T H E U N I V E R S I T Y O F M I C H I G A N

COLLEGE OF ENGINEERING
Department of Electrical Engineering
Space Physics Research Laboratory

Sounding Rocket Flight Report

NASA 18.51 THERMOSPHERE PROBE EXPERIMENT

Prepared on behalf of the project by

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ORA Project 07065

under contract with:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER
CONTRACT NO. NAS 5-9113
GREENBELT, MARYLAND

administered through:

OFFICE OF RESEARCH ADMINISTRATION   ANN ARBOR

May 1969

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ACKNOWLEDGMENTS

The Thermosphere Probe launchings were conducted under Contract No. NAS 5-9113 as part of a cooperative undertaking of the Goddard Space Flight Center and the Space Physics Research Laboratory of The University of Michigan. Over one hundred persons contributed to the success of the NASA 18.51 Thermosphere Probe Experiment. Some of the personnel with specific responsibilities are listed below.

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Kartlick, W. G.	Omegatron Technician
Kimble, R. G.	Telemetry Technician
Maurer, J. C.	Payload Engineer
McCormick, D. L.	Machinist
Niemann, H. B.	Neutral Particle Scientist
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1. INTRODUCTION

The results of the launching of NASA 18.51, a Nike-Tomahawk sounding rocket, are presented and discussed in this report. The payload, a Thermosphere Probe (TP), described by Spencer, Brace, Carignan, Taeusch, and Niemann (1965), was jointly developed by the Space Physics Research Laboratory (SPRL) of The University of Michigan and the Goddard Space Flight Center (GSFC), Laboratory for Atmospheric and Biological Sciences (LABS). The TP is an ejectable instrument package designed for the purpose of studying the variability of the earth's atmospheric parameters in the altitude region between 120 and 350 km. The NASA 18.51 payload included a "second generation" omegatron mass analyzer (for which a complete report is currently being prepared), a quadrupole mass spectrometer, an electron temperature probe (Spencer, Brace, and Carignan, 1962), and a solar position sensor. This complement of instruments permitted the determination of the daytime molecular nitrogen density and temperature and the electron density and temperature in the altitude range of approximately 145 to 280 km over Wallops Island, Virginia.

A general description of the payload kinematics, orientation analysis, and the techniques for the reduction and analysis of the data is given by Taeusch, Carignan, Niemann, and Nagy (1965) and Carter (1968). The orientation analysis and the reduction of the nitrogen data were performed at SPRL, and the results are included in this report. The electron temperature probe data were reduced at GSFC and are not discussed here. The quadrupole data were reduced at SPRL but are not discussed in the present report.

2. GENERAL FLIGHT INFORMATION

The general flight information for NASA 18.51 is listed below. Table I gives the flight times and altitudes of significant events which occurred during the flight. Some of these were estimated and are so marked. The others were obtained from the telemetry records and radar trajectory information.

Launch Date:	8 August 1968
Launch Time:	19:10:00.100 GMT, 15:10:00.100 EDT
Location:	Wallops Island, Virginia
	Latitude: 37°50'14.915" N
	Longitude: 75°29'01.693" W

Apogee Parameters:

Altitude:	287.85 km
Horizontal Velocity:	327.01 m/sec
Flight Time:	264.00 sec

TP Motion:

Tumble Period:	5.15 sec
Roll Rate:	144.6 deg/sec

TABLE I

TABLE OF EVENTS
(NASA 18.51)

Event	Flight Time (sec)	Altitude (km)
Lift-off	0	0
1st Stage Burnout	3.4	1.3 (est.)
2nd Stage Ignition	12.5	7.2
2nd Stage Burnout	20.2	18.1
Despin	43.4 (est.)	67.7 (est.)
TP Ejection	45.4	71.7
Quadrupole Breakoff	60.5	100.9
Omegatron Breakoff	81.2	137.2
Quadrupole Filament On	62.1	103.8
Omegatron Filament On, M28	81.9	138.4
Peak Altitude	264.0	287.8
L.O.S.	510.0	———

3. LAUNCH VEHICLE

The NASA 18.51 launch vehicle was a two-stage solid propellant Nike-Tomahawk combination. The first stage, a Hercules M5E1 Nike motor, had an average thrust of 49,000 lb and burned for approximately 3.4 sec. The Nike booster, plus adapter, was 145.2 in. long and 16.5 in. in diameter. Its weight unburned was approximately 1325 lb. The sustainer stage, Thiokol's TE416 Tomahawk motor, provided an average thrust of 11,000 lb and burned for about 8 sec. The Tomahawk, 141.1 in. long and 9 in. in diameter, weighed 530 lb unburned. The TP payload, which was 93.9 in. long and weighed 170 lb, including despin and adapter modules, made the total vehicle 380.2 in. long with a gross lift-off weight of 2025 lb. The vehicle is illustrated in Figures 1, 2, and 3.

The launch vehicle performed flawlessly and reached a summit altitude of 287.85 km at 264.00 sec of flight time.

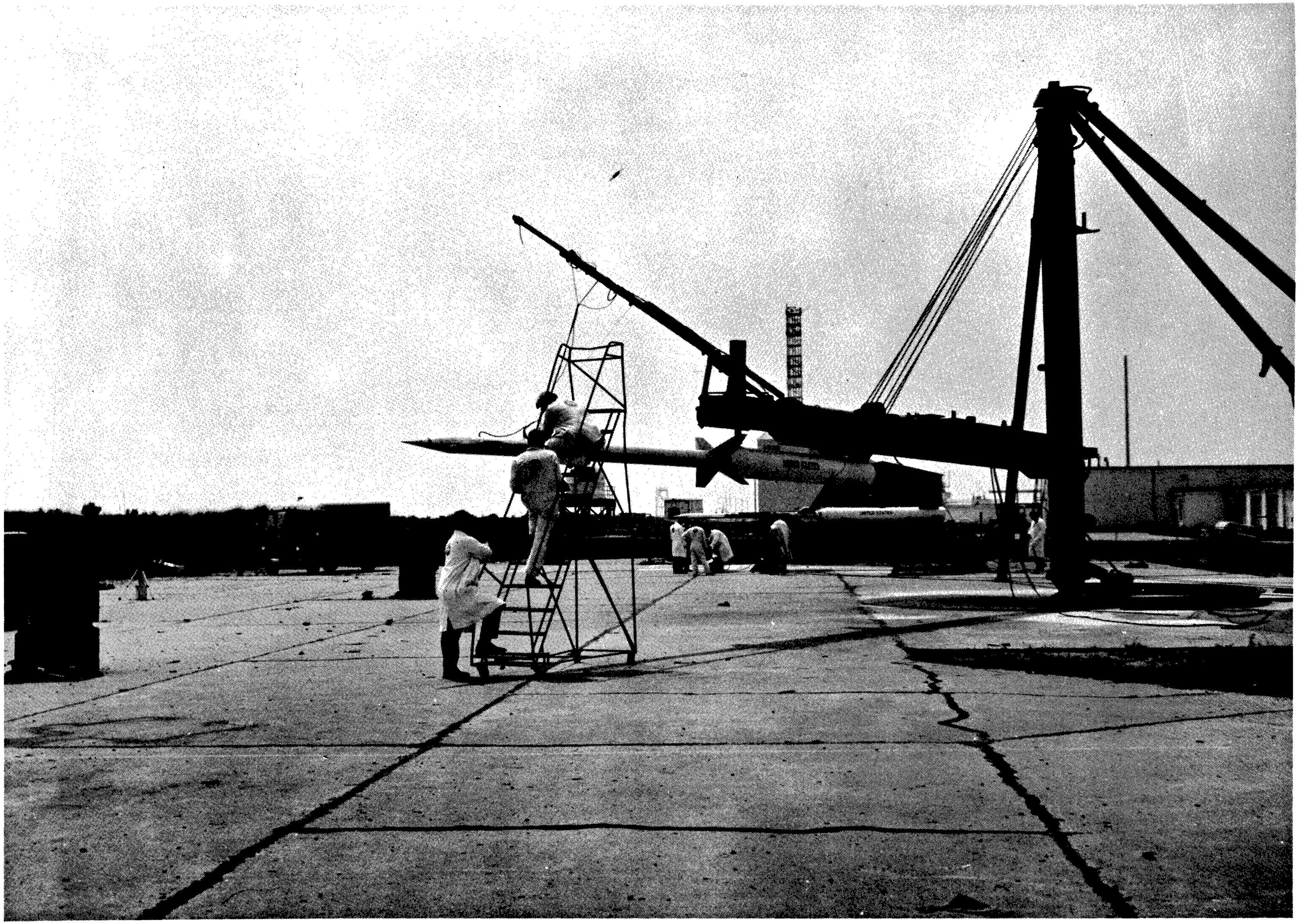


Figure 1. Nike-Tomahawk with thermosphere probe payload.

