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D-REGION ELECTRON DENSITY MEASUREMENTS DURING THE SOLAR ECLIPSE OF 12 NOVEMBER 1966

by

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William A. Dean

January 1970

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U.S. ARMY ABERDEEN RESEARCH AND DEVELOPMENT CENTER
BALLISTIC RESEARCH LABORATORIES
ABERDEEN PROVING GROUND, MARYLAND

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Signature and Propagation Laboratory

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B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

REPORT NO. 1464

HTLootens/WADean/nll
Aberdeen Proving Ground, Md.
January 1970

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ABSTRACT

Under the sponsorship of the Defense Atomic Support Agency (DASA), and in cooperation with the Brazilian Space Commission (CNAE), the National Aeronautics and Space Administration (NASA) and Sandia Corporation, the Ballistic Research Laboratories (BRL) instrumented and launched five Nike-Javelin III rockets from the southeastern coast of Brazil before and during the total solar eclipse of 12 November 1966. Each payload carried a nose-tip Langmuir probe for electron density and temperature measurements, two receivers to provide data for a partial reflection experiment and for differential absorption measurements, and a parachute-borne blunt probe (ejected from the payload at apogee) for positive and negative charge conductivity measurements.

Electron densities derived from the Langmuir probe are presented as a function of time and altitude during the eclipse. Results from the other experiments have already been reported and are referenced.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

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I. INTRODUCTION

The National Aeronautics and Space Administration (NASA), the Defense Atomic Support Agency (DASA), Sandia Corporation and the Brazilian Space Commission (CNAE) cooperated in a sounding rocket program to study ionospheric changes during the total solar eclipse of 12 November 1966. The overall rocket program consisted of launching 15 two-stage rockets from a site that lay within the path of eclipse totality, located on the southeastern coast of Brazil at Cassino, near the city of Rio Grande. Figure 1 shows the arrangement of the rocket range instrumentation and facilities. A detailed account of site preparation, range operations and roll-up activities has already been published.[1*]

As a part of this program, the Ballistic Research Laboratories (BRL), under DASA sponsorship, served as technical coordinator for all DASA-funded groundbased and rocket projects, and coordinated the air and water shipment of equipment for all experimenters. In addition, BRL instrumented and launched five payloads on Nike-Javelin III rocket vehicles (DASA Project 6.3E). Four payloads were launched on eclipse day; the fifth was launched one week earlier to provide reference data, to realistically exercise range procedures and to certify payload instrumentation. Experimental instrumentation was identical in each of the five payloads and consisted of (1) a rocket nose-tip Langmuir probe to measure electron densities and temperatures, (2) a receiver tuned to 2.4 MHz to provide calibration information for a partial reflection experiment, (3) a receiver tuned to 185.5 kHz for differential absorption measurements and (4) a blunt probe experiment, parachute-borne after ejection from the payload at apogee, for the measurement of positive and negative charge conductivities.

The White Sands Missile Range (DASA Project 9.5) provided and installed the rocket launchers, and furnished and launched all the DASA rockets. The partial reflection experiment (DASA Project 6.5E) was under

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References are listed on page 29.

