THE UNIVERSITY OF MICHIGAN

COLLEGE OF ENGINEERING
Department of Electrical Engineering
Space Physics Research Laboratory

Sounding Rocket Flight Report

NASA 18.56 THERMOSPHERE PROBE EXPERIMENT

Prepared on behalf of the project by

R. W. Simmons

ORA Project 07065

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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 18.56 Thermosphere Probe Experiment. Some of the personnel with specific responsibilities are listed below.

Goddard Space Flight Center

Spencer, N. W.	Project Director
Brace, L. H.	Scientist

Space Physics Research Laboratory

Carignan, G. R.	Laboratory Director
Taeusch, D. R.	Associate Laboratory Director
Caldwell, J. R.	Electronics Engineer
Campbell, B. J.	Design Draftsman
Crosby, D. F.	Electron Temperature Probe Engineer
Freed, P. L.	Head Technician
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
Pate, R. W.	Omegatron Engineer
Poole, G. T.	Head Programmer

LIST OF ILLUSTRATIONS

1. INTRODUCTION

The results of the launching of NASA 18.56, 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 18.56 payload included a "second generation" omegatron mass analyzer (for which a complete report is currently being prepared), an electron temperature probe (Spencer, Brace, and Carignan, 1962), and a lunar position sensor. This complement of instruments permitted the determination of the molecular nitrogen density and temperature and the electron density and temperature in the altitude range of approximately 150 to 295 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.

2. GENERAL FLIGHT INFORMATION

The general flight information for NASA 18.56 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:	9 August 1968
Launch Time:	07:02:00.090 GMT, 03:02:00.090 EDT
Location:	Wallops Island, Virginia
	Latitude: 37°50'14.915" N
	Longitude: 75°29'01.693" W

Apogee Parameters:

Altitude:	320.74 km
Horizontal Velocity:	299.58 m/sec
Flight Time:	279.60 sec

TP Motion:

Tumble Period:	1.71 sec
Roll Rate:	~158.3 deg/sec

TABLE I

TABLE OF EVENTS

(NASA 18.56)

Event	Flight Time (sec)	Altitude (km)
Lift-off	0	0
1st Stage Burnout	3.5	1.3 (est.)
2nd Stage Ignition	12.0	7.0
2nd Stage Burnout	20.9	20.0
Despin	43.3 (est.)	71.0 (est.)
TP Ejection	45.3	75.0
Omegatron Breakoff	74.5	133.0
Omegatron Filament On, M28	76.6	137.0
Peak Altitude	279.60	320.74
L.O.S.	539.0	---

3. LAUNCH VEHICLE

The NASA 18.56 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 3.5 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 9 sec. The Tomahawk, 141.1 in. long and 9 in. in diameter, weighed 530 lb unburned. The TP payload, which was 81.1 in. long and weighed 149 lb, including despin and adapter modules, made the total vehicle 367.4 in. long with a gross lift-off weight of 2004 lb. The vehicle is illustrated in Figures 1 and 2.

The launch vehicle performed flawlessly and reached a summit altitude of 320.74 km at 279.60 sec of flight time.

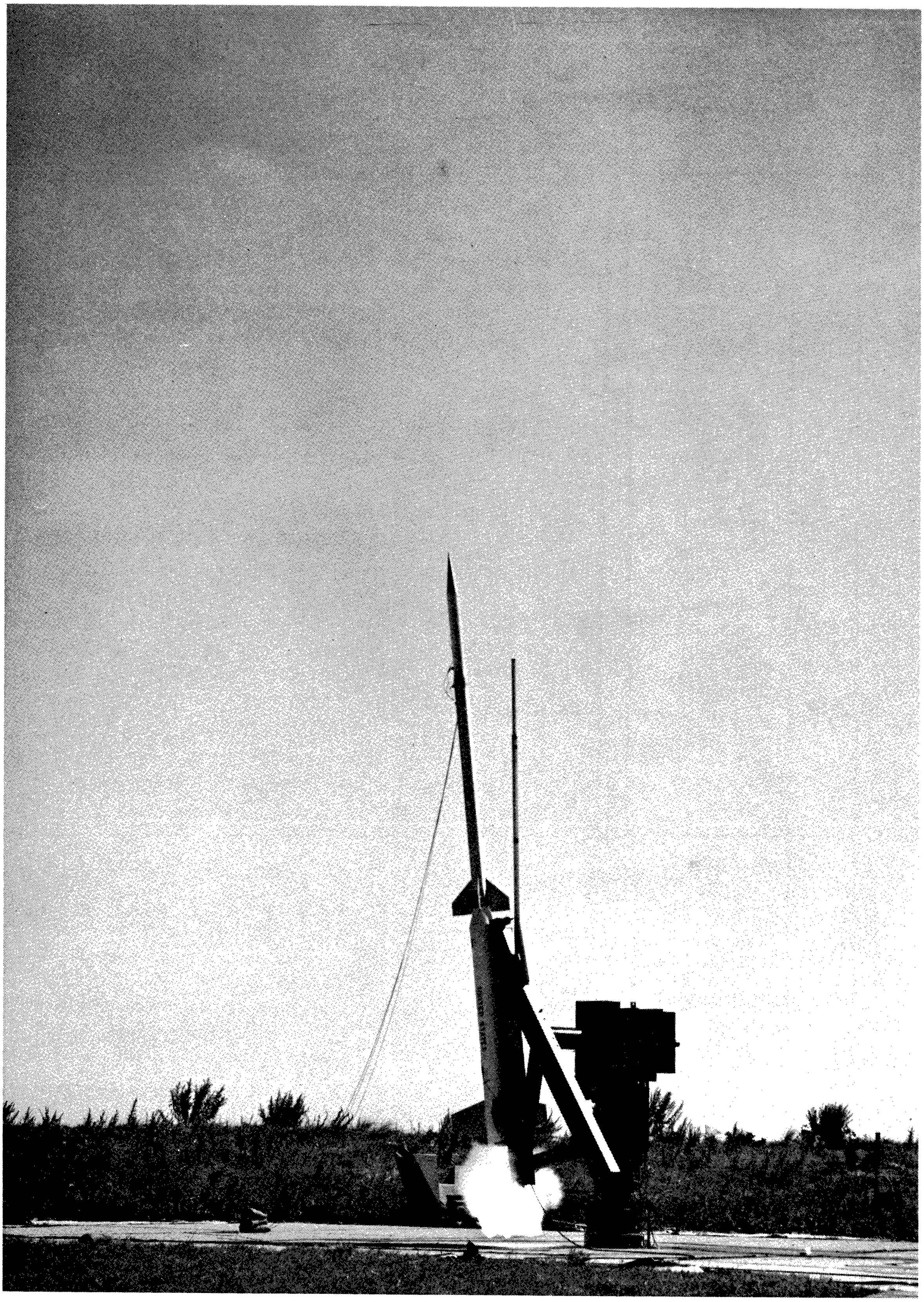

Figure 1. Nike-Tomahawk with thermosphere probe payload.

