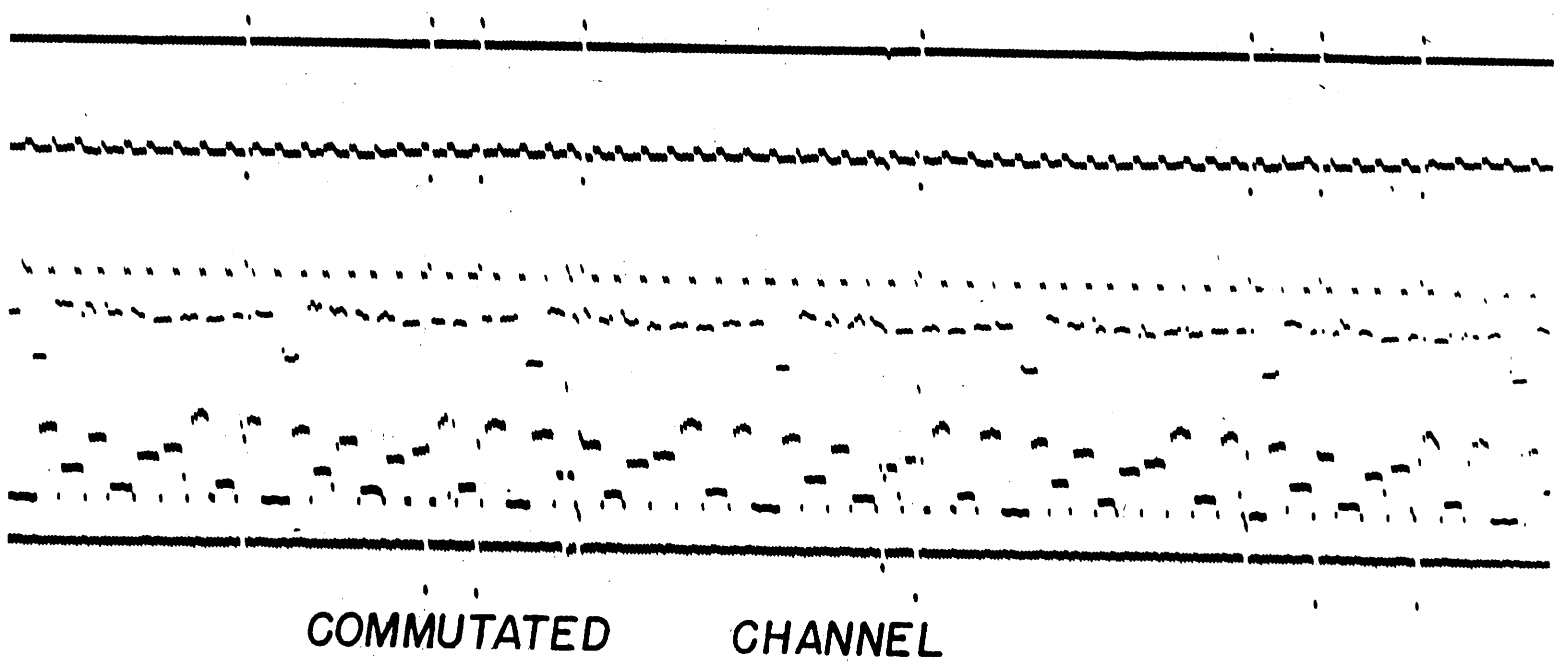
EACH SWITCH "S" OPERATED IN TIME SEQUENCE.

"N" NORMAL POSITION.

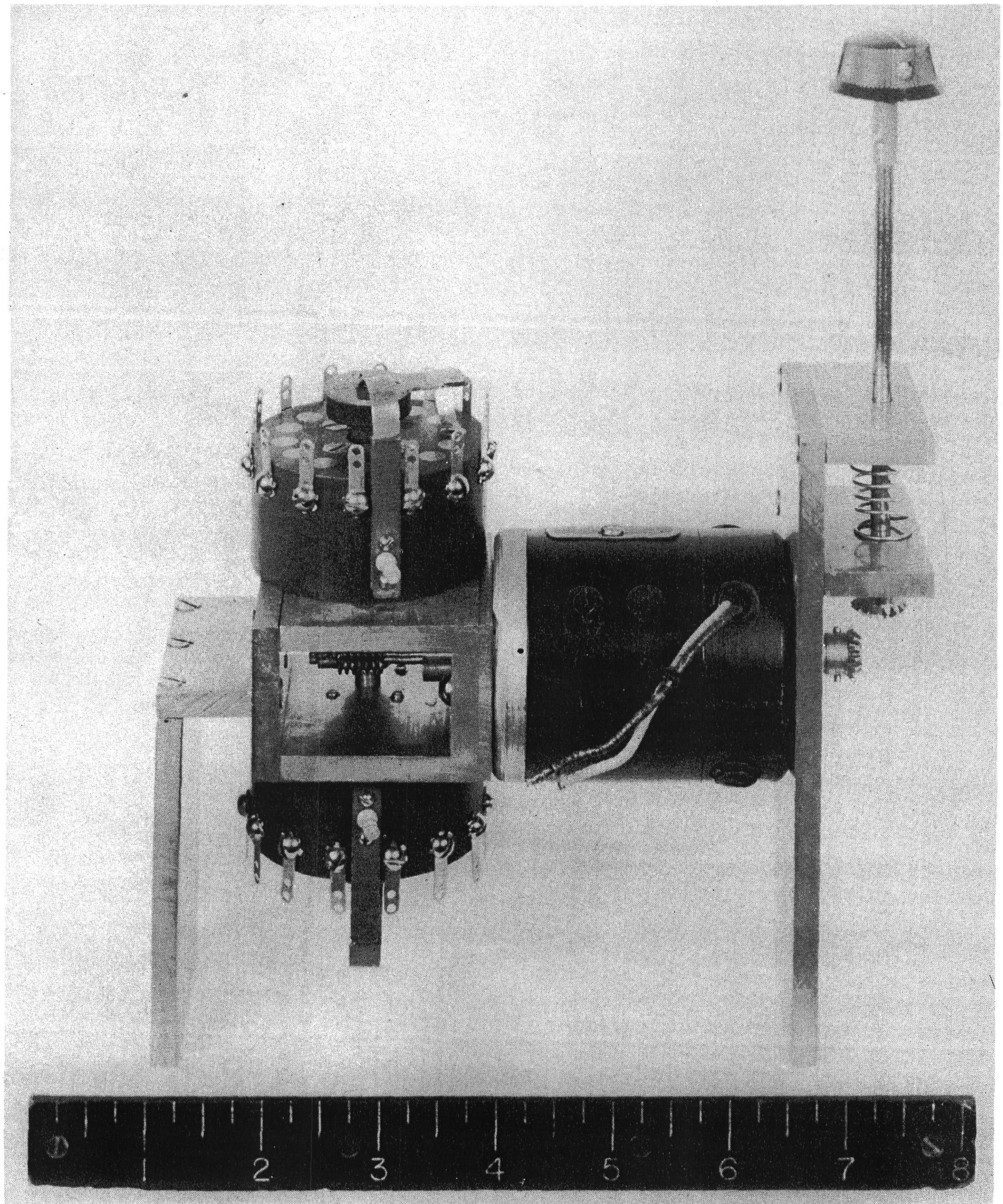
"C" CALIBRATE POSITION ½ SEC OF EACH 30 SEC.

CHANNEL #2 SHOWN IN +5 VDC CALIBRATING POSITION.

SCHEMATIC DIAGRAM OF AIRBORNE CALIBRATING UNIT

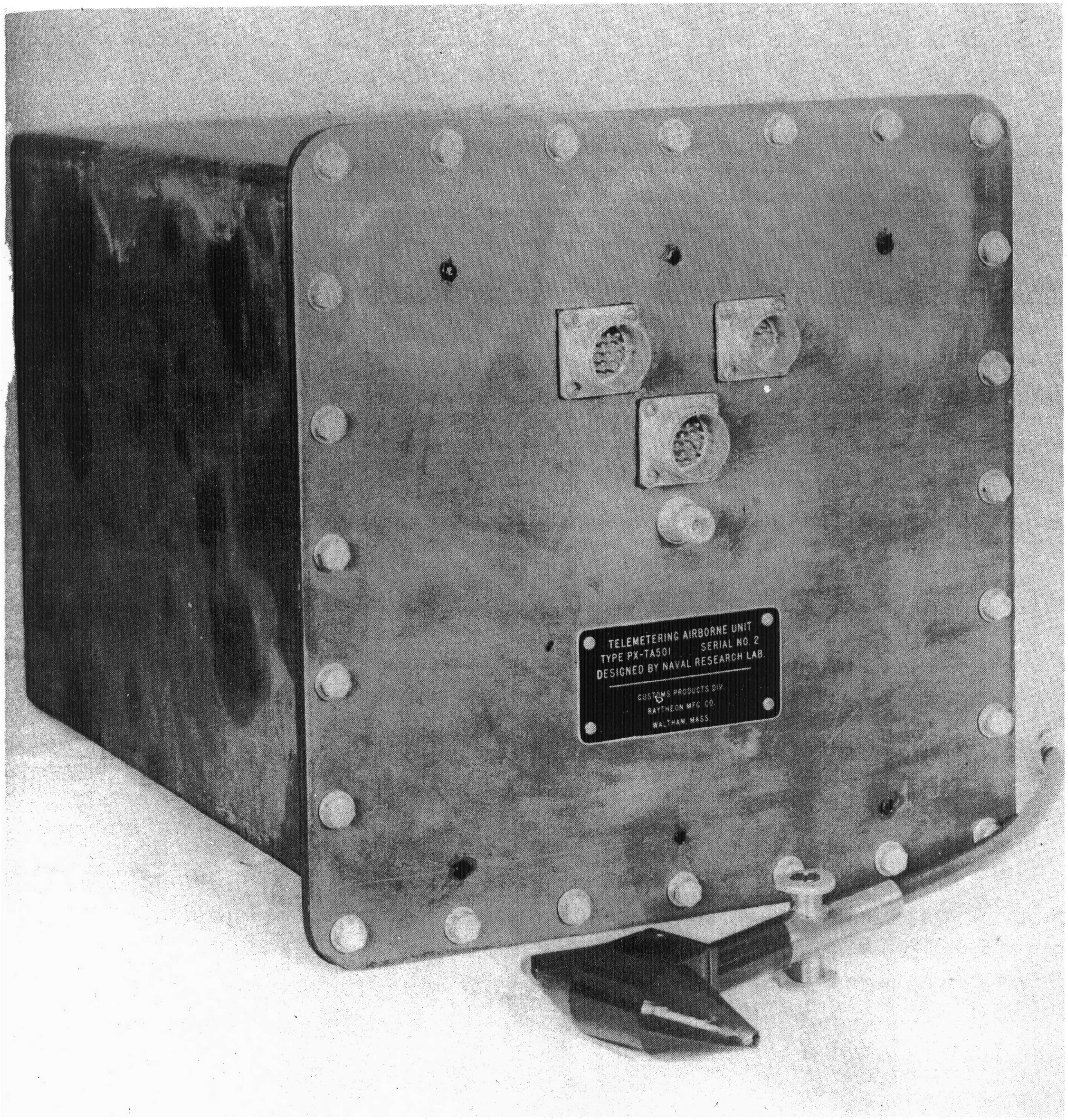


A SECTION OF THE TELEMETERING RECORD SHOWING ONLY
THE COMMUTATED PORTION OF THE RECORD AND THE TIME REFERENCE PULSES.

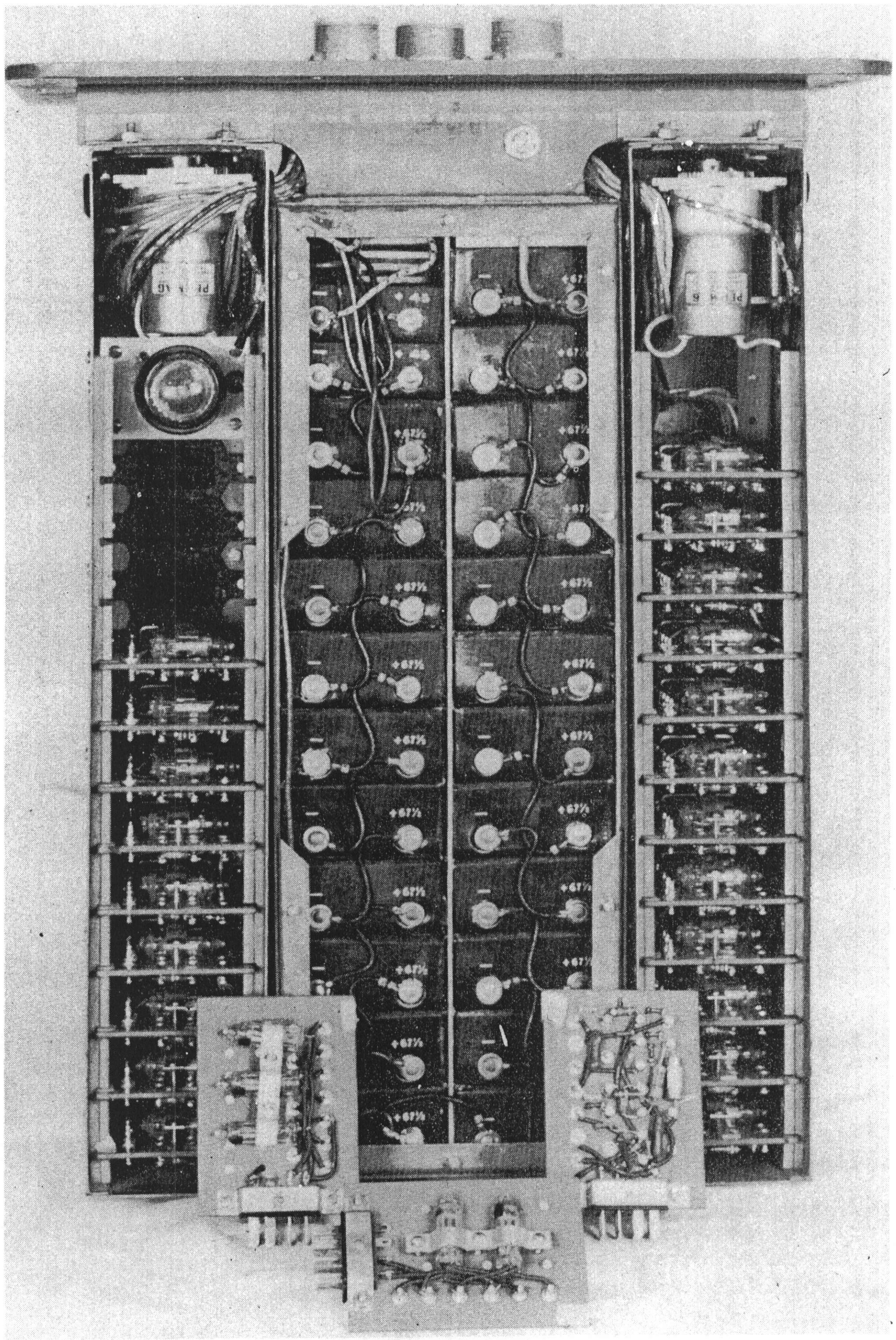


ATMOSPHERIC PHYSICS COMMUTATOR

R-2955 CH. II SEC. C FIG. 7

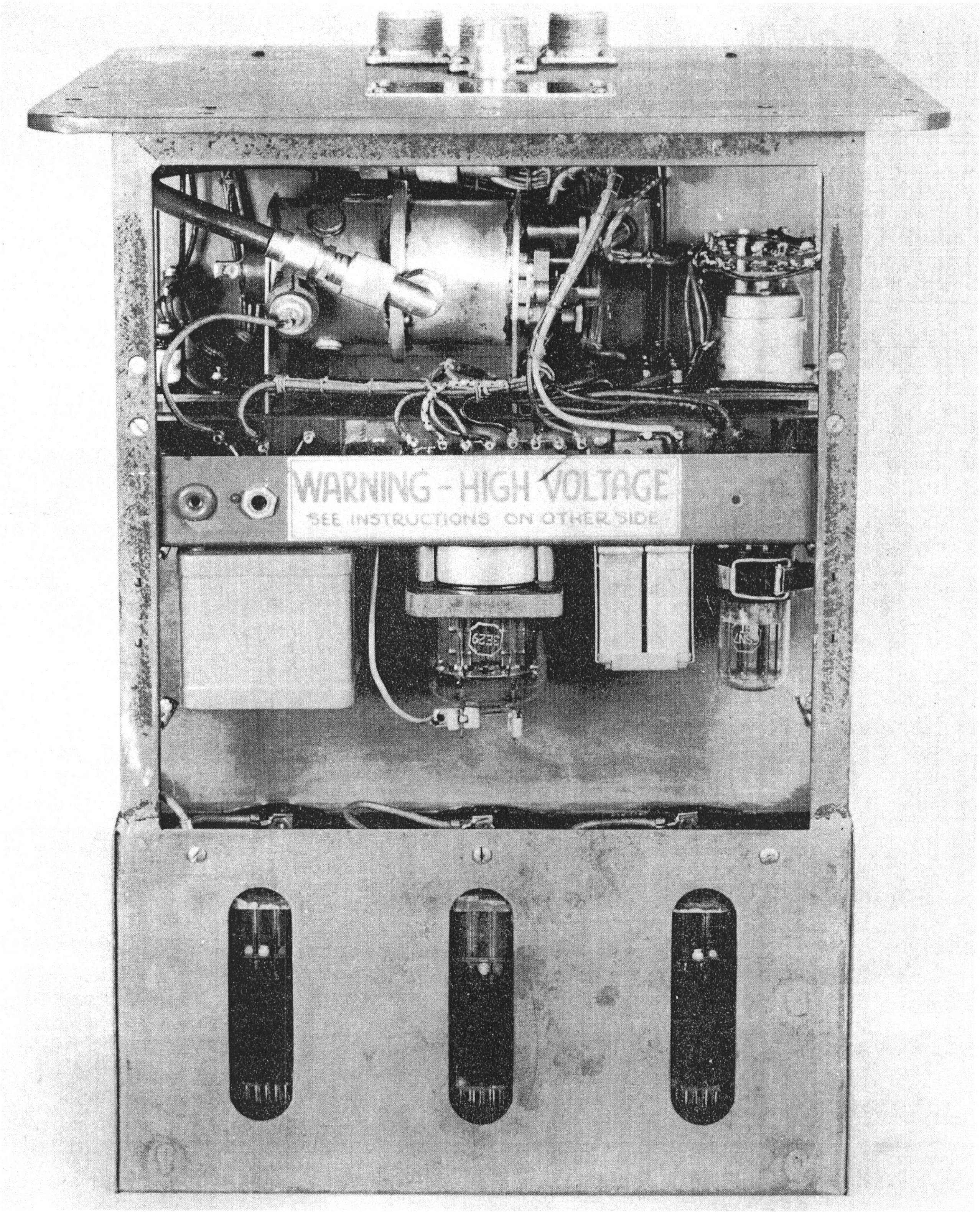


TELEMETERING AIRBORNE UNIT WITH ANTENNA

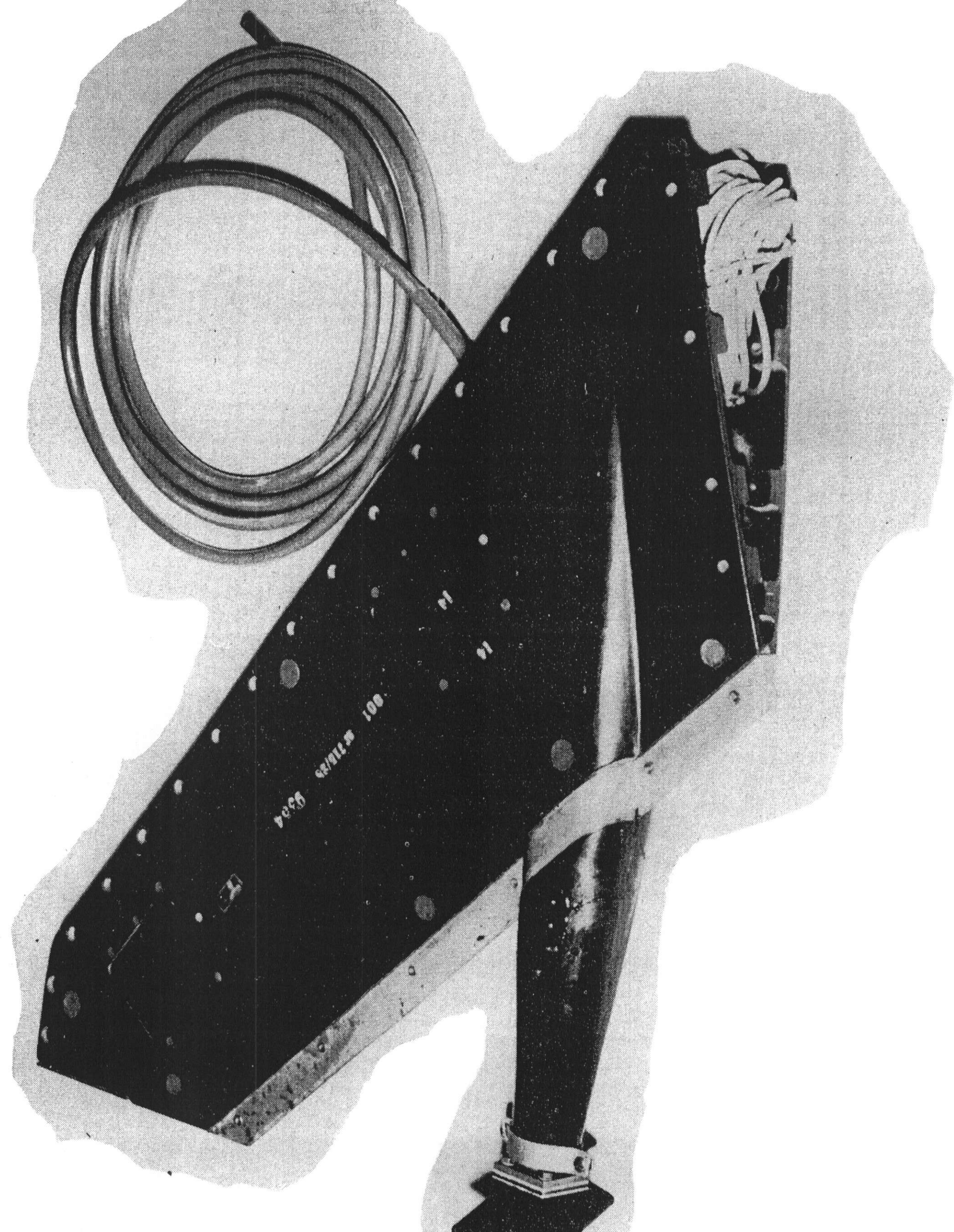


VIEW OF AIRBORNE UNIT SHOWING PULSE TIME MODULATOR

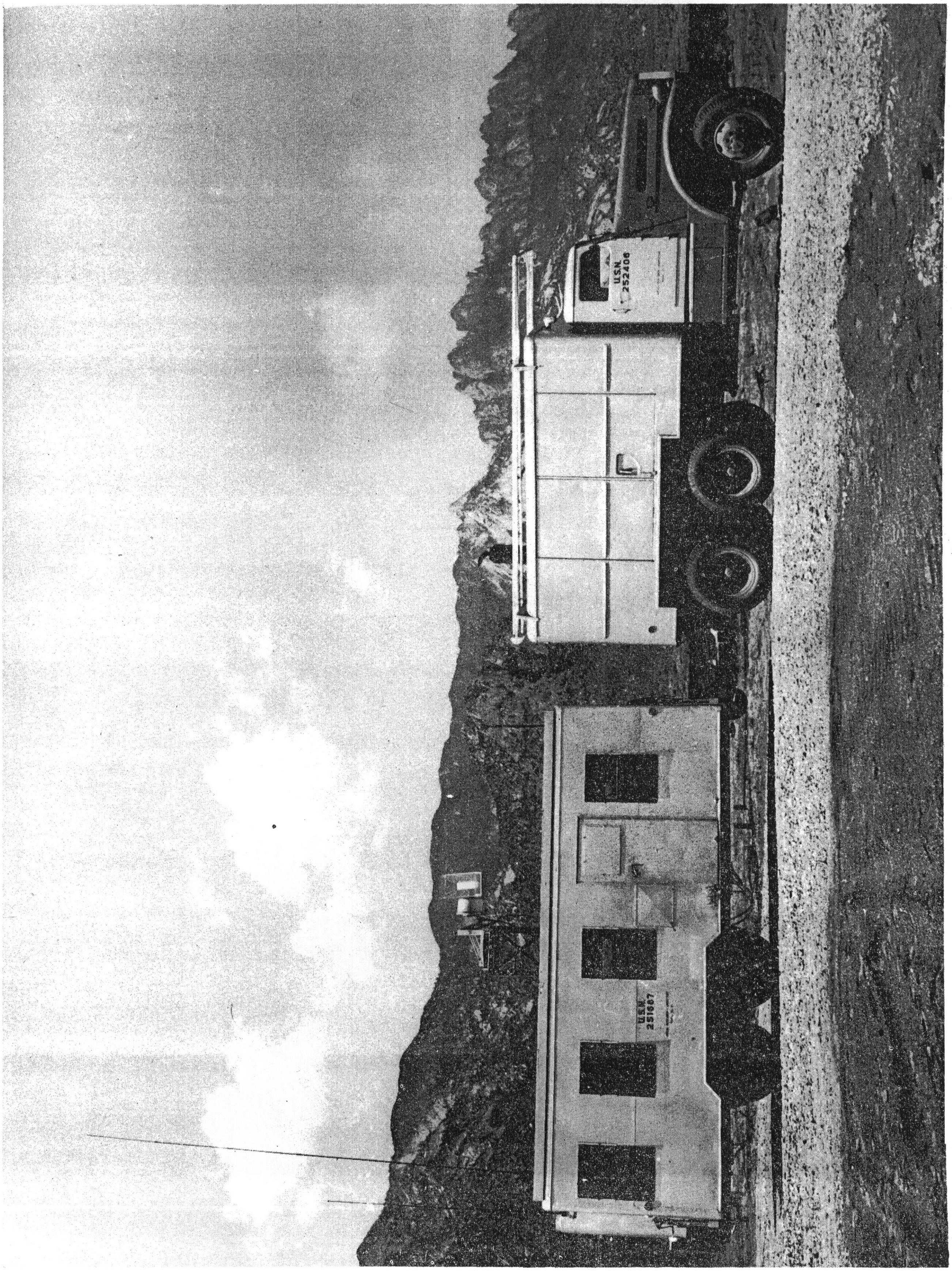
R-2955 CH. II SEC. C FIG. 9



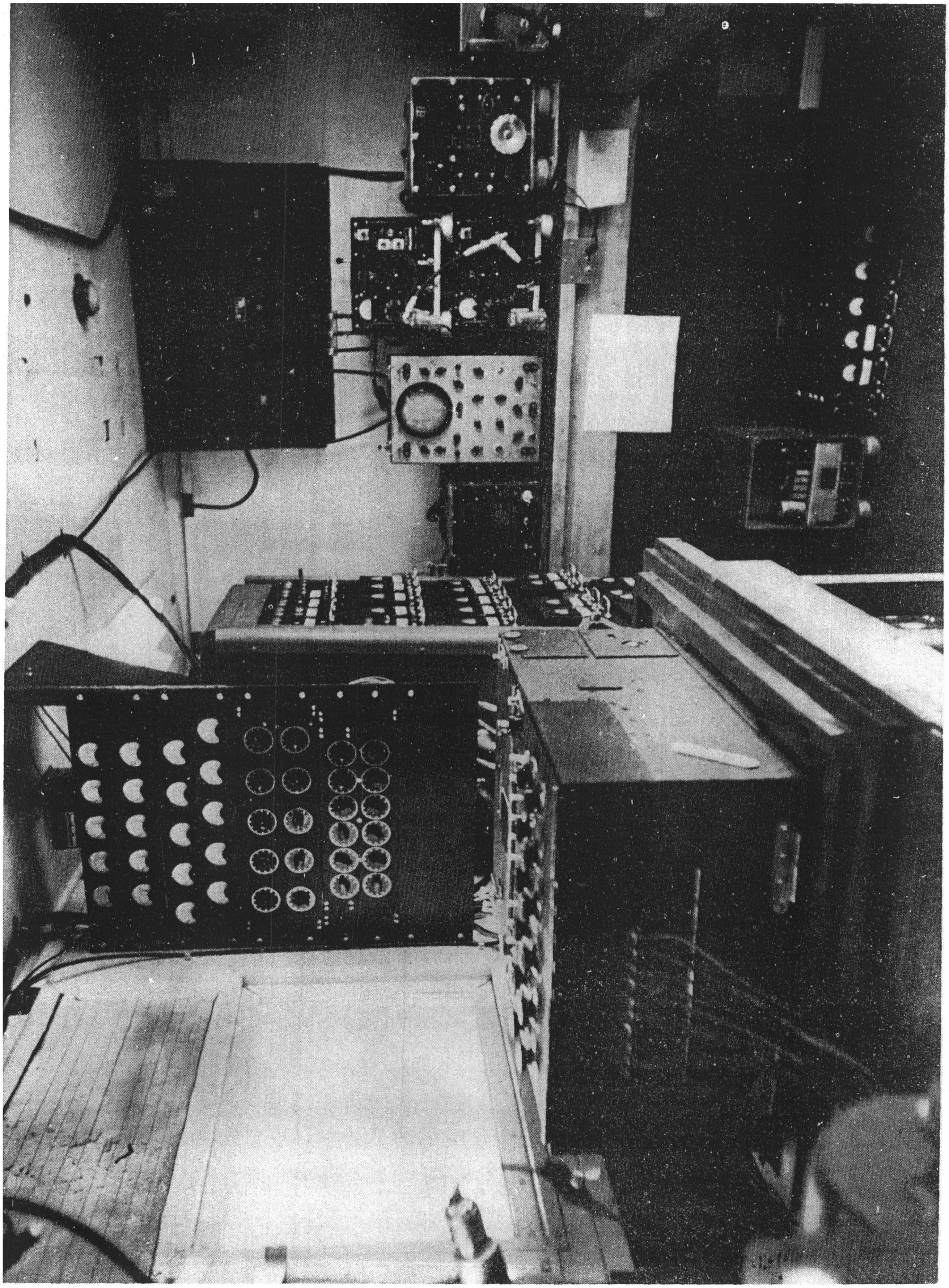
VIEW OF THE AIRBORNE UNIT SHOWING MODULATOR AND
OSCILLATOR CAVITY



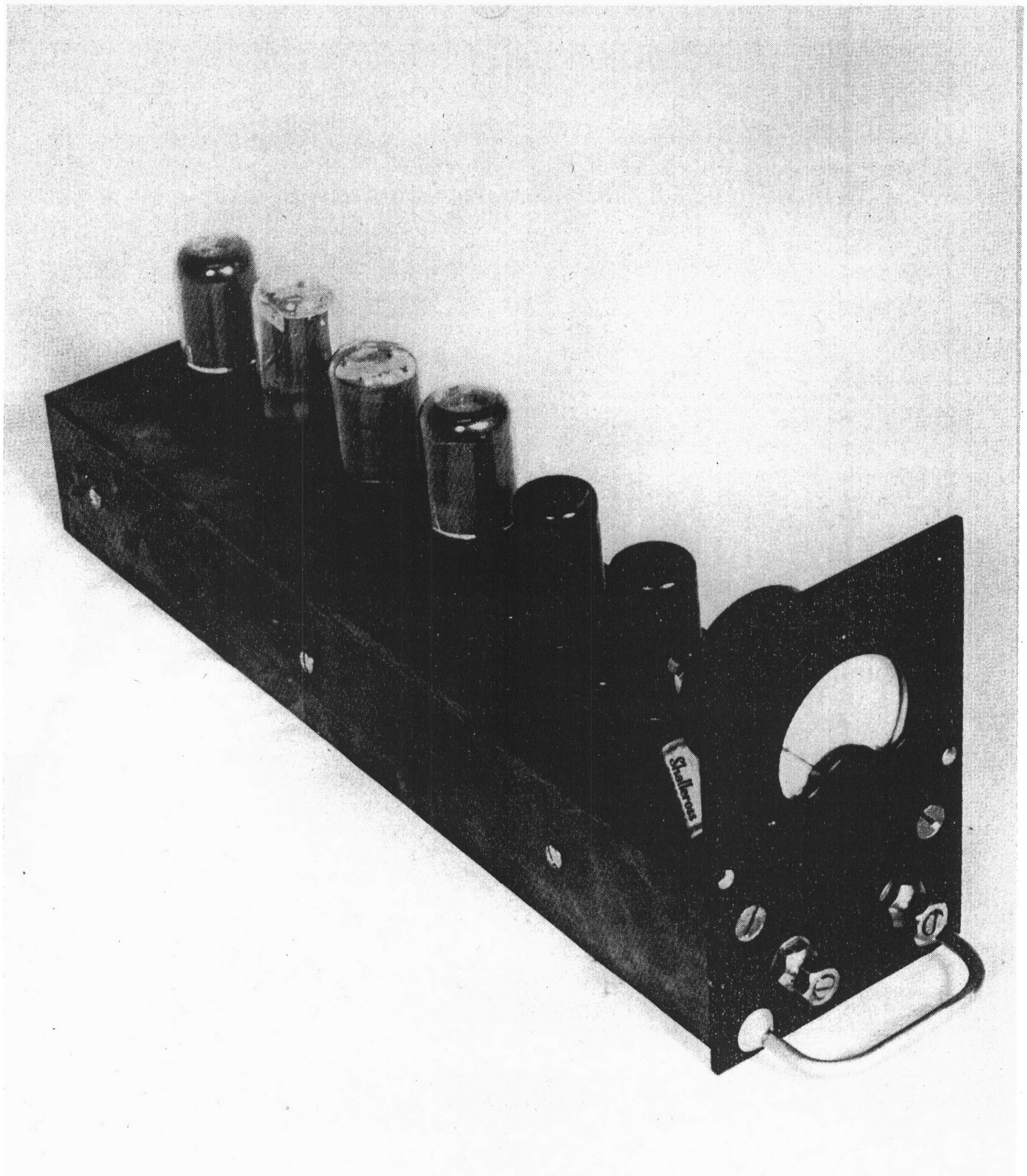
TELEMETERING ANTENNA MOUNTED ON BAKELITE SECTION
OF V-2 FIN



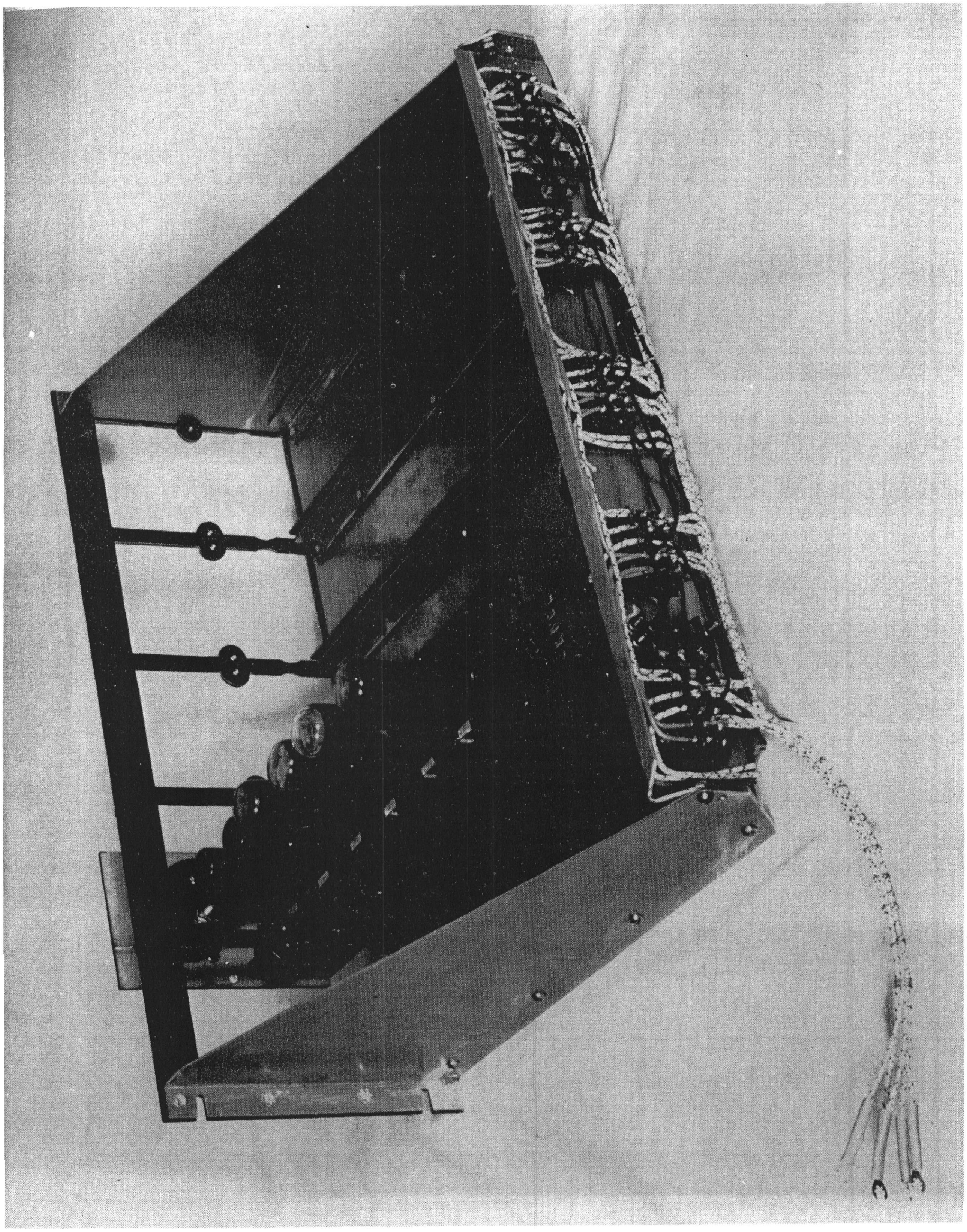
MOBILE TELEMETERING GROUND STATION



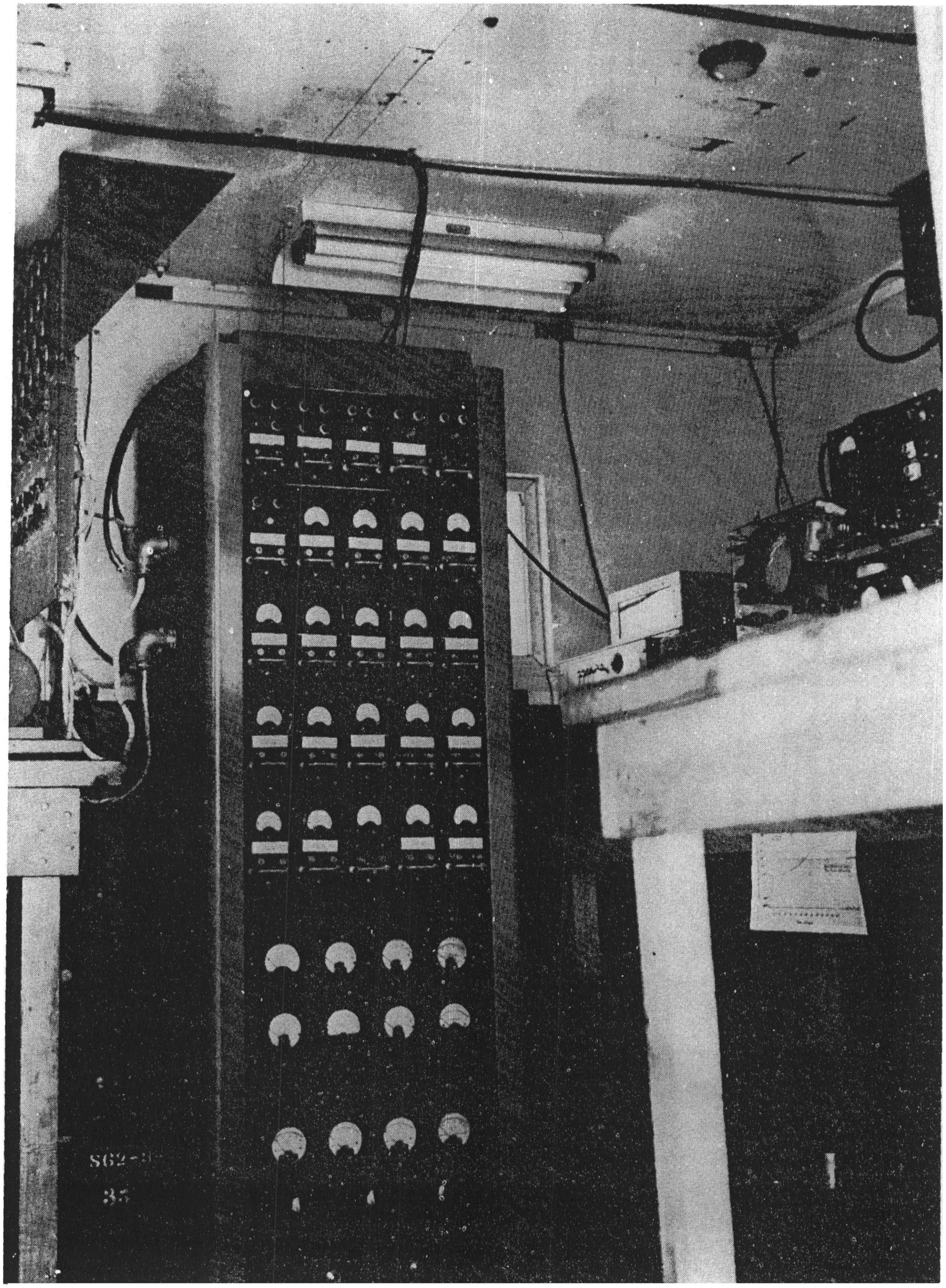
INTERNAL VIEW OF MOBILE GROUND STATION



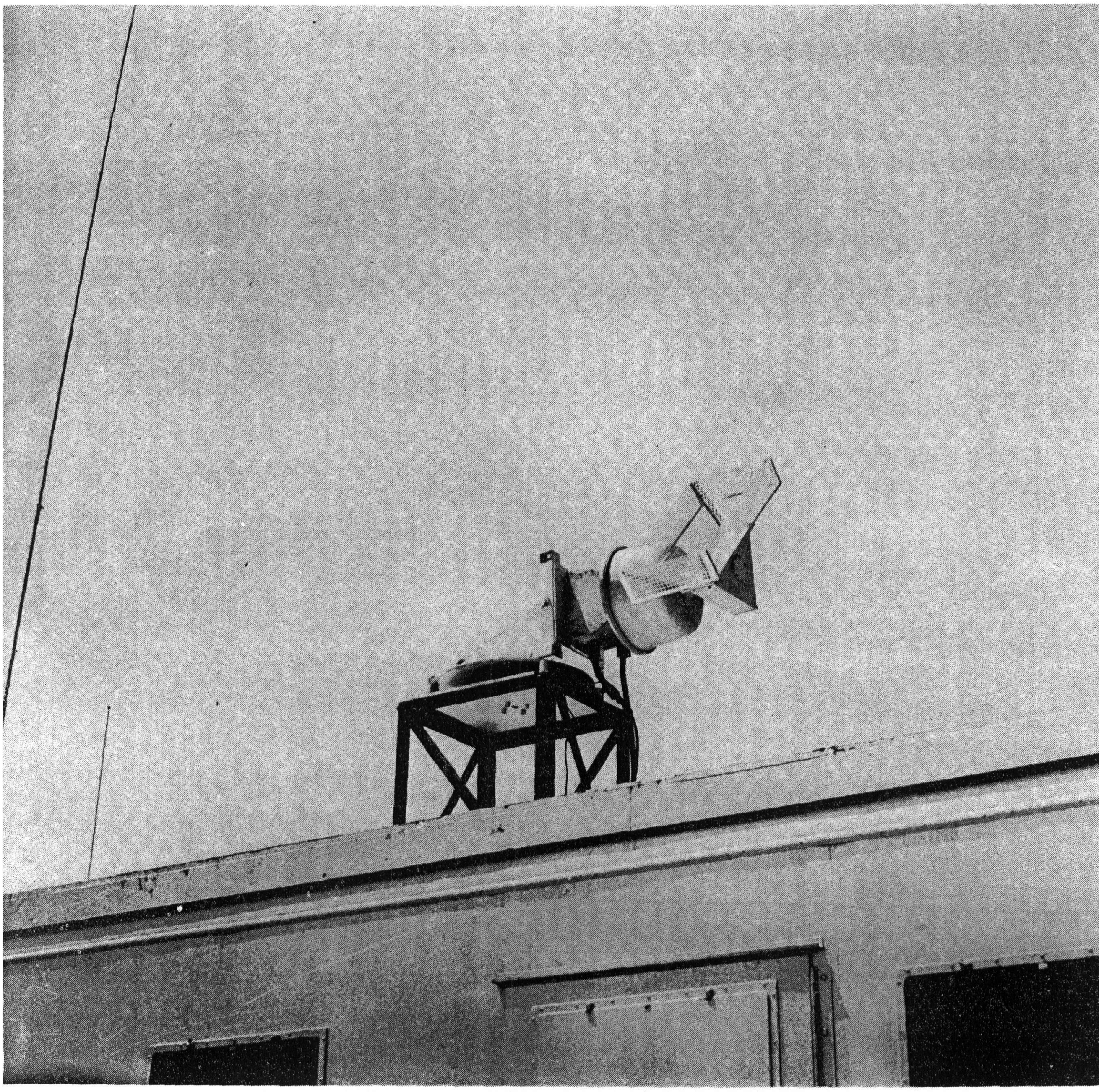
SINGLE DECODER PLUG-IN UNIT



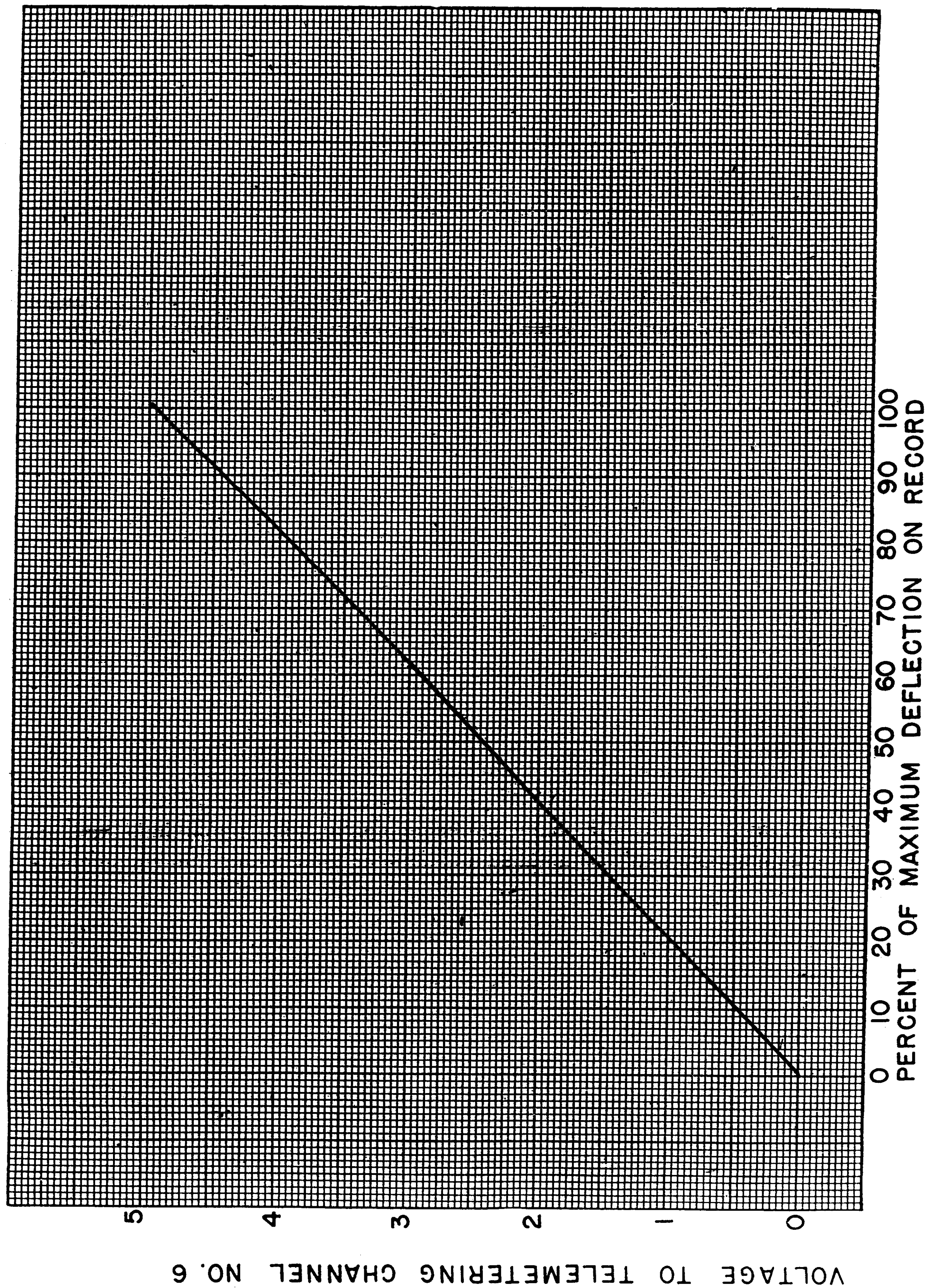
UNASSEMBLED VIEW OF CHANNEL RACK FOR DECODER