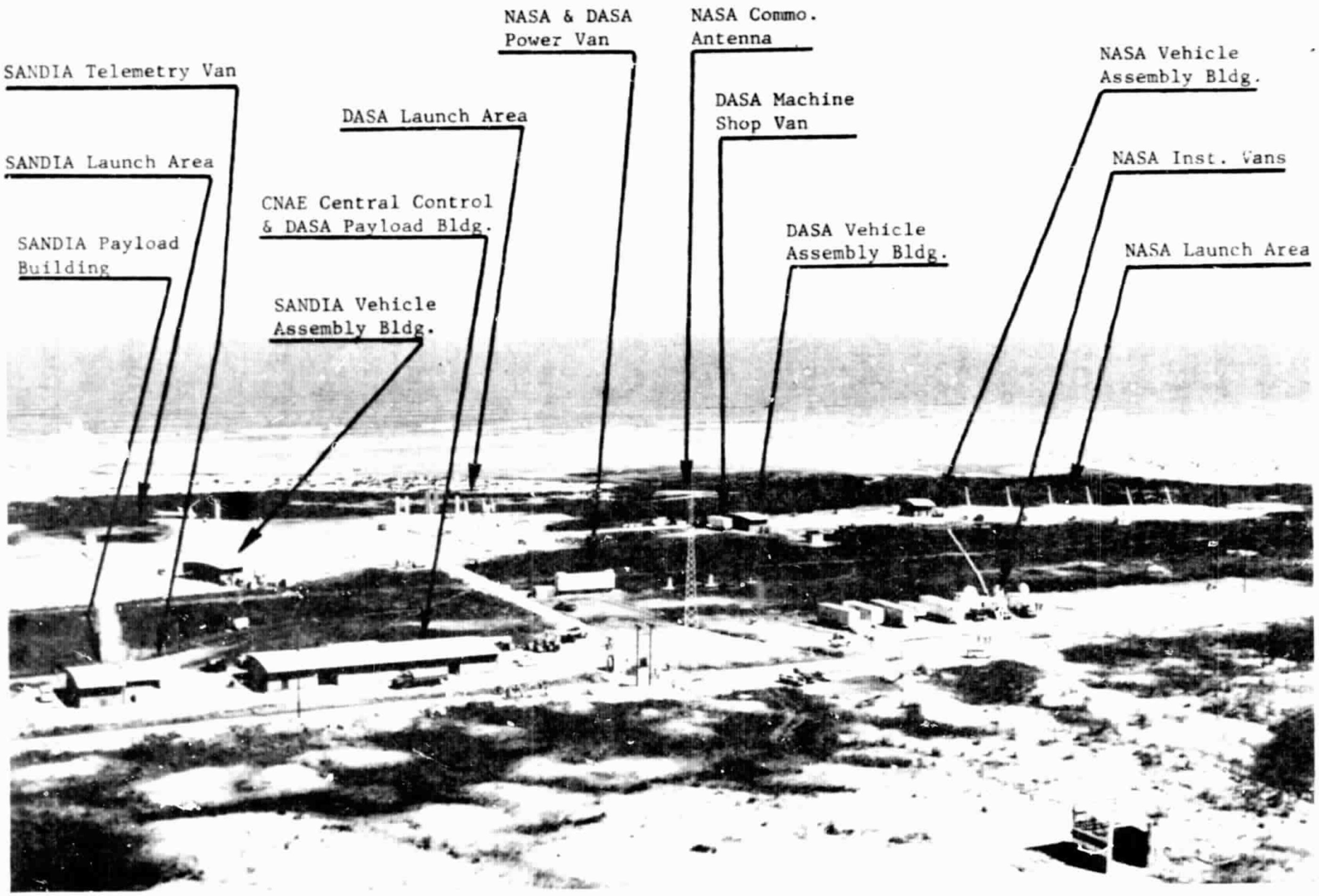

Figure 1. NASA/CNAE Rocket Range Instrumentation and Facilities Near Rio Grande, Brazil for the Solar Eclipse of 12 November 1966

the technical direction of the Cornell Aeronautical Laboratory (CAL).[2,3]

The differential absorption and blunt probe experiments were conducted by the Pennsylvania State University (PSU) under contract to the BRL.[4,5] The Langmuir probe experiment was supplied by the GCA Corporation, also under contract to the BRL, and the electron density data derived from probe measurements are the subject of this report.

II. ROCKET VEHICLE AND PAYLOAD STRUCTURE

A. Rocket Vehicle

The Nike-Javelin III rocket and payload is a two-stage, solid propellant rocket combination consisting of a Nike booster and a Javelin second stage. Both stages are fin-stabilized and nominal spin rates for the first and second stages are 4 and 8 rps, respectively. Typically, the Nike motor burns for 3.5 seconds and drag-separates at burnout. The second stage coasts for 16.5 seconds, ignites at T+20 seconds (where T represents launch time), and burns for approximately 8 seconds. At burnout, the second stage reaches a velocity of approximately 5600 feet per second.

Nominal length of the two stages and payload launched during the eclipse project was 31 feet, and total launch weight including ballast was approximately 1965 pounds. The Nike booster (with interstage adapter) was 12 feet long, 17 inches in diameter and weighed 1340 pounds. The Javelin III motor and payload were 19 feet long, 9 inches in diameter and weighed 625 pounds. Physical dimensions of the rocket vehicle and payload are summarized in Table I.

Table I.

Nike-Javelin III Rocket Vehicle and Payload Dimensions (DASA Project 6.3E)

	Booster	2nd Stage	Payload	Total
Designation	M5E1	J-33	6.3E	---
Number of fins	3	4	0	---
Fin area per panel (sq. in.)	665	136	---	---
Launch weight (lbs.)	1341	401	225	1967
Diameter (in.)	17	9	9	---
Length (in.)	145	101	122	368

B. Payload Structure

The DASA Project 6.3E eclipse payload was 9 inches in diameter, 122 inches in length and weighed 150 pounds without ballast. A drawing of the payload is shown in Figure 2 and three payload/rocket combinations on the launchers are shown in Figure 3. A full description of the payload design and construction has already been reported,[6] so only a brief outline of the major items will be presented here. The payload consisted of four major components: the ogive, the blunt probe payload and parachute, the payload ejection system and the ballast. These are described below.

1. Ogive. The four-caliber tangent ogive was made of 1/8-inch thick steel with a cylindrical fiberglass section at the aft end. Overall length of the ogive and cylindrical section was 37 inches. It housed the PSU differential absorption experiment and the CAL partial reflection experiment together with their associated ferrite rod antennas, the Langmuir probe and electronics, pyrotechnics for separating the ogive from the payload proper, ogive ejection springs, barometric switches and batteries. Ogive separation, programmed to occur at T+133 seconds, was accomplished by means of a flexible linear shaped charge (FLSC) wrapped circumferentially around the inside of the ogive at the point where it mated with the blunt

