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ROCKETSONDE TECHNIQUES FOR THE MEASUREMENT

OF TEMPERATURE AND WIND IN THE STRATOSPHERE

BY

HAROLD N. BALLARD

FEBRUARY 1965

US ARMY
ELECTRONICS
RESEARCH & DEVELOPMENT
ACTIVITY
WHITE SANDS MISSILE RANGE
NEW MEXICO

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ROCKETSONDE TECHNIQUES FOR THE MEASUREMENT OF TEMPERATURE AND WIND IN THE STRATOSPHERE

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ENVIRONMENTAL SCIENCES DIRECTORATE
U. S. ARMY ELECTRONICS RESEARCH AND DEVELOPMENT ACTIVITY
WHITE SANDS MISSILE RANGE
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ABSTRACT

The upper-atmosphere rocket sounding system described in this report is in operation at White Sands Missile Range, New Mexico, and is representative of the systems in operation at 22 other locations which serve as Meteorological Rocket Network stations. Basic system components and the theory of operation are discussed. The various facilities and operational procedures described may serve as a guide to any group which plans to use such a system for obtaining measurements of stratospheric temperature and wind.

FOREWORD

I wish to thank the following people of the U.S. Army Electronics Research and Development Activity at White Sands Missile Range who have developed the rocketsonde techniques described in this publication:

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Mr. O. Thiele, Research Leader, Upper Atmosphere Analysis Branch
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Mr. J. Quast, Chief, Rocket Section
Mr. R. Getz, Rocket Section
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C O N T E N T S

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TABLES

I. INTRODUCTION

The upper-atmosphere rocket sounding system herein described is that which is presently in operation at White Sands Missile Range (WSMR), New Mexico and is representative of the systems that are in operation at many other locations.* It is hoped that the various system facilities and operational procedures which have been developed over a period of several years and which are described herein will serve as a useful guide to any group which plans to make use of such a system for obtaining temperature and wind measurements in the stratosphere.

The basic system components are listed and the theory of operation of the system is outlined in Section II. The succeeding sections describe in considerable detail each of these items and are a compilation of information related to the Arcas rocket temperature and wind sensing system that was obtained from the personnel at WSMR who perform the various operations and from the several publications pertaining to the various aspects of the overall system.

II. A SUMMARY OF THE BASIC SYSTEM COMPONENTS AND THE THEORY OF OPERATION

The basic components and facilities necessary for the effective operation of the Arcas stratospheric rocket sounding system are:

1. a proper launching range,
2. a rocket launching facility to include rocket storage building, launching pad, and launching control center,
3. the rocket system to include the rocket motor assembly, the parachute assembly and the nose-cone assembly (nose-cone, temperature sensing device and transmitter),

*There are presently in operation 23 stations which serve as Meteorological Rocket Network Stations. These stations are listed in Section XII of The Meteorological Rocket Network System.

4. a rocket impact prediction system,
5. an instrument calibration and preparation facility,
6. a ground-based receiver station for the reception of transmitted temperature data as a function of time,
7. a ground-based radar system for obtaining instrument position as a function of time,
8. a system for the generation of a time base,
9. an effective communication system between the various installations, and
10. a data reduction facility to obtain temperatures and wind velocities as functions of altitude.

Making use of these basic facilities, the Arcas temperature and wind sensing system is designed to carry the temperature sensing device, parachute and small transmitter, to an altitude of approximately 240,000 ft (73 km) where the instrument package is separated from the burned-out rocket and then descends on a 15-foot diameter radar-reflective parachute. The transmitted signal is modulated in accordance with the sensor resistance values (corresponding to sensor temperature values) and redeived by a ground-based receiver. The received signal is demodulated to obtain resistance values as a function of time. From a calibration curve which relates sensor resistance to sensor temperature, the resistance values are converted to temperature values corresponding to thermistor temperatures at the position of the sensor at time t. The tracking of the radar-reflective parachute by the ground-based radar system determines the position of the instrument in terms of slant range, azimuth and elevation angles as functions of time, (r,ϕ,θ,t). The combining of the sensor and radar data serves to determine the temperature and wind velocities as functions of altitude. Figure 1 is a pictorial representation of the Arcas rocket temperature and wind sensing system.

III. THE ROCKET RANGE

The following recommendations concerning the selection of a range and site for the launching of the Arcas rocket system are based upon information gained from the firing of many Arcas rockets at WSMR and upon a study made by the Atlantic Research Corporation (ARC), Alexandria, Virginia.[1]

The range should be relatively free of natural obstructions and within the effective range of the radar and telemetry systems. Range-safety requirements dictate that a minimum number of people be exposed to a minimum hazard for a minimum period of time. The

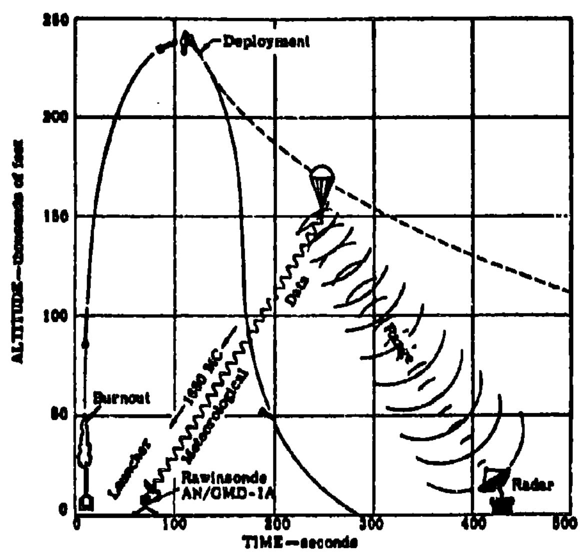


FIGURE 1

ARCAS TEMPERATURE AND WIND SENSING SYSTEM trajectory of the Arcas rocket system is such that the launching range should include a region which is unpopulated for a radial distance of at least 55 miles from the launch site in the direction of the rocket trajectory when the rocket is fired at elevation angles which are within 10 degrees of vertical. The corresponding range area will then be determined primarily by the variability of the prevailing surface winds (0 - 10,000 ft, 0 - 3 km) at the launch site. This is due to the flight characteristics of the Arcas rocket, the trajectory of which is very much influenced by the surface winds. Seventy-six per cent of the ballistic wind effect on the Arcas rocket trajectory is caused by the winds between the surface and an altitude of 2,000 ft (.6 km) with ninety per cent of the ballistic wind effect being caused by the winds to an altitude of 10,000 ft (3 km). These values are valid at a launch speed of 175 ft/sec.

The width of WSMR is approximately 50 miles throughout its length which is oriented in a north-south direction. The Arcas rocket launcher is located at approximately the middle of the southern end of the range with most of the rockets being launched (in a general northerly direction) at elevation angles which are between 80 and 87 degrees.

Arcas rockets have been launched at wind speeds up to 30 miles/hr. Data concerning the Arcas launchings during the years 1961, 1962, and 1963,

1961 - 89 launchings
1962 - 108 launchings
1963 - 116 launchings

indicate that it was necessary to cancel a scheduled launching approximately six times per year due to adverse wind conditions. These cancellations were based upon the empirical rule that a given rocket launching would be cancelled if the computed ballistic wind effect was such that the predicted point of impact was more than thirty miles from the predicted no-wind impact point. Under this restriction, and with the quadrant-elevation and azimuth angles determined by the Automatic Rocket Impact Prediction System, all of the rocket motors impacted within the confines of the range at various distances, none of which exceeded a value of 40 miles relative to the rocket launcher.

These data are perhaps indicative of an adequate range area for the launching of the rocket system. The Automatic Rocket Impact Prediction System is discussed in more detail in a following section of this report.

IV. THE ROCKET LAUNCHING FACILITY

The launching facility consists essentially of the rocket pad and launcher, the launch control and rocket storage buildings, the communication and warning systems, and the firing line.

A. THE ROCKET PAD AND LAUNCHER

A concrete pad at least 12 ft square and 8 in thick is required for mounting the launcher. Specific information with regard to securing the launcher to the pad may be found in the ARC Manual concerning the Arcas Rocket System.[1] The major component assemblies of the launcher are the launching tube assembly, the free-volume-cylinder assembly and the azimuth-table assembly. These are shown in Figures 2 and 3. The launching tube assembly consists of three flanged sections which are bolted together. Gaskets are used between sections to prevent gas leakage. The launching tube assembly is connected to the free-volume cylinder by bolting through the flange on the lower tube section. A gasket is also used at this junction. The two bosses on the lower tube section, just above the flange, are for connecting the gas generator pressure hose. The two stop pins which fit holes at the base of the tube are used to hold the rocket in position when the launcher is elevated. The free-volume cylinder is a pressure vessel for the purpose of retaining entrapped rocket exhaust gases. The cylinder assembly is mounted on the launcher azimuth table assembly through pillow blocks that permit rotation of the cylinder through 180° in a vertical plane. The graduated elevation scale mounted on the quadrants permits direct reading of the elevation angle. A stop nut assembly can be installed on the quadrant to limit the elevation angle to the desired maximum value. Access to the free-volume cylinder is provided through an opening in the base of the cylinder which is equipped with a hinged breech plate secured by six clamps. A gasket is installed between the breech plate and the bottom of the cylinder assembly. The breech plate also contains a bulkhead connector to receive the firing line and the ignitor leads from the rocket motor. A threaded opening for the installation of the auxillary gas generator is provided in the side of the free-volume cylinder.

The azimuth-table assembly supports the free-volume cylinder and launching tube and provides a mechanism for rotation of the launcher assembly through 360° in a horizontal plane. The base of this assembly must be mounted on a concrete base by using anchoring bolts in the pad which are inserted through three of the six mounting lugs on the base. The remaining three lugs contain screws for leveling the table assembly. The azimuth table rests on the base and is supported by four bearings that ride on a bearing track in the base, thus allowing the table to rotate

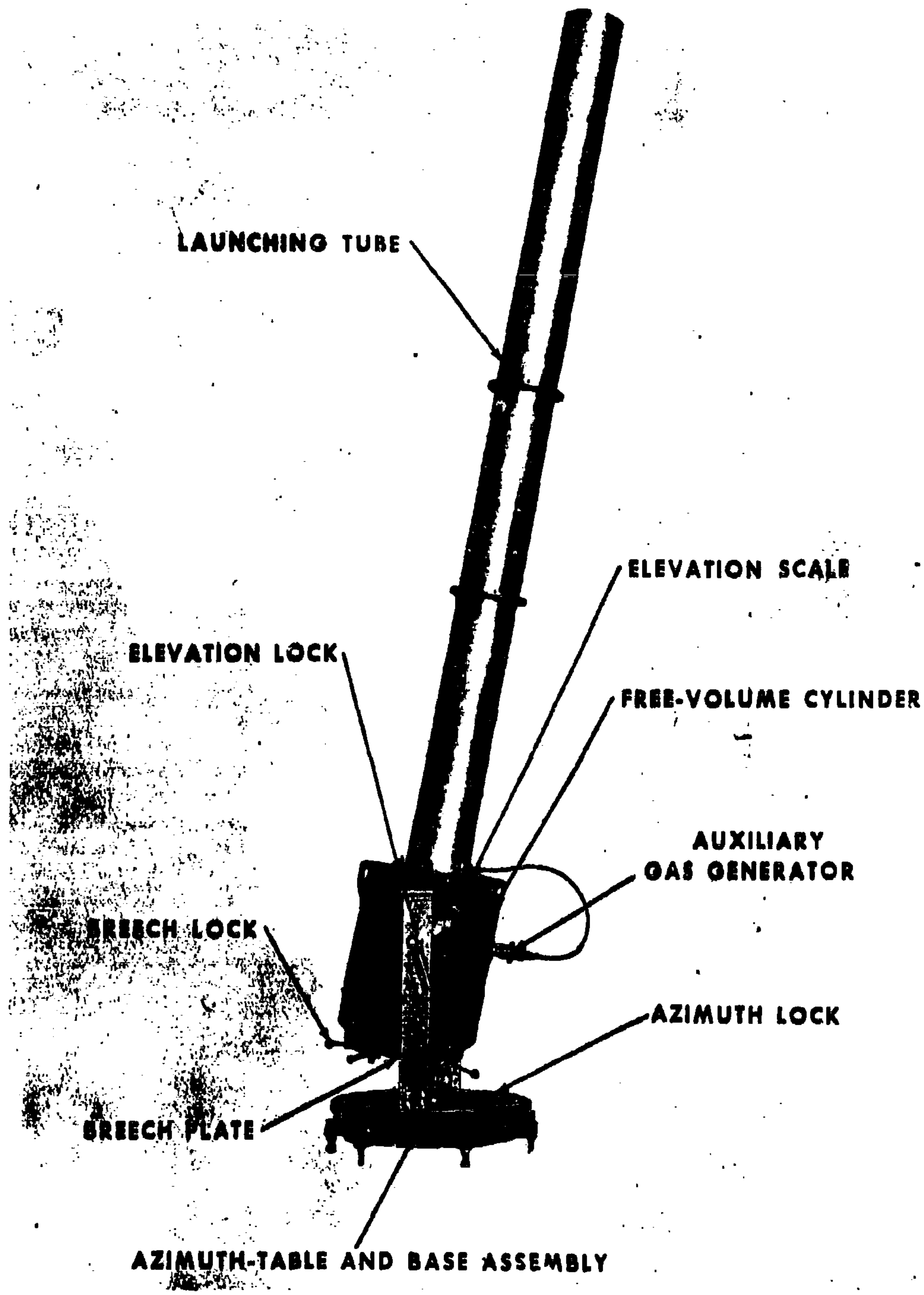


FIGURE 2

MAJOR COMPONENTS OF CLOSED-BREECH ARCAS LAUNCHER

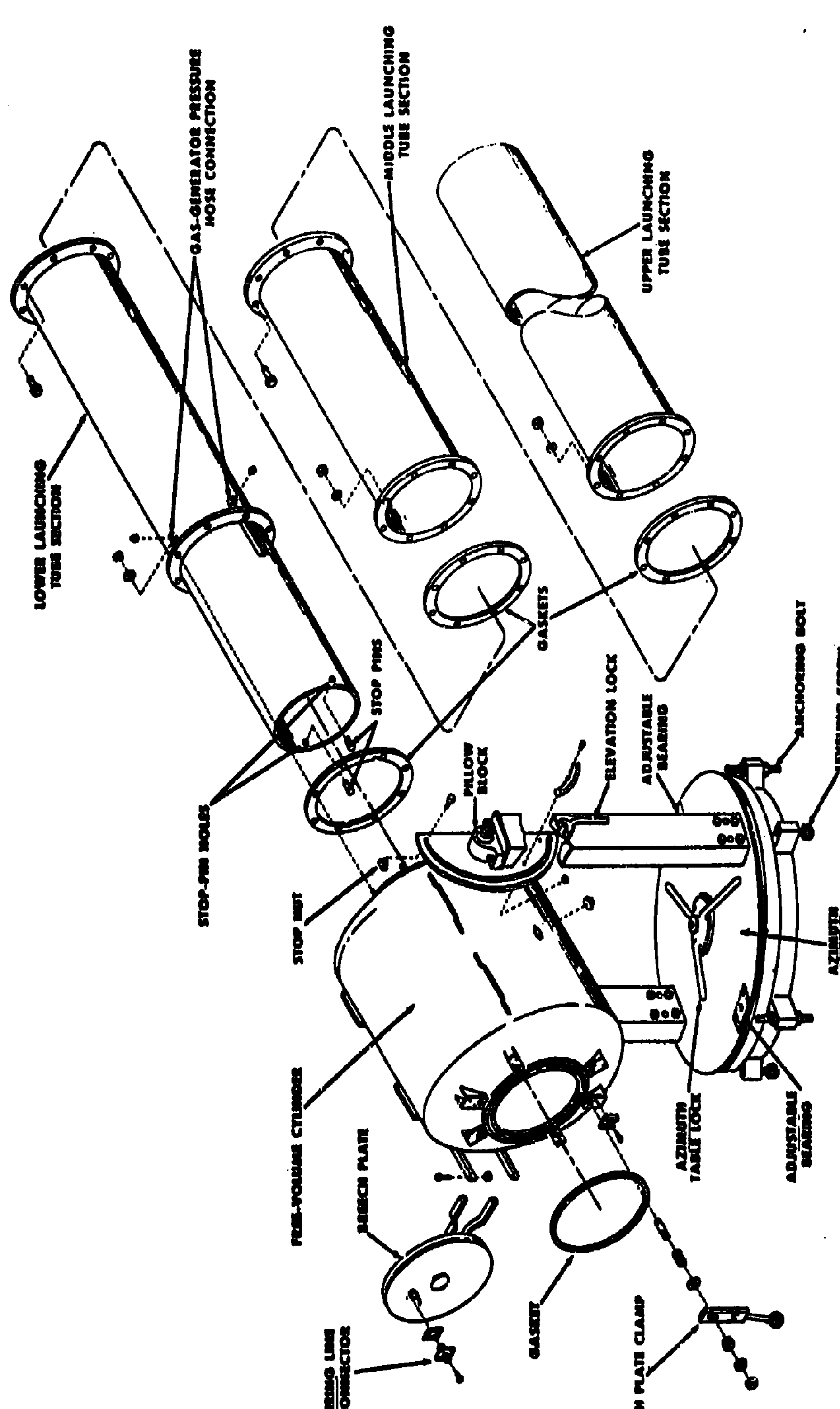


FIGURE 3

MAJOR SUBASSEMBLIES OF THE ARCAS ROCKET LAUNCHER on the base. The azimuth table is attached to the base and locked into position through the azimuth table lock. A rubber seal is installed in the bottom of the azimuth tube to keep dust out of the bearing track. Two stanchions are an integral part of the azimuth table. Pillow blocks which support the free-volume cylinder are attached to the top of the stanchions. Two elevation locks and the elevation index are also mounted on the stanchions. The azimuth index is mounted on the base after assembly.

The principle of operation of the Arcas launcher is illustrated in Figure 4. The free-volume cylinder entraps the exhaust gases of the ignited rocket motor. Pressure which is developed in the cylinder by these entrapped gases exerts a force on a piston attached to the nozzle end of the rocket thus accelerating the rocket along the tube of the launcher. The rocket is centered and supported in the tube during launching by four plastic spacers which fall away from the rocket along with the piston as the rocket leaves the launcher.

The auxiliary gas generator, supplied as a separate kit with the launcher, is a mechanical pressure-activated device that fires a small propellant charge to generate additional gas pressure in the free-volume cylinder of the launcher. The charge is fired by the action of the gas pressure from the launching tube which is transmitted through the connecting hose. The gas-generator charge is fired when the piston is forced inward and the firing pin on the piston strikes the percussion cap of the charge.

The gas generator piston is retained in the armed position by spring loaded detents until the pressure on the piston is sufficient to overcome the restraining force of the detents. The piston is then forced past the detents, firing the charge. Increased pressure is thus generated in the launcher as the rocket travels along the last three-fourths of the launching tube.

The velocities and accelerations realized with the auxiliary gas generator are dependent upon which of the two pressure outlets in the launcher tube is used for attaching the gas generator pressure hose. One outlet leads directly into the tube and the use of this outlet develops a launching velocity of 230 ft/sec with a peak launching acceleration of 70 g. This velocity is adequate for launching the rocket in surface winds up to 25 miles/hr. The second outlet on the launching tube leads into a duct that enters the launching tube at a lower point. Use of this outlet causes the gas generator to fire earlier in the sequence thus providing a launching velocity of 260 ft/sec with a peak acceleration of 100 g. This velocity is adequate for launching the rocket in surface winds up to 30 miles/hr. The rockets which are fired without using the auxiliary gas generator attain a launching velocity of 150 ft/sec with a corresponding acceleration of 40 g. This velocity is adequate for rocket launchings in surface

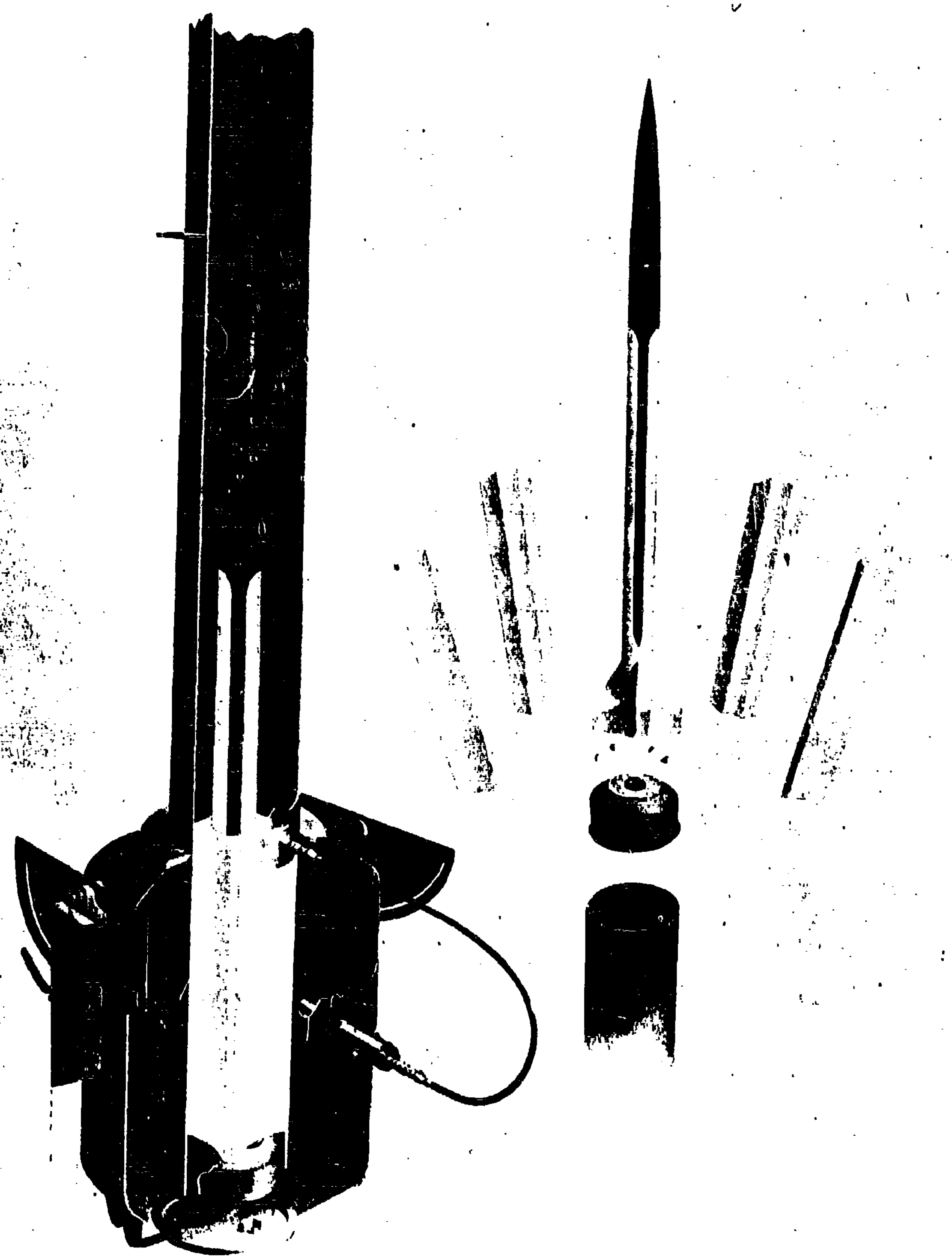


FIGURE 4

PRINCIPLE OF OPERATION OF THE ARCAS CLOSED-BREECH LAUNCHER winds up to 20 miles/hr. The 230 and 260 ft/sec launching velocities increase the peak altitude reached by the rocket vehicle by approximately 4 and 7 per cent respectively over that achieved with a launching velocity of 150 ft/sec. More detailed information concerning launcher operation and installation procedures can be found in the ARC Manual.[1] The effect of the surface winds upon the rocket trajectory is discussed more fully in connection with the Automatic Rocket Impact Prediction System. Figure 5 is a photograph which shows the launching pad configuration at WSMR.

B. THE LAUNCH CONTROL AND ROCKET STORAGE BUILDINGS

Figure 6 is a diagram of a typical launching site layout, one of many possible designs that might be devised. The distances indicated in Figure 6 have been established from actual experience and are conservative estimates for relative safety from a runaway rocket and fire hazards incurred in dealing with a Class 2 explosive which is the classification of the Arcas rocket propellant. Usually distances will be dictated by local safety regulations and ordnance safety requirements at the given site. Since Class 2 explosives exhibit a low order of detonation, the greatest hazard is from fire and the quantity-distance relationships indicated are established upon this basis. In instances where space is not a problem, the distances may be increased since those given here are minimum requirements. Increased spacing between the launching pad and the launch-control building permits the use of a lower cost construction. The launching-site at WSMR makes use of an increased spacing between the various elements of the launching facility. Figure 7 is a diagram giving the relative location of the various buildings which are all of cement block construction.

C. COMMUNICATION AND WARNING SYSTEMS

All elements of the launching and data acquisition facilities have direct communication with each other in the form of voice-radio and telephone. Fifteen minutes before the time of firing, a warning is given in the form of a siren blast and a flashing red light is turned on at the location indicated in Figure 7. The launching pad area and range is then cleared of all personnel.

D. THE FIRING LINE

A low-resistance, shielded, two-conductor line capable of carrying a direct current of 2.0 amps at 110 volts is suitable for serving as the firing line. It must include provisions for disconnecting and shunting. The end of the firing line must be fitted with an MS3106B-145-9P male connector to mate the corresponding female connector provided in the launcher. The firing

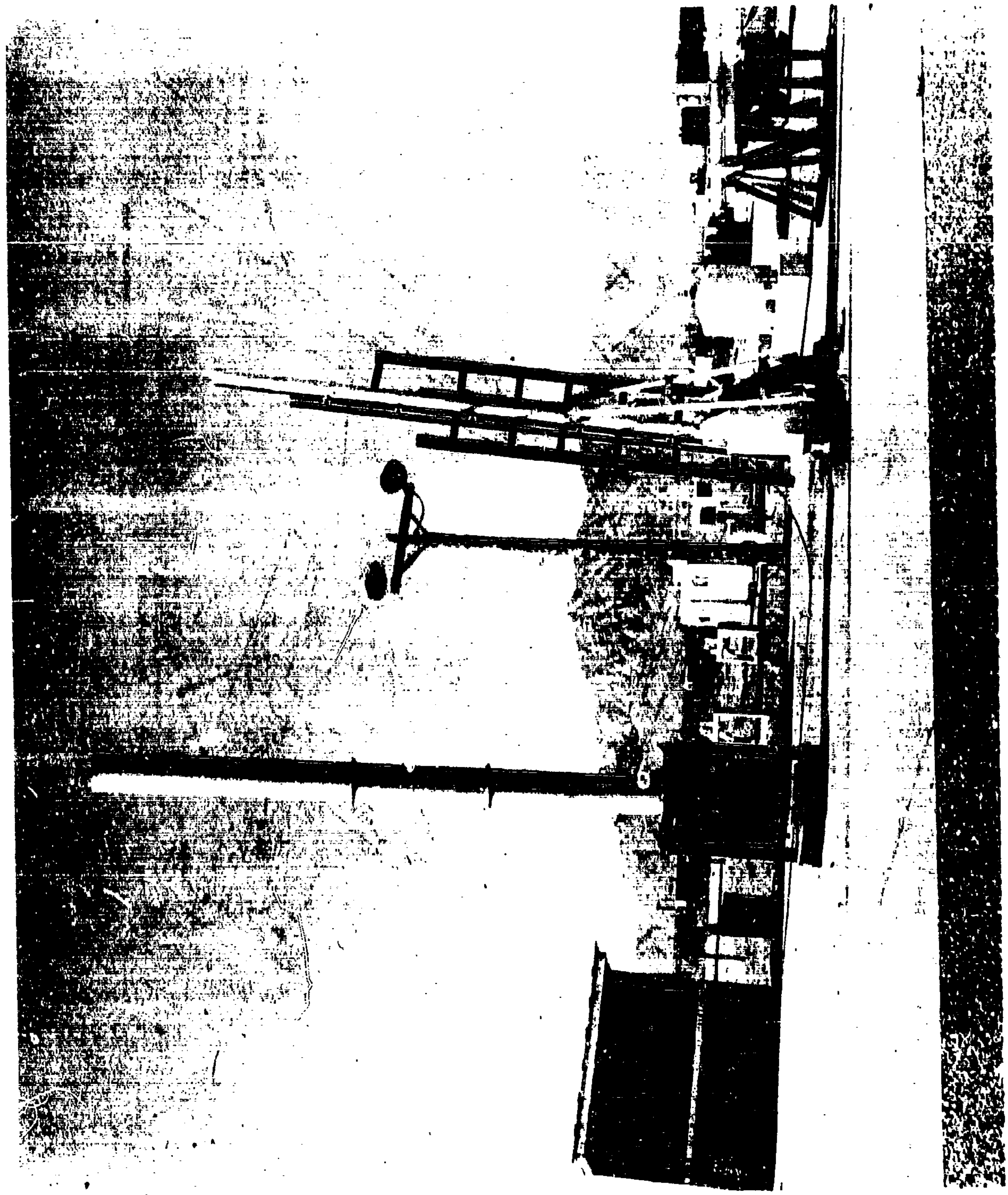


FIGURE 5

LAUNCHING PAD AT THE SMALL MISSILE RANGE
AT WHITE SANDS MISSILE RANGE, N.M.

