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 18.102 THERMOSPHERE PROBE EXPERIMENT

Prepared on behalf of the project by

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ORA Project 027700

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1. INTRODUCTION

The results of the launching of NASA 18.102, 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 developed jointly by the Space Physics Research Laboratory (SPRL) of The University of Michigan and the Goddard Space Flight Center (GSFC), Laboratory for Planetary Atmospheres. 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 18.102 payload included a "second generation" omegatron mass analyzer, an electron temperature probe (Spencer, Brace, and Carignan, 1962), and two solar position sensors. 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 145 to 310 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 f(s) curve fitting technique for reduction of the omegatron data is not described here but will be presented in a future report, currently in preparation. 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 18.102 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:	21 August 1969
Launch Time:	15:09:00.115 GMT, 11:09:00.115 EDT
Location:	Wallops Island, Virginia
	Latitude: 37°50'14.915" N
	Longitude: 75°29'01.693" W

Apogee Parameters:

Altitude:	322.14 km
Horizontal Velocity:	399.82 m/sec
Flight Time:	280.67 sec

TP Motion:

Tumble Period:	1.47 sec
Roll Rate:	~115.2 deg/sec

TABLE I

TABLE OF EVENTS

(NASA 18.102)

Event	Flight Time (sec)	Altitude (km)
Lift-off	0	0
1st Stage Burnout	3.6 (est.)	1.3 (est.)
2nd Stage Ignition	11.8	6.7
2nd Stage Burnout	21.3	20.2
Despin	43.0	69.3
TP Ejection	45.2	74.0
Omegatron Breakoff	74.9	133.2
Omegatron Filament ON, M28	76.8	136.7
Peak Altitude	280.67	322.14
L.O.S.	532.0	---

3. LAUNCH VEHICLE

The NASA 18.102 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 3.6 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 78.4 in. long and weighed 139 lb, including despin and adapter modules, made the total vehicle 364.7 in. long with a gross lift-off weight of 1994 lb. The vehicle is illustrated in Figures 1 and 2.

The launch vehicle performed flawlessly and reached a summit altitude of 322.14 km at 280.67 sec of flight time.