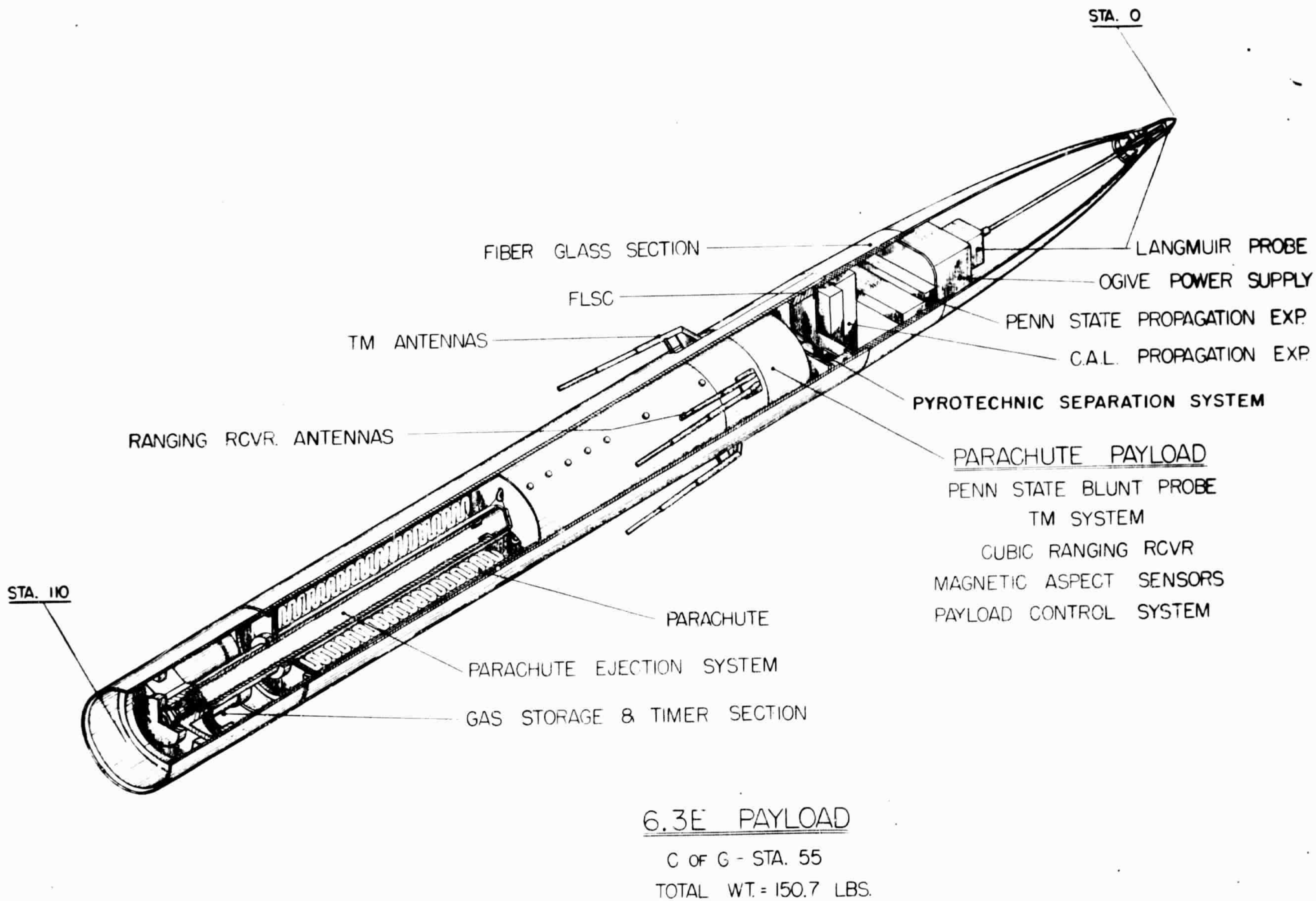

Figure 2. DASA Project 6.3E Payload for the Solar Eclipse of 12 November 1966

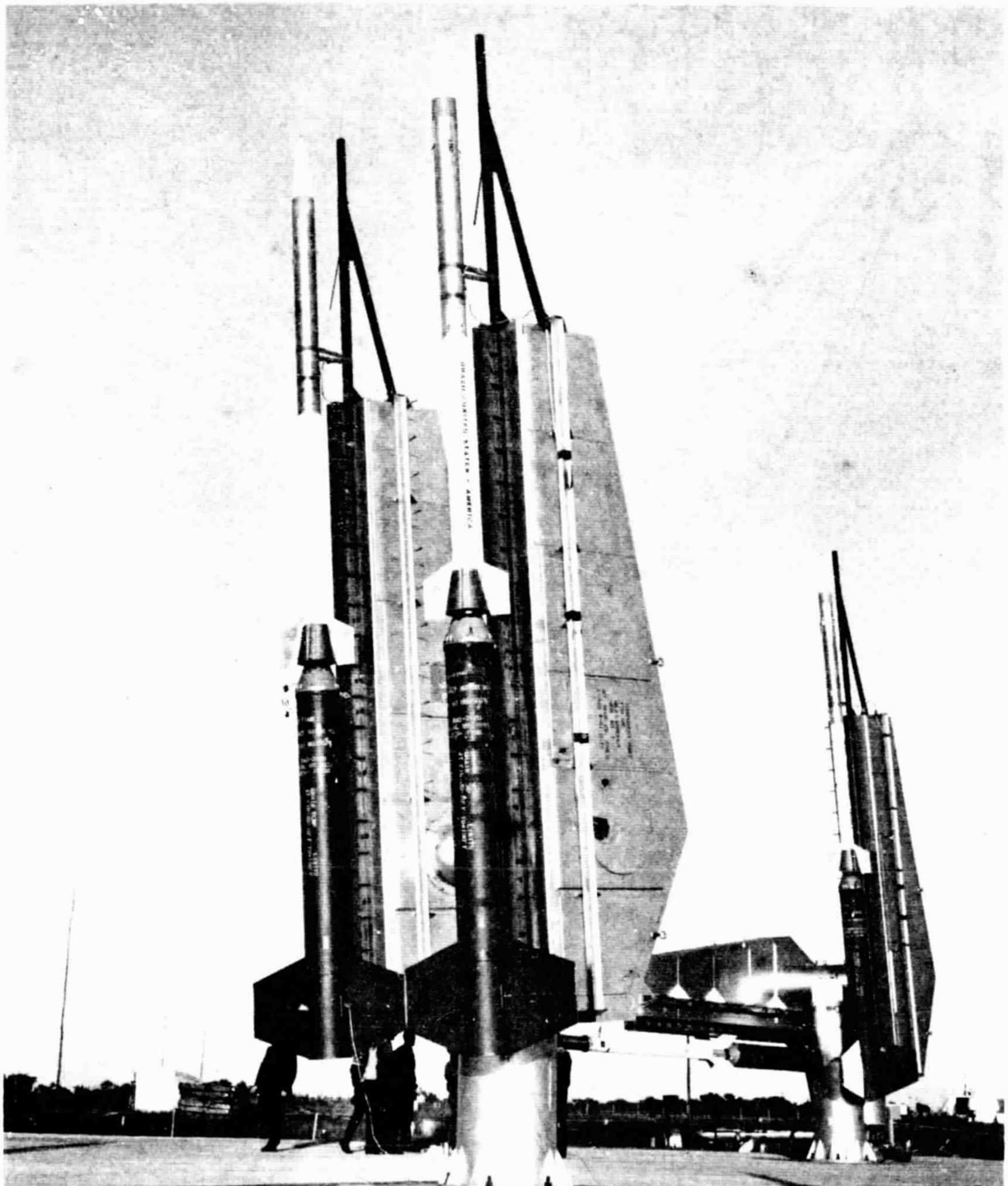

Figure 3. DASA Project 6.3E Payloads on Launchers for the Solar Eclipse of 12 November 1966

probe payload section. Detonation of the shaped charge sheared the ogive from the blunt probe section and the spring-loaded ogive was ejected, as shown in Figure 4.