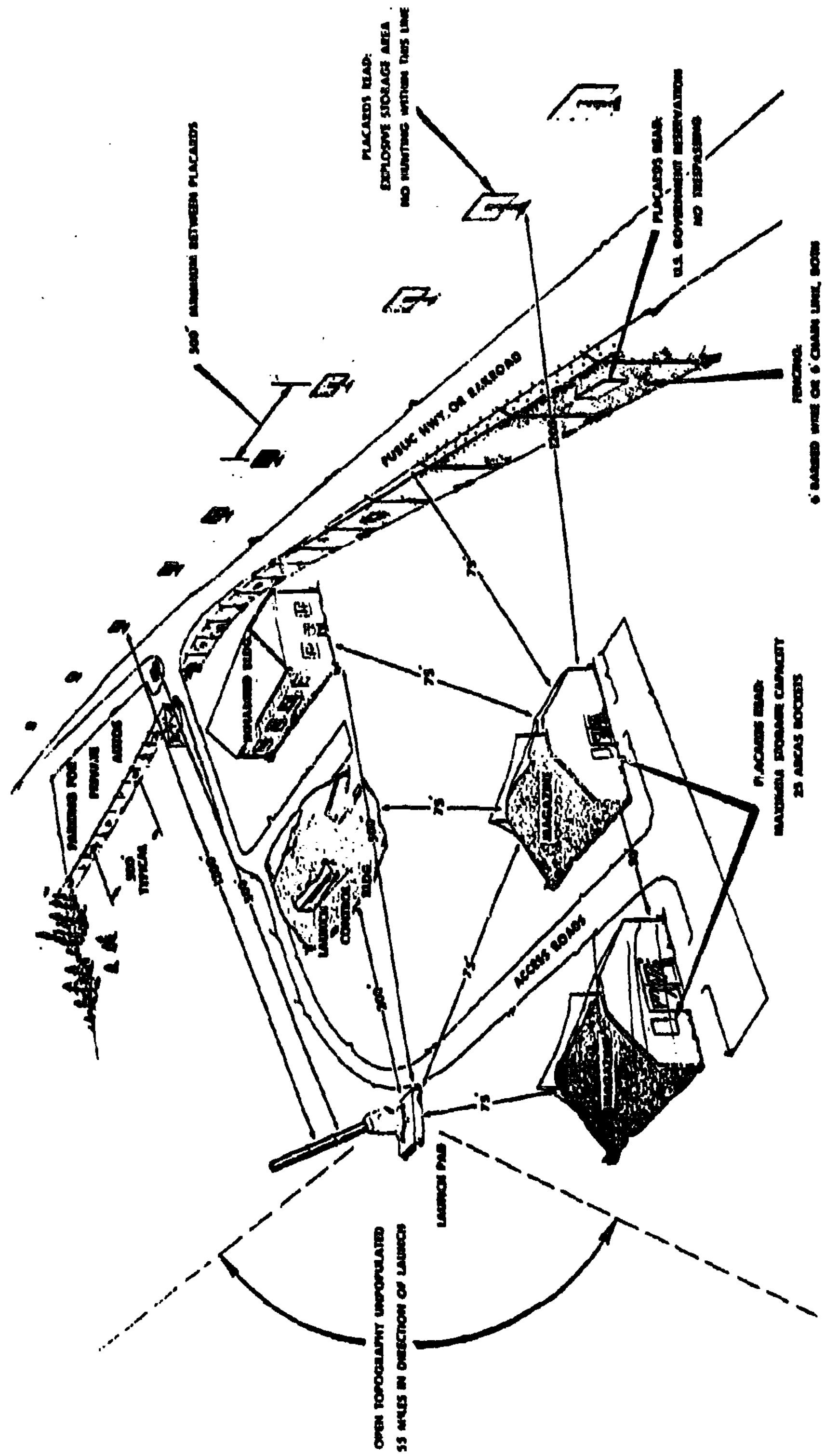
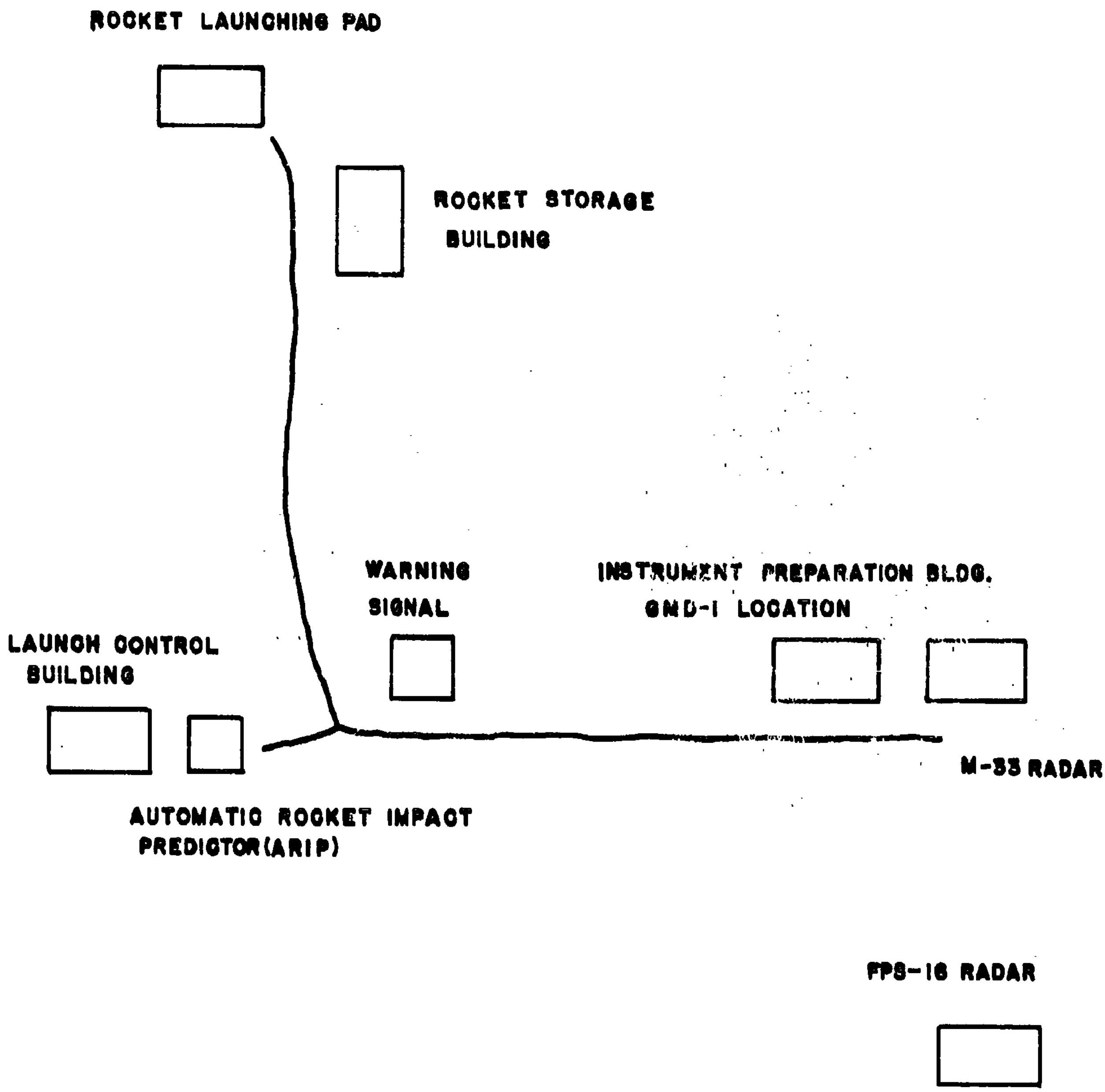


FIGURE 6

LAYOUT OF A TYPICAL ARCAS LAUNCHING SITE



THE ROCKET LAUNCHING AND DATA ACQUISITION FACILITIES AT THE SMALL MISSILE RANGE, WSMR

FIGURE 7

cable may be buried, strung on poles, or laid on the ground consistent with the specific launch-site requirements for safety and permanence. Various types of sequences and lock devices may be used to insure that the rocket cannot be fired accidentally. A 24 volt battery is suitable for supplying the firing voltage. For convenience, a rectified 110 volt regulated current source may be used if it is properly designed and shielded. At WSMR a standard 60 cycle, 110 volt line source is utilized.

V. THE ARCAS ROCKET SOUNDING SYSTEM

The Arcas rocket vehicle is fundamentally an end-burning rocket motor that can accommodate a variety of payloads. The altitude performance of the Arcas vehicle with various payload elements is shown in Figure 8, for a quadrant elevation angle of 85 degrees. The principal dimensions of the Arcas system designated as Arcas Ex 6-Mod 0 are shown in Table 1, while a photograph of the Arcas rocket system is shown in Figure 9. The Judi Rocket System is also shown in this figure with reference to the Judi Rocket System which is described in the Appendix. The presently used nose-cone, temperature sensor package (designated as Delta I) and parachute assembly weigh 3.0, 3.5 and 5.0 lbs respectively, thus giving a total payload weight of 11.5 lbs for the Arcas temperature and wind sensing system.

A. THE ROCKET MOTOR ASSEMBLY

The major components of the Arcas vehicle, including the launching piston, plastic spacers and ignitor are shown in Figure 10. The vehicle is powered by a high-performance rocket motor using an end-burning charge of plastisol-type solid propellant. The rocket motor case consists of a one-piece steel outer casing with an insulating liner. Four hollow aluminum fins are bonded to the case. The nozzle structure is a tapered graphite insert supported by the tapered after-end of the motor case. The steel retaining ring, welded to the head end of the case, secures the motor head closure and also provides a joint for the attachment for the vehicle payload section. The flange at the nozzle end of the motor case is provided for the attachment of the launching piston. A pyrotechnic device for payload separation is an integral part of the motor head closure. This device contains a delay column of pyrotechnic material that is ignited as the combustion of the rocket propellant nears

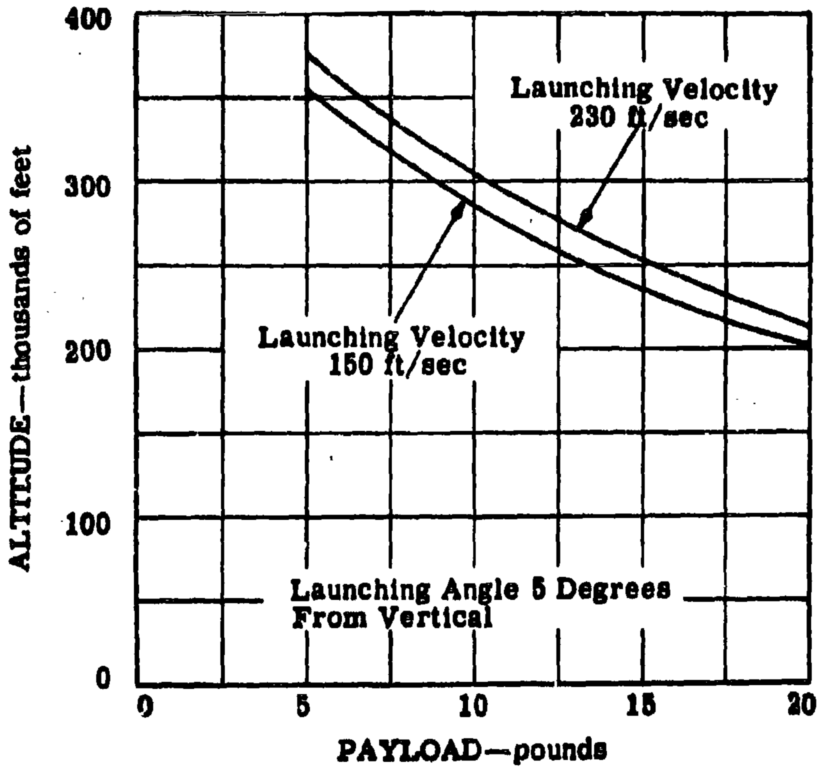


FIGURE 8

ALTITUDE PERFORMANCE OF THE ARCAS VEHICLE
WITH VARIOUS PAYLOAD WEIGHTS

TABLE 1

PRINCIPAL DIMENSIONS OF THE ARCAS SOUNDING ROCKET

PARAMETER	DIMENSIONS - MOD O ARCAS
Length, inches	
Over-all	90.9
Rocket-motor assembly	60.8
Parachute container	12.0
Nose-cone assembly	18.1
Diameter, inches	04.5
Fin span, inches	13.0
Fin area (4 fins), in^2	94.0
Internal volume, in^3	
Parachute container	140.0
Nose-cone	170.0

FIGURE 9

CONFIGURATION OF THE ARCAS AND JUDI ROCKET SYSTEMS

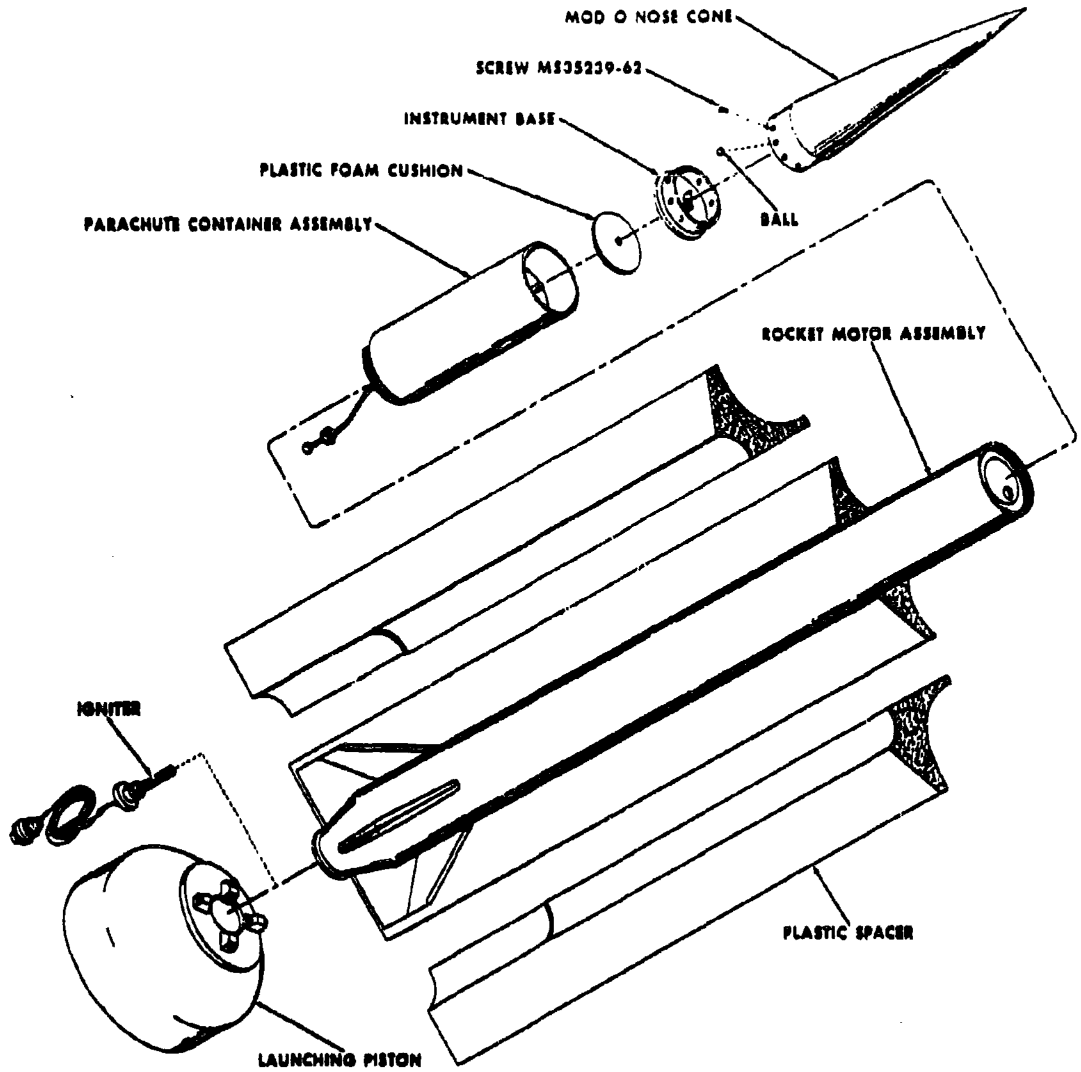


FIGURE 10

THE MAJOR COMPONENTS OF THE ARCAS VEHICLE completion. After burning for a predetermined length of time (130 sec), the delay column ignites a gas generating charge that separates the payload from the expended rocket motor at peak altitude. Figure 11 is a cutaway diagram of the motor case. The thrust and burning time of the rocket propellant are such that an average thrust of approximately 300 lbs for a period of approximately 30 sec gives a total impulse of approximately 9000 lb-sec to the system.

The temperature range for satisfactory burning of the rocket is from 0 to 100°F. Temperature limits for storage of the rocket motor are from 10 to 100°F. The service life of the rocket motor and igniter is one year from the date of loading. The expiration date is marked on each rocket motor.

The igniter of the rocket motor is installed through the nozzle just before firing. The igniter employs an electrically activated squib and 5 grams of pyrotechnic booster compound. The electrical circuit characteristics of the igniter are given in Table 2.

B. THE PARACHUTE ASSEMBLY

The Arcas parachute assembly consists of an instrument mounting base and a radar-reflective parachute (diameter 15 ft) packaged inside a cylindrical parachute container. A cutaway diagram of the parachute assembly is shown in Figure 12. The parachute container is a sealed unit which is attached to the forward retaining ring of the motor case. A lanyard connects the after-closure of the parachute container to the head-end closure of the rocket motor. The instrument package to be used is attached to the instrument base and inserted into the nose-cone. When the payload is assembled, the cone is secured to the instrument bases by six steel balls that are held in place by the collar of the parachute container. The instrument base is attached to the forward closure of the parachute container by joining the stud of the parachute container closure with the stop-nut mounted on the instrument base. A plastic spacer is used between the parachute container and the instrument base to absorb some of the shock of separation. The process for the assembly of the payload will be outlined in much greater detail in the discussion of the rocket launching procedure.

The principle of separation of the Arcas payload assembly is illustrated in Figure 13. Pressure generated by the separation charge acts on the after-closure of the parachute container and the pressure is transmitted through the inner cylinder of the container assembly. The shear pins which secure the forward closure of the parachute container break, thus allowing the nose-cone, instrument package and parachute pack to be ejected.

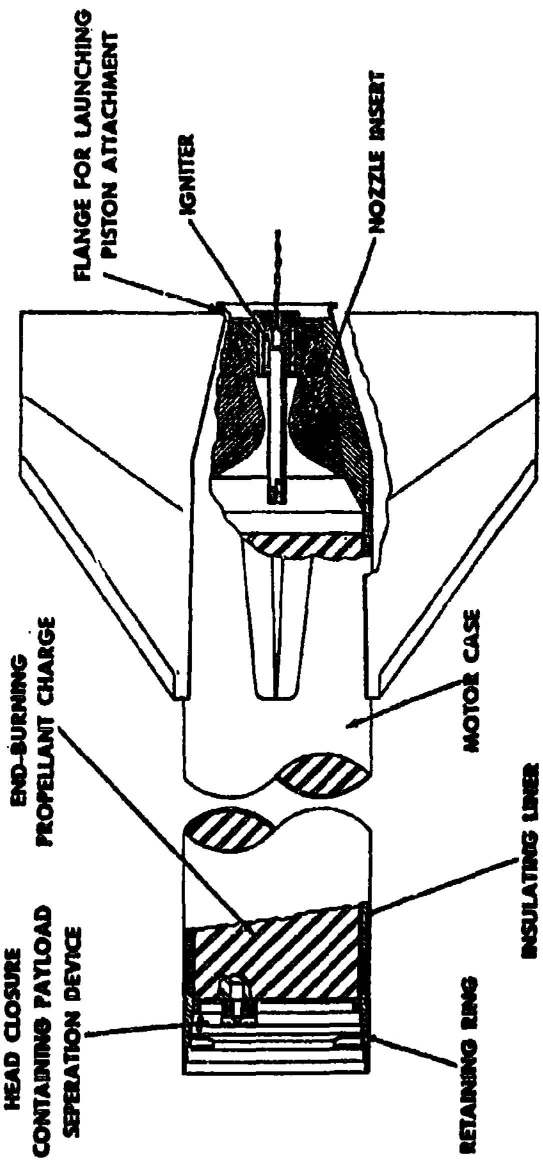


FIGURE 11

CUTAWAY DIAGRAM OF THE MOTOR CASE SHOWING THE COMPONENT PARTS

TABLE 2

CIRCUIT CHARACTERISTICS OF THE IGNITER

ITEM	VALUE
Maximum no-fire current, amperes	0.30
Maximum recommended test current, amperes	0.10
Circuit resistance (with 36 inches of lead wire) ohms	0.7 to 1.3
Minimum recommended firing current, amperes	2.0
Recommended firing voltage, volts d-c	24 to 110

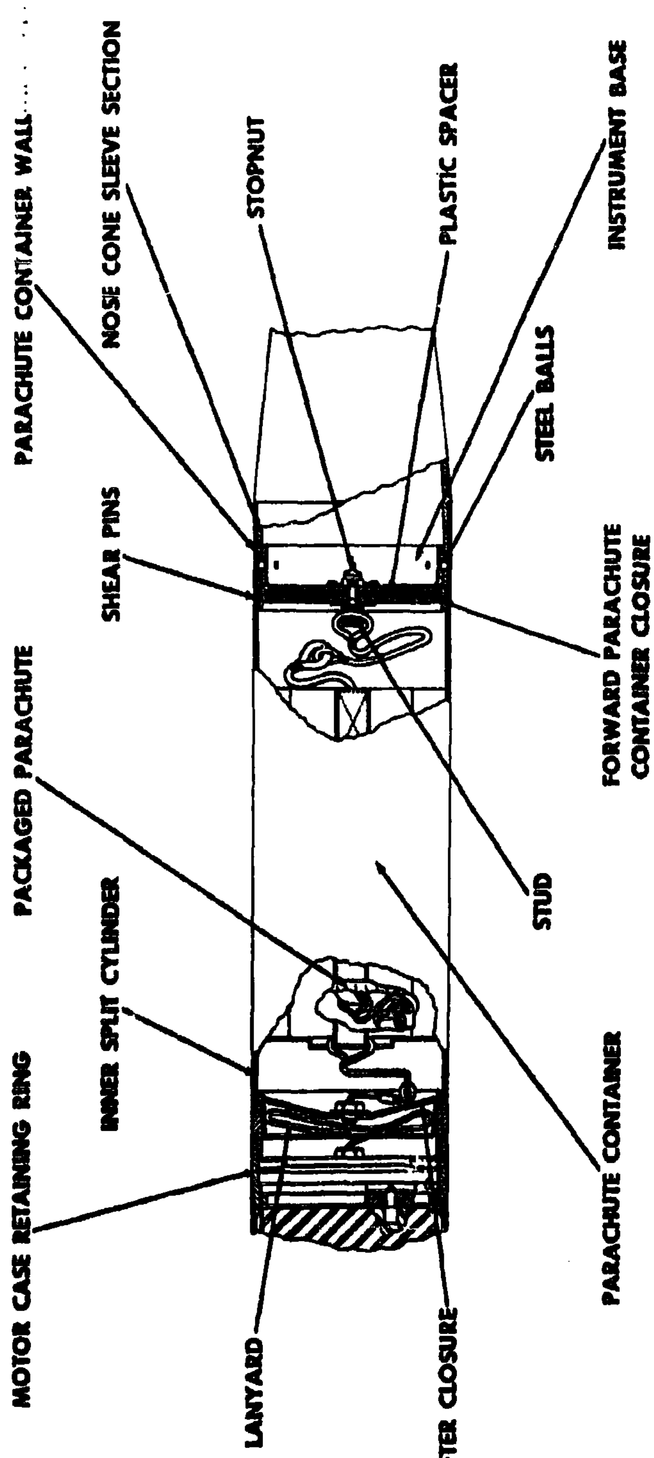


FIGURE 12

CUTAWAY DIAGRAM OF THE ARCAS PAYLOAD ASSEMBLY SHOWING THE COMPONENT PARTS

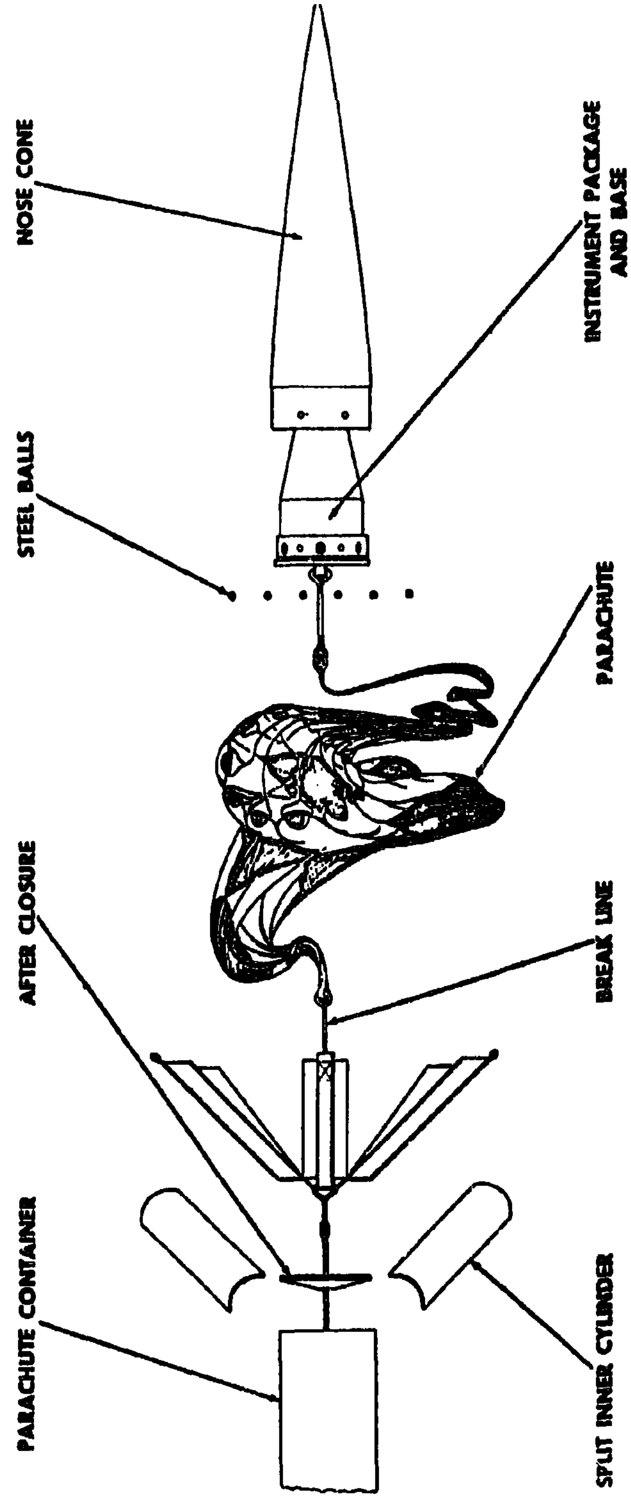


FIGURE 13

PRINCIPLE OF SEPARATION OF THE ARCAS PAYLOAD ASSEMBLY

The parachute and lanyard retain the after-closure assembly of the parachute container. When the parachute is fully extended the snap line attached to the crown of the parachute breaks and the steel balls joining the instrument base and nose-cone fall away thus allowing the nose-cone to separate from the instrument base and package.

Figure 14 gives the dimensions of the parachute and the configuration of the parachute and payload after expulsion. The velocity of the fall V of a parachute [2] can be expressed by the equation,

$$V = \sqrt{2\ mg/\rho\ C_d A_x} = \frac{k}{\sqrt{\rho}} \quad \rightarrow \quad k = \sqrt{2\ mg/C_d A_x}$$

where

m = mass

g = gravitational acceleration

ρ = density

C_d = drag coefficient

A_x = cross-sectional area of chute.

The fall rate of the Gentex 15-foot diameter parachute with an instrument package weight of 3.5 lbs is shown in Figure 15.

C. THE NOSE-CONE ASSEMBLY - DELTA I SYSTEM

The block and schematic circuit diagrams of the Delta I Rocketsonde Temperature Sensing and Telemetry System are shown in Figures 16 and 17 respectively. A photograph of the system is shown in Figure 18. The system which is presently in use is an outgrowth of several previous models [3-5]. The system consists of:

1. the telemetry transmitter,
2. the blocking oscillator circuit,
3. the modulator circuit,
4. the variable resistor (dependent on the thermistor temperature),
5. the reference resistor and switching circuit, and
6. the power supply.

The transmitter oscillates at a nominal frequency of 1680 megacycles and generates approximately 500 milliwatts of power at a plate voltage of 120 volts. This gives an extreme range of approximately 100 miles for small quadrant elevation angles when