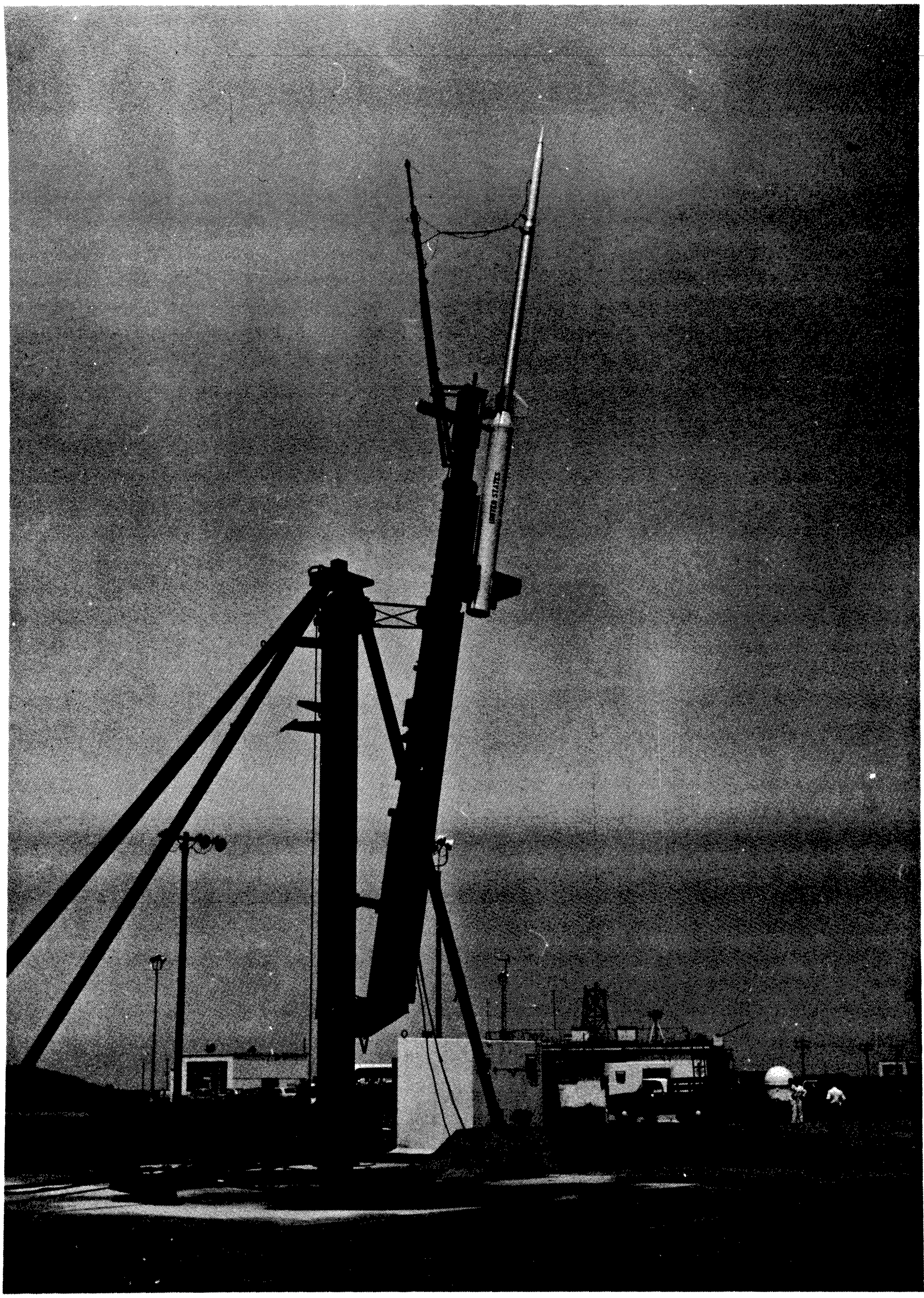


Figure 2. Nike-Tomahawk with thermosphere probe payload.

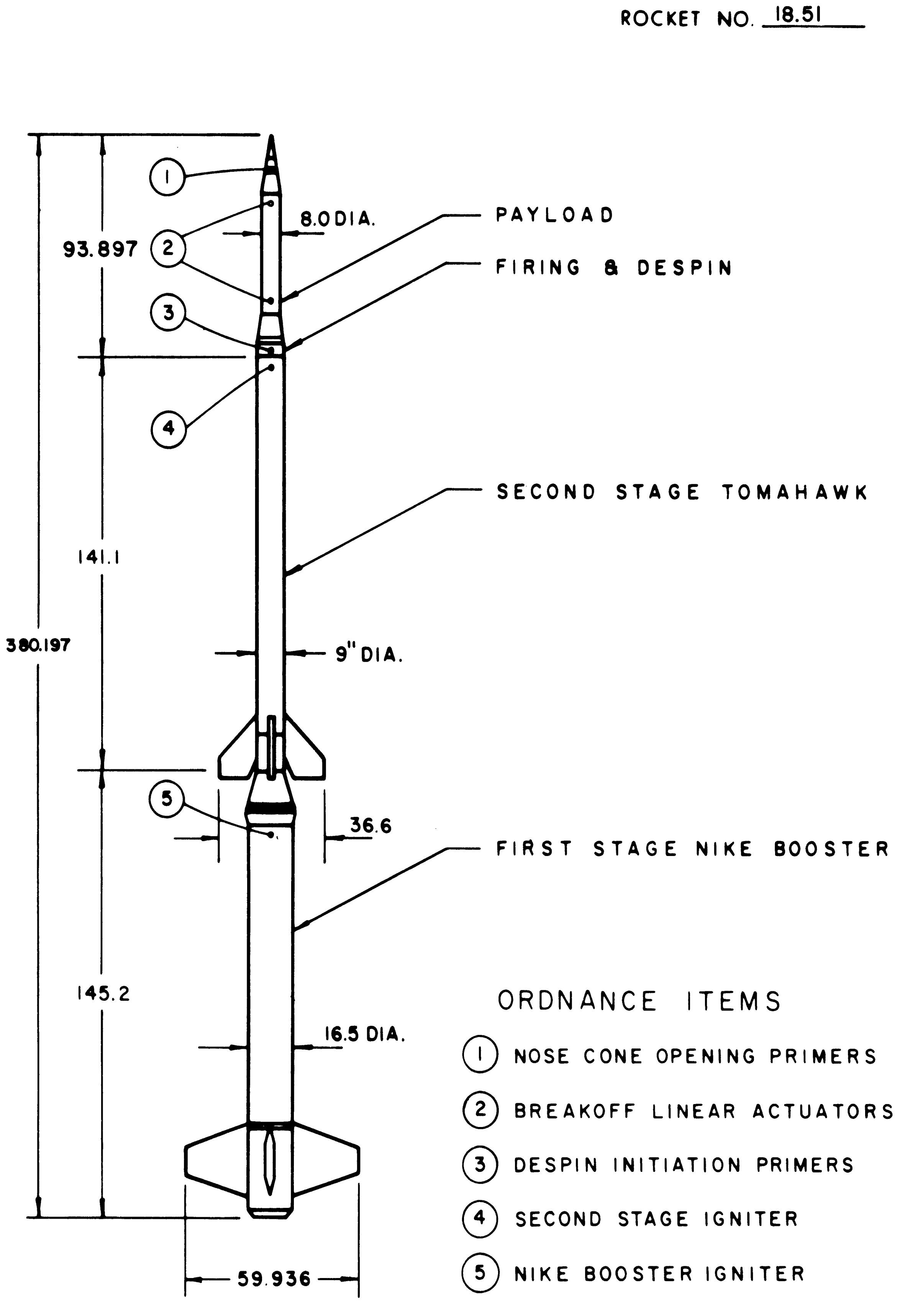


Figure 3. Nike-Tomahawk dimensions.

4. NOSE CONE

A diagram of the NASA 18.51 payload including the nose cone, the despin mechanism, and the adapter section is shown in Figure 4. An assembly drawing of the 8-in. nose cone is given in Figure 5.

The ejection system was designed for a tumble period of 2 sec by using a 6.0 lb Neg'ator* force and by limiting the travel of the plunger to 3.0 in. (Carter, 1968). An apparent failure of the despin mechanism caused an abnormal ejection and the design tumble period of 2 sec was not achieved. The ejection occurred at 72 km (45 sec after launch), and the resulting tumble period was 5.15 sec. The breakoff device of the omegatron was removed at 137 km (81 sec after launch), and the omegatron filament was turned on approximately 2 sec later.

*Neg'ator is a trade name.

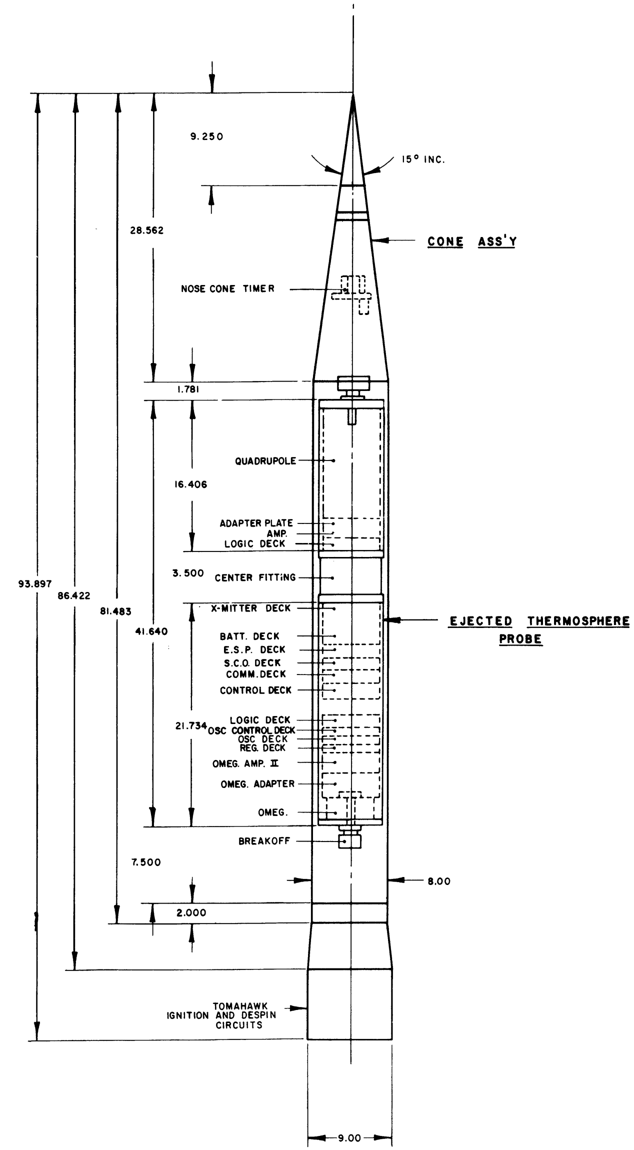


Figure 4. Thermosphere probe instrumentation design.

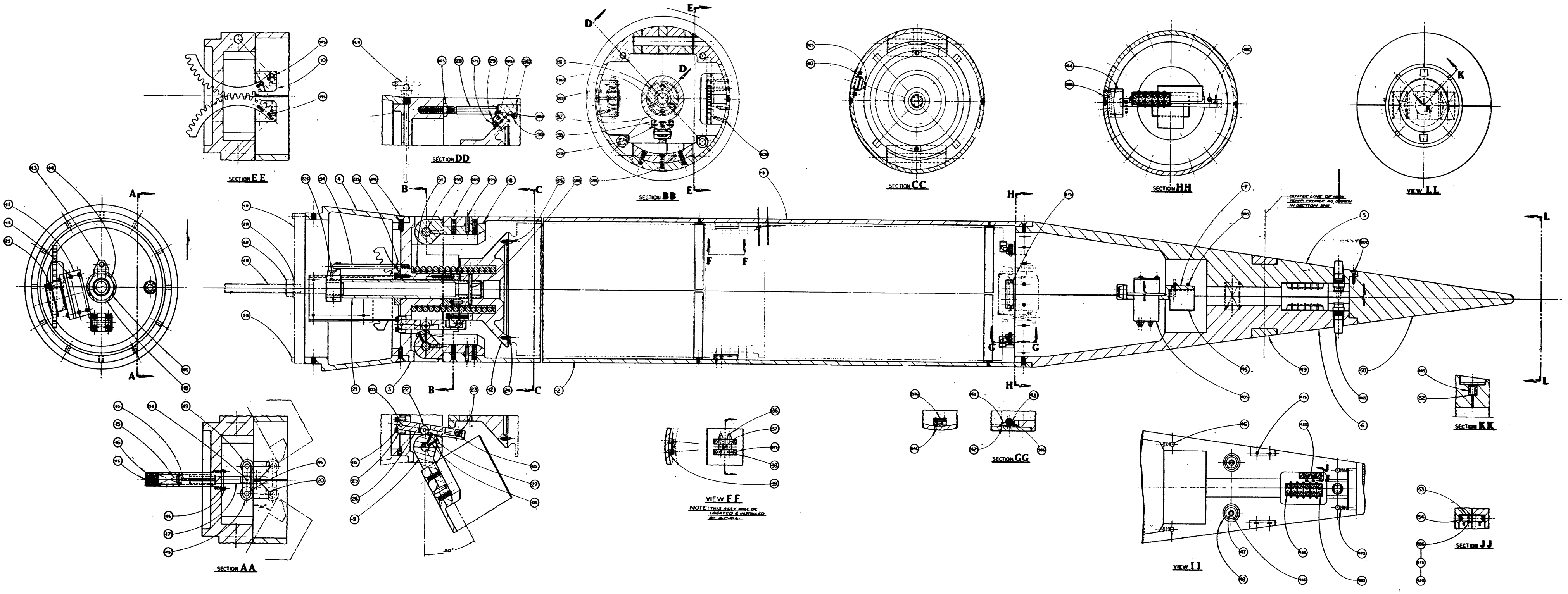


Figure 5. Assembly drawing, 8-in. nose cone.