2. Blunt Probe Payload. This part of the payload was a cylindrical section 28 inches long located inside the forward end of the cylinder housing the blunt probe ejection system and parachute. It contained the PSU parachute-borne blunt probe experiment, a telemetry system and four modified guadraloop antennas, a Cubic Corporation ranging receiver with two quadraloop antennas, a thermal element to cut the parachute lines, a "g" activated timer and barometric switch connected in series to activate the thermal element, a solar cell for payload aspect, and accelerometers, magnetometers and batteries. The blunt probe experiment was designed to operate only during parachute descent, following ejection from the rest of the payload. After the probe experiment had descended to 30 km altitude, the thermal element cut the parachute lines, allowing the probe package to free-fall to earth.

3. Payload Ejection System. This system was housed in a cylindrical section 73 inches long. It consisted of a nitrogen reservoir pressurized to 1600 psi, a piston and explosive bolt to release the piston, a "g" activated timer and barometric switch, and batteries. This section also housed the blunt probe experiment canister and four ribbon parachutes, which were attached to the aft end of the canister. The piston was released at T+143 seconds, 10 seconds after the ogive had been ejected, by detonation of the explosive bolt, which was actuated by the series-connected timer and baroswitch. The gas pressure thrust the piston forward, ejecting the blunt probe canister and deploying the ribbon parachutes (see Figure 5).

4. Ballast. A 75-pound ballast section and a drag skirt on the rocket second-stage fin section were used to restrict payload apogee to 85 km.

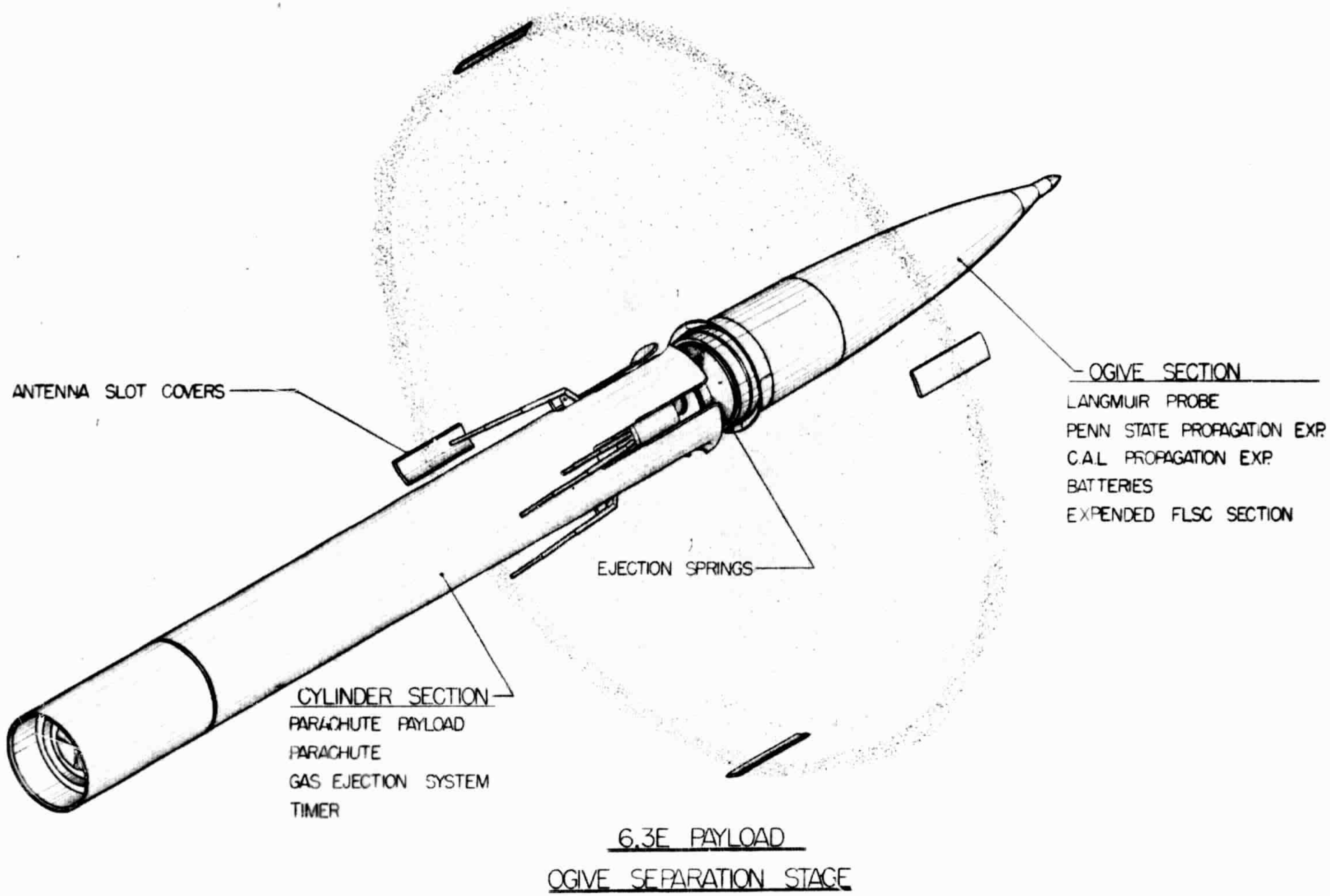

Figure 4. Ogive Separation on DASA Project 6.3E Payload for the Solar Eclipse of 12 November 1966