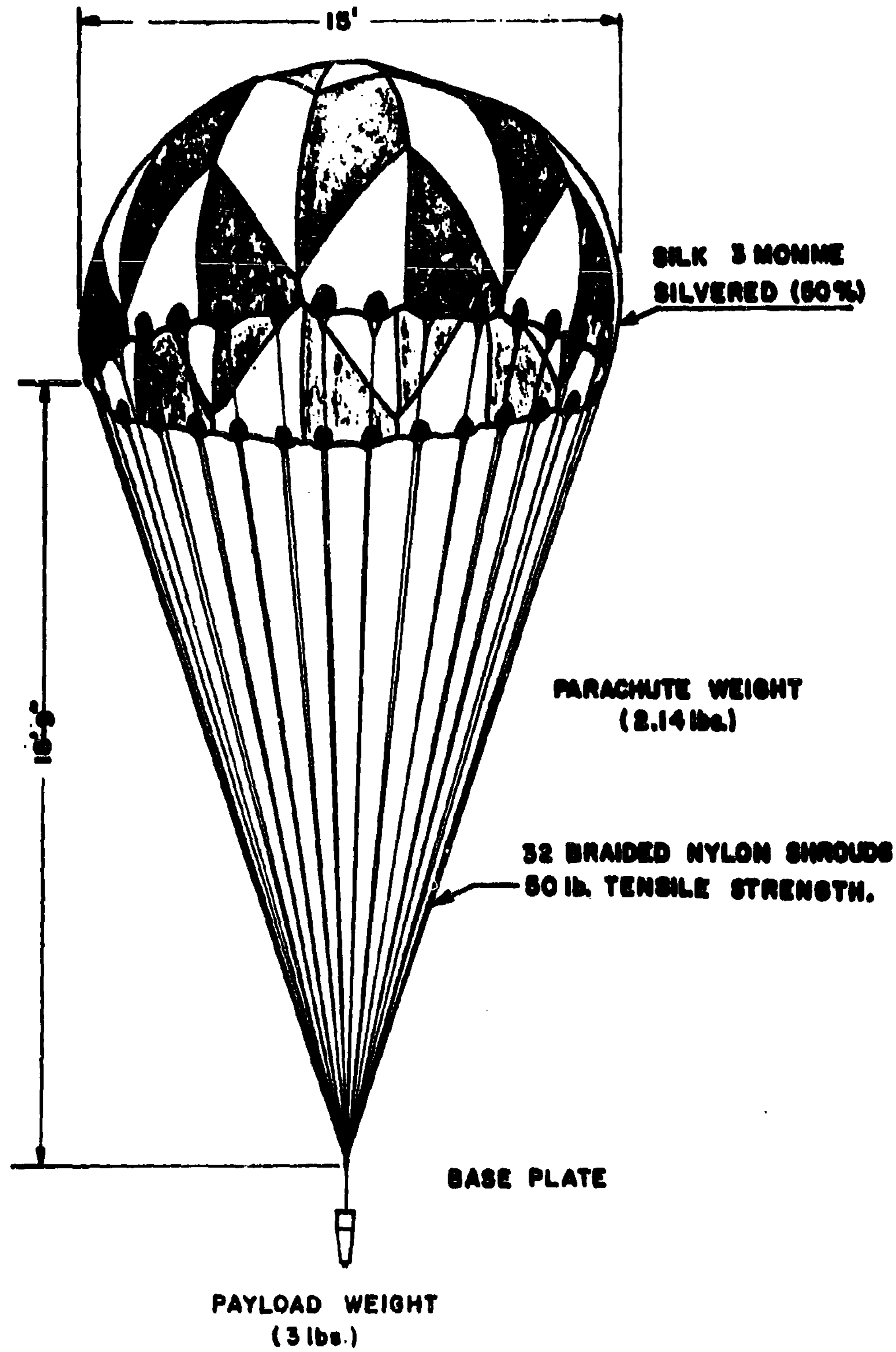


FIGURE 14

ARCAS PARACHUTE AND PAYLOAD AFTER EXPULSION

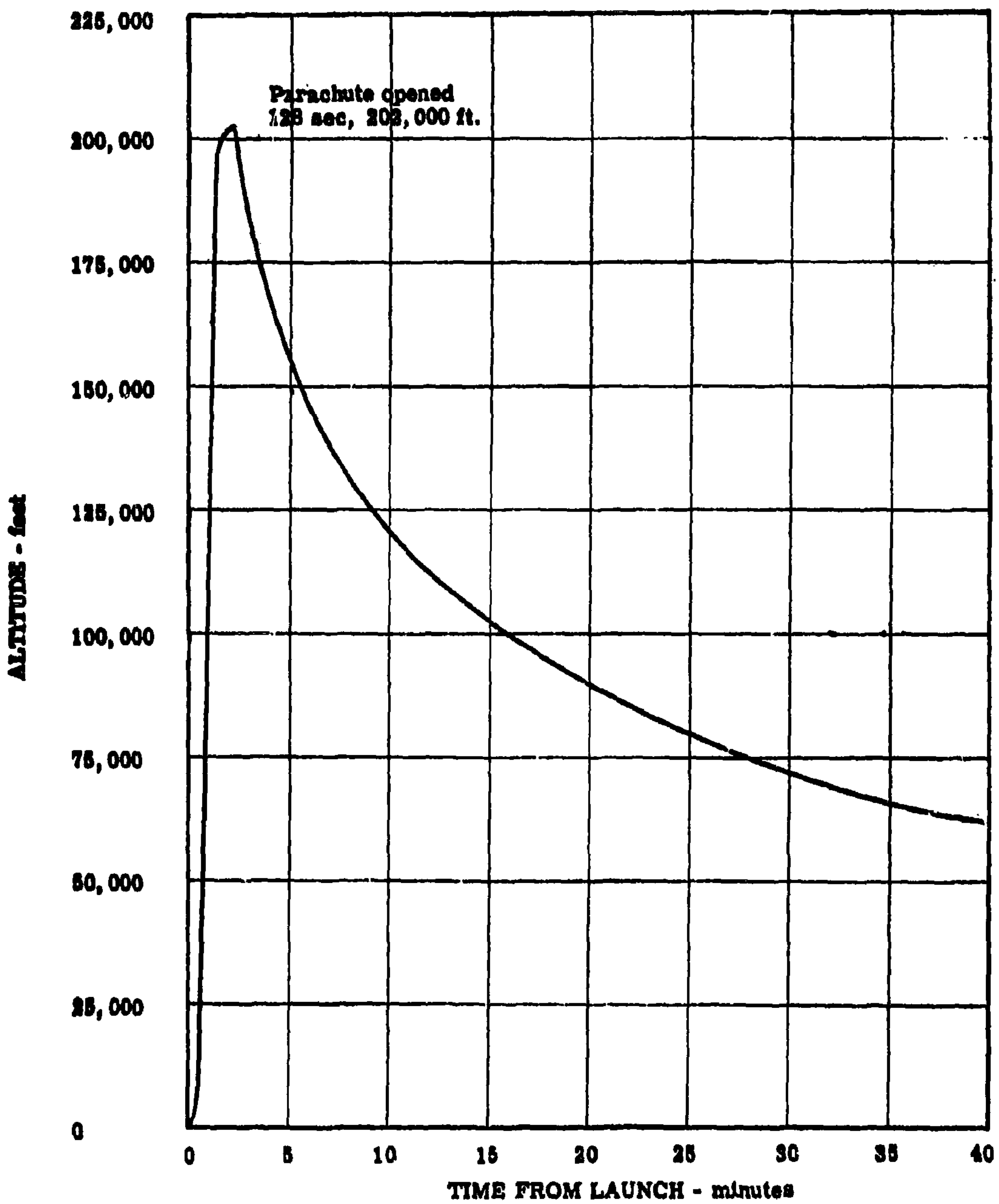


FIGURE 15

FALL RATE OF THE GENTEX PARACHUTE

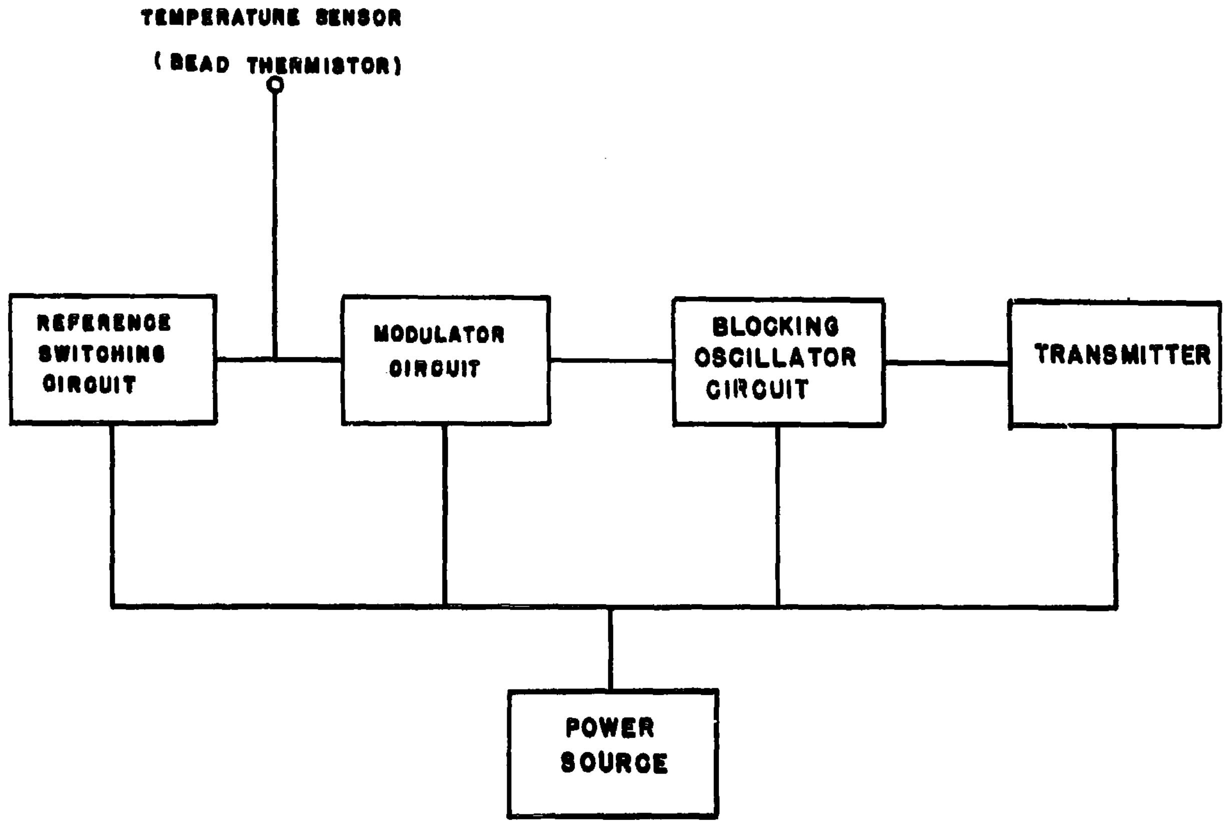


FIGURE 16

BLOCK DIAGRAM OF THE DELTA I TEMPERATURE SENSING SYSTEM

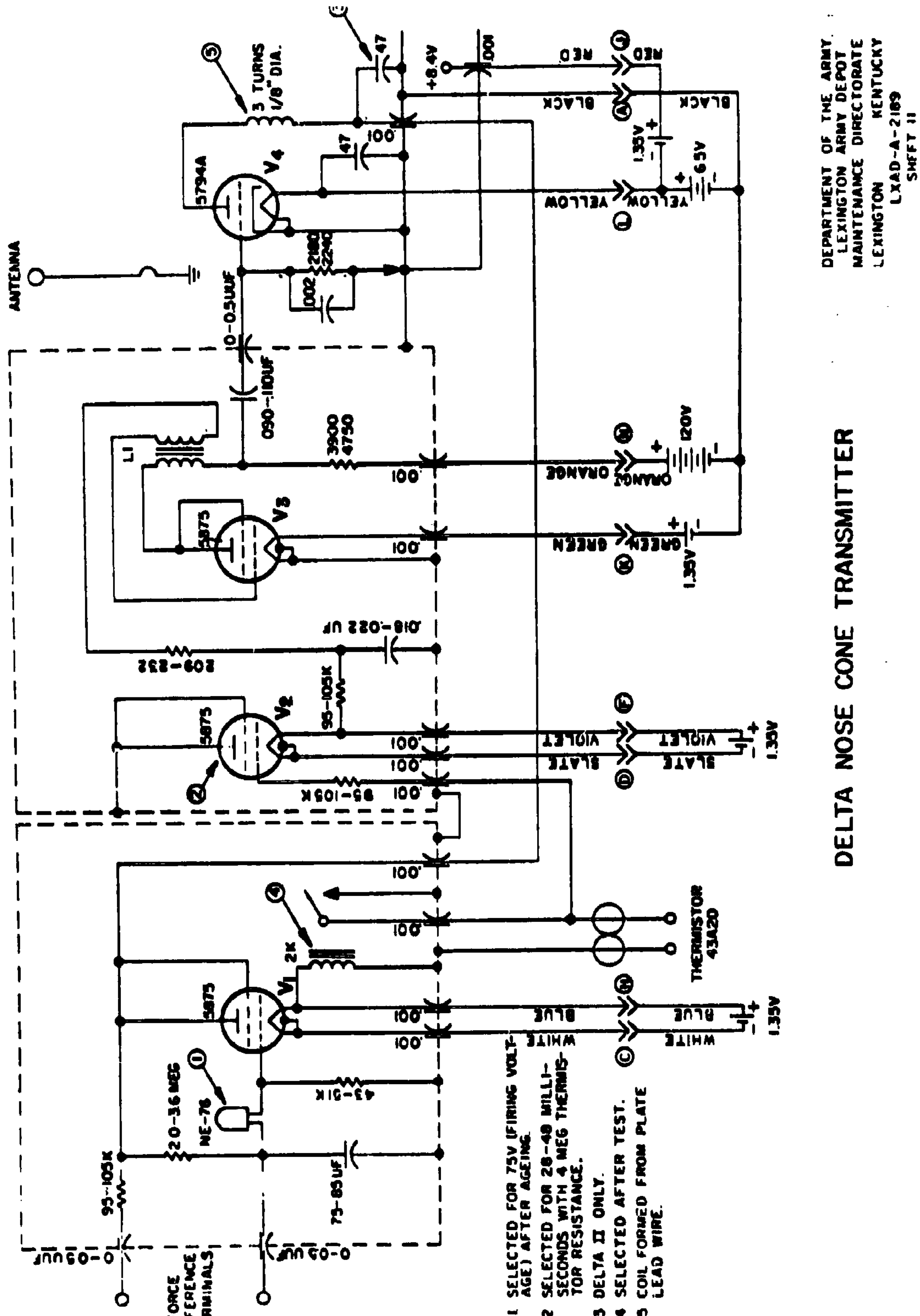


FIGURE 17

SCHEMATIC DIAGRAM OF THE DELTA I TEMPERATURE SENSING SYSTEM

FIGURE 18

PHOTOGRAPH OF THE DELTA I TEMPERATURE SENSING SYSTEM used in conjunction with the Rawin sets AN/GMD-1 and AN/GMD-2 receivers.

The transmitter tube is a radio frequency oscillator of the pencil-tube and integral cavity type, RCA-5794A. The antenna is a brass dipole above (or below) a copper, conically shaped ground-plane and serves to match the tube impedance to that of the antenna. Figures 19, 20 and 21 are diagrams of the antenna and ground-plane orientation and the corresponding relative intensities of the horizontal component of the electric field as determined at a distance of 20 ft from the transmitting antenna.

The blocking oscillator and modulator tube circuits serve the purpose of converting the variations in resistance of the thermistor to variable-rate voltage pulses which when applied to the grid of the transmitter tube cause the tube to cut off for the duration of each pulse. The pulse-recurrence frequency of the blocking oscillator is determined by the RC time constant in the grid circuit of the blocking oscillator tube V3. The effective resistance in the grid circuit of V3 is determined by the operating point of tube V2 which in turn depends upon the value of the resistance in the grid circuit of the modulator tube V2. This resistance value is determined by the fixed reference resistor R_f and the temperature variable resistance of the thermistor. Thus the pulse-recurrence frequency of the blocking oscillator is modified as the resistance of the thermistor changes in accordance with the changes in temperature of the medium in which it is immersed. The carrier signal from the transmitter tube is then turned off at the pulse-recurrence frequency of the blocking oscillator when the pulses occur at the grid of the transmitter tube. The carrier is thus pulse-modulated in accordance with the existing temperature of the thermistor which corresponds to the temperature of the environment when the thermistor and its environment are in thermal equilibrium. The reception and demodulation of the carrier signal is discussed in connection with the section dealing with the AN/GMD-1 ground-receiving system.

The reference switching circuit serves to short the thermistor from the grid circuit of the modulator tube thus setting a fixed pulse recurrence frequency for the blocking oscillator which corresponds to the value of R_s. When the voltage across the fixed capacitor C_s reaches the ignition value of the neon tube, the capacitor discharges through the grid resistor of the tube V1. This voltage pulse on the grid of V1 causes the relay to be energized which then shorts the thermistor to the ground of the system. The rate of charge of the capacitor C_s is determined by the time constant R_sC_s which in turn controls the rate at which the reference pulse is introduced.

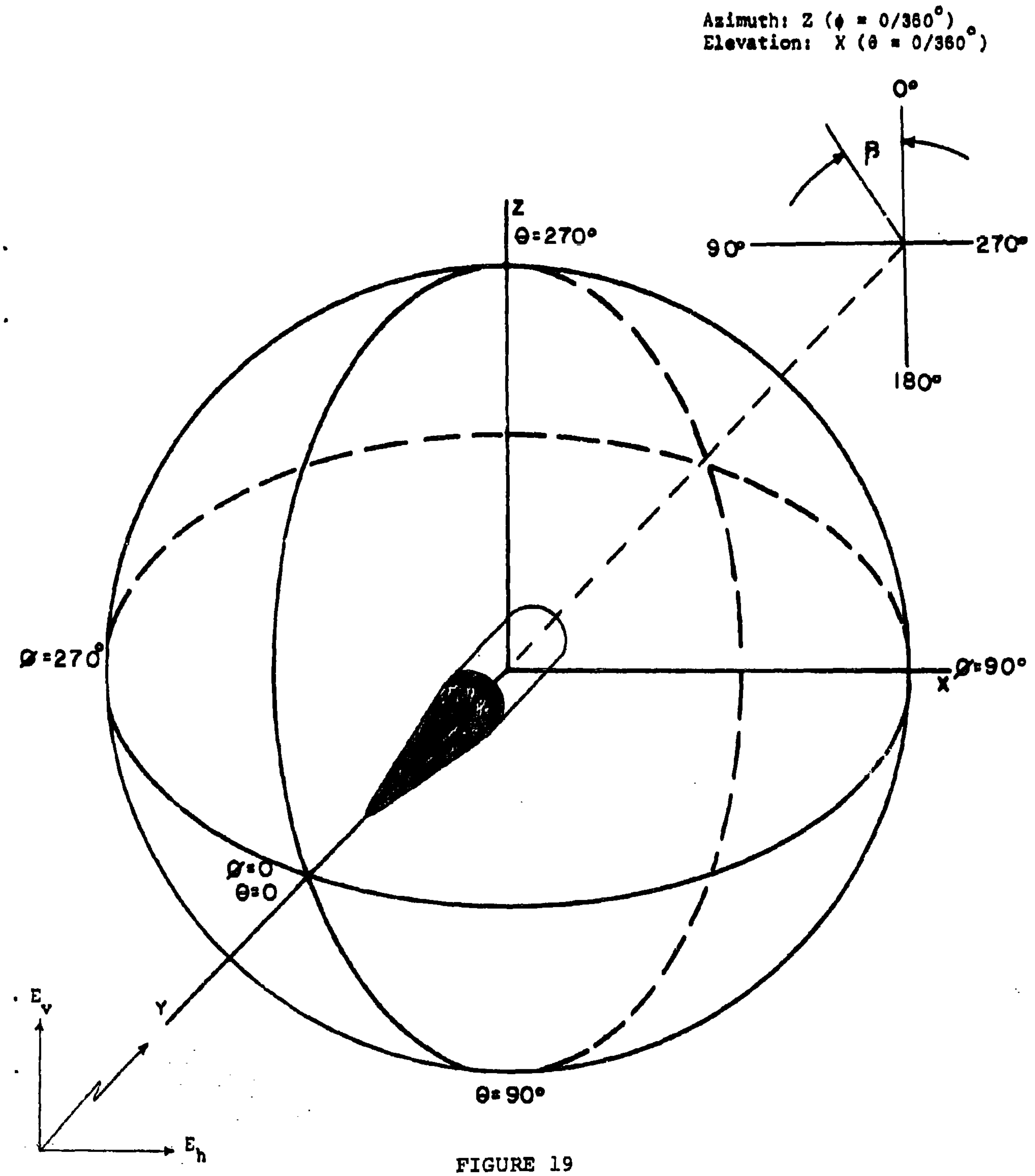


FIGURE 19

DELTA I ANTENNA AND GROUND PLANE ORIENTATION

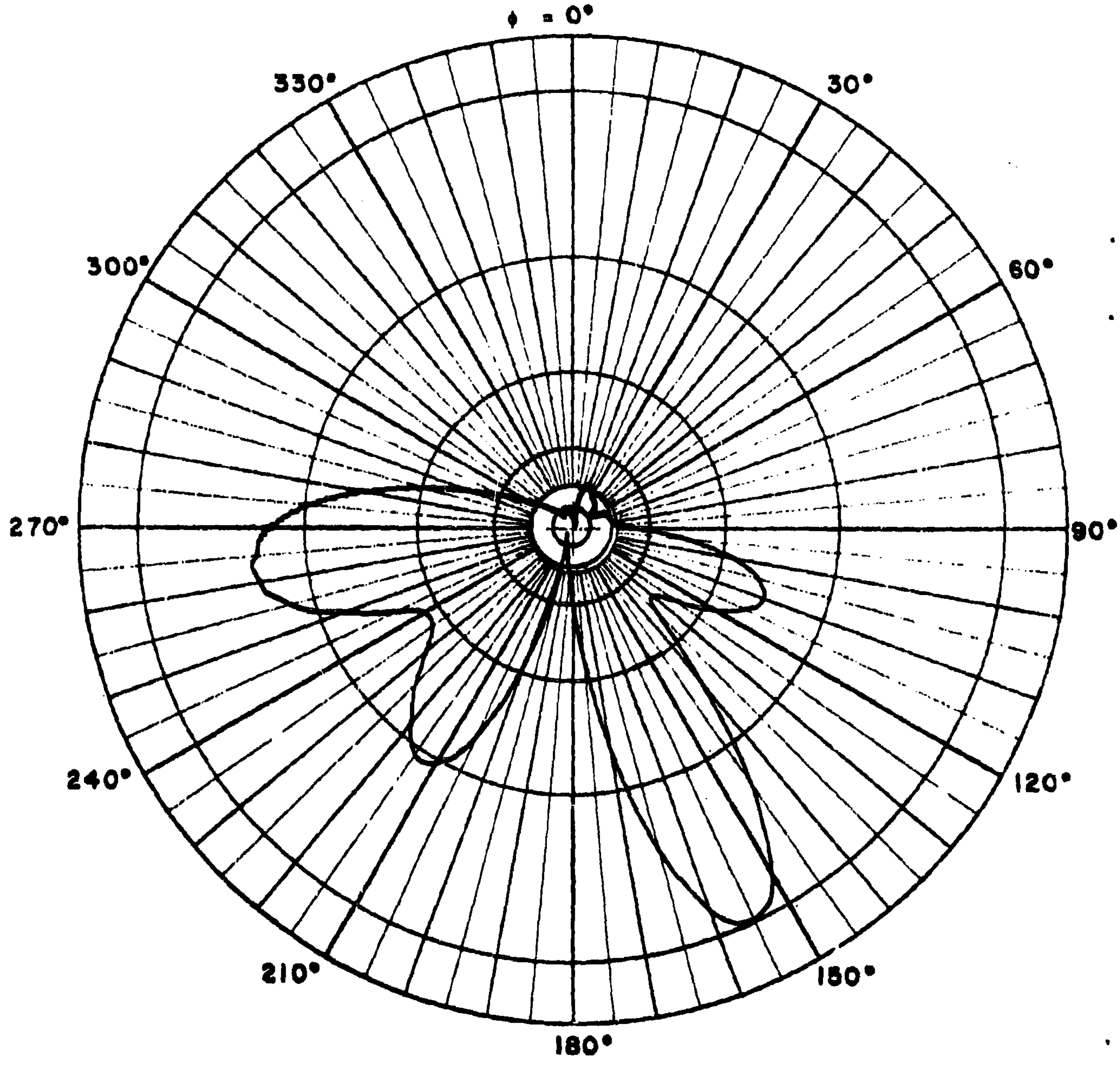


FIGURE 20

RELATIVE INTENSITIES OF THE HORIZONTAL COMPONENTS OF THE ELECTRIC FIELD CORRESPONDING TO THE ORIENTATION SHOWN IN FIGURE 19

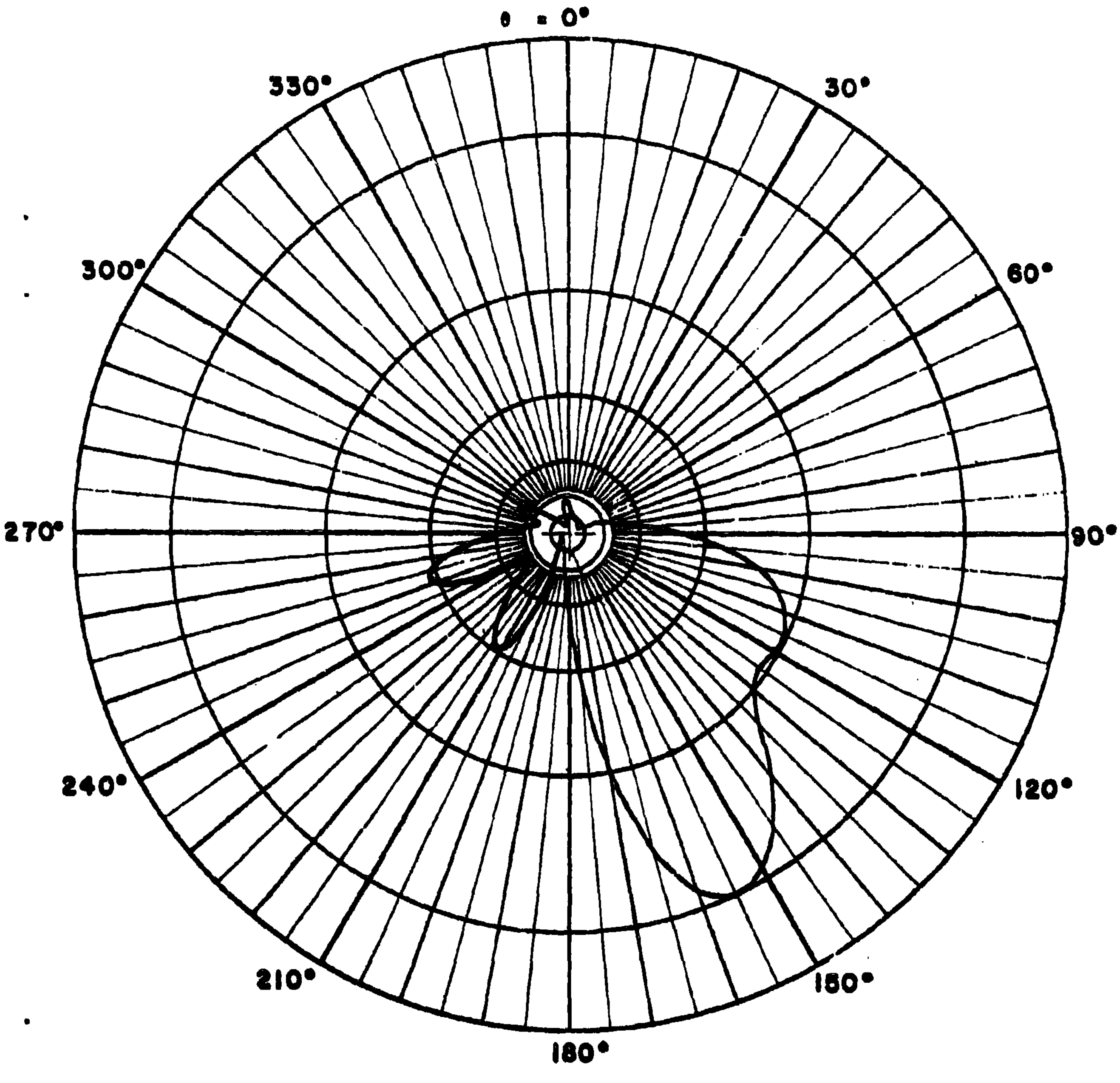


FIGURE 21

RELATIVE INTENSITIES OF THE HORIZONTAL COMPONENTS OF THE ELECTRIC FIELD CORRESPONDING TO THE ORIENTATION SHOWN IN FIGURE 19

The power supply for the Delta I system consists of Burgess alkaline dry cell batteries. The nominal operating voltages existing at various points in the instrument circuit are indicated in the schematic diagram of Figure 17. The supply voltages for the various tubes are:

TUBE		BATTERY TYPE AND NUMBER
5875	Plate-120 volts	Burgess KT-20 (4 in series)
5794-A	Filament-6.5 volts	Burgess MN-1500 (5 in series)
5875	Filament-1.35 volts	Burgess MN-1500 (one for each tube)

The NE-76 tube fires when the voltage across the tube reaches a value of 76 volts.

VI. THE AUTOMATIC ROCKET IMPACT PREDICTION SYSTEM

Before a rocket vehicle is fired there must be a maximum assurance that, if the vehicle functions properly, it will impact within the designated range area. This is vital from the standpoint of range safety and vehicle recovery.

Analytical expressions have been developed which describe the behavior of the ballistic missile[6]. The equations are based upon the Wind Weighting Theory in which the atmosphere between the surface and 100,000 ft (30 km) is divided into three broad layers that are classified for ballistic purposes as low, medium and high altitude layers. The surface layer extends from the surface to 112 ft, the medium layer extends from 112 to 2,000 ft while the high layer extends from 2,000 to 100,000 ft. The average wind in each of these layers affects the trajectory of the rocket with the larger effects taking place in the lower layers. It has been found that, with wind conditions existing at WSMR, 76 per cent of the ballistic wind effect on the Arcas rocket trajectory is caused by the winds between the surface and 2,000 ft with 90 per cent of the ballistic wind effect being caused by the winds up to an altitude of 10,000 ft.

The low-altitude layer (surface to 112 ft) is further subdivided into four layers and a tower mounted wind sensor is placed at the mid-point of each layer to furnish wind velocity data for that particular layer.

The medium-altitude layer (112 - 2,000 ft) is subdivided into ten equal layers. Wind speed and direction in this height interval are determined from data obtained by pilot-balloon tracking theodolites. This technique has proven feasible since the horizontal velocity of a helium-filled balloon at a given altitude closely approximates the wind's actual velocity at that altitude. These two theodolites are utilized in tracking the balloon to give balloon position as a function of time.

The winds in the high-altitude layer (2,000 - 100,000 ft) are determined by tracking a balloon-borne radiosonde (Friez Instruments AMT-413) with an AN/GMD Rawin receiver. The GMD records the azimuth and elevation angles while the height of the balloon is determined from the time rate of rise of the balloon.

The various components of the Automatic Rocket Impact Predictor (ARIP) which has been developed at WSMR are shown in the block diagram of Figure 22. The computer accepts data from the three sources (tower mounted wind sensors, pilot-balloon tracking theodolites and the GMD) and determines, (1) the atmospheric layer wind effect and (2) the predicted impact point. The impact point of the rocket is determined when the effect of the wind in each layer is determined. The rocket trajectory is simulated as if no wind is present to influence the trajectory and a no-wind impact point is established. A second rocket trajectory is simulated with a one mile/hr wind present throughout the flight and a unit wind impact point is established. The straight-line distance between the two simulated impact points is defined as the "unit wind effect", d_{uw}.

With the unit wind effect established, the wind effect contributed by each atmospheric layer is determined. A trajectory is simulated with the unit wind acting upon the trajectory from the time of launch until the rocket attains an altitude h_1. At altitude h_1 the unit wind condition is removed and the rocket completes a simulated flight through a zero-wind environment and impacts at a distance d_1 from the theoretical no-wind impact point. The ratio of the distance d_1 to the distance d_{uw}, d_1/d_{uw}, is termed the percentage unit wind effect due to the atmospheric layer h_1 and is defined as the ballistic weighting factor due to wind in layer h_1. A second trajectory is simulated with the unit wind acting upon the rocket until it reaches an altitude $h_2 > h_1$. At altitude h_2 the unit wind condition is removed and the rocket completes a simulated flight through a zero-wind environment and impacts at a distance d_2 from the no-wind impact point. The percentage wind effect due to the layer $h_2 - h_1$ is obtained from the

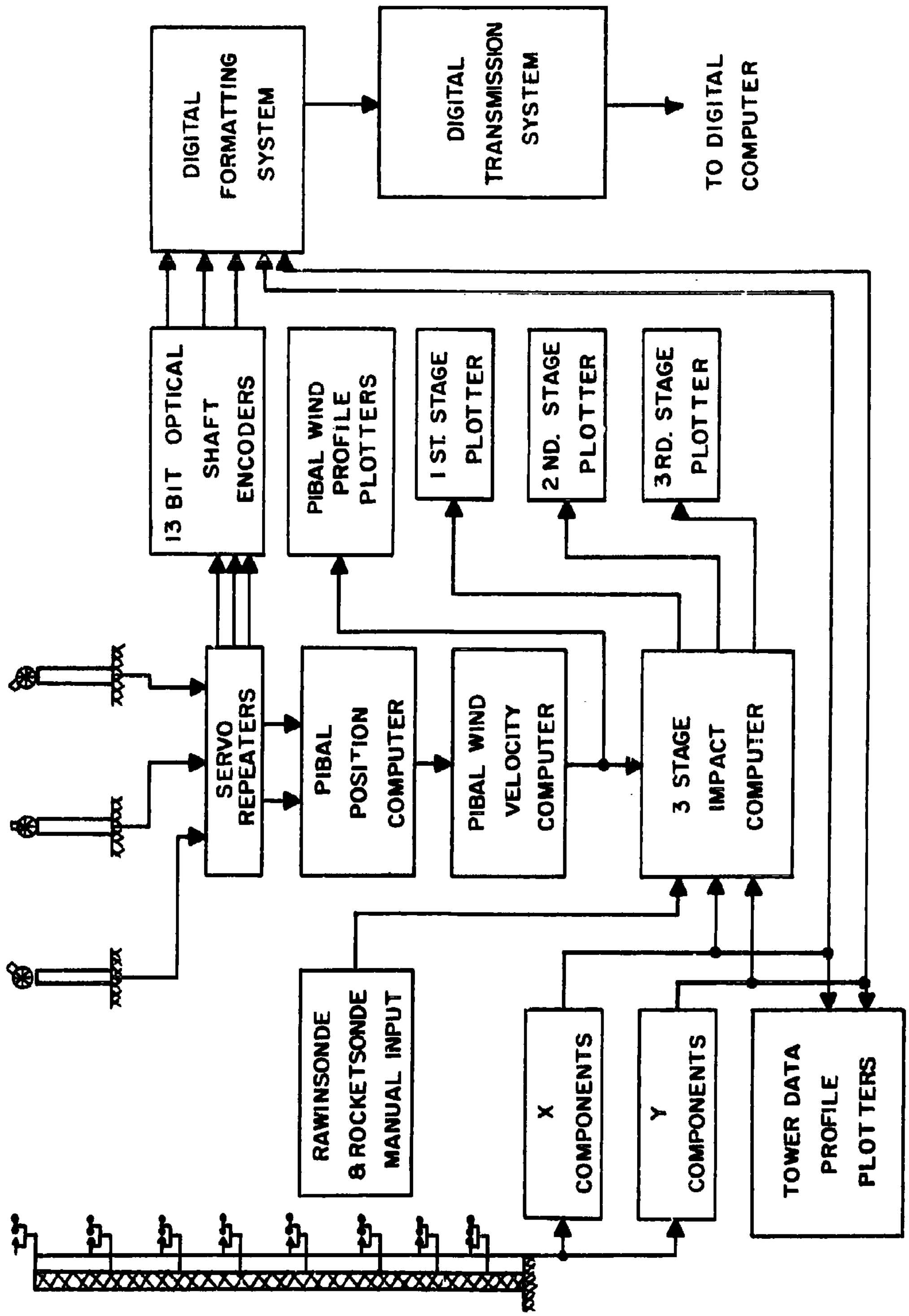


FIGURE 22

BLOCK DIAGRAM OF THE AUTOMATIC ROCKET IMPACT PREDICTION SYSTEM ratio difference $d_2/d_{uw} - d_1/d_{uw}$. This procedure is continued until the ballistic weighting factor of each atmospheric layer is determined.