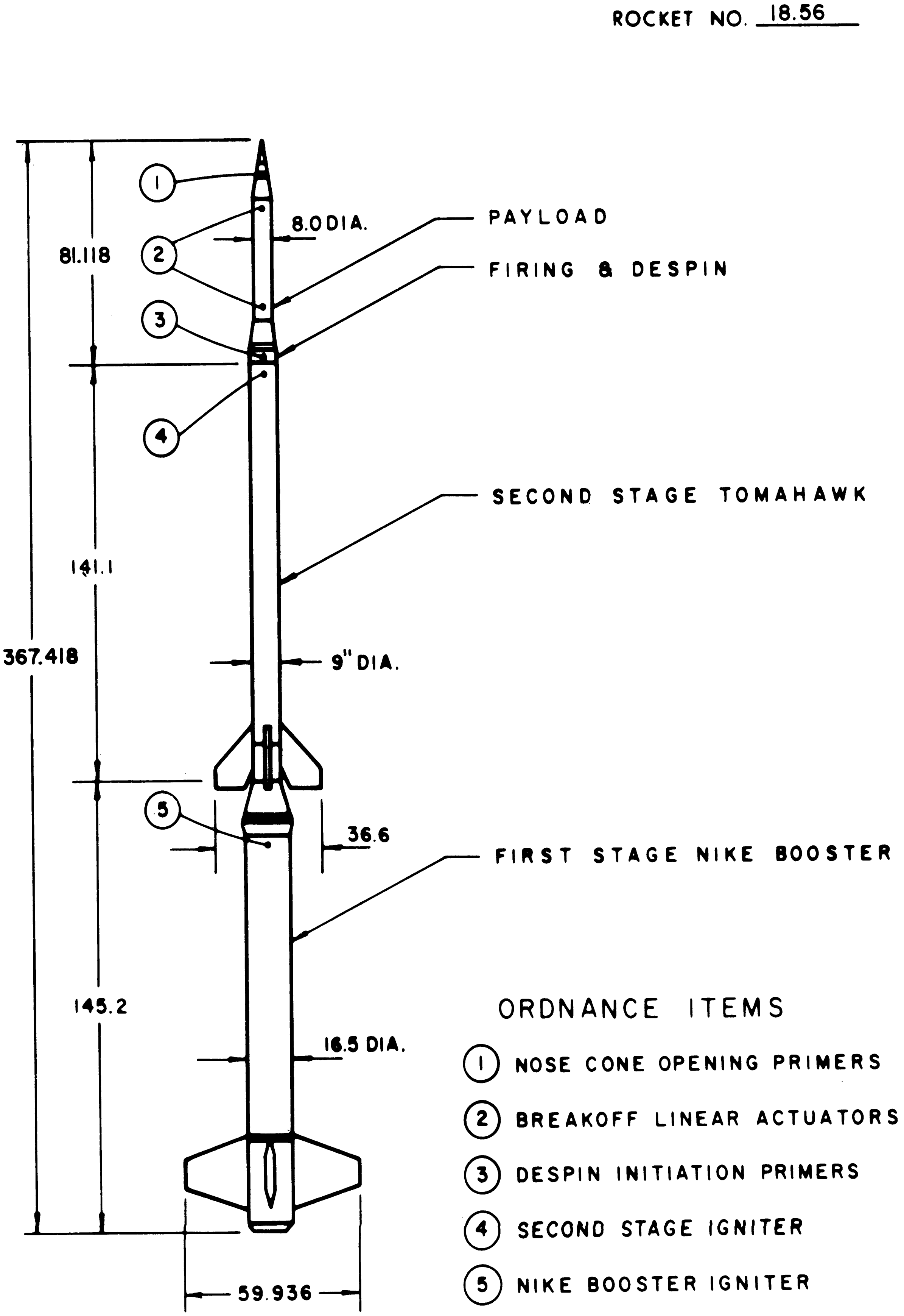

Figure 2. Nike-Tomahawk dimensions.

4. NOSE CONE

A diagram of the NASA 18.56 payload including the nose cone, the despin mechanism, and the adapter section is shown in Figure 3. An assembly drawing of the 8-in. nose cone is given in Figure 4.

The payload was despun at 71 km altitude (43 sec after launch), and the ejection began at 75 km (45 sec after launch). The resulting tumble period of the payload was 1.71 sec. The omegatron breakoff device was removed at 133 km (75 sec after launch), and the omegatron filament was turned on approximately 2 sec later.

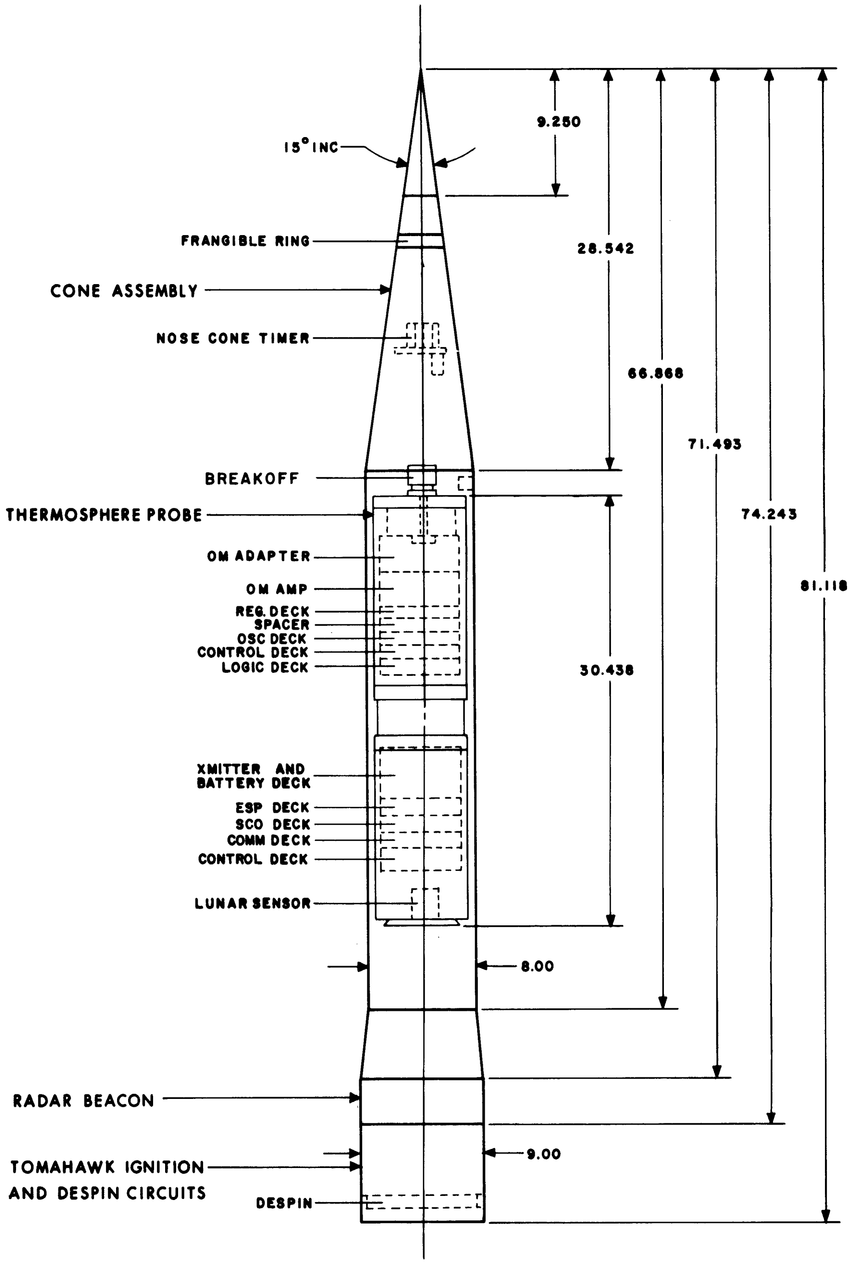

Figure 3. Thermosphere probe instrumentation design.

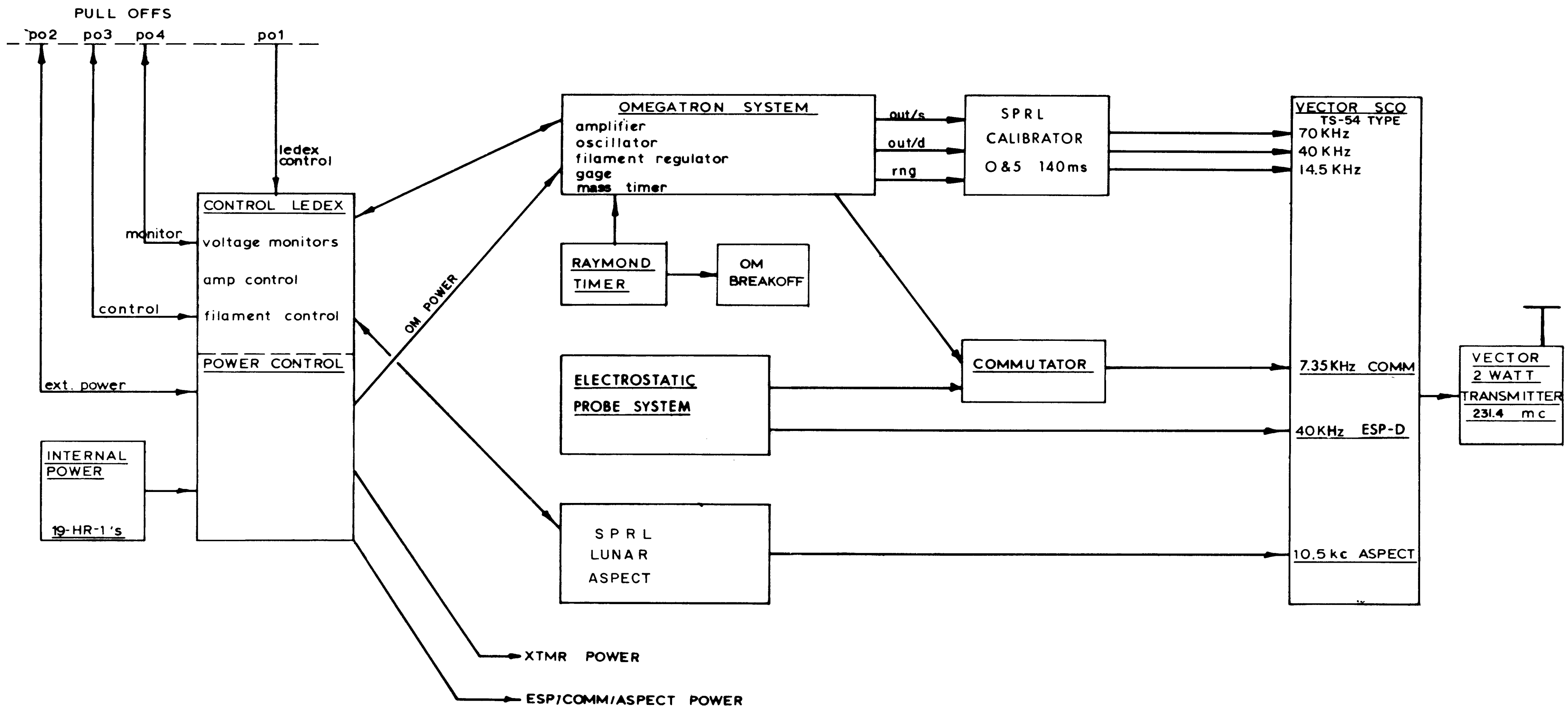

Figure 5. Thermosphere probe system block diagram.