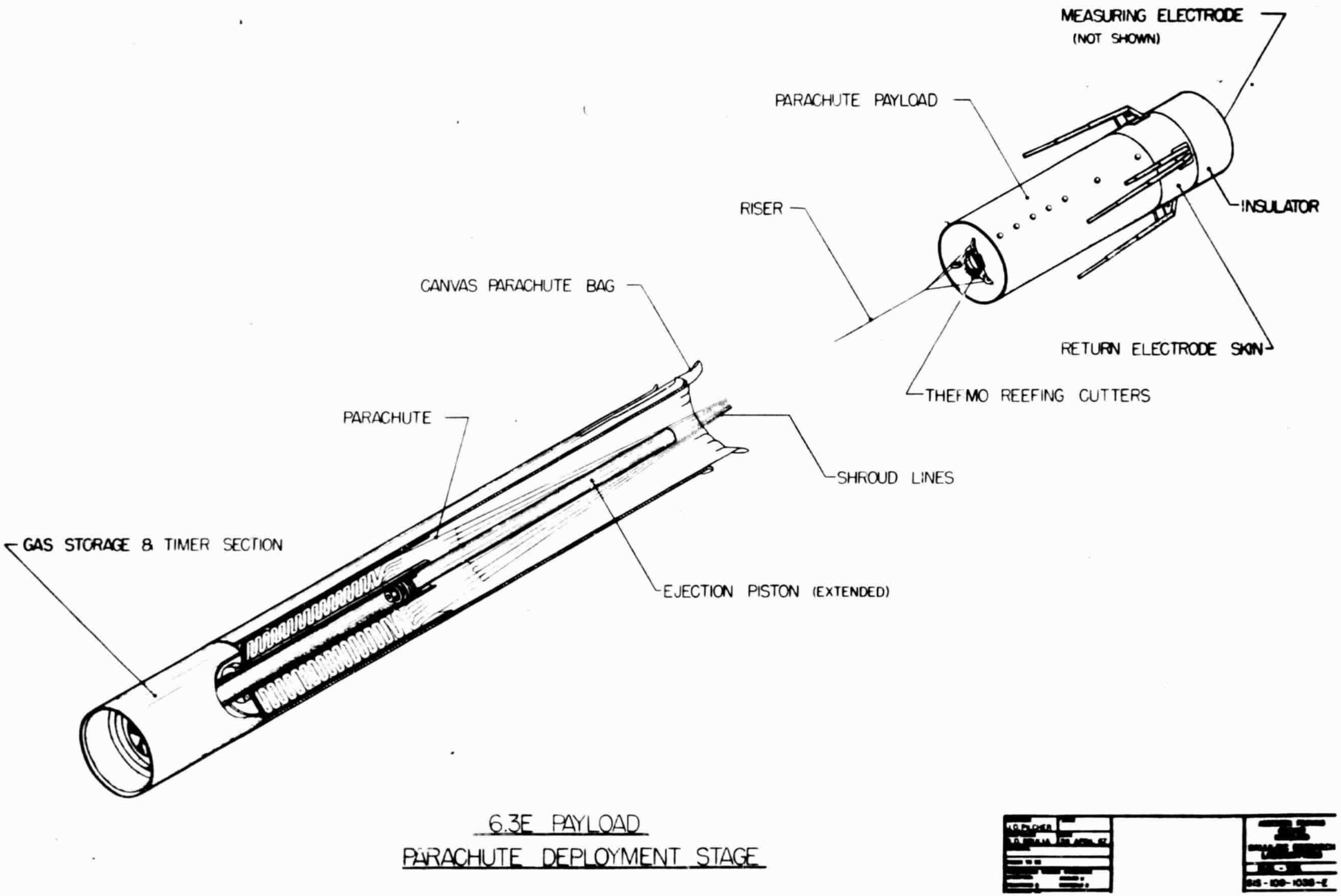

Figure 5. Blunt Probe Ejection and Parachute Deployment on DASA Project 6.3E Payload for the Solar Eclipse of 12 November 1966

III. PAYLOAD INSTRUMENTATION

A. General

As mentioned previously, each payload carried the following scientific instrumentation:

(1) a nose-tip Langmuir probe to measure electron density and electron temperature up to rocket apogee (85 km). These measurements were made only during rocket ascent.

(2) a blunt probe experiment to measure positively and negatively charged particle conductivity during descent through the 85 to 35 km altitude range using a parachute-borne instrument deployed at rocket apogee.

(3) a receiver tuned to 185.5 kHz to be used for differential absorption measurements during the upleg portion of the rocket trajectory. A 2-kw, ground-based transmitter broadcast a signal to the rocketborne receiver and receiver AGC was telemetered.

(4) a receiver tuned to 2.4 MHz to monitor a ground-based transmitter during rocket ascent. The transmitter carrier frequency was received in the payload and receiver AGC was telemetered to the ground to provide a reference for the CAL partial reflection experiment (DASA Project 6.5E).

In addition, the payloads each carried a Cubic Corporation ranging system, a telemetry system and miscellaneous aspect, control, timing and pyrotechnic devices. We shall briefly discuss the theory and operation of the Langmuir probe, since this report deals primarily with the results derived from that experiment.

B. Langmuir Probe

The Langmuir probe experiment, used to derive electron density and electron temperature, typically consists of an electrode (collector) and associated electronics. During operation, the potential on the collector is repeatedly swept from a small negative to a small positive value, and the resulting current flow to the collector is measured. The current-voltage relationship is subsequently analyzed in the laboratory to yield electron density and electron temperature values.[7]

The probes flown on these payloads were furnished by the GCA Corporation. The collector formed the nose tip of the steel ogive, and was insulated from the ogive by an alumina section. The collector surface area was approximately 40 square centimeters. Probe electronics consisted of a ramp generator and an electrometer-amplifier. The latter, an operational amplifier with five decades, had a logarithmic feedback element to allow the measurement of collector currents from 10^{-9} to 10^{-4} amperes, where 10^{-5} amperes is equivalent to approximately 4×10^{4} electrons per cubic centimeter.

The ramp generator was programmed to provide a sweep linear with time, varying from -2.7 volts to +2.7 volts in 0.4 second. At the end of each sweep, the voltage was held constant for 0.1 second at a pedestal level of +2.7 volts. Probe electronics were housed in the center of the ogive section. Electrical connections between the collector and the electronics were made through a shielded cable routed longitudinally inside the ogive.

IV. FIELD OPERATIONS AND TRACKING

The five BRL (DASA Project 6.3E) rockets were deployed as shown in Table II.

The rocket vehicles all performed as expected and, in general, the instrumentation operated satisfactorily. In all instances, the blunt probe canister was ejected properly but the parachutes failed to inflate fully. Despite this drawback, conductivity measurements were made and the results published.[5]

Each payload carried a 0.25-watt, FM/FM telemeter unit operating at frequencies ranging from 250.7 to 259.7 MHz. These units transmitted with four modified quadraloop antennas which gave left-hand circular polarization during the upleg portion of the trajectory and apparent right-hand circular polarization during the parachute descent of the blunt probe experiment.