5. THE THERMOSPHERE PROBE (TP)

The TP used for the NASA 18.51 payload was a cylinder 41.6 in. long and 7.25 in. in diameter which weighed 79 lb. The major instrumentation for this payload included an Omegatron II mass analyzer, a quadrupole, and an electron temperature probe. Supporting instrumentation included a solar aspect sensor for use in determining the attitude of the TP. The diagram in Figure 4 shows the location of instrumentation and supporting electronics in the nose cone. Figure 6 is the system block diagram.

5.1. OMEGATRON

The omegatron (OM II) used in the payload is a new design and is described in a forthcoming SPRL report. Table II lists the operating parameters of the gauge and associated electronics. The characteristics of the linear electrometer amplifier current detector, used to monitor the omegatron output current, are also listed. The omegatron envelope and breakoff configuration are shown in Figure 7. The calibration of the NASA 18.51 OM II, performed at SPRL during June 1968, is shown in Figure 8.

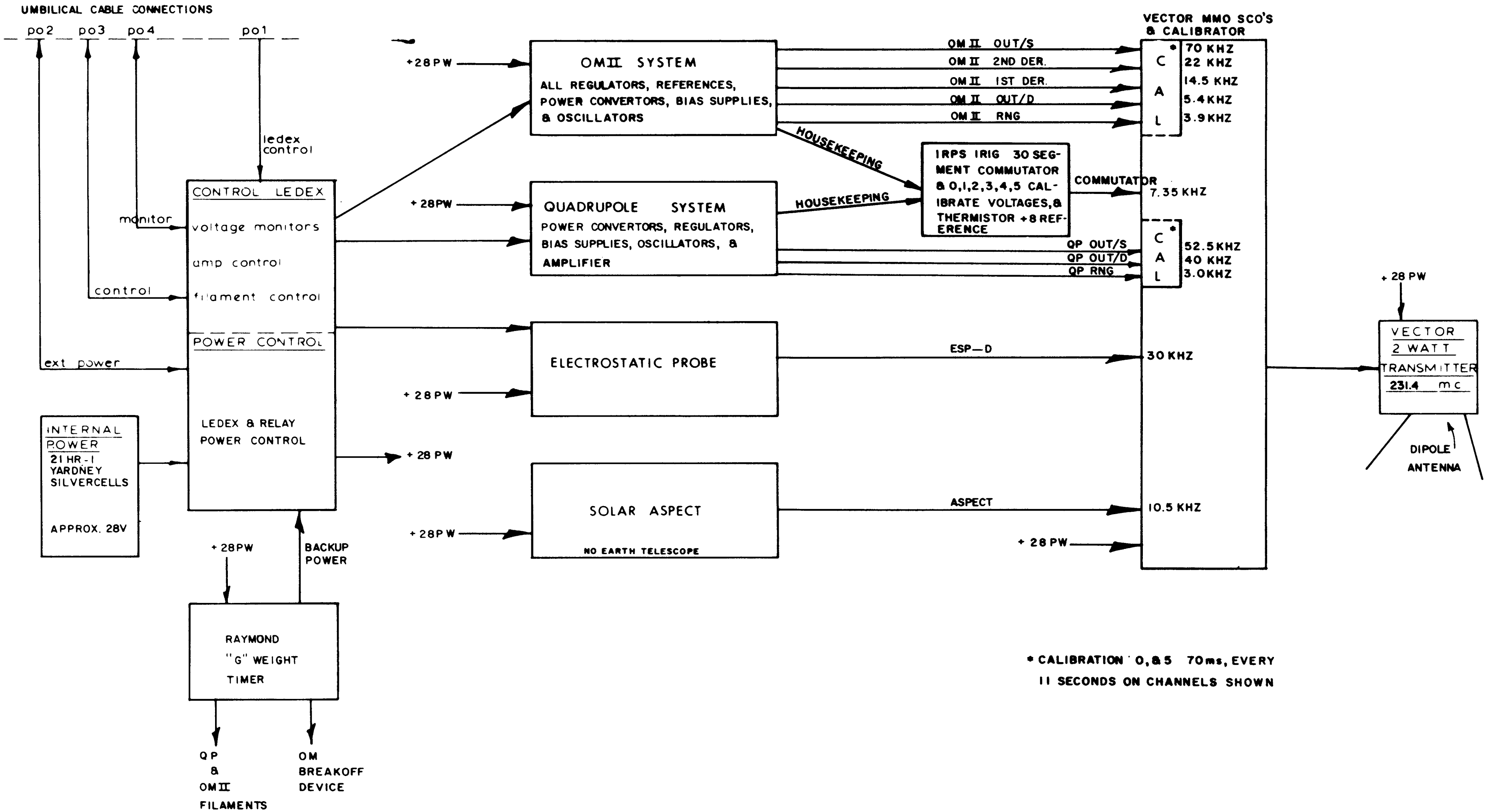
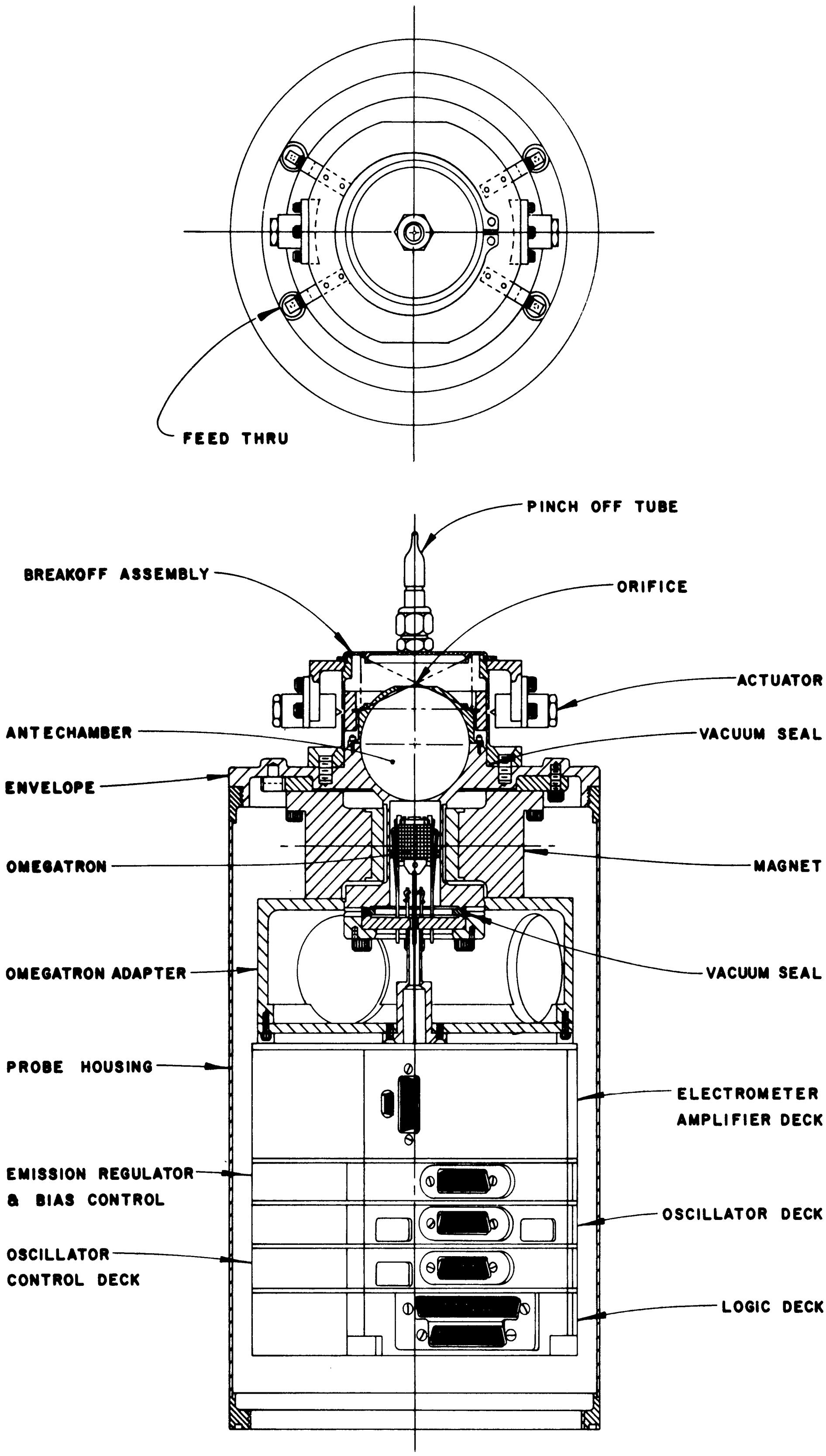


Figure 6. Thermosphere probe system block diagram.



OMEGATRON II

Figure 7. Omegatron II.