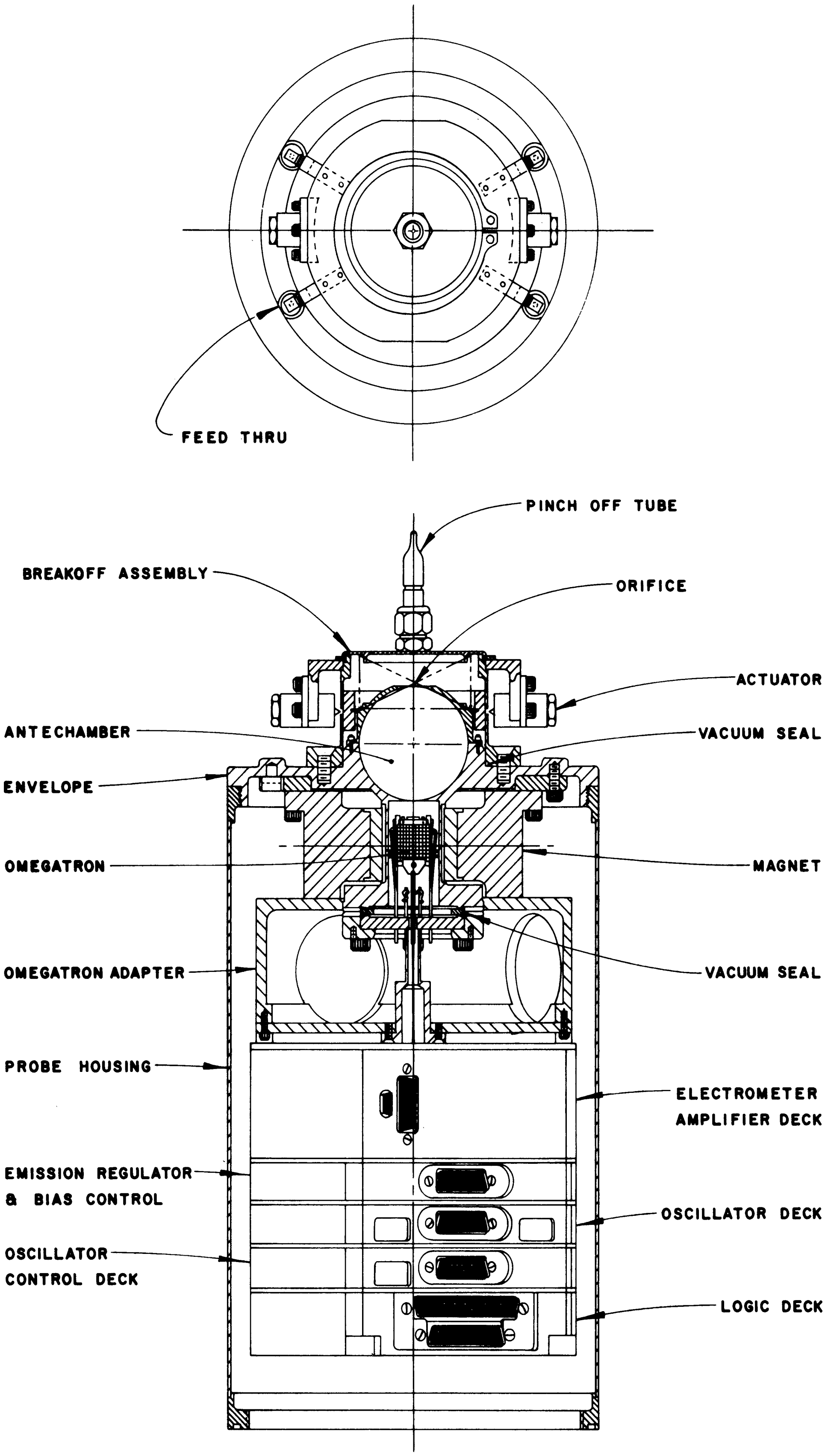

Figure 6. Omegatron II.

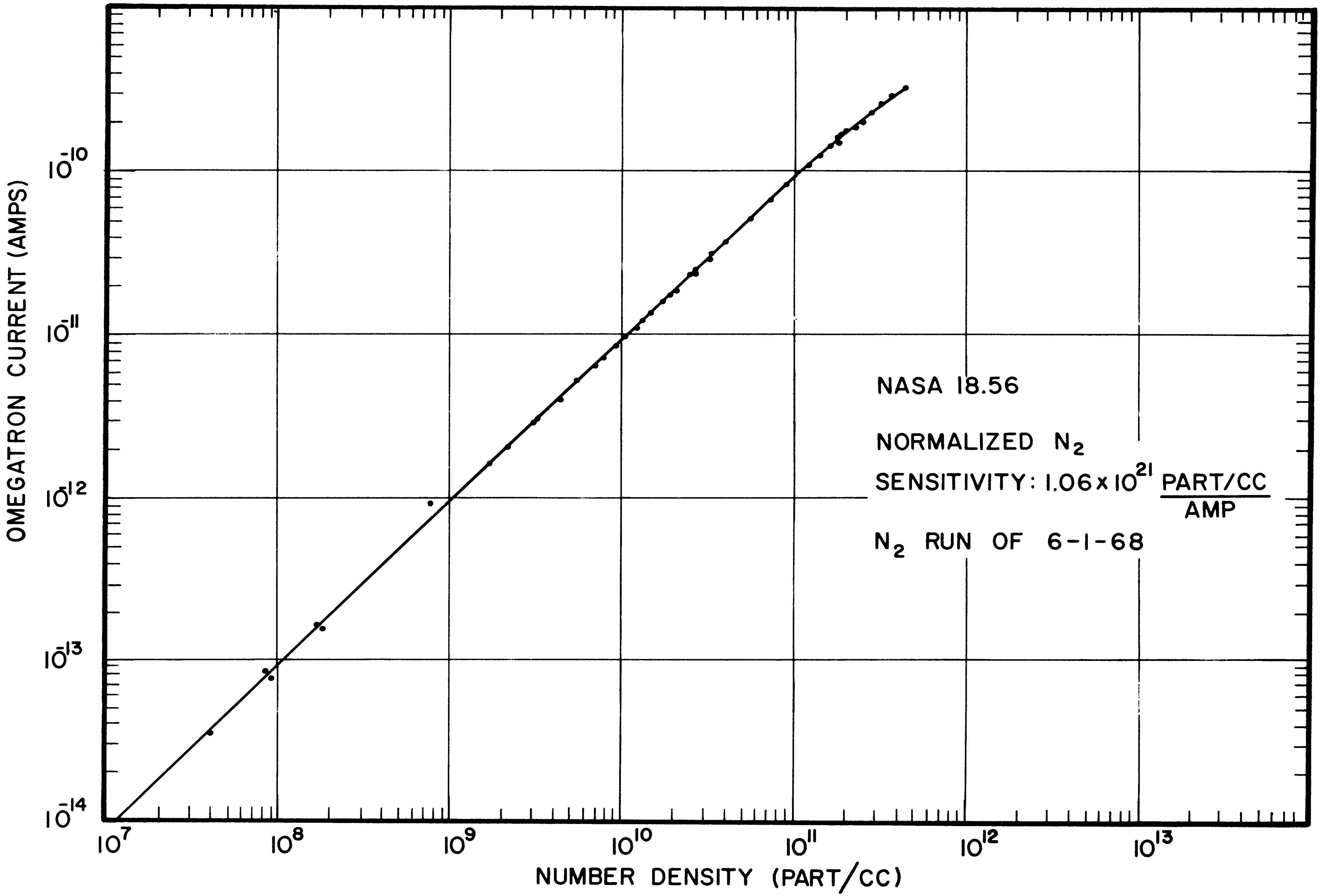

Figure 7. Final calibration of the omegatron.