Table II.

Launch and Flight Data for BRL Eclipse Rockets

Rocket	Launch Date and Time*	Apogee	Apogee Time
D-16-C**	5 Nov 66, 1135:00 UT	79.7 km	1537:22 UT
D-3	12 Nov 66, 1338:00 UT	79.3 km	1340:20 UT
D-10	12 Nov 66, 1407:30 UT	79.3 km	1409:49 UT
D-15	12 Nov 66, 1450:00 UT	79.5 km	1452:22 UT
D-16	12 Nov 66, 1535:00 UT	79.3 km	1537:20 UT

*The center of totality on the earth's surface at the launch site occurred at 1410:09 UT.

**Certification rocket.

Cubic Corporation DME/AGAVE equipment was used for payload tracking. A groundbased 1-kw transmitter, operating at 427 MHz, was used to transmit three ranging tones to each payload. These tones were received in the payload with a linearly polarized antenna and re-transmitted to the ground via the telemetry link. The Cubic equipment, shown in Figure 6, was located approximately two miles from the rocket launchers, aft along the flight aximuth. This equipment was capable of tracking four rockets simultaneously. When scheduling permitted, NASA MPQ-19 skin-tracking radars were used to obtain trajectory data on some of the Project 6.3E payloads.

V. DATA REDUCTION AND RESULTS

A. Data Reduction

As noted earlier, the Langmuir probe consisted of a nose-tip electrode with a surface area of approximately 40 square centimeters, a ramp generator and an electrometer-amplifier. The amplifier, a five-decade, operational amplifier with a logarithmic feedback element, allowed the measurement of currents from 10^{-9} to 10^{-4} amperes. The ramp generator

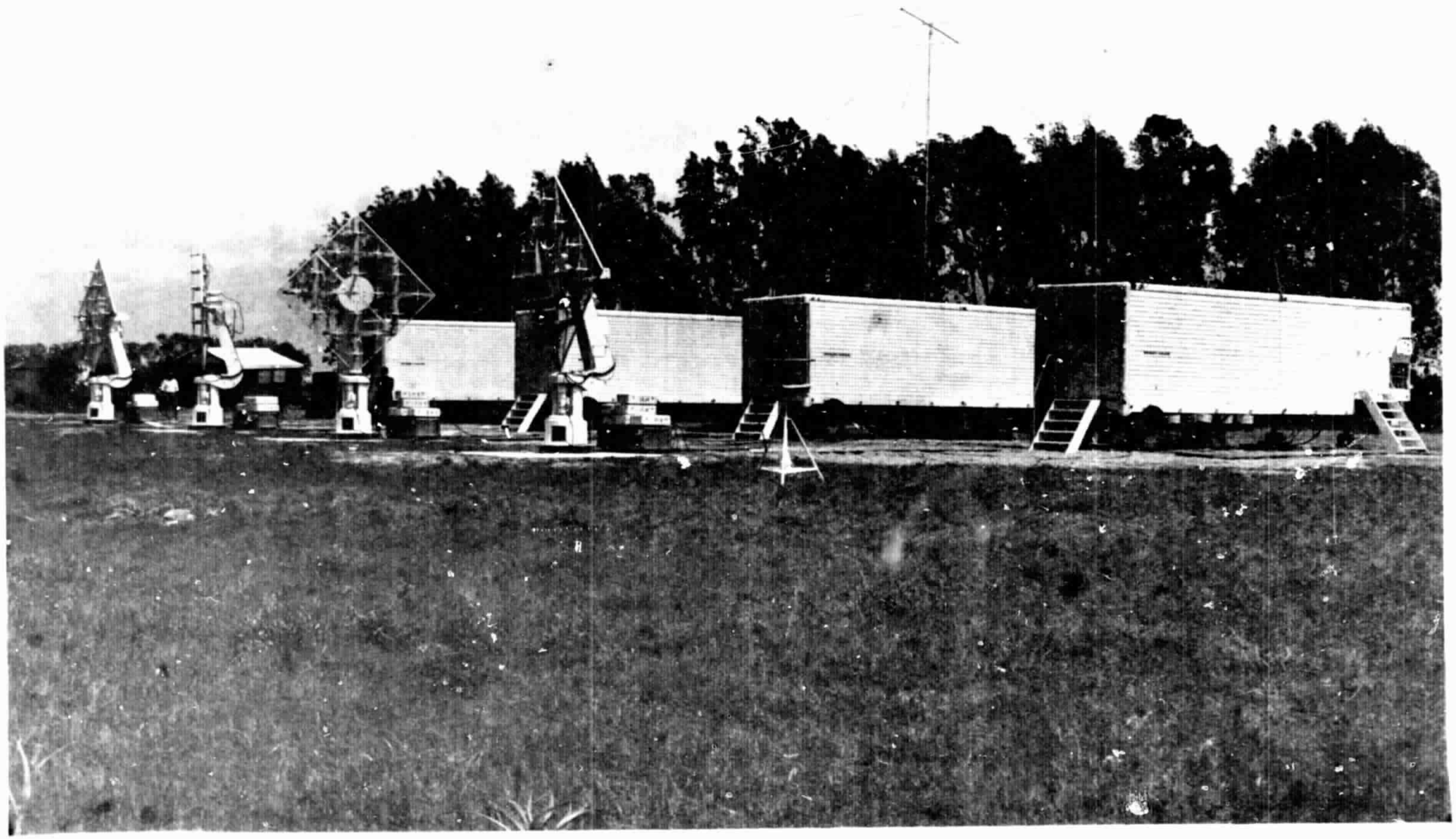

Figure 6. Cubic Corporation DME/AGAVE Instrumentation Near Rio Grande, Brazil for the Solar Eclipse of 12 November 1966

was programmed to provide a sweep voltage to the electrode. This sweep voltage varied linearly with time from -2.7 to +2.7 volts in approximately 0.4 second, and then was held constant at a pedestal level of +2.7 volts for approximately 0.1 second.