The ballistic weighting factor for a given layer is then multiplied by the average wind velocity in that layer. The products thus obtained are summed with the resulting quantity representing a displacement of the predicted impact point relative to a theoretical no-wind impact point. Based upon this information, the azimuth and quadrant elevation angles for the Arcas rocket launcher are determined. Figure 23 is a diagram showing the actual impact points of 116 missiles relative to the predicted point of impact. Out of this number of rocket firings, 26 were fired when the wind at the surface was greater than 10 miles/hr, 12 were fired when the surface wind was greater than 15 miles/hr, while 5 were fired when the surface wind was in excess of 20 miles/hr. The mean impact error for all firings was 9.2 miles.

More detailed information concerning the various components of the ARIP system and their function can be obtained from the listed references. [7-10]

VII. THE INSTRUMENT PREPARATION AND CALIBRATION FACILITY

The instrument preparation and calibration facility may be housed at any location which is convenient to the launching pad and the GMD receiver. This facility at WSMR is located in the same building (location shown in Figure 7) which houses the GMD receivers and recorders used for the reception of the transmitted temperature data from the rocketsonde temperature sensor.

Minimum requirements and equipment at the instrument calibration facility include:

1. a work bench,
2. a resistor box containing resistors whose resistance values range from 15 k ohms to 10 megohms and which are known to be correct within at least 1%,
3. a source of 60 cycle/sec a.c. power,
4. a meter for the determination of the transmitter frequency
5. a calibrated thermometer for the determination of room temperature to within ±0.5°C,
6. a soldering iron and solder,

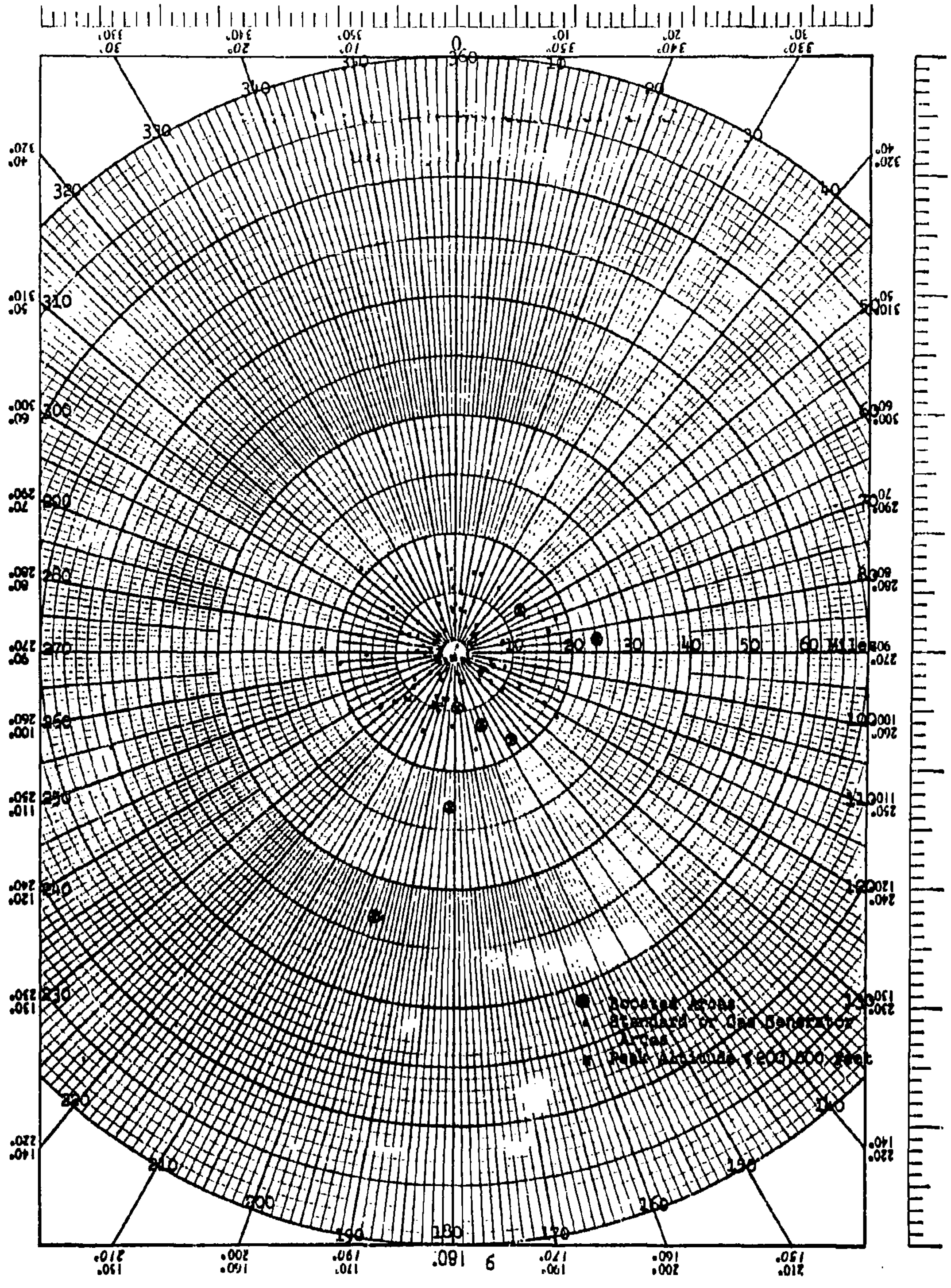


FIGURE 23

SCATTER DIAGRAM OF THE PREDICTED VERSUS ACTUAL ARCAS IMPACTS FOR 1963

7. a supply of instrument base plates,
8. a supply of parachutes and parachute containers,
9. rocket nose-cones,*
10. tools and screws for attaching the instrument package to the instrument base plate,
11. a voltmeter and ammeter, and
12. a battery test instrument.

Additional desirable equipment would include an oscilloscope, a refrigerator for instrument storage and a drill press.

VIII. GROUND-BASED INSTRUMENTATION FOR THE DETERMINATION OF TEMPERATURE AND WIND VELOCITY AS FUNCTIONS OF ALTITUDE

The rocketsonde temperature telemetry system and supporting parachute are tracked by three separate systems at WSMR. The transmitter of the rocketsonde is tracked by the Rawin Set AN/GMD-1 R.F. receiver while the metalized parachute is tracked by M-33 and FPS-16 radar systems. The M-33 serves as a back-up for the FPS-16. The received and detected signal from the GMD system serves to determine temperature at the instrument position as a function of time while instrument position (slant range, azimuth and elevation angles) as a function of time is determined by the radar system. The combining of the sets of data from the GMD-1 and FPS-16 radar systems then gives the temperature as a function of altitude while the position and time data from the radar system serve to determine the wind velocity as a function of altitude.

A. THE AN/GMD-1 RECEIVER

The Rawin Set AN/GMD-1 which is used in tracking the rocketsonde temperature telemetry system is essentially an electronic theodolite and radio receiver. The directional antenna of the Rawin set tracks the parachute-borne transmitter which operates at a nominal frequency of 1680 megacycles/sec. The angles of azimuth and elevation of the transmitter relative to the receiver can be determined from the antenna orientation. In addition the

*The supplier for nose-cones, parachutes, parachute containers and instrument base plates is Atlantic Research Corp., Alexandria, Va.

Rawin set receives the pulse-modulated R.F. signal from the rocketsonde, amplifies and detects this signal and passes the detected signal to a calibrated recorder which in turn serves to translate the detected signal into values of temperature-sensor-resistance as a function of time; then from the plot of the temperature-sensor-resistance as a function of temperature, temperature as a function of time is determined. These data coupled with the position data from the radar system determine the temperature at a given altitude as determined by the rocketsonde temperature sensing system.

The development of a sufficiently precise transponder for the determination of slant range to the instrument package and parachute is proceeding. The incorporation of the transponder system into the GMD system which presently measures the azimuth and elevation angles to the instrument will allow the determination of temperature and wind velocity as functions of altitude at locations where radar systems are not available.

A photograph and block diagram of the AN/GMD-1A set are shown in Figures 24 and 25. The set is divided into five systems to include antenna, receiving, antenna positioning, position indicating and recording (azimuth and elevation angles), and meteorological data transmission systems.

1. <u>The Antenna System</u>

The antenna system consists of a parabolic reflector, an eccentric cup which is rotated by a drive motor and hollow drive shaft, a dipole antenna and transmission line. The rocketsonde transmitter transmits a pulse modulated R.F. signal (1680 megacycles/sec). The antenna lobe (received signal intensity pattern) rotates slowly. When the rocketsonde is in line with the electrical axis of the antenna reflector, the signal intensity of the dipole has a constant value; when the rocketsonde drifts to a point off the electrical axis of the antenna reflector, the intensity of the signal at the dipole varies with the rotation of the eccentric cup. Some of the R.F. energy from the transmitter is received by the parabolic reflector and reflected to the dipole antenna. As a result, the amplitude of the R.F. signal at the dipole takes the shape of a modulated sinusoidal wave. The relative phase and amplitude of the sinusoidal modulation is indicative of the angular distance of the rocketsonde transmitter from the axis of the antenna.

2. <u>The Receiving System</u>

In the receiving system, the modulated wave is beaten against the output of the local oscillator to produce a 30 megacycle/sec I.F. which retains the pulse modulation and amplitude variations. The I.F. signal is then amplified and detected and the demodulated

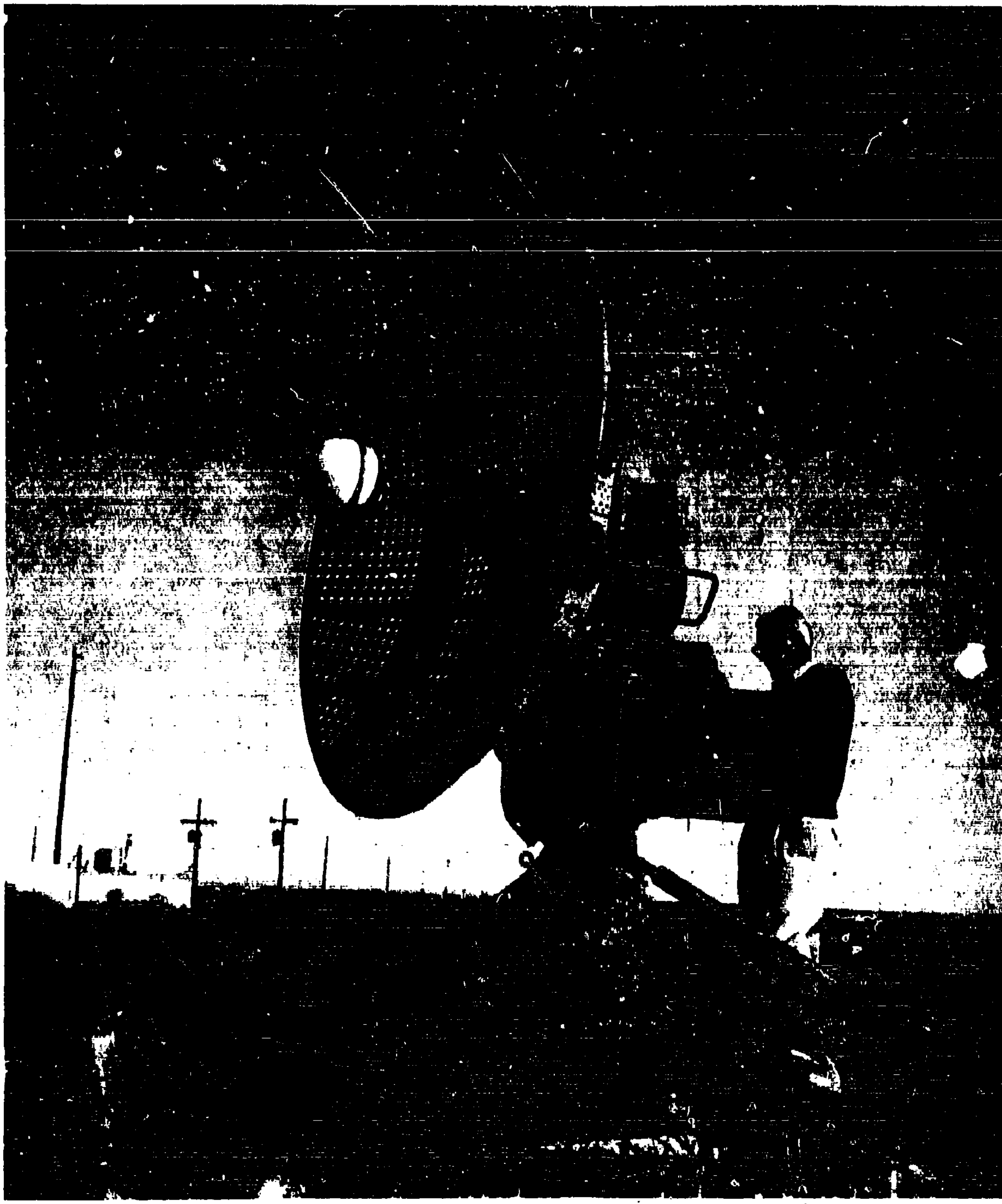


FIGURE 24

PHOTOGRAPH OF THE AN/CMD-1A SET

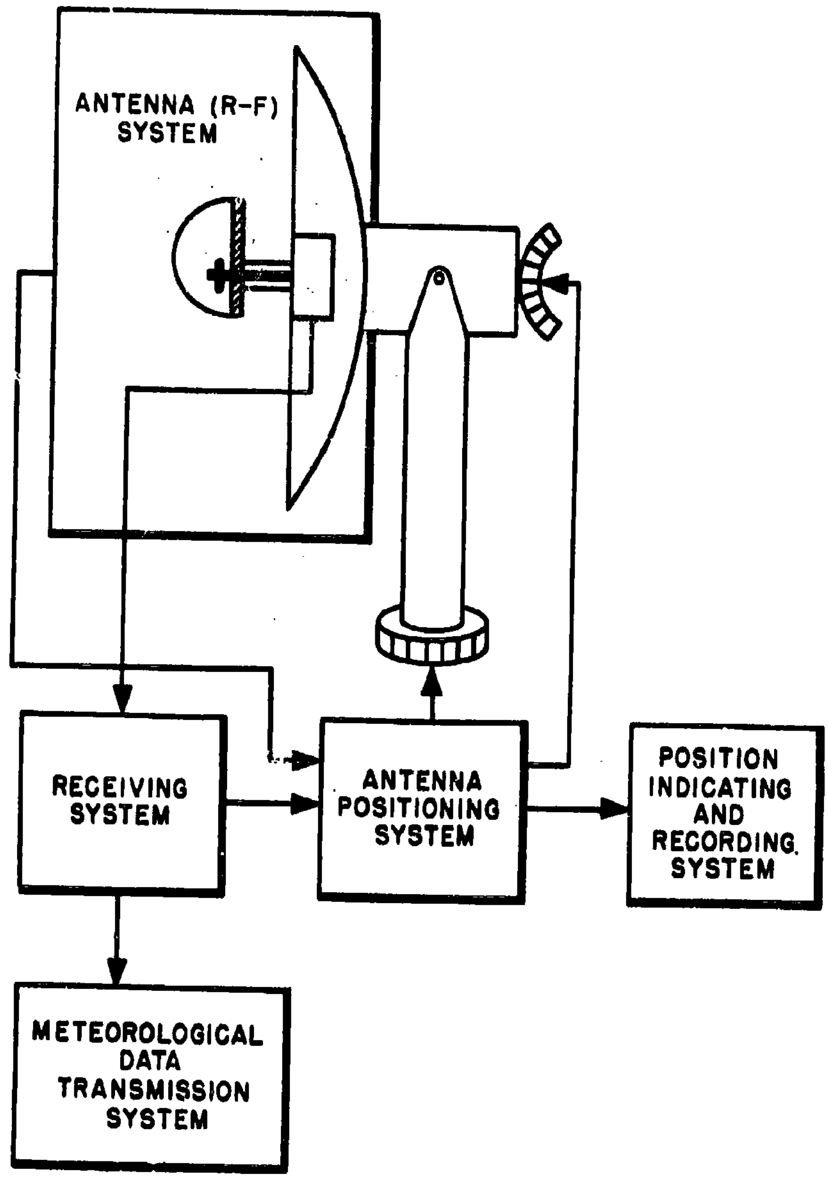


FIGURE 25

RAWIN SET AN/GMD-IA, SYSTEMS

signal (30 cycle/sec sine wave and pulses) is passed to the antenna positioning system and to the meteorological data transmission system. The receiving system also contains an AFC circuit to maintain a constant 30-mc/sec I.F. and a service meter for checking various currents and voltages present in the Rawin set.

3. The Antenna Positioning System

The antenna positioning system receives the detected sinusoidal signal from the receiving system. It rejects the pulse modulation and then amplifies and compares the sinusoidal content with two reference voltages from the reference voltage generators. These reference voltages correspond to the elevation and azimuth components of the position of the antenna axis. This results in two dc voltages, one for elevation and one for azimuth. The magnitude and polarities of these voltages are indicative of the magnitude and direction of the angular difference of the radiosonde with respect to the electrical axis of the antenna. The azimuth error voltage is applied to the azimuth drive to position the antenna reflector in azimuth. The elevation error voltage is applied to the elevation drive to position the antenna in elevation. Since the position of the rocketsonde is constantly changing, the azimuth and elevation drives are constantly positioning the antenna reflector to track the rocketsonde. Error voltages can also be introduced so as to manually track the rocketsonde.

4. The Position Indicating and Recording System

The elevation and azimuth angles of the antenna are indicated and recorded by the Rawin set and are recorded at successive instants of time.

5. The Meteorological Data Transmission System

The meteorological data transmission system receives the detected signal from the receiving system. It then rejects the sinusoidal modulation for antenna positioning, shapes and amplifies the meteorological pulses and passes them to the meteorological recorder. The meteorological recorder (which is not an integral part of the Rawin set) converts the pulses, whose rate is determined by the sensor resistance, into a graphical representation of sensor resistance as a function of time. More detailed information concerning this receiving system can be found in the technical manual concerning the receiver[11].

6. The Meteorological Recorder AN/TMQ-5

The meteorological recorder AN/TMQ-5 is used in conjunction with the AN/GMD-1 receiver. A photograph and block diagram of the recorder are shown in Figures 26 and 27. The variable-rate pulses from the receiver are fed to the frequency converter of the recorder which converts them to a dc voltage. The value of the dc voltage at any instant is proportional to the pulse frequency which created it. This dc voltage excites a servo system that positions a pen whose displacement from its zero position on a calibrated chart is again proportional to the pulse frequency which in turn was determined by the value of the temperature-sensor-resistance in the rocketsonde. The determination of the recorder pen position as a function of time, combined with the pre-flight calibration of the recorder giving recorder pen position as a function of the rocketsonde-sensor-resistance, serves to determine sensor-resistance as a function of time. The combining of these data with the sensor calibration (giving sensor resistance as a function of temperature) and with the position of the instrument as a function of time (as determined from the radar track of the radar-reflective rocketsonde parachute) serves to determine the temperature as a function of altitude.

Detailed information concerning the meteorological recorder can be found in the technical manual [12] concerning the recorder. A more detailed discussion of the recorder calibration is given in Section X, TYPICAL PROCEDURES FOR ROCKET LAUNCHING AND DATA ACQUISITION.

B. RADAR SYSTEMS FOR THE DETERMINATION OF INSTRUMENT POSITION

Several types of radar systems are currently in use for the determination of instrument position at the various stations of the Meteorological Rocket Network. They are the mobile systems M-33 (X-band), AN/MPQ-12 (X-band), AN/MPQ-12 & 18 (S-band) and the stationary system AN/FPS-16 (C-band). The pertinent characteristics of these radar systems are given in Table 3. Currently the FPS-16 radar system is the one most suitable for tracking meteorological rockets, in that it can skin-track the rocket during its flight and then immediately track the wind sensor at the time of its expulsion from the rocket. A prototype slaving unit has been developed by Duff* for use in conjunction with the M-33 Radar system. This unit slaves the radar system to the GMD system, thus greatly reducing the possibility of losing the rocket after it is launched. All of the above radar systems determine instrument position (in terms of slant range, r, azimuth angle, ϕ, and elevation angle θ) as a function of time.

*Information concerning the development of this system can be obtained from A. Duff, Upper Atmosphere Research Division, White Sands Missile Range, New Mexico.

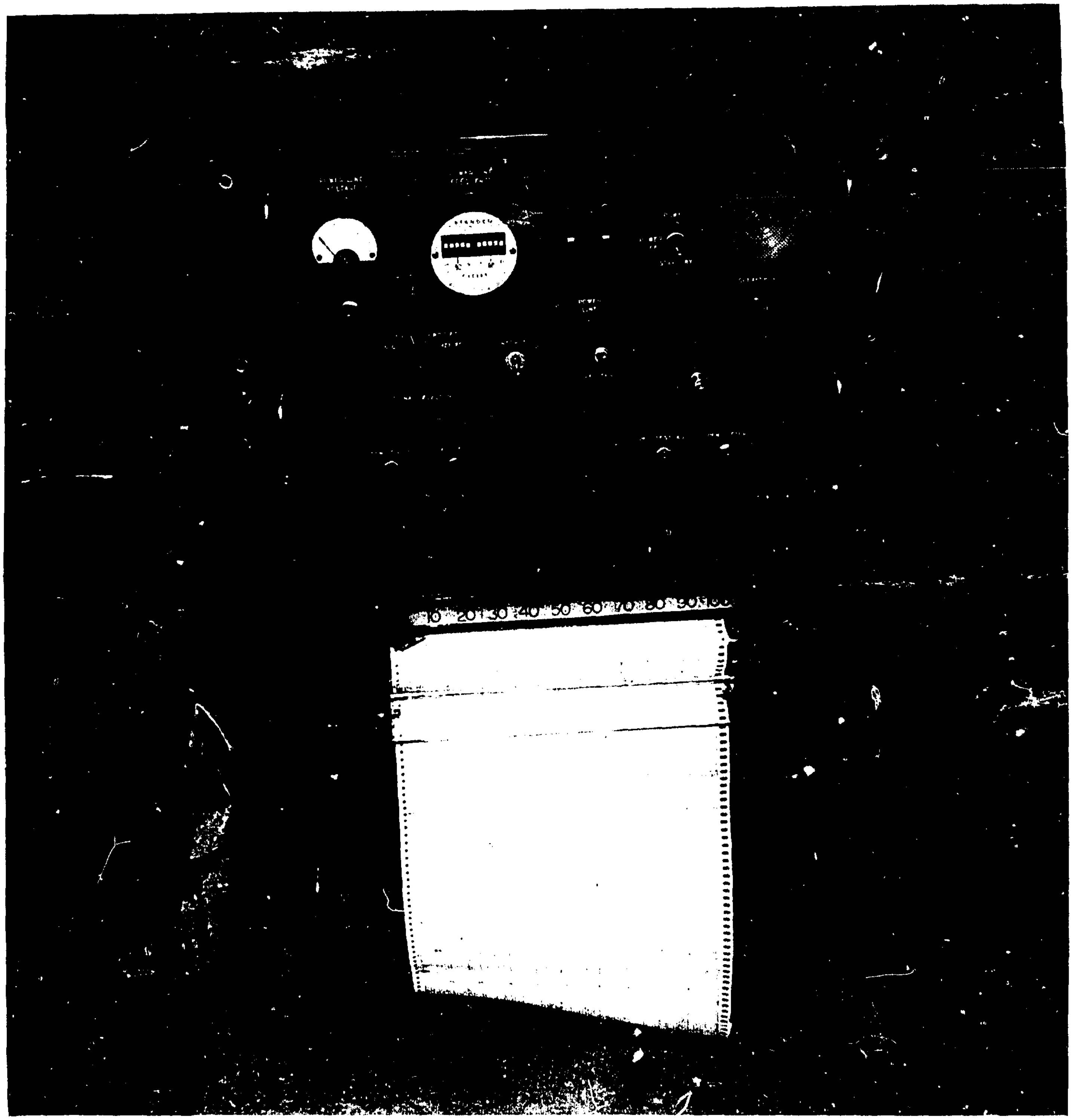


FIGURE 26

PHOTOGRAPH OF THE TMQ-5 RECORDER

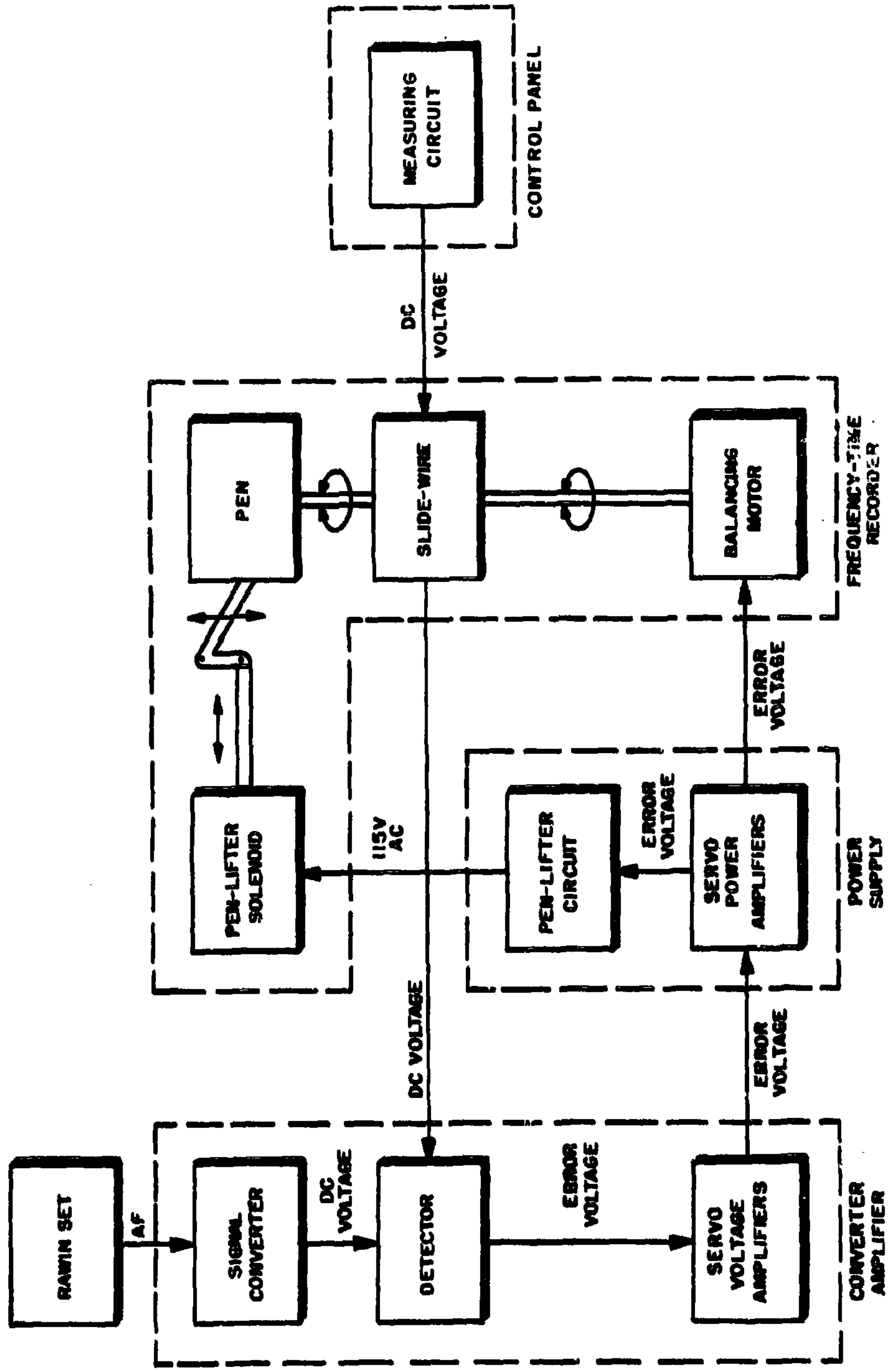


FIGURE 27

BLOCK DIAGRAM OF THE TMQ-5 RECORDER

TABLE 3

RADAR CHARACTERISTICS

	X-BAND SYSTEM (900 Mc)	X-BAND SYSTEM (900 Mc)	S-BAND SYSTEM (2700 Mc)	C-BAND SYSTEM (5500 Mc)
TYPE	M-33 - modified	AN/MPQ-12	AN/MPQ-12 & 18	AN/FPS-16
ANTENNA	10-foot parabolic	8-foot parabolic	10-foot parabolic	12-foot parabolic
BEAM WIDTH	.75 degree	0.9 degree	2.9 degrees	1.1 degrees
POLARIZATION	Vertical	Vertical, horizontal and circular	Linear, rotating and circular	Vertical, horizontal and circular
PEAK POWER	225 KW	200 KW	250-300 KW	1,000 KW
MAXIMUM RANGE	100,000 yards	100,000 yards	400,000 yards	400,000 yards
TRACKING PRECISION	Approx ±2 mils and ±25 yards	Approx ±2 mils and ±40 yards	Approx ±2 mils and ±40 yards	±0.14 mil and ±15 yards
PRF	1,000 pps	Variable	Variable	Variable
OVERALL SENSITIVITY (Including Antenna Gain)	-145 dbm	-140 dbm	-140 dbm	-158 dbm

Two methods are used at WSMR to record the instrument position as a function of time. In one, the position data are fed to the FPS-16 computer which converts spherical coordinates of position (r,ϕ,θ) to the Cartesian coordinates of position (x,y,z). Here x, y and z are the east-west, north-south and altitude coordinates respectively. These position coordinates are displayed on two plotting boards of the FPS-16 system in terms of an (x,y) plot and (r,z) plot. Time corresponding to these positions, as determined by a central range timing system, is marked at successive intervals on both plotting boards. From these data the instrument position and the east-west and north-south components of wind velocity as functions of altitude are determined. In the other, time and the position data from the FPS-16 radar system in terms of the Cartesian coordinates (x,y,z) are stored on magnetic tape at the rate of 10 data points/sec. These tapes serve for reference purposes and for use with data reduction techniques which are more refined than those discussed in Section XI.

IX. TIME BASE AND COMMUNICATION SYSTEMS

The rocket launching pad, the launching control center, the rocket impact prediction center, and the ground-based R.F. receiver and radar locations at WSMR have direct voice communication with each other and have access to central range timing.

The time T-0 is assigned to the time at which the rocket is fired. The electrical impulse which ignites the rocket motor serves also to generate a pulse at the range timing center. The actual instant at which the pulse occurred is determined from Range Timing which is synchronized with WWV time signals.

The elapsed time from T-0 is recorded at successive intervals on the calibrated chart of the AN-TMQ-5 meteorological recorder and on the (x,y) and (r,z) plots of the rocket position as displayed on the plotting boards of the FPS-16 and M-33 radar systems. Here again x, y and z are the east-west, north-south and altitude coordinates of position respectively, while r is the slant range.

In addition, the elapsed time from T-0 and the (x,y,z) coordinates of rocket or instrument position are recorded on magnetic tape at the FPS-16 radar site.

X. TYPICAL PROCEDURES FOR ROCKET LAUNCHING AND DATA ACQUISITION

The following is a description of the typical procedures for instrument preparation and calibration, rocket launching, and data acquisition which have been developed and are utilized at WSMR in conjunction with the Arcas rocket temperature and wind sensing system.