TABLE II

OMEGATRON DATA

(NASA 18.56)

Omegatron Gauge Parameters	OM II
Beam Current:	2.13 μA
Electron Collector Bias:	68.63 V
Filament Bias:	- 88.95 V
Cage Bias:	- 0.21 V
Top Bias:	- 0.61 V
RF Amplitude, Mass 28:	4.10 V_{p-p}
RF Frequency, Mass 28:	134.90 kHz

Monitors

Filament	
OFF:	0.01 V
ON:	3.00 V
Beam	
OFF:	0.01 V
ON:	2.13 V
Thermistor Pressure ("zero" pressure)	
Filament OFF:	1.91 V
Filament ON:	1.86 V
Bias:	4.84 V
RF:	4.22 V

Calibration

Normalized N_2 Sensitivity:	3.04×10^{-5} A/torr

TABLE II (Concluded)

Electrometer Amplifier, OM II

OUT/S, Gain: -1.0185

Range	Range Indicator	Range Resistor	Mass 28 ZPV	Offset
1-1	0.48 V	9.04×10^{11}	3.01 V	3.004
1-2	0.78 V	9.04×10^{11}	3.01 V	- 1.011
1-3	1.07 V	9.04×10^{11}	3.01 V	- 5.019
1-4	1.37 V	9.04×10^{11}	3.01 V	- 9.024
1-5	1.67 V	9.04×10^{11}	3.01 V	-13.035
1-6	1.97 V	9.04×10^{11}	3.01 V	-17.053
1-7	2.27 V	9.04×10^{11}	3.01 V	-21.071
2-1	2.86 V	6.67×10^{10}	3.01 V	3.004
2-2	3.16 V	6.67×10^{10}	3.01 V	- 1.011
2-3	3.46 V	6.67×10^{10}	3.01 V	- 5.019
2-4	3.76 V	6.67×10^{10}	3.01 V	- 9.024
2-5	4.06 V	6.67×10^{10}	3.01 V	-13.035
2-6	4.36 V	6.67×10^{10}	3.01 V	-17.053
2-7	4.66 V	6.67×10^{10}	3.01 V	-21.071

OUT/D, Gain: -0.2498

Range	Range Indicator	Range Resistor	Mass 28 ZPV	Offset
1	0.87 V	9.04×10^{11}	0.002 V	- 0.0005
2	2.88 V	6.67×10^{10}	0.002 V	- 0.0005

Miscellaneous

+28 power current all on: 270 mA

Preflight gauge pressure (N_2): 2×10^{-5} torr

Magnetic field strength: 2350 gauss

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. A typical Langmuir probe is shown in Figure 8. Probe 1, for this flight, is stainless steel and probe 2 is rhodium-plated stainless steel.

The electronics unit consists of a dc-dc convertor, the 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 9. The pertinent system parameters follow.

(a) Input Power
 2.2 W at 28 V

(b) Sensitivity

Range 1	10	μA full scale (5 V)
Range 2	1	μA full scale (5 V)
Range 3	0.1	μA full scale (5 V)

(c) Ramp Voltage (ΔV)

High ΔV	80.1	V/sec
Low ΔV	24.2	V/sec
Period	125.1	msec

(d) Output

Voltage	- 0.68 V to + 5.8 V
Resistance	2600 Ω
Bias Level	1.05 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 18.56 TP utilized a lunar sensor made at SPRL identical to ones used on previous nighttime shots. The system functioned properly throughout the flight and the aspect data were analyzed by the technique which uses the velocity vector as a reference (Taeusch, Carignan, Niemann, and Nagy, 1965). The resulting angle of attack, determined to an estimated accuracy of ±5 deg, is plotted versus altitude in Figure 10.

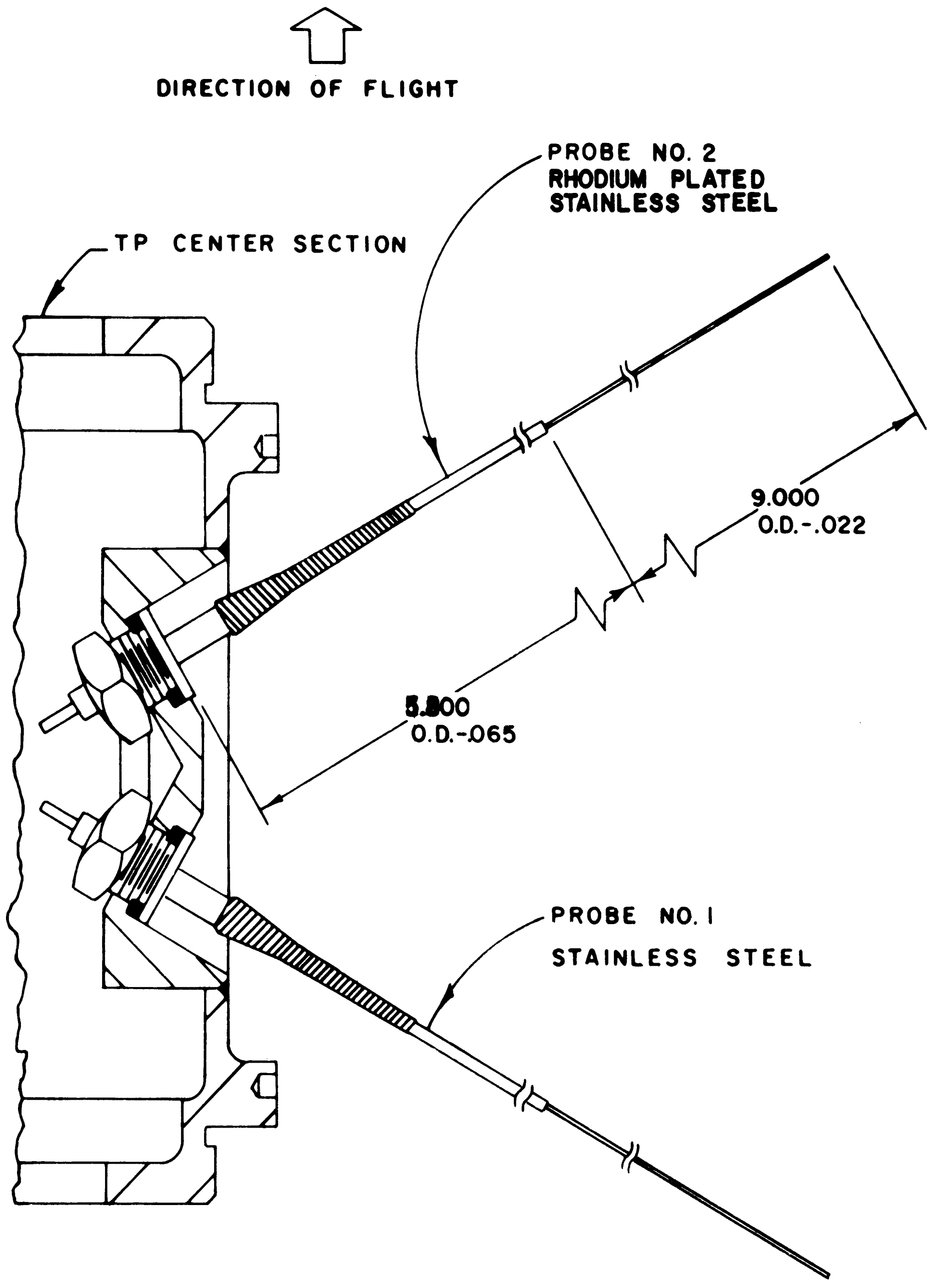

Figure 8. ETDP mounting configuration.