There is presently no acceptable theory for deriving electron temperatures from Langmuir probe data that are obtained at altitudes lower then about 90 km. Therefore, since these payloads attained apogees of slightly less than 80 km, we did not compute electron temperatures, but only electron densities, using the data associated with the +2.7-volt pedestal level.

Several experimenters have found that electron density is proportional to electron current at the lower altitudes, and that the ratio of proportionality remains constant over the altitude range from approximately 55 to 90 km. Under these conditions, it is usually necessary to determine the ratio of proportionality by comparison of the probe electron current data with electron densities determined from some independent source such as an ionosonde. In this case, we determined a ratio of proportionality by comparing the observed probe electron current with the electron densities derived from the PSU propagation experiment for one rocket flight. We then used this ratio for converting the probe currents to electron densities for all five flights.

Two sets of calibration data were available for each of the probes flown, with the exception of the probe flown on the certification rocket (D-16-C), for which no calibration data were furnished. The other four probes were bench-calibrated before delivery to BRL and were calibrated again in the field during pre-launch checkout. These latter calibrations were used exclusively for data reduction. Since the calibration data for each of these probes yielded essentially the same calibration curve, we merely averaged these four curves to produce a calibration curve for the certification rocket.

A switchable resistor box, with precision resistors ranging from 10^{10} to 10^{4} ohms, was employed during the calibration procedure in the field. With a knowledge of the ramp voltage (in this case, we were concerned with only the 2.7-volt pedestal voltage), the current through the probe was calculated. This current, driven across the resistors in the amplifier circuits, produced a voltage which was passed through the payload telemetry system. From these data, calibration curves relating voltage controlled oscillator (VCO) voltage to probe current were produced.

All of the Langmuir probe data were recorded on magnetic tape in the field and then re-recorded on analog charts at BRL. One voltage level was measured on that portion of each probe sweep associated with the +2.7-volt ramp pedestal (approximately one reading per half second). Unfortunately, common telemetry practices were not followed for these flights in that the probe data were not periodically interrupted for the insertion of precision voltage levels (normally 0 and 5 volts). These voltage levels serve as VCO in-flight calibrations and can be used to eliminate any drift or other irregularities which might occur in the VCO characteristics. As a consequence, a limited amount of data manipulation was required to correct for voltage level changes which we construed as VCO drift or other malfunction. The final results, when compared with measurements from other experiments, indicate that measurement errors were small (approximately ± 10 electrons per cubic centimeter).

B. Results

The probes functioned properly on all payloads and data were obtained to the lower limit of probe sensitivity, which for these units was approximately 7 electrons per cubic centimeter. Electron density as a function of altitude is shown in Figure 7. In Figure 8, the data are replotted to indicate the variations of electron density with time and altitude during the progress of the eclipse.

VI. CONCLUSIONS

In comparison with other rocket probe measurements and the several radio propagation experiments fielded during the eclipse project, the data given here are in good agreement except for the measurements at eclipse totality. We believe, however, that electrons are being lost