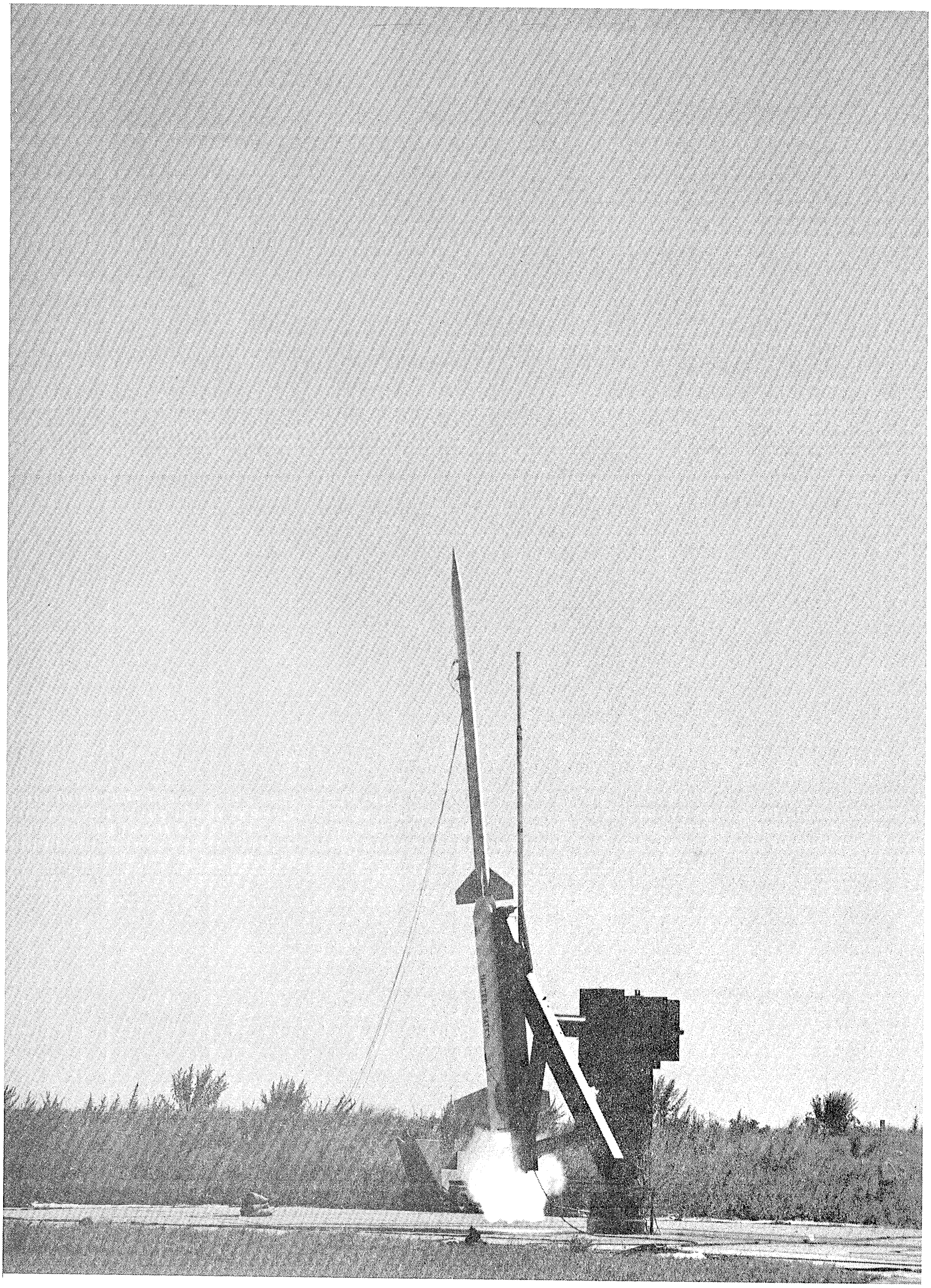

Figure 1. Nike-Tomahawk with thermosphere probe payload.