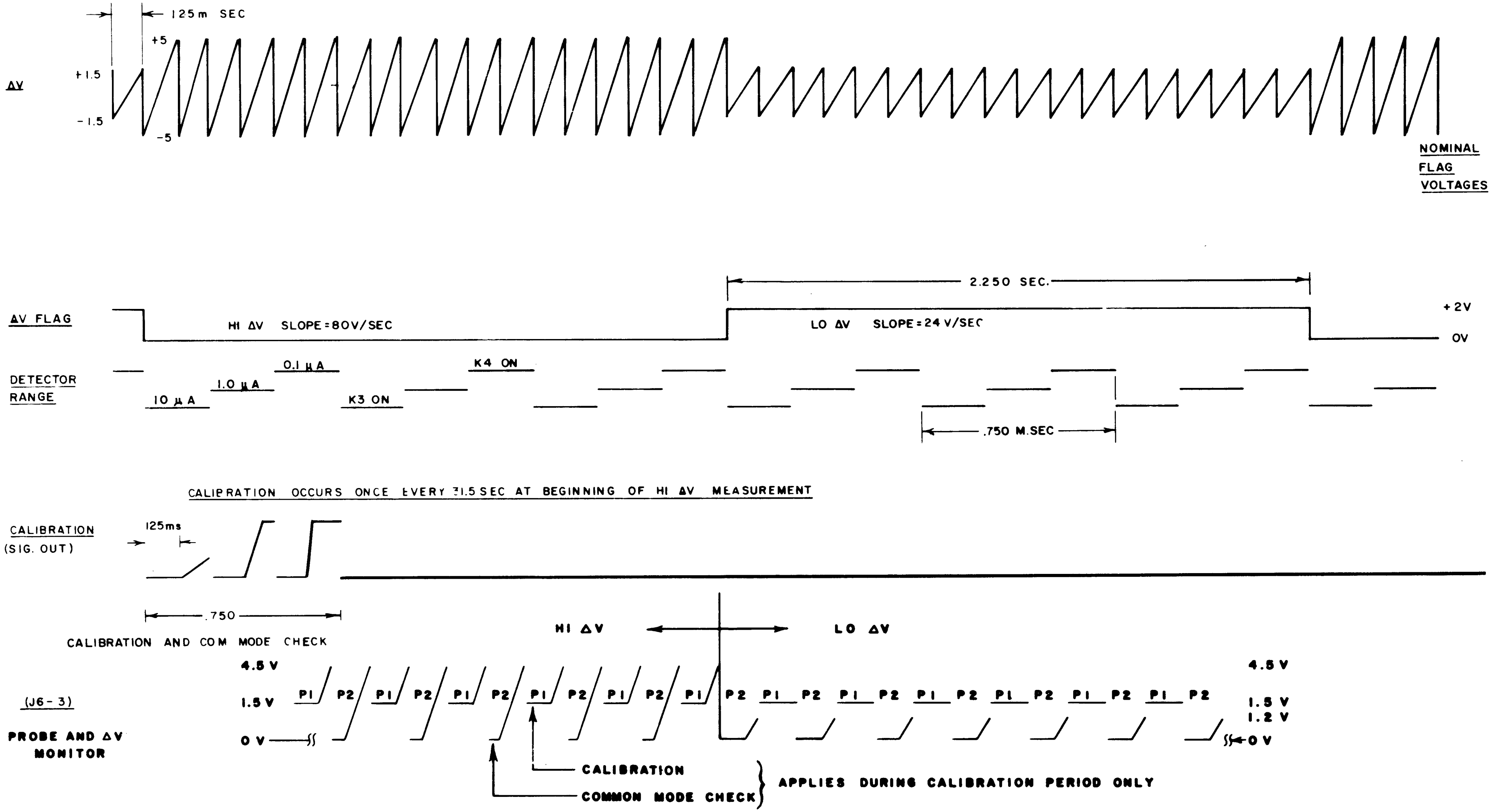

Figure 9. ETDP system timing and output format.

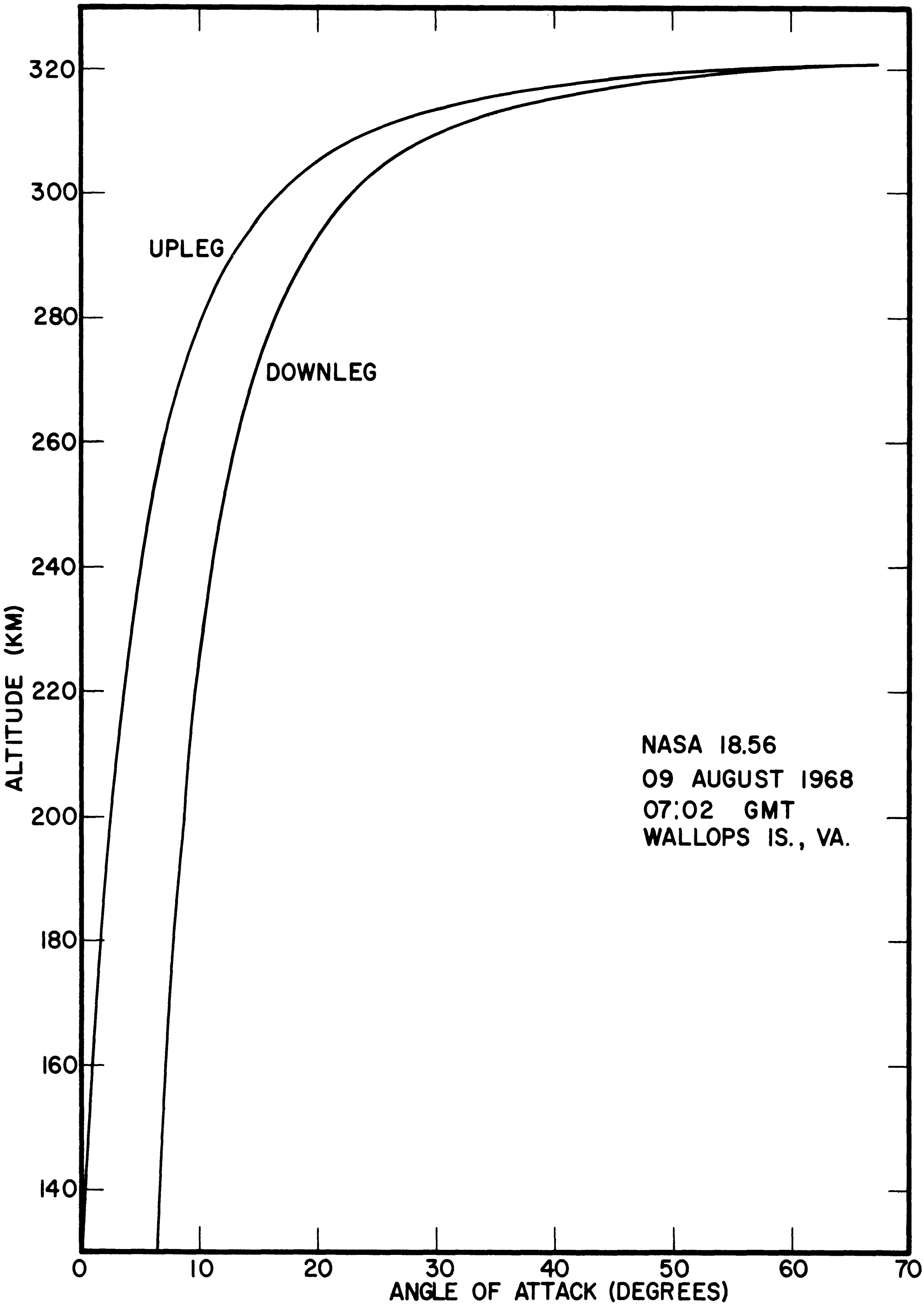

Figure 10. Minimum angle of attack vs. altitude.

5.3.2. Telemetry

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

Transmitter: Driver TRPT-251RAO-1, Serial No. 2530
Power Amplifier TRFP-2V, Serial No. 405
Mixer Amplifier TA59A, Serial No. 1134
Subcarrier channels (SCO Type TS58)

IRIG Band	Serial No.	Center Frequency	Function	Low Pass Filter Used
18	3475-25	70 kHz	OUT/S	450 Hz CD
16	1951-25	40 kHz	OUT/D	450 Hz CD
14	2532-25	22 kHz	ESP-D	330 Hz CD
13	2491-25	14.5 kHz	OM RANGE	220 Hz CD
12	1693-5	10.5 kHz	Aspect	330 Hz CA
11	1647-5	7.35 kHz	Commutator	120 Hz CD

Instrumentation power requirements totaled approximately 30 W, supplied by a Yardney HR-1 Silvercell battery pack of a 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 18.56

Segment Number	Segment Assignment
1	OUT/D
2	Bias Voltage Monitor
3	Filament Monitor
4	RF Voltage Monitor
5	Emission Current Monitor
6	RY Monitor
7	Comparator Ramp Monitor
8	Open
9	Open
10	Open
11	Open
12	Open
13	Battery Voltage Monitor
14	Internal Pressure Monitor
15	Thermistor - Gauge Temperature
16	Thermistor - Amplifier Temperature
17	Thermistor - Filament Regulator Temperature
18	Thermistor - Transmitter Temperature
19	Open
20	Open
21	Open
22	Open
23	Open
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 FPQ-6 and MPS-19 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} versus altitude has already been given in Figure 10. Figure 11 shows the occurrence of significant events during the flight.