A. PRE-FLIGHT CHECKS OF THE GMD-1 RECEIVER AND TMQ-5 RECORDER

Two hours prior to the scheduled time of firing of the rocket systems, electrical power is supplied to the meteorological receiver and recorder systems. After a warm-up time of 30 minutes the receiver and recorder are checked for proper operation and the recorder sensitivity and calibration are adjusted by the following procedure:

1. Turn the signal selector switch to the 60 CPS position.
2. Momentarily depress the REC. TEST ADJ. switch. This will cause the recorder pen to be displaced up scale and then back to the 30 ordinate position.
3. Quickly rotate the signal selector switch to the SC position and return it to the 60 CPS position. This will momentarily displace the recorder pen down scale from the 30 ordinate position.
4. Alternate at 15-second intervals the two above procedures so that a total of 5 pen displacements are made on each side of the 30 ordinate position. (See Figure 32.) Each time the pen is displaced the left hand edges of the pen trace should be displaced from a straight line by no more than 0.2 ordinates. If displacement is more than this amount adjust the SENSITIVITY control by turning until the displacement is less than 0.2 ordinates. A sensitivity setting which is too high will result in pen instability or oscillation.
5. Turn the signal selector switch to the SC position. A short circuit is placed across the signal converter amplifier in this position.
6. Throw the power switch from STANDBY to the POWER ON position. The pen should record at zero on the recorder chart. If the pen does not record at zero, the REC. ZERO control is rotated until the pen does record at zero.
7. Hold the REC. TEST switch in its down position. In this case the pen should go to 95 on the recorder chart. Upon release of the REC. TEST switch the pen should return to zero.

8. Rotate the signal selector switch to 60 CPS. The pen should go to 30 on the recorder chart. If it does not, the pen position is set at 30 by rotating the REF. ADJUST. (The chart reading is one-half the line frequency.)
9. Rotate the signal selector switch to 120 CPS. The pen should go to 60 on the recorder chart. If it does not, set the pen to the best compromise position for 60 or 30. The pen position is set at 60 by rotating the REF. ADJUST. control.
10. Rotate the signal selector switch to SIG. This completes the sensitivity adjustment and calibration of the recorder.

B. INSTRUMENT PREPARATION AND PRE-FLIGHT CALIBRATION (DELTA I INSTRUMENT)

The instrument is prepared for flight at the instrument reparation facility described in Section VII. The block and schematic diagrams of the Delta I system are shown in Figures 16 and 17 respectively while a photograph of the system is shown in Figure 18.

1. The instrument base plate of the parachute assembly (Figures 12 & 18) is attached to the Delta I instrument package by four screws (1/2", 10/32 Flathead) which pass through four drilled holes (#3 drill) in the base plate into the base of the instrument package. The base plate is shown attached to the instrument in Figure 28.
2. The instrument power supply is connected by mating the female plug at the end of the power supply leads with the male plug on the instrument case (Figure 28). The color-code and operating voltages are given in Figure 16.
3. The output of the transmitter tube is then monitored through use of a test set (TS-538-C/U, Allen D. Cardwell Electric Corporation) and the frequency of the transmitter tube is set at the assigned operating frequency (1670-1695 megacycles/sec) by turning the slotted screw on the side of the transmitter tube.
4. The terminals of a resistance box (22k - 5 megohms) are connected to a male plug (Switchcraft micro-plug 850) which in turn is inserted into the corresponding female jack (Switchcraft micro-jax TR-2A) on the instrument case (Figure 29). This disconnects the thermistor from the circuit and replaces it with the variable resistances (±1%) of the resistance box. Values of resistance between 22 k and 5 megohms (the resistance range of the thermistor between +40 and -70°C) are placed in the circuit which modulates the output of the transmitter as described in Section V-C. The output of the transmitter is received by the GMD System and recorded on the TMQ

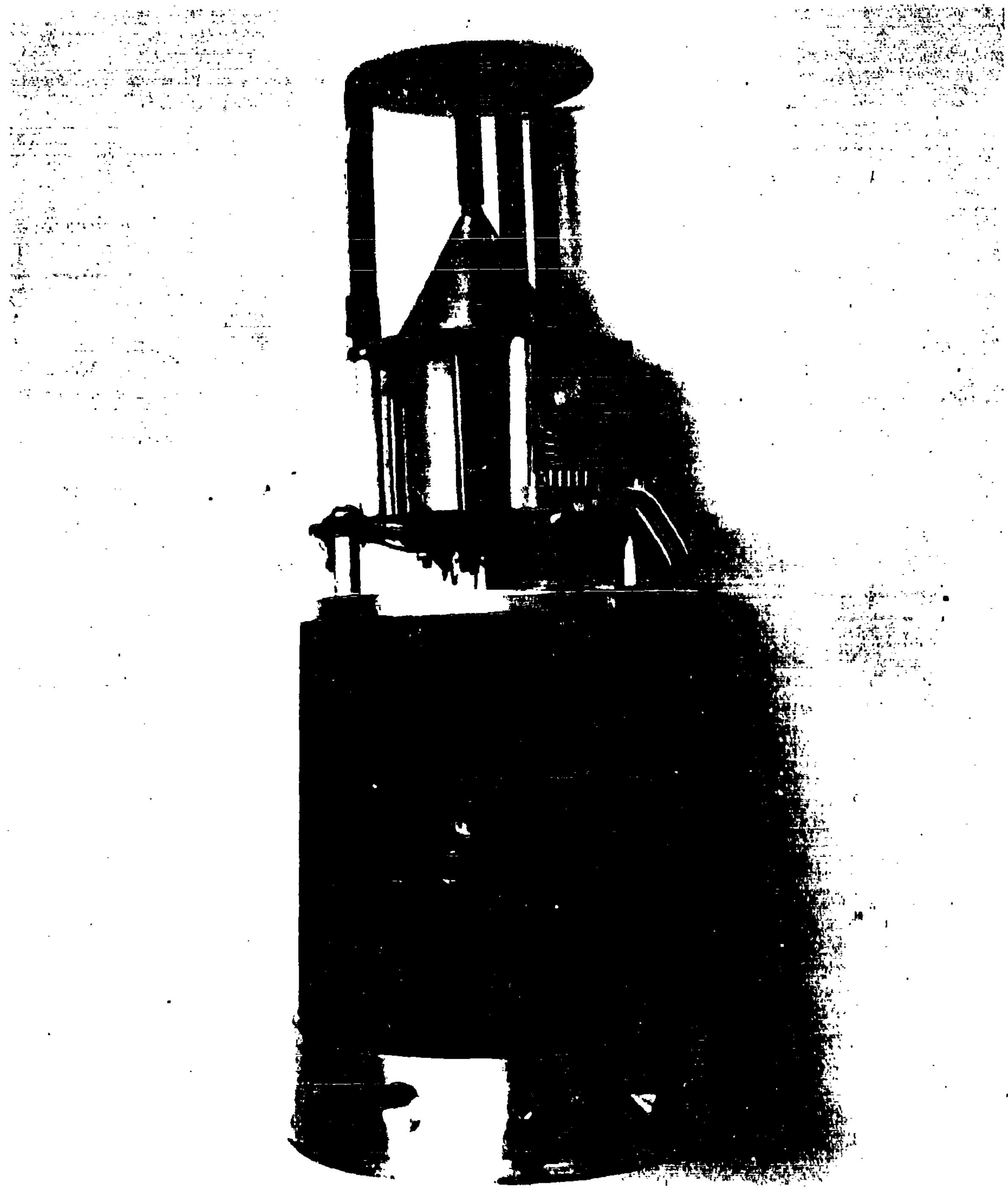


FIGURE 28

DELTA I INSTRUMENT SHOWING BASE PLATE

recorder as described in Section VIII-A. This procedure calibrates the telemetry system and gives the recorder pen position corresponding to the value of resistance in the instrument.

5. The recorder pen position corresponding to the value of the reference resistance is recorded.
6. The thermistor is connected into the circuit by removing the plug which joins the resistance box to the instrument. The overall accuracy of the system (temperature sensor, receiver and recorder) is then determined. The resistance of the thermistor at the existing room temperature is determined from the pen position of the calibrated recorder. The thermistor temperature corresponding to this value of thermistor resistance is determined from the calibration giving thermistor resistance as a function of temperature which accompanies the instrument. The temperature value thus obtained is then compared with the temperature as determined by a calibrated thermometer ($\pm 0.5°C$) placed in the immediate vicinity of the instrument thermistor.
7. The instrument is disconnected from the power supply by removing the battery plug, thus conserving the energy of the power supply until just prior to the time that the instrument is placed in the rocket nose-cone. An attempt is made to keep the time that the battery is utilized during calibration to no more than 10 minutes.
8. The contacts on the jack used in instrument calibration are then soldered so as to insure that the thermistor is not removed from the circuit by the malfunction of the plug contacts due to the high accelerations experienced at rocket launch and sensor expulsion from the rocket. At approximately T-30 minutes the Delta I instrument, parachute container, and nose-cone are taken from the instrument preparation facility to the rocket launching pad. At T-20 minutes the instrument is connected to its power supply and a check is made with the GMD-1 location to determine if the transmitted signal is being received. The instrument is then placed in the nose-cone of the rocket.
9. At T-2 minutes, the calibrated recorder chart of the TMQ-5 recorder is turned on and runs at a speed of 1 in/minute. A recording is made of thermistor resistance as a function of time from T-2 minutes to the end of the instrument flight (approximately T+45 minutes).

C. ROCKET LAUNCHING PROCEDURES

1. The Automatic Rocket Impact Prediction System (ARIP)

The manner in which the ARIP system accepts wind data from the radiosonde, pilot balloons, and tower-mounted wind sensors and then based upon the Wind Weighting Theory, predicts the impact point of the rocket motor is outlined in Section VI.

Two hours prior to the scheduled launching time of the rocket (T-0) a radiosonde instrument is released on a balloon and tracked by a GMD-1 Rawin receiver. The rate of rise of the balloon is such that at the end of one hour wind data to an altitude of approximately 60,000 ft is available to the ARIP system.

Also beginning at T-2 hours standard pilot weather balloons (tracked by theodolites) are released at intervals of every 30 minutes until the time of T-45 minutes is reached. From T-45 minutes until T-30 minutes, the pilot balloons are released at intervals of 15 minutes, while from T-30 to T-0, they are released at 10-minute intervals. Wind data, thus obtained, to an altitude of 2,000 ft is supplied to the ARIP system.

Wind data to an altitude of 112 ft is furnished continuously to the ARIP system from the tower-mounted wind sensors. At T-45 minutes, based upon the above three sources of wind data supplied to the ARIP computer, a preliminary rocket launcher setting is given to the launch control center and to the launching pad. Based upon the subsequent wind information from the tracking of the pilot balloons and from the tower-mounted wind sensors, continuing predictions are made of the rocket impact point until at T-10 minutes a final launcher setting in terms of azimuth and quadrant elevation angles is given to the launching pad. If the computed ballistic wind effect is such that the predicted point of rocket motor impact is more than thirty miles from the predicted no-wind impact point, the launch-control center is informed that it is not advisable to launch the rocket.

2. The Launching Pad

The procedures utilized on the launching pad at WSMR for physically launching the rocket are considered among the more important ones with regard to the successful flight of the rocket system. Reference to Figures 2, 4, 5, 7, 10, 11, 12 and 13 may prove helpful in visualizing the various steps in the preparation of the Arcas rocket temperature and wind sensing system for flight.

At 60 minutes prior to the scheduled launch time of the rocket (T-60 minutes) the parachute and parachute container are taken from the instrument preparation building to the rocket pad; the rocket motor is taken from the rocket-storage building to the pad. The metal bands, screws and lid are removed from the rocket motor container. Then

a. The styrofoam spacers for the launcher are removed.

b. The rocket motor is removed from the container and placed on a work-bench as shown in Figure 29. The rocket motor body is grounded through the grounding-strap on the rocket pad. Care is taken that the rocket is never lifted while holding the fins.

c. The igniter, launcher piston and arms, and gas generator-charge are removed from the container.

d. The igniter is placed in a 1/4" steel container with a sliding cover in which is placed a hole. The electrical leads of the igniter are brought out through the hole and the cover is then closed. The shunting wire of the igniter is removed and the resistance of the igniter circuit is determined with an ohmmeter while the maximum test current is limited to 0.10 amperes. The igniter is considered satisfactory if its resistance lies between .75 and 1.50 ohms. The shunting wire is replaced on the igniter and it is left in the steel container until installation in the rocket motor.

e. The metal arms are attached to the launcher piston with screws which are mounted on the piston.

f. The serial number of the rocket motor is recorded. The weight of the parachute container and Delta I instrument with base plate attached are determined and recorded.

g. The lanyard on the after-end of the parachute container is attached to the head-end closure of the rocket motor by screwing the nut on the end of the lanyard into the fitting on the head-end closure. A 9/16" end-wrench is used to tighten the nut to a "just snug" position. The lanyard is then coiled smoothly into the after-end of the parachute container and the container is secured to the rocket motor by turning the threads of the parachute container in a clockwise direction (as viewed from the nose of the rocket) into the corresponding threads on the head-end of the rocket motor. Since the parachute container is made of aluminum, care is taken that the parachute container does not support any part of the rocket motor weight while it is resting on the cradles of the work-bench.

h. A 1/8" thick rubber shock-absorber is placed over the center stud in the head-end of the parachute container.

i. The firing pin on the gas generator charge is armed by screwing the arming tool into the hole in the top of the gas generator body and pulling upward. The arming tool is then removed and the charge is placed in the charge receptacle on the launcher.

j. The gas generator hose is connected.

FIGURE 29

ARCAS ROCKET ON THE LAUNCHING PAD

k. The launcher tube is greased with MIL-G-10924 grease before each shot and is inspected to determine that it is clear.

l. A knife is used to cut a strip 1.25" wide from one side of three of the styrofoam spacers. The one remaining spacer is not cut on the edges. In addition, the corners on the front-end of all spacers are removed by cutting. Experience has shown that this trimming is necessary in order to place the rocket and four spacers in the launcher.

m. At T-30 minutes the Delta I instrument and nose-cone are taken to the pad. The Delta I instrument package is connected to the power source by mating the plug of the battery leads with the corresponding plug on the instrument case. The R.F. receiver location is then contacted to determine if the transmitted signal is being received.

n. The ball bearings (six) are passed through the ball-bearing holes in the nose-cone to insure that the holes are large enough to prevent the ball bearings from hanging in the holes at nose-cone separation. If the holes are too small they are filed cautiously until the ball bearings just pass through the holes. <u>Care is taken that the holes in the nose-cone used for shipping are not mistaken for the ball-bearing holes</u>.

o. The nose-cone is inspected to see that no loose material is contained therein. The nose-cone is then placed over the instrument package and the ball-bearing holes are aligned with the counter-sunk holes in the instrument base plate. The six ball-bearings are then placed in the holes, the ball bearings in the bottom positions being held in place with the fingers. The nose-cone is then slipped into the head-end of the parachute container and secured in place by mating the hole in the instrument base plate with the stud in the head-end of the parachute container.

p. The nose-cone is then turned in a clock-wise direction (as viewed from the tip of the nose-cone) until the nose-cone body is snug against the body of the parachute container. <u>Care is taken not to overtighten since this may cause the shear pins that secure the forward closure of the parachute container to break.</u> To check the tightness of the assembly, a force of approximately five pounds is exerted on the tip of the nose-cone. If the gap between the nose-cone and the parachute container is less than 1/32 of an inch the assembly is sufficiently tight. This completes the rocket motor and instrument assembly. The center of gravity of the rocket system is determined by balancing the rocket on a knife-edge.

q. The firing line is checked by connecting a voltmeter to the electrical plug in the breech plate of the launcher. The launch control center is contacted for a firing line check and the short circuit is removed from the firing line. A voltage is applied to the firing line at the launch control center and the firing line voltage is determined by the voltmeter. A voltage of 110 volts is considered satisfactory. The firing line is again short-circuited and the voltmeter is removed.

r. The rocket is loaded in the launcher by placing the uncut styrofoam spacer (see item m) on the bottom of the launcher tube so that the end of the spacer that is formed to conform with the fins of the rocket is directed outward and extends beyond the breech of the launcher. Two men then place the rocket on the spacer that has been placed in the tube and slide the rocket forward into the tube with the fins straddling the spacer until the after edges of the fins are within a short distance of the after end of the spacer. Care is taken that the fins are protected during the operation. The three remaining spacers are placed in position between the fins with the ends of the spacers that are formed to conform with the fins directed toward the rear of the launcher. (See Figure 30)

s. The launcher piston is held flush against the nozzle end of the rocket with the hole in the piston centered on the rocket nozzle and with the two piston rocker arms running parallel with the launcher tube, between the fins and along the inside of the spacers on the two sides of the rocket motor. The piston and rocket are then pushed forward into the launcher by exerting a steady force at the center of the piston until the after-end of the piston just clears the stop-pin holes located at the bottom of the launcher tube. The stop-pins are then inserted into the stop-pin holes and secured by placing nuts on the threads in the stop-pins. (See Figure 31)

t. The igniter is removed from the protective steel container (item e) for installation in the rocket motor. The shunted firing line is connected to the female connector on the outside of the launcher breech plate. The shipping plug is then unscrewed from the nozzle of the rocket and the igniter is inserted into the rocket nozzle and secured in place by turning the threads on the igniter in a clockwise direction until the igniter is fully seated. The shorting wire is removed from the connector in the igniter-leads and the igniter connector is mated with the connector on the inner side of the launcher breech plate.

u. The launcher breech plate is then closed and locked in position. The final azimuth and quadrant elevation settings are relayed from the launch control center and the launcher is set accordingly. The short-circuit is removed from the rocket pad end of the firing line and the range is cleared of all personnel.

D. DATA ACQUISITION

FIGURE 30

PLACING THE ROCKET IN THE LAUNCHER

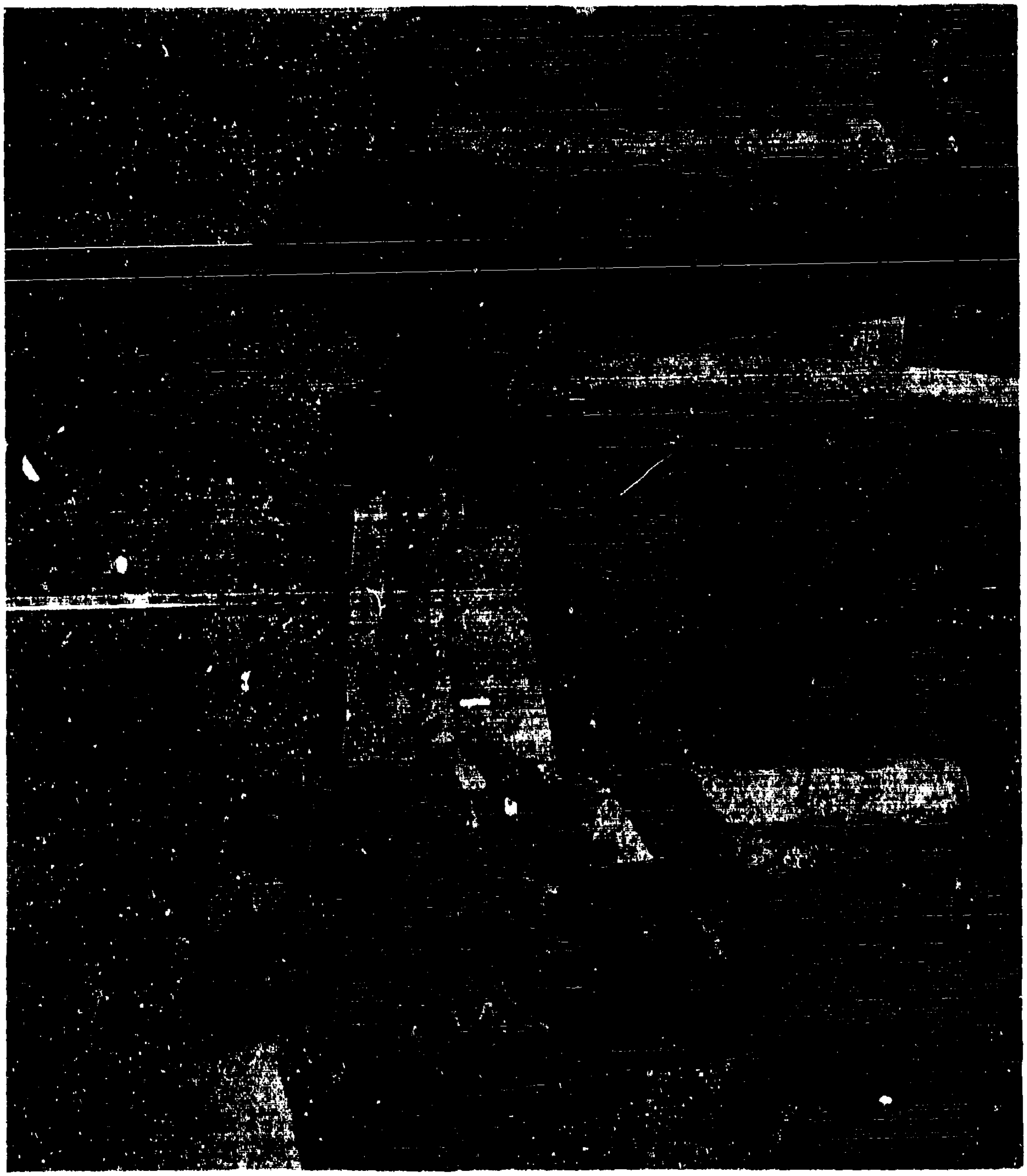


FIGURE 31

PLACING THE ROCKET IN THE LAUNCHER

1. The GMD-1 Receiver and TMQ-5 Recorder

At T-2 minutes the GMD-1 antenna receives the transmitted signal from the Delta I instrument in the nose-cone of the rocket which is in the launcher on the pad and the TMQ-5 recorder chart is turned on and runs at a speed of 1 in/min. The recorder pen plots the pulse-recurrence frequency (as determined by the resistance of the instrument thermistor) on the calibrated recorder chart as a function of time. The elapsed time from T-2 minutes until the end of the instrument flight is determined from the chart speed. At the time T-0 the rocket is launched and ascends to a height of approximately 220,000 ft (67 km) which it reaches at approximately 130 seconds after launch time. At this time the parachute and temperature-sensing instrument are separated from the rocket motor. When the parachute deploys, the nose-cone falls free from the instrument and the GMD-1 continues to receive and demodulate the transmitted signal. The pen position of the calibrated recorder continues to record the pulse recurrence frequency as determined by the thermistor resistance (corresponding to the temperature of the thermistor) in the instrument at the time t.

Figure 32 is a typical recording giving the Delta I pulse recurrence frequency (proportional to recorder pen displacement from zero) as a function of time as received by the GMD-1 system and recorded by the TMQ-5 Meteorological recorder.

The manner in which these data are treated to give temperature as a function of altitude is discussed in Section XI, DATA REDUCTION PROCEDURES TO OBTAIN TEMPERATURES AND WIND VELOCITIES.

2. The Radar Systems (M-33 and FPS-16)

At T-2 minutes the M-33 radar antenna is slaved to the GMD-1 receiver system. The FPS-16 radar antenna is trained on the rocket at the launching pad. At T-0 the rocket is fired. The M-33 radar antenna is positioned by the GMD system until the Delta I instrument and parachute are separated from the rocket motor. When the radar reflective parachute is deployed and presents a suitable target, the M-33 system is then automatically disengaged from the GMD-1 system and tracks the descending parachute to give parachute position as a function of time. The FPS-16 radar system skin-tracks the rocket as it ascends, and then upon separation of the instrument package and parachute, tracks the radar reflective parachute to give parachute position as a function of time.

At meteorological rocket stations where the FPS-16 radar system is not available, the M-33 or AN/MPQ systems are utilized to determine the parachute position.

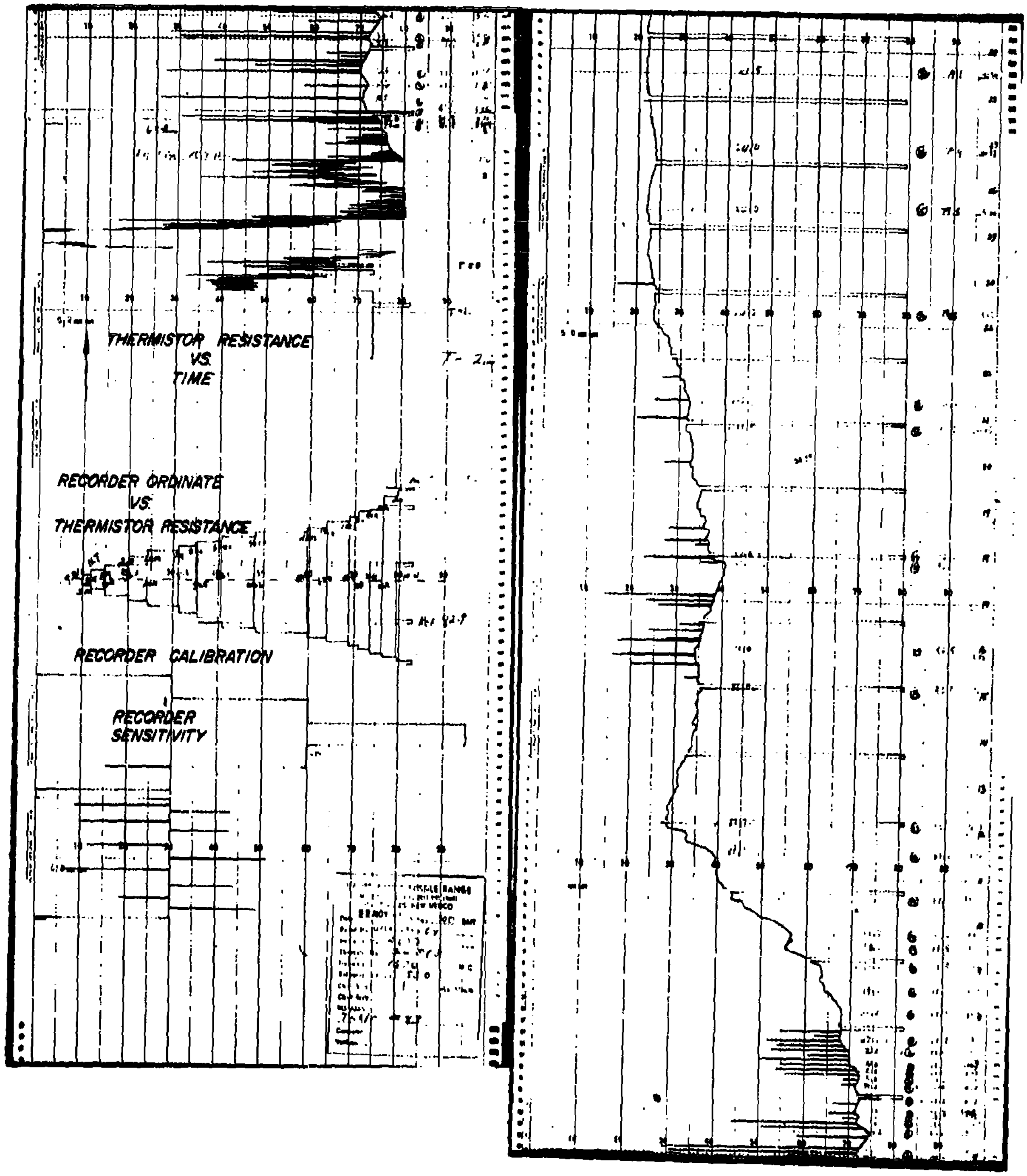


FIGURE 32

A TYPICAL RECORD FROM WHICH
STRATOSPHERIC TEMPERATURE IS DETERMINED

Since the FPS-16 radar system is available at WSMR and since it has a somewhat higher tracking precision than the other radar systems listed in Table 3, it is used to determine the parachute position. The position data are fed to the FPS-16 computer which converts the spherical coordinates of position (r,ϕ,θ) to Cartesian coordinates of position (x,y,z). These position coordinates are displayed on two plotting boards associated with the FPS-16 system, one in terms of an east-west and north-south coordinate plot and the other in terms of slant range, r, as a function of altitude z. Time is periodically recorded on both records of position. Figure 33 is a typical record of rocket and parachute position as determined by the FPS-16 radar system.

The manner in which these data are treated to give wind velocity as a function of altitude is discussed in XI, <u>DATA REDUCTION PROCEDURES TO OBTAIN TEMPERATURES AND WIND VELOCITIES</u>.

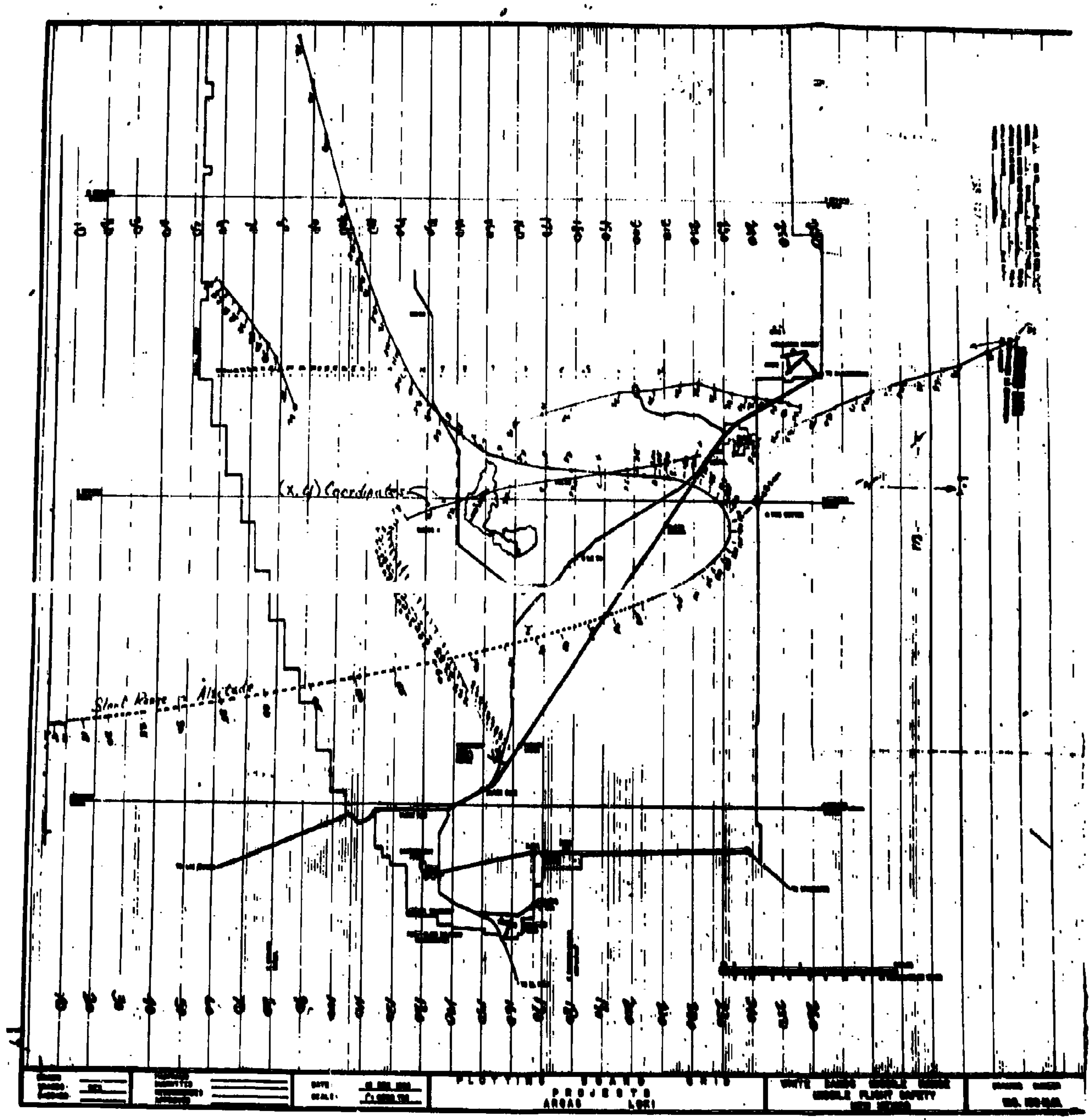


FIGURE 33

THE RECORD OF THE PARACHUTE POSITION AS DETERMINED BY THE FPS-16 RADAR SYSTEM

E. TIME SCHEDULE SUMMARY OF X-A,B,C,D

TYPICAL PROCEDURES FOR ROCKET LAUNCHING AND DATA ACQUISITION

Time Schedule Summary of Section X - A, B

Time	A. Preflight Checks of GMD-1 Receiver and TMQ-5 Recorder	B. Instrument Preparation and Recorder Calibration
T-2 hrs	Power is supplied to the Receiver and Recorder to allow time for circuit stabilization.	
T-90 min	Receiver and Recorder are checked for proper operation. Recorder sensitivity is adjusted. (Section X-A, Steps 1-6).	
T-60 min	The transmitted signal is received from the Delta I instrument. After recorder calibration the receiver and recorder are placed in standby status.	Power is supplied to the Delta I instrument and it is checked for proper operation. The frequency is set at the assigned value. The recorder is calibrated to give temperature sensor resistance as a function of recorder pen position. The instrument is disconnected from the power supply. The calibration jack is soldered. (Section X-B, Steps 1-7)
T-30 min		The Delta I instrument is taken to the rocket pad.
T-20 min	The transmitted signal is received from the Delta I instrument at the rocket pad.	The Delta I instrument is connected to its power supply. Signal reception is checked with the GMD-1 receiver.
T-2 min	The recording chart is turned on to run at a speed of 1 inch/minute.	
T-0	The rocket is launched and tracked by the GMD-1 system.	