ROCKET NO. 18.102

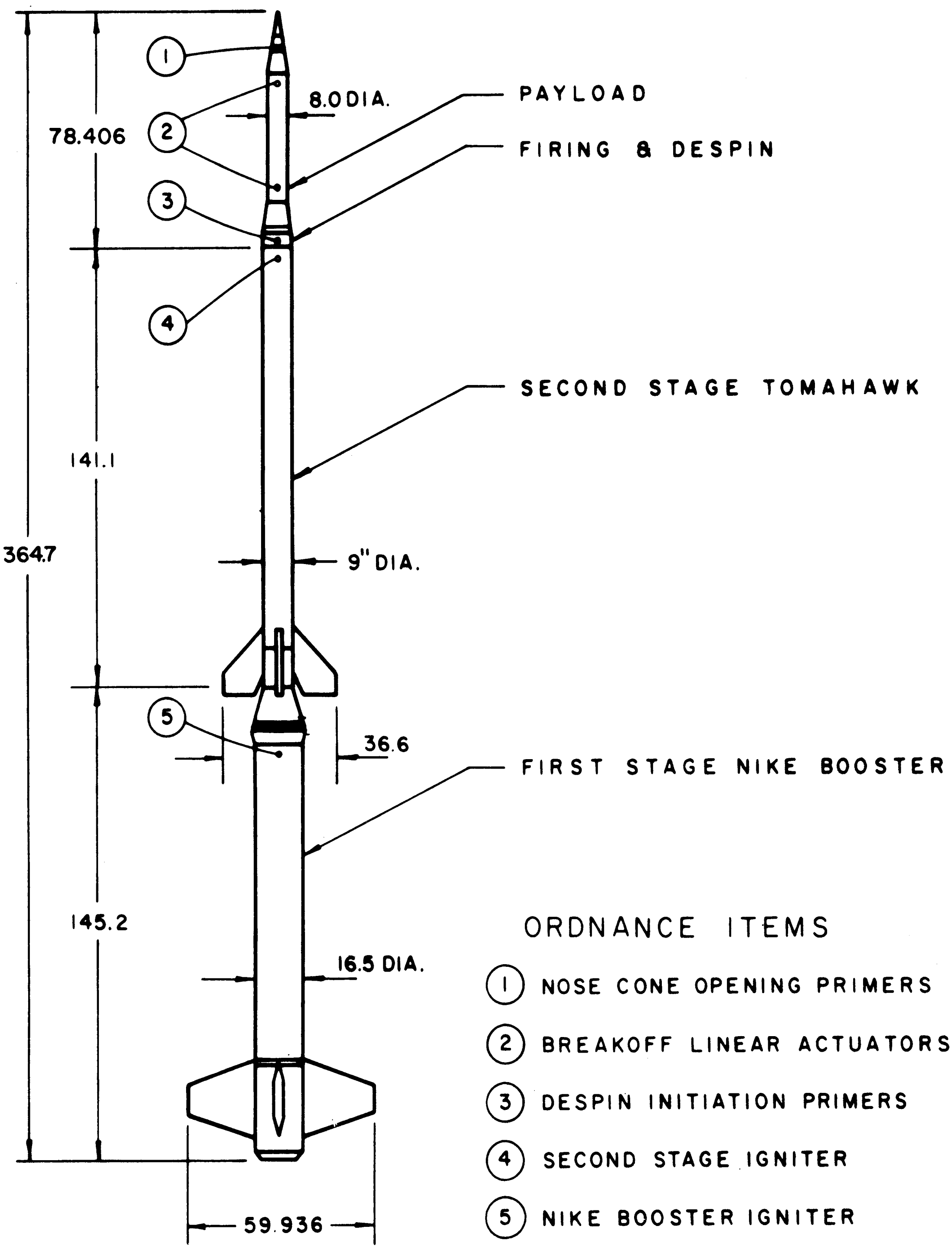

Figure 2. Nike-Tomahawk dimensions.

4. NOSE CONE

A diagram of the NASA 18.102 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 69 km altitude (43 sec after launch), and the ejection began at 74 km (45 sec after launch). The resulting tumble period of the payload was 1.47 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.