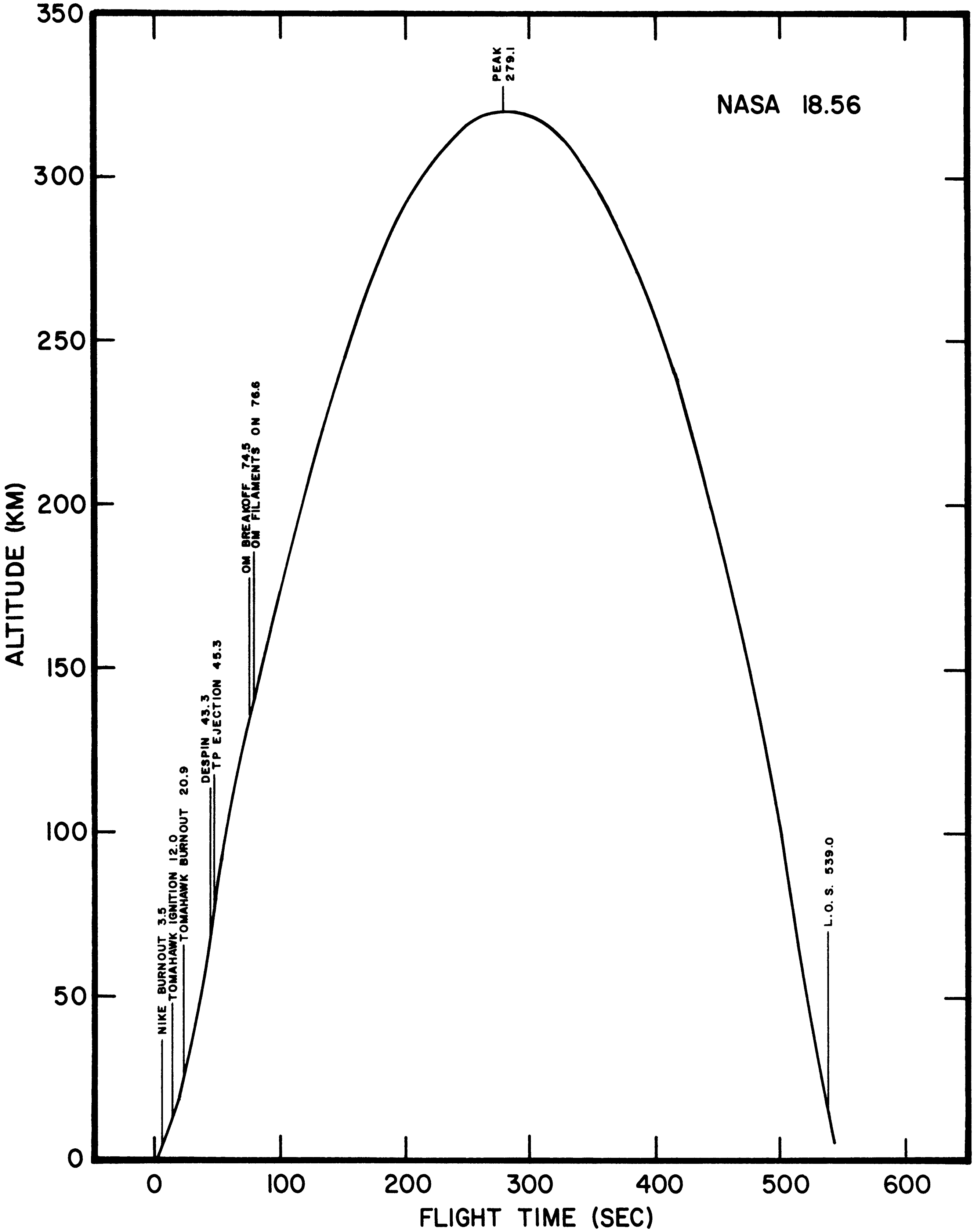

Figure 11. Sequence of events.

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:

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

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 versus flight time is shown in Figure 12. 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 10 shows that the minimum angle of attack for the upleg is generally less than 10 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 versus altitude, is shown in Figure 13. As can be seen, the maximum correction is about 8%, or $K(S_o,\alpha) = .92$ at about 140 km altitude for the upleg data. The correction factor, determined from empirical and theoretical studies, is believed known to better than 2%.

The resulting ambient N_2 number density, obtained from the measured quantities described above, is shown in Figure 14 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.

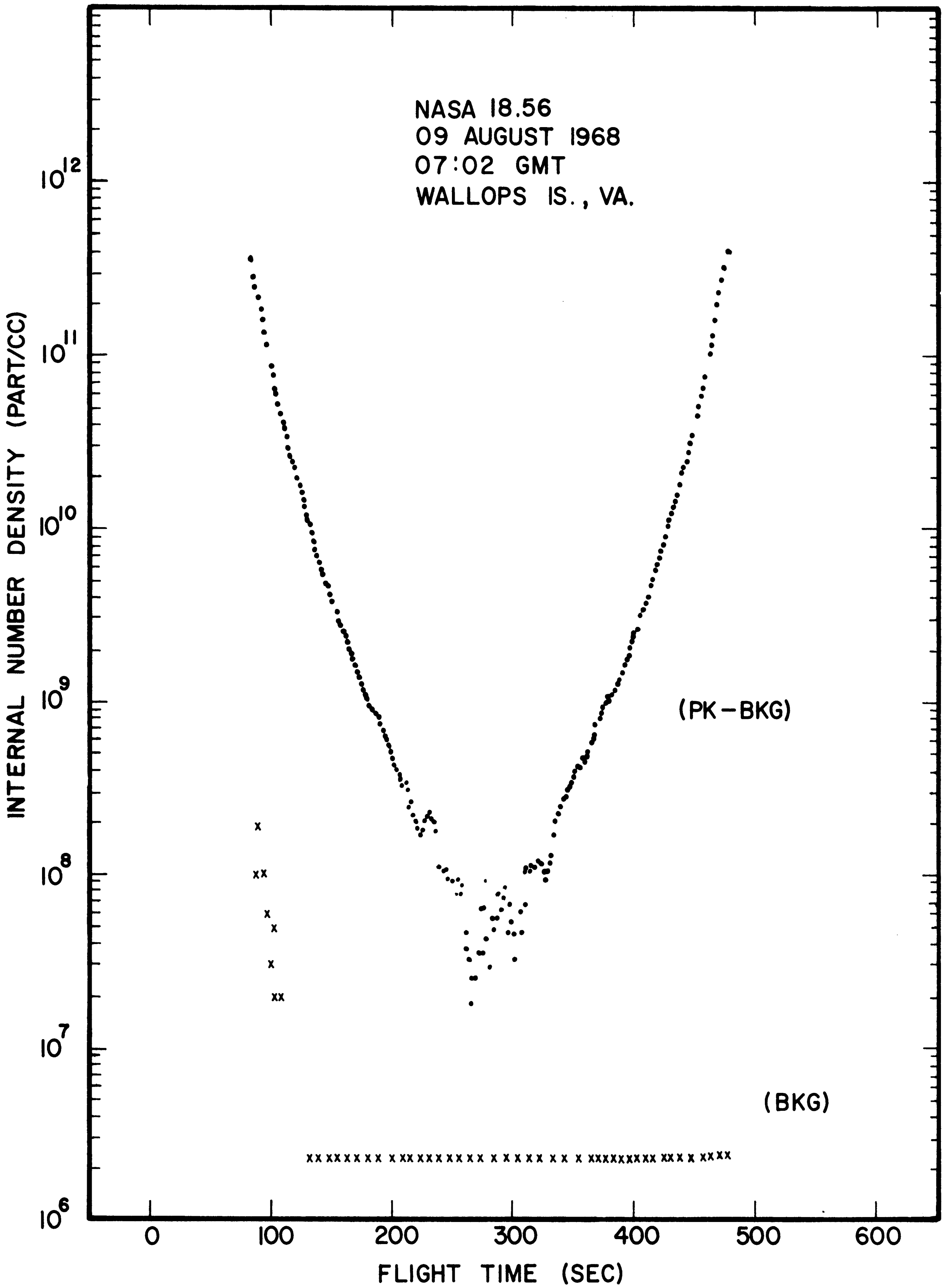

Figure 12. Omegatron current vs. flight time.

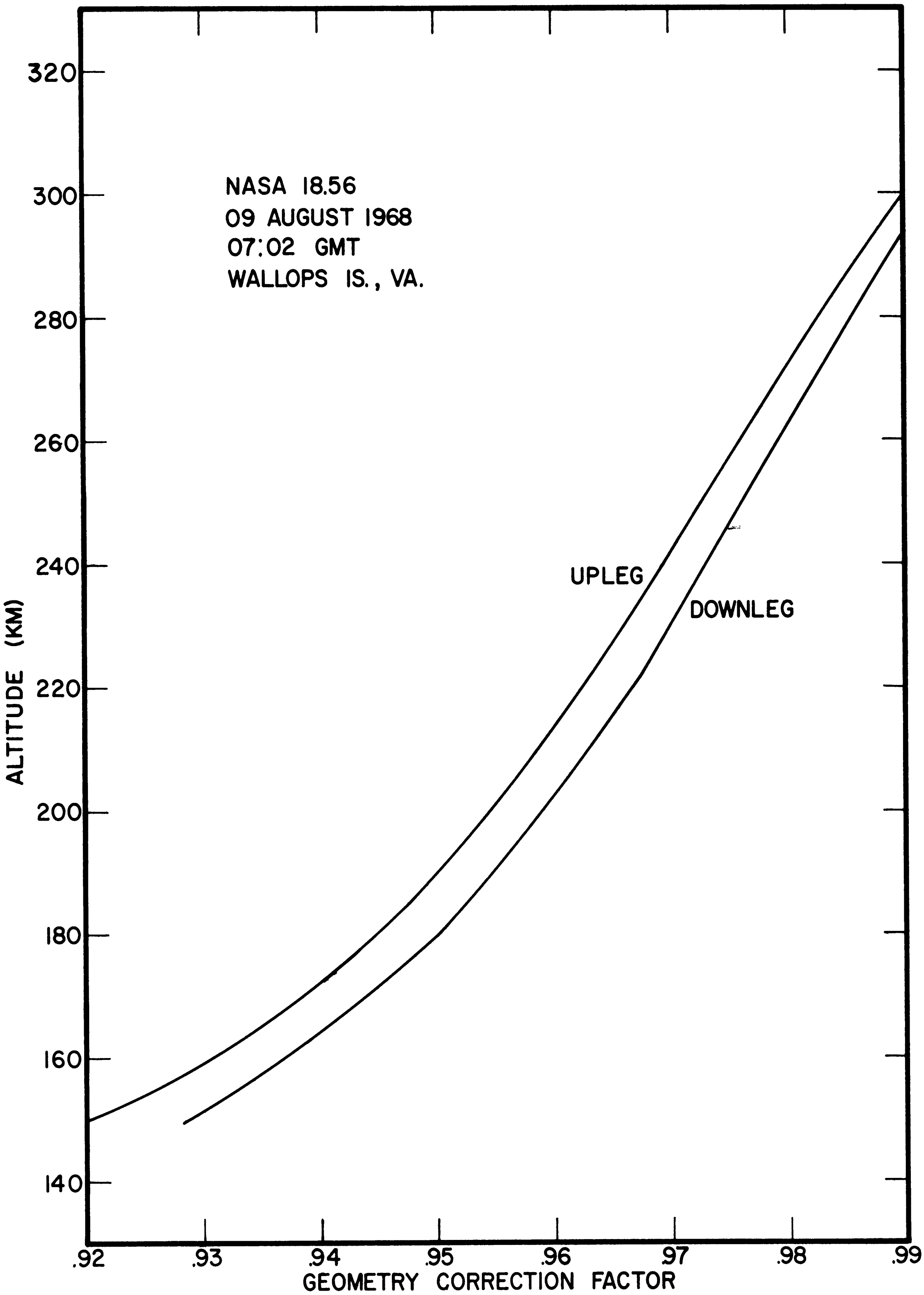

Figure 13. $K(S_o,\alpha)$ vs. altitude.