TABLE II

OMEGATRON DATA
(NASA 18.51)

Omegatron Gauge Parameters	OM II
Beam Current:	2.00 μA
Electron Collector Bias:	73.49 V
Filament Bias:	-87.30 V
Cage Bias:	- 0.20 V
Top Bias:	- 0.60 V
RF Amplitude, Mass 28:	4.00 V_{p-p}
RF Frequency, Mass 28:	137.00 kHz

Monitors	
Filament	
OFF:	0.11 V
ON:	2.74 V
Beam	
OFF:	0.84 V
ON:	4.18 V
Thermistor Pressure ("zero" Pressure)	
Filament OFF:	1.79 V
Filament ON:	1.68 V
Bias:	3.88 V
RF:	3.62 V

Calibration	
Normalized N_2 Sensitivity:	2.36 x 10^{-5} A/torr

TABLE II (Concluded)

Electrometer Amplifier, OM II

OUT/S, Gain: -0.9986

Range	Range Indicator	Range Resistor	Mass 28 ZPV	Offset
1-1	0.81 V	9.64×10^{11} Ω	2.98 V	+ 2.9662
1-2	1.10 V	9.64×10^{11} Ω	2.98 V	- 0.9701
1-3	1.41 V	9.64×10^{11} Ω	2.98 V	- 4.9065
1-4	1.70 V	9.64×10^{11} Ω	2.98 V	- 8.8409
1-5	2.00 V	9.64×10^{11} Ω	2.98 V	-12.7783
1-6	2.29 V	9.64×10^{11} Ω	2.98 V	-16.7161
1-7	2.63 V	9.64×10^{11} Ω	2.98 V	-20.6500
2-1	3.18 V	6.67×10^{10} Ω	2.98 V	+ 2.9662
2-2	3.48 V	6.67×10^{10} Ω	2.98 V	- 0.9701
2-3	3.78 V	6.67×10^{10} Ω	2.98 V	- 4.9065
2-4	4.08 V	6.67×10^{10} Ω	2.98 V	- 8.8409
2-5	4.37 V	6.67×10^{10} Ω	2.98 V	-12.7783
2-6	4.67 V	6.67×10^{10} Ω	2.98 V	-16.7161
2-7	4.97 V	6.67×10^{10} Ω	2.98 V	-20.6500

OUT/D, Gain: -0.2495

Range	Range Indicator	Range Resistor	Mass 28 ZPV	Offset
1	0.87 V	9.64×10^{11} Ω	0.008 V	- 0.0025
2	2.88 V	6.67×10^{10} Ω	0.009 V	- 0.0025

Miscellaneous

+28 power current all on:	430 mA
Preflight gauge pressure (N_2):	1×10^{-5} torr
Magnetic field strength:	2450 gauss

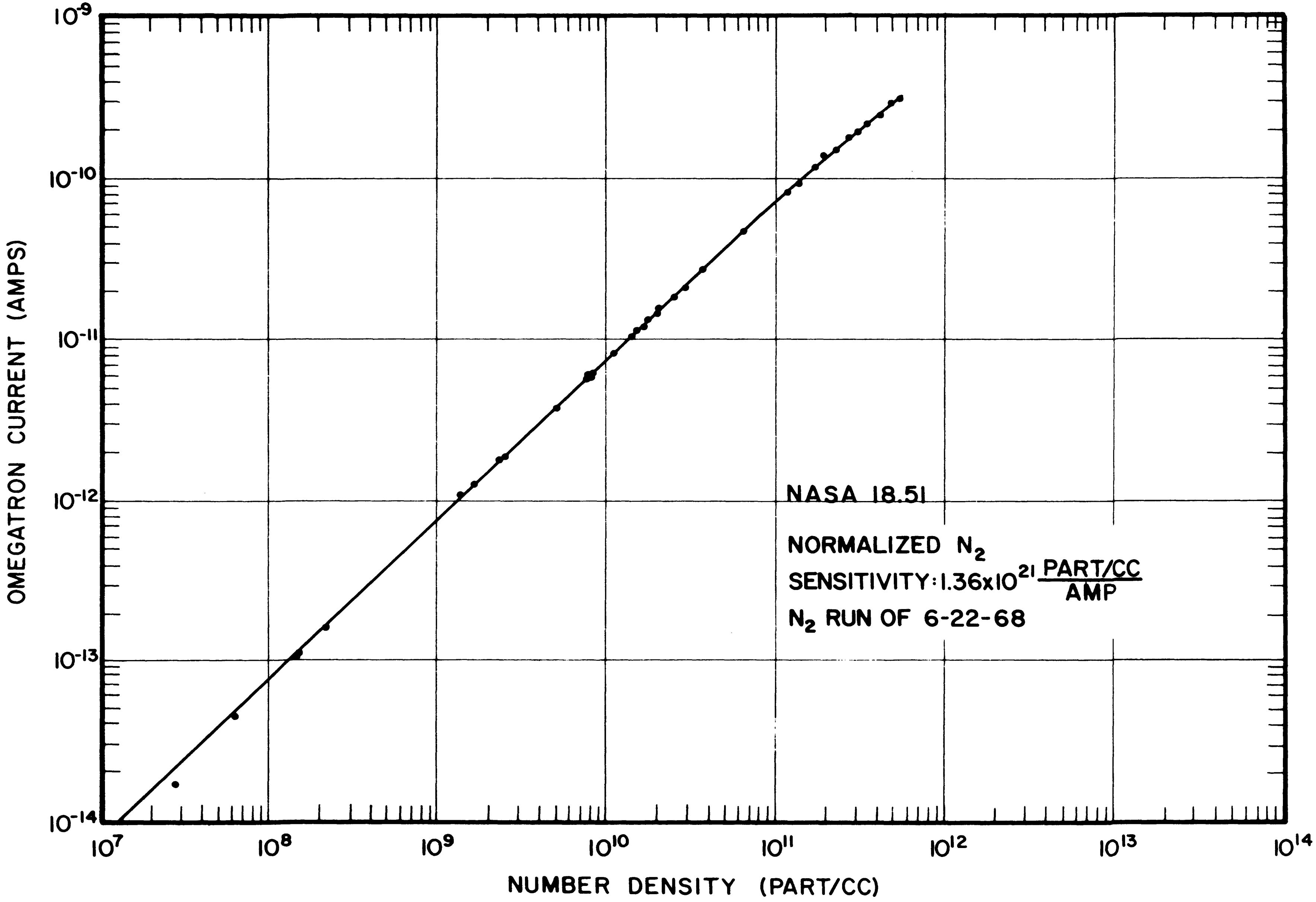


Figure 8. Final calibration of the omegatron.

5.2. ELECTRON TEMPERATURE AND DENSITY PROBE

The electron temperature and density probe consists of two cylindrical Langmuir probes placed in the plasma and an electronics unit which measures the current collected by the probes as they are swept through a series of ramp voltages. The probes are shown in Figure 9. Probe 1 is stainless steel and probe 2 is rhodium-plated stainless steel.

The electronics unit consists of a power converter, a ΔV ramp generator, a three range current detector, and associated logic and control circuits. Timing and sequencing of the various functions are shown in Figure 10. The pertinent system parameters follow.

(a) Input Power

2.26 W at 28 V

(b) Sensitivity

Range 1	20 μA full scale (5 V)
Range 2	2 μA full scale (5 V)
Range 3	0.2 μA full scale (5 V)

(c) Ramp Voltage (ΔV)

High ΔV	79 V/sec
Low ΔV	23.6 V/sec
Period	124.9 msec

(d) Output

Voltage	-0.6 V to + 6 V
Resistance	2600 Ω
Bias Level	1.0 V

(e) System Calibration

Calibration occurs every 31.5 sec for a duration of 750 msec.

5.3. SUPPORT MEASUREMENTS AND INSTRUMENTATION

5.3.1. Aspect Determination System

The NASA 18.51 TP utilized a solar aspect sensor made by Adcole Corporation which is identical to the ones used on previous daytime shots. This system functioned properly throughout the flight. The attitude of the TP was determined by using the method of referencing the solar vector and the velocity vector (Carter, 1968). The resulting minimum angle of attack, determined to an estimated accuracy of ±5 deg., is plotted vs. altitude in Figure 11.

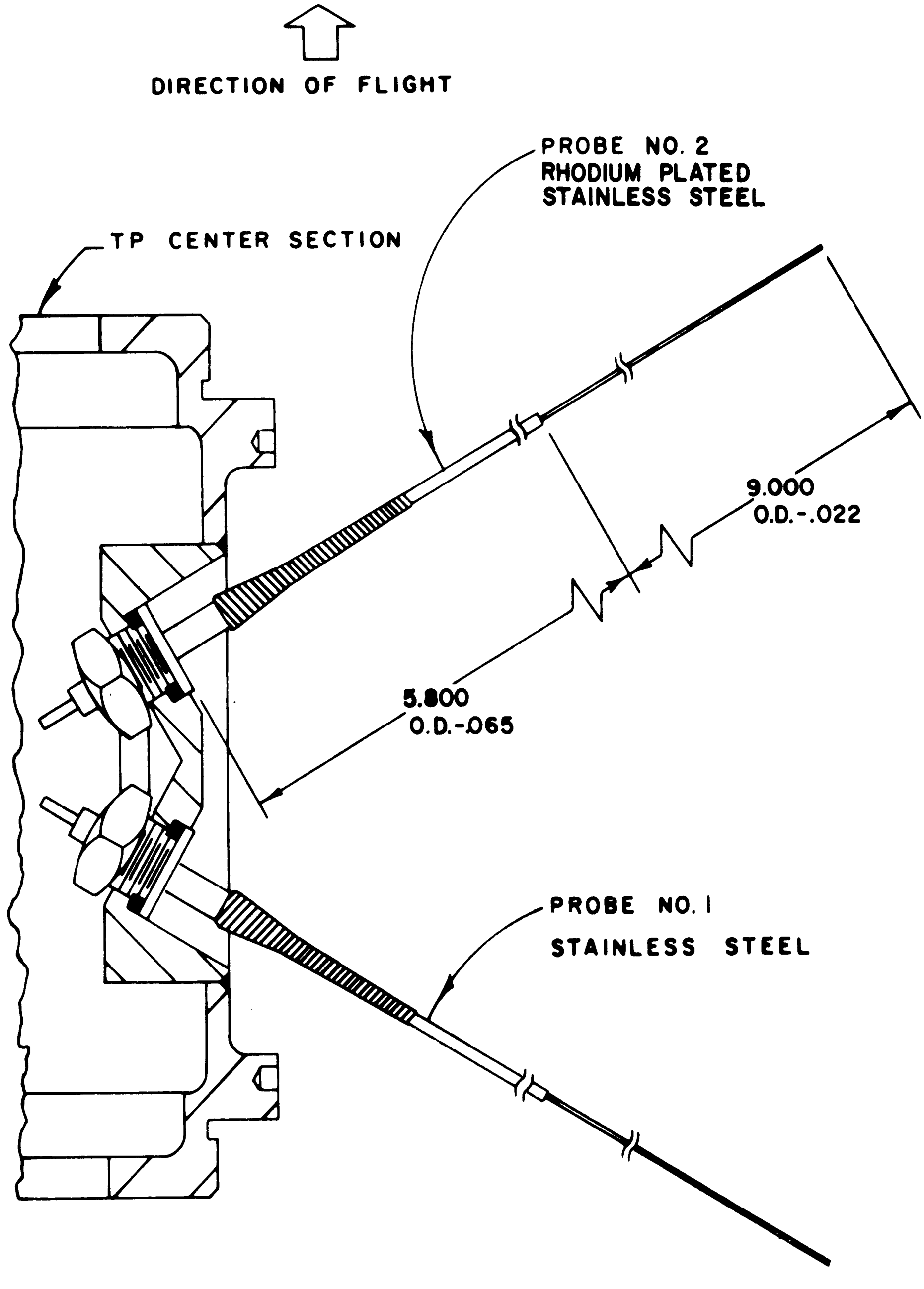


Figure 9. ETDP mounting configuration.