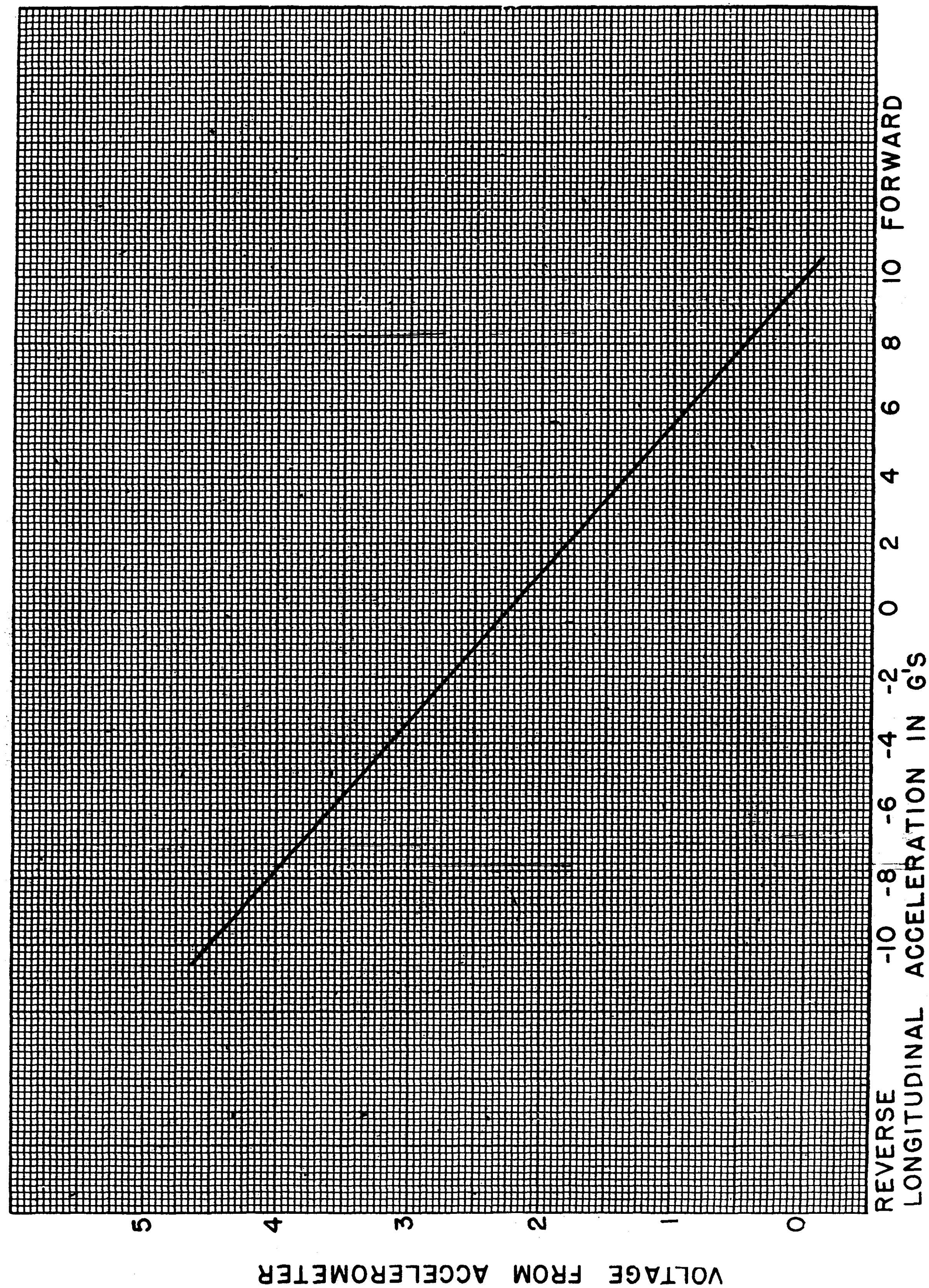
GROUND STATION DECODER



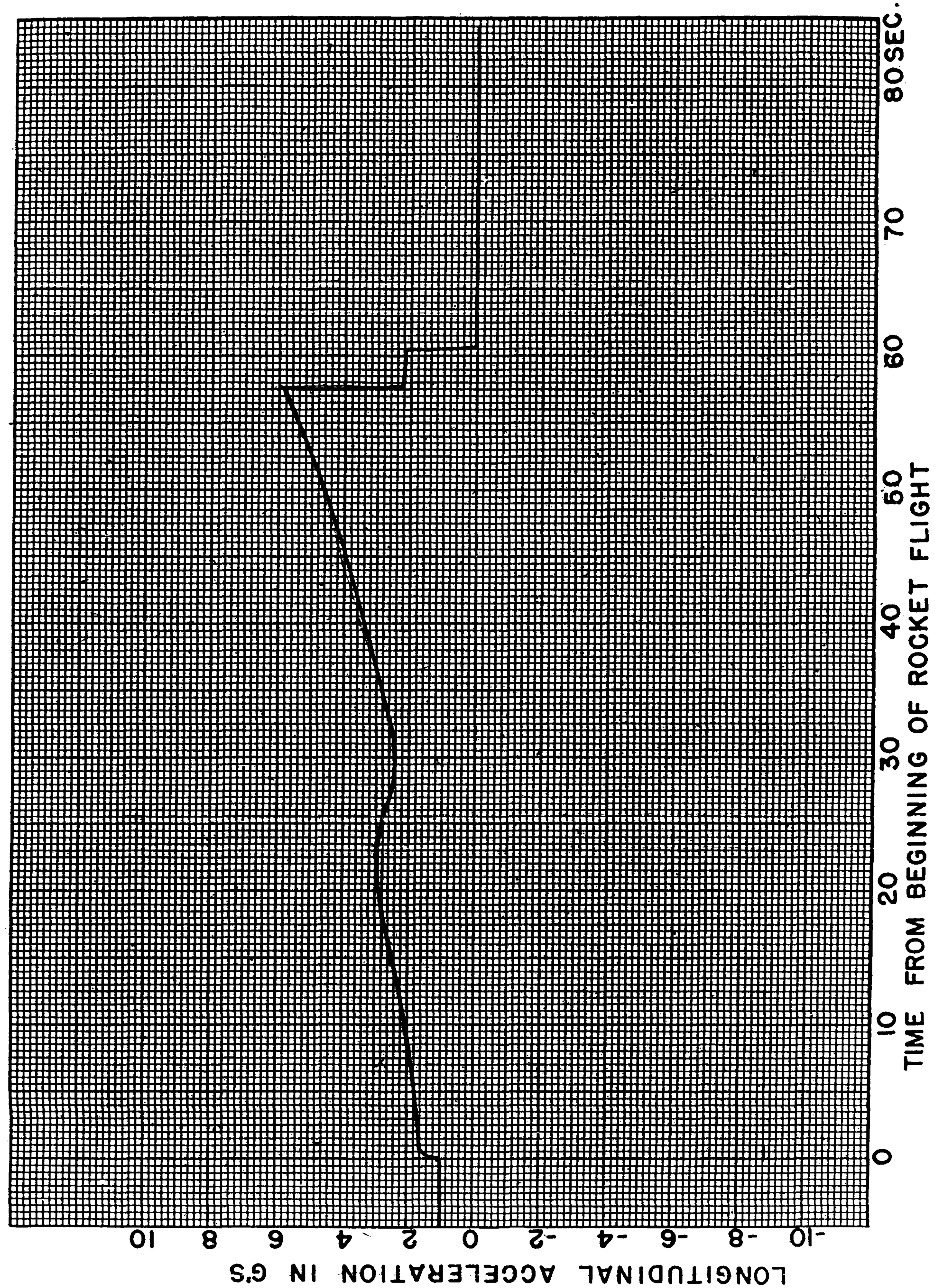
TELEMETERING GROUND STATION ANTENNA



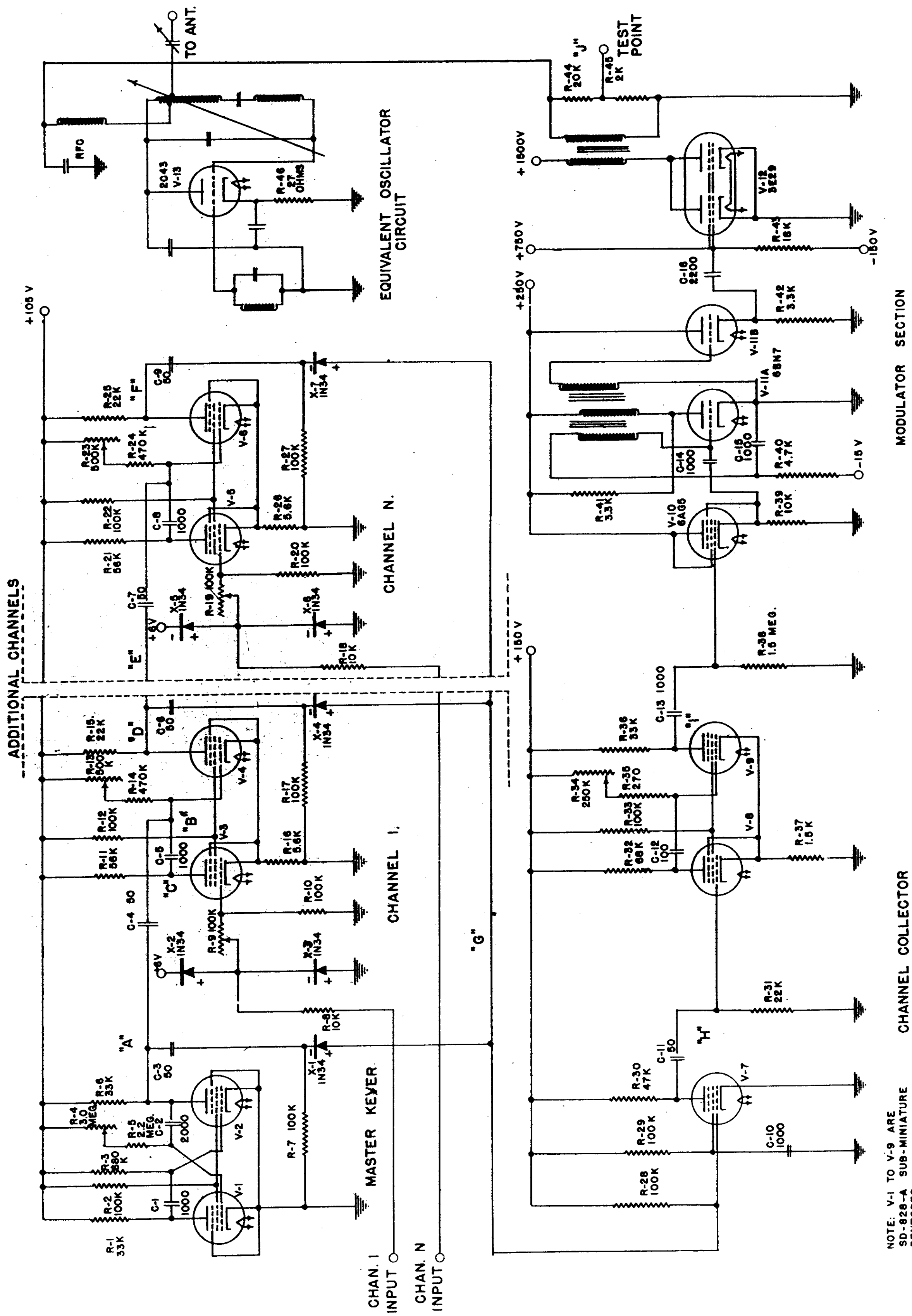
CALIBRATION OF TELEMETERING CHANNEL FOR ACCELEROMETER



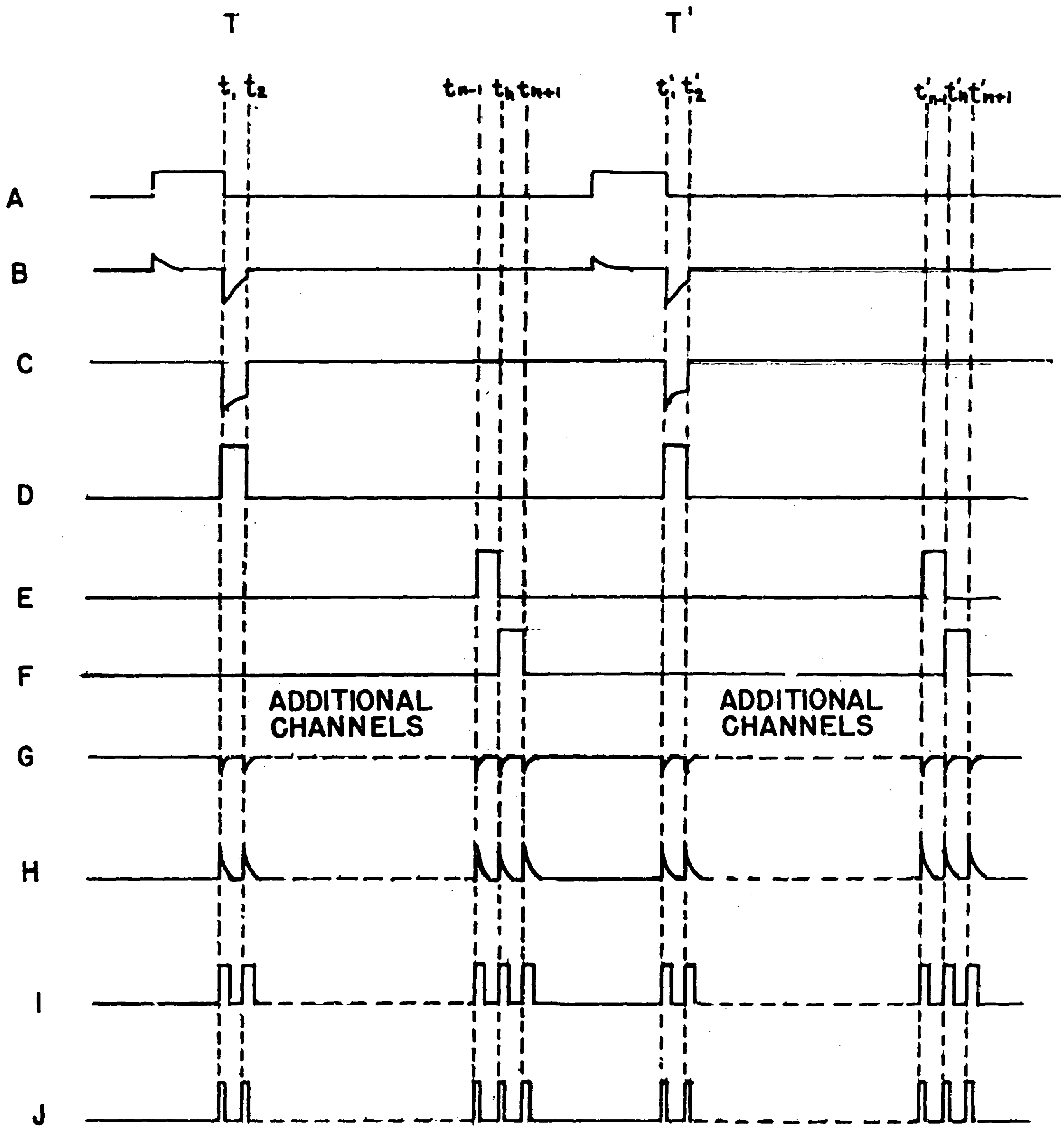
CALIBRATION OF D.C. VOLTAGE OUTPUT OF ACCELEROMETER



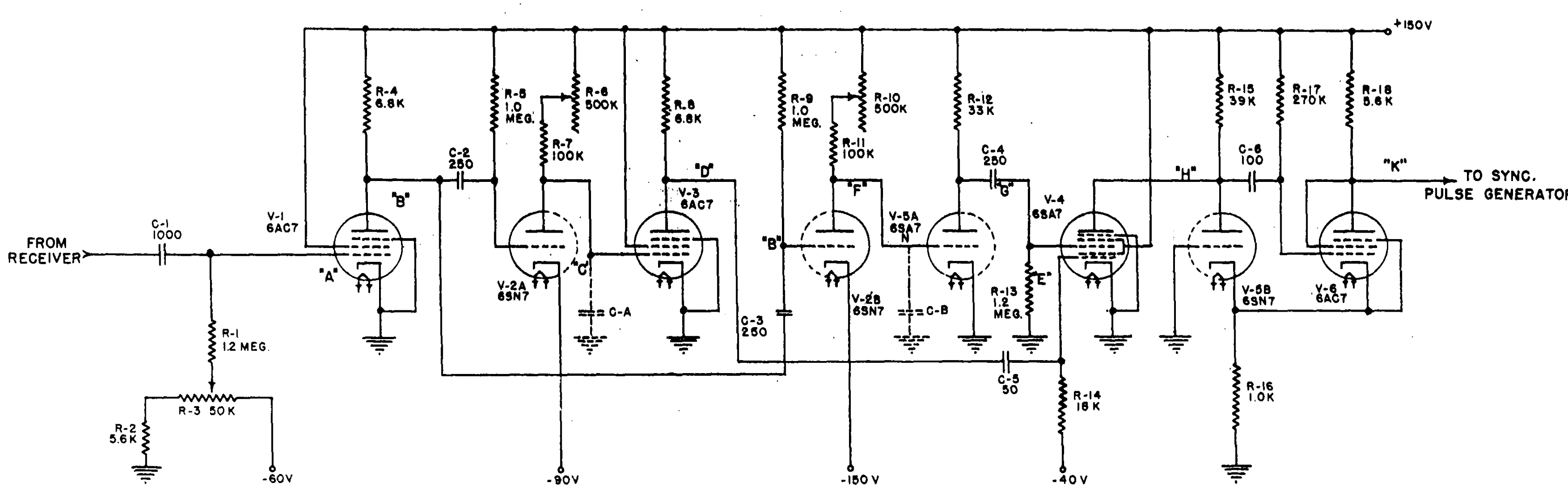
DATA PLOT OF ACCELEROMETER RECORD



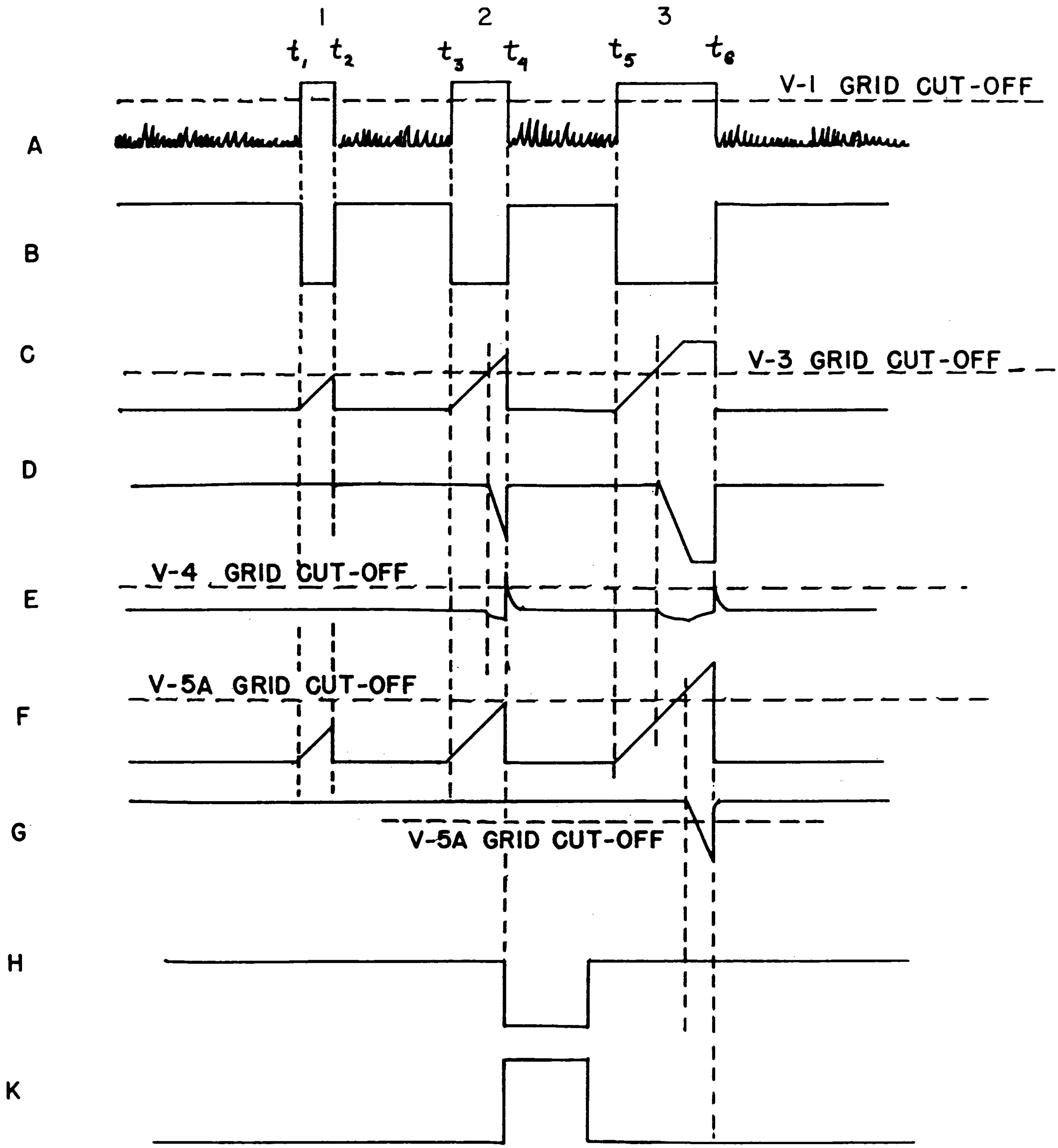
SCHEMATIC DIAGRAM OF TELEMETERING AIRBORNE UNIT



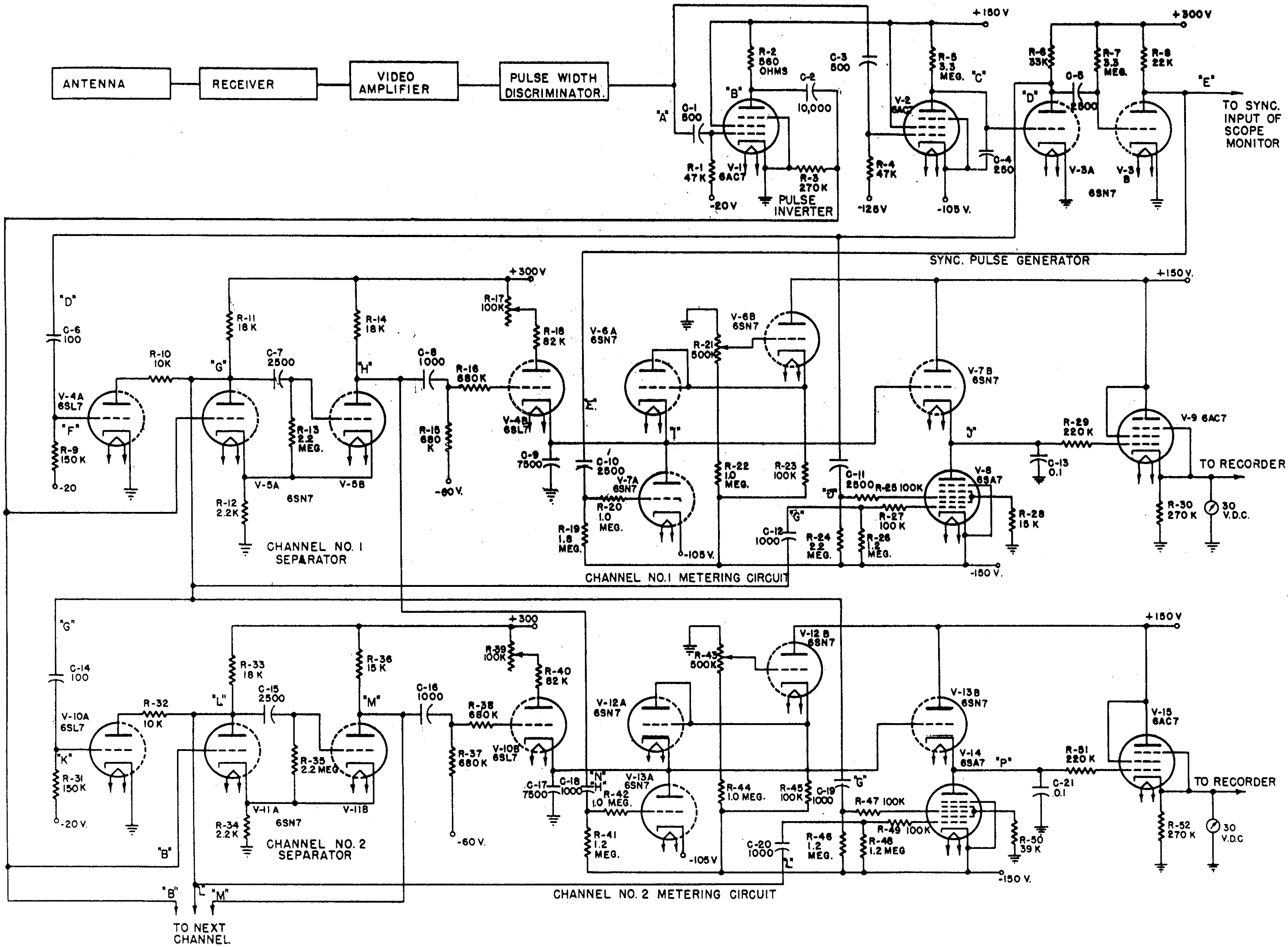
WAVE FORMS FOR FIGURE 21 SCHEMATIC DIAGRAM



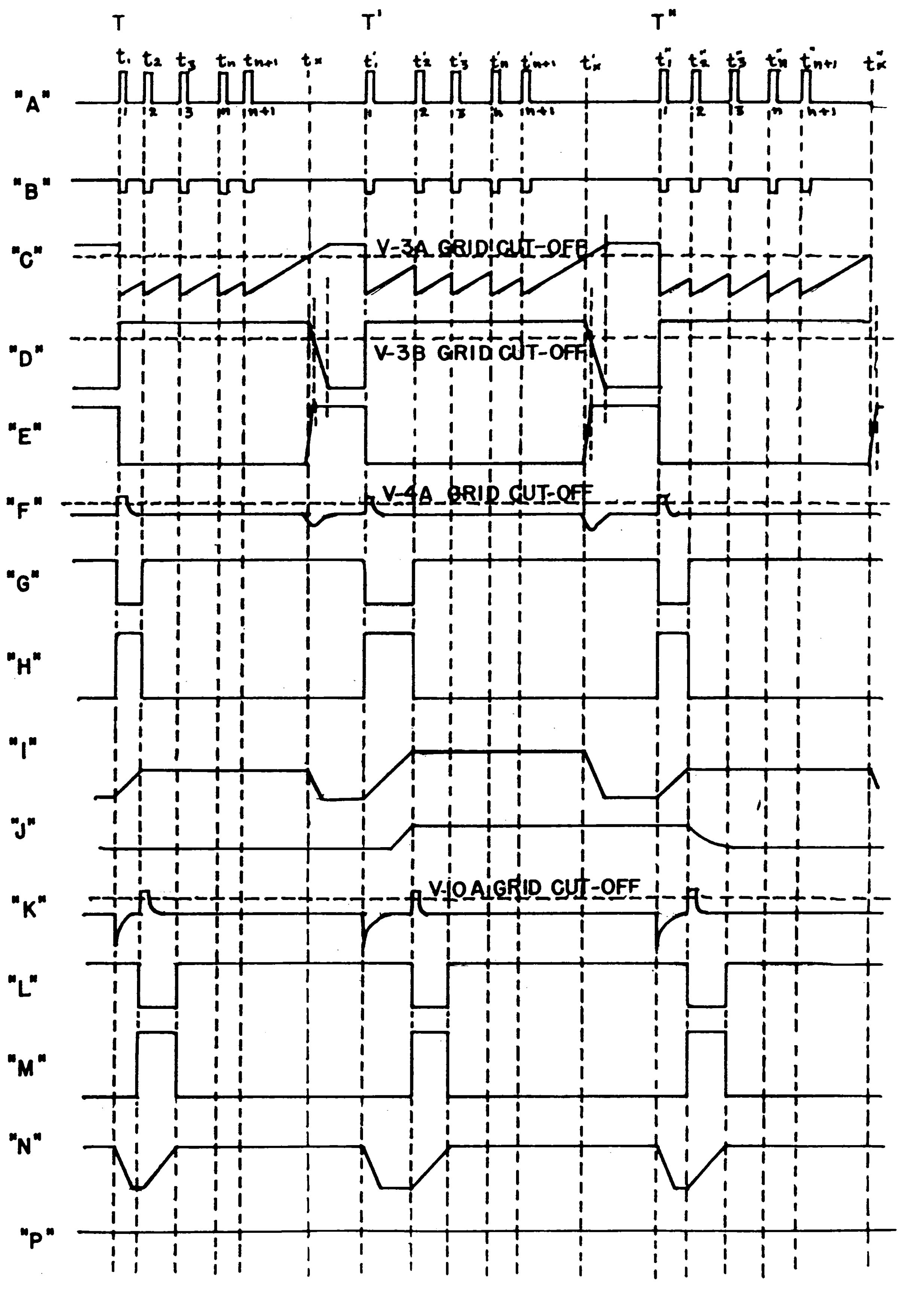
SCHEMATIC DIAGRAM OF PULSE WIDTH DISCRIMINATOR IN GROUND STATION



WAVE FORMS FOR FIGURE 23 SCHEMATIC DIAGRAM



SCHEMATIC DIAGRAM OF DECODER FOR GROUND STATION



WAVE FORMS FOR FIGURE 25 SCHEMATIC DIAGRAM

CHAPTER III

UPPER ATMOSPHERE RESEARCH CONDUCTED BY THE NAVAL RESEARCH LABORATORY

Introduction and General Description of the June 28 Flight

As indicated above in the General Introduction, primary responsibility for research in the June 28 firing fell to the Naval Research Laboratory. During the flight, experiments were conducted to determine the nature of the primary cosmic radiation, and the pressure and temperature of the upper atmosphere. At the same time, many problems arising in connection with the investigation of the ionosphere were also solved. An attempt was made to photograph the spectrum of the sun in the region below 3300Å from the vantage point of the upper atmosphere.

At 12:35 PM, Mountain Standard Time, the rocket took off normally, rising to a vertical height of 68 miles and returning to earth after 354 seconds at a point 43 miles north of the launching site. Throughout its trajectory the V-2 was tracked by radar, by optical instruments, and by doppler equipment. The data shown in the table below were taken from the various tracking records for the June 28 flight.

Table of June 28 Flight Data

Maximum altitude	68 miles
Horizontal range	43 miles
Time of flight	354 seconds
Cutoff time	67 seconds
Cutoff altitude	86,000 feet
Cutoff velocity	4,200 ft/sec

At 320 seconds after take-off the radio link transmitter was activated which was to cause the detonation of the charges intended to cause an air burst. Simultaneously a puff of smoke practically enveloping the rocket was seen by several observers at the radio transmitter. Another observer, using 25 power binoculars, observed the puff of smoke and also observed that the rocket remained intact. Telemetering and doppler equipment both located in the control chamber near the explosive charges continued operation after the blast. Upon impact a cloud of sand mushroomed up which was estimated to be between 500 and 1000 feet in height. Bearings from various observation sites were radioed back to the launching area and served to locate the impact site. The crater formed by the impact was quickly observed by plane and somewhat later was inspected by personnel on the ground.

A view of the rocket's crater is shown in Fig. 1 of Section H. It is 80 feet in diameter and as deep as the angle of repose of loose material on its sides will permit. It is believed that the rocket penetrated to a somewhat greater depth where it disintegrated and became a part of the debris of which the rims and bowl of the visible crater are composed. Several small fragments of the rocket were found scattered around the crater. These were all badly twisted and some steel pieces showed evidence of having been melted. When asked to estimate how hot one of these fragments had become, members of the Metallurgy Division at the Naval Research Laboratory put forth as a very rough guess the figures of from 1300°F to 1600°F.

Although the probability of recovering the spectrographic film intact and in usable condition is believed small, arrangements have been made with Army Ordnance officials at White Sands Proving Ground, to employ Army personnel and equipment to excavate the crater. This operation is underway and a report is expected soon.

The sections of Chapter III form a series of articles on the scientific problems the solutions of which were sought during the V-2 flight just described. Pertinent history is provided, and carefully detailed descriptions of the experiments carried out or attempted, and of the instrumentation required, are set forth.

The first three sections cover the work done on cosmic rays. Sections D and E are devoted to a description of the temperature and pressure measurements, while the work on the ionosphere is reviewed in Sections F and G. A careful description of the solar spectrograph carried by the V-2, and of the spectrograph experiment appears in Section H. The importance of recovery methods to the successful performance of experiments such as the spectrograph experiment described in Section H makes the development of workable ejection and recovery schemes imperative. A discussion of the work done in the Rocket Sonde Research Section on this important problem is given in Section I. The biological studies conducted by Harvard University are discussed in Section J.

UPPER ATMOSPHERE RESEARCH CONDUCTED BY THE NAVAL RESEARCH LABORATORY

A. The Cosmic Ray Experiment

by

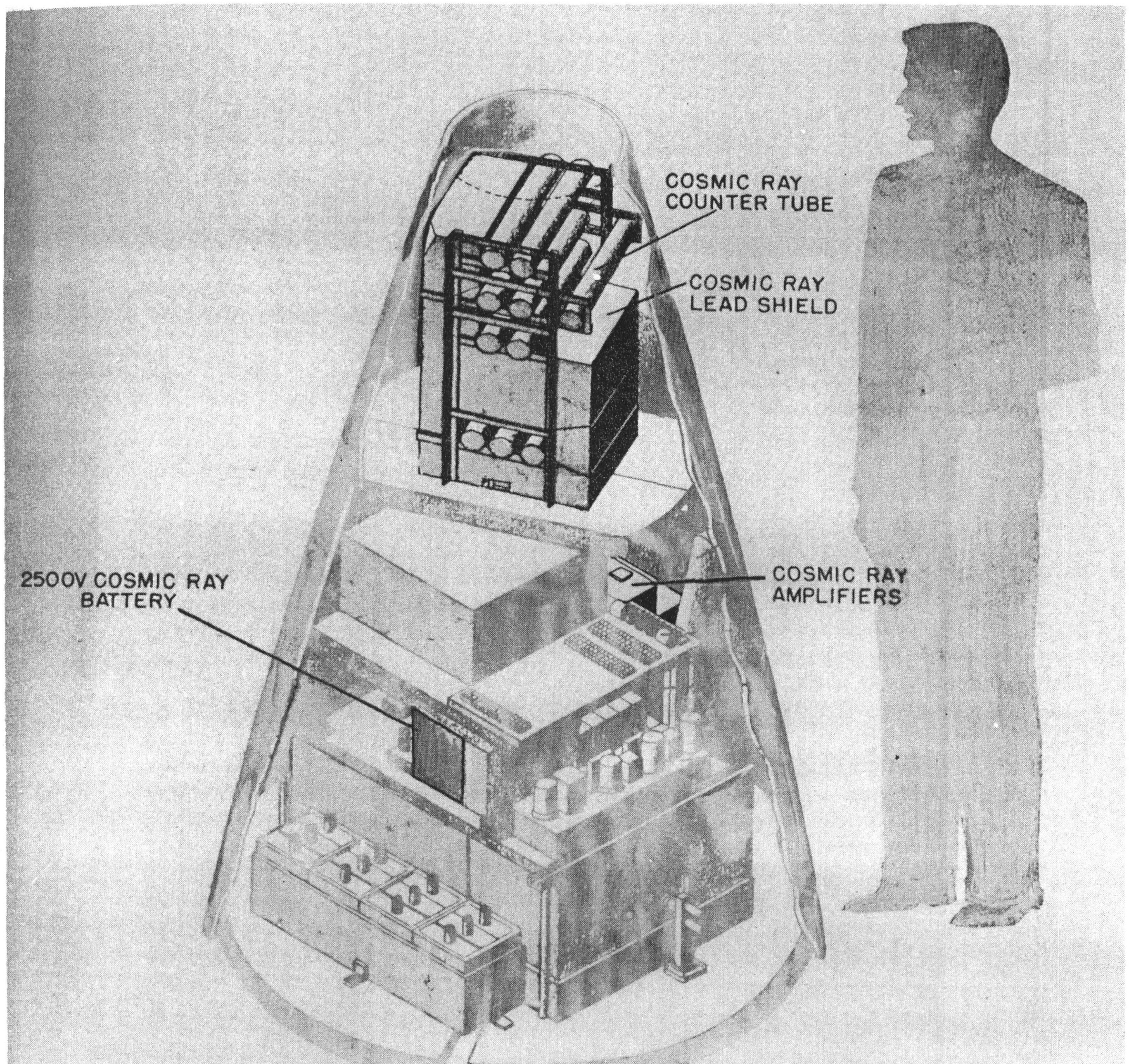
H. E. Newell, Jr. and G. J. Perlow

To the physicist the chief importance of cosmic rays lies in the fact that their study affords a means of investigating processes of interaction among the elementary particles of nature with energies considerably greater than can at present be obtained in the laboratory. The reason for using a rocket in such a study is that the cosmic radiation present in outer space is very strongly changed in character by even small amounts of air, so that even the highest balloon flights feasible cannot provide a precise description of the primary radiation, or of the reactions between it and matter. The rocket, however, can serve as a vehicle to carry experimental equipment far into the outer atmosphere.

The radiation which reaches sea level has been carefully analyzed by many experimenters, and has been found to consist mainly of three types of simple rays. These are electrons of both positive and negative charge, gamma rays which are equivalent to very energetic X-rays, and mesotrons. The last are charged particles which may be either positive or negative and most, if not all, of which have a mass about 200 times greater than that of the electron. In addition, the mesotron is radioactive, decaying into an electron of the same charge. Other types of particles are also found at sea level, but in small numbers; these are protons and neutrons. In addition, certain types have been postulated as being present at sea level, although their character is such that they have not yet been observed with present techniques. In this category are the neutral mesotrons and neutrinos.

It is believed by many that the primary cosmic rays are almost entirely protons, and that these, in traversing a small amount of atmosphere produce numbers of mesotrons of several types by interaction with the nuclei of the atmospheric atoms. Some of the mesotrons reach the earth before decaying and form the principal part of the sea level radiation.

Those which decay before reaching the earth generate the so called atmospheric showers; that is, in traversing the atmosphere the



COSMIC RAY WARHEAD INSTRUMENTATION
(VIEW-I)

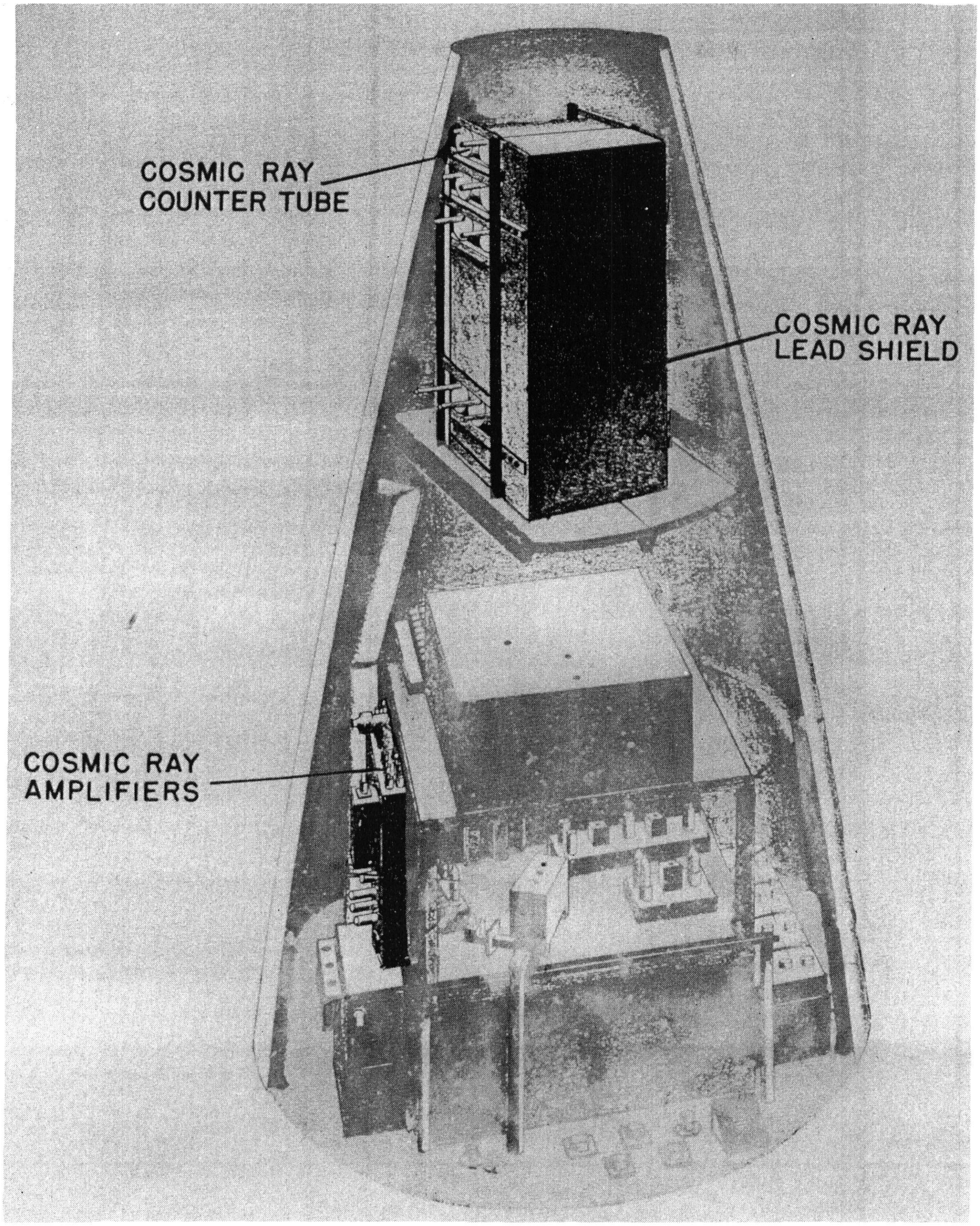
decay electrons first emit very energetic gamma rays, which in turn produce additional electrons, the process repeating many times, thereby increasing the original number of electrons many fold.