*T-0 is the scheduled launching time.

TYPICAL PROCEDURES FOR ROCKET LAUNCHING AND DATA ACQUISITION

Time Schedule Summary of Section X-C

Time	C. Rocket Launching Procedures 1. Automatic Rocket Impact Predictor	2. The Launching Pad
T-2 hrs	A radiosonde is launched and is tracked by a GMD-1 to give winds up to 100,000 ft. A pilot balloon is launched and tracked by theodolites to give winds up to 2,000 ft.	
T-90 min	The second pilot balloon is launched and tracked by theodolites. Wind data from the tower-mounted wind sensors is recorded.	
T-60 min	The third pilot balloon is launched and tracked by theodolites. Tower-mounted wind sensor data is recorded. At T-45 minutes preliminary launcher setting is given. Pilot balloons are released at intervals of 15 minutes until T-0 is reached.	The parachute container and parachute are taken to the pad. The rocket is brought from the storage bunker. The rocket motor and parachute container are assembled. The igniter circuit is checked and the gas generator charge is installed. (Section X-C-2, Steps a-m)
T-30 min		The Delta I instrument and nose-cone are taken to the pad.
T-20 min		The power supply is connected to the Delta I instrument and reception is checked with the GMD-1 receiver. The nose-cone is assembled and the center of gravity is determined. The rocket is loaded in the launcher. The firing line is checked and the igniter installed. (Section X-C-2, m-t)
T-10 min	The final launcher setting is given.	Launcher breech is locked, final azimuth and elevation angles set, firing line short circuit removed at the pad, and the area cleared. (Section X-C-2, Step u)
T-0		The rocket is launched.

TYPICAL PROCEDURES FOR ROCKET LAUNCHING AND DATA ACQUISITION

Time Schedule Summary of Section X-D

Time	D. Data Acquisition 1. The GMD-1 Receiver and TMQ-5 Recorder	2. The Radar System
T-2 min	The GMD-1 antenna trained on the rocket at the pad. The TMQ-5 recorder chart is turned on to run at 1 inch/minute.	The M-33 system antenna is slaved to the GMD-1 receiver system. The FPS-16 radar system antenna is trained on the rocket at the pad.
T-0	The rocket is launched. The GMD-1 tracks the signal from the Delta I system in the nose-cone of the rocket as it ascends. The pen of the recorder records pulse-recurrence frequency as a function of time on the calibrated recorder chart.	The M-33 radar follows the rocket position as determined by the GMD-1 system. The FPS-16 skin-tracks the rocket as it ascends. The (x,y) coordinates of rocket position are plotted on one FPS-16 plotting board while slant range, r , as a function of altitude, z, is plotted on the other. Time is periodically recorded on the plotting board records.
T+128 sec	Delta I instrument, parachute and nose-cone separate from rocket motor. Nose-cone separates from Delta I instrument. GMD-1 tracks on the transmitted signal and the pen of the recorder continues to record pulse-recurrence frequency as function of time.	Three possible radar targets exist. The M-33 and FPS-16 systems track on the 15 foot metalized parachute which supports the Delta I instrument. The (x,y) and (r,z) coordinates of position are plotted. Time is recorded on the plot at periodic intervals.
T+45 min	Delta I instrument and parachute reach an altitude of approximately 50,000 ft. Tracking of instrument by the GMD-1 is discontinued.	Delta I instrument and parachute reach an altitude of approximately 50,000 ft. The M-33 and FPS-16 systems discontinue tracking of parachute.

XI. DATA REDUCTION PROCEDURES TO OBTAIN TEMPERATURE AND WIND VELOCITIES

The records shown in Figures 32 and 33 were obtained 22 November 1964 at WSMR with the Arcas Meteorological Sounding Rocket serving as the instrument vehicle. The temperature data of Figure 32 was transmitted from the Delta I temperature sensing instrument, received by the GMD-1 Rawin system and recorded on the TMQ-5 meteorological recorder. The instrument position, as shown in Figure 33, was determined by an FPS-16 radar system.

The various aspects of the missile range, the characteristics of the Arcas rocket sounding system, the characteristics of the data receiving and recording systems, the characteristics of the various radar systems, and the procedures for rocket launching and data acquisition are discussed in the preceding sections of this report. In that which follows, a somewhat detailed description is given of the various steps which have been developed and are utilized at WSMR to obtain temperature and wind velocity as functions of altitude from the records as shown in Figures 32 and 33.

A. THE DETERMINATION OF TEMPERATURE AS A FUNCTION OF ALTITUDE

The typical GMD-1 Receiver and TMQ-5 Meteorological Recorder record of Figure 32 shows, as indicated on the figure:

1. the pre-flight check of recorder sensitivity (Section X-A),
2. the pre-flight recorder calibration relating the recorder pen displacement from zero (the recorder ordinate) to thermistor resistance (Section X-B),
3. the recorder ordinate corresponding to the reference resistance at the time of pre-flight calibration,
4. the recorder ordinate corresponding to the value of thermistor resistance during the time of instrument flight (Section X-D), and
5. the recorder ordinate corresponding to the value of the reference resistance during the time of instrument flight.

The step-by-step manner in which these data are combined with,

1. the calibration curve of Figure 34 giving thermistor resistance as a function of thermistor temperature,
2. the radar determination of instrument altitude as a function of time (Figure 33), and

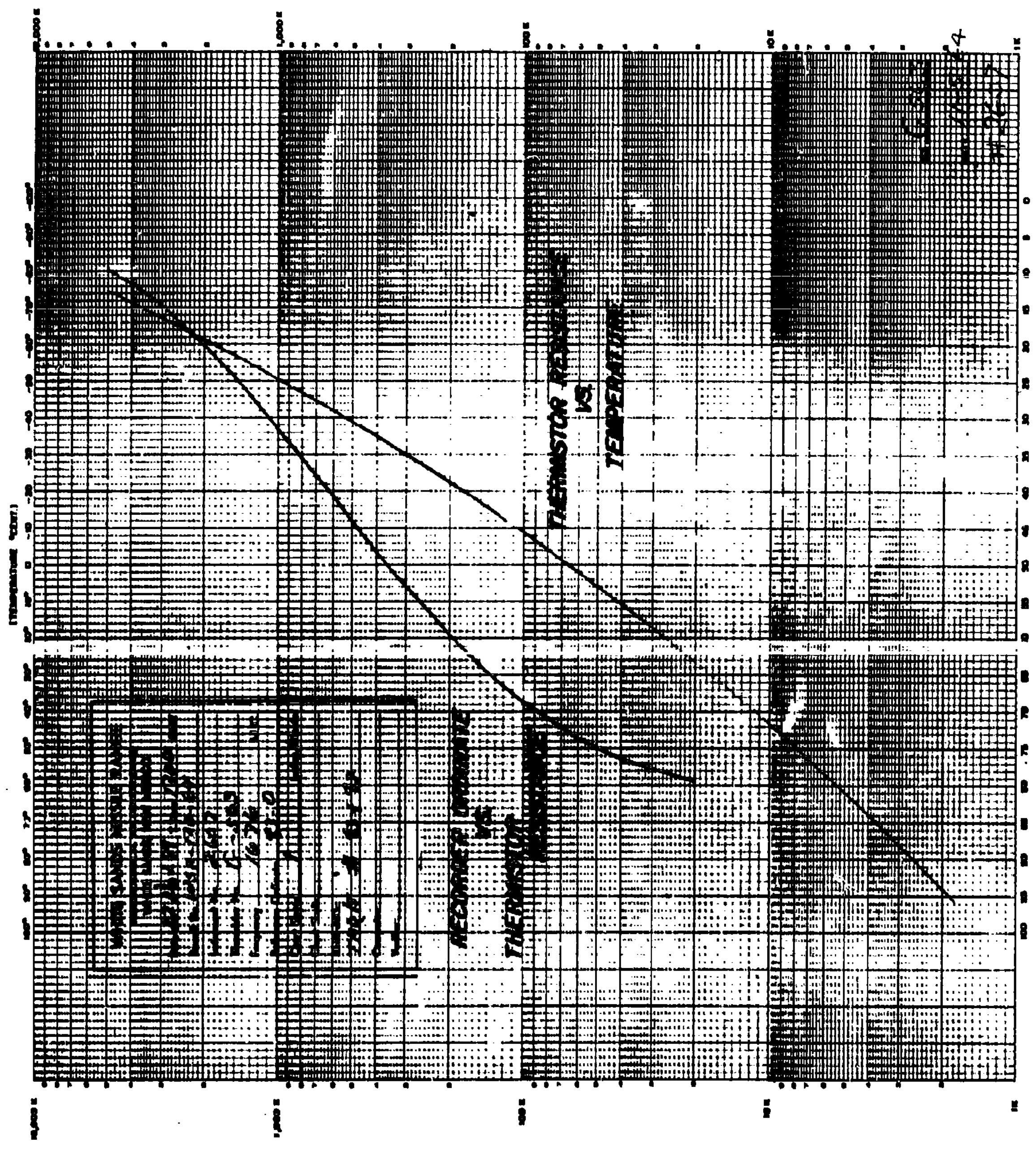


FIGURE 34

3. the Wagner* Correction to the observed thermistor temperature (Table 4),

to give temperature as a function of altitude is presented in that which follows. Each element of data, as it is determined, is recorded in the tabular form as shown in Table 5.

Refer to Figures 32, 33 and 34 and Tables 4 and 5. All times are determined relative to T-0, the launching time of the rocket, and are recorded in terms of minutes and seconds.

1. Determine the time and corresponding altitude of instrument and parachute expulsion from the radar plot of Slant Range vs Altitude, z. (Figure 33) Record the expulsion altitude. (Table 5)
2. Determine and record the time at which the parachute reached an altitude of 213,200 ft (65 km) from Slant Range vs Altitude (Figure 33). The temperature data above 65 km is considered invalid. Determine the time at which the record ends from Figure 32. These two times were recorded as 3:05 and 43:12 respectively in Table 5.
3. Determine from Figure 32 the recorder ordinate corresponding to the pre-flight reference resistance. This was recorded as 82.9 ordinates in Table 5. (The recorder ordinate x 2 = pulse-recurrence frequency corresponding to the reference or thermistor resistance.)
4. Determine the thermistor resistance as a function of recorder ordinate from the recorder trace labeled Thermistor Resistance vs Recorder Ordinate in Figure 32. This trace was produced by introducing standard known resistance values (±1%) ranging from 20 K ohms to 5 megohms into the Delta I circuit as is described in Section X-B. Each ordinate value is identified with the resistance value which produced it. As a matter of uniform procedure, the ordinate corresponding to the left-edge of the recorder-pen trace, when looking at the record in the direction of increasing time is read. To account for any nonlinearity in the recorder, the recorder chart is run at a speed of 1 in/minute and the values of resistance are varied from 20 K ohms to 5 megohms and then

*The Wagner Correction accounts for differences between observed thermistor temperature and the kinetic temperature of the environment in which it is immersed, as caused by forced convection, infrared and solar radiation, compressional heating, lead wire conduction and internal heating of the temperature sensing element. A summary of the Wagner Correction is given in the Appendix. For a complete discussion of the correction see N.K. Wagner, "Theoretical Accuracy of a Meteorological Rocketsonde Thermistor," Journal of Applied Meteorology, Vol. 3, Number 4, August, 1964.

INITIAL EXPULSION ALTITUDE 60 km

Total temperature corrections, in Celsius degrees, for fall rates as indicated:

Altitude	% faster than standard												Standard	% slower than standard												Altitude
in km	40%	30	20	18	16	14	12	10	8	6	4	2%	+0	2%	4	6	8	10	12	14	16	18	20	30	40%	in km
58	20.0	19.5	18.5	18.5	18.0	18.0	18.0	17.5	17.5	17.5	17.5	17.0	17.0	17.0	17.0	16.5	16.5	16.5	16.5	16.5	16.0	16.0	16.0	15.5	15.5	58
57	16.5	16.0	15.0	15.0	15.0	15.0	14.5	14.5	14.5	14.5	14.0	14.0	14.0	14.0	14.0	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.0	13.0	12.5	57
56	13.5	12.5	12.0	12.0	12.0	11.5	11.5	11.5	11.5	11.5	11.0	11.0	11.0	11.0	11.0	11.0	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.0	10.0	56
55	11.5	11.0	10.5	10.0	10.0	10.0	10.0	10.0	10.0	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.0	9.0	9.0	9.0	9.0	9.0	9.0	55
54	10.0	9.5	9.0	9.0	9.0	9.0	9.0	9.0	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.0	54
53	9.0	8.5	8.5	8.5	8.5	8.5	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	7.5	53
52	7.5	7.5	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	52
51	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	51

INITIAL EXPULSION ALTITUDE 65 km

Total temperature corrections, in Celsius degrees, for fall rates as indicated:

Altitude	% faster than standard												Standard	% slower than standard												Altitude
in km	40%	30	20	18	16	14	12	10	8	6	4	2%	±0	2%	4	6	8	10	12	14	16	18	20	30	40%	in km
62	33.0	31.5	30.0	30.0	29.5	29.5	29.5	29.0	29.0	28.5	28.5	28.0	28.0	28.0	27.5	27.5	27.0	27.0	27.0	26.5	26.5	26.5	26.5	25.5	25.0	62
61	29.5	28.0	27.0	27.0	26.5	26.5	26.0	26.0	26.0	25.5	25.5	25.0	25.0	25.0	24.5	24.5	24.5	24.0	24.0	24.0	23.5	23.5	23.5	23.0	22.5	61
60	25.5	24.5	23.5	23.0	23.0	23.0	22.5	22.5	22.0	22.0	22.0	21.5	21.5	21.5	21.0	21.0	21.0	20.5	20.5	20.5	20.5	20.0	20.0	19.5	19.0	60
59	22.0	21.0	20.0	20.0	20.0	19.5	19.5	19.5	19.0	19.0	19.0	18.5	18.5	18.5	18.0	18.0	18.0	18.0	17.5	17.5	17.5	17.5	17.5	17.0	16.5	59
58	18.5	18.0	17.0	17.0	16.5	16.5	16.5	16.0	16.0	16.0	16.0	15.5	15.5	15.5	15.5	15.0	15.0	15.0	15.0	15.0	14.5	14.5	14.5	14.0	14.0	58
57	15.0	14.5	13.5	13.5	13.5	13.5	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.0	12.0	11.5	57
56	13.0	12.0	11.5	11.5	11.5	11.0	11.0	11.0	11.0	11.0	10.5	10.5	10.5	10.5	10.5	10.5	10.0	10.0	10.0	10.0	10.0	10.0	10.0	9.5	9.5	56
55	11.5	11.0	10.5	10.0	10.0	10.0	10.0	10.0	10.0	9.5	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	8.5	8.5	8.5	8.5	8.5	8.5	8.5	55
54	9.5	9.0	8.5	8.5	8.5	8.5	8.5	8.5	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	7.5	54
53	8.5	8.0	8.0	8.0	8.0	8.0	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.0	53
52	7.0	7.0	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	52
51	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	51

INITIAL EXPULSION ALTITUDE 70 km

Total temperature corrections, in Celsius degrees, for fall rates as indicated:

Altitude	% faster than standard												Standard	% slower than standard												Altitude
in km	40%	30	20	18	16	14	12	10	8	6	4	2%	±0	2%	4	6	8	10	12	14	16	18	20	30	40%	in km
65	41.5	40.0	38.5	38.0	37.5	37.5	37.0	37.0	36.5	36.5	36.0	36.0	35.5	35.0	35.0	35.0	34.5	34.5	34.0	33.5	33.5	33.5	33.0	32.5	31.5	65
64	37.5	36.0	34.5	34.5	34.0	34.0	33.5	33.0	33.0	32.5	32.5	32.0	32.0	32.0	31.5	31.5	31.0	31.0	30.5	30.5	30.5	30.0	30.0	29.0	28.5	64
63	34.0	33.0	31.5	31.0	31.0	30.5	30.5	30.0	30.0	29.5	20.5	20.0	20.0	20.0	28.5	28.5	28.0	28.0	28.0	27.5	27.5	27.0	27.0	26.5	25.5	63
62	31.5	30.0	28.5	28.5	28.0	28.0	28.0	27.5	27.5	27.0	27.0	26.5	26.5	26.5	26.0	26.0	25.5	25.5	25.5	25.0	25.0	25.0	25.0	24.0	23.5	62
61	28.0	26.5	25.5	25.5	25.0	25.0	24.5	24.5	24.5	24.0	24.0	23.5	23.5	23.5	23.0	23.0	23.0	22.5	22.5	22.5	22.0	22.0	22.0	21.5	21.0	61
60	24.5	23.5	22.5	22.0	22.0	22.0	21.5	21.5	21.0	21.0	21.0	20.5	20.5	20.5	20.0	20.0	20.0	19.5	19.5	19.5	19.5	19.0	19.0	18.5	18.0	60
59	21.0	20.0	19.0	19.0	19.0	18.5	18.5	18.5	18.0	18.0	18.0	17.5	17.5	17.5	17.0	17.0	17.0	17.0	16.5	16.5	16.5	16.5	16.5	16.0	15.5	59
58	18.0	17.5	16.5	16.5	16.0	16.0	16.0	15.5	15.5	15.5	15.5	15.0	15.0	15.0	15.0	14.5	14.5	14.5	14.5	14.5	14.0	14.0	14.0	13.5	13.5	58
57	14.5	14.0	13.0	13.0	13.0	13.0	12.5	12.5	12.5	12.5	12.0	12.0	12.0	12.0	12.0	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.0	11.0	10.5	57
56	12.5	11.5	11.0	11.0	11.0	10.5	10.5	10.5	10.5	10.5	10.0	10.0	10.0	10.0	10.0	10.0	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.0	9.0	56
55	10.5	9.5	9.5	9.0	9.0	9.0	9.0	9.0	9.0	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.0	8.0	8.0	8.0	8.0	8.0	8.0	55
54	9.0	8.5	8.0	8.0	8.0	8.0	8.0	8.0	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.0	54
53	8.0	7.5	7.5	7.5	7.5	7.5	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	6.5	53
52	6.5	6.5	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	52
51	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	51

TABLE 4

WAGNER CORRECTIONS FOR THE INDICATED
EXPULSION ALTITUDE AND FALL RATES

REFERENCE ORD. 82.9 EXPULSION ALTITUDE 70714 meters

No.	Time	Ordinate	Reference Drift	Corr. Ordinate	Thermistor Temp.	Corr.	Corr. Temp.	Altitude Feet x 10^{-3}	Altitude Meters x 10^{-1}
1	3:05	75.0	81.8	76.0	+9.5	-35.5	-26.0	213.2	6498
2	3:11	75.0	81.8	76.0	+9.5	-29.0	-19.5	208.0	6340
3	3:26	71.4	81.8	72.4	±0.0	-26.5	-26.5	203.2	6194
4	3:37	70.5	81.8	71.4	-2.5	-20.5	-23.0	197.5	6020
5	4:00	71.6	81.8	72.6	+0.5	-12.0	-11.5	188.2	5736
6	4:17	70.0	81.8	70.9	-4.0	-10.5	-14.5	182.8	5572
7	4:53	72.5	81.8	73.5	+2.0	-7.0	-5.0	172.7	5264
8	5:02	71.8	81.8	72.8	+0.5	-6.0	-5.5	170.2	5188
9	5:30	74.5	81.8	75.5	+8.0	-5.0	+3.0	163.3	4977
10	5:43	71.8	81.8	72.8	+0.5	-5.0	-4.5	160.3	4886
11	5:51	72.2	81.8	73.2	+1.0	-5.0	-4.0	158.2	4822
12	5:56	71.2	81.8	72.2	-1.0	-5.0	-6.0	156.9	4782
13	6:12	72.2	81.8	73.2	+1.0	-4.5	-3.5	153.7	4685
14	6:30	71.2	81.8	72.2	-1.0	-4.5	-5.5	150.7	4593
15	6:38	72.0	81.8	73.0	+0.5	-4.0	-3.5	149.7	4563
16	6:49	72.0	81.8	73.0	+0.5	-4.0	-3.5	148.2	4517
17	6:52	70.0	81.8	70.9	-4.0	-4.0	-8.0	148.0	4511
18	7:15	70.0	81.8	70.9	-4.0	-4.0	-8.0	144.4	4401
19	7:30	67.7	81.7	68.7	-9.0	-4.0	-13.0	142.0	4328
20	8:05	68.0	81.7	69.0	-8.5	-4.0	-12.5	137.0	4176
21	8:33	64.0	81.7	65.0	-15.0	-4.0	-19.0	133.6	4072
22	9:05	63.2	81.5	64.3	-16.0	-3.5	-19.5	130.3	3972
23	9:30	55.5	81.5	56.5	-26.0	-3.5	-29.5	127.4	3883
24	9:47	56.7	81.4	57.7	-24.5	-3.5	-28.0	126.0	3840
25	10:33	43.3	81.3	44.2	-38.5	-3.0	-41.5	121.6	3706
26	11:30	39.0	81.2	39.8	-43.0	-3.0	-46.0	116.8	3560
27	12:08	28.7	81.1	29.3	-53.0	-3.0	-56.0	113.6	3463
28	15:03	36.0	80.5	37.1	-45.5	-2.5	-48.0	102.7	3130
29	15:56	34.2	80.5	35.2	-47.0	-2.5	-49.5	100.2	3054
30	17:47	40.7	80.3	42.0	-41.0	-2.0	-43.0	094.8	2890
31	17:57	37.0	80.3	38.2	-44.5	-2.0	-46.0	094.4	2877
32	20:45	31.5	80.0	32.6	-49.5	-1.5	-51.0	087.4	2664
33	21:18	32.3	80.0	33.5	-48.5	-1.5	-50.0	086.2	2627
34	23:15	24.0	79.6	25.0	-56.5	-1.5	-58.0	082.9	2527
35	25:30	22.0	79.5	22.9	-58.5	-1.0	-59.5	079.0	2408
36	26:48	24.0	79.4	25.1	-56.5	-1.0	-57.5	077.7	2368
37	28:30	21.5	79.1	22.5	-59.0	-1.0	-60.0	074.7	2217
38	31:00	21.2	79.0	22.2	-59.0	-0.5	-59.5	071.3	2173
39	31:30	19.0	79.0	19.9	-61.5	-0.5	-62.0	070.8	2158
40	36:30	18.8	78.7	19.8	-61.5	0.0	-61.5	065.1	1984
41	37:50	17.0	78.7	17.9	-63.5	0.0	-63.5	063.6	1939
42	40:15	18.8	78.6	19.8	-61.5	0.0	-61.5	061.4	1871
43	43:12	16.4	78.5	17.3	-64.5	0.0	-64.5	058.8	1792

TABLE 5

SUMMARY OF TEMPERATURE VS ALTITUDE DATA

from 5 megohms to 20 K ohms. The two recorder pen positions corresponding to a given resistance value are then connected by a line. The ordinate at the midpoint of a given connecting line is taken as the ordinate value corresponding to the given resistance.

5. From the recorder ordinate and resistance values thus determined, plot a graph of Thermistor Resistance vs Recorder Ordinate (Figure 34).
6. Determine the ordinate values at various instants of time from the recorder trace designated as Thermistor Resistance vs Time in Figure 32. From the infinite number of data points obtainable, it is necessary, for reasons of data publication, to select no more than 50 data points which are representative of the entire record. The total time of the record is divided into increments of time Δt. The values of recorder ordinate in a given time interval Δt_n are averaged by drawing a fine pencilled straight line from the ordinate at the beginning of the time interval to the ordinate at the end of the time interval under the restriction that no average value of thermistor temperature thus obtained in the time interval, Δt_n, will differ by more than $\pm 2°C$ from any recorded value of thermistor temperature in the same interval. In addition to the average ordinate values thus obtained, instantaneous ordinate values are chosen as data points at times when the ordinate value changes abruptly. The ordinate tolerance corresponding to $\pm 2°C$ in each time interval is determined from the Recorder Ordinate vs Thermistor Resistance and Thermistor Resistance vs Temperature Curves. For example, from Figure 34, when the ordinate value is 60, the corresponding value of thermistor resistance is -22°C. A change of thermistor temperature of +2°C to -20°C would correspond to a thermistor resistance of 180 K ohms and a corresponding ordinate value of 61.5. Thus no averaged ordinate should differ from a recorded ordinate in the neighborhood of 60 by more than 1.5 ordinates.
7. From each ordinate value selected by the criteria outlined above in (6), draw a pencilled line to the corresponding time on the edge of the recorder chart. These times and the corresponding ordinate values are written in pencil on the record, given an identifying number and recorded in the columns headed Number, Time and Ordinate respectively on the data sheet (Table 5).
8. To determine the change in the characteristics of the temperature sensing instrument during the instrument flight, determine the change in the reference ordinate (the approximately constant height ordinates of Figure 32). Connect all reference ordinates with a fine pencilled line. Read the value of the reference ordinate

at the times corresponding to the chosen data points and record these values in the column headed Reference Drift on the data sheet (Table 5).

9. Make the correction for instrument drift according to the equation,

$$O_{ct} = \left(\frac{O_{ro}}{O_{rt}}\right) O_t$$

where O_{ct} is the corrected ordinate value at time t, O_{ro} is the reference ordinate value at t=0, O_{rt} is the reference ordinate value at time t, and O_t is the ordinate value at time t. List the corrected ordinate values thus obtained in the column headed Corrected Ordinate (Table 5).

10. From the two calibration curves, Recorder Ordinate vs Thermistor Resistance and Thermistor Resistance vs Temperature (Figure 34), determine the thermistor temperature at time t. For example from Table 5, for data point 20 at time = 8:05, the corrected ordinate value is 69.0. From Figure 34 the thermistor resistance corresponding to 69.0 is 100 K and the corresponding thermistor temperature is -8.5°C.

11. From the radar plot Slant Range vs Altitude (Figure 33), determine the altitudes corresponding to the temperature data time points. The altitude values, expressed in ft, are converted to meters and entered in the columns, Altitude (Feet x 10^{-3}) and Altitude (Meters x 10^{-1}) of Table 5.

12. The Wagner Corrections (see Appendix) to the observed thermistor temperatures are then made. The magnitude of the corrections are dependent upon the altitude of instrument expulsion and the instrument fall rate. Table 4 shows the computer calculated correction values for expulsion altitudes of 70, 65 and 60 km at the standard fall rate and at fall rates which differ from the standard by amounts ranging from 2% to 40%. All values are negative. These tabulated corrections have been made by the Meteorological Rocket Network Section, Data Analysis Center of Schellenger Research Laboratories, Texas Western College, El Paso, Texas. They are available for expulsion altitudes ranging from 80 to 60 km. The final data reduction for all stations of the Meteorological Rocket Network are carried out at this location. As is indicated in the discussion of the Wagner Correction in the Appendix of this report, no correction due to fall rate is necessary below altitudes of 50 km.

Thus to determine the Wagner Correction from the computed tables, the fall rate above 50 km must be determined. Figure 35 shows the standard fall rate and the observed fall rate for the particular instrument discussed here. The observed fall rate in this case was determined from $\Delta z/\Delta t$ for each altitude and time increment listed in the tabular summation of data, Table 5. The altitude assigned to a given fall rate was the altitude at the midpoint of the given time interval as determined from the Slant Range vs Altitude of Figure 33.

The percentage difference (relative to the standard fall rate) between the observed and standard fall rates at each altitude corresponding to a given temperature data point was determined from the fall rate curves of Figure 35. From Table 4 giving the Wagner corrections for an expulsion altitude of 70 km, the corrections to the thermistor temperature at altitudes from 65-51 km are determined and listed in the data sheet under Correction (Table 5). For example at an altitude of 57 km, the fall rate was found to be 4% greater than the standard fall rate. The corresponding correction in Table 4 is -12°C.

13. The corrections to the thermistor temperature as obtained in (12) above are then added algebraically to the observed thermistor temperatures and the corrected temperatures are recorded on the data sheet under Corrected Temperature (Table 5). This completes the procedure for the determination of temperature as a function of altitude.

B. THE DETERMINATION OF WIND VELOCITY AS A FUNCTION OF ALTITUDE

The following are the steps in the procedure for the determination of wind velocity as a function of altitude as determined from the radar plot of position of the radar-reflective parachute which supports the Delta I temperature sensor. All of the information necessary for the determination of wind velocities and corresponding altitudes is contained in the Cartesian coordinate (x,y) and the Slant Range vs Altitude traces of Figure 33. Time is recorded at successive intervals on each trace.

The current standard data reduction technique utilizes a variable time interval during the parachute descent. This is due to the relatively large fall rate of the parachute just after sensor expulsion from the rocket followed by a decreasing fall rate as the parachute descends. For this reason wind data points are chosen on the (x,y) radar trace of position as follows:

1. a one-half-minute interval in the time interval from 0-5 minutes,
2. a one-minute interval in the time interval from 5-20 minutes, and
3. a two-minute interval in the time interval from 20 minutes to the time at which the parachute reaches 25 km.