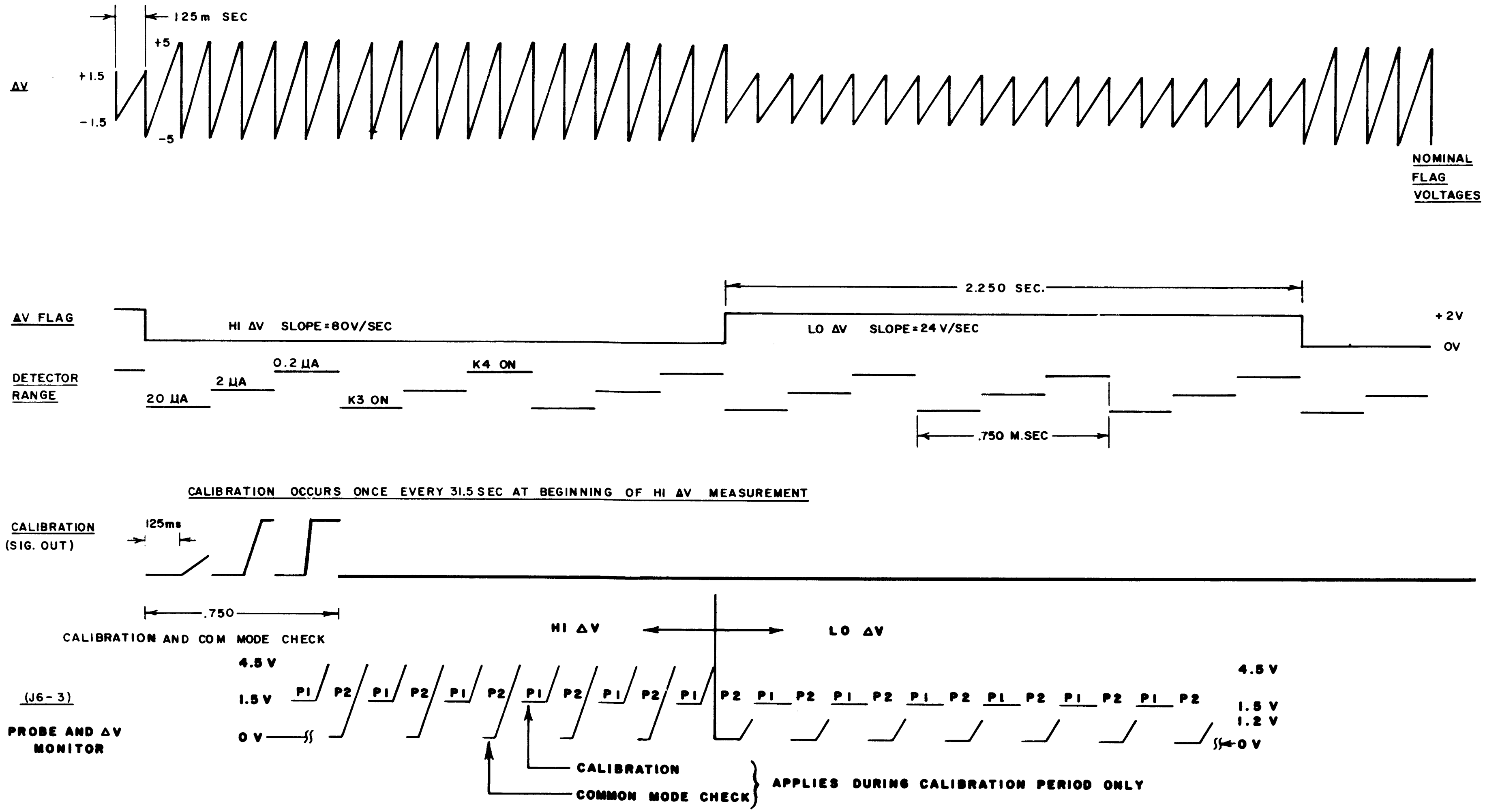


Figure 10. ETDP system timing and output format.

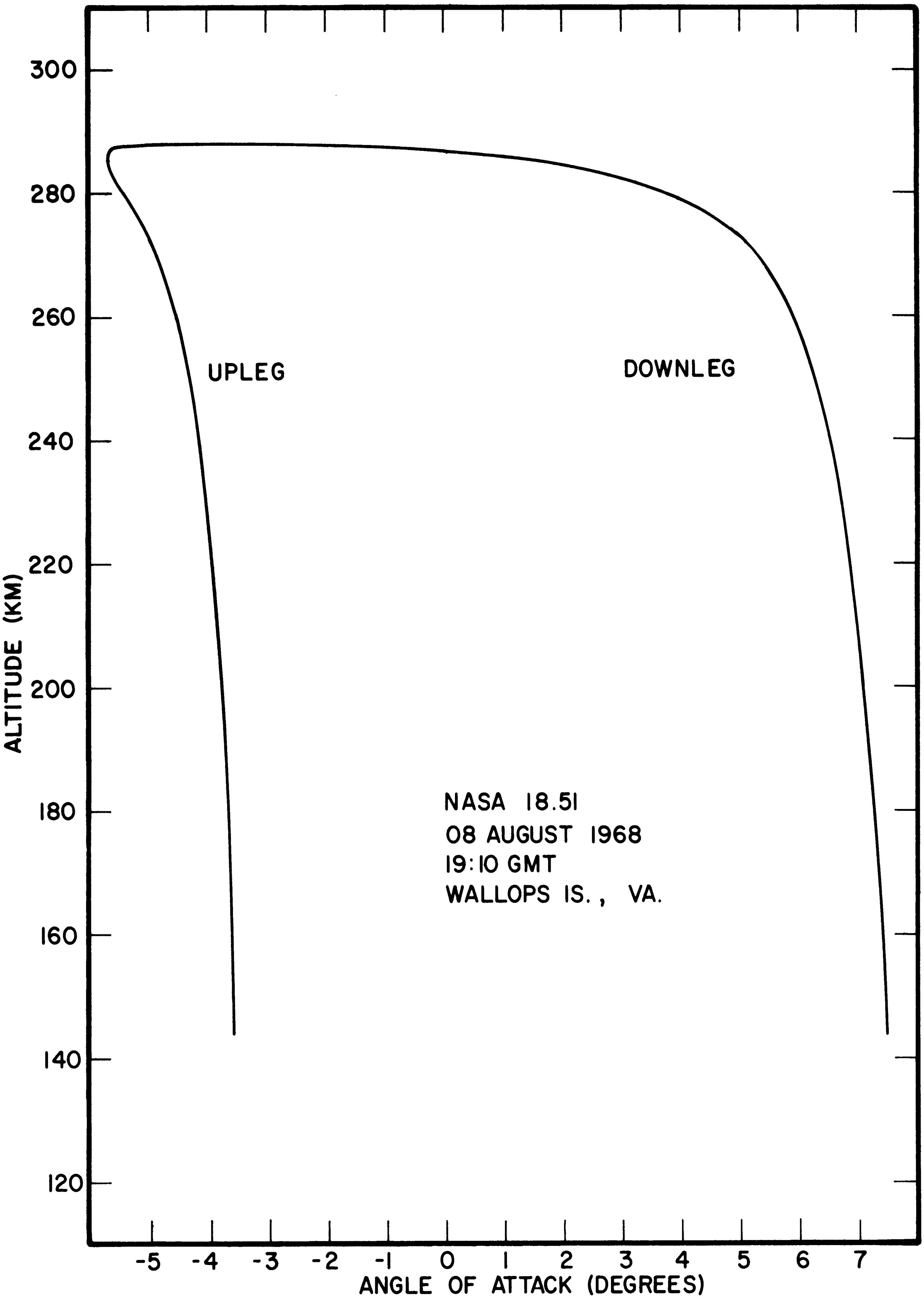


Figure 11. Minimum angle of attack vs. altitude.

5.3.2. Telemetry

The payload data were transmitted in real time by an eleven channel PAM/FM/FM telemetry system at 231.4 MHz with a nominal output of 2.5 W. The telemetry system used eleven subcarrier channels, as outlined below.

Transmitter: Driver TRPT-251RA0-1, Serial No. 2371
Power Amplifier TRFP-2VA, Serial No. 381

Subcarrier Channels (SCO Type TS58)

IRIG	Serial No.	Center Frequency	Function	Low Pass Filter Used
18	139	70 kHz	OM OUT/S	450 Hz CD
17	1596	52.5 kHz	QP OUT/S	450 Hz CD
16	7382	40 kHz	QP OUT/D	330 Hz CD
15	4694	30 kHz	ESP/D	450 Hz CD
14	8213	22 kHz	2nd Der	330 Hz CD
13	3631	14.5 kHz	1st Der	220 Hz CD
12	8105	10.5 kHz	Aspect	330 Hz CA
11	7222	7.35 kHz	Commutator	120 Hz CD
10	6747	5.4 kHz	OM OUT/D	160 Hz CD
9	2726	3.9 kHz	OM RANGE	120 Hz CD
8	N/A	3.0 kHz	QP RANGE	60 Hz CD

Instrumentation power requirements totaled approximately 65 W, supplied by a Yardney HR-1 Silvercell battery pack of nominal 28 V output.

5.3.3. Housekeeping Monitors

Outputs from various monitors throughout the instrumentation provided information bearing on the operations of the electronic components during flight. These outputs were fed to a thirty-segment commutator which ran at one rps. The commutator assignments were as follows:

COMMUTATOR FORMAT FOR NASA 18.51

Segment Number		Segment Assignment
1	OM	OUT/D
2	OM	Filament Monitor
3	OM	Emission Current Monitor
4	OM	Bias Voltage Monitor
5	OM	RF Voltage Monitor
6	OM	Comparator Ramp Monitor
7	OM	Comparator Ramp Monitor
8	OM	Internal Pressure Monitor
9	OM	Thermistor-Gauge Temperature
10	OM	Thermistor-Amplifier Temperature
11		Thermistor-Transmitter Temperature
12		Battery Voltage Monitor
13		Open
14	QP	Thermistor-Amplifier Temperature
15	QP	Thermistor-Oscillator Temperature
16	QP	Internal Pressure Monitor
17	QP	RF Oscillator Monitor
18	QP	Automatic Gain Control Monitor
19	QP	Lens Voltage Monitor
20	QP	Quadrupole Bias Voltage Monitor
21	QP	Mass Indicator
22	QP	Emission Current Monitor
23	QP	OUT/D
24		0 V Calibration
25		1 V Calibration
26		2 V Calibration
27		3 V Calibration
28		4 V Calibration
29		5 V Calibration
30		5 V Calibration

6. ANALYSIS OF DATA

The telemetered data were recorded on magnetic tape at the Wallops Island Main Base and the GSFC Station A ground Station facilities. Appropriate paper records were made from the magnetic masters, facilitating "quick look" evaluations. The aspect data were reduced to engineering parameters from paper records. The omegatron and housekeeping data were reduced by computer techniques from the magnetic tapes.