The electrons and gamma rays which are not absorbed in the atmosphere reach sea level and produce the so called soft component, the hard component being mainly mesotrons. The terms soft and hard are borrowed from the X-ray radiographer's lexicon, and refer to the penetrating quality of the radiation. Most mesotrons at sea level can penetrate 12 inches of lead, while most of the soft component is absorbed in 2 inches. It is not certain at the present time whether all the soft component arises from mesotron decay (and mesotron collision processes) nor whether all the mesotrons arise directly from primary protons.

The principal tools for experimentation with cosmic rays are the ionization chamber, Geiger counters, the Wilson cloud chamber, and photographic emulsions. Each of these has advantages and disadvantages; but after careful consideration of all pertinent facts, the decision was made to devise an experiment for the June 28 flight, using a number of Geiger counters forming a system of counter telescopes. The relative ease with which counter data can be telemetered was a determining factor in making such a decision.

The type of counter which was used, is a cylinder 2 inches in diameter and 8 inches long, made of brass or copper and having a wall thickness of 1/16 inch or 1/32 inch. A tungsten wire of .003 inch diameter runs inside the cylinder along the axis. The wire passes out through the cylinder and through insulating metal-to-glass vacuum seals. The counters are filled with a mixture of argon and alcohol vapor in the ratio by pressure of 10:1, to a total pressure of 10 centimeters of mercury, and are then sealed off. The counters operate properly at about 1100 volts. The presence of the alcohol vapor makes the counter self-quenching; that is, discharge due to the passage of a ray stops very quickly, permitting the counting of another ray after about 750 microseconds. The current pulse through the counter is transformed to a voltage pulse by means of a series resistor, usually of the order of megohms. For the June 28 firing, 10 megohm resistors were used. The size of the voltage pulse depends on the counter voltage and upon the amount of capacitance between the center wire and ground. With the cables used on June 28, voltage pulses of about 6 volts were obtained.

The experiment performed was designed to furnish preliminary information on the character and intensity of the primary cosmic rays. Concerning character, it was desired to know whether the rays are hard or soft, using as criterion the ability to penetrate 6 inches of lead. It was also to be determined whether the radiation is shower producing. Intensity of the radiation could be obtained as a matter of course from observed counting rates.



COSMIC RAY WARHEAD INSTRUMENTATION
(VIEW-2)

Fig. 1 of Section B is a block diagram showing the arrangements of counters and the associated electronics used in the experiment. Some of the counters were paralleled as shown, in order to increase the counting rate. Four telemetering channels were initially allotted for cosmic rays experimentation. Channel No. 1 transmitted coincidences between counters 1, 2, and 3. This measured the total ionizing radiation. Channel No. 2 transmitted coincidences 2, 3, and 4. This measured the radiation which could penetrate 6 inches of lead. Channel No. 3 measured coincidences 1, 3, and 5. It may be observed that no single particle could cause such a coincidence. Therefore, channel No. 3 recorded the formation of showers produced in the walls of the rocket. Telemetering channel No. 4 transmitted coincidences between counters 3 and 5, these being used mainly as a check on the internal consistency of the data received on the ground.

At a later stage in the preparation of the experiment, three more telemetering channels were made available. These were then used to telemeter counts separately from counters 1, 4, and 5. Counters 1 and 5 measured the total count while 4 measured the hard count.

In general, single counter data is not so reliable as coincidence counting because the counting rate is influenced by the presence of radioactive contaminants. Coincidence counting, using counters with walls as thick as the ones used on June 28 is unaffected by the relatively low energy radiation found in naturally radioactive sources. On the other hand, since the duration of a rocket flight affords only a few minutes for carrying out any experiment, and since the counting rates are subject to statistical fluctuations, the greater rates measured in single counter experiments may be expected to yield smoother data.

CHAPTER III

UPPER ATMOSPHERE RESEARCH CONDUCTED BY THE NAVAL RESEARCH LABORATORY

B. Electronics of the Cosmic Ray Experiment

by

B. Howland, C. A. Schroeder
and J. D. Shipman

Although there are well known techniques for detecting cosmic rays, special problems had to be solved in setting up a cosmic ray electronic circuit suitable for use in the V-2 rocket. The electronic system described here and used in the June 28 firing was designed with such problems specifically in mind.

Fig. 1 is a block diagram of the system adopted. The pulses from the Geiger counter tubes are shaped and amplified by circuits A. The outputs from several such shaping circuits are applied to a coincidence circuit B. The output from circuit B activates a pulse storage circuit C. Every 200th of a second the telemetering system measures the output of the pulse storage circuit. If a count is stored there, this fact is telemetered and the pulse storage circuit is reset to receive and store another count. Pulses from the Geiger counter arrangements 1, 4 and 5 are lengthened by the pulse stretching circuits D, the outputs of which are telemetered.

Fig. 2 shows the basic circuits employed in the experiment. A negative pulse from a counter tube, or an arrangement of counter tubes in parallel, is applied to the control grid of V_1. The tubes V_1 and V_2 are in a biased multivibrator circuit with V_1 normally conducting. When the grid of V_1 is pulsed negatively the plate of V_2 falls in potential for 30 microseconds and then returns to its standby level. This signal is applied to the positively biased grid of a cathode follower, V_3 , which acts as a buffer stage and impedance transducer. The multivibrators are used chiefly to obtain convenient pulse shape and constant amplitude with which to operate coincidence circuits.

The outputs from several cathode followers corresponding to different counters are applied to the plates of a multiple plate diode, V_4 , the common cathode of which is connected to ground by a high resistor. Since the cathode-to-ground resistance is by far the largest part of the total resistance in any of the diode circuits, no more than one diode section need conduct to insure a cathode potential of approximately +60 volts. A significant drop in this voltage is obtained only if all the diode plates common to a given cathode fall simultaneously in voltage. This occurs only when a coincidence is registered in all counter tubes feeding the diode. If a circuit is constructed using n diode plates and n cathode followers to register an n-fold coincidence, clipping circuits must be used to distinguish at worst against an (n-1)-fold coincidence. A simple analysis shows that the latter event produces a cathode voltage change related to the former by the expression:

$$\frac{V_n - 1}{V_n} \sim \frac{1}{R_c} \left(\frac{1}{g_m} + R_D\right) \left(1 - \frac{1}{n}\right),$$

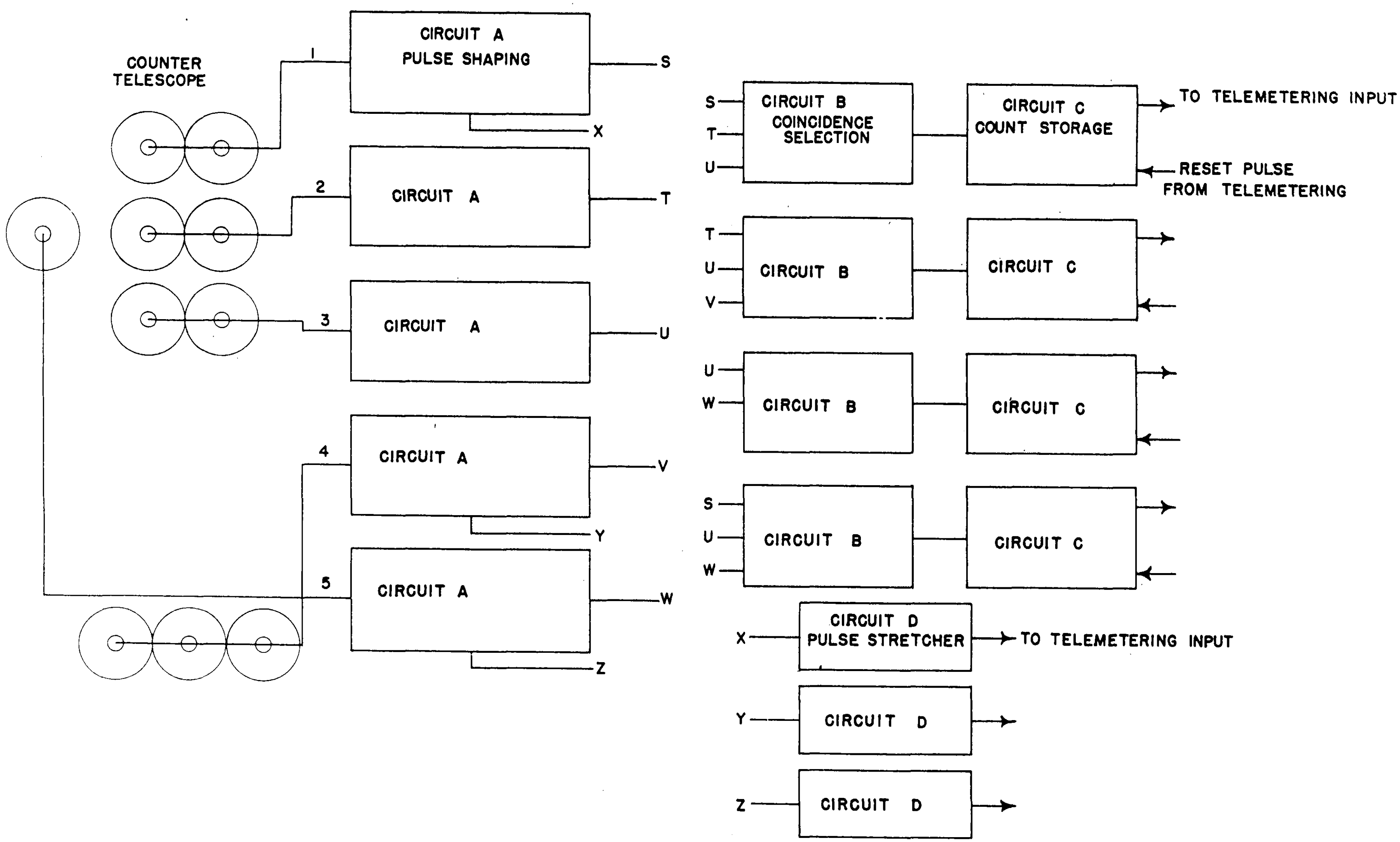
where R_c is the cathode resistance, R_D the resistance of a diode section and g_m the transconductance of a cathode follower at its operating bias. For ordinary tubes and large R_c, V_n-1/V_n is quite small compared to unity.

The diode cathode is coupled to the center tap on a resistor connected from the grid of V_5 to the +60 volt bus. A negative cathode pulse larger than 30 volts will overcome this bias and will actuate the pulse storage circuit (circuit C of Fig. 2). This circuit is of the Eccles-Jordan type using 6AS6 miniature pentodes. V_5 is conducting in the standby condition and the potential at the output point of the circuit, which is a tap on a voltage divider between the plate of V_5 and ground, is +0.5 volts. When a coincidence occurs, and the pulse storage circuit is triggered, the potential at the output point rises to +4.5 volts and remains at this level until measured by the telemetering system. The telemetering system immediately thereafter applies a negative pulse to the control grid of V_6, triggering the circuit back to its original condition. As shown in Fig. 1, the coincidence events recorded in this manner are 1, 2, 3; 2, 3, 4; 3, 5; and 1, 3, 5.

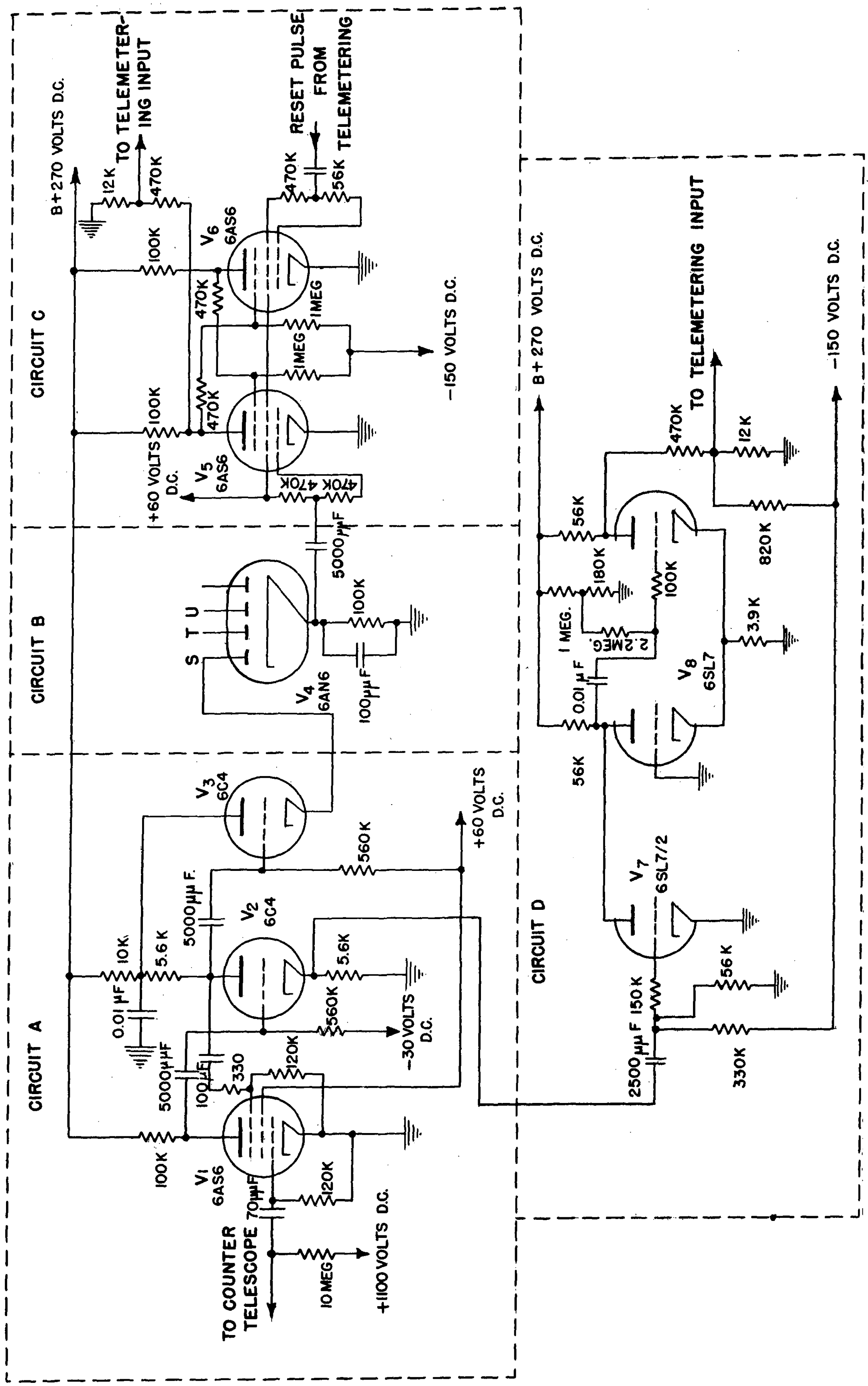
As described previously the biased multivibrator (circuit A) has an output pulse 30 seconds long. If a cosmic ray particle were to pass through counter arrangement 1, and within somewhat less than 30 microseconds other particles passed through counter arrangement 2 and 3, this phenomenon would be recorded as a coincidence when it actually was not, since a true coincidence is caused by a single particle passing through all the counter arrangements in about 10^{-9} seconds. The number of such accidental coincidences per unit time may be computed in terms of a time T, the coincidence resolving time. This is the interval within which all of the counters must fire in order to operate the coincidence circuits. To reduce accidentals, T is made as small as possible. In general a lower limit is set by the excessive current drains required for definition of narrow pulses. By measurement T was determined to be 20 microseconds and this was adequate for the experiment.

The diode type of coincidence circuit was used instead of the more universally used Rossi circuit, involving pentodes, for two major reasons. First, a supply of 6AN6 miniature diodes was available. These diodes have 4 plates and common cathode in one envelope. Their compactness minimized the size of the apparatus. Second, the diode circuit is considerably more economical in current drain.

In order to measure the individual counts of counter arrangements 1, 4, and 5 the pulse stretching circuits D were inserted as shown in Fig. 1. The circuits operate as follows: The positive pulse output of the cathode follower of circuit A is coupled to the grid of V_7, which triggers a biased multivibrator. When the multivibrator is triggered the potential at the output point rises from +0.5 volts to +4.5 volts, remains there for 7000 microseconds, then returns to +0.5 volts. The level at the output point of the biased multivibrator is sampled every 200th of a second or 5000 microseconds; therefore, each count is recorded on at least one telemetering cycle and sometimes on two. This system of relaying the information to the telemetering has the advantage of not having to be reset. This reduces the connections to the telemetering and eliminates the possibility of the reset failure. The first system, however, has the advantage of recording a single event on only one telemetering cycle, permitting higher counting rates.



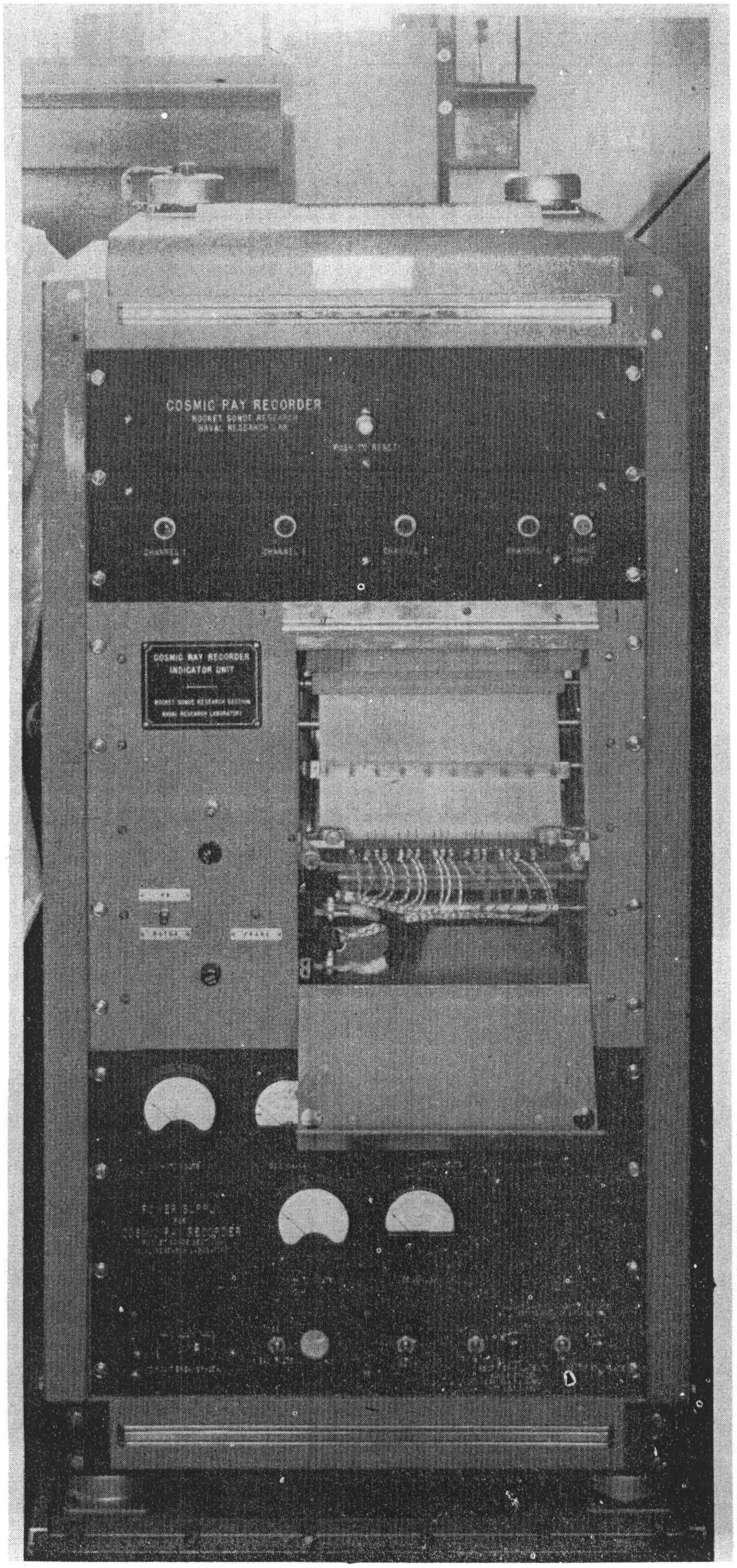
BLOCK DIAGRAM OF COSMIC RAY TELESCOPE AND CIRCUITS



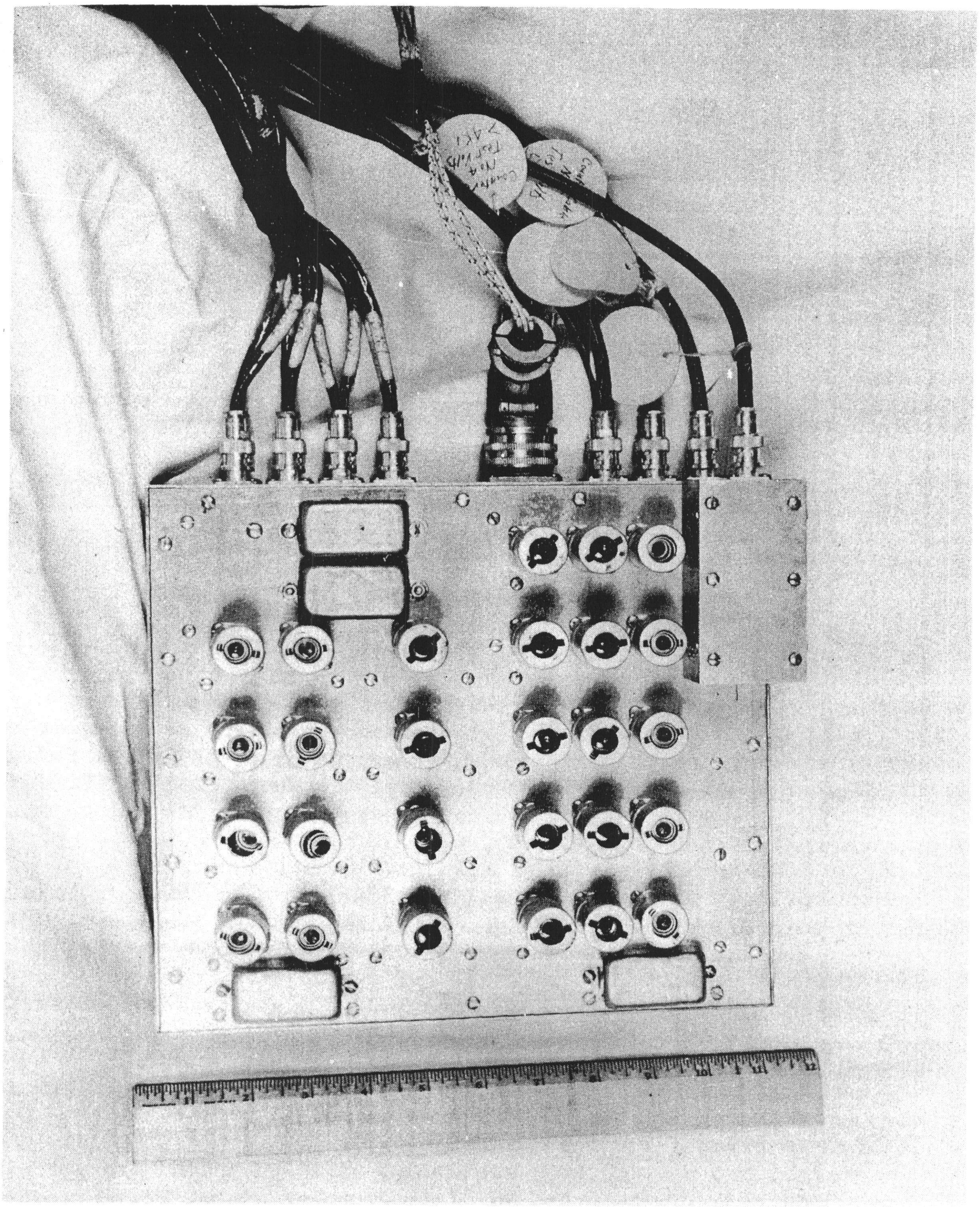
SCHEMATIC DIAGRAM OF COSMIC RAY CIRCUITS

R-2955

CH. III SEC. B FIG. 2



COSMIC RAY GROUND STATION RECORDER



COSMIC RAY ELECTRONIC WARHEAD EQUIPMENT

C. Letter to Physical Review on Cosmic Radiation Above 40 Miles

Most of the information derived so far from the reduction of cosmic ray data obtained on the V-2 flight of June 28, is summarized in a letter written to the editor of Physical Review. The letter is reproduced below.

Cosmic Radiation Above 40 Miles

by

S. E. Golian, E. H. Krause, and G. J. Perlow

July 15, 1946

We have obtained cosmic-ray data above the earth's atmosphere by means of an apparatus contained in a German V-2 rocket. The rocket was fired by the Ordnance Department, United States Army on June 28, 1946 in connection with a series of tests being made by the Army at its White Sands, New Mexico, proving grounds.

Data were transmitted back to a receiving station on the ground by means of a multi-channel radio equipment. Difficulties which developed in this and accompanying electronic circuits prevented satisfactory records below 200,000 feet. Forty-one seconds of data were obtainable after this time, all of it on ascent. Maximum altitude obtained was 350,000 feet.

Figure 1 is a schematic drawing of the cosmic-ray equipment as mounted in the warhead. Chamber A above the cosmic-ray chamber had a total weight, including contents, of 100 pounds, which was almost entirely steel. If this is considered spread uniformly across the top of chamber B, it is equivalent to about 7.8 centimeters of iron. Single counts in counters 1, 5, and 4 were transmitted, as well as coincidences (1, 2, 3), (2, 3, 4), (3, 5), and (1, 3, 5). In addition, coincidence between each of these various data could be read off the record on the ground. Coincidence resolving times in the rocket were 20×10^{-6} sec., while the resolving time for inter-channel coincidences on the ground was 5×10^{-3} sec. The cosmic-ray counters were fastened in a light aluminum rack which could be removed from the lead for solid angle calibration. A series of calibration runs was made both at Washington and at White Sands, (altitude 4000 feet, geomagnetic latitude 42°N).

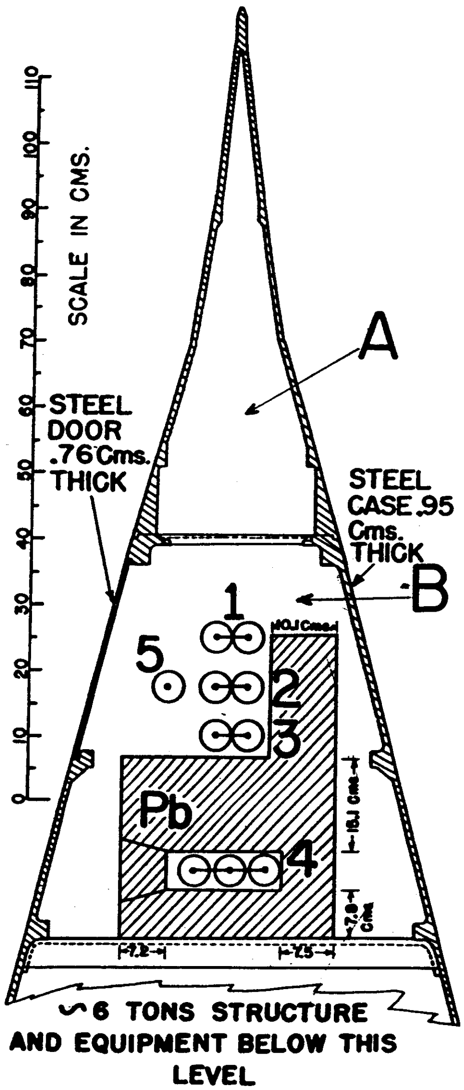
Considering first the data from the single counters, counters 1 showed an increase in rate above 200,000 feet over the rate on the ground of 21.3 ± 1.0 times. Counter 5 showed an increase of 20.7 ± 1.2 times. Counters 4 gave 34.9 ± 1.7 for this ratio. In a separate experiment on the ground at White Sands with a vertical telescope, it was determined that the ratio of hard count to total count was 0.651 ± 0.024. If the primary rays are all hard, then the shielded counters (4) should have a ratio of counting rate in flight to ground rate higher than that for the unshielded counters by the ratio 1 to 0.651. Reduction of the shielded counting rate by the reciprocal of this factor gives 22.7 ± 1.4, which agrees with the ratios for the other counters within probable error. Probable errors are determined from statistics only. Counting rates in flight were 36.2/sec., 22.0/sec., and 39.2/sec. for counters 1, 5, and 4, respectively.

The data from the coincidence channels were as follows: (1, 2, 3) increased by a factor of 56 over the ground rate, (3, 5) by a factor of 150, and (1, 3, 5) by a factor of 420. Channel (2, 3, 4) developed an electronic defect and furnished no usable data. Of the 61 counts observed in 28.6 sec. in the shower channel (1, 3, 5) 49, or 80%, accompanied coincidences (1, 2, 3). The latter channel in this time had 103 counts. Thus, 49/103 or 48% of the counts in (1, 2, 3) were accompanied by showers. This presumably accounts for the higher increase in counting rate than the single counter results indicate.

The effect of the warhead structure as determined in the ground calibration was to increase the soft part of the count in (1, 2, 3) by a factor of 2.2 over the rate without warhead. At the same time, a shower in (1, 3, 5) was recorded for each 6.6 soft counts recorded in (1, 2, 3) with the warhead in place. The high shower to total count ratio in flight probably indicates therefore, that showers of many particles are produced at high altitudes in the structure adjacent to the counters.

Further experimental work is being undertaken for future flights. The present data are perhaps best regarded as provisional pending subsequent corroboration. In particular, whatever effect the high shower count may have had on the single counters has not been completely determined.

The writers are indebted to their colleagues in the Rocket Sonde Section, Naval Research Laboratory, and to M. Schein for suggestions concerning the problem.



ARRANGEMENT OF COSMIC-RAY EQUIPMENT AS MOUNTED IN THE WARHEAD

CHAPTER III

UPPER ATMOSPHERE RESEARCH CONDUCTED BY THE NAVAL RESEARCH LABORATORY

D. Temperature Measurements in the V-2

by

R. J. Havens and H. E. LaGow

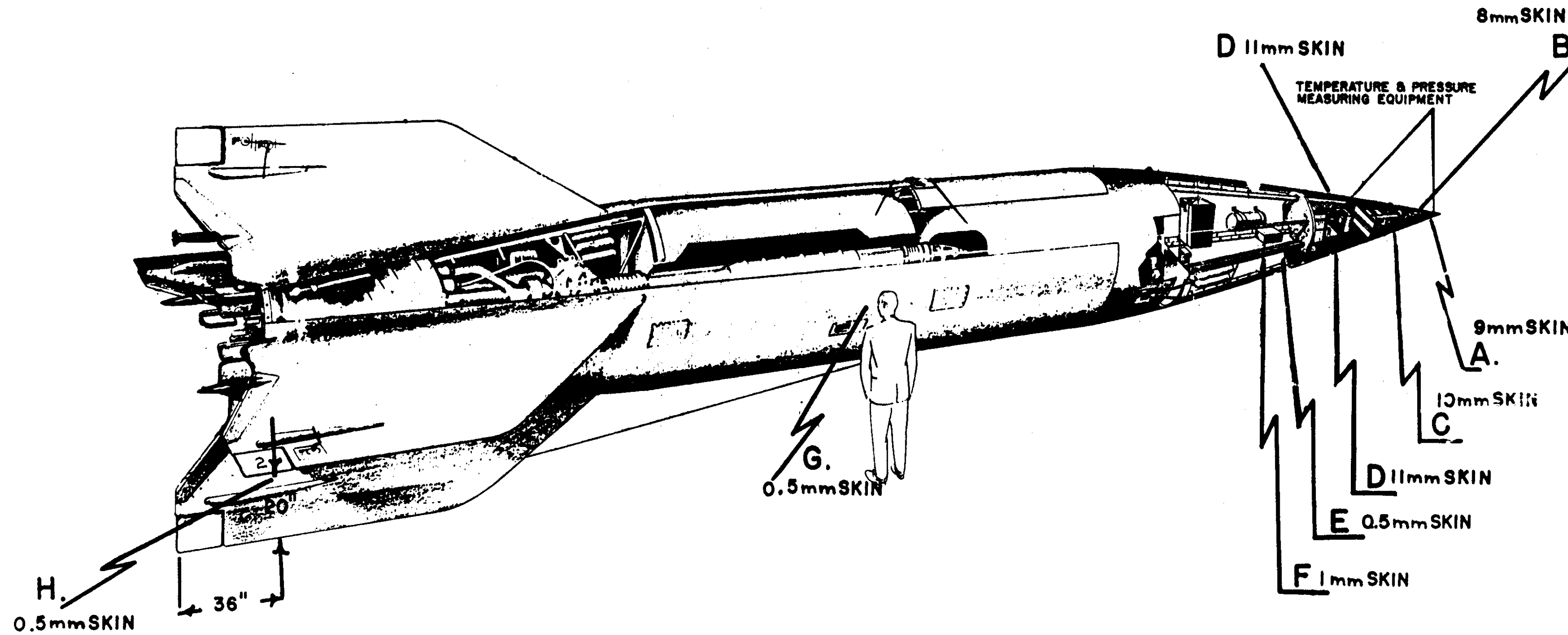
Skin temperatures of the V-2 were measured on the June 28 firing. The measurements were made to obtain data necessary for designing equipment to measure ambient temperatures and pressures, and for designing insulation and radiation shields to protect other instruments. The points at which temperatures were measured are shown in Fig. 1.

The telemetering record was satisfactory only for the period of flight from 89 seconds to 232 seconds after take-off. Since the outside pressure was low during this time there was little air friction or heating of the skin. The temperature was constant in the thick warhead during the time of measurement, but there was a decrease in temperature in the 1/2 millimeter skin due to radiation and conduction to heavier cross braces.

The temperatures were measured with platinum resistance wires, designed to record temperatures up to 700°C with an accuracy of roughly 2%. Since no telemetering record was obtained beyond the top of the flight, the high temperatures on descent were not recorded.

The platinum resistances, each in series with a 24 volt battery and a 150 ohm resistor, were one mil in diameter and 6 centimeters long. They were clamped between two 3 mil sheets of mica of dimensions 3 inches by 1/2 inch. A silver case enclosed the wire and mica. One end of the wire was spot welded to the silver case while the other end was spot welded to a silver ribbon which was clamped to a No. 18 copper wire between two small pieces of transite. The sandwich of wire, mica, and silver was then installed on the skin of the missile by means of 14 screws size 0-80. A large number of screws was necessary for good thermal contact between the wire and mica so that the large current of 1/7 ampere passing through the wire would not heat the wire. The small size of the screws kept the heat capacity at a minimum.

The voltages across the platinum wires were commutated and then sent directly to the telemetering input. At 30°C the direct current potential was about 1.8 volts and at 700°C it was about 5.0



LOCATIONS OF TEMPERATURE AND PRESSURE MEASURING EQUIPMENT IN TNE V-2 volts. Since the telemetering transmitted d.c. voltage between a range of 0 and 5 volts, no amplification was required.

Thermistors for measuring temperatures below 150°C were included but failed to operate because of circuit difficulties.

The following table is a list of the temperatures obtained.

TEMPERATURES OBTAINED AT VARIOUS POSITIONS ALONG THE V-2, THE TIME DURING WHICH THESE TEMPERATURES OCCURRED AND THE SKIN THICKNESSES CORRESPONDING TO THOSE POSITIONS

Distance from Nose Tip	Skin Thickness	Time	Temperature (°C)
Position:			
A 0.75 ft.	0.9 cm	av. 90 to 230 sec.	160° ± 15°
B 2.0 ft.	0.8 cm	do	160° ± 15°
C 4.0 ft.	1.0 cm	do	90° ± 10°
D 6.5 ft.	1.1 cm	do	75° ± 10° (180° apart) 75° ± 10°
E Control Chamber - 0.75 ft. from warhead	0.05 cm	90 sec. 230 sec.	190° ± 10° 150° ± 10°
F Control Chamber - 2.5 ft. from warhead	0.10 cm	av. 90 to 230 sec.	125° ± 10°
G Midsection of missile 10.5 ft. behind control chamber	0.05 cm	90 sec. 150 sec.	140° 85° - remained constant to 230 sec.
H Tail fin #3 - 20 inches from outside edge - 3 ft. from trailing edge	0.05 cm	av. 90 to 230 sec.	150° ± 20° - cooling not apparent - probably due to conduction from hotter outer part of fin.

CHAPTER III

UPPER ATMOSPHERE RESEARCH CONDUCTED BY THE NAVAL RESEARCH LABORATORY

E. Pressure Measurements in the V-2

by

N. R. Best, D. I. Gale,
and R. J. Havens

Pressures at altitudes above 25 miles, which must be less than 1 millimeter of mercury, have never been observed experimentally. Several theories have been formulated as to the nature of the upper atmosphere, but the various pressures predicted differ by factors of as much as 1,000 at heights above 100 miles.

The altitudes commonly attained by V-2's are greatly in excess of the 22 mile limit hitherto imposed upon the heights to which direct measurements of atmospheric pressure could be made with the aid of balloons. The missiles, therefore, afford a good means for extending direct observations of pressure to very high altitudes. Since ambient pressure can be deduced from stagnation pressure at the nose of the missile*, an attempt was made in the June 28 firing of the V-2 at White Sands, to measure the stagnation pressure with two Pirani gages. The gages used covered the range from 10 millimeters to 10^{-3} millimeters of mercury.

A Pirani gage operates on the principle that the heat conducted from a hot wire varies with the pressure. However, the rate of heat conduction does not change until the mean free path of the molecules is of the same order of magnitude as the diameter of the wire. The heat generated in a current carrying wire is lost by radiation, by air conduction, and by conduction down the wire. A long wire in a good vacuum loses almost all of its heat by radiation.

For pressures between 10 millimeters and 0.1 millimeters of mercury a 0.7 mil platinum wire was used. Put in series with a 280 ohm resistor and a 24 volt battery, it produced a one volt drop across it at high pressures and a 3 volt drop at low pressures. At 3 volts the temperature of the wire was 1000°C. In the other gage a 0.5 mil tungsten wire used in the same way gave voltage variations from 2.7 volts at 0.5 millimeter of mercury to over 5 volts at 0.01 millimeter of mercury. The voltages were fed through a commutator directly to the input of the telemetering. (See the discussion on

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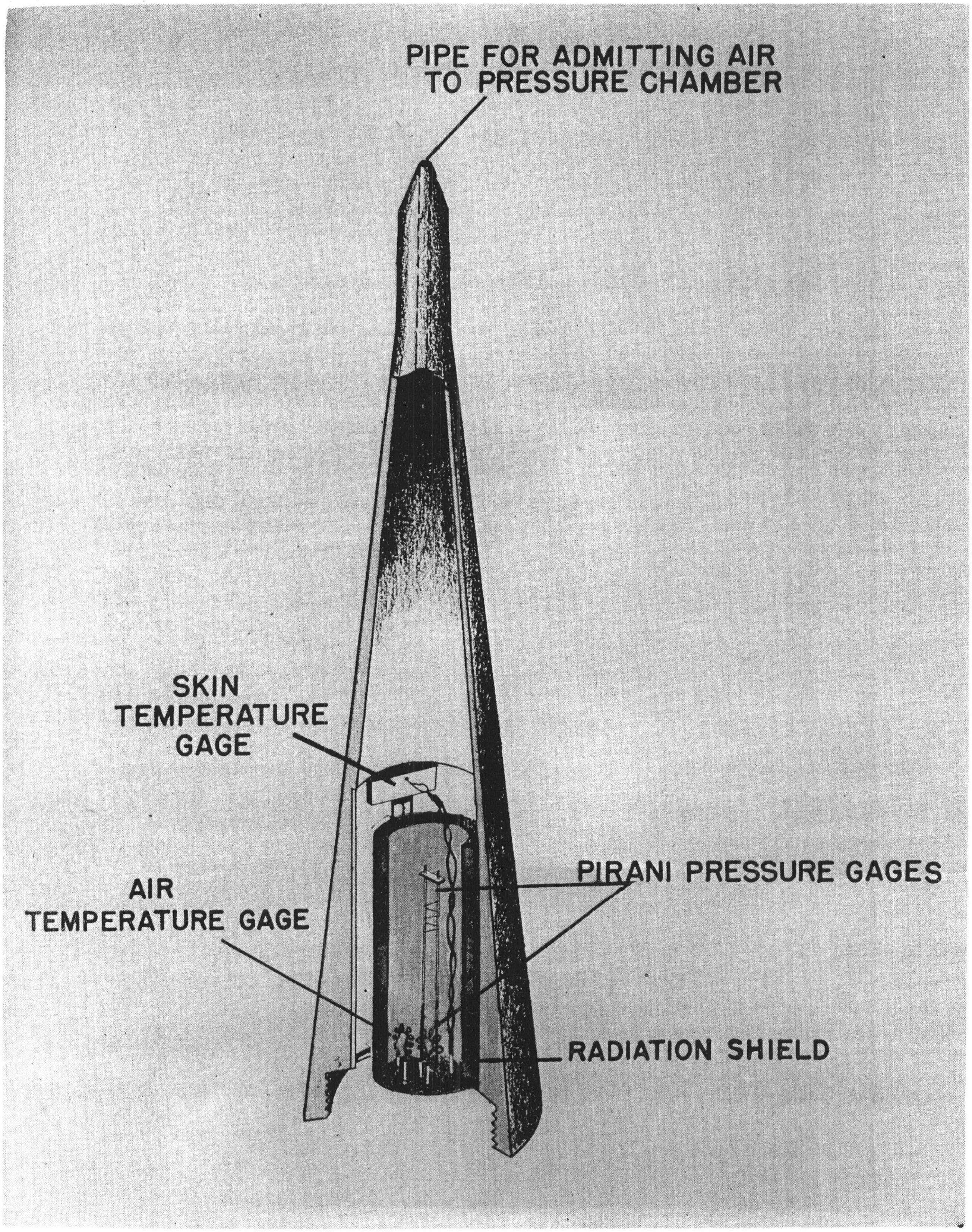
*See Appendix IV



PRESSURE AND TEMPERATURE INSTRUMENTATION IN THE NOSE the commutator given in Chapter II, Section C.)

Pressure within the spectrograph chamber was also measured with a Pirani gage, which at the top of the trajectory indicated a pressure between 2 and 100 microns. The measurement was not more definite because of limiter action on the voltage used to indicate the value of the pressure.

The pressure measurements were unsatisfactory for a number of reasons. Telemetering data were available only during the period of flight between 90 and 230 seconds. Thus no data were obtained from the high pressure range Pirani gage since measurable pressure changes for this gage occurred before 90 seconds. The limiting circuits, designed to protect the telemetering, operated at a lowered voltage due to excessive drain on the six volt battery in the warhead. This prevented the data voltages from rising linearly above 2.8 volts, consequently affecting the data from the low pressure gages. Between 90 and 230 seconds the measured wall temperature was 160°C. At this temperature large quantities of gas were evolved from the walls and, therefore, the pressure measured in the nose was not necessarily the true ram pressure at the tip of the nose, but probably much higher. The pressures measured varied from 300 ± 50 microns of mercury at 90 seconds to 100 ± 50 microns at 230 seconds.

The error in the Pirani gages due to the change in the air temperature was not large since the wall temperatures were not communicated to the air surrounding the pressure gages because of a high heat capacity shield between the nose skin and the gages. Measurements within the shield showed a temperature rise of less than 20°C.

CHAPTER III

UPPER ATMOSPHERE RESEARCH CONDUCTED BY THE NAVAL RESEARCH LABORATORY

F. Theoretical Discussion of the Ionosphere Experiment

by

J. C. Seddon and J. W. Siry

When the V-2 firings at White Sands were originally scheduled, they provided the first means of making measurements in the ionosphere itself. As vehicles for carrying experimental equipment into the upper atmosphere, they offered the possibility of obtaining data which could not be obtained from the ground. Customary measurements made from the ground fail to provide information on ion or electron density between the altitude of maximum density in one ionospheric layer and the altitude of similar density in the next higher layer. Moreover, a high degree of accuracy is difficult to obtain in such measurements.

So far the experimental work on the ionosphere has been concerned with the development and perfection of techniques for carrying on the investigation of the properties of the ionosphere. Various radio transmission and reception problems have been under investigation and much profitable experience has been obtained. The development of antennas which radiate properly and at the same time remain on the rocket during its flight is underway. This particular problem has been one of the most vexing to date, and is at present only partially solved.

A simple and direct method was adopted for developing and perfecting experimental techniques. An experiment was devised which, if successful, would provide valuable information about the ionosphere. The attempt to carry through this experiment successfully, immediately plunged the section into the midst of various complex and difficult problems. These are the problems, solutions of which are at present sought. Considerable progress has already been made in this direction, although the experiment itself has not been successfully performed.

Before proceeding with a description of the experimentation, it is perhaps advisable to outline the theoretical considerations which form the basis of this activity. The discussion of this section presents the theory of the ionosphere experiment. The experimental activities to date are covered in the next section.

The principal object of the experiment is to measure the ion density in the ionosphere. In an ionized medium the index of refraction n, is a function of the ion density N, and the angular frequency w of the radiation; specifically:

$$(1) \qquad n = \sqrt{K} = \sqrt{1 - \frac{4\pi N e^2}{w^2 m}} \,,$$

where e and m are the charge and mass of each ion. Thus any experiment designed to determine the index of refraction yields corollary information as to the ion density.

Suppose a wave train exists in an ionized medium for which the index of refraction corresponding to angular frequency w is $\bar{n}_w$. Then if the time variation of the electric vector at point P is given correctly by

$$(2) \qquad Ee^{iwt}$$

the corresponding time variation at a point Q, x units distant from P, is given by

$$(2a) \qquad Ee^{i(wt - \frac{w}{c}\bar{n}_w x)}$$

Similarly, if the radiation is of frequency Mw, and is in phase with (2) at P, then, at Q, the electric vector must be given by

$$(3) \qquad E_1 e^{i(Mwt - \frac{Mw}{c}\bar{n}_{Mw} x)}$$

where the index of refraction $\bar{n}_{Mw}$ is now referred to the frequency Mw. M may, in general, be any number, and, for experimental convenience it can be taken as a positive integer. In the ionosphere experiment M is a divisor of 48.