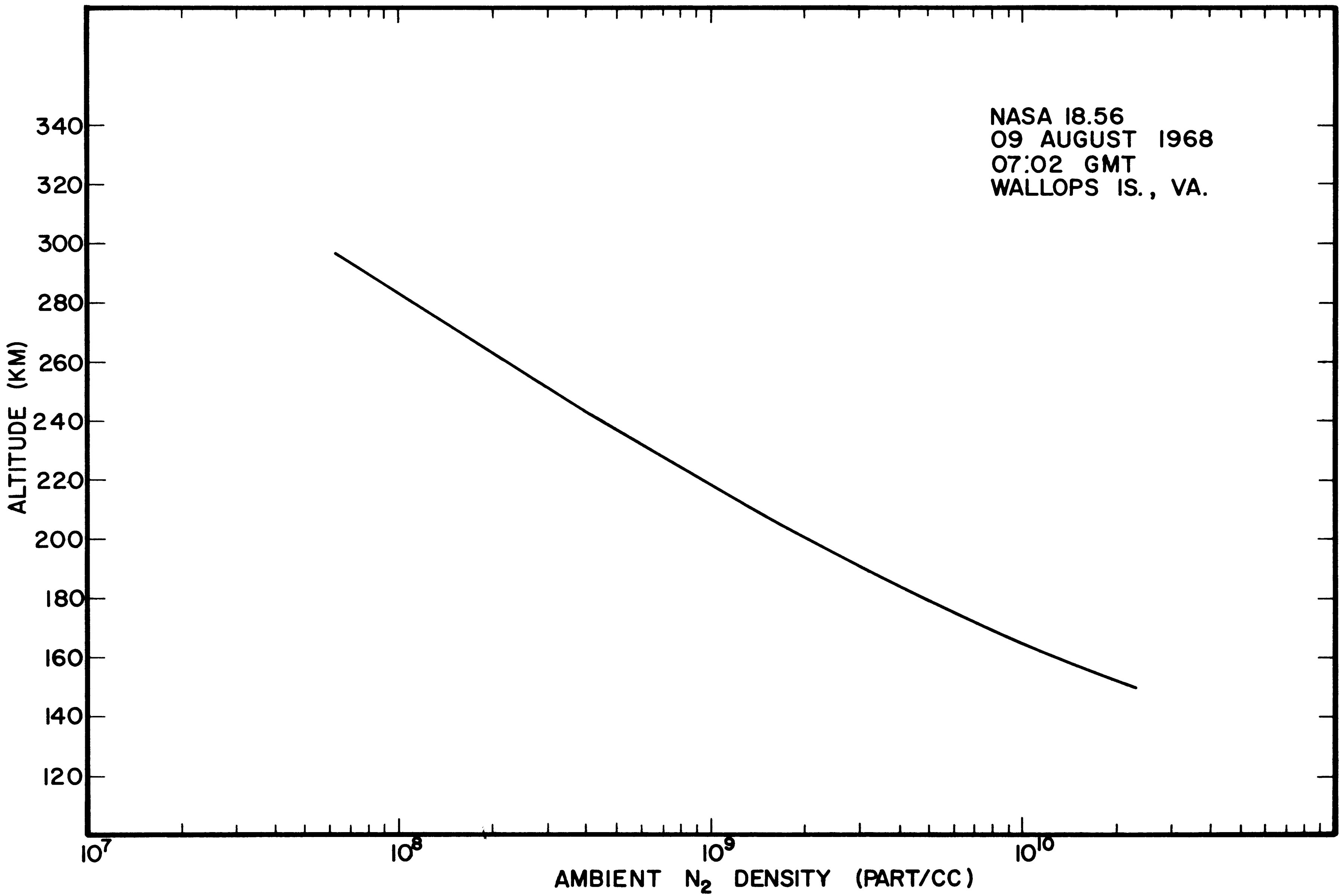

Figure 14. Ambient N_2 density vs. altitude.

TABLE III

N_2 AMBIENT DENSITY DATA
NASA 18.56
9 August 1968
07:02 GMT
03:02 EDT
Wallops Island, Virginia

Altitude (km)	Temperature (°K)	Density (part/cc)
150	618	2.29×10^{10}
155	644	1.73
160	670	1.31
165	694	1.01×10^{10}
170	718	7.80×10^{9}
175	740	6.05
180	760	4.77
185	780	3.79
190	794	3.04
195	807	2.47
200	818	2.01
205	827	1.66
210	835	1.36
215	842	1.12×10^{9}
220	848	9.27×10^{8}
225	854	7.69
230	861	6.40
235	866	5.32
240	872	4.41
245	878	3.68
250	882	3.07
255	887	2.57
260	891	2.15
265	895	1.80
270	899	1.51
275	902	1.28
280	904	1.08×10^{8}
285	906	9.10×10^{7}
290	908	7.71
295	909	6.55×10^{7}

Fit Parameters: T_∞ = 917°K
T_o = 613°K
P_b = 6.09×10^{-9} torr
σ = 2.14×10^{-2}

6.3. TEMPERATURE

The ambient temperature shown in Figure 15 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 16 and 17.

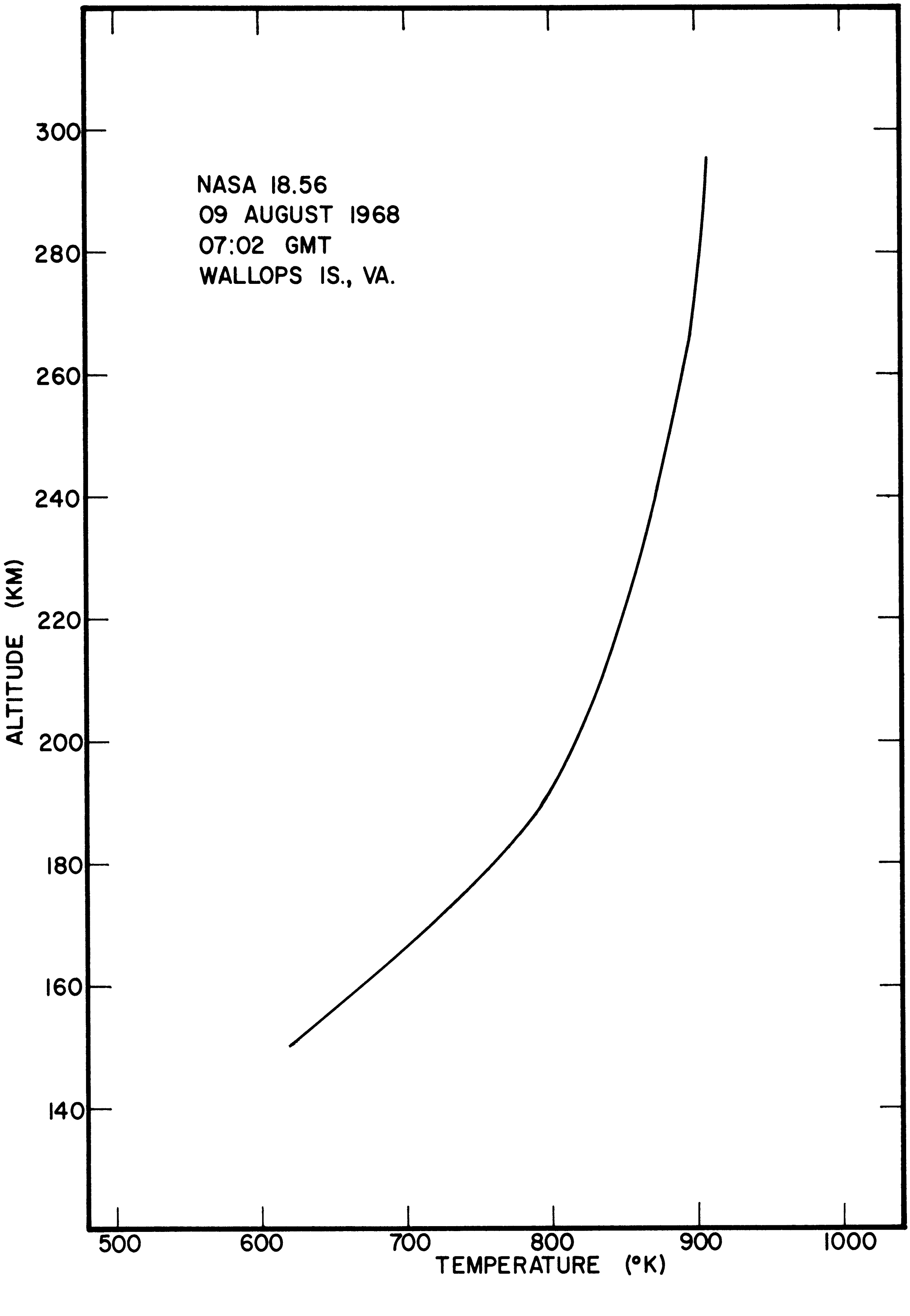

Figure 15. Neutral particle temperature vs. altitude.