6.1. TRAJECTORY AND ASPECT

The position and velocity data used to determine aspect, ambient N_2 density, and ambient temperature as a function of time and altitude were obtained by fitting a smooth theoretical trajectory to the FPS-16 radar data. The theoretical trajectory is programmed for computer solution similar to that described by Parker (1962). The analysis of minimum angle of attack (α_{min}) as described by Carter (1968) is also incorporated in the program. The output of the computer furnishes α_{min}, altitude, and velocity as a function of time. A plot of α_{min} vs. altitude has already been given in Figure 11. Figure 12 shows the occurrence of significant events during the flight.

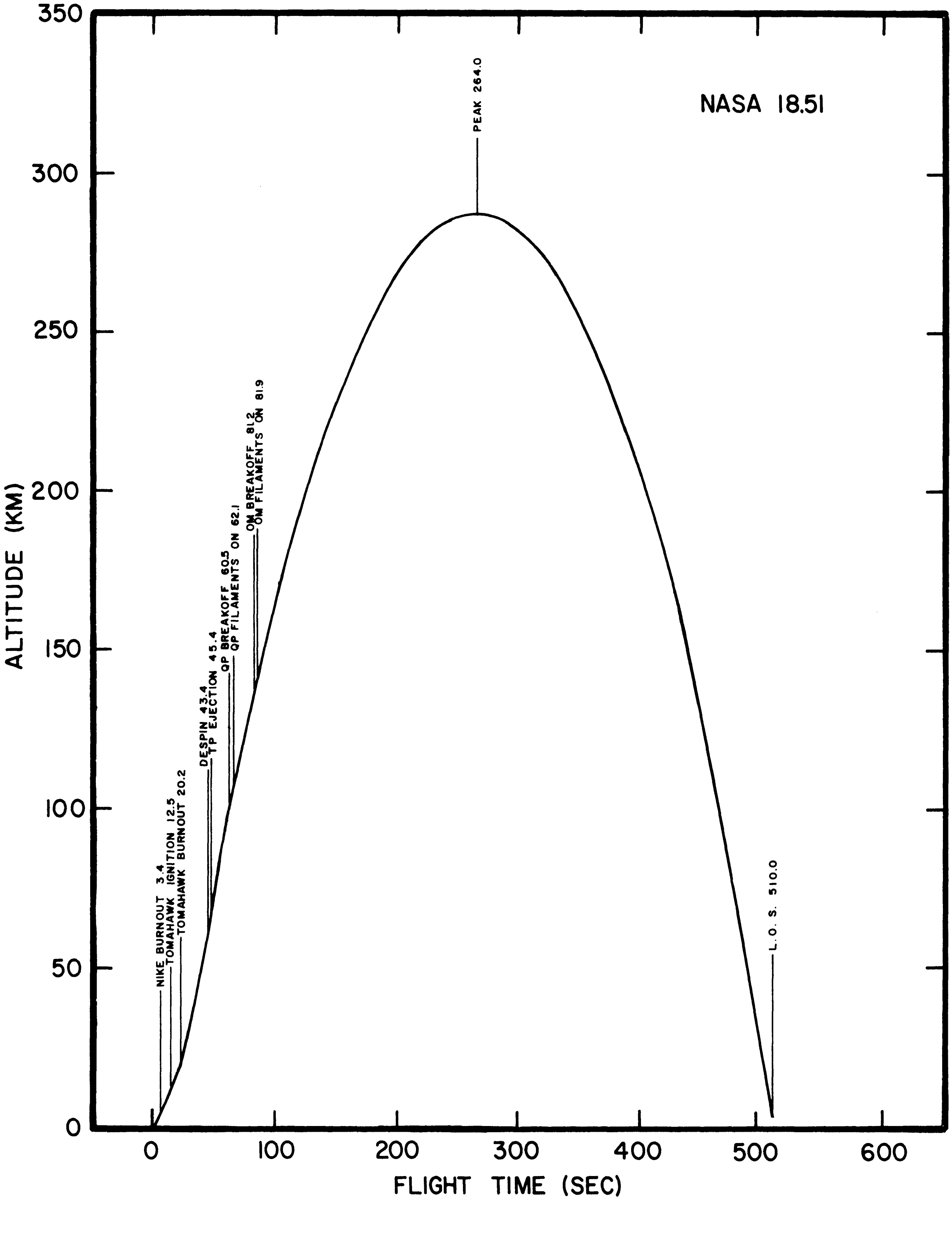


Figure 12. Sequence of events.

6.2. AMBIENT N_2 DENSITY

The neutral molecular nitrogen density was determined from the measured gauge partial pressure as described by Spencer, *et al.*, (1965, 1966), using the basic relationship:

$$n_a = \frac{\Delta n_i u_i}{2\sqrt{\pi}\, V \cos \alpha_{min}} K(S_o, \alpha)$$

where

n_a = ambient N_2 number density
Δn_i = maximum minus minimum gauge number density during one tumble, A x ΔI, where A is the sensitivity of the gauge
u_i = $\sqrt{2kT_i/m}$, most probable thermal speed of particles inside gauge
T_i = gauge wall temperature
V = vehicle velocity with respect to the earth
α_{min} = minimum angle of attack for one tumble
$K(S_o,\alpha)$ = the reciprocal of the normalized transmission probability as defined by Ballance (1967), referred to as the geometry correction factor.

ΔI, the difference between the maximum (peak) omegatron gauge current and the minimum (background) gauge current vs. flight time is shown in Figure 13. The background current is the result of the outgassing of the gauge walls, and the inside density is due to atmospheric particles which have enough translational energy to overtake the payload and enter the gauge. The outgassing component is assumed constant for one tumble and affects both the peak reading and the background reading, and, therefore, does not affect the difference. From calibration data obtained by standard techniques, the inside number density, Δn_i, is computed for the measured current.

By using the measured gauge wall temperature, the most probable thermal speed of the particles inside the gauge, u_i, is computed. The uncertainty in this measurement is believed to be about ±2% absolute.

V, the vehicle velocity with respect to the earth, is obtained from the trajectory curve fitting described previously and is believed to be better than ±1% absolute.

Cos α_{min} is obtained from the aspect analysis described by Carter (1968). Since the uncertainty in cos α_{min} depends upon α_{min}, for any given uncertainty in α_{min}, each particular case and altitude range must be considered separately. Figure 11 shows that the minimum angle of attack is less than ten degrees, so with an assumed maximum uncertainty in α_{min} of ±5 degrees, the resulting uncertainty in cos α_{min} is less than ±2%. The data for low angle of attack were used as control data.

$K(S_o,\alpha)$, the geometry correction factor vs. altitude, is shown in Figure 14. As can be seen, the maximum correction is about 6% or $K(S_o,\alpha) = .94$ at about 140 km altitude for the upleg data. The correction factor, determined from empirical and theoretical studies, is believed to be better than 2%.

The resulting ambient N_2 number density, obtained from the measured quantities described above, is shown in Figure 15 and is tabulated in Table III. The uncertainty in the ambient density due to the combined uncertainties in the measured quantities is thought to be 10% relative and 25% absolute.

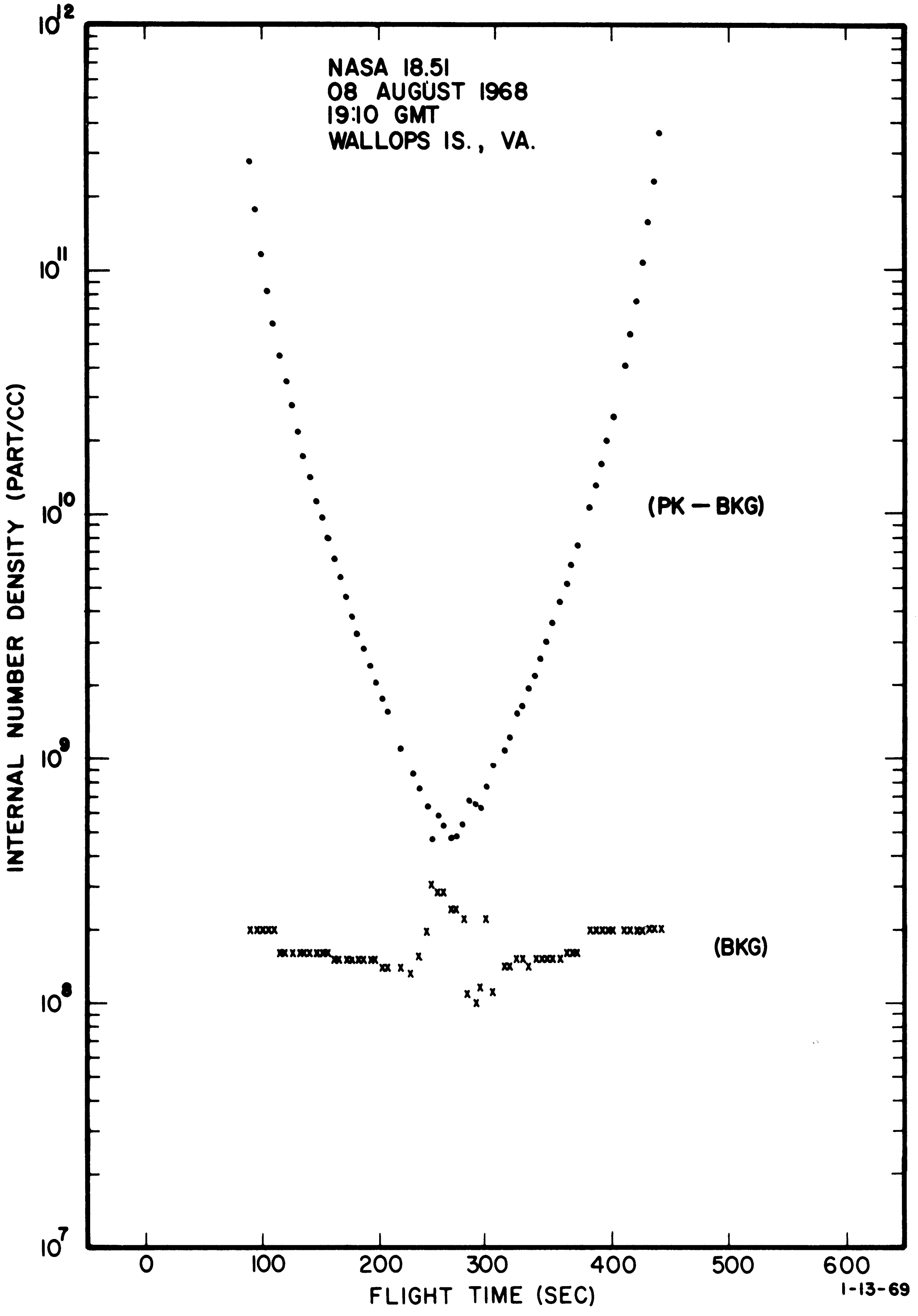


Figure 13. Omegatron current vs. flight time.