If at Q the frequency of the first radiation be multiplied by M and compared with that of the second radiation, the two will differ in phase by

$$(4) \qquad \phi_{w - Mw} = \frac{Mw}{c} x \left\{ \bar{n}_{Mw} - \bar{n}_w \right\}$$

It is this difference in phase which is used in the ionosphere experiment for determining ion density in the ionosphere.

Actually the ionosphere is not homogeneous, but rather is a region in which ion density varies considerably. There are, as is well known, regions of maximum densities to which it is customary to refer as ionospheric layers, as for example, the E layer and the F layers. A certain amount of ionization exists throughout the atmosphere, however, and it must not be thought that ionization of the atmospheric gases is confined to these layers.

For the purpose of this discussion the point P referred to above, is thought of as riding the rocket as it ascends into the atmosphere, while the point Q remains fixed on the earth. Radiation of frequencies w and Mw emanate from the point P and eventually reach Q at which point a phase difference similar to that exhibited in (4) usually exists.

The simple discussion preceding (4), however, does not apply inasmuch as the indices of refraction referred to a homogeneous region. To modify the analysis appropriately, consider a small variation dx in the distance of P from Q. In the region covered, $n_w(x)$ and $n_{Mw}(x)$ may be considered as constant. For the radiation of angular frequency w, the incremental phase shift corresponding to the path interval dx is $\frac{w}{c} n_w(x)\,dx$. The total phase shift occurring between P and Q is accordingly

$$\frac{w}{c} \int_0^x n_w(x)\,dx.$$

According to the discussion preceding equation (4), if the ion density between P and Q were constant, equal to $\bar{n}_w$, the phase shift would be $\frac{w}{c}\bar{n}_w x$. It is convenient to set these two quantities equal, and to solve for $\bar{n}_w$, thereby obtaining an "average" value for ion density. This average value is given by

$$\bar{n}_w = \frac{1}{x} \int_0^x n_w(x)\,dx, \tag{5}$$

which is seen to be merely the arithmetic average of n_w over the path from Q to P. Similar remarks apply to n_{Mw}.

Using the average values for n_w and n_{Mw} as obtained above, equation (4) can be applied to a discussion of ionosphere as it actually exists. Differentiating (4) with respect to the time:

$$(6)\quad \dot{\Phi}_{w-Mw} = \frac{M_w}{c}\dot{x}\left\{\bar{n}_{Mw} - \bar{n}_w\right\} + \frac{M_w}{c}x\left\{\dot{\bar{n}}_{Mw} - \dot{\bar{n}}_w\right\} + \frac{M_w}{c}x\left\{\frac{\partial \bar{n}_{Mw}}{\partial t} - \frac{\partial \bar{n}_w}{\partial t}\right\}$$

which may be written

$$(7)\quad \dot{\Phi}_{w-Mw} = \frac{M_w}{c}\dot{x}\left\{\bar{n}_{Mw} - \bar{n}_w + x\bar{n}'_{Mw} - x\bar{n}'_w\right\} + \frac{M_w}{c}x\left\{\frac{\partial \bar{n}_{Mw}}{\partial t} - \frac{\partial \bar{n}_w}{\partial t}\right\}$$

This equation may be simplified by differentiating equation (5) with respect to x:

$$(8)\qquad \frac{d\bar{n}_w}{dx} = -\frac{1}{x^2}\int_0^x n_w(x)\,dx + \frac{1}{x}n_w(x)$$

Multiplying both sides by x, replacing the integral by its value in terms of $\bar{n}_w$, and transposing:

$$(9)\qquad x\bar{n}'_w + \bar{n}_w = n_w$$

Similarly

$$(10)\qquad x\bar{n}'_{Mw} + \bar{n}_{Mw} = n_{Mw}$$

Substituting these results into equation (9)

$$(11)\quad \dot{\Phi} = \frac{M_w}{c}\dot{x}\left\{n_{Mw} - n_w\right\} + \frac{M_w}{c}x\left\{\frac{\partial \bar{n}_{Mw}}{\partial t} - \frac{\partial \bar{n}_w}{\partial t}\right\}.$$

This equation forms the basis of the ionosphere experiment.

If P were stationery x would not vary with the time, and the first term of the right member would vanish. During the V-2 experiment P moves with the V-2, Q remains on the ground, and P and Q separate at a rate given by $\dot{x}$. But even if $\dot{x}$ is zero, $\dot{\Phi}$ need not vanish. As is well known, the ion densities in the atmosphere may show considerable fluctuation with time. A striking example is provided by the sporadic ionization of the E layer. Under such circumstances the second expression on the right of (11) is in general not zero.

The effect of such variation in ion density is, however, usually considered to be small, and in what follows will be neglected, so that (11) simplifies to

$$\dot{\phi} = \frac{Mw}{c} \dot{x} \left\{ n_{Mw} - n_w \right\} \tag{12}$$

The quantities M and w are fixed upon in the design of the experiment, and c is the velocity of propagation in free space. The rate of separation $\dot{x}$, of P and Q, and the values of ϕ are all obtained by measurements at the various ground stations. The first of these, along with the altitude of the V-2, are taken from tracking data. The rate at which phase varies with the time is usually referred to as angular frequency. In the experiment, $\dot{\phi}/2\pi$ is detected as a beat frequency. Unless care is taken, additional phase changes are introduced by the receivers, transmitters, frequency multipliers, etc. These changes may also vary as a result of, for example, the Miller effect. For this reason considerable effort has been expended on the problem of designing receivers and other units in which time variations in phase change are either at a minimum, or are readily identifiable as to their origin. For the purposes of simplicity in this discussion, it is supposed that the only contributions to ϕ are those indicated by (12).

The experiment then allows the determination of

$$n_{Mw} - n_w \tag{13}$$

as a function of altitude.

From equation (1) it is seen that the only parameters remaining to be determined are e, m, and N. Assume that a particular type of ion predominates in the ionosphere; then e and m become known, and it is possible to calculate ion density as a function of altitude. Even if the type of ion existing in the ionosphere is not known, it is still possible to obtain an "equivalent electron density" by using for e and m the values of charge and mass of an electron.

The calculation of N may be considerably simplified by taking advantage of a feature of the experimental design, as follows. Radiation rising from a point on the earth's surface and normally incident upon a region such as the ionosphere, is totally reflected whenever n becomes equal to zero. From (1) we see that this occurs when $4\pi Ne^2 = w^2m$. Thus radiation of a given frequency rises until N, the ion density, increases to the value $w^2m/4\pi e^2$ at which point the wave is totally reflected. Since N has a maximum value, obviously, by making w sufficiently large, it will be possible to penetrate the ionosphere. The same analysis also applies, of course, to the more unusual case of the present experiment, in which the radiation originates from a point which is within the ionosphere, and, at times, above one or more of the relative maxima of N. The greatest lower bound of the penetrating frequencies is called the critical frequency. In this experiment w is taken just above the critical frequency. M is some integer between 3 and 16, depending upon the critical frequency as determined by the ionosphere conditions which exist at the time of the experiment. Usually M exceeds six. Since $4\pi Ne^2/w^2m \cong 1$, $4\pi Ne^2/M^2w^2m$ is smaller than unity by the factor $1/M^2$, i.e. by some number between 1/9 and 1/256, but probably not greater than 1/36. Thus $4\pi Ne^2/M^2w^2m$ is small compared to 1 and, for $M \geqslant 6$, the error involved in taking n_{Mw} as unity is less than $1\frac{1}{2}\%$. Equation (12) may then be written

$$\dot{\phi} = \frac{Mw}{c} \dot{x} \left(1 - n_w\right) \tag{14}$$

or,

$$n_w = 1 - \frac{c\dot{\phi}}{Mw\dot{x}} \tag{15}$$

and N is given by

$$N = \frac{w^2m}{4\pi e^2} \left[1 - \left(1 - \frac{c\dot{\phi}}{Mw\dot{x}}\right)^2\right]. \tag{16}$$

Consider what should be expected as the V-2 rises. Below the ionosphere $n_{Mw} = n_w = 1$, essentially, and, therefore, from equation (12) $\dot{\phi}$ vanishes. As the point P traverses the ionosphere, n_{Mw} continues to be nearly unity, while n_w decreases from unity to a minimum value slightly greater than zero at the point of maximum ion density in the E layer. $\dot{\phi}$ accordingly rises from zero to its maximum value. n_w then increases with increasing x, until P has reached the next relative minimum, whereupon n_w again begins to decrease. Correspondingly, $\dot{\phi}$ decreases, and then increases, successively, as long as relative maxima and minima of ion density are traversed by the V-2.

Consider, also, what happens to the absolute, rather than the relative, magnitudes of the two frequencies as the V-2 ascends. While the rocket is below the ionsophere, both frequencies are diminshed in the same ratio (up to 4 cycles per megacycle, depending upon the velocity of the missile) due to the Dopplereffect arising from the relative motion of the rocket at P and the observer at Q. The higher frequency, Mw, is chosen high enough so that, even in the ionosphere, its index of refraction, n_{Mw}, is very close to unity. Thus Mw, as received at the ground, is essentially constant as long as $\dot{x}$ is constant, whether the V-2 be in the ionosphere or not. It is propagated through the ionosphere, the ordinary atmosphere, and free space with a phase velocity equal, in the first order, to c. Hence it can be used as a reference frequency. If the transmitting system at P is stationary in the ionosphere, equation (4) shows that, at Q, ϕ is positive. Thus w is propagated through the ionosphere with a phase velocity exceeding c. If the point P ascends, $\dot{\phi}$ increases. In fact, as is shown in equation (12), $\dot{\phi}$ has the sign of $\dot{x}$. Thus, ignoring the Doppler effect for the moment, the effect of upward motion through the ionosphere is to raise slightly the apparent frequency of the radiation transmitted at the lower frequency w. Hence, when multiplied M times on the ground, this frequency appears to be slightly higher than the reference frequency which was transmitted at Mw. On the downward journey through the ionized regions $\dot{\phi}$ is negative with $\dot{x}$, ϕ decreases, and at Q the apparent frequency of w is slightly lowered.

So far in the discussion the effect of the Earth's magnetic field has not been considered. This effect is often described by drawing a rough analogy with a doubly refracting crystal from which an "ordinary" and an "extraordinary" ray are refracted. Electromagnetic radiation propagated in the ionosphere is split into two elliptically polarized waves. A refractive index is associated with each of these waves, and, in general, the two indices are distinct. However, their difference decreases as m, the mass of the ion, increases. For all ions except electrons, m is so large that the two indices are not distinguished, and, to a first approximation, the previous discussion of the non-magnetic case applies. Thus, if the ionosphere is composed predominantly of heavy ions, no new effects are to be expected. But for an electronic layer, a splitting of the frequencies may be observed. Some idea of the quantitative differences may be obtained from the fact that the effects of electrons and charged nitrogen molecules will be equal if the nitrogen molecules are 5×10^4 times more numerous than the electrons. At the present time, it is not certain what the ions are.

If the power fed into the antenna at P is telemetered to the ground station at Q, the telemetered value may be compared with the recorded strength of the received signal, thus affording a means for making a rough estimate of any attenuation experienced by radiation propagated through the ionosphere. Information concerning long range propagation through the ionosphere can be obtained from signals recorded at distant stations.

In the actual experiment the fundamental frequency is 534 KC. the 3rd, 4th, 6th, 8th, 12th, and 48th harmonics are used. This provides a low frequency, 534 KC, a middle range from 1.602 to 6.408 mc, and a high frequency of 25.632 mc. The critical frequency varies from about 1.5 mc to 3.5 mc, depending on the physical state of the ionosphere. Thus, in the notation of the preceding pages, one of the frequencies in the middle range serves as w, just above the critical frequency. So far, the 6th harmonic 3.204 mc, and the 8th harmonic, 4.272 mc, have each been used twice as the middle frequency, w. The 12th harmonic is just above the critical frequency of the sporadic E layer and may be used to investigate that region if it appears at the time of a firing. The 48th harmonic serves as the high frequency, Mw, in investigating the E layer and the sporadic E layer. In investigating regions whose ion density is less than that found in the E layer by a factor of about 10^2, the fundamental is used as the low frequency w, and the middle range frequency, as the high frequency, Mw. This makes it possible to measure ion densities of the order of 10^3 ions per c.c.

A discussion of the multiplicity of practical problems which have arisen in connection with carrying out the experiment, and of the equipment and techniques which have been developed so far, is given in the next section.

CHAPTER III

UPPER ATMOSPHERE RESEARCH CONDUCTED BY THE NAVAL RESEARCH LABORATORY

G. Development of Equipment and Techniques for the Ionosphere Experiment

by

J. F. Clark, C. Y. Johnson,
T. M. Moore, and J. C. Seddon

The discussion of the preceding Section profides a description of the theory underlying the ionosphere experiment. The experimental work in the field so far has had primarily to do with the development and perfection of equipment and techniques. In the course of this activity the experiment has been attempted several times, but unsuccessfully.

Preliminary to any attempt to carry through the experiment, two antennas of the delta type described below were used on the June 13 flight principally to determine whether or not they would stay on the missile during its flight. Measurements of their transmission properties were also sought.

The reception of a signal from one of the antennas during the interval from 70 to 170 seconds after take-off, showed that that antenna did remain with the missile. No signal at all was obtained from the other antenna. The signal which was received also served to show that for the antenna used at the frequency of 12.6 mc, a power input of approximately 6 watts was adequate to provide a clearly discernible signal on the ground received from an approximate altitude of 65 miles and horizontal range of 8 miles.

On June 28, the complete experiment, except for the long range measurements, was tried, but failed completely, almost certainly due to the transmitters' being inoperative.

Following the failure of the June 28 attempt, the ionosphere experiment was again tried in the July 9 flight. Low frequency signals (.534 mc) did not appear at all due to the failure of that particular transmitter. The intermediate frequency of 3.204 mc came through fairly steadily, but weakly, during the period from 0 to 80 seconds after launching. The high frequency, 25.632 mc, was similarly observed for the first 75 seconds of the flight.

One can conclude that the antennas remained on the rocket and were satisfactory from the mechanical point of view. Also, inasmuch as the signals which were received died away gradually, it appears that insufficient power was being radiated. This may have been due to improper tuning or to detuning due to changing capacitance with the ground as altitude increased. At any rate it appears unlikely that the loss of signal after 80 seconds was due to equipment breakdown.

The experiment was again included in the July 19 flight, together with one trailing wire antenna, installed purely for test purposes. The signals for the ionosphere experiments were never received, owing to transmitter failure. For 27 seconds, however, the signal was received from the 14.5 mc trailing wire antenna at ground stations as far away as 50 miles. At 27 seconds after take-off, the missile exploded, terminating the flight.

The July 30 rocket also carried equipment for the ionosphere experiment, this time using three trailing wire antennas. Signals at .534 mc came in for the first 75 seconds, but with two sharp drops in intensity, indicating the sudden development of trouble. The intermediate frequency of 4.272 mc was observed for the first 64 seconds, with one sudden drop in intensity, similar to the two noted above, but apparently not correlated with either. A 25.632 mc signal was received for 44 seconds after take-off, with extreme variations in intensity of an approximate period of 3 seconds. At the 44th second the signal suddenly dropped out completely.

The table at the end of the section provides a tabulation for all flights to date, of the period of time during which each signal was received, its frequency, and the type of antenna employed. With the exception of the three between 12 and 20 mc, the frequencies are those which apply to the electron density measurements in the ionosphere.

For all flights except that of July 30, the ionosphere transmitters have been located in the pressurized warhead (see Fig. 2 of Chapter II, Section A) as a part of the electronic equipment and batteries. On July 30, the transmitters were installed in a pressurized box in control chamber quadrant IV.

Two different types of antennas have been used: delta antennas extending from the midsection of the rocket to the fins; and trailing antennas, which are towed from the fins behind the rocket. Due to the high velocity of the V-2, unusually high drag values, temperatures, and vibrations are present in wires external to the rocket, necessitating special design. Fig. 1 shows how the antenna wires are usually installed.

The delta antennas are fixed at the midsection 1-1/2 inches away from the main body and are covered by a fairing so as to cause a minimum disturbance to the air flow. This is shown in Fig. 2. Tension in the wires is maintained by four springs in each fin, as shown in Fig. 3, providing a maximum tension of 380 pounds and a tension of 225 pounds after a 2-3/4 inch elongation of the wire. Such an elongation would be caused by a temperature rise of 600°C, which was allowed for to take care of high temperatures caused by windage. It is felt that the 600°C figure provides a good safety factor. The springs allow for the expansion of the wire and provide a tension believed sufficient to limit the lateral deflection due to windage to 1/2 inch. The spring assemblies were constructed so that temperature rises would increase the tolerance between moving parts.

The wire used between the fins is copper-clad steel. Slack is allowed, as shown in Figs. 1, 2, and 4, to reduce the stress in the fixtures at the ends of the catenary. It was feared at one time that forced vibrations due to windage might break the wire, but flight tests have indicated that no damping is necessary. The tensile strength of the wire used is 1000 pounds but it is reduced to 700-800 pounds at the stand off bushings and spring assemblies where silver soldered joints are made.

As brought out above, tests have also been made using trailing wire antennas. These consist of 1/8 inch diameter twisted steel cable mounted on the fins and trailing behind the rocket as shown in Fig. 1. Fig. 5 shows the post for holding the wire to the rocket, and the container for releasing the wire and the drag body in position for launching.

Fig. 6 shows the July 30 missile just after take-off with the trailing wire antennas partially unreeled. The tail section of the vehicle after impact is shown in Fig. 7, with the trailing antenna post intact, and the antenna wire lying on the ground. The wire had broken off 1/3 the way from the trailing end. Another antenna also broken off was found in the vicinity of the impact point.

It is still not known positively whether these antennas are the ones to use until further tests have been made. Signals received on the ground have decreased in quick steps while the rocket motor was running. Among the possibilities for the various failures experienced are: burning off of the wire in the rocket flame; tangling of the wires where more than one is used, due to spin of the rocket after fuel cutoff; and, whip and vibration in the wires. Two flight tests were made using drag bodies on the ends of the wires to aid in holding the wires taut. These were for wire lengths of 76 feet and 150 feet. By observation through field glasses it was learned that the drag bodies pitched and yawed violently. It is apparently better to leave the end of the wire free but to use a somewhat longer wire. Further tests must be made to decide the matter.

The antenna problem remains one of the most serious, and is receiving considerable attention.

Good radiation from the V-2 antennas is made all the more necessary by the fact that there is a severe limitation in reception on the ground due to high noise level. Around noon, the noise level on the desert is roughly 10 millivolts on peaks on 1/2 mc, a few millivolts on 4 mc, but generally less than 100 microvolts on peaks at 25 mc. Consequently reasonably strong signals are required to avoid obscuration of the data by noise. The nose is apparently due to lightning; almost continuous light has been observed in cumulous cloud formations on the horizon. Unusually close or severe flashes have been correlated with AVC voltage on the receiver. The noise follows a fairly regular daily pattern, being low in the morning starting to increase before noon, after which it increases rapidly to a very high maximum in late afternoon. The presence of very close thunderstorms alters the pattern.

Summarizing briefly, the status of the antenna problem is much as follows:

1. Mechanically the side antennas have proven satisfactory. There is still some question as to how much radiation is absorbed by the main body of the rocket, and also how much detuning of the antennas occurs due to leaving the ground.

2. The side antennas are difficult to install, but in the past have given steadier signals than the trailing wires. However, tests so far have been rather incomplete.

3. Further tests are necessary to determine whether trailing wire antennas can be used in their present form. One can perhaps use wire with a much higher melting point. It also appears feasible to extend the wire after the rocket motor has been cut off. In this latter case, the motion of the wire at high altitudes should be given further careful study.

4. Also, of those antennas which prove to be mechanically suitable only those with good radiation efficiency and acceptable pattern are usable, due to the high noise level on the ground.

5. A means of insuring that the transmitters will be properly loaded into the antennas after having left

The ground is under consideration, as it may prove to be a serious problem.

In concluding, the members of the Rocket Sonde Research Section wish to express their gratitude for kind assistance given by many outside agencies and persons. The National Bureau of Standards installed and are operating at White Sands Proving Ground a portable pulsed radio ionosphere height finding equipment, which furnishes invaluable data for the ionosphere experiment. The General Electric Company kindly permitted the installation of ionosphere equipment on three of the V-2's assigned for their own use, and assisted in that installation. The Applied Physics Laboratory of Johns Hopkins University graciously made available space in their missile for Naval Research Laboratory equipment. The Aberdeen Proving Ground Ballistic Research Laboratory cooperated in the study of radio frequency interference problems on the V-2's.

It is also desired to express thanks for the idea of using the delta type antenna which originally came from Dr. M. H. Nichols, then at Princeton University.

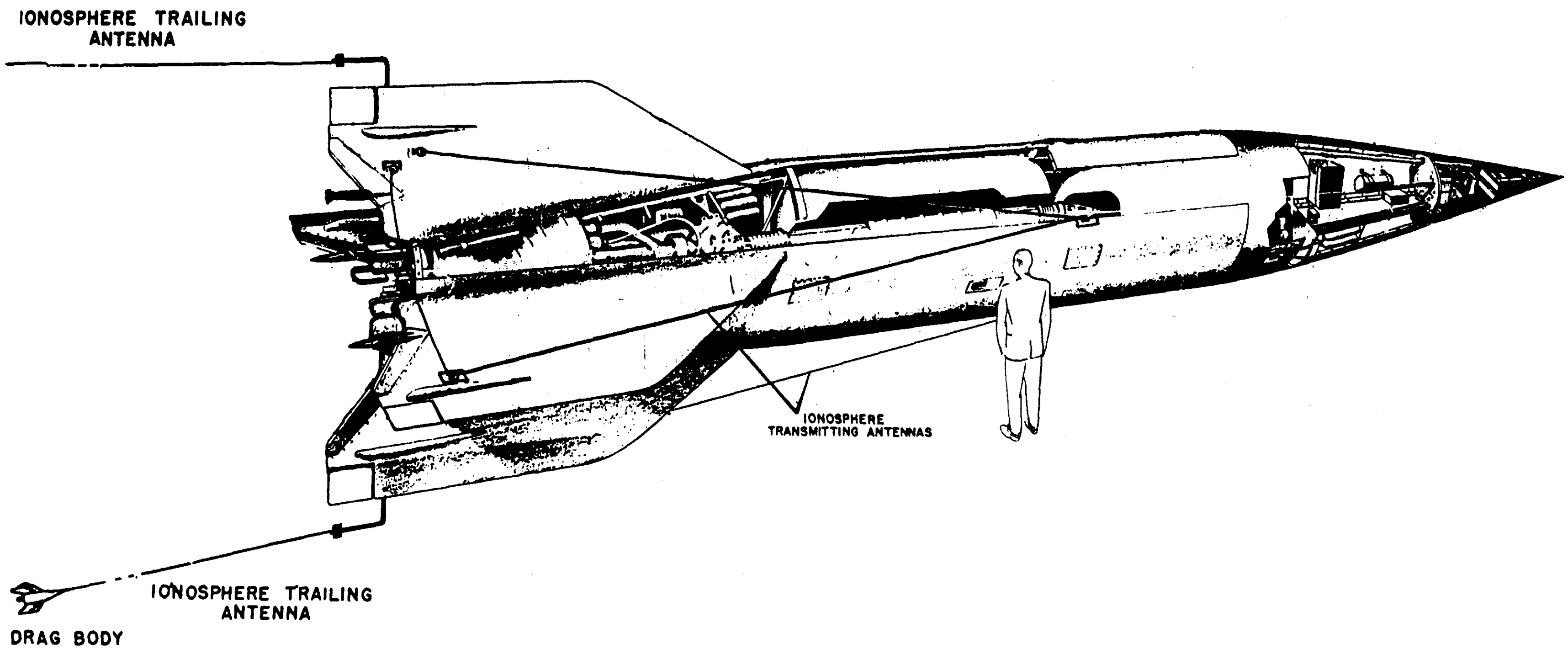
Thanks are also due to the Chemistry Division of the Naval Research Laboratory for the preparation of special silicone rubber gasket material needed for the initial V-2 antenna installations.

V-2 IONOSPHERE ANTENNAS

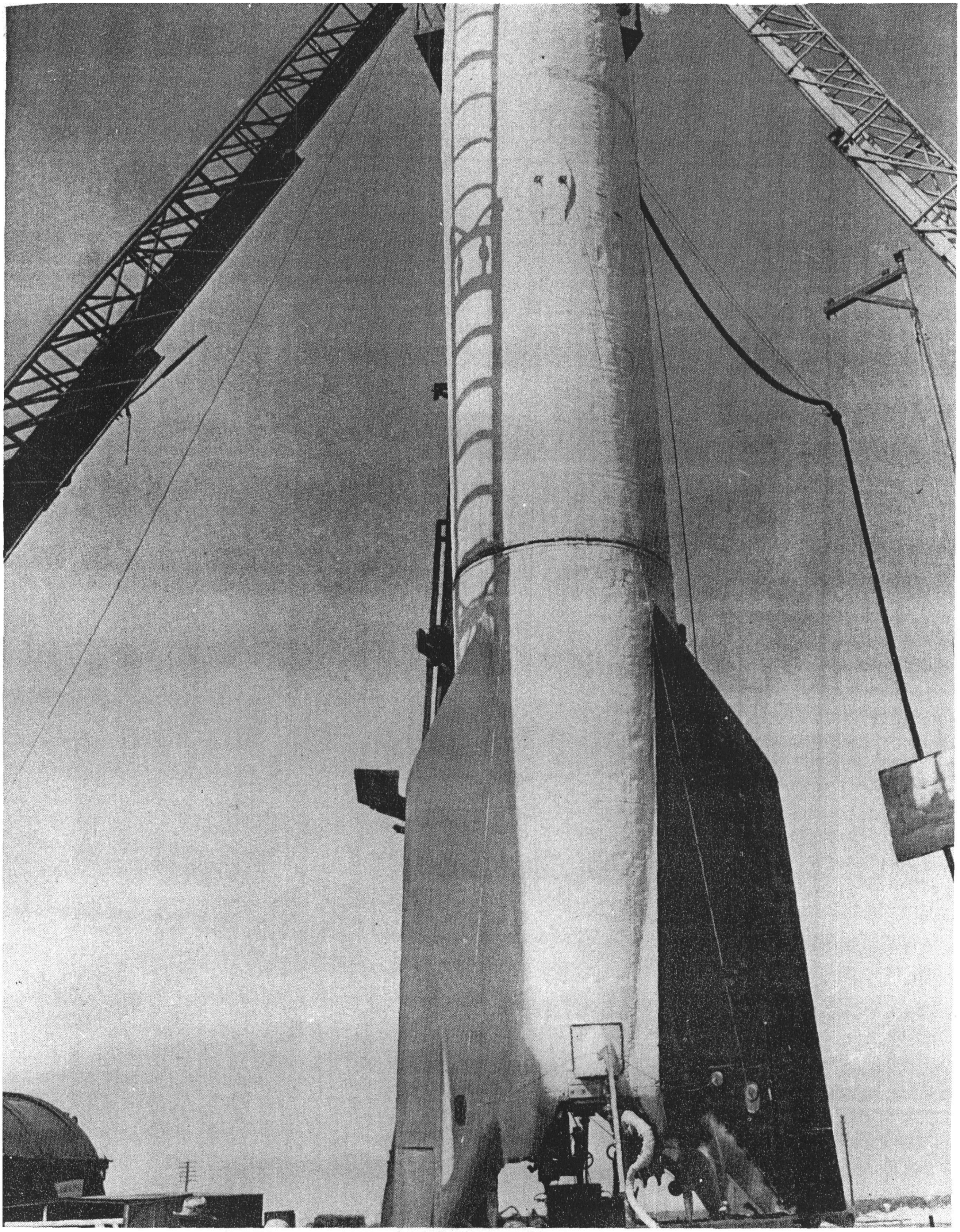
June and July, 1946

Date of Firing	June 13	June 27	July 9	July 19	July 30
Type of Antenna					
Side Antennas:	Frequency in MC.				
Midsection to Fin 1	12.6	25.632	25.632	25.632	---
Midsection to Fin 4 to Fin 1	12.6	3.204	3.204	4.272	---
Midsection to Fin 2 to Fin 3 to Midsection	19.6	0.534	0.534	0.534	---
Trailing Wire Antennas:					
Fin 1	---	---	---	14.5	25.632
Fin 2	---	---	---	---	4.272
Fin 4	---	---	---	---	0.534
Side Antennas:	Length of Antenna Wire in Feet				
Midsection to Fin 1	26	26	26	26	---
Midsection to Fin 4 to Fin 1	31	31	31	31	---
Midsection to Fin 2 to Fin 3 to Midsection	56	56	56	56	---
Trailing Wire Antennas:					
Fin 1	---	---	---	150	75
Fin 2	---	---	---	---	110
Fin 4	---	---	---	---	150
Side Antennas:	Period of Received Signal in Seconds				
Midsection to Fin 1	0[1]	0[3]	75	0[3]	---
Midsection to Fin 4 to Fin 1	0[1]	0[3]	80	0[3]	---
Midsection to Fin 2 to Fin 3 to Midsection	70-170[2]	0[3]	0[3]	0[3]	---
Trailing Wire Antennas:					
Fin 1	---	---	---	27[4]	44
Fin 2	---	---	---	---	64
Fin 4	---	---	---	---	75

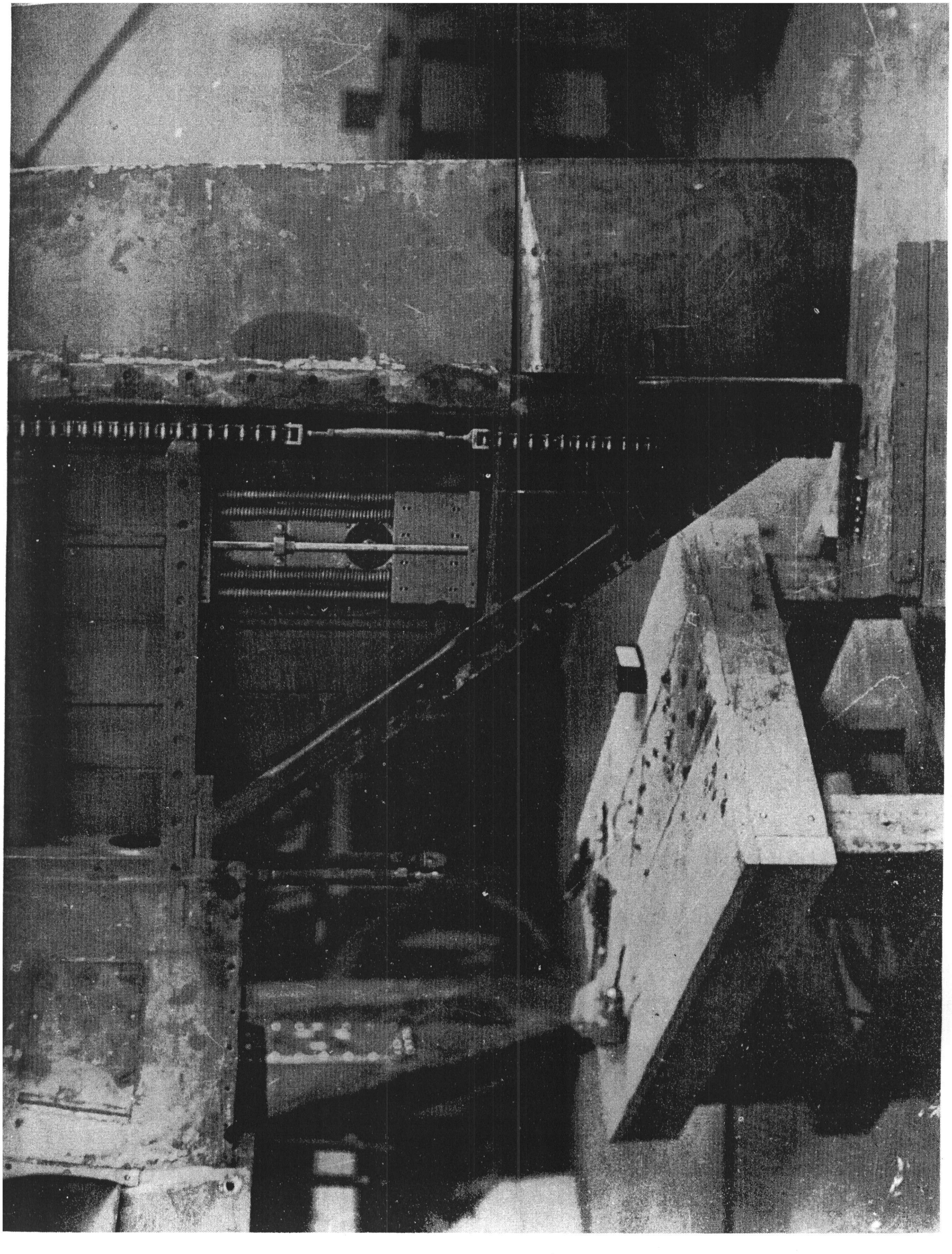
1. No signal received.
2. Signal tuned in 70 seconds after firing, and heard for 100 seconds.
3. No signal received due to failure of transmitter.
4. Rocket blew up at 27 seconds after firing.



IONOSPHERE TRANSMITTING ANTENNAS: "SIDE" POSITION AND TRAILING WIRES



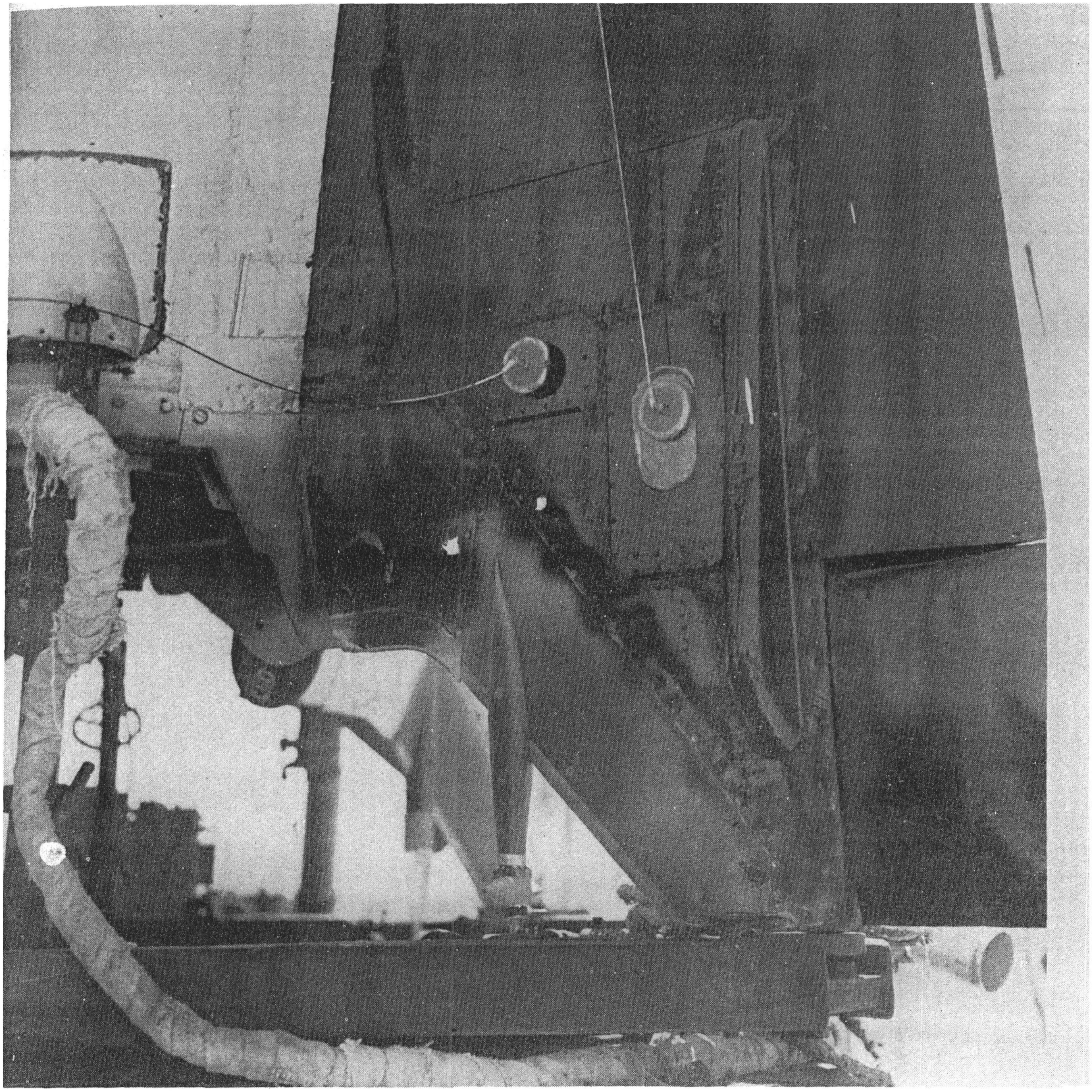
IONOSOPHERE "SIDE" ANTENNAS



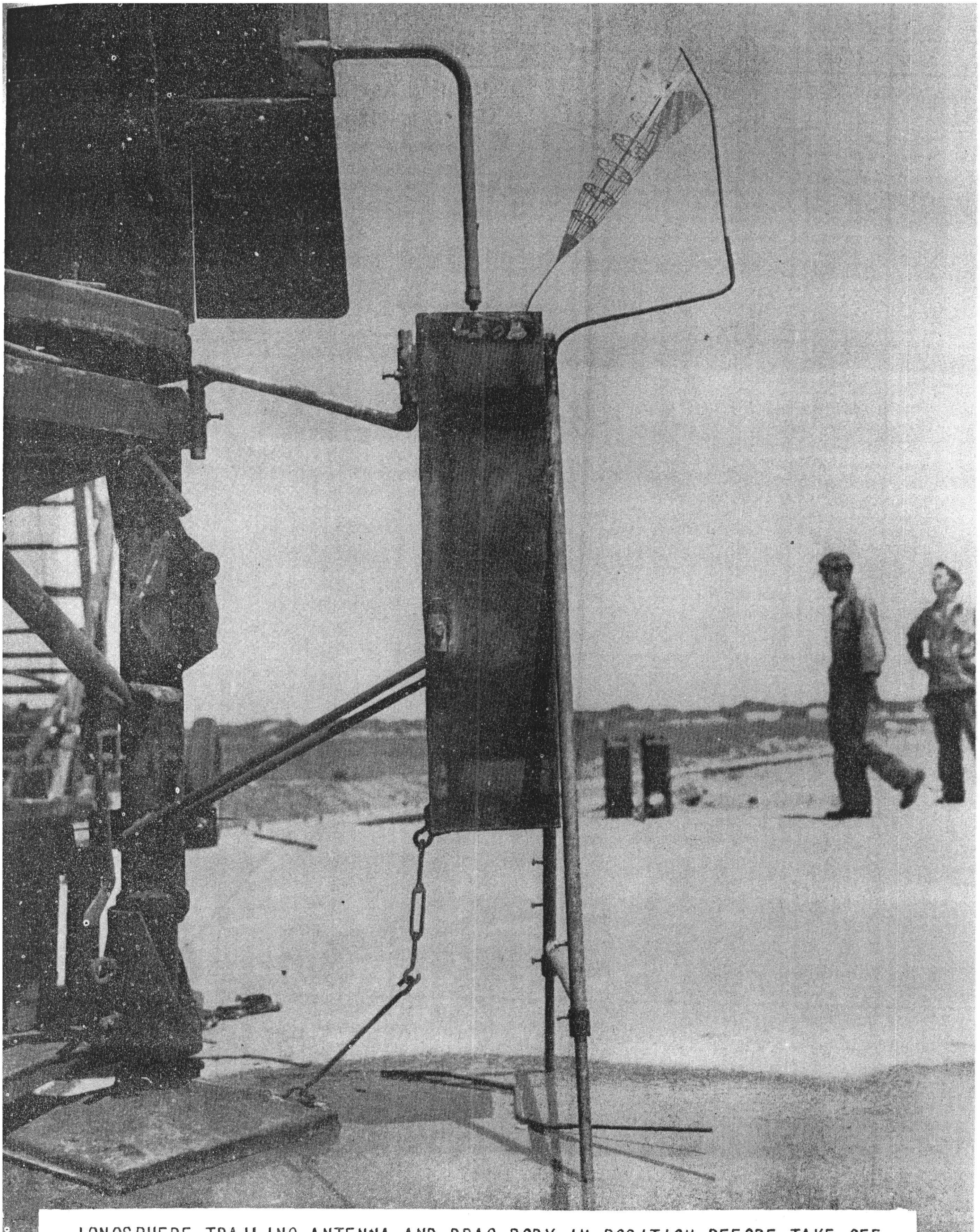
IONOSPHERE "SIDE" ANTENNA SPRING ASSEMBLY MOUNTED IN THE TAIL OF THE ROCKET

R-2955

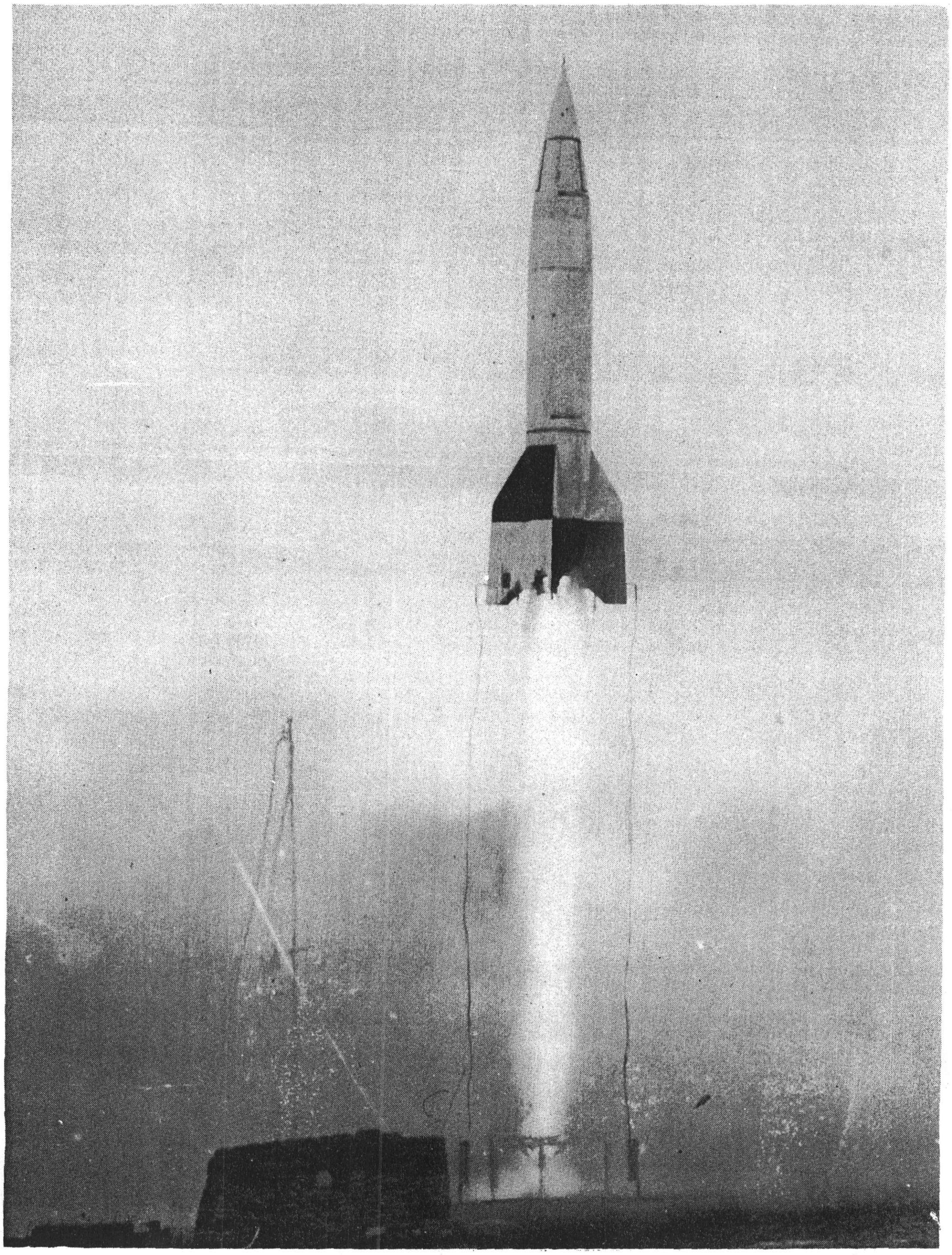
CH III SEC. G FIG. 3



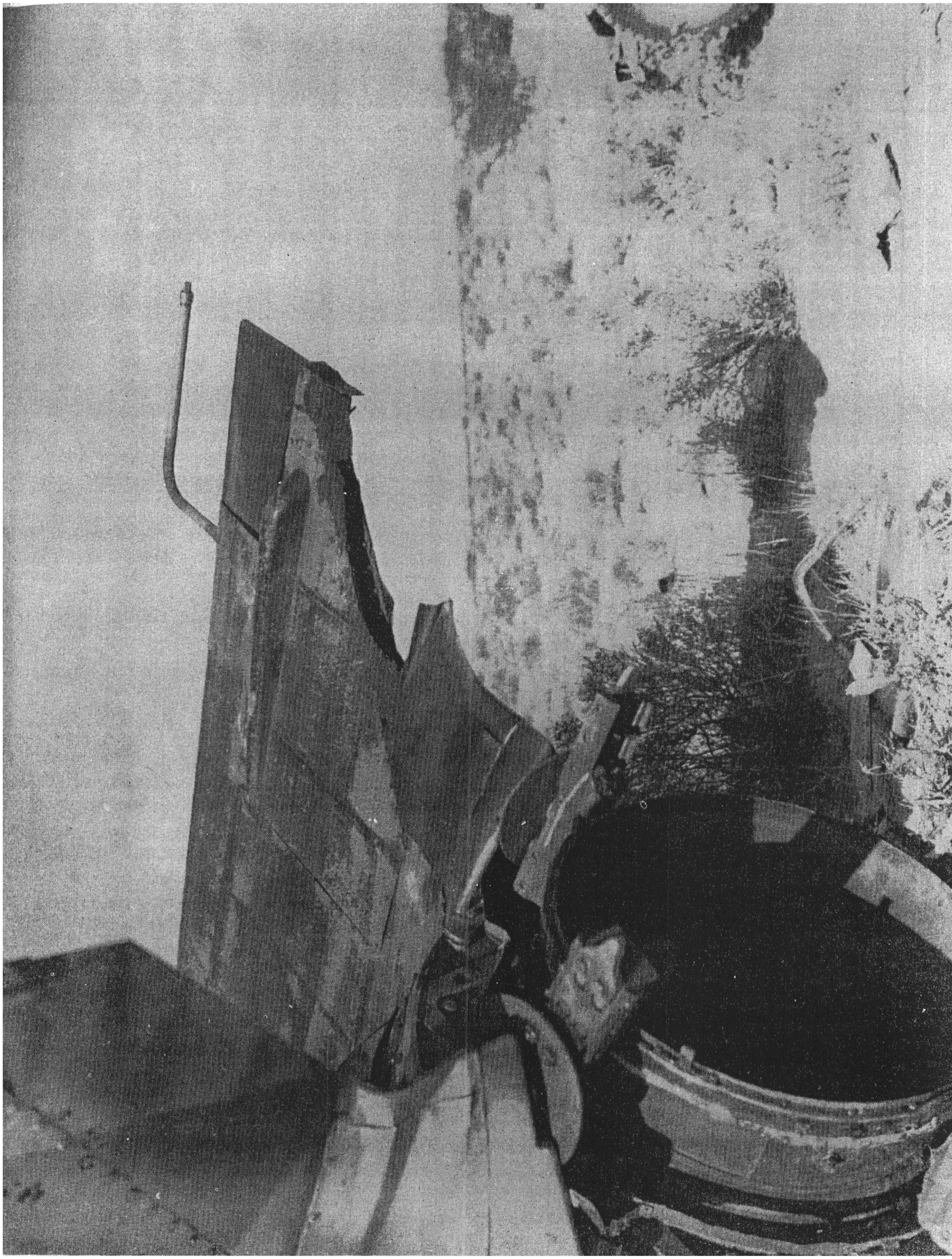
IONOSPHERE "SIDE" ANTENNA STAND-OFF BUSHINGS



IONOSPHERE TRAILING ANTENNA AND DRAG BODY IN POSITION BEFORE TAKE-OFF



IONOSPHERE TRAILING ANTENNAS DURING FLIGHT. PICTURE RETOUCHED TO BRING OUT POSITION OF WIRE AND RELEASE BOX



ROCKET AFTER IMPACT SHOWING ANTENNA-POSTS INTACT AND THE ANTENNA WIRE ON THE GROUND

UPPER ATMOSPHERE RESEARCH CONDUCTED BY THE NAVAL RESEARCH LABORATORY

H. Solar Spectroscopy from the V-2

by

W. A. Baum*, M. L. Greenough, F.S. Johnson*,
J. J. Oberly, C. V. Strain, and R. Tousey*

Introduction. This report includes a brief discussion of high altitude solar spectroscopy, a description of the design and performance of the spectrograph carried in the nose section of the V-2 fired on June 28, and an account of the steps taken to ensure the greatest possible chance of recovering the data recorded during the flight. The rocket buried itself in a deep crater, and at this writing the spectrographic film has not been recovered. Thus, there are as yet no results to report.