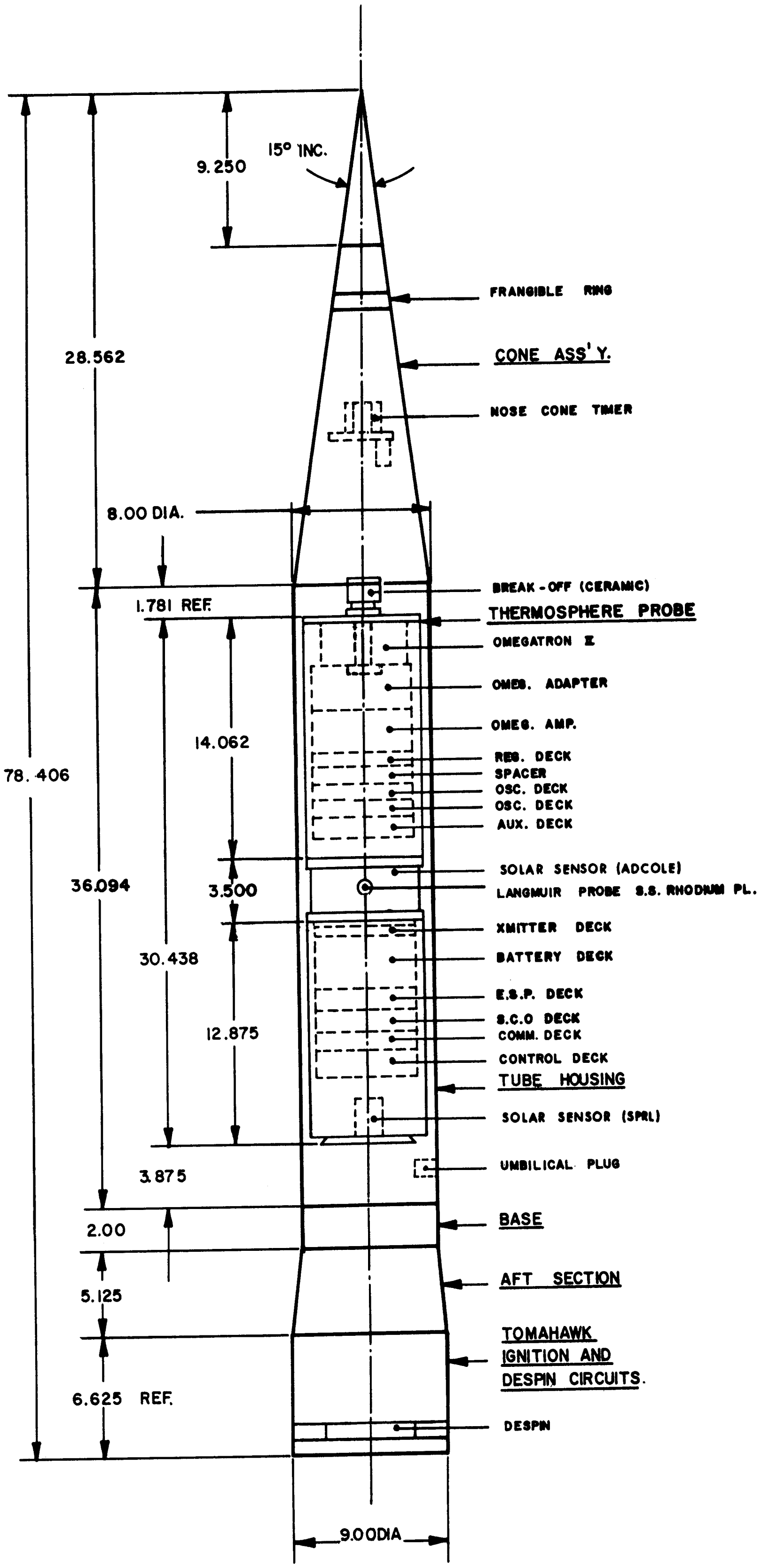

Figure 3. Thermosphere probe instrumentation design.

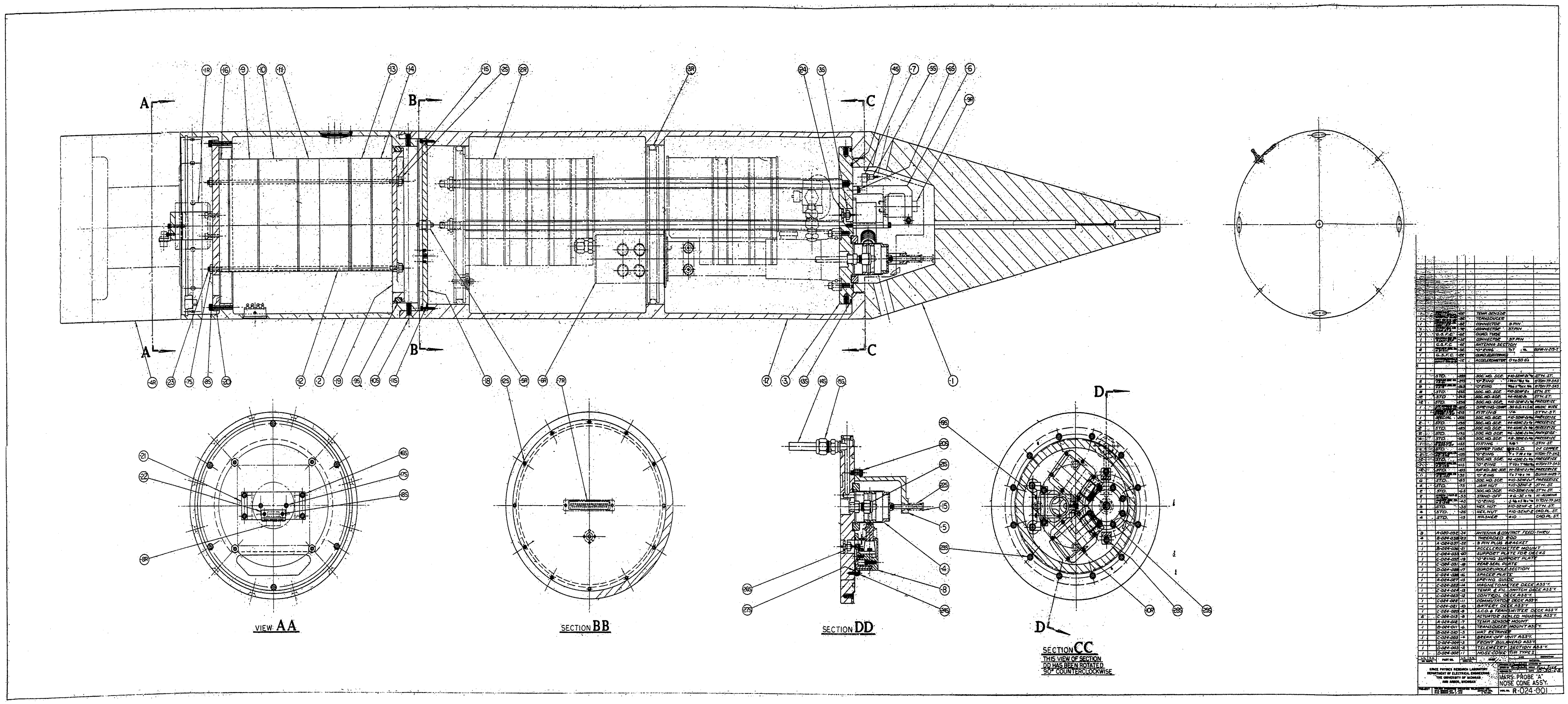

Figure 4. Payload assembly.