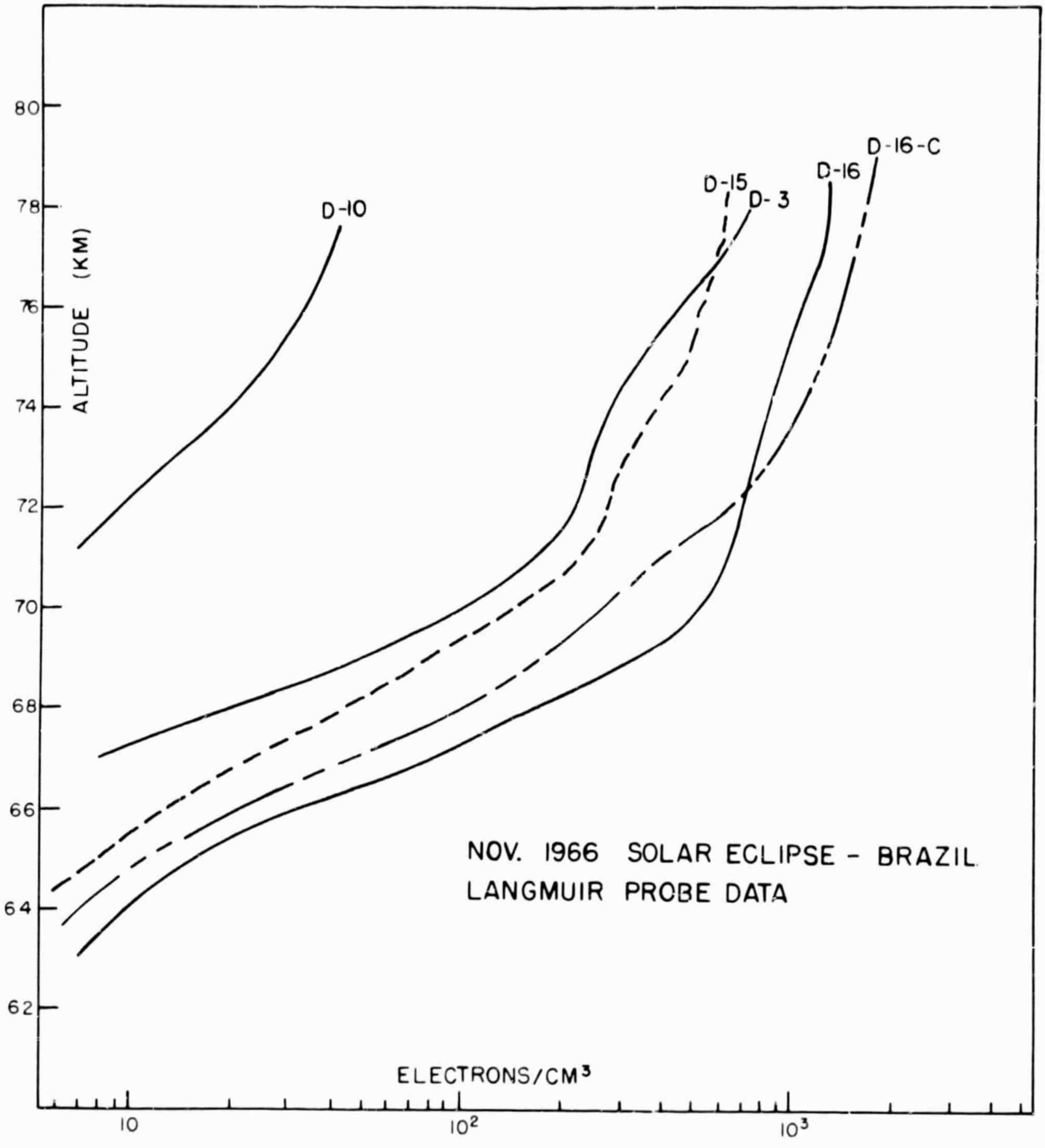

Figure 7. Electron Density as a Function of Altitude Derived from Langmuir Probe Experiment Flown on DASA Project 6.3E Payloads During the Solar Eclipse of 12 November 1966

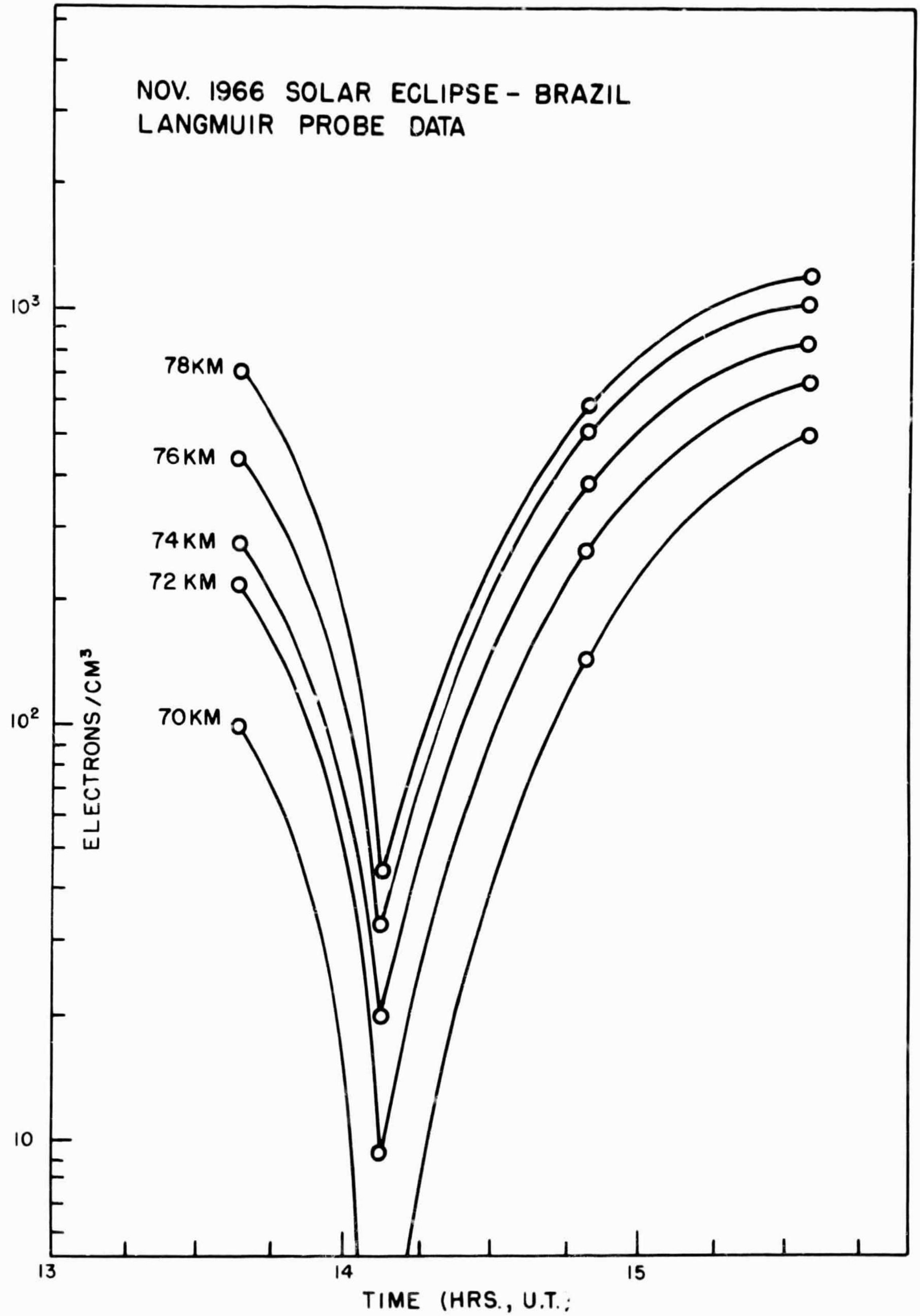

Figure 8. Variations in Electron Density as a Function of Altitude and Eclipse Time Derived from Langmuir Probe Experiment Flown on DASA Project 6.3E Payloads During the Solar Eclipse of 12 November 1966

so rapidly in the shadow region that time and altitude variations at totality are comparable in magnitude and, hence, great care is needed to separate the effects of these two parameters. The matter is particularly critical for the BRL probe measurement, since payload altitude is changing very slowly above 75 km. Consequently, the time factor becomes increasingly more predominate as the payload approaches apogee, and electron density variations observed near apogee are almost exclusively the result of a time-varying ionosphere rather than a change in payload altitude.

We suggest that, for future probe flights in this altitude region, it might be more profitable to apply a constant voltage to the probe rather than using a ramp generator sweeping from a small negative voltage to a small positive voltage. This constant voltage would provide better time resolution in the data and would improve the determination of fine structure in the electron density profiles.

ACKNOWLEDGEMENTS

The successful completion of this project is a tribute to the technical competence and the cooperation between personnel from CNAE, NASA, DASA, Sandia Corporation, Cubic Corporation and the Air Force Cambridge Research Laboratories.

The BRL personnel who conducted the field program deserve special recognition for their excellent performance in view of the unusually severe field conditions and the rigid firing schedule.

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