The solar spectrum provides most of the available information about our sun, yet a large portion of its spectrum is completely unknown to us because of absorption by the atmosphere high above the earth. The experiment described in this report is a first attempt to obtain the ultraviolet portion of this unrecorded spectrum by sending a vacuum spectrograph to altitudes above the absorbing layers of the atmosphere.

The spectral distribution of solar intensity at or near the surface of the earth is a function not only of the radiation characteristics of the sun but of the transmission properties of the earth's atmosphere. In the ultraviolet the latter depend on incompletely known factors and also vary with terrestrial and solar conditions. Fig. 1 shows a curve of approximate vertical atmospheric transmission values for the optical spectrum[1]. A plot is also given of the estimated wave length distribution of solar radiation in outer space. The portion of the curve below approximately 2900 Angstroms has never been measured directly and is an estimate made by assuming that the sun radiates in the ultraviolet as a black body of the temperature which corresponds to known solar radiation in the visible spectrum. Not shown in the curve are the main Fraunhofer lines due to absorption by the atmosphere of the sun.

Fig. 2 is based on a very rough calculation of the vertical atmospheric transmission in the ultraviolet[1]. It can be seen that the transmission of wave lengths below approximately 2900 Angstroms is

*Members of the Optics Division at the Naval Research Laboratory. The experiments on solar spectroscopy have been carried on as a joint project by the Micron Waves Section, R. Tousey, Head, of the Optics Division, E. O. Hulburt, Superintendent; and the Rocket Sonde Research Section, E. H. Krause, Head, of the Electronic Special Research Division, J. M. Miller, Superintendent.

tremendously small and it is little wonder that this portion of the spectrum cannot be recorded at sea level. Also shown in Fig. 2 are the altitudes for which the atmospheric transmission is 0.15 as calculated from absorption coefficients for the atmospheric gases measured in the laboratory. The results are considered to be only very rough, but they do give some indication of the altitudes required for observation of the ultraviolet solar spectrum. For the spectral range sought in this experiment, namely from 1100 to 2900 Angstroms, the altitude required to obtain spectra is believed to be about 90 kilometers or 56 miles. Such altitudes are actually exceeded by the V-2.

Many previous experimenters have endeavored with balloon carried instruments to obtain ultraviolet spectra, particularly in the region immediately below the sea level cut-off near 2900 Angstroms. On July 31, 1934, Erich and Viktor Regener reached an altitude of 31 kilometers with sounding balloons. The spectra obtained from that flight faded out at 2875 Angstroms. Previous to the Regeners, F. W. P. Goetz claimed solar spectra extending to 2863 Angstroms. In 1935 the stratosphere balloon[2], "Explorer II", carried with it an ultraviolet spectrograph for ozone studies to an altitude of 22 kilometers. The spectral cut-off lay near 2950 Angstroms. It will be observed from Fig. 2 that the spectral band from 2000 to 2200 Angstroms should theoretically be observable from altitudes already reached. Radiation in this band was reported in 1934 by Meyer, Schein and Stoll[3] who worked on the Jungfraujoch (11,400 feet) and made use of exceedingly sensitive photon counters. Their results have never been repeated and the details of their work were not published. In the present experiments from V-2 rockets it is anticipated that a sufficient altitude will be reached so that atmospheric absorption will not prevent observation of the spectrum. The lower wave length limit will be set, rather, by the spectrograph itself and the transmission characteristics of the optical materials which must be used in the instrument.

By means of rocket-borne spectrographs it should be possible to obtain information of extreme interest concerning the sun. One important item is the continuous spectrum of the sun. From its nature in the visible and near ultraviolet as known at present, it is possible to estimate the temperature of the sun, or to be more precise, to estimate the temperatures of layers in the surface of the sun. Deviation of the solar continuum from Planck's radiation law for a single black body of uniform temperature is expected to exist. Within the known part of the spectrum it is related in general to the fact that the hot gaseous surface layers of the sun are semi-translucent and radiate at different color temperatures at different depths, the coolest being on the outside. However, at present it is very uncertain how much effect this phenomenon may have on the solar ultraviolet continuum. Moreover, the highly ionized condition of the outer layers of the sun's atmosphere would require temperatures in the neighborhood of 1,000,000° C if due to thermal causes, and hence would seem to demand an entirely different explanation. Determination of the solar ultraviolet continuum should go a long way toward clarifying these matters.

Another important subject for investigation is the solar ultraviolet line spectrum. The fundamental lines of many atoms lie in the ultraviolet range to be investigated in this experiment. Such elements unquestionably play important roles in the processes by which the sun radiates energy; consequently, extension of the solar ultraviolet line spectrum ought to provide much new information on the composition and physical states of layers above the surface of the sun. It is possible that lines will be observed from elements hitherto undetected in the sun.

A particularly interesting line, which it is hoped will be recorded, is the first line of the Lyman series of hydrogen at 1215.7 Angstroms in the vacuum ultraviolet. The absorption of this line by air has been measured by several workers in the laboratory. Preston[4] determined that the absorption by dry air was 0.063 cm^{-1} at N.T.P. From this datum a calculation of atmospheric transmission gives 0.15 transmission at 79 kilometers and 0.01 at 73.5 kilometers. Similar data published by Williams[5] are in disagreement and give as altitudes 114 and 105 kilometers respectively. Above 100 kilometers much of the molecular oxygen responsible for this absorption is expected to be disassociated to atomic oxygen which should be more transparent. Hence, it appears likely that the Lyman alpha line will be transmitted to altitudes reached by the spectrograph. It is probable that it will appear as an emission line rather than as a Fraunhofer line in the solar continuum. Observation of its intensity should add greatly to the knowledge of the extreme ultraviolet and the processes by which it is radiated from the sun.

Still another subject of interest in rocket spectroscopy is the nature and composition of upper layers of the earth's atmosphere. For years scientists have tried to obtain information regarding the distribution of ozone and also of atomic oxygen. From absorption variations observed in the solar ultraviolet spectrum as a rocket ascends, it should be possible to chart the atmosphere far above the present balloon ceiling. Related to this matter is the brightness of the sky at various altitudes and in various regions of the spectrum. It is well known that the sky light is caused by scattering by air molecules. Spectra of the sky in the ultraviolet should appear on the film along with the sun and give additional information concerning the composition of the atmosphere.

Knowledge of the transmission of the earth's atmosphere may make possible a radiation altimeter for rockets. Such a device is very speculative however until detailed and accurate spectroscopic results are obtained.

Measurement of the solar radiation in the unknown portion of the ultraviolet is of interest in connection with the ionosphere, which has so great an effect on radio transmission. It is believed that the ionosphere is produced by ionization by extreme ultraviolet solar radiation. It is important to determine at what wave lengths and with what intensities this ultraviolet is radiated in order to understand the exact processes by which the several layers of the ionosphere and radio transmission phenomena are connected with variations in the ultraviolet. Eventually it may be possible to send up spectrographs in rockets at times of extreme solar activity to study these effects further and also to extend the spectral range recorded by the spectrograph to wave lengths below 1100 Angstroms.

<u>The Spectrograph</u>. The designing of an ultraviolet vacuum spectrograph for use in a V-2 rocket involves many added complications not encountered in the design of an ordinary laboratory instrument. The space available is but a fraction of the usual spectrograph dimensions, and the shape of the instrument is rigidly determined by the shape of the rocket. The spectrograph must be ruggedly constructed to operate while undergoing acceleration up to 5g and while subjected to considerable mechanical vibration. Moreover the problem of getting light into the spectrograph continuously during the flight, is a serious and difficult one. The rocket ascends without tilting more than 11° from vertical until fuel burn out (Brennschluss), and during this period of approximately one minute the rocket is stabilized and does not rotate. Thereafter although its attitude changes little until after reaching maximum altitude it may rotate slowly and it is this rotation which introduces the principal difficulty in directing light into the spectrograph.

The spectrograph constructed for the V-2 experiments is a completely automatic mechanism which, (1) continues to receive light from the sun as the orientation of the rocket changes, (2) opens and closes its shutters according to a chosen exposure cycle, (3) moves the spectrographic film between exposures, and (4) provides a time or altitude scale. The spectrographic film is protected to survive the impact when the rocket lands, since the success of solar spectrograph experiments depends upon recovery of a photographic record after the rocket crashes to earth. Unfortunately the enormous detail in the solar spectrum, cannot at present be telemetered satisfactorily with electronic equipment.

The space allocated to the spectrograph for the June 28 experiment was near the nose. It is shown in Fig. 3. The spectrograph section was entirely separate and independent of the rest of the warhead except for electrical connections. Measuring along the axis from the nose, the spectrograph occupied the space between the 10 inch and 31 inch points. The outer shell of this section was a steel casting weighing about 60 pounds.

The optical system of the spectrograph is shown in Figs. 4 and 5. A concave grating of 40 centimeter radius of curvature is mounted well forward in the nose of the rocket. Diametrically opposite the grating, and on the Rowland circle, is a film holder, to guide the strip of 35 millimeter film, which is pulled along frame by frame in somewhat the same manner that motion picture film is handled. On one side of the film holder and also on the Rowland circle is the entrance slit, or rather its virtual image. It is at such a position that the ultraviolet range of the first order spectrum falls across the film. An identical virtual image of a second entrance slit is located symmetrically on the other side of the film holder and, when this side of the spectrograph is illuminated, forms a similar spectrum on the film but in the reverse direction. The two virtual slit images are formed in mirrors M_1 and M_2 from the true slits at the sides of the spectrograph. Thus when the optical system is fitted into the rocket's warhead, the real entrance slits "look" out of the sides of the warhead in a forward direction at an angle of 45 degrees from the axis of the rocket. The film and shutter mechanism, which requires considerable space, occupies the base of the conical spectrograph section.

The two small plane mirrors which direct light forward to the grating from the entrance slits are plane aluminized glass blanks. Front surface reflectivity is nearly 90 per cent down to 2000 Angstroms but decreases to about 20 percent at the lower end of the spectral range covered. These mirrors are each tilted 2-1/2 degrees, one forward and one backward, in order to separate the spectra of the two slits on the photographic film. This is necessary because these two spectra, formed by the same grating, are dispersed in opposite directions.

The concave reflection grating is ruled with 15,000 lines per inch on aluminized glass blank of 40 centimeters radius of curvature. It is two inches in diameter and has a ruled surface three centimeters high and four centimeters wide. Light is incident upon the grating at an angle of 7.3 degrees. The spectrum from 1000 to 3300 Angstroms covers a strip of film 5.2 centimeters long, giving a dispersion of 44.1 Angstroms per millimeter. The grating is mounted in a cell attached rigidly to the spectrograph chassis and is prevented from rotating by a key cemented to its back.

The spectrograph must continue to receive light from the sun in spite of any changes in the orientation of the rocket. Further, it is important that the light be received with sufficient intensity to permit short exposures. The high speed with which the rocket ascends makes many short exposures necessary if any degree of detail is to be recorded in the various atmospheric layers such as, for example, the ozone layers. A diffusing surface placed in front of the slit is the conventional method of slit illumination where light must be received over a large solid angle, but the intensity of the light entering the slit is low. To increase the intensity a lens may be used, but then, because the rocket changes its orientation very greatly during flight, it would be necessary to use, in addition, an automatic tracking device, such as a tipping mirror, which would always keep the sun's image on the slit. Because of the complications involved, and the lack of space, such a system was not considered seriously.

A further important consideration is that in designing a spectrograph to work down to 1100 Angstroms it is essential to use a minimum number of lenses, ground as thinly as possible. Even the purest lithium fluoride, the most transparent material known for the ultraviolet, does not transmit wave lengths much below 1100 Angstroms, and transmits 1200 Angstroms to a useful degree only in thin clean plates[6]. For this reason large and complicated lens systems are out of the question. It would be highly desirable to illuminate the slit by reflection only, without any lens or diffusing plate, but a practical method of accomplishing this has not been devised.

The system of slit illumination finally fixed upon, is simple and novel, and meets most of the requirements. A conventional slit is not used. It is replaced by a small sphere of lithium fluoride, two millimeters in diameter. This sphere is, in reality, a spherical lens producing a tiny image of the sun which is almost a point. The point image of the sun produces a line spectrum on the film, rather than a point spectrum, due to the astigmatism of the grating system.

The advantages of the bead, or spherical, lens over the diffusing plate and slit are several. The bead, like the diffusing plate, has a field of view of a hemisphere, or even a trifle more, and the spectrum produced is many times more intense. Although intensity is lost because of the action of astigmatism in producing lines from the point image of the sun, the sphere gives spectra ten to a hundred times more intense than a diffusing plate and slit of width equivalent to the bead system. With the bead, the thickness of lithium fluoride in the optic path is not over two millimeters, which is about the same as would be required with a diffusing plate. Further, it is probable that a ground, or diffusing, surface of lithium fluoride could not be cleansed as effectively as the polished surface of the bead, and therefore radiation below 1300 Angstroms would be transmitted more completely by the bead than by the diffusing plate. In the case of both the bead and the diffusing plate systems the intensity of the recorded spectrum falls off as the sun passes off the axis of the system. However, the former system is superior to the latter in this respect. Examples of the intensity distribution curves for the bead and a representative diffusing plate are shown in Fig. 6.

The principal disadvantage of the bead is that the position of the point image changes slightly as the sun's image moves away from the optical axis of the system. This may have some tendency to smear the spectrum during the portion of the flight beyond Brennschluss. However since the rocket is essentially stable during powered flight, one may expect unsmeared spectra during this period, during which the ozone layer is traversed.

The motion of the image, as the sun moves off the optic axis, may be resolved into three components. One component, perpendicular to the plane of the spectrograph causes the spectrum to move on the spectrographic film so as merely to lengthen the lines, the increase in length being less than the diameter of the sphere. A second component of the motion lies in the plane of the spectrograph and is perpendicular to the optic axis. Its effect is to cause a shifting of spectral lines in such a way as to smear them. The design of the spectrograph takes advantage of the fact that roll is the only rapid change in the rocket's orientation. Roll causes the first effect principally, thus lengthening rather than smearing the lines. The third component of the motion is parallel to the optic axis, and causes defocusing of the instrument. The amplitude of this motion depends somewhat upon which astigmatic image produced by the bead is considered. These motions are depicted by the curves of Fig. 6. Since the ratio of the grating aperture to the radius of curvature is about 1 to 10, defocusing broadens lines by an amount equal to one tenth of the movement of the image along the optic axis. The effective slit width is about 0.02 millimeters, or about 1 Angstrom, and the factors described above are thus expected to cause a smear amplitude as great as 0.2 millimeters, corresponding to 9 Angstroms.

The intensity of illumination at the grating falls off rapidly as the angle between the sun and the optic axis increases. At 70° it has dropped to about 10 per cent of the maximum valve. This also, is shown by a curve in Fig. 6. Because of the low intensity and poor focusing or large angles, no attempt is made to see the sun when it is more than 70° degrees from the optic axis. Each sphere, or "eye" thus has a field of view which is conical, of vertex angle 140 degrees. Since the two optic axes are inclined at an angle of 45 degrees to the axis of the rocket, they are mutually perpendicular, and the cones of view overlap.

Fig. 7 is a photograph of a mount for the lithium fluoride sphere. The outer shell of this mount screws into the chassis of the spectrograph and butts snugly against a small brass contour plate attached to the outer shell casting of the warhead. Immediately behind the mount is a sector disk, which functions as a shutter. The lithium fluoride bead looks out through a hole 0.029 inches in diameter (approximately 1/2 the diameter of the bead). This entrance pupil is sufficiently large to allow all rays entering within the 140° cone of view to reach the grating. A tiny retaining collar on the inside holds the bead in place; its inside shoulder diameter is only 0.002 inch less than the diameter of the bead. Pressure is applied to this collar by a light helical spring. Behind the spring is a non-rotating washer and a retaining ring which screws into the shell. Non-rotating tabs on the washer prevent the assembly from turning and scratching the soft lithium fluoride bead when the ring is screwed in.

To grind the lithium fluoride spheres it is necessary to use a pitch lap. In grinding flats, pitch or beeswax are avoided since present techniques do not permit the removal of all traces of these substances. Instead, a lap of silk and rouge is used. The most effective cleaning procedure is found to consist of a prolonged soaking in warm benzene, followed by glow discharge cleaning in a vacuum. Any subsequent cleanings which may become necessary should consist of several baths in absolute ether. As a result of these processes, the absorption of light by the surface layers of the bead is greatly reduced, allowing the transmission of considerable ultraviolet at 1200 Angstroms, and even some at 1130 Angstroms.

As in most spectrographs, it is important to minimize the amount of scattered light by adequate baffling and masking. The structure around the beads and shutters is so designed that only light traveling in the general direction of the grating can enter the spectrograph. Light is further baffled before it reaches the grating, by a limiting aperture in front of each mirror and four baffles between the mirrors and the grating. A mask clamped against the grating shields the unruled portions of the circular blank. The spectra returning from the grating to the film pass through the same four baffles mentioned above, plus an additional one behind the mirrors. Two parallel slots in the film mask provide for the separate spectra from the two beads and limit them to the desired range of wave lengths. All parts of the spectrograph, except for a few shafts and gears, are chemically blackened.

In order to photograph spectra in the vacuum ultraviolet it is necessary to use a specially sensitized film because wave lengths below approximately 2200 Angstroms are absorbed in the gelatine emulsion of ordinary films. The customary method of sensitizing film to this region of the spectrum is to overcoat the emulsion with material which absorbs the ultraviolet and fluoresces in the visible and near ultraviolet. Thus the actual exposure is produced by the fluorescent radiation. Almost any oil will do this, but an improvement over oil is the fluorescent lacquer-like overcoat supplied by the Eastman Kodak Company. In photographic speed the Eastman Kodak sensitization is found to be approximately the same as pump oil, deposited by bathing the film in a 10 per cent solution of oil in petroleum ether; im resolution and handling ease it is superior.

A further consideration in connection with the film is the possibility of fogging due to static electrical discharge as the film is unrolled in a vacuum. This condition is regarded as highly likely by the Eastman Kodak Company. To minimize this effect the film is backed with rim jet black, which provides a conducting layer. Tests in a vacuum chamber showed no static marks on the film, so the backing is considered a success. A further use for the backing, of course, is to aid in protecting the film from fog in case the container is cracked to some extent in the crash landing of the V-2.

The mechanical system of the V-2 spectrograph consists of an automatic mechanism for making a series of exposures on a 25 foot length of film. It provides for a cycle of three exposures, the shortest being 0.1 second and the longest 3.0 seconds. The intermediate exposure duration of 0.55 second is the logarithmic mean of the other two. Following each exposure is an interval of slightly more than 1.0 second during which the shutter is closed and the spectrographic film is advanced for the next exposure. The total period of this three exposure cycle is 6.67 seconds. Shutters consist of two sector disks (illustrated in Fig. 8), one behind each bead, which rotate continuously at a uniform rate. These are driven through a two step worm gear reduction by an Eicor 24 volt d.c. electric motor, which is chosen for its constancy of speed. Also connected to the gear train driven by this motor is an escapement device governing the film transport. It is a disk which rotates at the same speed as the shutters (6.67 seconds per revolution) and upon whose periphery are three small dogs spaced at intervals corresponding to the cycle of exposures. These dogs trigger an escapement pawl at the end of each exposure, and the pawl in turn frees a pair of gears connected to a film sprocket, allowing it to pass 2-1/4 inches of film. This provides 133 exposures on 25 feet of film.

The mechanism for winding the film is entirely independent of the system described above. It consists of a small Delco 24 volt d.c. motor (1 x 1 x 2 inches) which is powered continuously but which intermittently runs and stalls as the film is pulled along for successive exposures. This motor is connected through a worm gear to the film take-up reel and pulls continuously on the film. Whenever the escapement device is tripped following an exposure, this take-up motor quickly winds up the released length of film and then stalls, pulling the film taut until it is released again at the end of the next exposure. A spring is provided between the worm wheel and the shaft of the take-up reel to relieve the inertial shock which accompanies the abrupt halt of the take-up motors and gears when the escapement mechanism stops the film. The tensile strength of the film is relied upon to stop the motor; however, the spring prevents the perforations in the film from being torn by the sprocket when the latter is halted by the escapement catch. Considerable attention was given to the design of this spring. It was found, for example, that the energy stored in it by the motor as it comes to a stop is an aid in starting the film to move at the instant of release.

The film container, shown in Fig. 9, is made of armor piercing steel. Its wall thickness is 3/4 inch. A thick plug of the same material screws into the top of the container, sealing it. An off-set set-screw locks the plug in place. The film passes through a 35 millimeter slot in the side of the container. The slot is lined with velvet to make the container light-tight, and to protect the film from scratches. The film is then wound onto the take-up reel which is designed to accommodate 25 feet of 35 millimeter film with a 0.006 inch base. The core of the reel, 1/2 inch in diameter, has the usual slot in the center for holding the film. The end is secured from slipping by means of a tiny cylindrical pin which is pressed through the core slot to perforate the film. The shaft of the reel is flush with the bottom of the container and is engaged to the shaft of the worm wheel by a slot. Thus the reel may easily be lifted out of the container by removing the plug.

A time scale is provided for the spectrograph exposure cycle by a micro-switch operated by a cam on the shaft which carries the disk which trips the escapement device. This signal is telemetered to earth permitting each exposure cycle to be timed. The altitude of the rocket for each exposure may then be calculated.

The chassis of the spectrograph consists of a flat plate running parallel to the axis of the rocket, two circular cross bulkheads, a nose piece with a split ring collar which fits tightly into the front of the outer shell, and a long tube parallel to the axis through which a 10 wire cable from the nose section can be passed. The rocket axis lies midway between the flat plate and the tube. The optical system is referred to the plane passing through this axis, parallel to the flat plate. In fact, all of the optical components, except the lithium fluoride beads, are mounted on this plate. Photographs of the completed spectrograph are shown in Figs. 9, 10, and 11.

In order to photograph ultraviolet light in the range to be studied, provision must be made to evacuate the spectrograph chamber as the rocket rises into the rarified atmosphere. Since the rocket attains an altitude at which the pressure is about 10^{-7} atmospheres, and since the light path inside the spectrograph is less than 1 meter, a pressure inside the spectrograph of 10^{-4} atmospheres renders this path the absorption equivalent of roughly 1 kilometer of the rarified atmosphere outside the rocket. There is, accordingly, a need for evacuating the spectrograph chamber to about 10^{-4} atmospheres, or 100 microns, in the three and one half minutes during which the rocket is rising.

An obvious method is to cut a hole in the side of the warhead through which the air may escape as the pressure outside the rocket drops. It is absolutely essential, however, that the spectrograph chambers be kept light tight. For the June 28 flight, two air evacuation vents were provided, one just forward of the middle bulkhead and the other beneath the electric motors. The forward air vent, which can be seen on Fig. 12, was constructed with a concentric light baffle which demanded at least 4 black surface reflections of any light entering the spectrograph. The pumping speed of this vent and its baffle was calculated to be at least the equivalent of a 3/4 inch tube, several inches long. The air vent at the rear was provided with a light baffle demanding a minimum of 3 black surface reflections, and its pumping speed was equivalent to that of a 7/8 inch tube, several inches long. Although little was known about the effect of the supersonic velocities encountered on the pumping speed of such an opening, this method of evacuation was nevertheless attempted. All other methods considered seemed to be too complicated.

As the rocket ascends, air friction causes the skin temperature to rise. In the June 28 flight the temperature inside of the spectrograph shell increased by more than 100° C, according to resistance thermometer measurements. As the inside of the shell was oxidized, the surface undoubtedly gassed appreciably. According to laboratory tests the spectrograph itself also probably gassed to some extent. However, actual measurements made during the flight indicated that the pressure in the spectrograph fell to roughly 50 microns.

It is important that to unwanted light the spectrograph be as light tight as possible, especially around the openings in the outer shell through which the lithium fluoride beads look. The optical system is most vulnerable to stray light coming from those directions. Openings somewhat larger than the bead mounts are cut in the outer shell so that the spectrograph chassis can slide into it freely. Small tightly fitting covers, with holes for the beads to see through, are placed snugly over these openings after the spectrograph is inserted into the shell. These covers are contoured so as to interfere as little as possible with the passing air stream, in order to avoid extreme heating around the lithium fluoride beads due to air friction.

A ten wire cable connects the spectrograph to the main warhead. Two of the wires supply 24 volts d.c. to the electric motors. A noise filter is inserted in this line to prevent motor noise from interfering with other instruments in the warhead. Another pair of wires is connected to the micro-switch which telemeters the exposure cycle to earth. Still another pair connects a Pirani gage to the telemetering system, so that the pressure inside the spectrograph chamber can be measured during the upper part of the rocket's trajectory. The remaining four wires are connected to three resistance thermometers which are used to telemeter temperature information. Two of the thermometers are attached to the inside of the spectrograph shell, and the third is fastened to the chassis.

Laboratory Results. The optical performance of the V-2 spectrograph was thoroughly studied in the Laboratory in a variety of ways. In most of the experiments the final instrument was used; for some, a special vacuum spectrograph, built earlier at the Naval Research Laboratory, was employed. Optically the latter is exactly like the final instrument save for omission of the two mirrors which folded the path in the V-2 spectrograph. The lithium fluoride beads were used, as well as quartz beads, a conventional slit, and a slit with a diffuser. The properties of these various system components were compared.

An unexpected spurious spectrum was discovered early in the experiments. It consisted of a second spectrum weaker than the principal spectrum, and reversed in wavelength. It was caused by mirror reflection of the spectrum itself in the grating; enough light was emitted by fluorescence on the film at each strong spectral line to form a mirror image on the film at such a position that the normal to the grating was half way between each spectral line and its reflected image. Spurious spectra of this type were removed from the principal spectra by introducing a small amount of asymmetry. This was accomplished by tilting the grating and changing the tilt of one of the aluminized mirrors.

In order to determine the speed and resolving power of the spectrograph, spectra of the sun were photographed from the roof of the Naval Research Laboratory in Washington. Fig. 13a shows a sample spectrum for a three second exposure, with the sun near the axis. The spectrum weakens rapidly below 3100 Angstroms, due to the ozone absorption, and disappears at about 2950 Angstroms. Many Fraunhofer lines can be seen as far as 3300 Angstroms, the long wave length limit of the spectrograph. The resolution varies from about 2 Angstroms when the sun is nearly on the axis of the bead to 6 or 8 Angstroms when the sun is at a large angle to the axis. The streak above the spectrum is not scattered light, but is the spectrum of the part of the sky seen by the bead, with the resolution reduced to perhaps 50 Angstroms due to the large image formed of the sky. It is much weaker than the solar spectrum and does not interfere with intensity measurements of the solar spectrum. At high altitudes it will not be present. From the sky spectra, however, it will be possible to derive some data on the spectral intensity distribution of sky light as a function of altitude. It is apparent from Fig. 13a that the spectrum is not completely uniform along the spectral lines. This lack of uniformity is due to a corresponding lack of uniformity in the grating itself. It appears in the spectrum because the lines are produced by astigmatism.

The film emulsion finally used was Eastman 103-O, overcoated as described previously. This is the fastest spectrographic emulsion produced by Eastman. It is not dye sensitized, since this would not increase the speed in the ultraviolet, but would rather increase the fog due to scattered visible light. With this emulsion, a 3 second exposure to the sun at Washington, and a 2 millimeter bead, solar spectra at 3300 Angstroms were very much overexposed, and a trace of scattered visible light appeared on the film from 1100 to 2950 Angstroms. This, then, was considered to be the optimum maximum exposure for the spectra at high altitude, for the scattered light would serve to increase the film speed and yield greater sensitivity for the weak ultraviolet from 1100 to 1800 Angstroms. The shortest exposure satisfactory to photograph the sun was found to be approximately 0.1 second. From these results it was estimated that the amount of light scattered from the grating was exceptionally small, perhaps less than 0.1 per cent of the intensity of the solar continuum near 3300 Angstroms. Since this light was very uniform, it is believed that a stray light correction can be made fairly satisfactorily.

Fig. 13b shows a spectrum taken with a direct current iron arc in air. It can be seen that the spectrum extends to about 1850 Angstroms. The limit is due to absorption by air.

In order to photograph spectra down to 1100 Angstroms it was necessary to evacuate the whole spectrograph. This was not easy to do in the conventional manner. It was effected, however, by placing the whole spectrograph, and the source, under the large bell jar of a vacuum evaporation unit, and pumping out the air. An open end discharge tube, with hydrogen as the gas, served as the source. Hydrogen was admitted under the whole bell jar, filling the spectrograph as well as the discharge tube. Pressure was maintained at a value suitable for the discharge. Fig. 13c shows the result. Due to the size and closeness of the source, the definition is not as great as with the iron arc. Fig. 13d is a similar spectrum produced with a small laboratory spectrograph with a similar grating, but without a mirror between the slit and the grating. Fig. 13e is a hydrogen spectrum made with an excellent laboratory spectrograph under ideal conditions. Details in the spectra differ because of different conditions in the discharge tube. It can be seen, however, that the first line of the Lyman series of hydrogen at 1216 Angstroms does appear in the spectrum made with the lithium fluoride bead and that the spectrum can be observed to 1130 Angstroms. By comparing Figs. 13c and 13d it can be seen that the spectrum using the lithium fluoride bead became weakened rapidly below 1300 Angstroms. This was due to the increased absorption of the lithium fluoride and to the decreased reflectivity of the aluminized mirror. It was concluded from these results that the spectrograph would photograph the Lyman alpha line in the solar spectrum, provided it is present in moderate intensity, but that if it were weak, an improved lithium fluoride bead, or a method of slit illumination using reflection only, would be required.

It was hoped for the June 28 experiment that the final film would permit at least semiquantitative spectral intensity measurements.

For calibration purposes, therefore, exposures were made to a General Electric S-4 quartz mercury arc run on direct current, with the glass envelope removed. Spectra were obtained to 1850 Angstroms, and a long series of 0.1, 0.55 and 3.0 second exposures were made with various sector disks placed before the beads of the spectrograph. From this film it will be possible to obtain complete characteristic curves of the film from 1850 to 3300 Angstroms. In addition, 3 cycles of exposures to the S-4 arc were made on the final film used in the June 28 flight. The spectral intensities of the lines in the arc itself are to be measured, and these data will permit relative intensities to be calculated for the final solar spectra from 1850 to 3300 Angstroms. Below 1850 Angstroms there are no established methods for heterochromatic spectrophotometry. Only qualitative spectral intensity measurements can be made in this spectral region at the present time.

<u>The Recovery Problem</u>. Experience in Germany indicates that recovery of parts may be possible, should the rocket experience an air burst near the end of flight. For the June 28 flight plans were worked out jointly with Army Ordnance personnel for producing such an air burst. Four half pound explosive charges, one against each longitudinal structural member, were placed in the control chamber. The firing was successful and the rocket ascended to an altitude of 68 miles. Telemetering indicated that the mechanism of the spectrograph was operating normally, and it is believed that the exposures were properly made. On the descent, after the film had run through into the container, the explosive was detonated by radio. Observers watching through powerful binoculars saw a puff of smoke, but saw that no air burst occurred. The rocket descended in one piece, in normal fashion, and buried itself in the desert, forming a deep crater.

The probability of recovering the film from the impact crater is doubtless small. In spite of the fact that the June 28 film container was designed to be as strong as possible, consistent with the size requirements, and was made of armor piercing steel, it is not impossible that it was broken upon impact. Further damage may have been caused by the temperatures which the container attained during impact, for photographic film is easily ruined by heat. It may be that alkali laden water has seeped into the container spoiling the film. Nevertheless there is a remote possibility that the film container lies intact in the debris, and that the film is undamaged.

The excavation of the crater by Army personnel is under way, but as yet the spectrographic film has not been recovered.

ACKNOWLEDGMENT

It was possible to design and build the June 28 V-2 rocket spectrograph in the short period from February to June, 1946, because of kind and helpful cooperation of a number of persons. Dr. G. H. Dieke, Dr. John Strong, and Dr. R. W. Wood, of Johns Hopkins University, gave helpful advice on grating specifications, and provided the gratings for the spectrographs. Important assistance in matters pertaining to securing and polishing lithium fluoride of high quality was given by Professors Theodore Lyman of Harvard University, and Donald C. Stockbarger of the Massachusetts Institute of Technology, and by Dr. H. C. Kremers of the Harshaw Chemical Company. Mr. A. J. Devlin, Superintendent of the Optical Shop of the Naval Gun Factory, perfected the method of grinding small spheres of lithium fluoride, and so provided the "eyes" of the spectrograph. Within the Naval Research Laboratory, Dr. G. R. Irwin of the Physics Special Research Division aided in the design of the armored film container, and Dr. Peter King of the Chemistry Division advised on the cleaning of lithium fluoride after optical grinding. Actual manufacture, and a part of the mechanical design, of the spectrograph were accomplished by the Baird Associates, Cambridge, Massachusetts, under contract to this Laboratory. Particular thanks are due to Drs. Walter Baird and H. M. O'Bryan of the Baird Associates for accepting the task of building the spectrograph in time for the firing of June 28.

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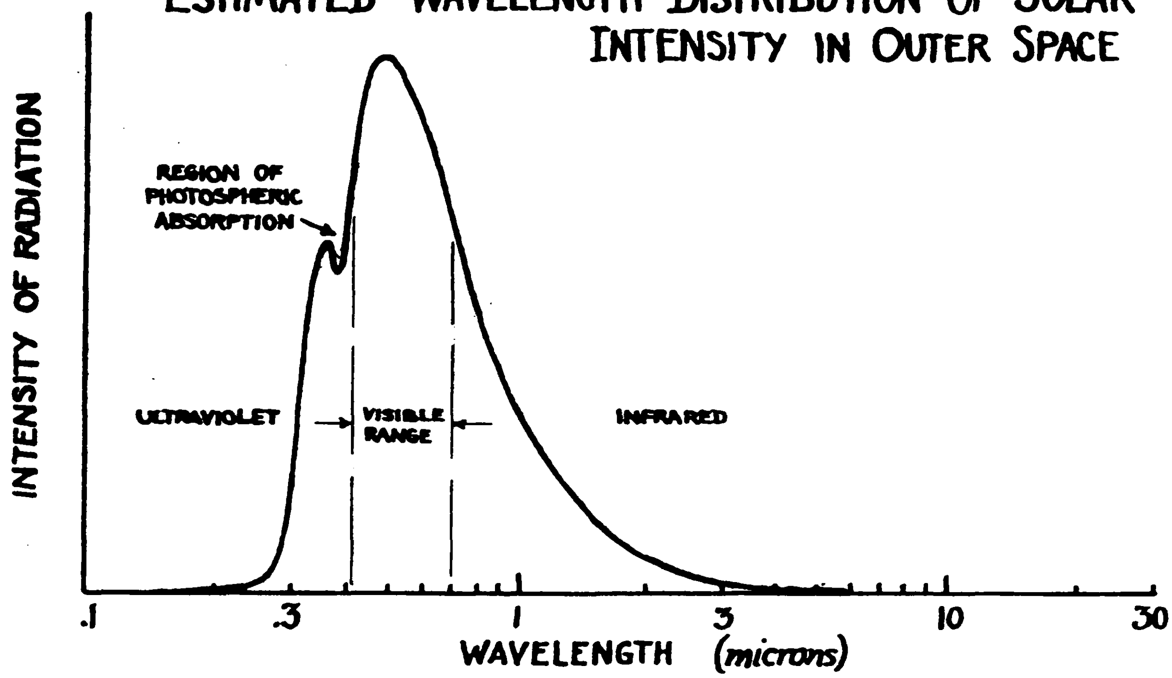
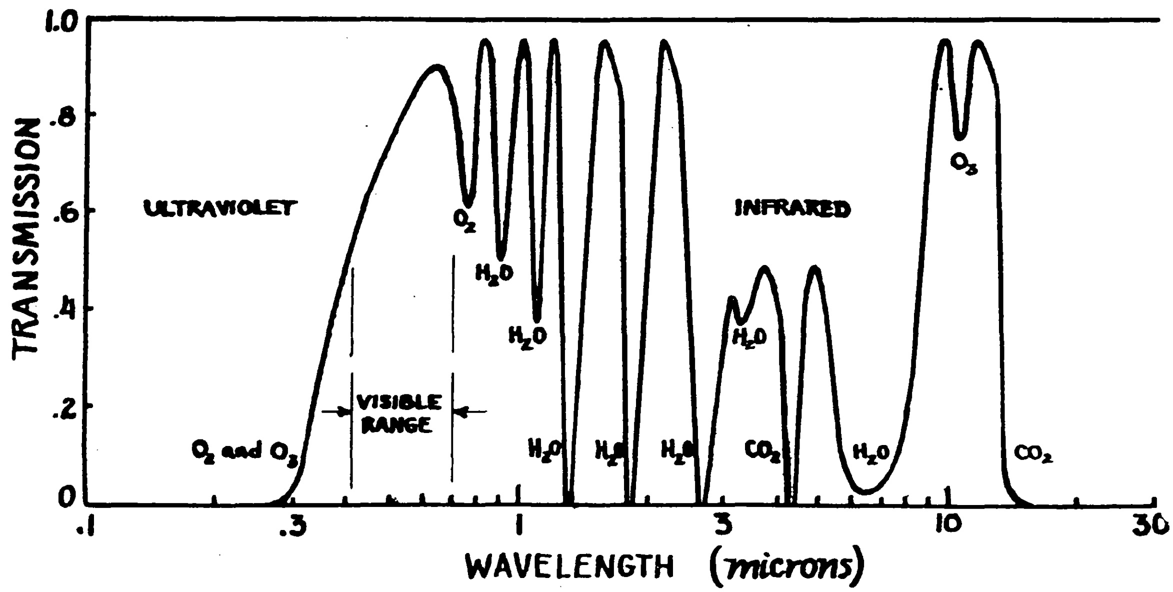
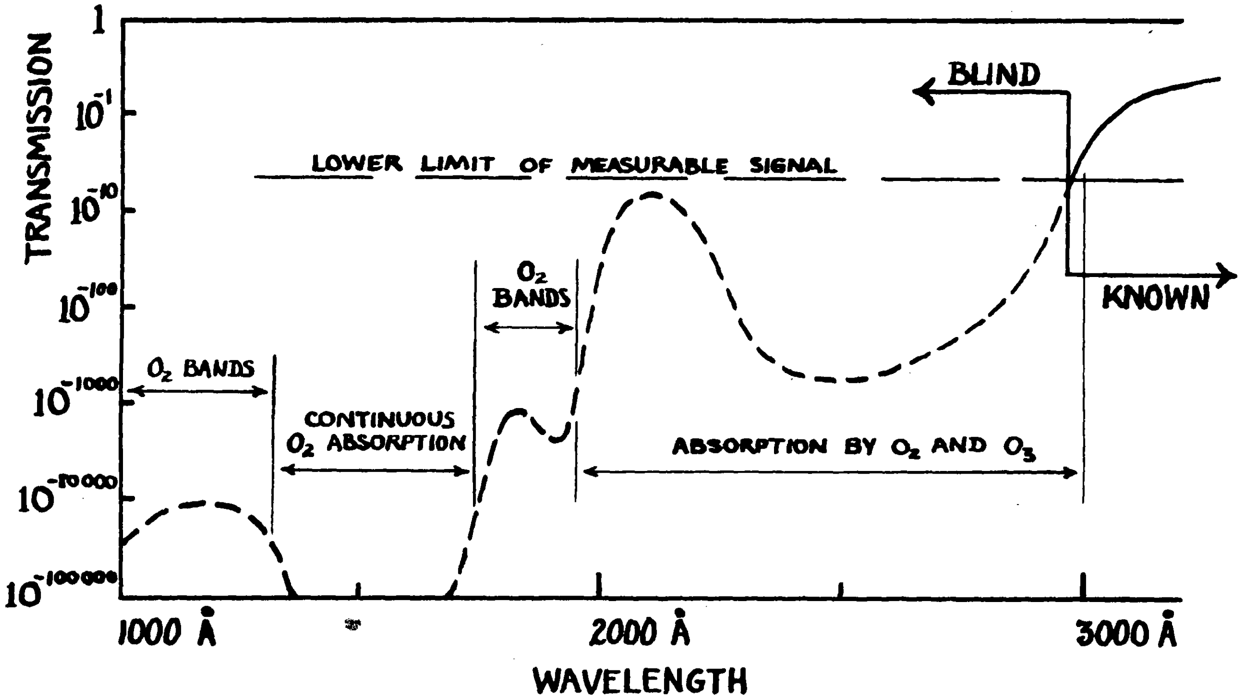
ESTIMATED WAVELENGTH DISTRIBUTION OF SOLAR INTENSITY IN OUTER SPACE



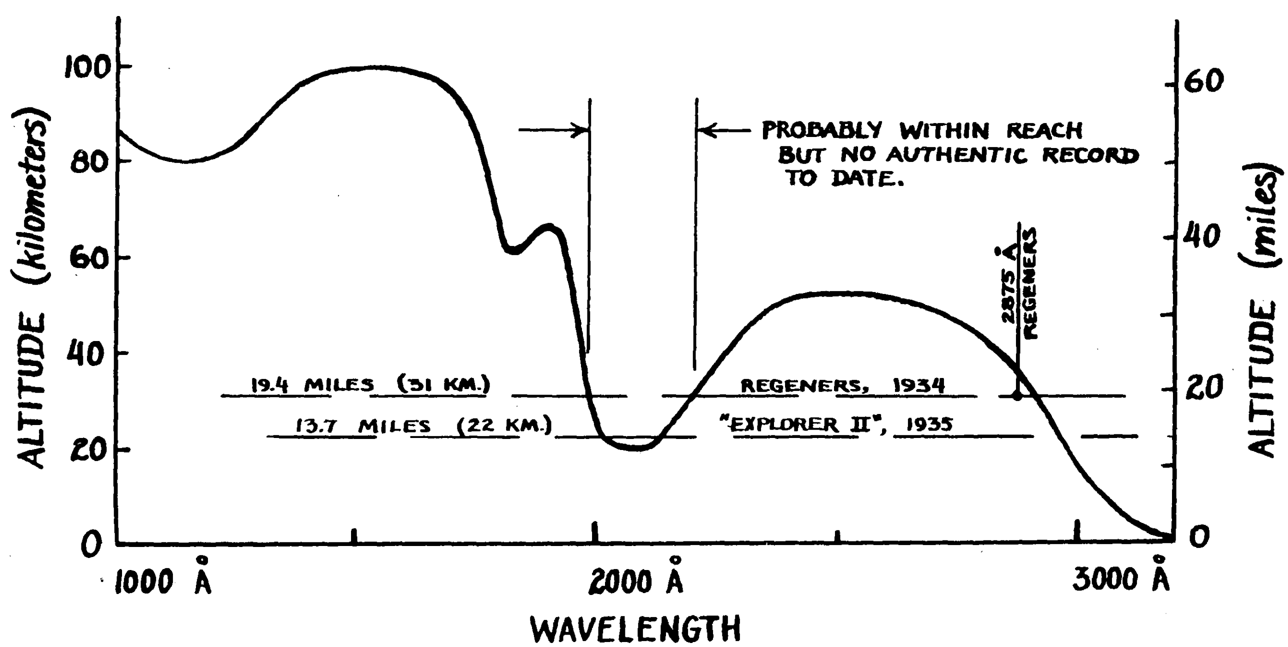
APPROXIMATE VERTICAL TRANSMISSION OF THE EARTH'S ATMOSPHERE (ABSORPTION BANDS LABELLED)