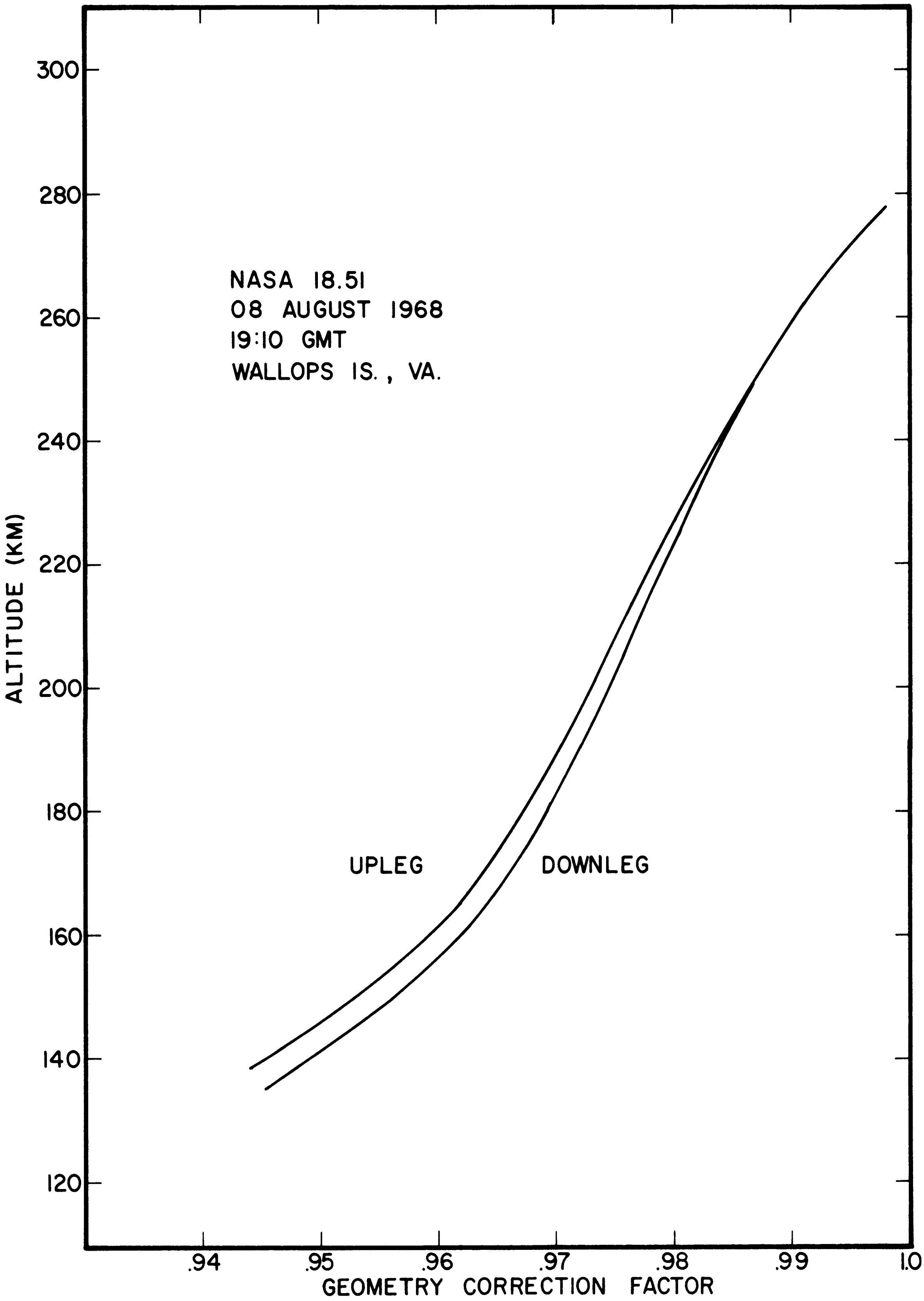


Figure 14. $K(S_o,\alpha)$ vs. altitude.

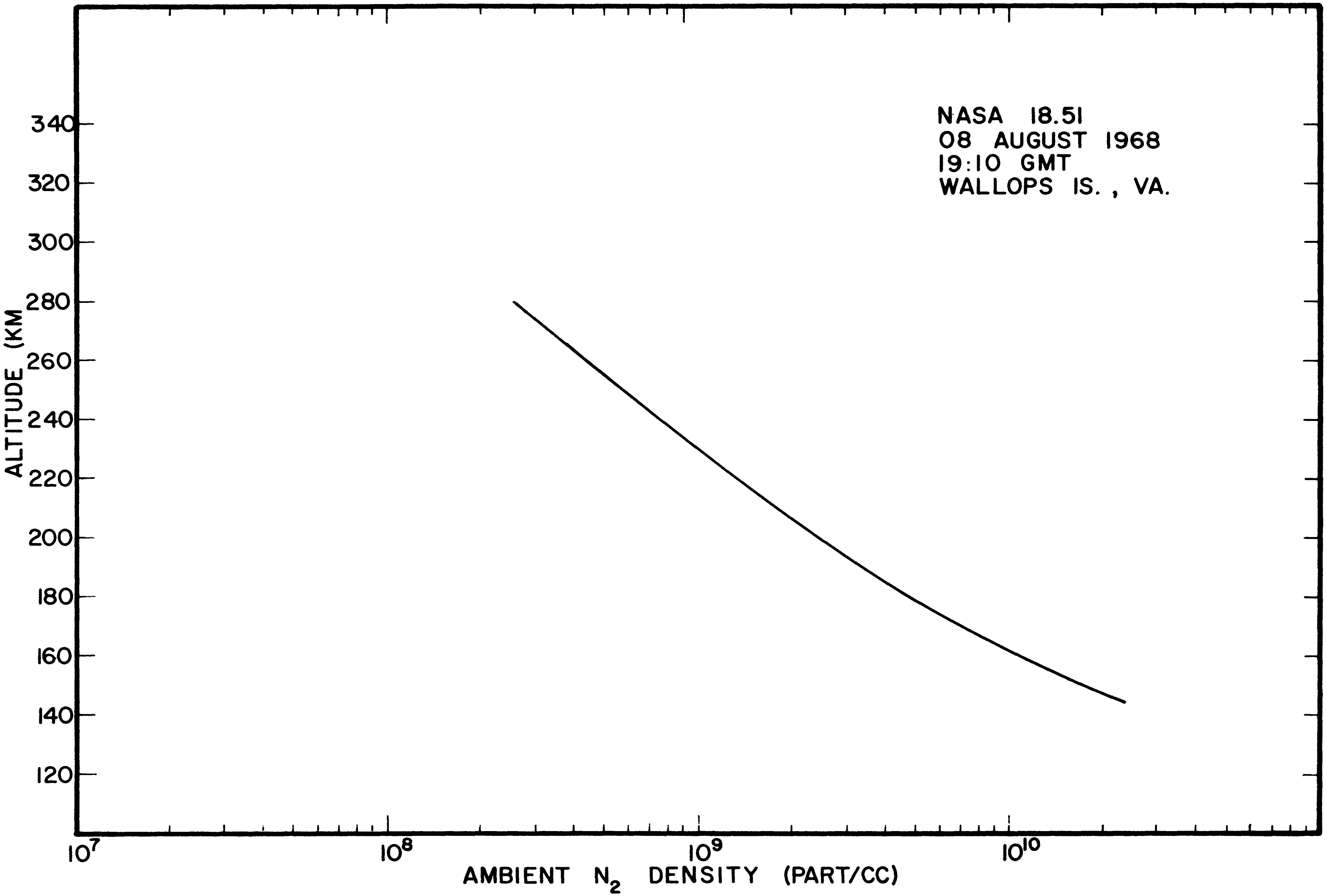


Figure 15. Ambient N_2 density vs. altitude.

TABLE III

N_2 AMBIENT DENSITY DATA

NASA 18.51
8 August 1968
19:10 GMT
15:10 EDT
Wallops, Island, Virginia

Altitude (km)	Temperature (°K)	Density (part/cc)
145	726	2.36×10^{10}
150	766	1.81
155	806	1.41
160	846	1.11×10^{10}
165	883	8.85×10^{9}
170	922	7.12
175	959	5.80
180	994	4.77
185	1025	3.96
190	1052	3.32
195	1070	2.82
200	1082	2.42
205	1090	2.08
210	1097	1.79
215	1104	1.55
220	1109	1.34
225	1115	1.16
230	1120	1.01×10^{9}
235	1125	8.75×10^{8}
240	1130	7.60
245	1134	6.61
250	1139	5.76
255	1144	5.01
260	1148	4.37
265	1152	3.82
270	1157	3.33
275	1161	2.91
280	1165	2.55×10^{8}

Fit Parameters: $T_\infty = 1174$ °K
$T_o = 705$ °K
$P_b = 3.08 \times 10^{-8}$ torr
$\sigma = 2.71 \times 10^{-2}$

6.3. TEMPERATURE

The ambient temperature shown in Figure 16 and tabulated in Table III was obtained by integrating the hydrostatic equation using the measured N_2 density profile to obtain a partial pressure profile, and by relating the known density and pressure to the temperature through the ideal gas law. In this procedure the assumptions of hydrostatic equilibrium and perfect gas behavior are implicit. It can be shown that the density integral is stable and highly convergent when carried out in the direction of increasing density. The pressure or temperature at the initial (upper) boundary of integration is determined analytically by means of a least squares fitting procedure using a fitting function based on the empirical expression for the temperature profile given by Jacchia (1964), and more particularly by Walker (1965). The procedure is described in detail by Simmons (1969). The fit parameters listed in Table III are the apparent exospheric temperature (T_∞), the reference temperature at the lower boundary (T_o), the apparent N_2 partial pressure at the upper boundary (P_b), and an estimate of the exponential model shape factor (σ).

6.4. GEOPHYSICAL INDICES

The 10.7 cm solar flux ($F_{10.7}$) and the geomagnetic activity indices (a_p) for the appropriate periods are shown in Figures 17 and 18.