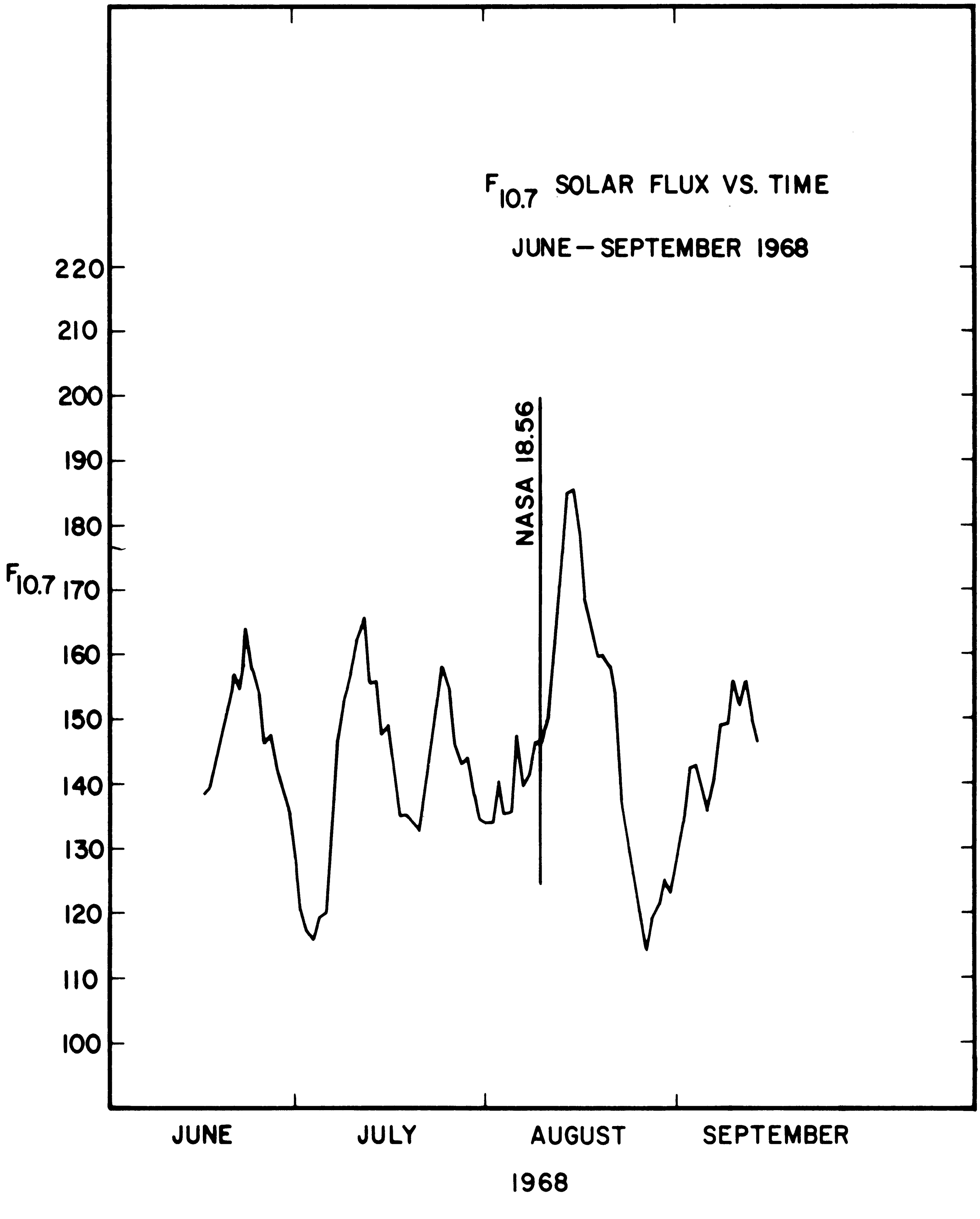

Figure 16. Solar flux at 10.7 cm wavelength.

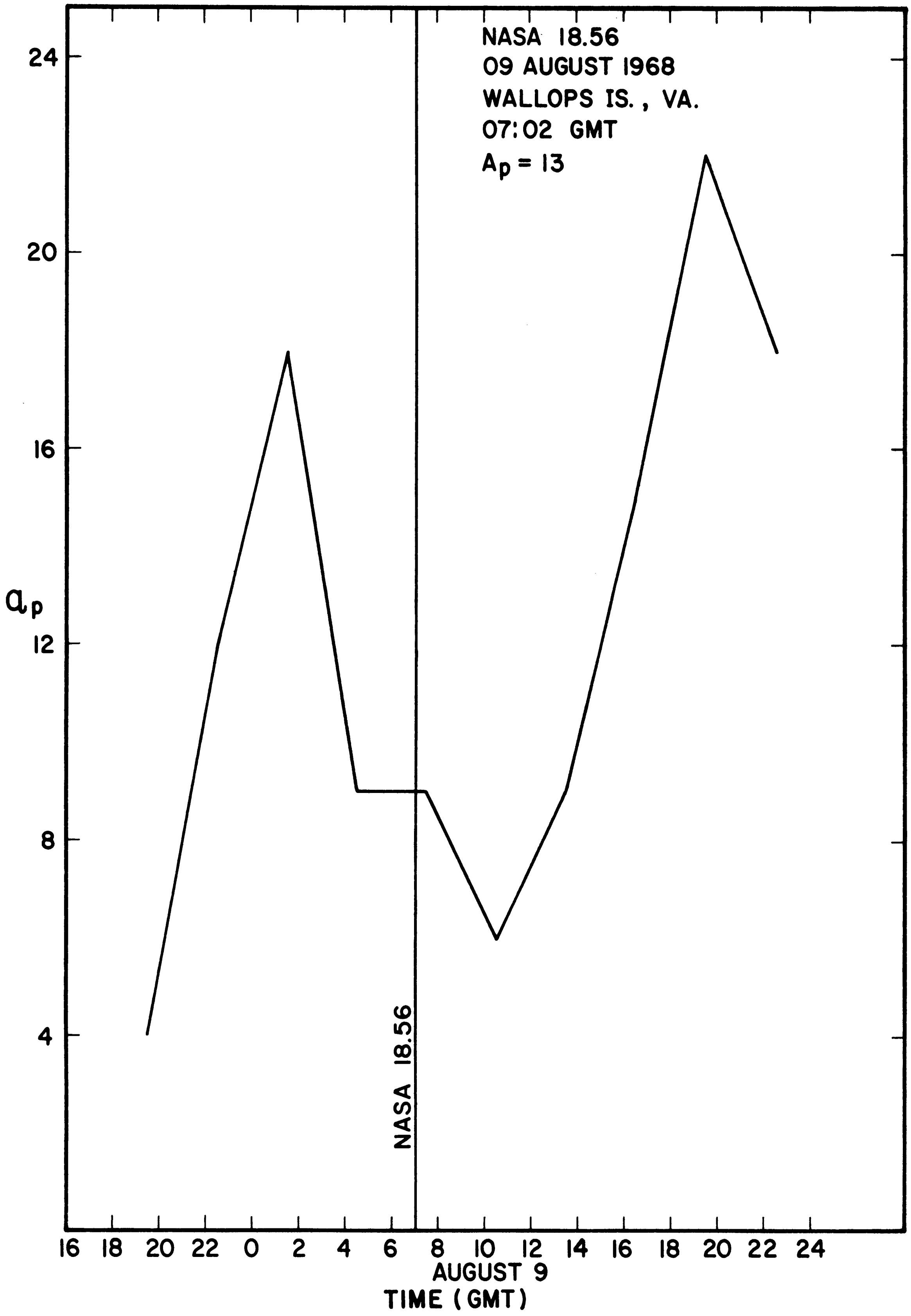

Figure 17. Three-hour geomagnetic activity index (a_p).

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