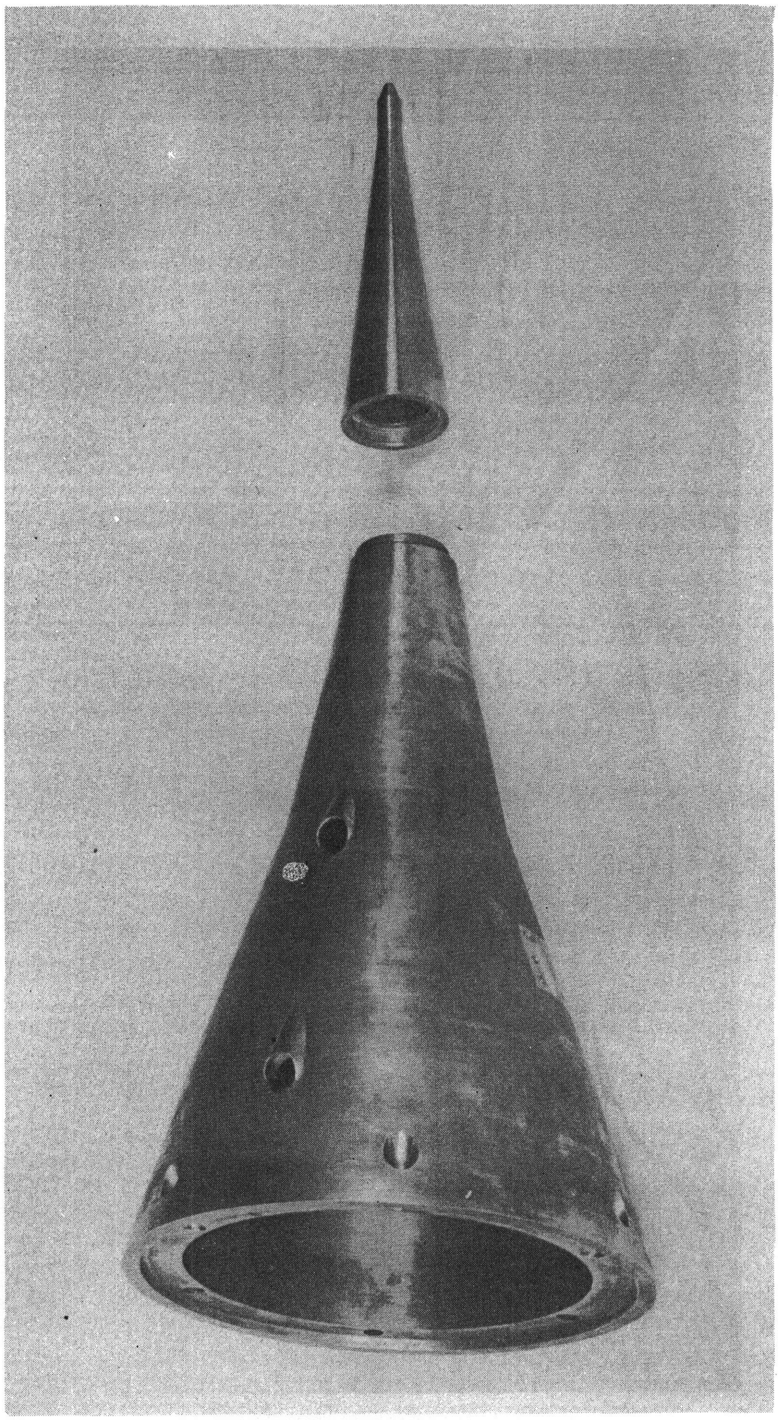


Very Rough Estimates of Atmospheric Transmission At Sea Level



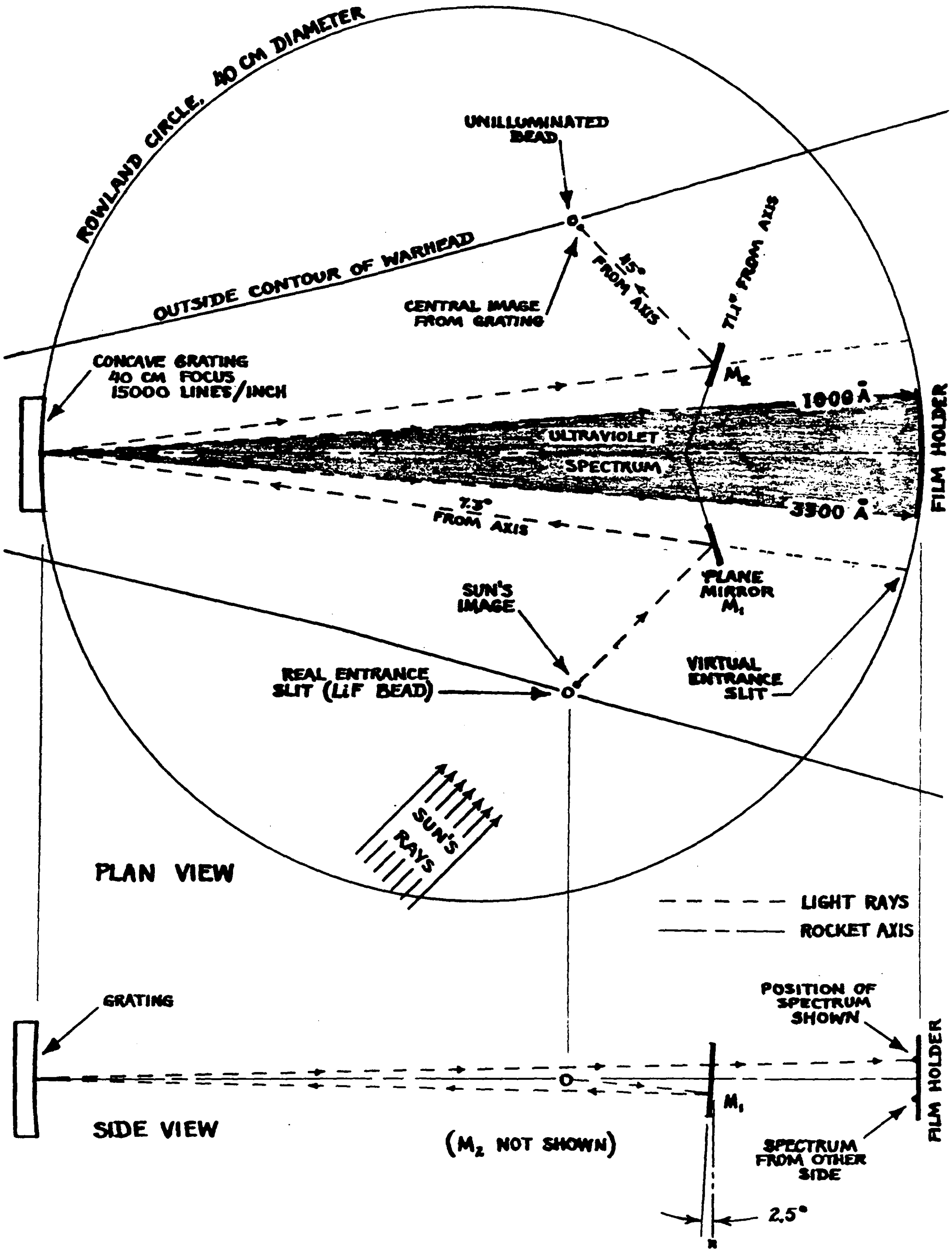
Estimated Altitudes for Which Transmission = .15

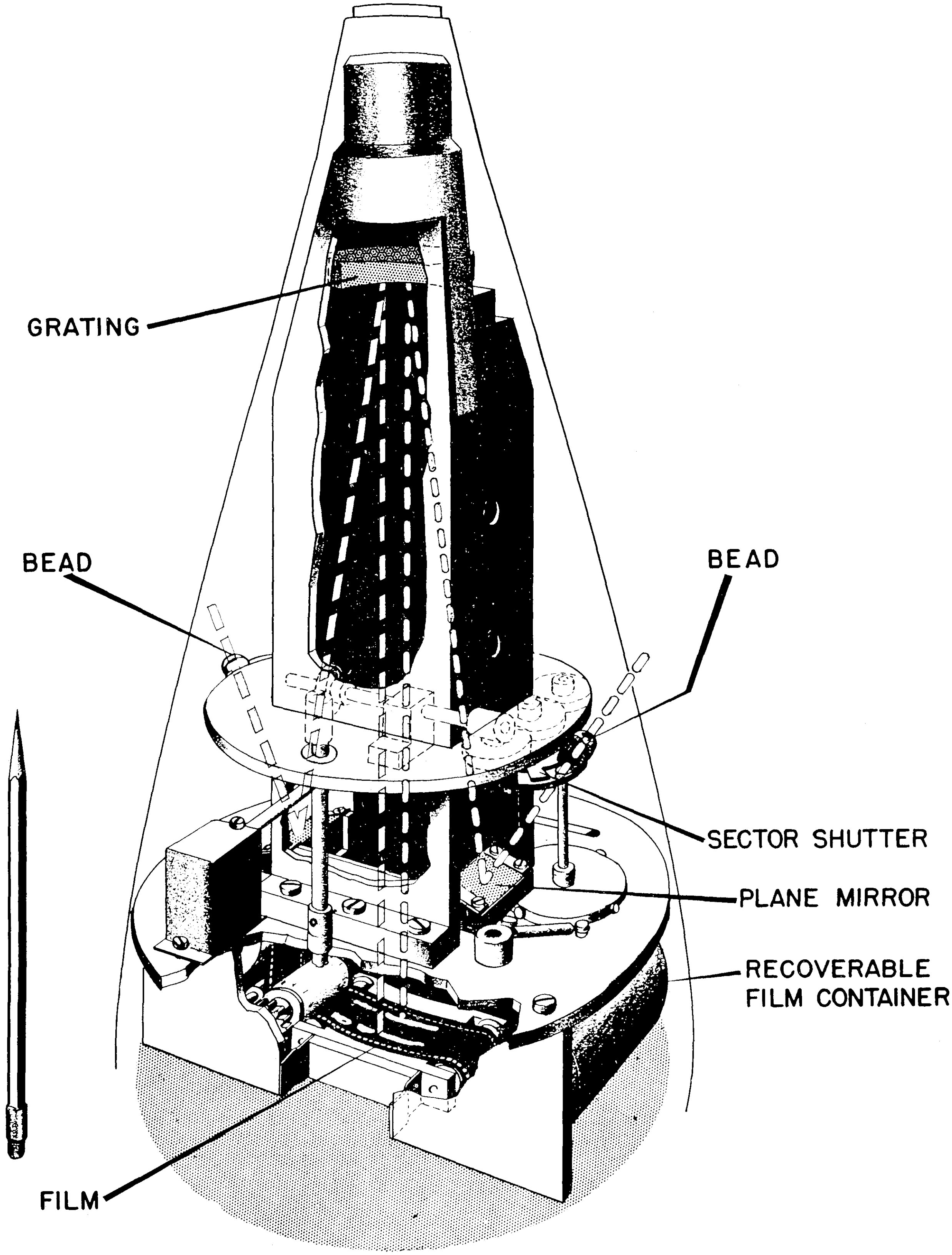




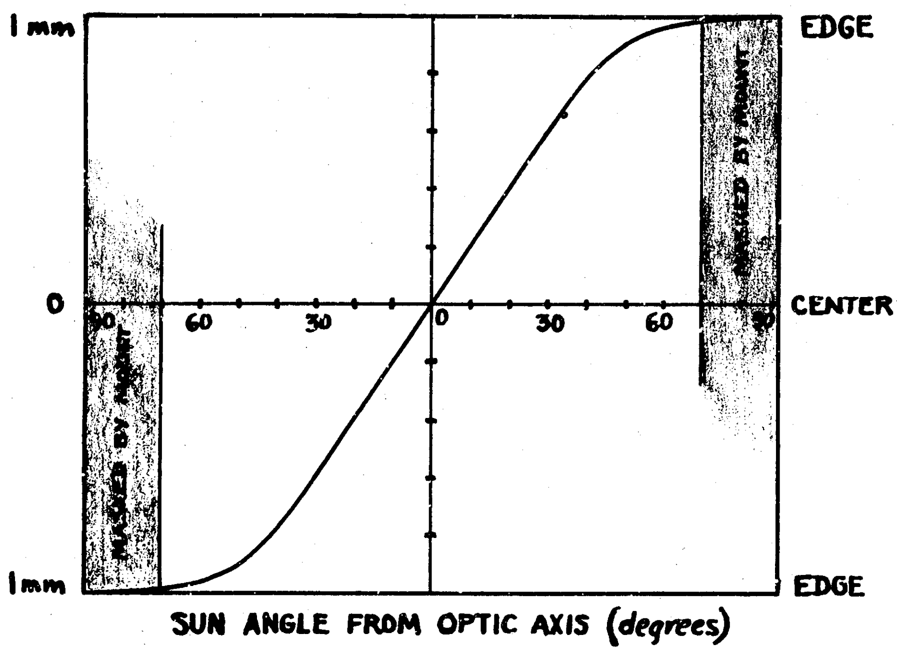
SPECTROGRAPH SHELL CASTING SHOWING AIR VENT CONTOURS

SCHEMATIC DIAGRAM OF V-2 SPECTROGRAPH OPTICAL SYSTEM

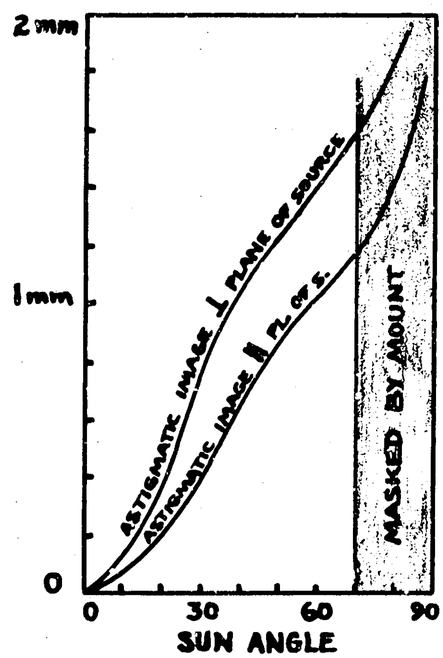




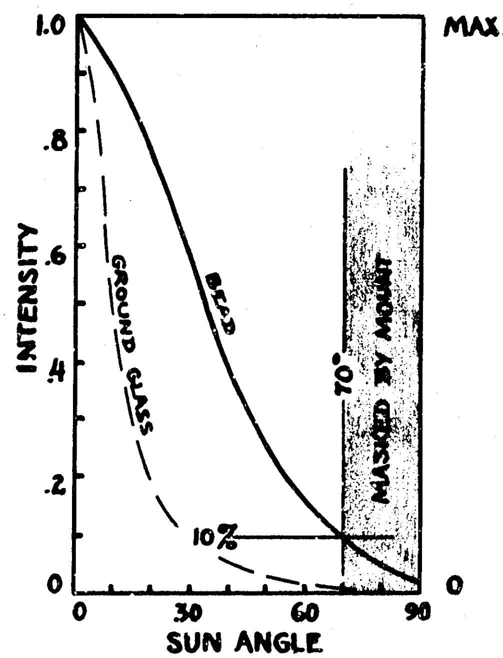
SPECTROGRAPH



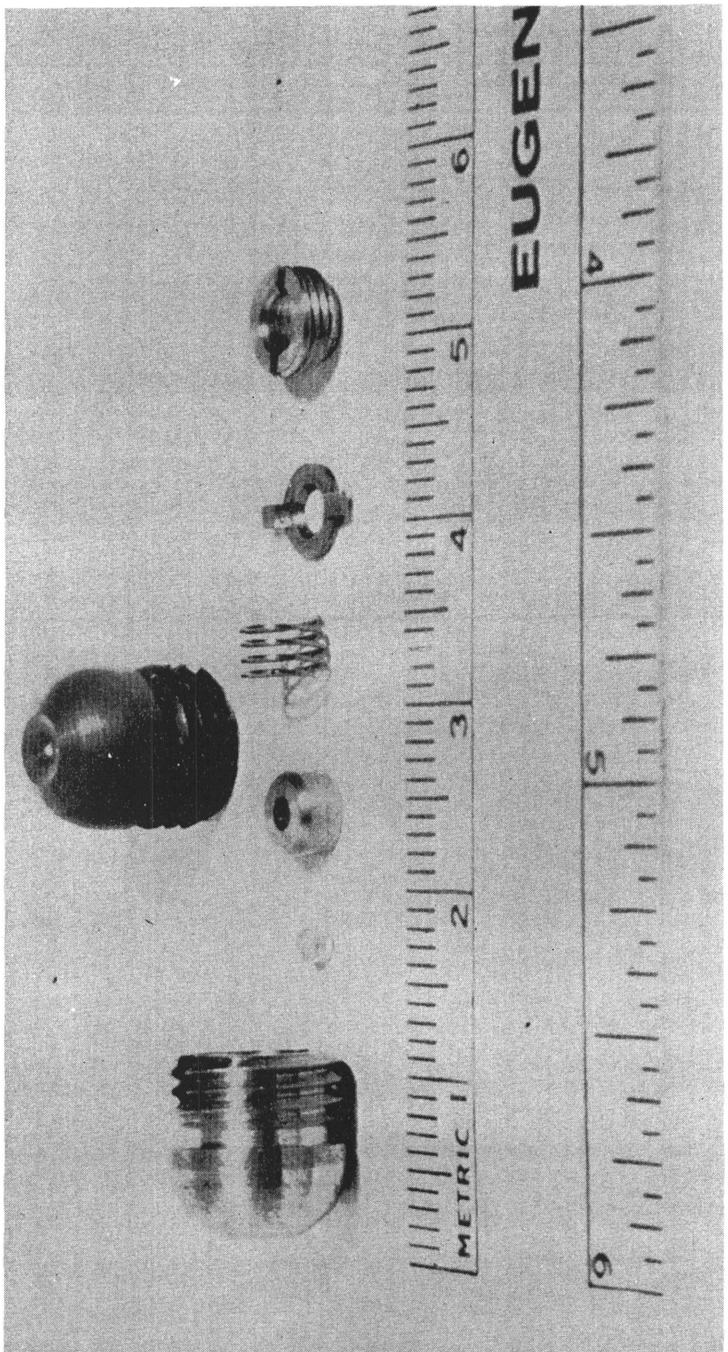
MOTION OF SUN'S IMAGE AS SUN ANGLE CHANGES



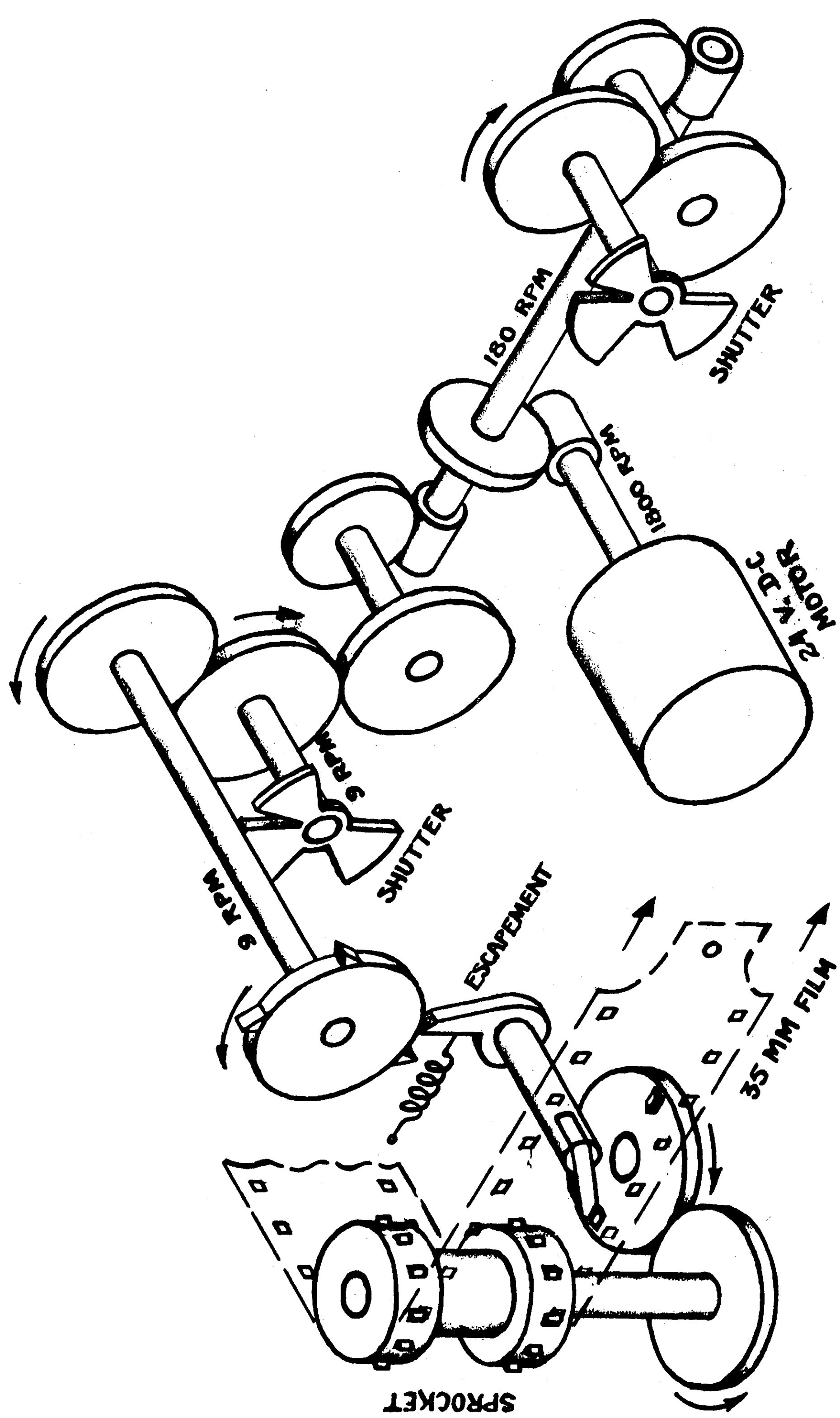
DEFOCUSSING OF IMAGE
FORMED BY 2MM BEAD



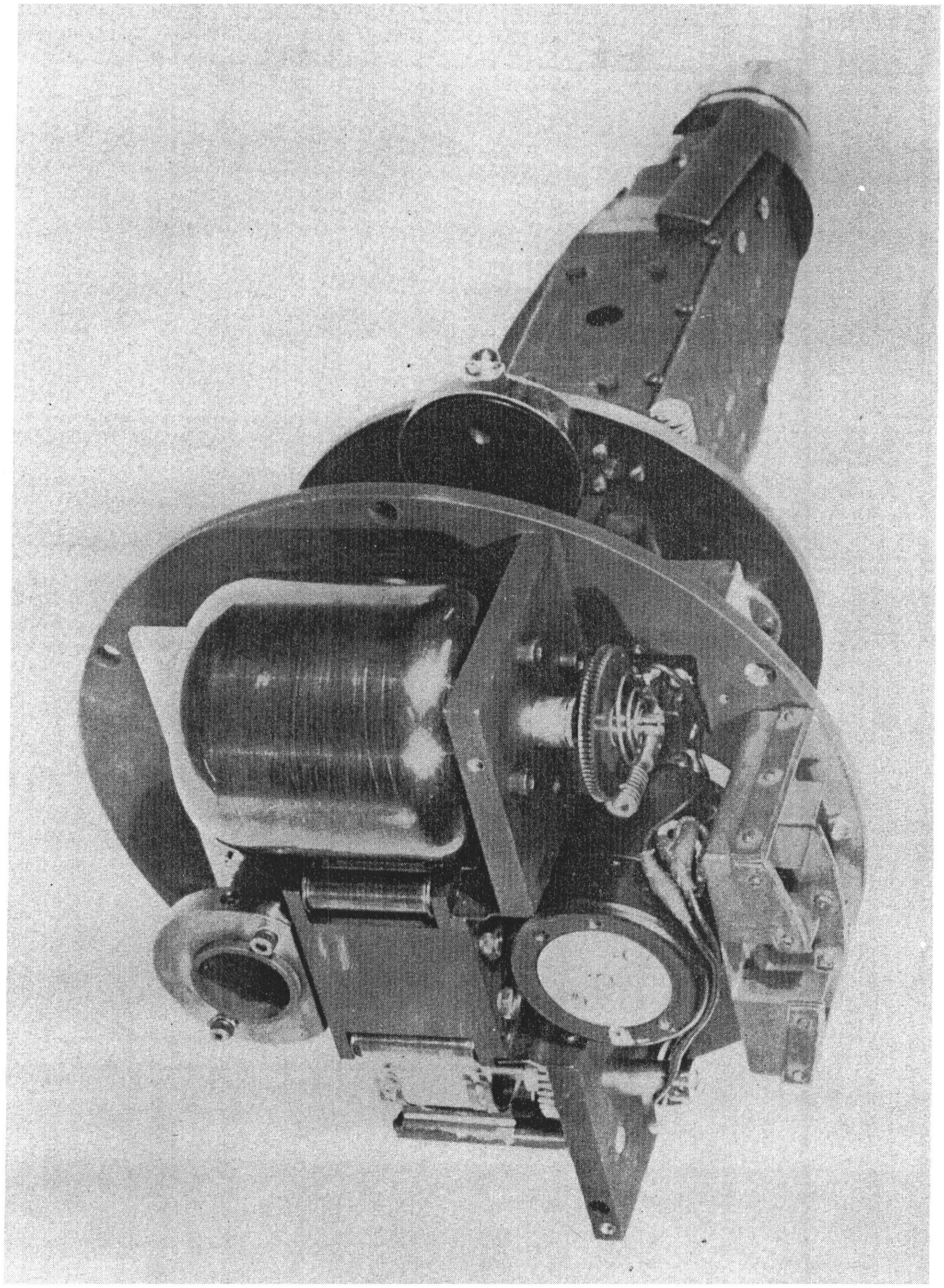
INTENSITY OF SUN'S IMAGE
FORMED BY 2MM BEAD



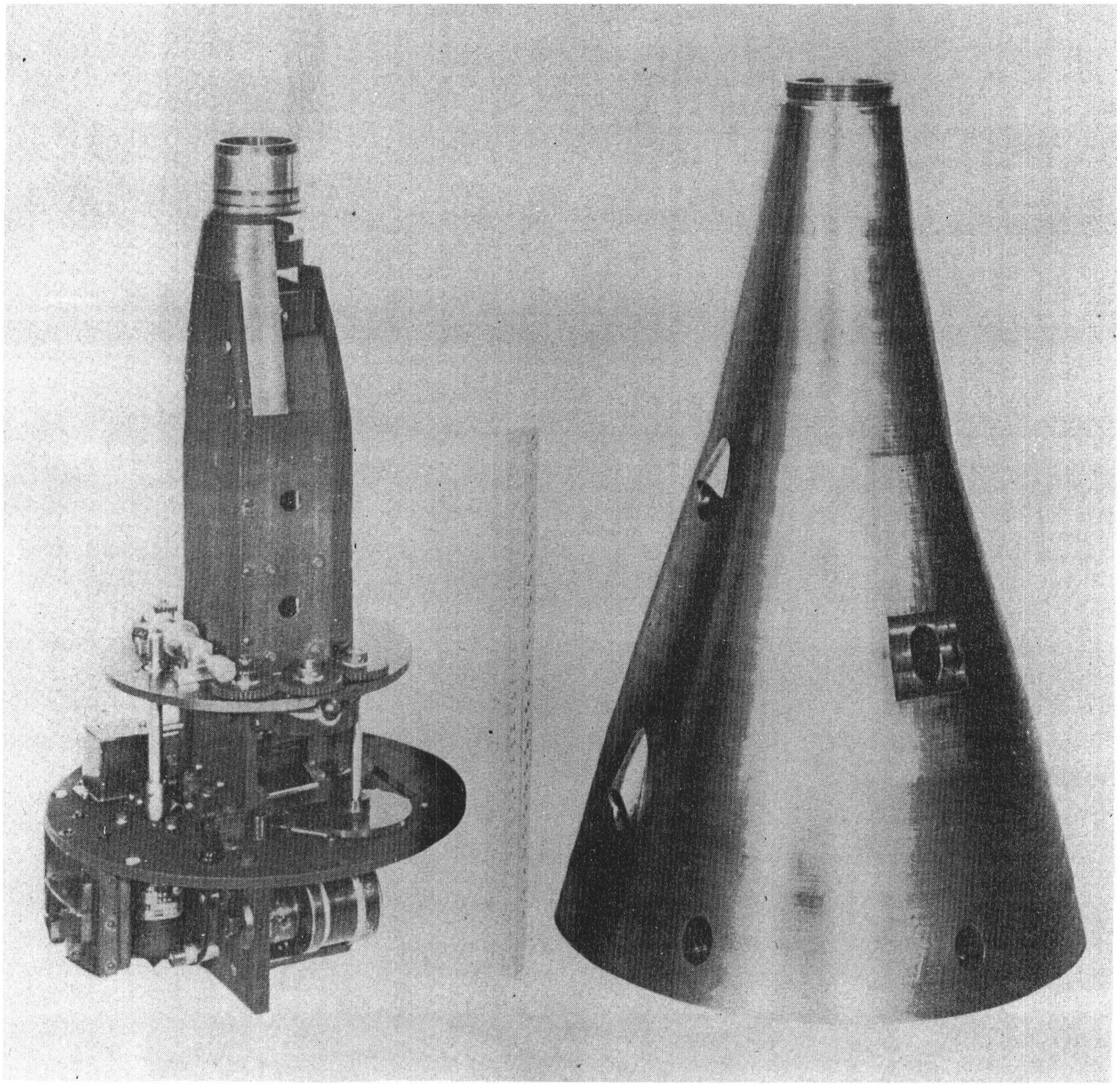
"EXPLODED" VIEW OF BEAD MOUNT WITH AN ASSEMBLY MOUNT IN THE BACKGROUND



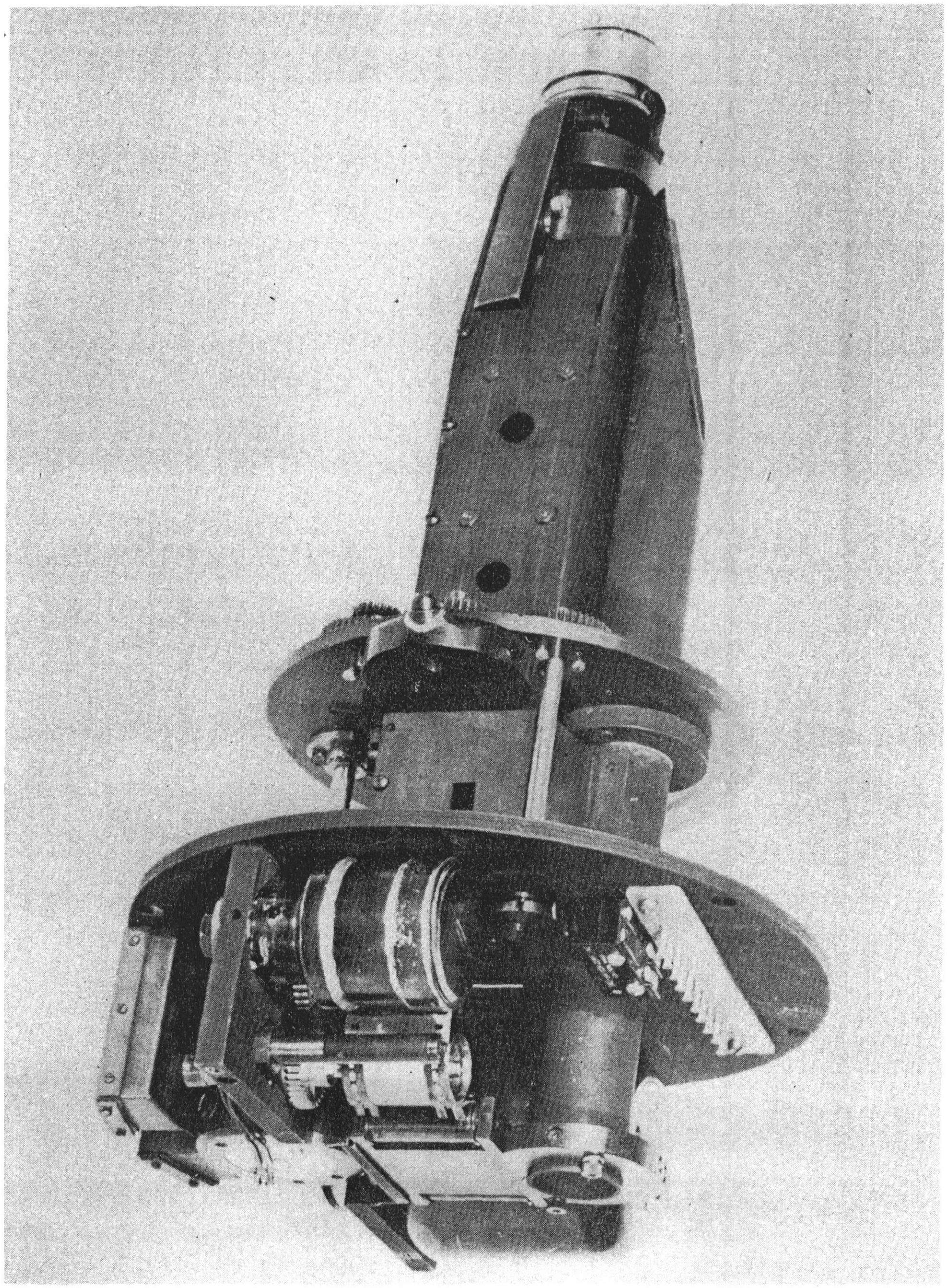
GEAR SCHEMATIC OF SHUTTER AND ESCAPEMENT MECHANISM



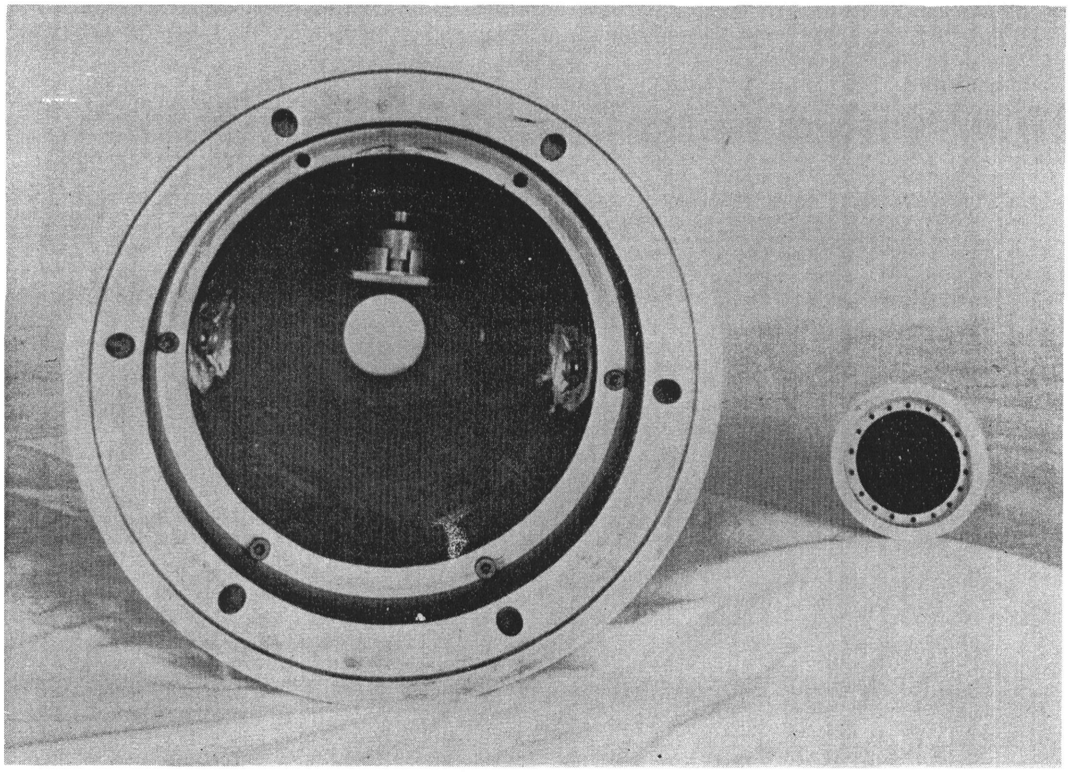
REAR VIEW OF SPECTROGRAPH SHOWING FILM TAKE UP DEVICE AND STEEL CASETTE IN THE FOREGROUND



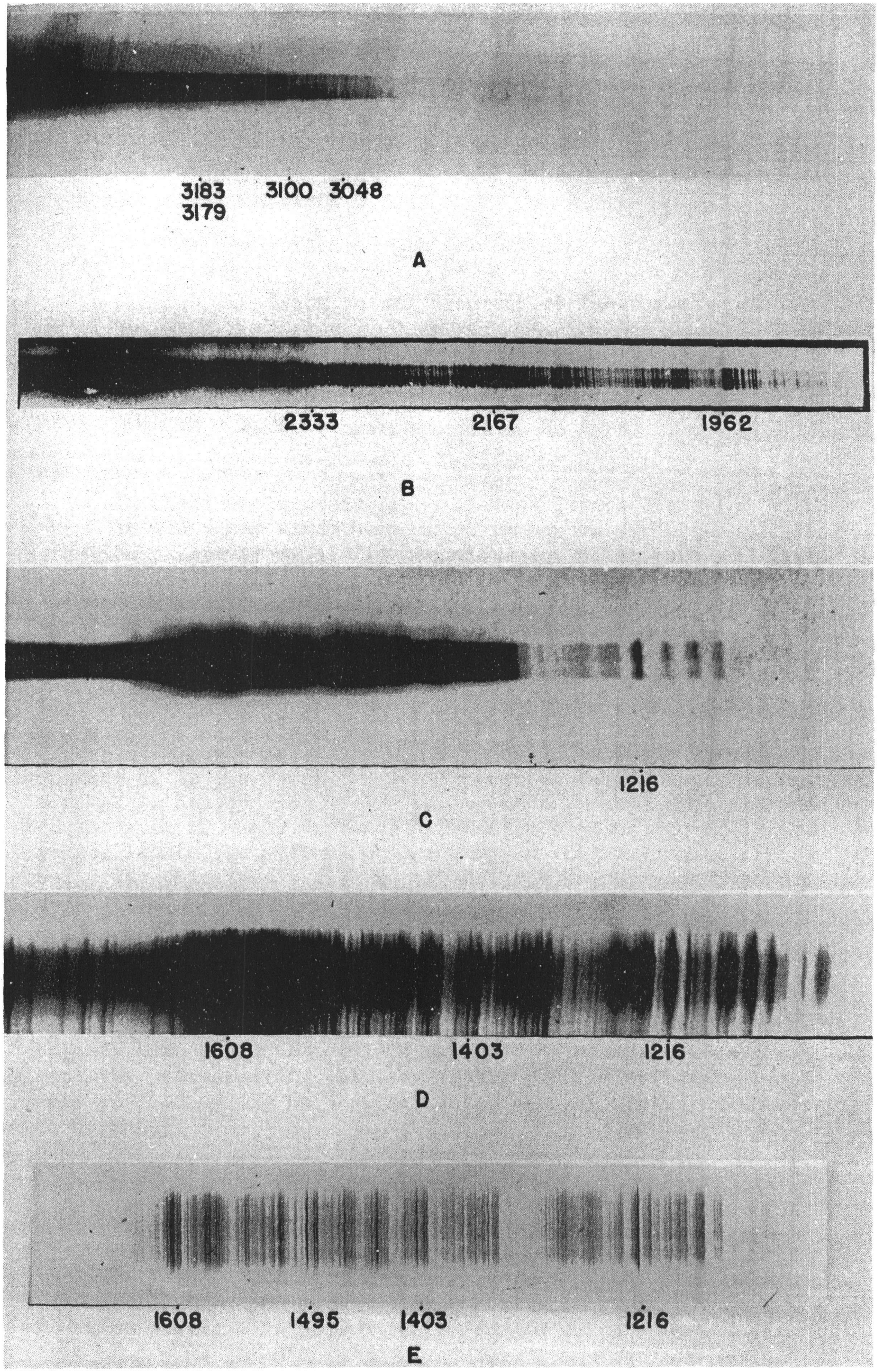
SPECTROGRAPH AND ITS SHELL COMPARED TO 1 FOOT SCALE



SIDE VIEW OF SPECTROGRAPH SHOWING FILM RESERVOIR AND SPROCKET. BEAD MOUNT AND SHUTTER HOUSING CAN BE SEEN ON MIDDLE BULKHEAD



REAR VIEW OF SPECTROGRAPH SHELL CASTING SHOWING WINDOWS FOR BEADS AND FORWARD AIR VENT BAFFLE


3183
3179
3100
3048
A
2333
2167
1962
B
1216
C
1608
1403
1216
D
1608
1495
1403
1216
E

SPECTRA

CHAPTER III

UPPER ATMOSPHERE RESEARCH CONDUCTED BY THE NAVAL RESEARCH LABORATORY

I. The Ejection and Recovery of Instruments

by

T. A. Bergstralh, M. W. Rosen,
E. D. Schreiner, and C. H. Smith

There are certain types of experiments connected with research in the upper atmosphere which cannot be performed successfully using the presently available techniques of telemetering. Those rocket borne experiments which require the recovery of samples such as biological specimens, certainly fall into this category. Telemetering of solar spectra is at present not feasible. On the other hand, the use of photographic film for recording spectra within the rocket which carries the spectrograph into the upper atmosphere, poses an exceedingly difficult problem of finding the film after the flight.

The seriousness of the problem of recovery became all too apparent after the first few V-2 flights at White Sands had resulted in complete destruction of the rocket upon impact. The failure to recover much of value from the tremendous craters formed by the early rockets led to the attempt on the June 28 flight to blow off the warhead. The unfortunate failure of this device has been mentioned above.

Supplementing the attempts to solve the recovery problem by causing an air burst of the rocket, a program was initiated to devise a means whereby data could be separated from the rocket at altitudes in excess of fifty miles, and, in falling, be decelerated enough by air drag on the containing envelope or on special parachutes to make possible a non-destructive landing. At the same time, to attain a completely satisfactory solution to the problem at hand, a workable means of finding the data after it had been brought safely to earth, was sought.

The containers used in the first two ejection experiments were laminated wooden blocks encased in a skin of twenty gage steel. These blocks were roughly cubical in shape, each edge being about one foot in length. Calculations made at the Naval Research Laboratory indicated that such a block would be decelerated from a maximum velocity of 4000 feet per second in the stratosphere to 500 feet per second at an altitude of 50,000 feet. The calculations were based on an effective cross-sectional area of one square foot, a subsonic drag coefficient of 1.2 (verified by a series of airplane drop tests) and an assumed supersonic drag coefficient of 2.0. The landing velocity of such a block was estimated to be 250 feet per second. Tests showed that the block would not be greatly damaged by such an impact, permitting the recovery of material enclosed in the block.

In the first trial, made July 9, eight drag plates were included as part of the separate fall assembly. These consisted of approximately one foot squares of 20 gage aluminum alloy suspended by copper cables from the block to each of the four corners of the plates so that the assembly would string out in falling, with the plates five feet apart and trailing the block, and with each plate perpendicular to the line of fall. It was estimated that each plate would add as much as 40% to the drag of the block. An armored film container holding a roll of exposed 35 millimeter film was placed at the center of the block. A cavity was cut into each of the four side faces of the block and skin. In the compartments so formed, film was placed so as to be exposed to the radiation of the upper atmosphere. The film was unexposed 35 millimeter positive, and was covered with a sheet of 0.003 inch aluminum. The openings were protected by pieces of copper mesh. At the front of the block, a package of seeds was embedded in the wood about one half inch below the surface, and at the rear a container with a special film for the detection of neutrons was inserted under the metal skin. The block was ruptured in air and although much of its contents was recovered, the experimental containers were destroyed.

The block for the second ejection experiment was made shorter in one dimension so that a parachute pack could be installed. The ejection of the block from the rocket was to open the chute. Unfortunately, the premature explosion of the July 19 rocket at 18,000 feet destroyed the block before ejection.