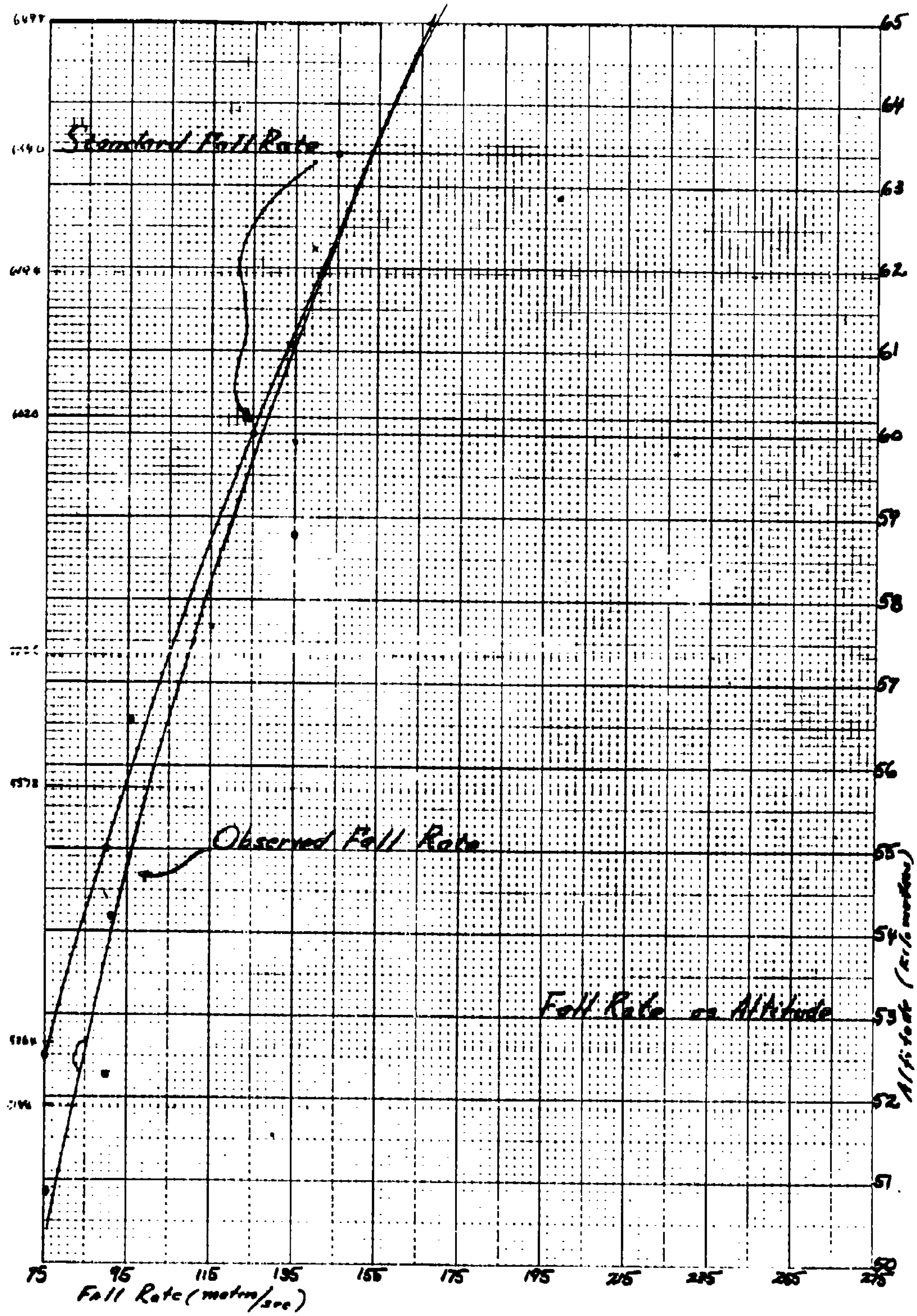


FIGURE 35

STANDARD AND OBSERVED FALL RATE

When the parachute is tracked to an altitude below 25 km, a four-minute interval is utilized when the fall rate decreases to 500 ft/minute and a six-minute interval is utilized when the fall rate is 250 ft/minute or less.

All of the above times are measured relative to the time T-0. Expulsion time of the temperature sensor and parachute is usually from 135 to 140 seconds after the rocket is launched with the parachute becoming wind sensitive within an additional 15 to 45 seconds. The (x,y) coordinate trace of Figure 33 indicates that the parachute was wind sensitive at 3.0 minutes (180 seconds) relative to T-0, the time at which the rocket was launched. Refer to Figure 33 with regard to the steps listed below for obtaining wind velocity as a function of altitude.

1. Determine the time at which the parachute becomes wind sensitive. The trace of the parachute position usually shows a marked change in direction at this time unless the wind direction is along the line of the rocket trajectory.
2. Draw a fine-pencilled vertical line (a z axis) approximately in the center of the (x,y) grid.
3. Project onto this z axis the values of parachute altitude, z, corresponding to the times chosen as wind data points.
4. Determine the average value of z in each interval corresponding to the time intervals of (3) above (the midpoint of the interval). As a matter of consistent notation the average value of z in the z interval corresponding to the time interval t_n to t_{n+1} is assigned to the time t_{n+1}. For example in Figure 33, the average value of z, corresponding to the time interval from 3.0 to 3.5 minutes is assigned to the time 3.5 minutes.
5. Read and record these average values of z and the corresponding times on the Standard Meteorological Form SELWS-MR-1031 shown in Table 6. The values of z are expressed in tens of meters.
6. On the (x,y) plot of parachute position, construct north-south and east-west components of the parachute displacement between each time data point utilized. For this purpose, it is essential that the radar plot have an orientation marking.
7. A template is constructed in the form of a plastic overlay (the scale corresponding to that of the radar plot) to determine directly wind speed in meters/sec when applied to a one-minute time interval.
8. Wind velocities in each time interval are recorded in Table 6. South and west components are assigned a (+) sign while north and east components are assigned a (-) sign. This completes the determination of the wind velocity components as a function of altitude.

METEOROLOGICAL ROCKET SOUNDING DATA

Reporting Point Code	Date YR	Date MO.	Date DAY	Time (Z) -Rocket-	Alt. Type Code	Reporting Point Name and Place
23037	64	11	22	1800	01 02 01	WSMR, NEW MEXICO

Rocket Winds: Time (M)	Alt. (MSL) Tens of M	Component Winds − North + South	Component Winds − East + West	Thermodynamics: Alt. (MSL) Tens of M	Temp. Deg. C
035	6264	012	050	6196	-240
040	5980	026	078	6340	-195
045	5692	026	060	6194	-265
052	5397	026	088	6020	-350
060	4977	021	109	5774	-115
070	4618	011	093	5573	-145
080	4540	016	093	5264	-050
090	4070	015	073	6188	-055
100	3825	020	071	4777	050
110	3771	025	048	4666	-045
120	3566	010	062	4872	-040
130	3353	010	070	4782	-040
140	3216	023	060	4685	-015
150	3185	016	058	4392	-016
160	3040	017	041	4063	-035
170	3001	026	042	4517	-015
180	2717	025	062	4511	-050
190	2818	013	048	4401	-270
200	2765	014	058	4376	-130
220	2658	012	024	4174	-135
240	2584	002	022	4075	-170
260	2441	006	024	3972	-195
280	2331	002	016	3988	-225
300	2257	-006	014	3840	-270
320	2177	-004	015	3706	-415

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METEOROLOGICAL ROCKET SOUNDING DATA

Reporting Point Code	Date YR	Date MO.	Date DAY	Time (Z) -Rocket-	Alt. Type Code	Reporting Point Name and Place
23037	64	11	22	1900	01 02 01	WSMR, NEW MEXICO

Rocket Winds: Time (M)	Alt. (MSL) Tens of M	Component Winds − North + South	Component Winds − East + West	Thermodynamics: Alt. (MSL) Tens of M	Temp. Deg. C
340	2103	-008	012	3560	-460
360	2037	000	022	3462	-560
380	1966	-008	042	3130	-470
400	1792	-001	016	3046	-475
420	1856	-008	016	2898	-430
440	1778	-002	007	2877	-460
				2664	-516
				2627	-530
				2557	-570
				2508	-575
				2348	-575
				2217	-606
				2172	-615
				2158	-626
				1964	-617
				1929	-625
				1871	-615
				1772	-645

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TABLE 6

STANDARD METEOROLOGICAL ROCKET SOUNDING FORM - SELWS-MR-1031

XII. THE METEOROLOGICAL ROCKET NETWORK

When all data reduction, correction and computation are complete, the temperature and wind data which were obtained by the procedures in Sections XI-A and XI-B are entered on form SELWS-MR-1031 shown in Table 6 and data from this form are plotted in the graphical form of Figure 36. The legend on Figure 36 indicates

1. the east-west components of wind velocity,
2. the north-south components of wind velocity,
3. the temperature according to the 1962 U.S. Standard Atmosphere,
4. the observed temperature as determined by the Delta I temperature sensor (uncorrected), and
5. the corrected temperature (Wagner Correction),

all as functions of altitude.

In the standard operational procedures for stations of the Meteorological Rocket Network, temperature, altitude and pressure data from a radiosonde observation (raob) are obtained. These data are included on the form SELWS-MR-1031 (Table 6) and plotted in graphical form to give temperatures and wind velocities from the surface to approximately 65 km. From the measured rocketsonde temperatures and the determination of the altitude corresponding to the 50 millibar pressure level from the raob, the pressure, density and speed of sound are calculated at various altitudes according to the equations:

$$P_z = P_{50} \exp -\frac{mg}{kT} [z - z_{50}]$$

$$g_z = g_e \left(\frac{R_e}{R_e + z}\right)$$

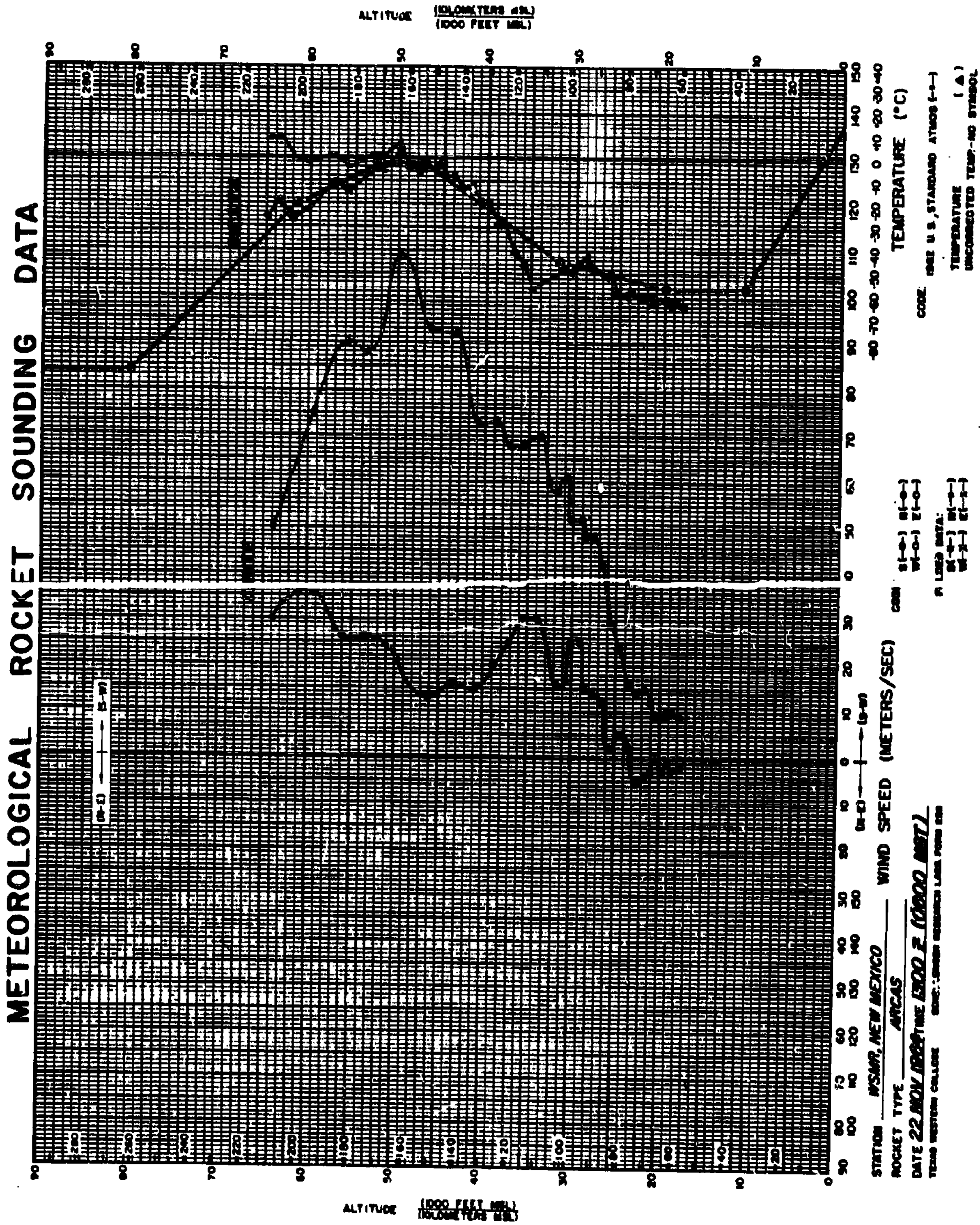
$$\rho = \frac{mP}{kT}$$

$$c_z = \sqrt{\frac{\gamma k T_z}{m}}$$

where

P_z = the pressure at the altitude z.

P_{50} = the pressure at the altitude z_{50} (50 millibars).



METEOROLOGICAL ROCKET SOUNDING DATA
ALTITUDE (KILOMETERS MSL) (1000 FEET MSL)
TEMPERATURE (°C)
WIND SPEED (METERS/SEC)
STATION WSMR, NEW MEXICO
ROCKET TYPE ARCAS

FIGURE 36

m = the mass/molecule of the atmosphere.

g_e = the gravitational acceleration at mean sea level.

g_z = the gravitational acceleration at the altitude z.

k = Boltzmann's Constant.

T_z = the absolute temperature at the altitude z.

ρ_z = the density at the altitude z.

c_z = the speed of sound at the altitude z.

γ = the ratio of the specific heats for air.

R_e = the radium of the earth.

These data are also entered on the Standard Meteorological form SELWS-MR-1031 under the headings Pressure, Density and Speed of Sound. The data on the completed standard form are punched on IBM cards from which duplimat printouts are obtained. These printouts along with ekatlith masters of the graphical presentations, yield the data presentations found in IRIG document 111-64. This work is performed at the Data Analysis Center of Schellenger Research Laboratories, Texas Western College, El Paso, Texas under the direction of the Upper Atmosphere Research Division of the U.S. Army Electronics Research and Development Activity (USA ERDA), White Sands Missile Range, New Mexico.

Effective January 1965, data collection and reduction methods were changed to require that each participating station of the Meteorological Rocket Network be responsible for the reduction of and the accuracy of the data acquired at the participating station. The data reduced at each station will then be entered on form SELWS-MR-1031 and forwarded to the U.S. Army Electronics Research and Development Activity, White Sands Missile Range, New Mexico for publication in the IRIG-111-64 document.

The following listed locations have stations which are participating members of the Meteorological Rocket Network:

Antigua MRN Station - British West Indies
Ascension MRN Station - Ascension Air Force Base, Ascension Island
Barking Sands MRN Station - Kauai, Hawaii
Cape Kennedy MRN Station - Cape Kennedy, Florida
Eglin MRN Station - Eglin Air Force Base, Florida
Eleuthera MRN Station - Bahama Islands
Eniwetok MRN Station - Eniwetok Atoll, Marshall Islands
Ft. Churchill MRN Station - Ft. Churchill, Canada
Ft. Greely MRN Station - Ft. Greely, Alaska

Grand Turk MRN Station - Grand Turk Islands
Green River MRN Station - Green Riber, Utah
Hill MRN Station - Hill Air Force Base, Utah
Keeweenaw MRN Station - Keeweenaw Peninsula, Michigan
Kwajalein MRN Station - Marshall Islands
McMurdo MRN Station - Antarctica
Point Mugu MRN Station - Point Mugu, California
San Nicolas MRN Station - San Nicolas, California
San Salvador MRN Station - San Salvador Island
Thule MRN Station - Thule Air Force Base, Greenland
Tonopah MRN Station - Tonopah, Nevada
Wallops MRN Station - Wallops Island, Virginia
White Sands MRN Station - White Sands Missile Range, New Mexico

These locations are shown in Figure 37.

FIGURE 37

PRESENTLY EXISTING METEOROLOGICAL

ROCKET NETWORK STATIONS

APPENDIX

I. THEORETICAL ACCURACY OF A METEOROLOGICAL ROCKETSONDE THERMISTOR

The following is taken directly from the abstract of Wagner's paper.*

"The ability of the bead thermistor currently used in the meteorological sounding rockets to measure the ambient kinetic temperature is examined theoretically. A non-steady state heat transfer environment including forced convection, infrared and solar radiation, compressional heating, lead wire conduction and internal heating is considered along with the normal variations to be expected in this environment. The average temperature measurement error is found to range from less than 5°C at heights below 50 kilometers to 33.5°C at 65 km. Correction for this error should yield ambient temperature values to within ±2 per cent up to 60 km with the correction accuracy decreasing to ±3.8 per cent at 65 km. The correction accuracy deteriorates rapidly above 65 km suggesting that either a different type sensing element or a different sounding technique will be necessary for temperature measurement above this level."

A. THE ENERGY EQUATION FOR THE THERMISTOR

The temperature sensitive element treated is that currently used in the meteorological rocketsonde in the form of an approximately spherical bead thermistor with an effective diameter of

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*That which is presented here is an attempt to summarize, only for the purpose of reference in this publication, the work of Wagner as presented in detail in his article, "Theoretical Accuracy of a Meteorological Rocketsonde Thermistor," N.K. Wagner, Journal of Applied Meteorology, Vol. 3, N. 4, August, 1964. The theoretical results described therein are those obtained from research conducted under Contract DA-23-072-ORD-1564 with the U.S. Army Signal Missile Support Agency, White Sands Missile Range, New Mexico.

.032 cm and with 0.0025 cm diameter lead wires. The thermistor is coated with White Krylon resulting in a short-wire absorptivity of approximately 0.2 and a long-wire absorptivity of nearly 1.0.

The net energy flow per unit time (dL/dt) to which the thermistor is exposed is written as the sum of the various energy inputs and outputs to and from the thermistor respectively. The thermistor is considered to be in an environment where forced convection H, radiation Q, self-heating L, viscous dissipation M, and lead-wire conduction N are the only significant modes of heat transfer. Thus

$$\frac{dE}{dt} = H + Q + L + M + N \tag{1}$$

Let C, the heat capacity of the thermistor, be considered as constant. Then

$$\frac{dE}{dt} = \frac{dE}{dT}\cdot\frac{dT}{dt} = C\frac{dT}{dt} \qquad C = \frac{dE}{dT} \tag{2}$$

Equation (1) may then be written

$$C\frac{dT}{dt} = H + Q + L + M + N \tag{3}$$

The various terms on the right-hand side of (3) are expressed as follows:

$$H = h(T_e - T) \tag{4}$$

$$Q = .25JAa + \sigma A(.5T_{be}^4 + .06T_{ai}^4 + .44T_{ae}^4 - T^4) \tag{5}$$

$$L = \frac{hW}{S} \tag{6}$$

$$M = \frac{rhV^2}{2c_p} \tag{7}$$

$$N = \frac{2\kappa\beta}{X}(T_s - T) \tag{8}$$

The above symbols are defined as follows:

T = the temperature of the thermistor (°K).

T_e = the temperature of the free atmosphere environment (°K).

T_{be} = the effective black-body radiative temperature of the environment below the thermistor (°K).

T_{ae} = the effective black-body radiative temperature of the atmosphere environment above the thermistor (°K).

T_{ai} = the effective black-body radiative temperature of the instrument above the thermistor (°K).

T_s the temperature of the lead wire support posts.

X = the length of one lead wire.

V = the fall velocity.

A = the surface area of the thermistor.

β = the cross-sectional area of the lead wires.

h = the convective heat transfer coefficient for the thermistor.

J = the solar radiation flux incident upon the thermistor.

a = the solar absorbtivity of the thermistor.

σ = the Stefan-Boltzmann constant.

$\dot{W}$ = the electrical power dissipated by the thermistor.

S = the dissipation constant of the thermistor ($1/S$ is the change in temperature of the thermistor per microwatt of power dissipated by the thermistor).

r = the thermal recovery factor for the thermistor. (This quantity represents the efficiency of the reconversion of kinetic energy into thermal energy.)

c_p = the specific heat capacity at constant pressure for air.

κ = the thermal conductivity of the lead wires.

In writing equation (5), an expression for Q, the following assumptions were made:

1. The total radiation flux may be divided into short wave (solar) and long wave (infrared) components.
2. The infrared radiation flux directed toward the thermistor may be divided into two parts; that from the environment above the thermistor and that which comes from below the thermistor.
3. The instrument package above the thermistor subtends an angle which encompasses six per cent of the total surface area of the thermistor.
4. The thermistor absorbs and emits infrared radiation as if it were a black-body.

Let the time constant of the thermistor be defined as:

$$\lambda = \frac{C}{h} = \frac{T_e - T}{\frac{dT}{dt}} \tag{9}$$

Let

$$\frac{dT}{dt} = V\frac{dT}{dz} \text{ (z is the thermistor altitude)} \tag{10}$$

Substitution of equations (4) through (10) into equation (3) for dT/dt gives:

$$\begin{aligned} dT/dz = [&-\sigma AT^4/C - (\lambda^{-1} + 2\kappa\beta/XC)T \\ &+ \lambda^{-1}(T_e + rV^2/2c_p + W/S) + JAa/4C \\ &+ \sigma A(.5T_{be}^4 + .06^4_{ai} + .44T_{ae}^4)/C + 2\kappa\beta T_s/XC]/V \end{aligned} \tag{11}$$

The quantities T_e, T_{be}, T_{ae}, T_{ai}, T_s, V, λ, r, and S are then expressed as functions of altitude (summarized below) while W is expressed as a linear function of temperature such that dT/dz may be written as

$$\begin{aligned} \frac{dT}{dz} &= [f_1(z)]T^4 + [f_2(z)]T + f_3(z) \\ \frac{dT}{dz} &= f(T,z) \end{aligned} \tag{12}$$

If equation (12) is solved for the thermistor temperature as a function of altitude, the temperature error is then determined by subtracting the specified environmental temperature from that indicated by the thermistor.

B. EXPRESSIONS FOR T_e, λ, V, r, T_{be}, T_{ae}, T_{ai}, T_s, AND 1/S AS FUNCTIONS OF ALTITUDE AND W AS A FUNCTION OF TEMPERATURE

1. T_e as a Function of Altitude

The assumed environmental temperature distribution was the 1962 U.S. Standard Atmosphere [13],

$$T_e = \begin{cases} 492.775-3.9016z & 80.0>z>61.5 \\ 373.268-1.9584z & 61.5>z>52.4 \\ 270.650 & 52.4>z>47.4 \\ 140.344+2.7491z & 47.4>z>32.1 \\ 196.795+0.9905z & 32.1>z>30.0 \end{cases} \tag{13}$$

2. The Time Constant λ as a Function of Altitude

The values of thermistor time constant [14] were based upon the findings of Wright [15] and are approximated closely by,

$$\lambda = \begin{cases} \exp(0.000885z - 1.755) & 80>z>50 \\ \exp(0.000582z - 0.997) & 50>z>30 \end{cases} \tag{14}$$

3. The Fall Rate (Ventilation speed) V as a Function of Altitude

The expression for V was derived by fitting a second-degree polynomial by least-squares techniques to three years of observational data concerning the fall rate of parachute-borne temperature sensors in the altitude interval from 30 to 65 km at WSMR, New Mexico. The fall rate is given by,

$$v = 0.000508 \exp\left(\sqrt{0.81148z-5.61536} - 1.07395\right) \tag{15}$$

4. The Recovery Factor r as a Function of Altitude

The values for the recovery factor for the thermistor were based upon the work of Drake and Kane [16] and Oppenheim [17]. The recovery factor may be expressed approximately by,

$$r = \begin{cases} 0.0173z-0.024 & 80.0>z>53.4 \\ 0.90 & 53.4>z>30.0 \end{cases} \tag{16}$$

5. T_{be}, T_{ae} and T_{ai} as Functions of Altitude

These expressions are based upon the work of Aagard [18] and are given by,

$$\begin{aligned} T_{be} &= 249.6-0.09z \\ T_{ae} &= 123.3-1.25z \\ T_{ai} &= 288.0-4.12z_0+0.032z_0^2+4.12z-0.032z^2 \end{aligned} \tag{17}$$

Here z_0 is the expulsion altitude of the thermistor from the rocket vehicle.

6. T_s as a Function of Altitude

The expression for the binding post temperatures as a function of altitude was based upon the experimental data of Baldwin [19] and is given by

$$T_s = \begin{cases} \dfrac{T_{s0}-276}{z_0-45}(z-45)+276 & 80>z>45 \\ T_e+12 & 45>z>30 \end{cases} \quad (18)$$

7. The Dissipation Constant S as a Function of Altitude

The expression for the reciprocal of the dissipation constant is based upon the experimental work of Ballard [20] and the assumption of a linear variation with altitude to give,

$$\frac{1}{S} = 0.000667z + .01 \quad (19)$$

8. The Power Dissipation W as a Function of Temperature

An estimate of the power dissipation was based upon the work of Beyers [14] and is given by,

$$W = \begin{cases} 1.143T-224.9 & T>258K \\ -0.829T+283.8 & T>258K \end{cases} \quad (20)$$

C. COMPUTATIONAL RESULTS

The above expressions as functions of altitude z, for the various variables were substituted in equation (11) for dT/dz and the resulting expression was solved on the CDC 1604 computer of the University of Texas. (The value for solar flux J is about 35 per cent larger than the solar constant in order to account for atmospheric and terrestrial reflection and scattering.) The following values were assigned to the equation constants:

$J = 0.045$ cal cm^{-2} sec^{-1}

$c_p = 1.004 \times 10^{-3}$ km^2 sec^{-2}K^{-1}

$C = 8.03 \times 10^{-6}$ cal K^{-1}

$\sigma = 1.38 \times 10^{-12}$ cal cm^{-2} sec^{-1} K^{-4}

$A = 3.22 \times 10^{-3}$ cm^2

$\beta = 5.1 \times 10^{-6}$ cm^2

$\kappa = 0.074$ cal cm^{-1} sec^{-1} K^{-1}

The following reference as (standard) conditions were utilized:

$$a = 0.1$$

$$z_0 = 80.0 \text{ km}$$

$$T_0 = 323 \text{ K}$$

$$T_{s0} = 298 \text{ K}$$

$$X = 0.6 \text{ cm}$$

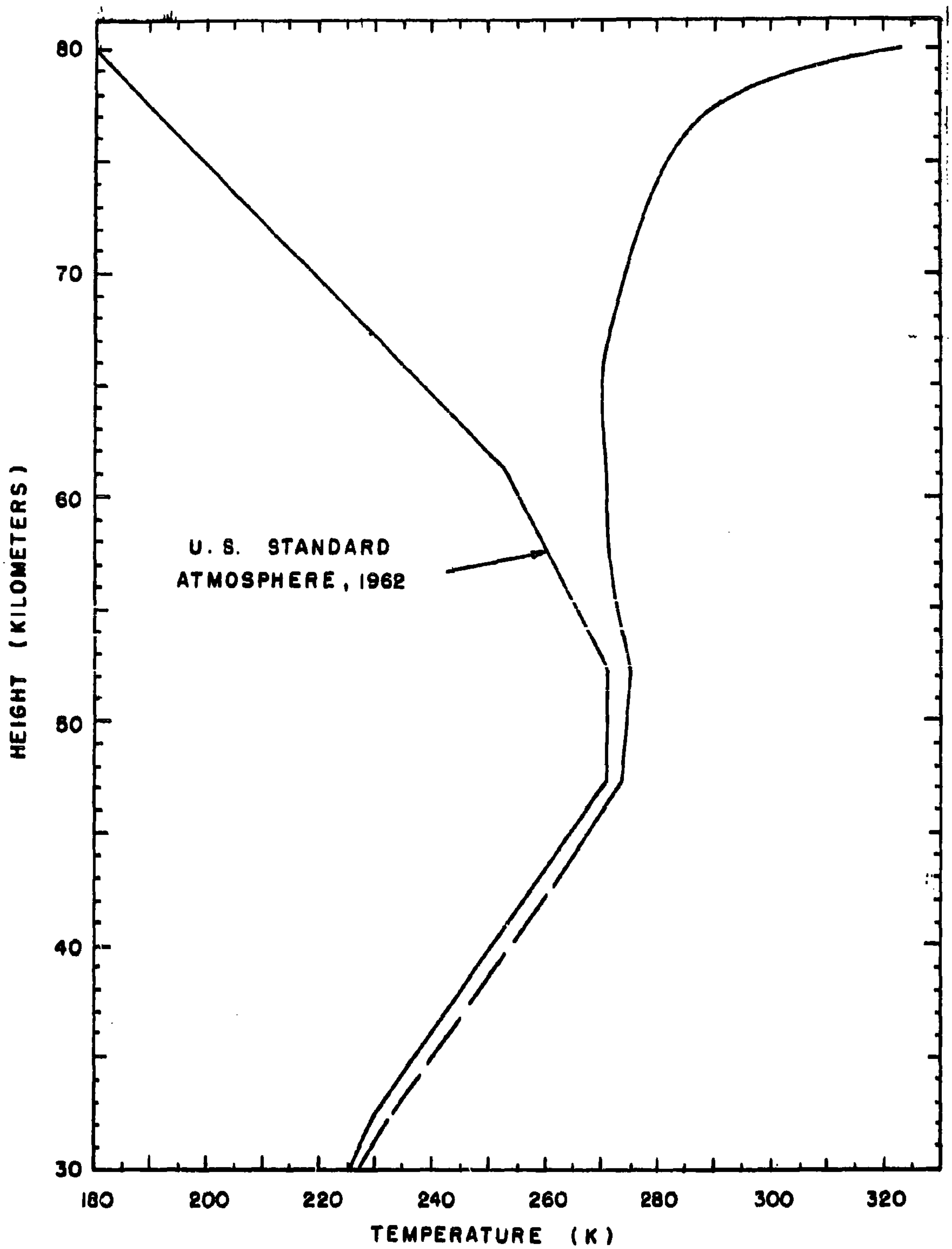
Here z_0 is the expulsion altitude from the rocket vehicle while T_0 and T_{s0} are the temperatures of the thermistor and thermistor support posts at the time of expulsion. The solution yielded the thermistor temperature as a function of altitude as shown in Figure 38. The error of 142°C at a height of 80 km decreases rapidly with altitude becoming 54°C at 70 km and 15°C at 60 km.

A study was then made by Wagner to determine the effects of expected deviations from the chosen reference conditions upon the theoretical thermistor temperature based upon these reference conditions. Variations in expulsion altitude z, initial thermistor temperatures T_0, fall velocity V, initial support temperature T_{s0}, solar absorptivity a, lead wire length X, effective infrared radiation temperature below the thermistor T_{be}, time constant λ and the power dissipation in the thermistor W were considered. The results of the deviation of these parameters from the assumed reference values are summarized in graphical form in Figures 39, 40 and 41. In addition the variations, in the assumed environmental temperature T_e, were considered.

D. SUMMARY

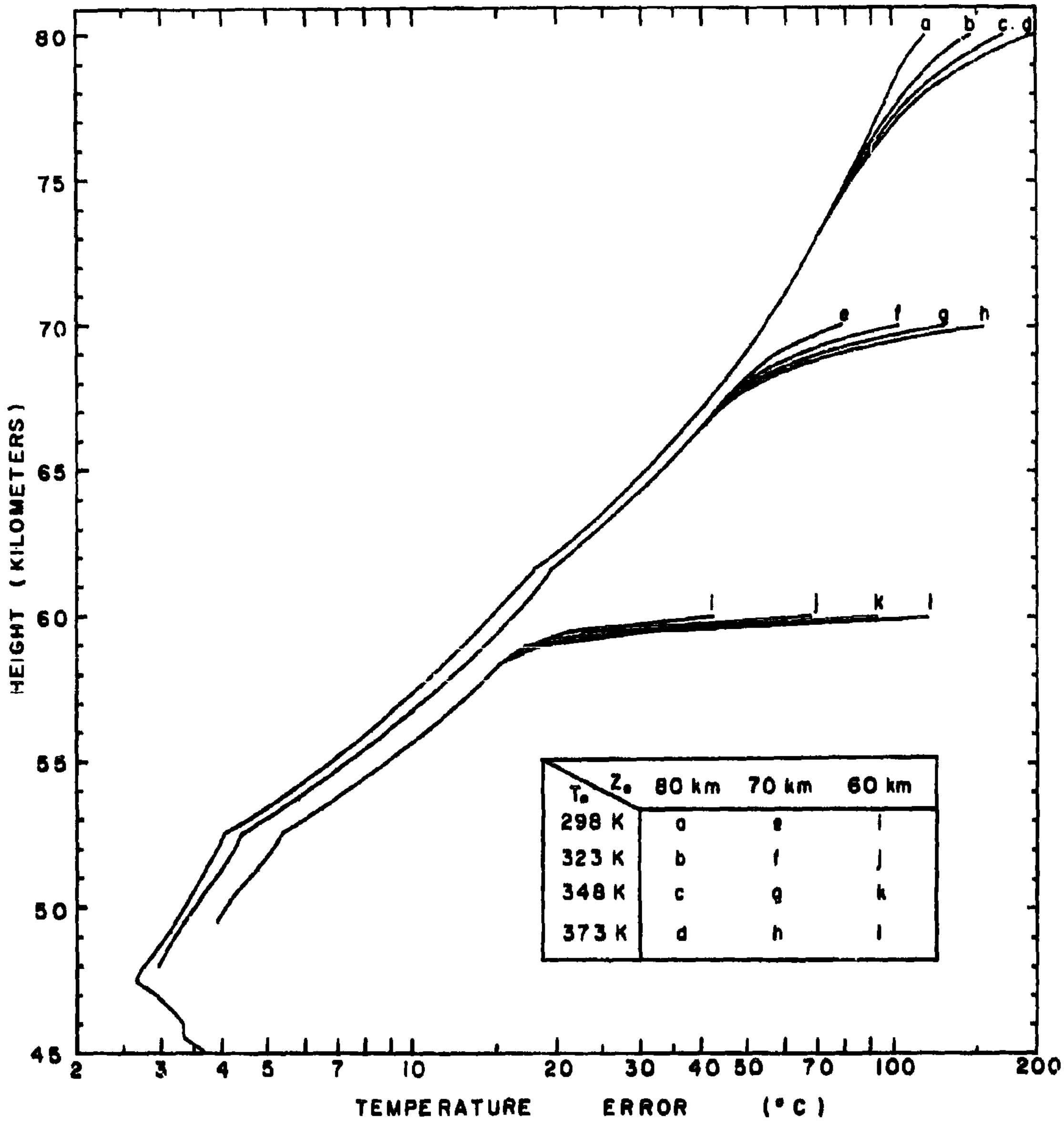
1. Figure 39 shows the effects of variations in the expulsion temperature and altitude of the thermistor and indicates that the effects of the various initial temperatures of the thermistor become insignificant very quickly. The temperature error increases as the expulsion altitude is decreased.