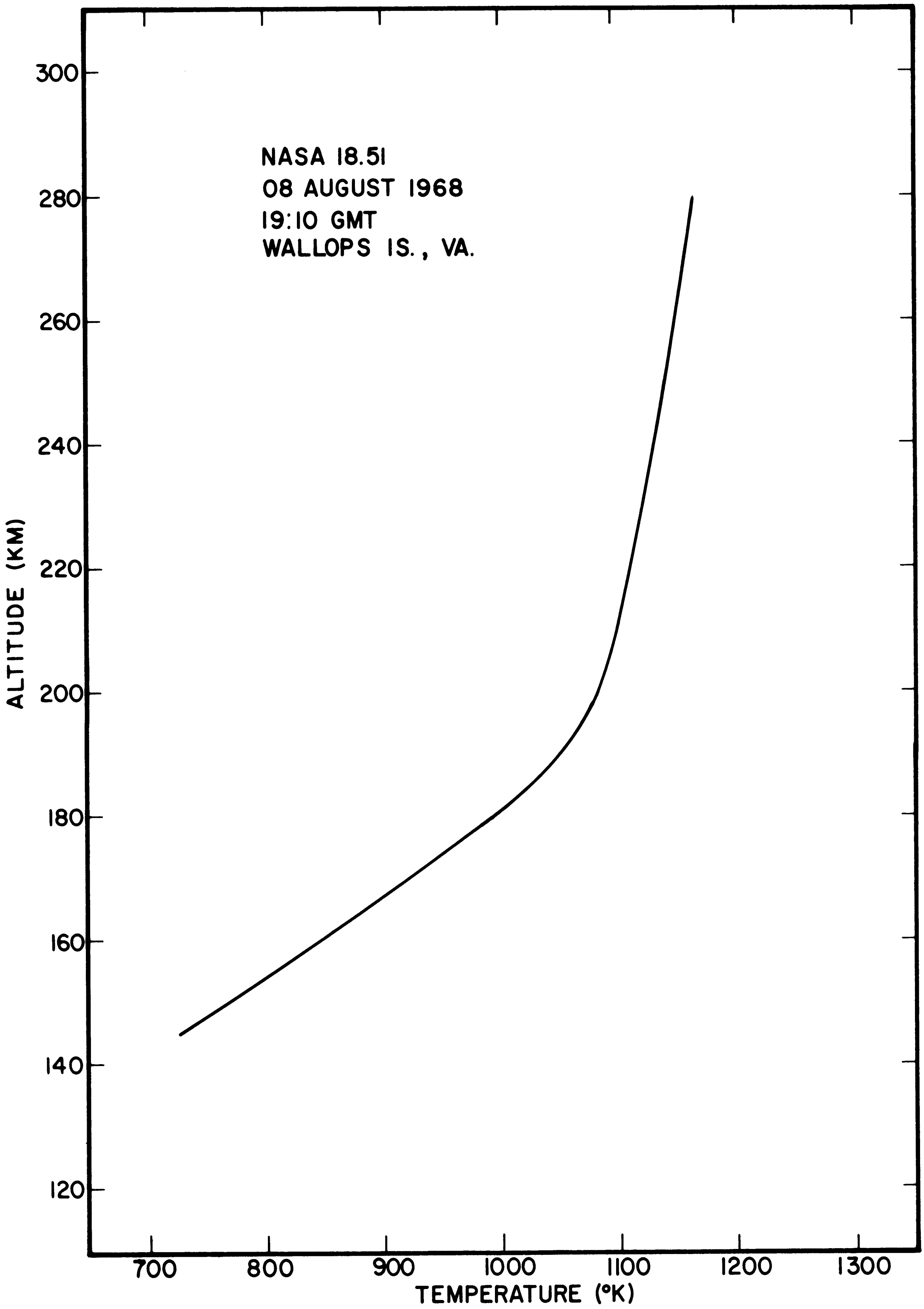


Figure 16. Neutral particle temperature vs. altitude.

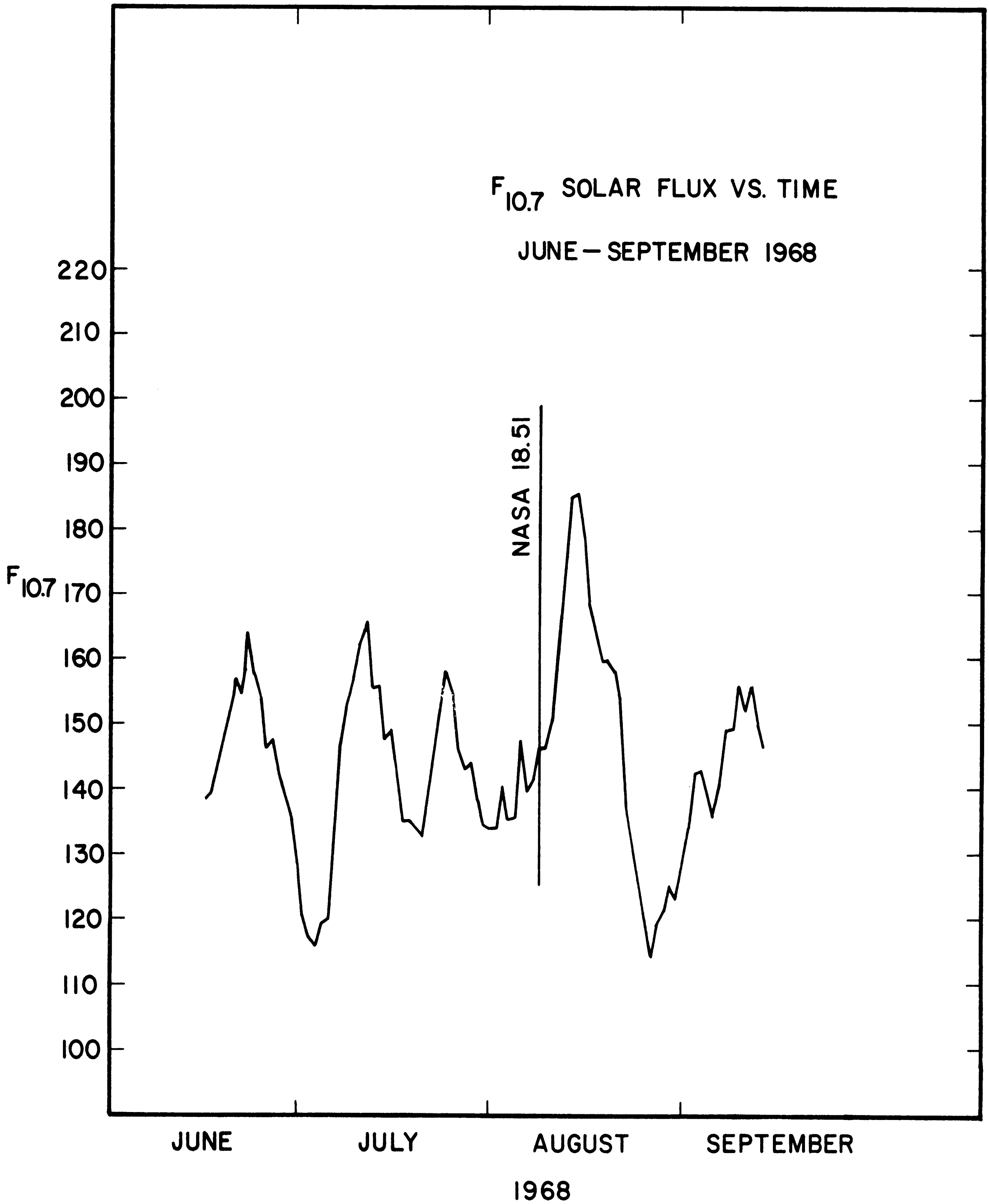


Figure 17. Solar flux at 10.7 cm wavelength.

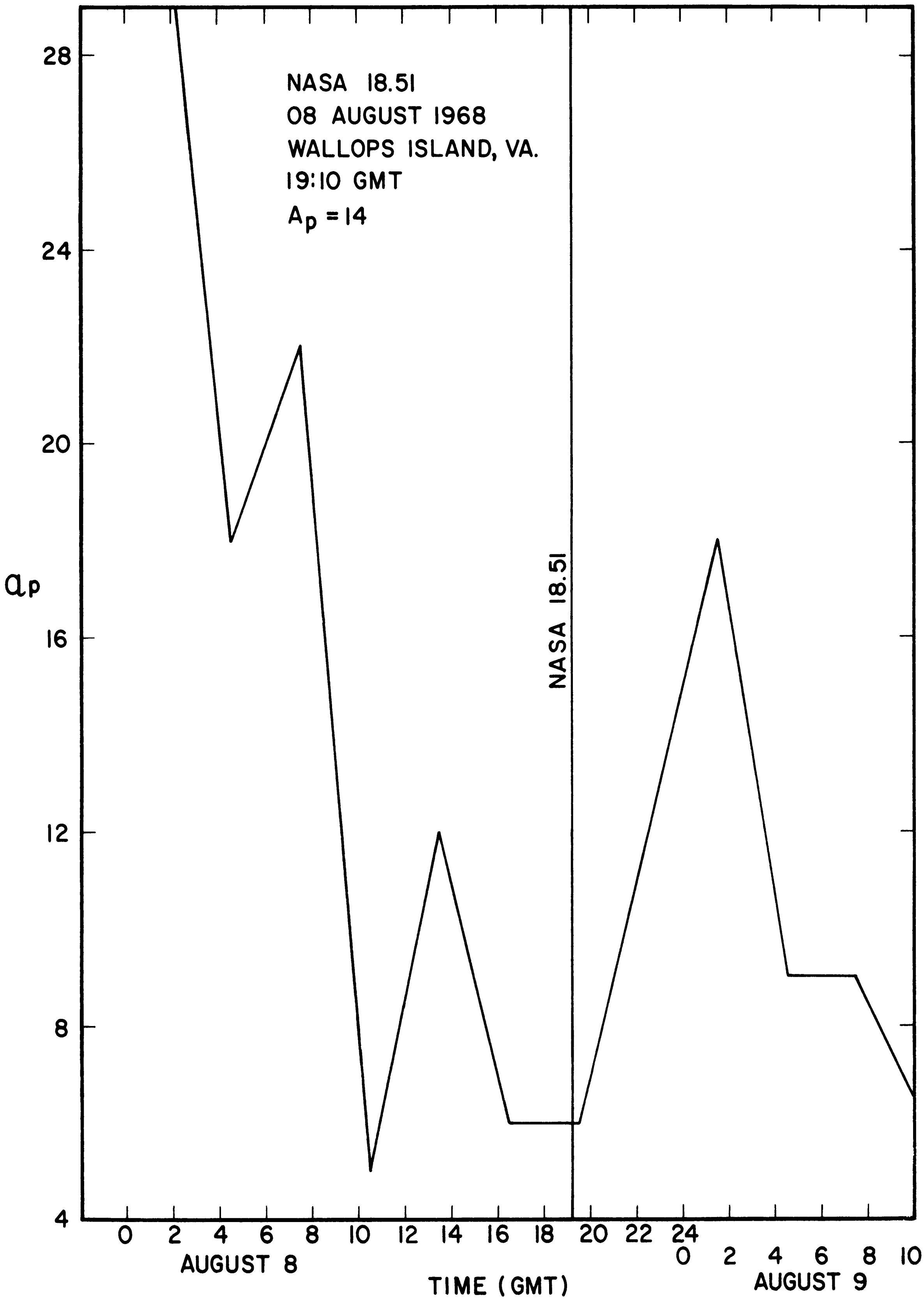


Figure 18. Three-hour geomagnetic activity index (a_p).

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