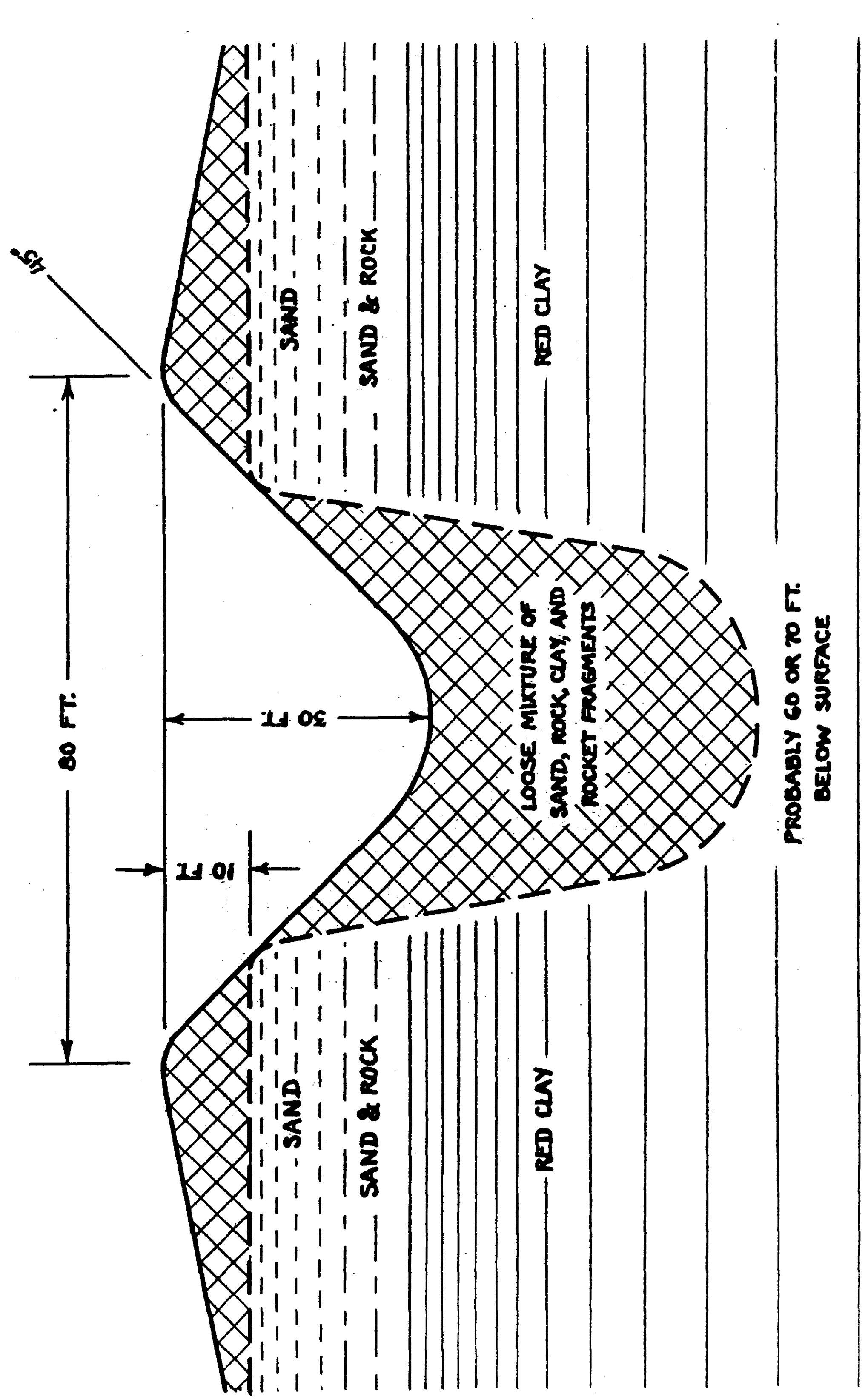
The assembly used for ejection consists essentially of a steel box designed to fit into compartment IV of the V-2 control section. There is a spring loaded push plate in the back of the box, and a trigger mechanism to permit the release of the ejected container at a specified time. The box fits snugly against the door of the compartment into which an opening has been cut. This opening is fitted with a hinged door so arranged that it is under the rocket skin at the top and over it at the bottom. The purpose of the door is to prevent the tearing away of the skin which would result from air drag in the absence of such protection. The trigger mechanism consists of a solenoid coil mounted on top of the box to operate a plunger at the appropriate moment. The motion of the plunger releases a pin which projects through the top of the box into a guiding track mounted on the ejection block. The spring, which has a maximum force of 110 pounds, is compressed by inserting the block through the opening in the rocket and is restrained by the holding action of the pin in the block. When the solenoid is energized, the block slides forward due to the force of the spring, frees the latch on the door, opens the door, and slides out of the rocket. The door, box, and solenoid are plainly shown in Figs. 3 and 4.

The ejection process is set for 240 seconds after launching. At this moment, the missile should be just beyond the peak if following the normal mean trajectory, and in any case should be safely into the upper atmosphere.

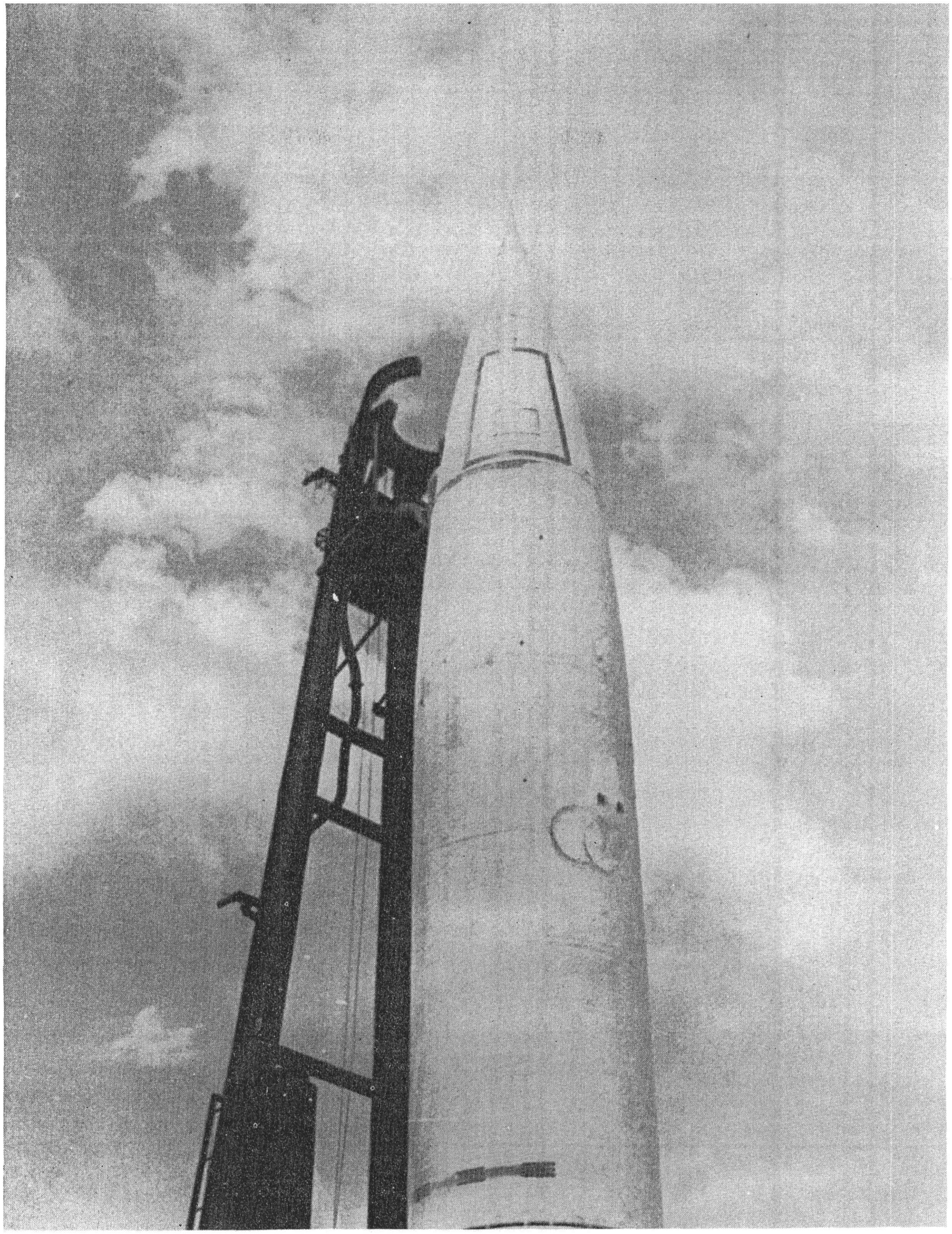
The only flight from which useful information has been obtained is that which took place on July 9, when the block was equipped with the drag plates. From a recovery point of view, the flight was only partially successful because, although the block did come out of the rocket, it was recovered only as fragments spread out over an area of a half square mile. Since pieces of the block were intermingled with parts of a rocket fin, it is believed that the block was ejected after the rocket had entered the denser portion of upper atmosphere. The block then was carried back against the fin, shattering both.

Fig. 8 shows the pieces which were picked up by combing the desert. There are variously sized pieces of the block, and parts of the block casing, drag plates, and ejection spring. The condition of the spring clearly illustrates the tremendous forces which can be developed at supersonic velocities. When installed, the spring consisted of twenty-five turns of quarter inch steel wire; when recovered it had been nearly straightened to two turns, while one end had been broken under tension. The conclusion seems forced that ejections should be made in the comparative vacuum of the higher altitudes.

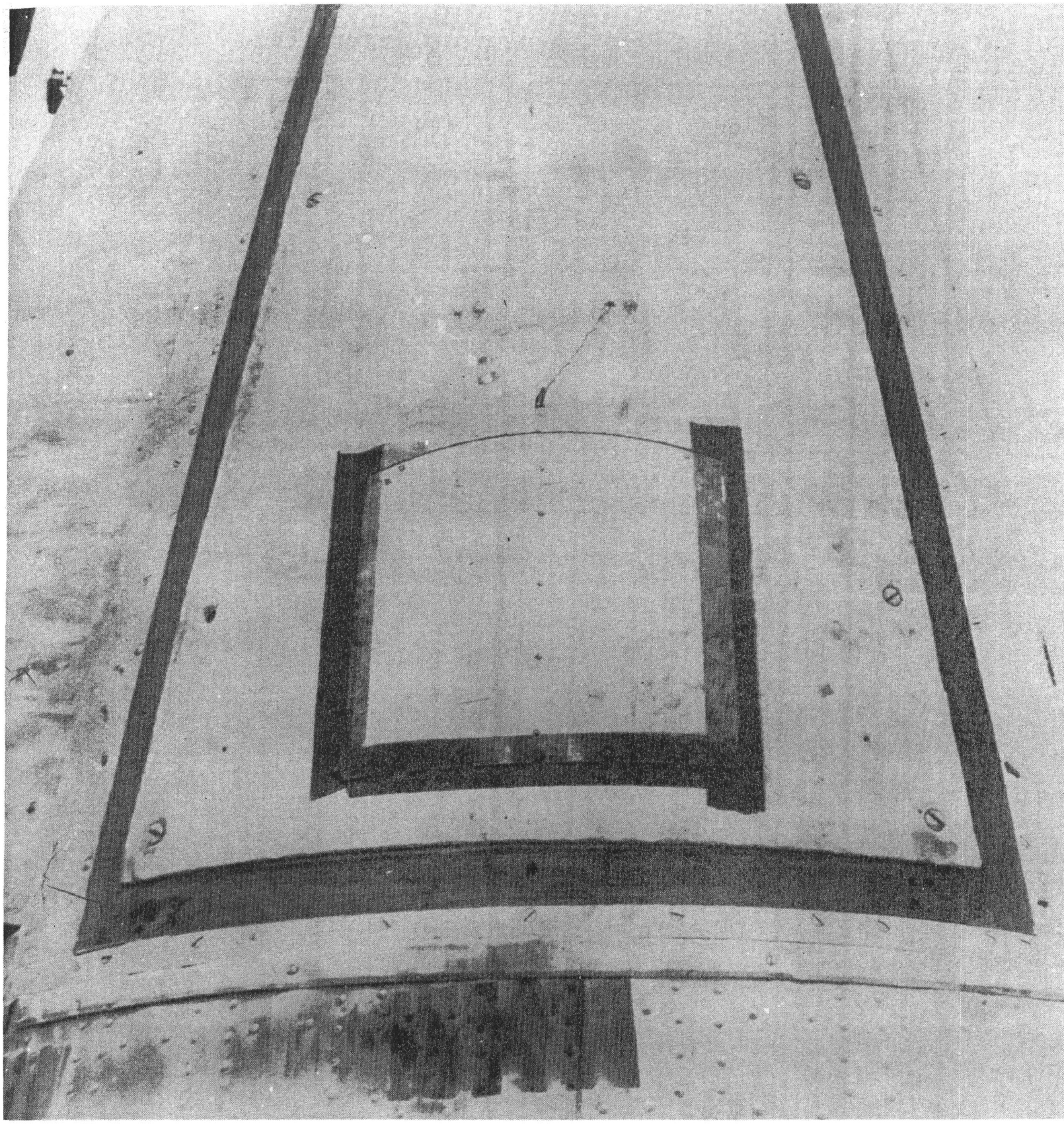
IMPACT CRATER RESULTING FROM JUNE 28 FIRING



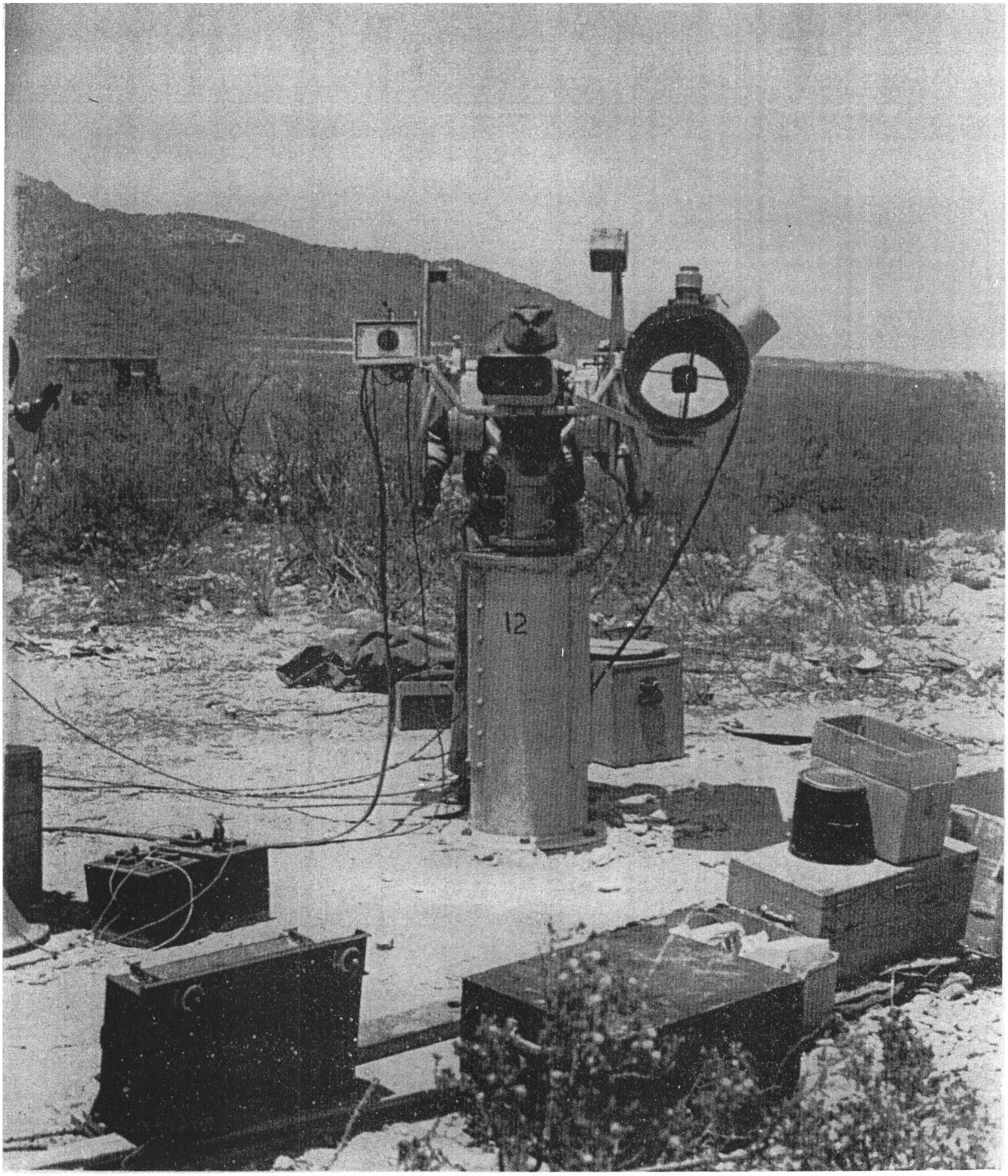
DIAGRAMMATIC REPRESENTATION OF IMPACT CRATER



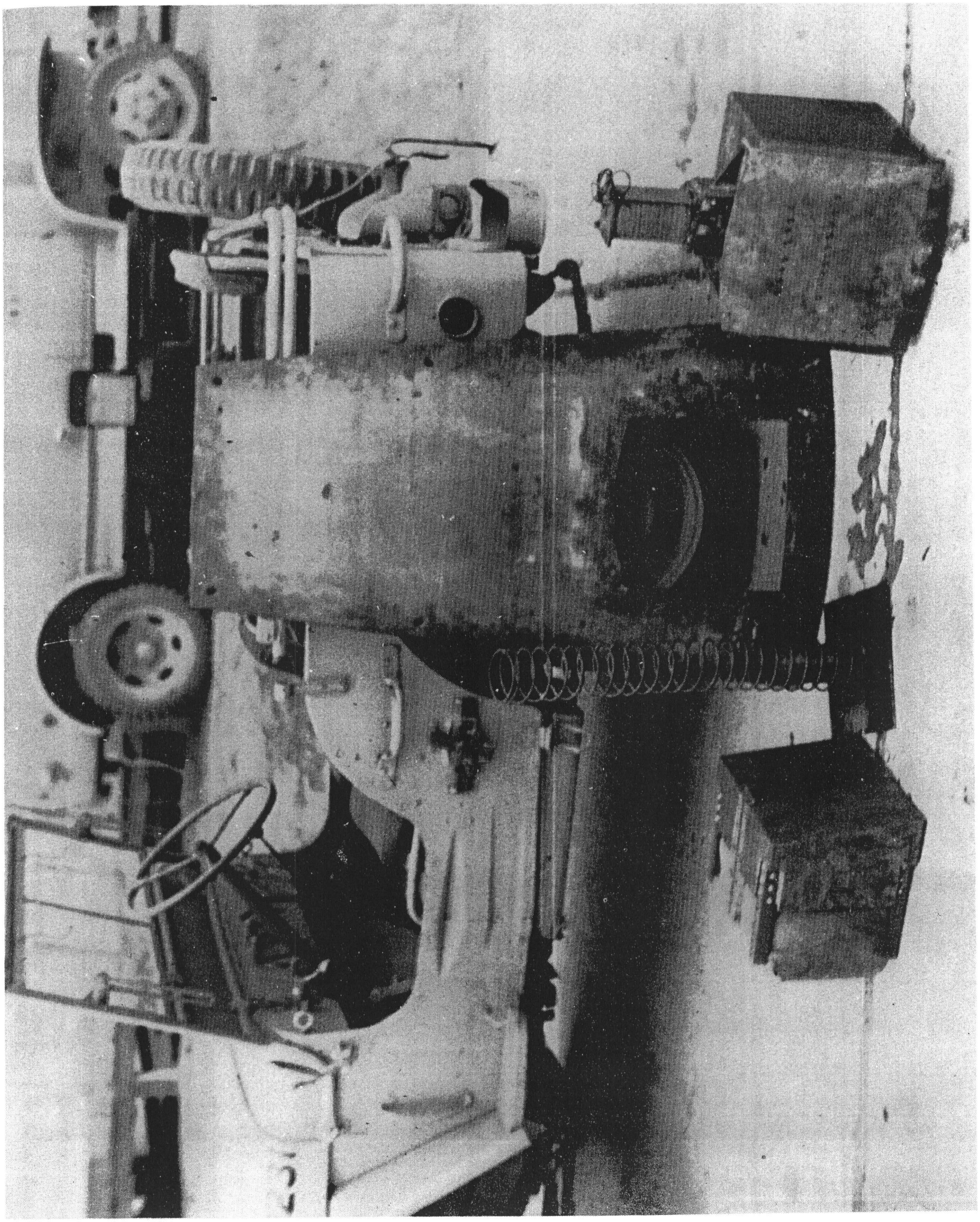
THE V-2 SHOWING EJECTION DOOR IN CONTROL COMPARTMENT



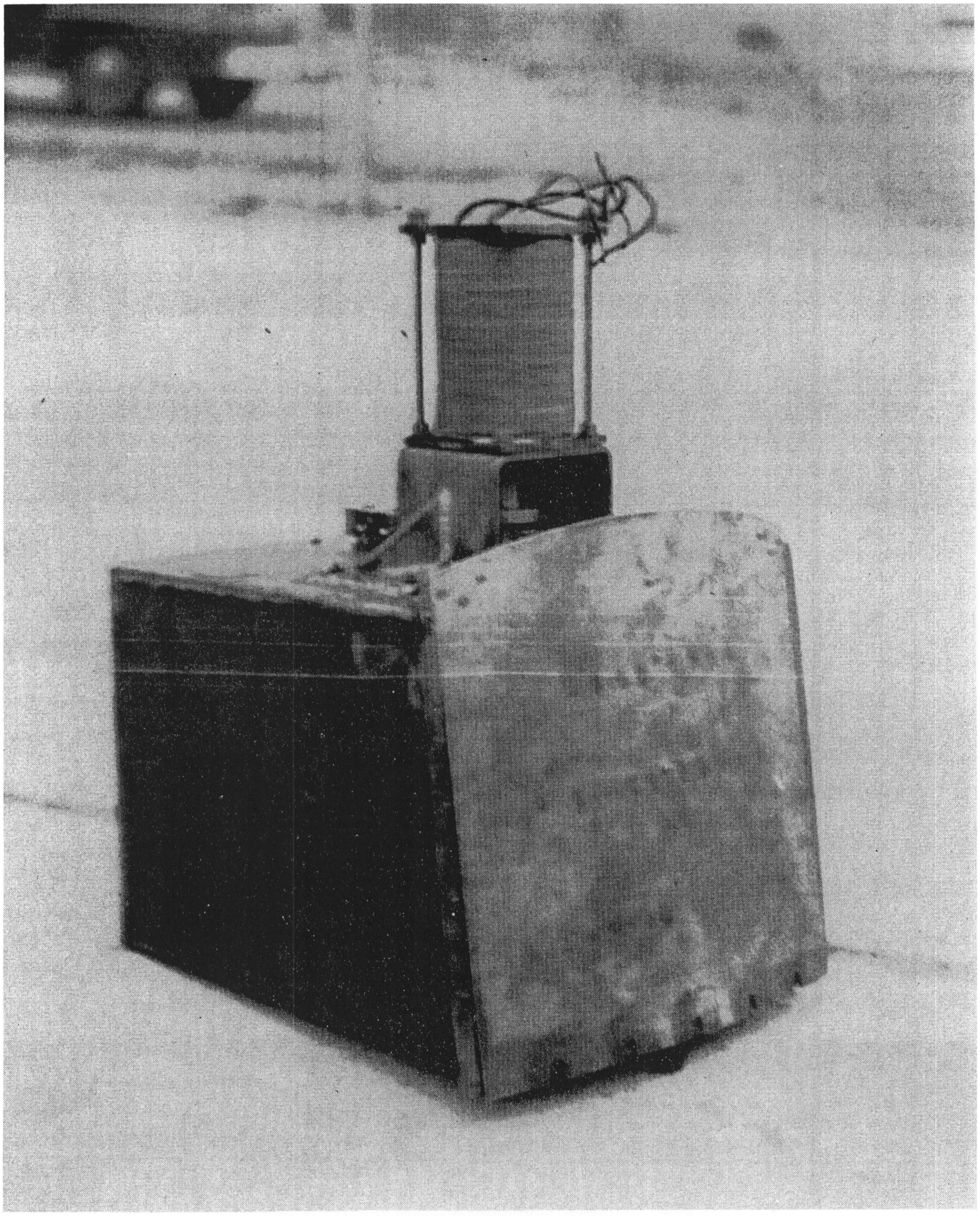
CLOSEUP OF EJECTION DOOR



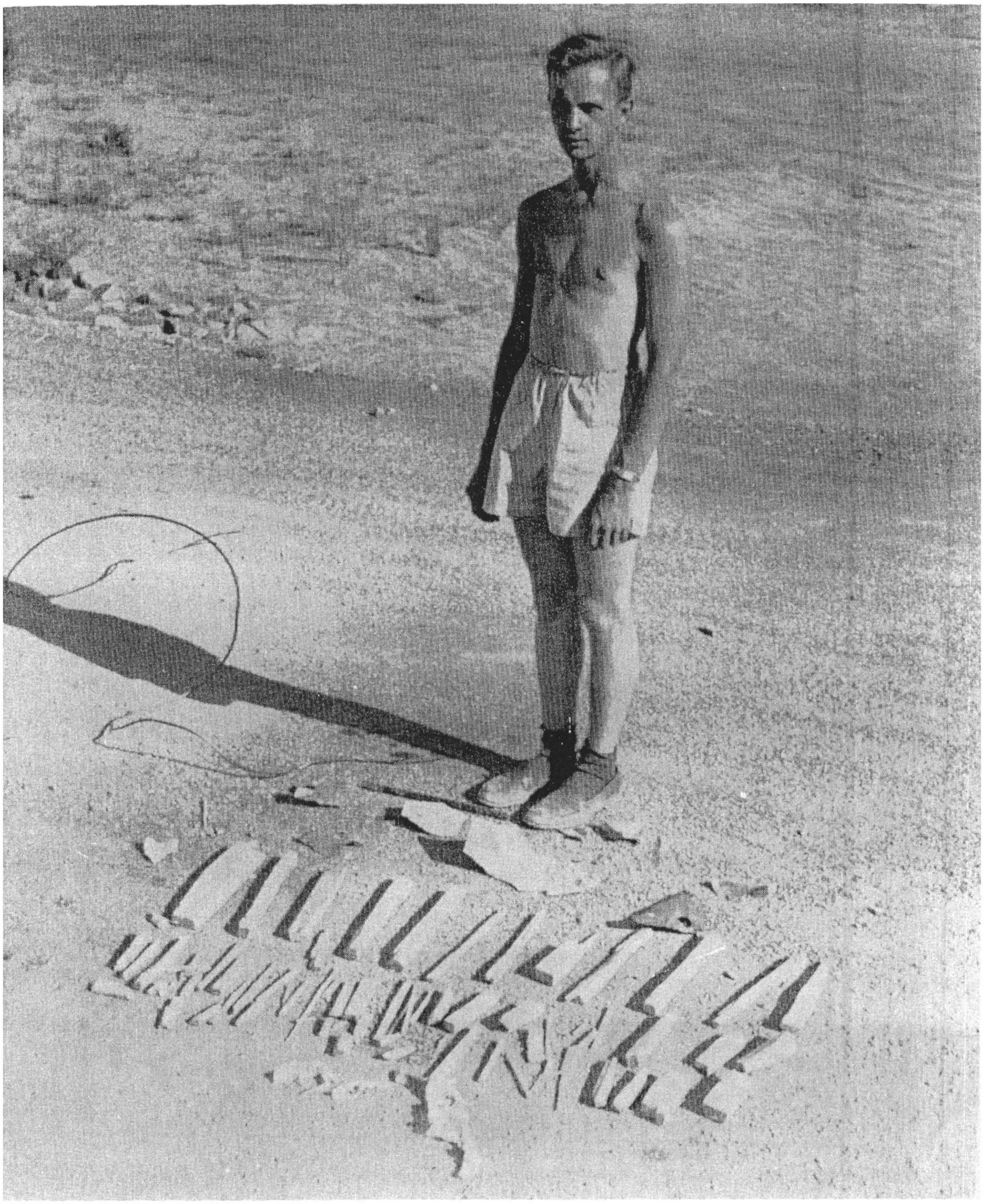
BINOCULAR OBSERVATION STATION



COMPONENTS OF EJECTION MECHANISM



CLOSE-UP OF EJECTION WELD AND SOLENOID



FRAGMENTS OF EJECTED BLOCK AND SPRING RECOVERED
FROM JULY 9, FIRING

CHAPTER III

UPPER ATMOSPHERE RESEARCH CONDUCTED BY THE NAVAL RESEARCH LABORATORY

J. Biological Experiments in the V-2

The Naval Research Laboratory is collaborating with Harvard University in sending biological specimens into the upper atmosphere. Biologists at Harvard wish to determine the effects, if any, of the radiation at high altitudes on the characteristics of seeds, eggs, etc. Particular interest attaches to the possibility of mutations. For this purpose they provided a quantity of specially developed strains of seeds, samples of which were incorporated into the July 9 and July 19 flights. Unfortunately, the seeds never were recovered.

During the final preparations for the No. 9 missile, scheduled for firing on July 30, it was noticed suddenly at White Sands Proving Ground that the Harvard supply of seeds had run out. Since, by that time, little hope was held for recovery of any equipment or material from a rocket after flight, no attempt was made to replenish the supply for the July 30 firing. Instead, a package of ordinary corn seeds was purchased in a Las Cruces store for inclusion in the flight. As fate would have it, the flight broke all altitude and all recovery records.

The seeds which were recovered, along with some which had been withheld for a standard, have been forwarded to Harvard for analysis.

ACKNOWLEDGMENT

The Rocket Sonde Research Section gratefully acknowledges the invaluable assistance it received from various persons and groups who cooperated in the V-2 firings.

Acknowledgments of gratitude for help received in connection with the work of the different fields of research have appeared earlier at the ends of the various discussions.

It is desired here to extend thanks to Col. H. N. Toftoy and Lt. Col. J. G. Bain of the Office of the Chief of Ordnance, War Department, Rocket Development Division, without whose aid the work of the Rocket Sonde Research Section could not have been carried out successfully. Thanks are also due Lt. Col. H. R. Turner, commanding officer at the White Sands Proving Ground, for the aid he accorded the Section at White Sands, and especially for his cooperation and courtesy in postponing the June 27 flight to June 28. Major H. L. Karsh and Mr. L. D. White, General Electric representative, both at White Sands Proving Ground, are to be thanked for their help and advice on matters pertaining to the operation of the rocket. Dr. R. W. Porter of General Electric spent considerable time in assisting members of the Rocket Sonde group.

It is desired also to thank the many members of the Naval Research Laboratory outside the Rocket Sonde Research Section, whose continued assistance helped to make the V-2 experiments possible.

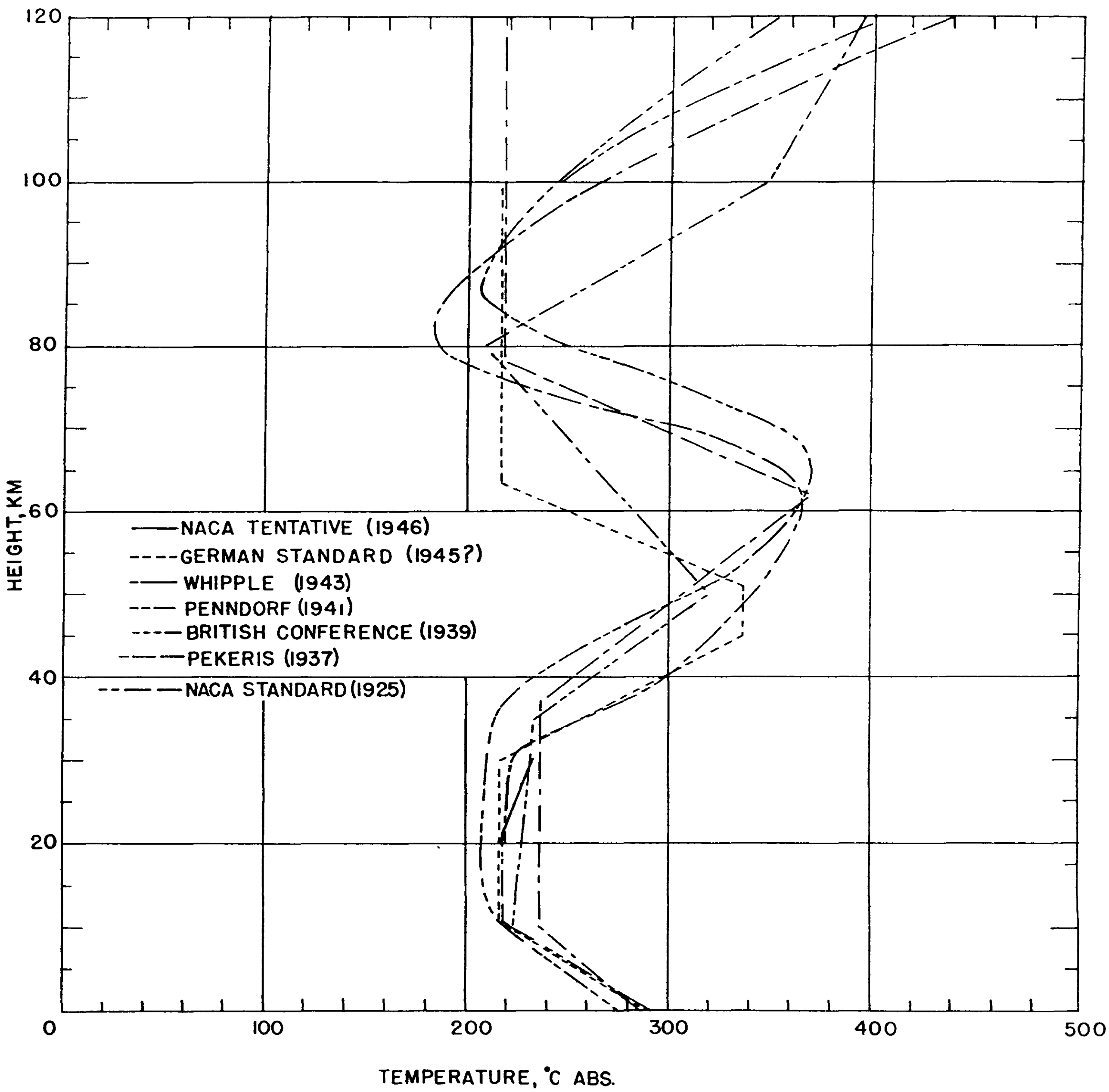
APPENDICES

The material presented in the following appendices was found useful in planning experiments, designing equipment and interpreting results. References are given to show the sources of data used.

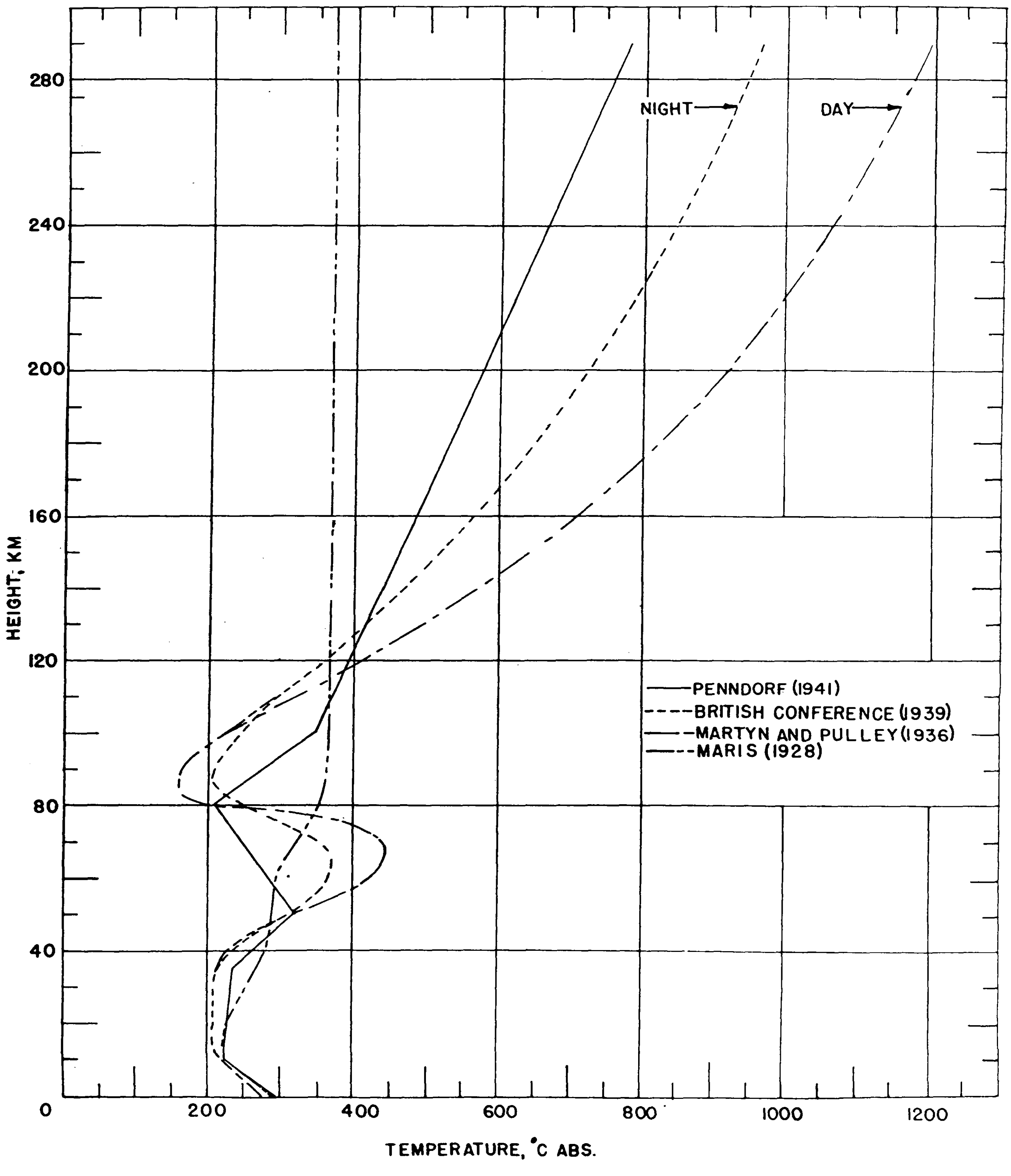
APPENDIX I

Existing Estimates of Upper Atmosphere Temperatures

For the purpose of designing experiments and equipment to measure upper atmospheric data, it is necessary to have a preliminary estimate of such data. The following charts summarize the best available information on temperature versus altitude. The data were compiled for the Special Subcommittee on the Upper Atmosphere of the National Advisory Committee for Aeronautics from sources which are briefly indicated on the charts. Complete references to these sources are given in the bibliography.



EXISTING CURVES OF ATMOSPHERIC TEMPERATURE VS. ALTITUDE 0-120 KM.



EXISTING CURVES OF ATMOSPHERIC TEMPERATURE VS. ALTITUDE, 0-290 KM

APPENDIX II

Mass of Air Traversed in Entering the Atmosphere

by

H. E. Newell, Jr. and E. Pressley

The attached figures show the mass of air traversed in moving rectilinearly from a point outside the earth's atmosphere to a specific station within the atmosphere, and are so drawn as to exhibit the functional dependence of this mass upon (1) height Z of the station above the earth, and (2) zenith angle ζ made by the path in question.

In the figures:

The value of Z in kilometers is given in the upper right-corner.

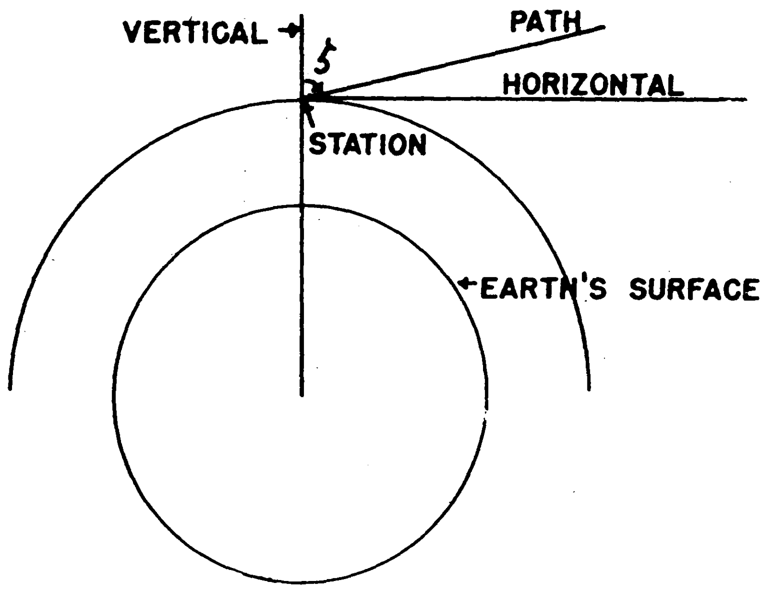
The abscissa gives the zenith angle ζ in degrees.

The extreme left hand scale gives the mass of air in grams per square centimeter.

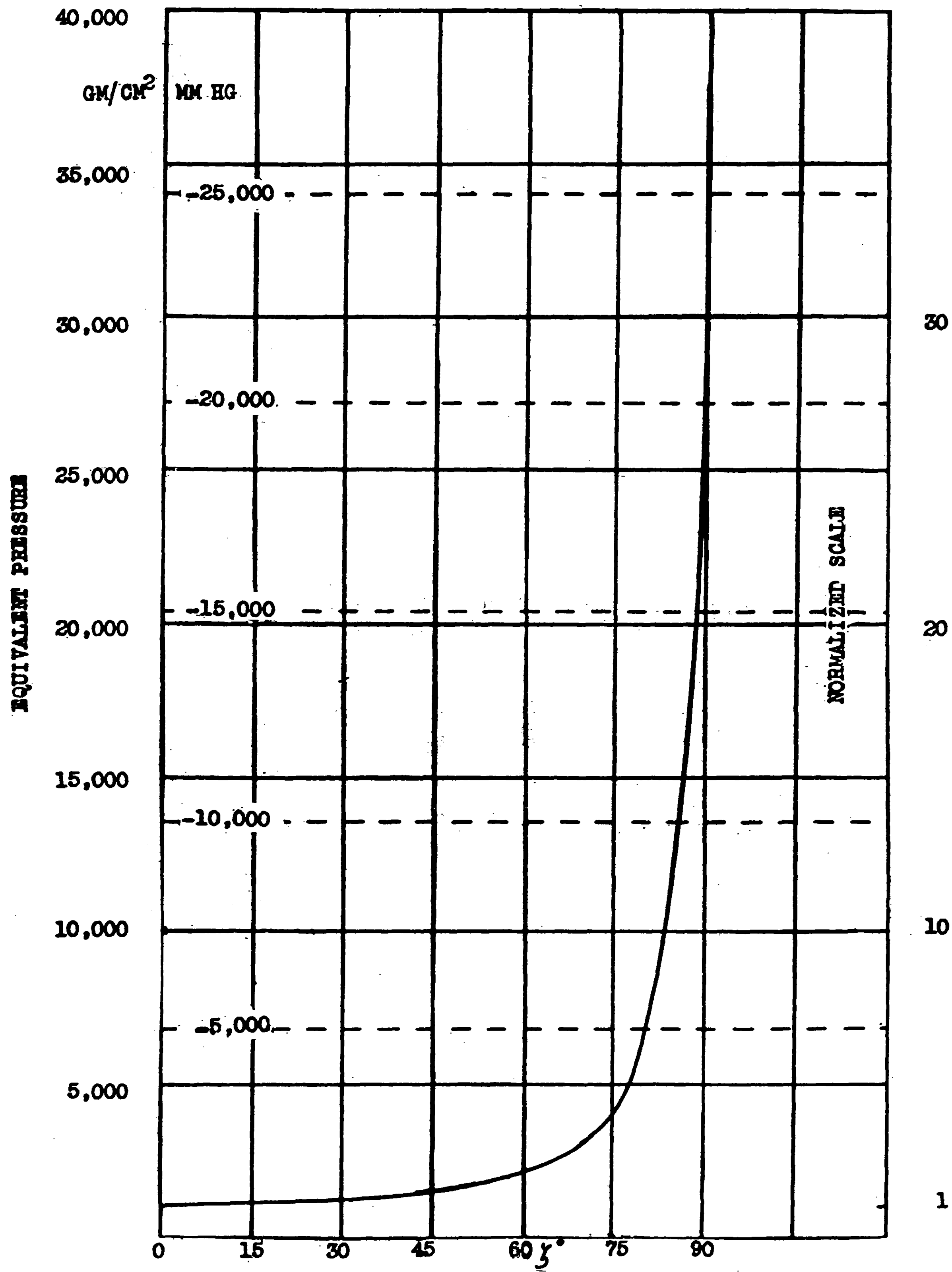
The inner left hand scale gives the equivalent mass in terms of millimeters of mercury.

The scale on the extreme right is a normalized scale in which the unit is the mass traversed along the vertical path.

The calculations underlying the graphs are based on an extended extrapolation of the earth's atmosphere as given by Whipple's assumed curves in Meteors and the Earth's Upper Atmosphere, Reviews of Modern Physics, Volume 15, Number 4, 1943.