2. Figure 40 indicates the significance of the variations in fall rate and support post temperature upon the thermistor temperature. The deviation from the theoretical reference temperature errors are shown for changes of ±20% in the fall rate (Figure 40a) while Figure 40b shows the error dependence upon the support post temperature at the time of expulsion. The temperature error becomes smaller with decreased fall speed while the temperature error becomes greater with increased fall speed. The error associated with the support post temperature at the time of expulsion is not negligible.



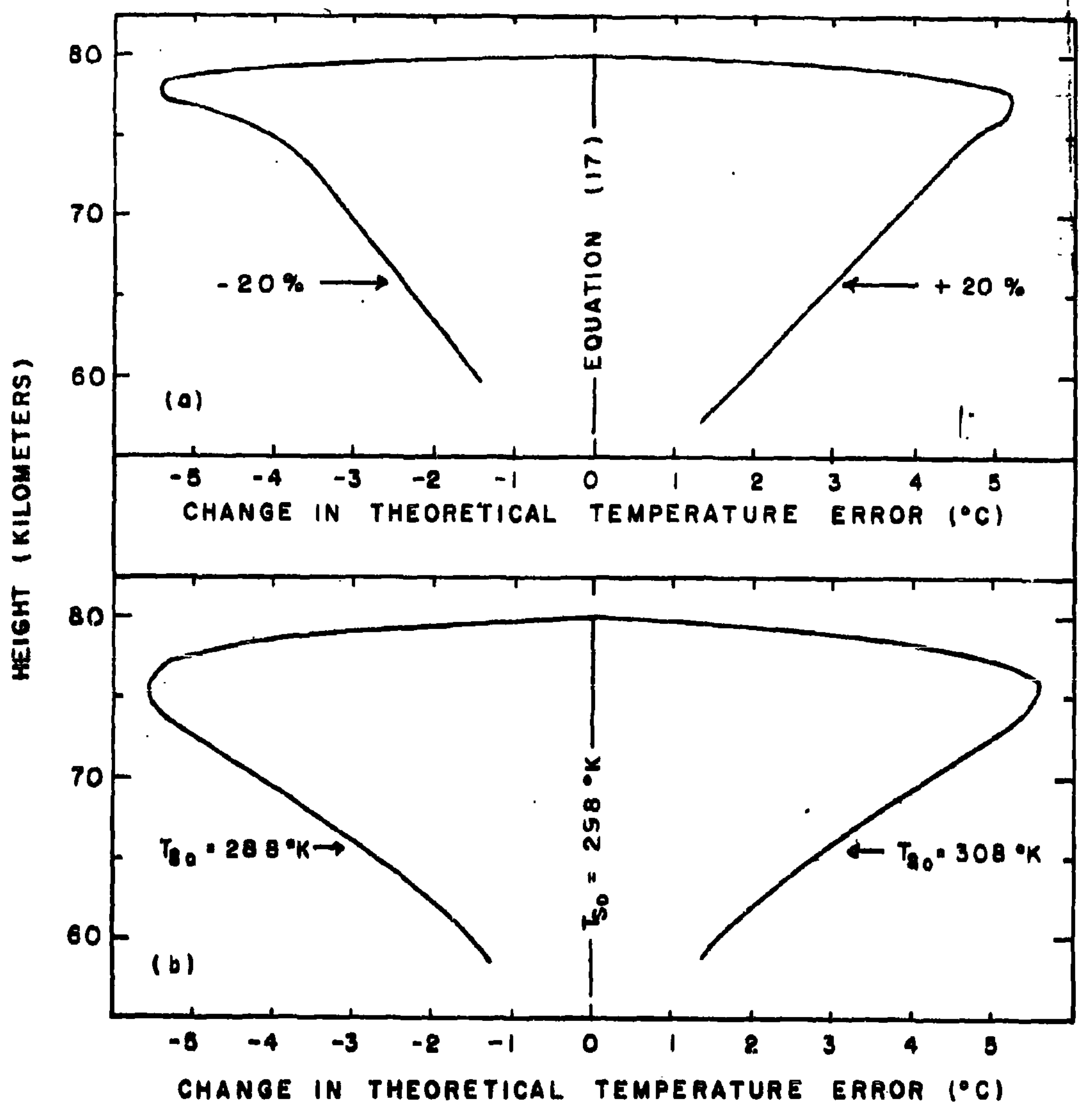
VARIATION IN TEMPERATURE WITH HEIGHT
FOR REFERENCE CONDITIONS

FIGURE 38



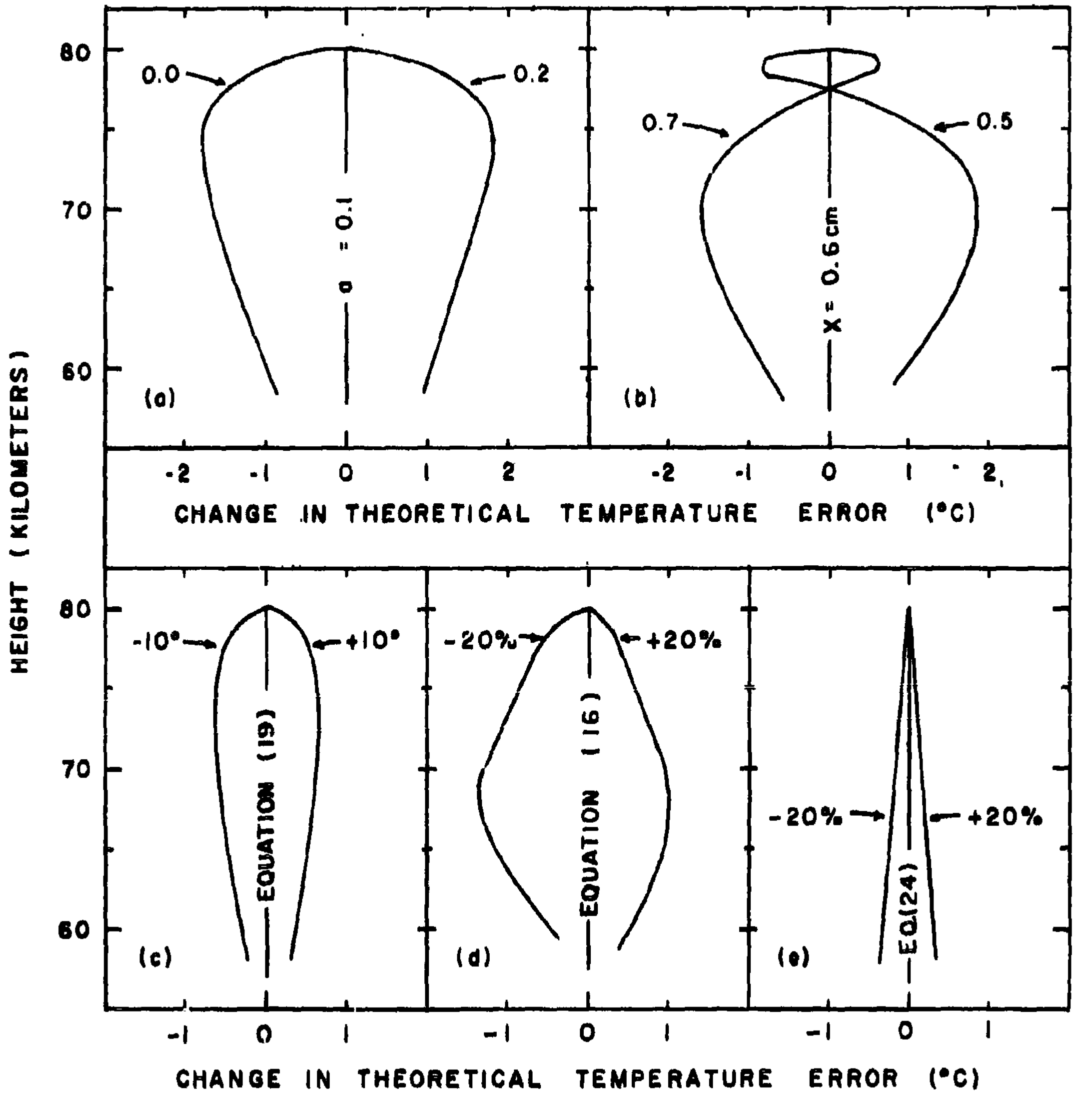
TEMPERATURE ERROR ASSOCIATED WITH DEVIATIONS FROM REFERENCE CONDITIONS FOR INITIAL HEIGHT AND INITIAL THERMISTOR TEMPERATURE

FIGURE 39



TEMPERATURE ERROR VARIABILITY ASSOCIATED WITH DEVIATIONS FROM REFERENCE CONDITIONS FOR (a) FALL VELOCITY, AND (b) INITIAL SUPPORT POST TEMPERATURE

FIGURE 40



TEMPERATURE ERROR VARIABILITY ASSOCIATED WITH DEVIATIONS FROM REFERENCE CONDITIONS FOR (a) SOLAR ABSORPTIVITY, (b) LEAD WIRE LENGTH, (c) EFFECTIVE INFRARED RADIATION TEMPERATURE BELOW THE THERMISTOR, (d) TIME CONSTANT, AND (e) POWER DISSIPATION IN THE THERMISTOR

FIGURE 41

3. The variation in the total temperature error brought about by changes in solar absorptivity, lead wire length, effective infrared radiation temperature below the thermistor, time constant and power dissipation in the thermistor as shown in Figure 41 are relatively small being less than 1.5°C at altitudes below 65 km for all quantities.

4. The errors associated with the variations in the temperature of the environment T_e through the assumption of three model atmospheres were within ±5°C of each other up to an altitude of 65 km. Table 7 summarizes Wagner's calculations and gives the mean temperature error, the error variability and the correction accuracy for altitudes from 65 to 40 km. Below 40 km the corrections are negligible. The tables of corrections shown in Table 4 are based upon the theoretical values obtained by Wagner for reference conditions. Since the expulsion altitude and fall rate are observable quantities, deviations from the reference conditions for these quantities are accounted for in the reduction of the temperature data as described in Section XI of this publication, DATA REDUCTION PROCEDURES TO OBTAIN TEMPERATURE AND WIND VELOCITIES.

II. THE JUDI METEOROLOGICAL ROCKET SYSTEM

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A. INTRODUCTION

The Judi meteorological rocket system (Figure 42) is used for atmospheric soundings between 30 and 60 kilometers. This system has essentially the same specifications and functions in a manner similar to the Loki sounding system. Depending upon the payload, it is capable of measuring winds, pressure, temperature, and density as a function of altitude.

The dart body is propelled to a height of approximately 250,000 feet by the Judi booster motor. At apogee, an expulsion charge is detonated which expels the payload. In most cases these payloads are chaff dipoles which are tracked by radar as they fall toward the surface. As the chaff falls, it is carried horizontally by the wind, and a wind profile is derived from this lateral movement.

TABLE 7

TABULAR SUMMARY OF WAGNER'S CALCULATION

Height (km)	Error (C)	Error variability (C)	Accuracy of correction (%)
65	33.5	±9.0	±3.8
64	30.0		
63	27.0		
62	24.5		
61	22.0		
60	19.0	±5.0	+2.0
59	16.0		
58	13.5		
57	11.0		
56	9.0		
55	7.5	±5.0	±1.9
54	7.0		
53	6.5		
52	6.0		
51	5.5		
50	5.0	±3.5	±1.3
49	5.0		
48	5.0		
47	4.5		
46	4.5		
45	4.5		

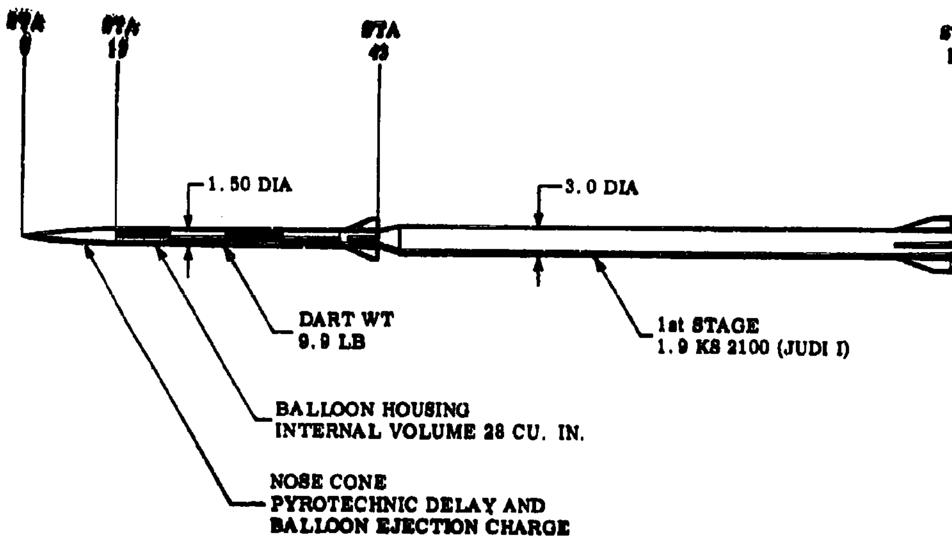

Figure 42

JUDI METEOROLOGICAL ROCKET (ROBIN BALLOON)

In addition to chaff, other types of payloads may be carried by the dart. These include parachutes, inflatable spheres, and temperature sensor packages. All of these payloads have been flown at White Sands Missile Range (WSMR) in conjunction with various research and development tests.

B. DESCRIPTION

The Judi meteorological rocket system is comprised of two stages: the Judi booster motor and the unpowered dart which carries the payload. The Judi motor is an internal burning motor which burns for approximately 2 seconds and reaches a velocity of 4,900 feet per second at burnout. At this time the motor is separated from the dart, which coasts to an altitude in excess of 250,000 feet from a 4,000-foot launch elevation. At altitude (approximately 135 seconds) the payload is ejected. The ejection time is achieved by means of a pyro-delay fuze which is activated at the same time that the motor is ignited.

C. JUDI CHAFF DART VEHICLE

The Judi chaff dart (Figure 43) is capable of achieving an altitude of 240,000 feet when launched from sea level, and 270,000 feet when launched from a 4,000-foot launch site. The type of chaff used in the payload varies with the user's requirement. The type commonly used for firings at White Sands Missile Range is S-band copper, .005 inch in diameter, while X-band copper of the same diameter is used at the Fort Greely Meteorological Rocket Network site. The type of chaff to be used is determined by the type of radars available. At White Sands, S-band radars are utilized, while at Fort Greely the modified M-33, an X-band radar, is used to obtain the information.

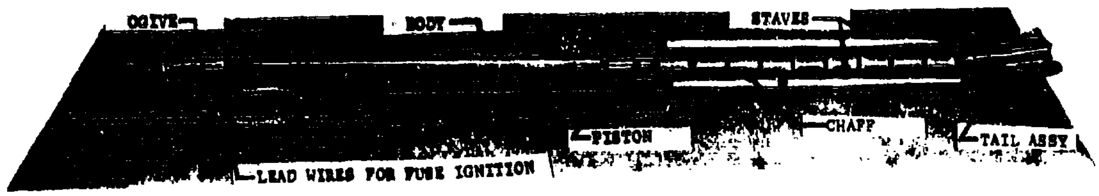

FIGURE 43

JUDI CHAFF DART

The copper chaff will sense winds from approximately 215,000 to 60,000 feet, at which point it fails to give a satisfactory radar track due to excessive dispersion. Another type of chaff is available and has been used to acquire wind data above 215,000 feet. This is .0035 nylon chaff which will sense winds from 285,000 to 200,000 feet before it becomes too widely dispersed to form a good radar target.

Several darts have been flown utilizing a special Judi booster with slight modifications and have achieved altitudes slightly below 300,000 feet. These darts have carried payloads of both .0035-inch-diameter nylon chaff and .005-inch-diameter copper chaff. At expulsion the heavier copper chaff falls rapidly while the lighter chaff falls more slowly. Within ten seconds after expulsion there is enough space differential between the two types for the radars to distinguish between the light and the heavier chaff. With one radar tracking the light chaff and another tracking the heavier, a wind profile can be derived from 285,000 to 60,000 feet with approximately a 15,000-foot overlap between the two types of chaff. The complete system reliability of the Judi chaff dart vehicles is 90%. This includes achieving the desired altitude and ejecting the chaff at this altitude.

An advantage of the Judi dart system is its high acceleration which makes the vehicle very insensitive to wind. This vehicle has been launched at 80° launcher elevation in winds as high as 40 knots with less than 4° azimuth deviation.

The advantage in using the chaff dart vehicle is that the chaff cloud can be acquired without great difficulty when using most radars having the necessary range capability.

D. JUDI PARACHUTE DART VEHICLE

The Judi parachute dart vehicle contains an 8-foot parachute and ballast. The vehicle is the same as the chaff dart vehicle except for the different type payload. The parachute dart will yield wind measurements only, the same as the chaff dart.

The parachute target has an advantage over the chaff target in that the parachute is a point source and is not subject to scattering as is the chaff cloud which yields large wind errors as it approaches the surface and becomes widely dispersed in the lower atmosphere. The main disadvantage in utilizing the parachute dart vehicle is radar acquisition of the parachute upon expulsion. The parachute presents a much smaller target; therefore, it requires more refined radar equipment and techniques. This fact has been borne out at Fort Greely where the only radar used for target acquisition is an M-33 track radar. A number of parachute dart vehicles were fired, followed by a chaff dart vehicle 30 minutes later. In each case the radar was not able to acquire the parachute after 25 minutes of search, but did acquire the chaff targets immediately after expulsion. However, at a missile range where more sophisticated radars are available, the parachute dart vehicle may be utilized with great success.

The parachute used is an 8-foot diameter momme silk, silvered for radar reflectivity. This parachute has a fall rate of 450 feet per second at 200,000 feet altitude when a 13-ounce ballast weight is used.

E. JUDI-ROBIN BALLOON DART VEHICLE

The Judi-Robin balloon dart carries the standard U.S. Air Force Robin Balloon, 1 meter in diameter and constructed of 0.5-mil mylar, as a payload. This dart has a slightly larger diameter than the chaff dart in order to accommodate the Robin balloon; otherwise, it is identical to the chaff dart vehicle. The advantage of the balloon dart vehicle is that both wind and density can be derived, whereas the chaff or parachute darts can be used to measure winds only.

Disadvantages of this system are the requirement for a high precision radar and the complexities involved in proper inflation of the mylar sphere. Several balloon darts have been flown at WSMR without success. The apparent failure of these payloads to derive valid data was seemingly due to the sphere's not being properly inflated on expulsion.

F. JUDI INSTRUMENTED DART VEHICLE

The Judi dart vehicle has the same configuration as the other dart vehicles with the exception of a slightly larger diameter and the telemetry payload. This dart contains an 8-foot silverized parachute, a telemetry package, and a bead thermistor temperature sensor. The telemetry system operates on a frequency of 1680 mc making it compatible, without modification, to the standard radiosonde ground recording equipment. The telemetry package consists of a transmitter (utilizing the standard radiosonde tube), modulator, power supply (converter), rechargeable battery pack, in-flight calibrator, and the bead thermistor. The bead thermistor is placed in a small metal type loop which extends outward from the package upon ejection. This allows the bead thermistor to be in an optimum position in relation to the air stream and the RF field. Because the dart body itself is electrically insulated, it acts as a dipole antenna. This has the advantage of insuring that the instrument is operating prior to launch and it also allows the AN/GMD to track the package to expulsion, eliminating the need to search for the instrument upon expulsion.

The package is placed in a phenolic tube to shield it from the temperature effects of aerodynamic heating and to increase its resistance to launch and ejection accelerations. The transmitter has an umbilical connector which allows the instrument to be switched into various operating modes of internal or external power, shut down, or the charging of the batteries. The payload is suspended from a metalized cloth parachute, which deploys upon ejection and serves as a radar target.

A number of these rounds have been fired at WSMR with qualified success. The instrument dart was launched and the payload ejected with the instrument transmitting over a period of 15 minutes. However, in the cases where the instrument was able to transmit, the temperature recording appeared rather erratic, making it difficult to reduce the data for an accurate temperature profile. The overall system functioned normally through launch, ejection, and deployment with the exception of the required accuracy of the temperature trace.

This system is highly desirable due to its simplicity and relatively low cost, but there is a requirement for continued effort to develop an optimum operating system.

G. ADVANTAGES AND DISADVANTAGES

The Judi chaff dart vehicle is the simplest of the Judi dart vehicles and requires the least amount of personnel and refined equipment. The vehicle simply carries the chaff dipoles to apogee and expels them. Once expelled, the tracking radar is able to acquire the chaff target quite readily because of its large size. This system lends itself to operation at remote sites where less sophisticated radars and equipment must be utilized for tracking purposes. It has proved to be highly successful in the acquisition of wind data at these sites.

One of the disadvantages of this vehicle is that it is capable of measuring only the upper winds. Also, as a wind sensor, the accuracy of the derived winds decreases as the chaff falls into the lower atmosphere and disperses over a large area. This spreading causes the radar to focus on various chaff bundles within the chaff cloud, resulting in errors in wind speeds.

The Judi-parachute dart vehicle is similar to the chaff vehicle except for the parachute payload. The parachute is deployed at apogee and remains a point source; therefore, the accuracy of the winds does not deteriorate as with the chaff. However, at expulsion the parachute does not present a large target, making acquisition more difficult. For this system to operate with success, it is necessary to have a more sophisticated radar system and a highly refined search technique.

The Judi balloon dart vehicle has the capability of measuring winds and density properties of the upper atmosphere. At expulsion the sphere is inflated by means of a gas capsule. A corner reflector is placed inside the sphere and is fully extended when the sphere is inflated. The corner reflector allows the sphere to be tracked by radar as it is carried down to the surface.

The principal advantage of this system is found in the relative simplicity of the rocket hardware and launch equipment. The disadvantages are in the requirements for complex radar tracking equipment and detailed data reduction utilizing a computer. The density data are largely dependent upon whether the balloon is able to retain its spherical configuration. This has presented a problem in that a complete failure of the balloon to inflate can be determined from the fall rate; however, in the case where the fall rate is not excessive, it becomes difficult to determine if there is a slow leak in the balloon which results in a deformation of the sphere and makes the data invalid.

The Judi instrumented dart vehicle has the capability of measuring temperatures and winds. This system has an advantage over present rocketsonde systems due to its higher launch velocity. This makes the system less sensitive to launch winds and allows the vehicle to be launched under adverse weather conditions. Another attractive feature of this system is that it eliminates the requirement for meteorological support for rocket body impact, thereby greatly reducing the number of personnel and the equipment ordinarily required. As indicated by the flight tests at WSMR, more work has to be completed before this system is considered operational.

H. CURRENT STATUS

The type of vehicle used most extensively at present is the chaff dart vehicle. This vehicle is being fired at WSMR and at remote sites such as Fort Greely, Alaska, and Green River, Utah. This system is considered operational and has an operating level of 96% in acquisition of useful wind data.

The Judi parachute dart vehicle has not been used as extensively as the chaff dart; however, test flights have proved this type of system to be an effective sensor of winds.

The Judi balloon dart vehicles which have been flown at WSMR have been unsuccessful in acquiring density data because of improper sphere inflation. The only data derived from these firings have been wind data from the radar track of the corner reflector. At this time there is no anticipated requirement utilizing this particular system.

The Judi instrumented dart vehicle is still in the development stage. The last few tests indicate the feasibility of launching this type of vehicle and receiving telemetry data. Further work must be undertaken before this system will be operational and considered as a replacement for the rocketsonde systems now being used in the field.

I. FUTURE STATUS

Use of the Judi chaff dart vehicle will be continued at remote sites. At sites where the radars are more sophisticated, the plans are to utilize more of the parachute rounds, since this type of sensor is more accurate at the lower levels.

The Judi instrumented dart vehicle holds the most promise for future requirements, and the work in this area to date has proved the feasibility of this type of vehicle. It is anticipated that further development will improve the instrumentation to the point where it will become operational.

III. LAUNCHING PROCEDURES FOR THE JUDI ROCKET SYSTEM

The following is the procedure which was developed and is utilized at WSMR for the launching of the Judi Rocket System.

The steps of the procedure are applicable for Judi systems with chaff or parachute darts serving as the payloads for the determination of wind velocities up to altitudes of 60 km. The chaff or parachute payload is tracked by radar after expulsion from the dart. The data reduction procedures for obtaining wind velocity as a function of altitude is the same as that described in Section XI-B, THE DETERMINATION OF WIND VELOCITY AS A FUNCTION OF ALTITUDE. (Refer to Figures 9, 42, 43 and 44 with reference to the following steps.)

1. Take the rocket booster, the dart and leads for the expulsion charge from the bunker.

2. Place the booster in the cradle on the rocket pad and ground the booster. Remove the shorting wire from the pyro-delay.

3. Connect the leads to the pyro-delay in the expulsion charge to the forward end of the dart.

4. Check the resistance of the pyro-delay with an ohmmeter. The resistance should lie between 0.75 and 1.50 ohms.

5. Remove the leads and reinsert the shorting wire in the pyro-delay. Lower the launcher and tape the expulsion leads to the side of the launcher tube. (Figure 44)

6. Mate the dart with the booster by aligning the 1/8" diameter hole in the tail of the dart with the 1/8" diameter hole in the forward end of the rocket motor. Insert the 1/8" diameter shear pin in these holes.

7. Determine the center of gravity of the system by placing the booster and the dart on a knife edge.

8. Obtain a firing line check by unshorting and placing a voltmeter across the firing line. The voltage should read 110 volts.

9. Place the booster and dart in the launcher so that the expulsion charge outlets are in front of the forward end of the launcher.

10. Connect the leads to the pyro-delay of the expulsion charge. Tape the leads to the dart body and push the rocket into the launcher until the rocket booster is snug against the stops in the after end of the launcher.

11. Raise the launcher and secure in an elevated position with the launcher pins.

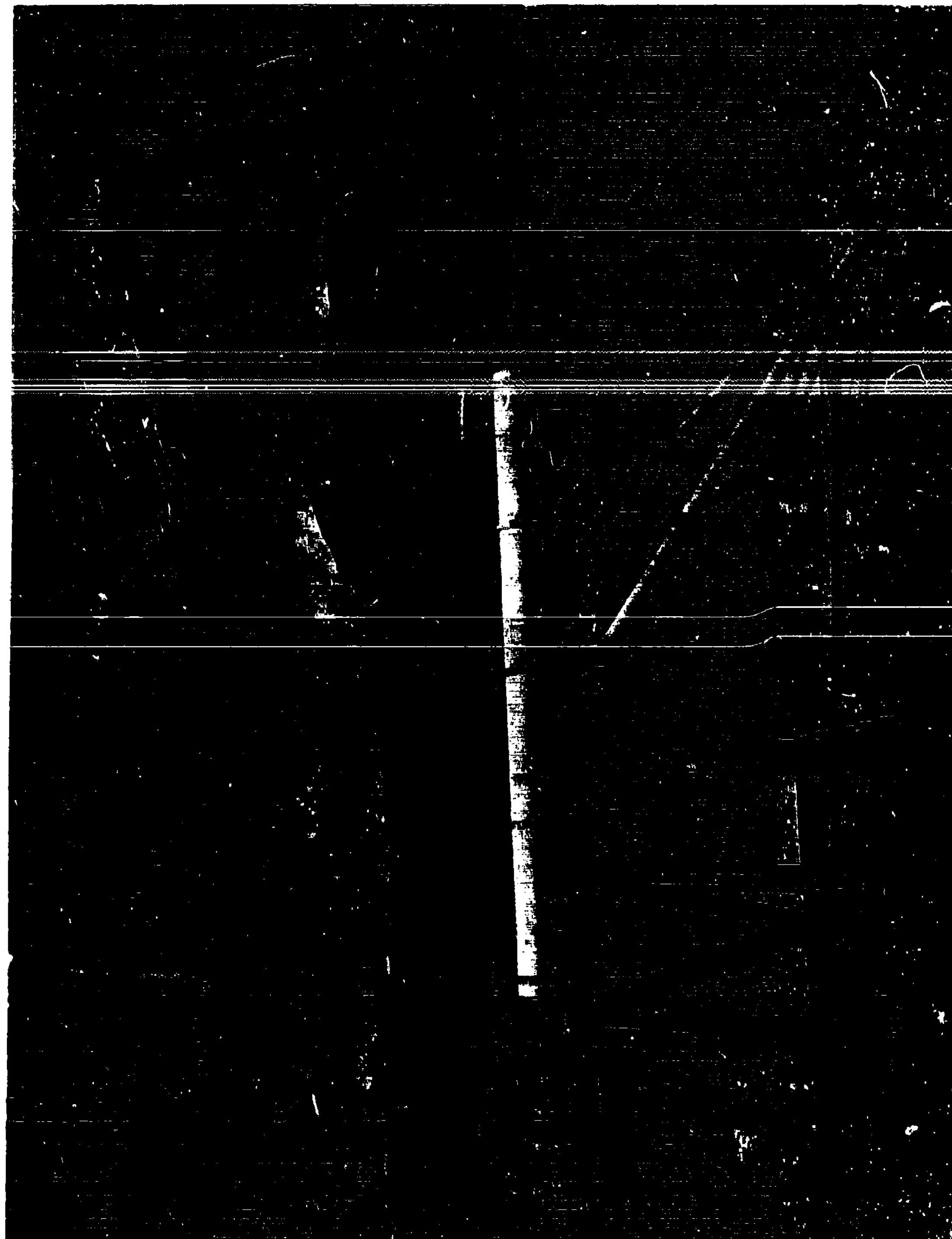

FIGURE 44

THE JUDI ROCKET LAUNCHER

12. Recheck the resistance in the pyro-delay to insure that the leads have not become disconnected.

13. At T-10 minutes, tie the igniter leads and the pyro-delay leads in parallel and then connect these leads in series with the firing line.

14. Check with the launch control center to determine that the firing line is clear. Unshort the firing line at the launching pad and clear the area of all personnel.

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13. ABSTRACT

The upper-atmosphere rocket sounding system described in this report is in operation at White Sands Missile Range, New Mexico, and is representative of the systems in operation at 22 other locations which serve as Meteorological Rocket Network stations. Basic system components and the theory of operations are discussed. The various facilities and operational procedures described may serve as a guide to any group which plans to use such a system for obtaining measurements of stratospheric temperature and wind.

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