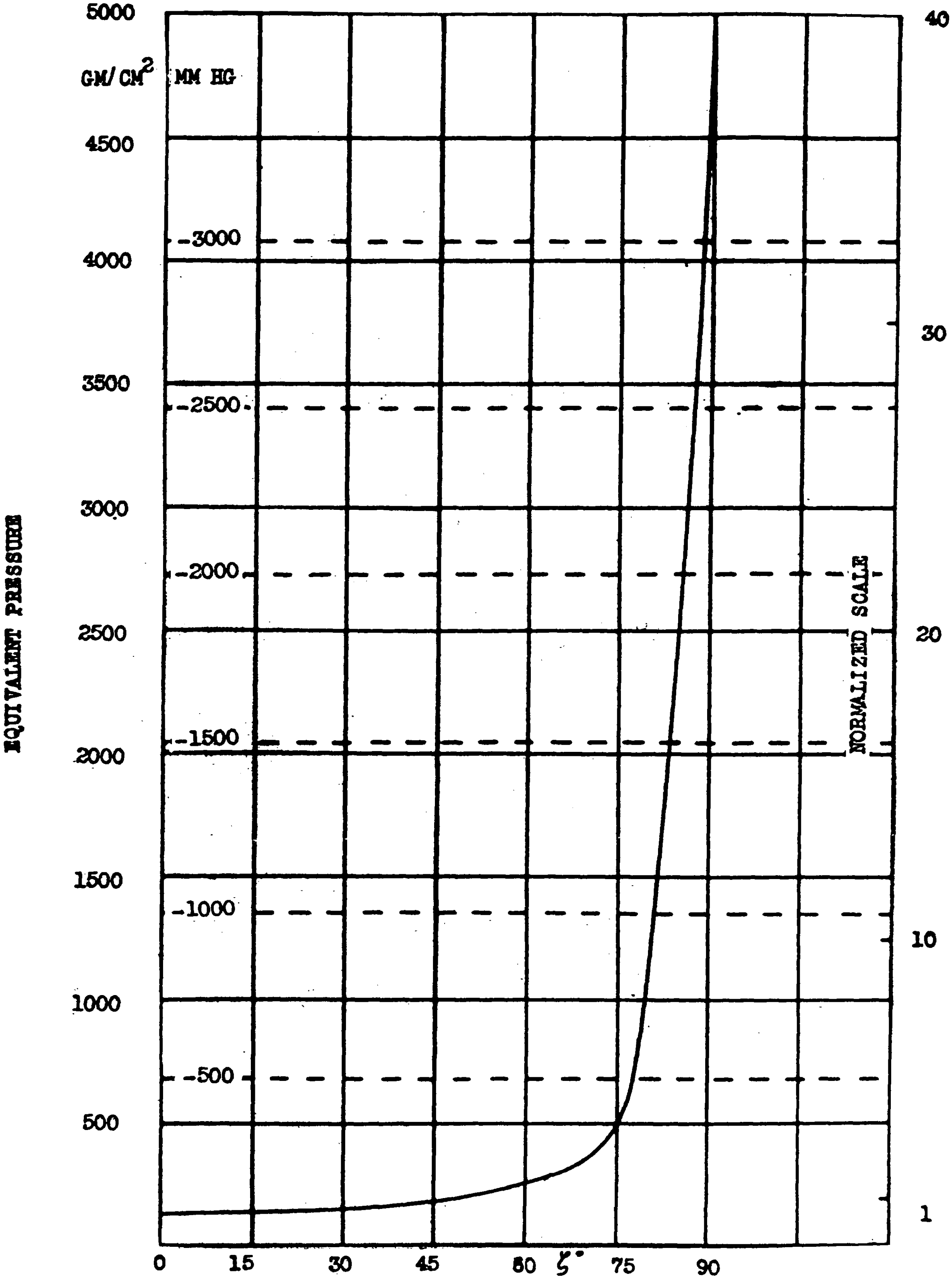


APPENDIX II FIG. 1



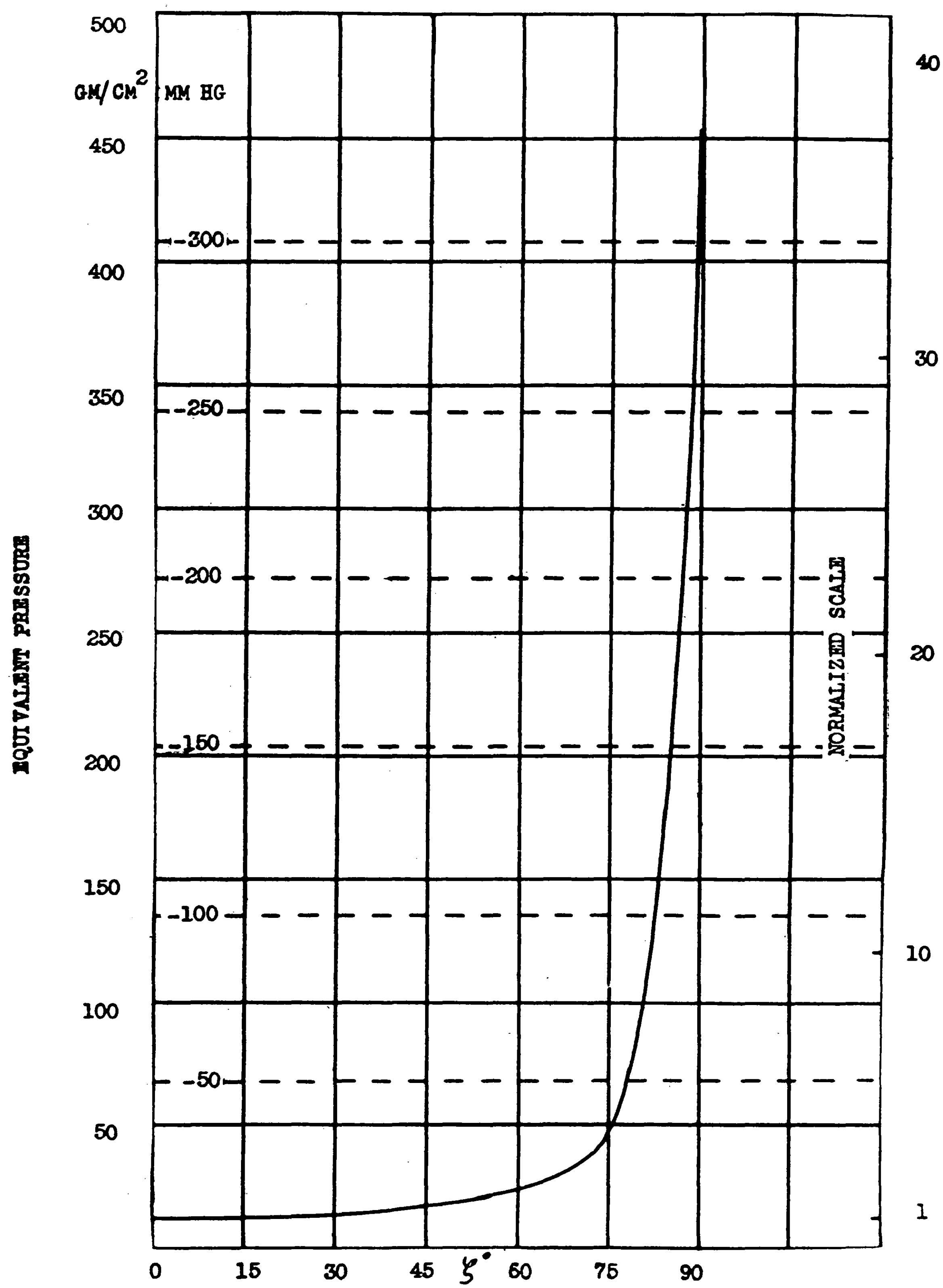
EQUIVALENT PRESSURE FOR VARIOUS ZENITH ANGLES AT SEA LEVEL

R-2955 APPENDIX II, Fig. 2



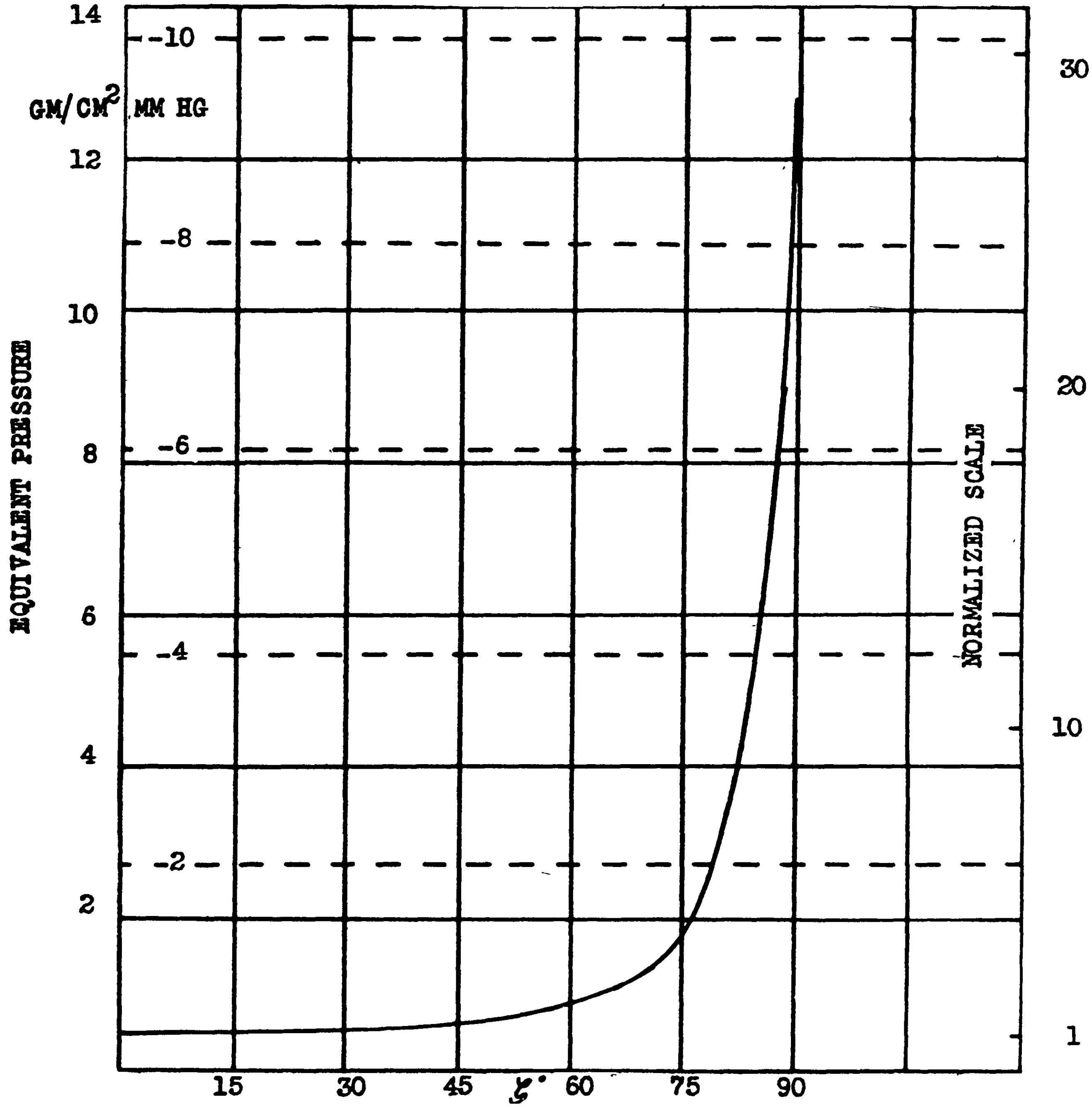
EQUIVALENT PRESSURE FOR ZENITH ANGLES AT AN ALTITUDE OF 15 KM

R-2955 APPENDIX II, Fig. 3



EQUIVALENT PRESSURE FOR VARIOUS ZENITH ANGLES AT AN ALTITUDE OF 30 KM

R-2955 APPENDIX II, Fig. 4



EQUIVALENT PRESSURE FOR VARIOUS ZENITH ANGLES AT AN ALTITUDE OF 60 KM

R-2955 APPENDIX II, Fig. 5

APPENDIX III

Rocket Performance Curves

by

M. W. Rosen and H. Spitz

The accompanying figures are designed to aid in estimating the maximum altitude attained by a rocket in vertical flight when several characteristics of the rocket are varied within practical limits. The curves were computed by numerical integration of the differential equation of motion at five second intervals.

List of Symbols Used in Figures

h_{max} = Maximum altitude attained.

h_o = Launching altitude.

V_o = Initial velocity.

I = Specific impulse.

δ = Ratio of fuel weight to total weight of rocket.

D = Diameter of maximum cross-section of the rocket perpendicular to the major axis.

C_D = Coefficient of drag.

The following series of curves are presented:

Figure 1: Maximum altitude vs specific impulse for several values of fuel to weight ratio.

Figure 2: Maximum altitude vs specific impulse for several values of initial velocity.

Figure 3: Maximum altitude vs specific impulse for several drag coefficient characteristics.

Figure 4: Maximum altitude vs diameter of rocket for a given I and δ.

Figure 5: Maximum altitude vs launching altitude for a given I and δ.

The basic parameters for rocket performance in vacuo are I (specific impulse), δ (fuel-weight ratio), and a_o (initial acceleration). Effective jet velocity, $c = I_g$ may be used in place of I. For flight through a resisting medium A (maximum cross sectional area), C_D (drag coefficient), ρ (density of the medium) and W (total weight of rocket) must be included. The basic equation for vertical, powered flight can be derived from the forces acting on the rocket.

$$\sum \text{Forces} = 0 = F - W - D - \frac{W}{g} a \qquad (1)$$

$$a = -g + \frac{F}{W/g} - \frac{D}{W/g} \qquad (2)$$

Noting that W is a function of t, eq. (2) may be expressed in terms of a_o, t, c, ρ, C_D, V, and constants.

$$a = -g + \frac{(a_o + g)}{1 - \frac{t(a_o + g)}{c}} - \frac{g \rho V^2}{2 \; 1 - \frac{t(a_o + g)}{c}} \cdot \frac{C_D \; A}{W_o}$$

Since direct integration of equation (3) is difficult, V and h were obtained using step by step integration in 5 second intervals with t taken at the center of the interval, ρ and V taken at the start of the interval. The effect of drag was included below 120,000 feet and neglected above that height. At the end of powered flight, the height gained by coasting (h_c) was computed from the free flight equation:

$$h_c = \frac{V_t^2}{2g}, \quad \text{where} \begin{cases} h_c = \text{height due to coasting} \\ V_t = \text{velocity at end of powered flight} \end{cases}$$

The following restrictive assumptions were made:

(a) g was assumed constant at 32 feet/sec^2.

(b) The initial weight of the rocket (W_o) was taken as 5000 pounds. An initial weight must be specified when the effect of drag is included.

(c) A_o was taken equal to g. This has been shown by Malina* to be an optimum value. It fixes F_o (initial thrust) at 10,000 pounds

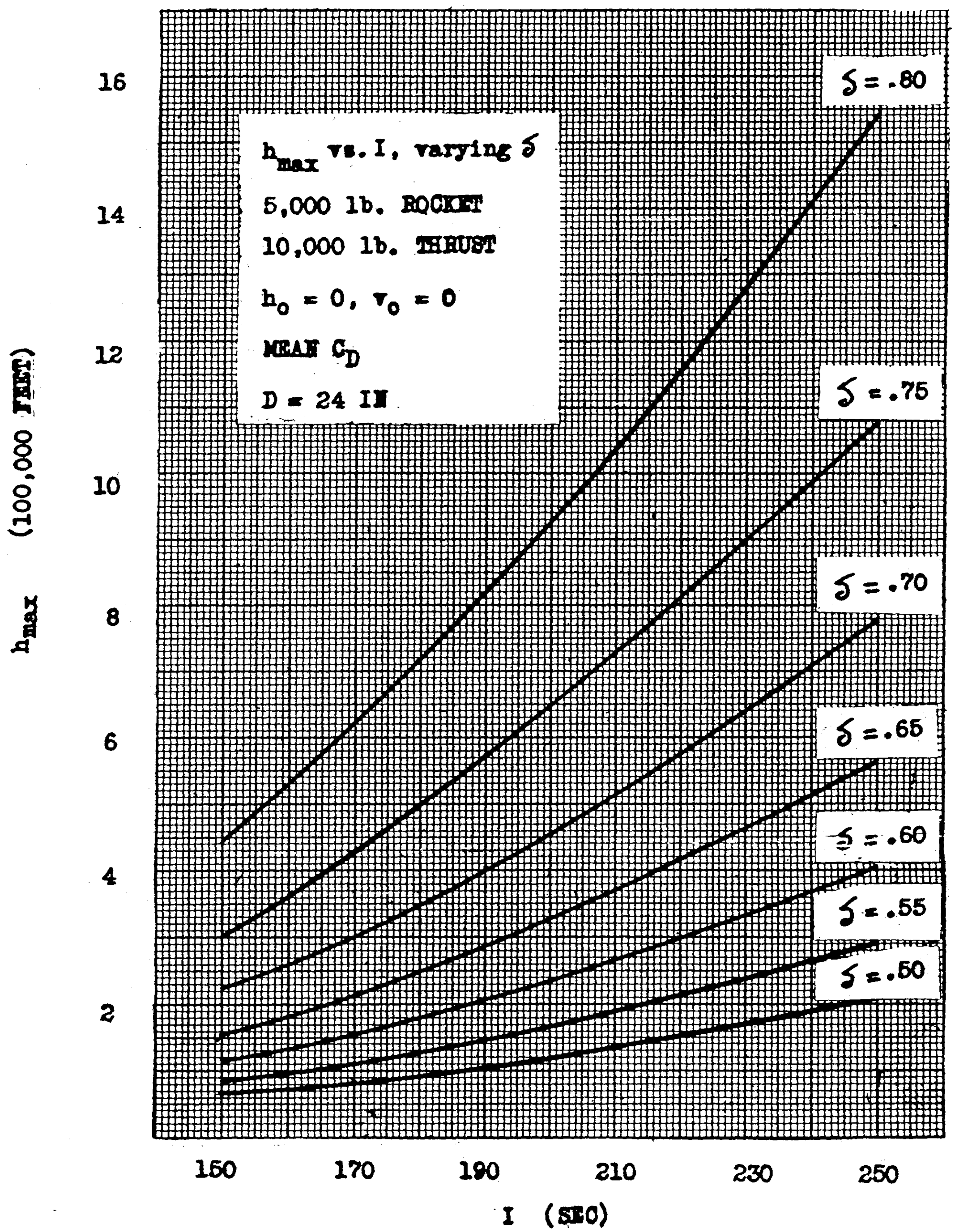
*See Malina, F. J. and Smith, A. M. O.: Flight analysis of the sounding rocket, J. Aer. Sci., vol. 5, pp. 199-202, 1938.

(d) The thrust of the rocket was assumed to be constant. In an actual rocket, thrust changes with increasing altitude because of the decrease in exhaust pressure.

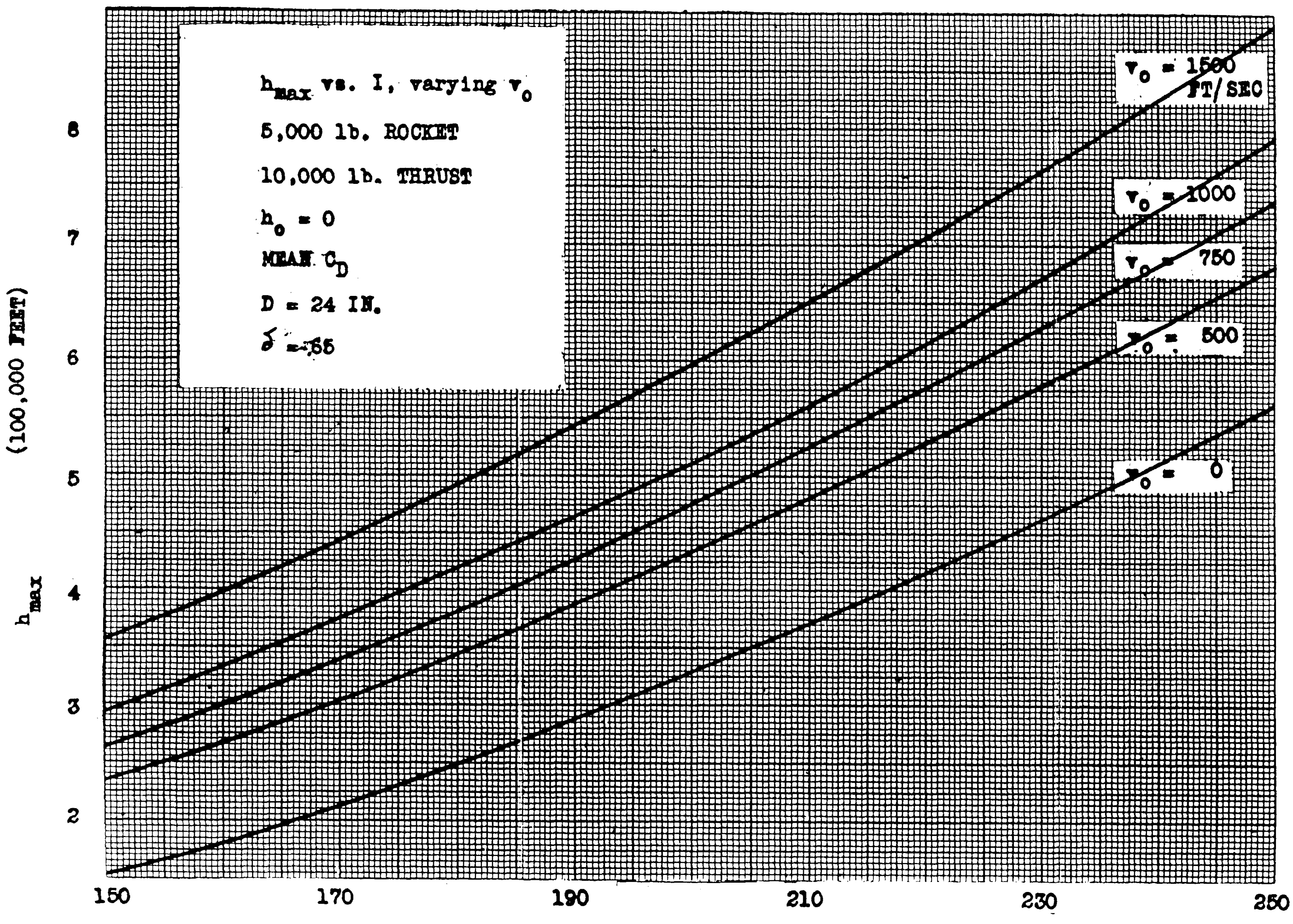
(e) The value of C_D for various Mach numbers was taken as the mean of such values for the Corporal and Wac Corporal except in Fig. 3 where three separate values of C_D (Corporal, Wac Corporal and Mean) were used.

(f) The diameter of maximum cross-section was taken as 24 inches except for Fig. 4 where D was varied.

(g) Launching at sea level ($h_o = o$) was specified except for Fig. 5 where h_o was varied.

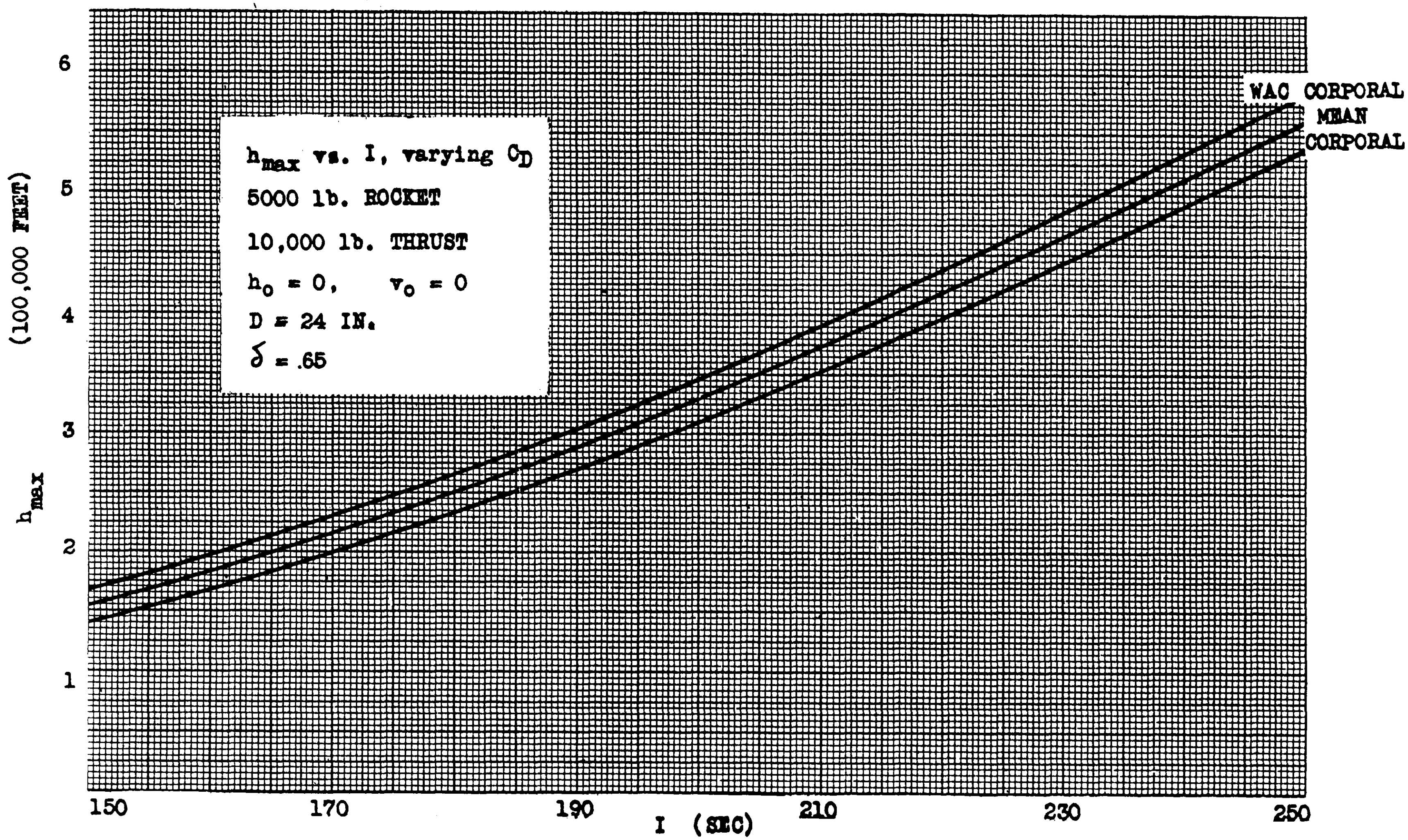


MAXIMUM ALTITUDE VS SPECIFIC IMPULSE FOR SEVERAL VALUES OF FUEL WEIGHT RATIO

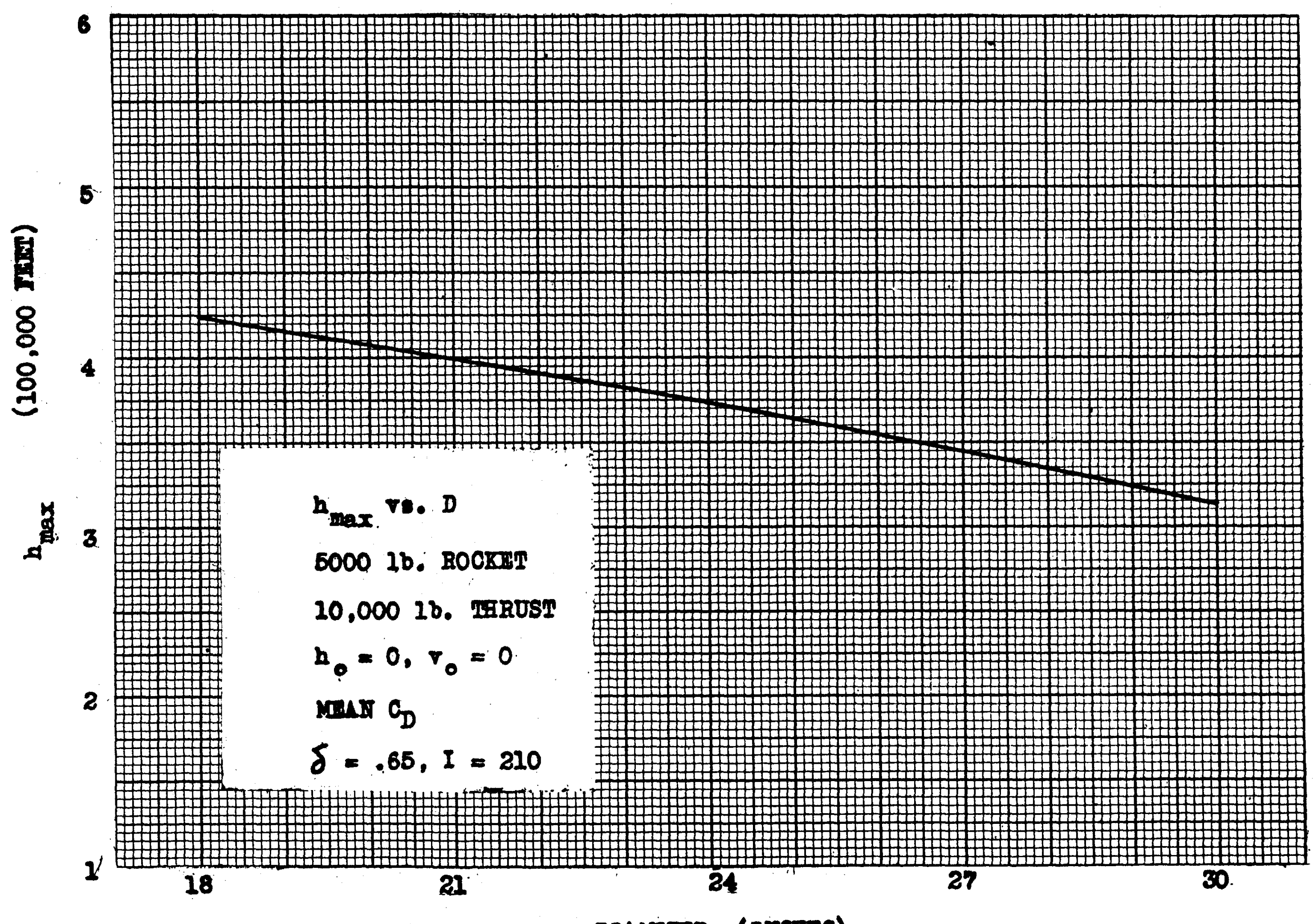


MAXIMUM ALTITUDE VS SPECIFIC IMPULSE FOR SEVERAL VALUES OF FUEL TO WEIGHT RATIO

R-2955 APPENDIX III, Fig. 2

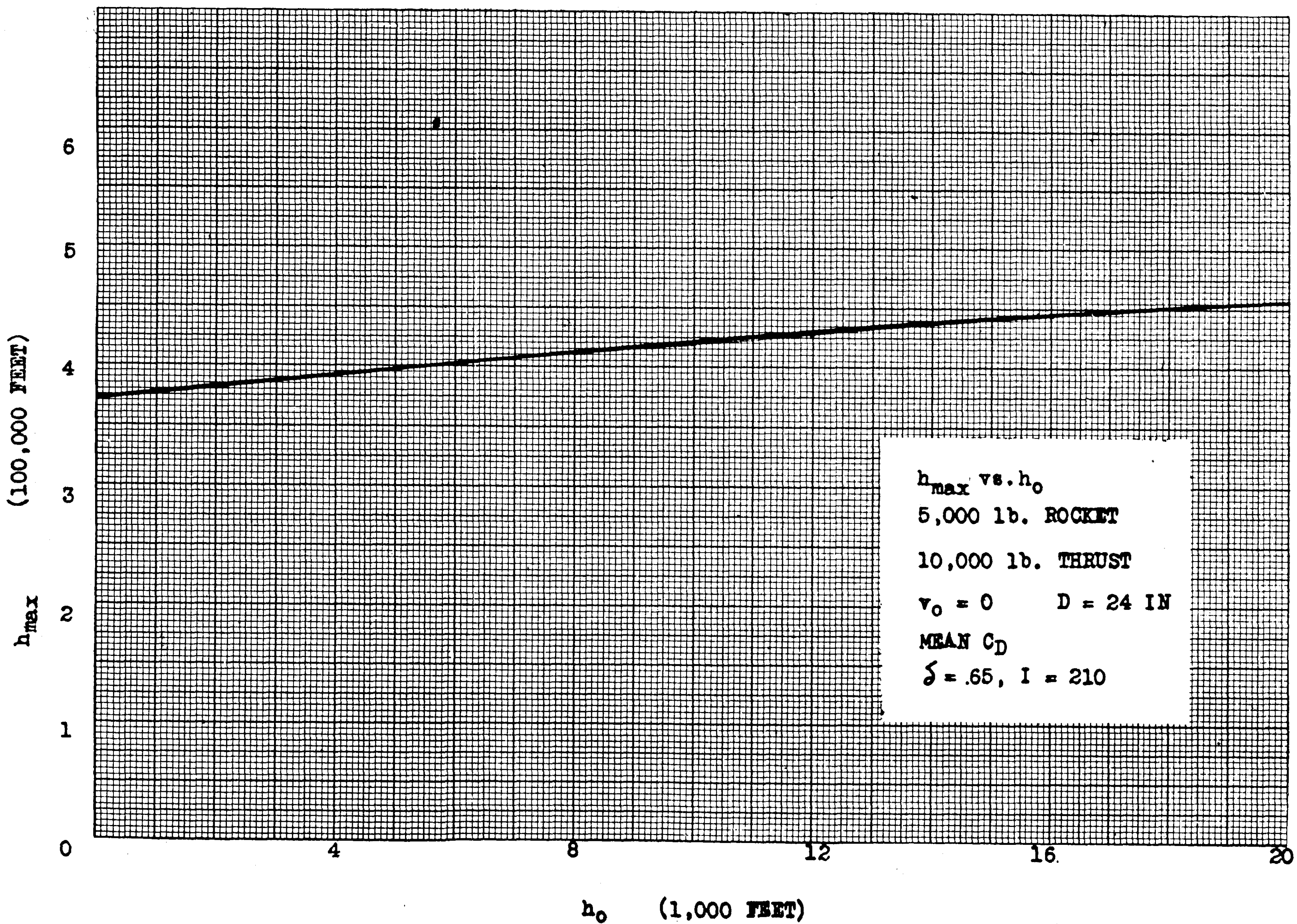


MAXIMUM ALTITUDE VS SPECIFIC IMPULSE FOR SEVERAL DRAG COEFFICIENT CHARACTERISTICS



MAXIMUM ALTITUDE VS DIAMETER OF ROCKET FOR A GIVEN I AND δ

R-2955 APPENDIX III, Fig. 4



MAXIMUM ALTITUDE VS LAUNCHING ALTITUDE FOR A GIVEN I AND δ

R-2955 APPENDIX III, Fig. 5

APPENDIX IV

A Graphical Method for Computing Atmospheric Pressure and Density from the Pressure and Density on the Nose of a Supersonic Missile

by

M. A. Garstens and H. Spitz

The warhead of the V-2 fired at White Sands on June 28 was ogival in shape, surmounted by a true cone. However, the nose of the warhead did not terminate in the usual sharp tip of a cone, since an open hole was present to admit air for pressure measurements.

The familiar Taylor-Maccoll theory* describing airflow about a cone does not apply in discussing the shock wave set up by such a nose tip. Actually, the resultant shock wave at such a nose probably resembles that formed in front of a pitot tube moving at supersonic velocities. It is, within a limited region, a plane wave at right angles to the direction of motion. Rayleigh's theory of planar shock waves** is, therefore, a valid approximation to the flow conditions at the nose. As usually presented, this theory permits the pitot pressure to be calculated from known values of ambient pressure, density, and flow velocity.

In interpreting the pressure data of experiments such as the June 28 V-2 firing, the inverse problem is encountered: the ambient pressure is not known and it is required to calculate it from the measured pressure and density of the air admitted into the nose, together with the known velocity of the missile. Since the Rayleigh method is not directly applicable to this inverse problem, a graphical procedure is developed here for the purpose.

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*See Taylor, G.I. and Maccoll, J.W.: "The Air Pressure on a Cone Moving at High Speeds", Proc. Roy. Soc., Series A, Vol. 139, No. A838, Feb. 1, 1933.

**See Bairstow, Leonard: Aerodynamics, Longmans Green, second edition 1939, p. 587 ff.; also, Taylor, G.I. and Maccoll, J.W.: "The Mechanics of Compressible Fluids", vol. III, division H of Durand, W.F., Aerodynamic Theory, Springer 1935.

The first step in the Rayleigh theory is the development of equations relating the pressure p_2 and density ρ_2 immediately behind the shock wave to the ambient pressure p_1, density ρ_1, and missile velocity u_1. These equations, derived from the laws of conservation of mass and momentum and the equation of Rankine-Hugoniot, are:

$$\frac{p_2}{p_1} = \frac{2\gamma}{\gamma+1}\left(\frac{u_1}{a_1}\right)^2 - \frac{\gamma-1}{\gamma+1}$$

and

$$\frac{\rho_2}{\rho_1} = \frac{(\gamma+1)\left(\frac{u_1}{a_1}\right)^2}{(\gamma-1)\left(\frac{u_1}{a_1}\right)^2 + 2} \quad ,$$

in which the constant γ is the ratio of specific heat at constant pressure to the specific heat at constant volume, and a is the local velocity of sound, defined by:

$$a = \sqrt{\gamma p/\rho} \, .$$

The air immediately behind the shock wave undergoes an adiabatic deceleration and arrives at the nose with zero relative velocity. Bernoulli's equation for compressible flow therefore yields the following equations, relating the pressure ratios p_3/p_1 and density ratios ρ_3/ρ_1 at the nose to $\frac{p_2}{p_1}$ and $\frac{\rho_2}{\rho_1}$:

$$\frac{p_3}{p_1} = \frac{p_2}{p_1}\left[\frac{\gamma+1}{4}\left\{(\gamma+1) - (\gamma-1)\frac{p_1}{p_2}\right\}\right]^{\frac{\gamma}{\gamma-1}}$$

and

$$\frac{\rho_3}{\rho_1} = \left[\frac{(\gamma+1)\;(\rho_2/\rho_1)^{\gamma}}{(\gamma+1)\;(\rho_2/\rho_1) - (\gamma-1)}\right]^{\frac{1}{\gamma-1}}$$

The ratios p_3/p_1 and ρ_3/ρ_1 as given by these equations are plotted against Mach number u_1/a_1 in Fig. 1 using for γ the usual sea level value 1.4. Since the unknown quantities p_1 and ρ_1 are involved both in the ordinates and in the a_1 factor of the absicissa, as indicated earlier, these curves are not sufficient in themselves for the required calculations. However, they do supply sufficient data for plotting a curve of a_3/a_1 versus u_1/a_1 by use of the relation

$$a_3/a_1 = \sqrt{p_3/p_1 \cdot \rho_1/\rho_3} \ .$$

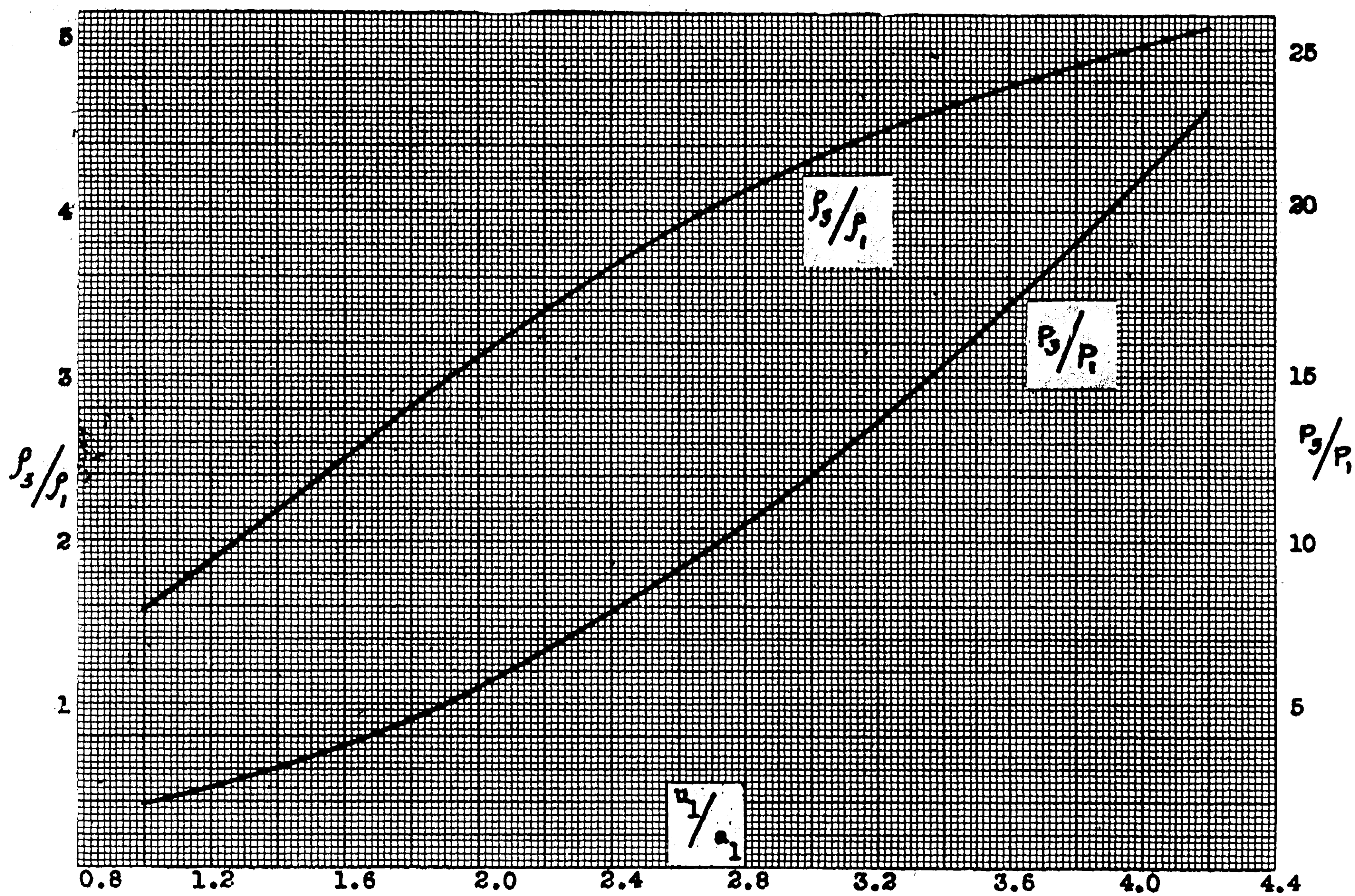
This curve is plotted in Fig. 2.

The method of finding ambient pressure p_1 and density ρ_1 from air pressure p_3 and density ρ_3 measured at the nose at known missile velocity u_1 is as follows: Compute the local velocity of sound a_3 at the nose, using the equation

$$a_3 = \sqrt{\gamma p_3/\rho_3} \ .$$

Draw a line with slope a_3/u_1 through the origin of Fig. 2. This line intersects the a_3/a_1 versus u_1/a_1 curve at a point whose abscissa is the Mach number u_1/a_1 corresponding to the given data. Fig. 1 now, yields the values of p_3/p_1 and ρ_3/ρ_1 for this Mach number. The ambient pressure p_1 is then obtained by dividing the measured value of p_3 by p_3/p_1. Ambient density ρ_1 is found in a similar way.

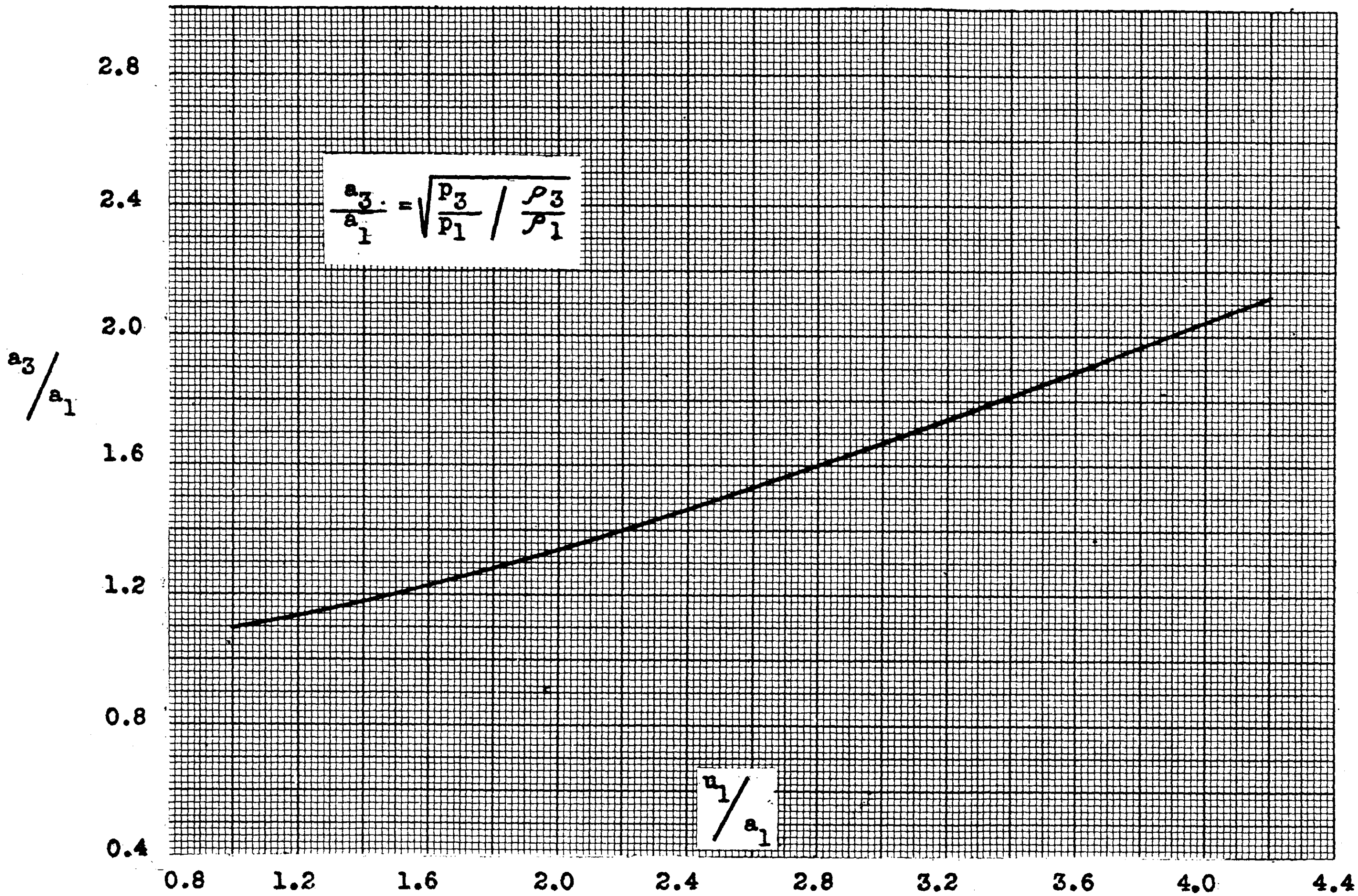
It is to be noted that the method outline depends on the knowledge of the value of γ for the region in question.



RATIOS OF PRESSURE AND DENSITY AT NOSE TO PRESSURE AND DENSITY AHEAD OF SHOCK WAVE VS MACH NUMBER AHEAD OF SHOCK WAVE

R-2955

APPENDIX IV, Fig. 1



RATIO OF VELOCITY OF SOUND AT NOSE TO VELOCITY OF SOUND AHEAD OF SHOCK WAVE VS MACH NUMBER AHEAD OF SHOCK WAVE

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