5. THE THERMOSPHERE PROBE (TP)

The TP used for the NASA 18.102 payload was a cylinder 30.4 in. long and 7.25 in. in diameter and weighed 54.2 lb. The major instrumentation of this payload included an Omegatron II mass analyzer and an electron temperature probe. Supporting instrumentation included two solar aspect sensors for use in determining the attitude of the TP. The diagram in Figure 3 shows the location of instrumentation and supporting electronics in the nose cone. Figure 5 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 6. The calibration of the NASA 18.102 OM II, performed at SPRL during August 1969, is shown in Figure 7.

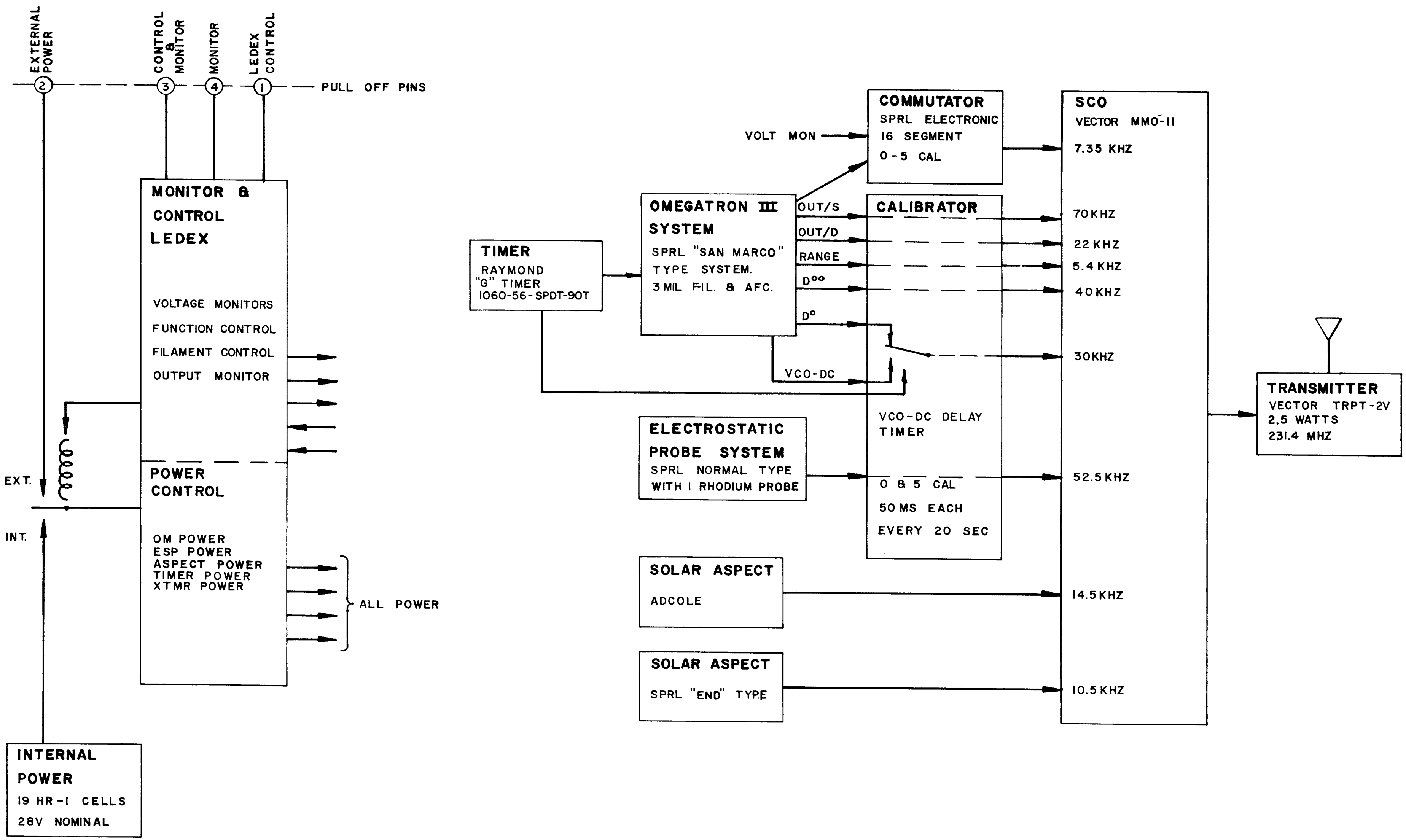

Figure 5. Thermosphere probe system block diagram.

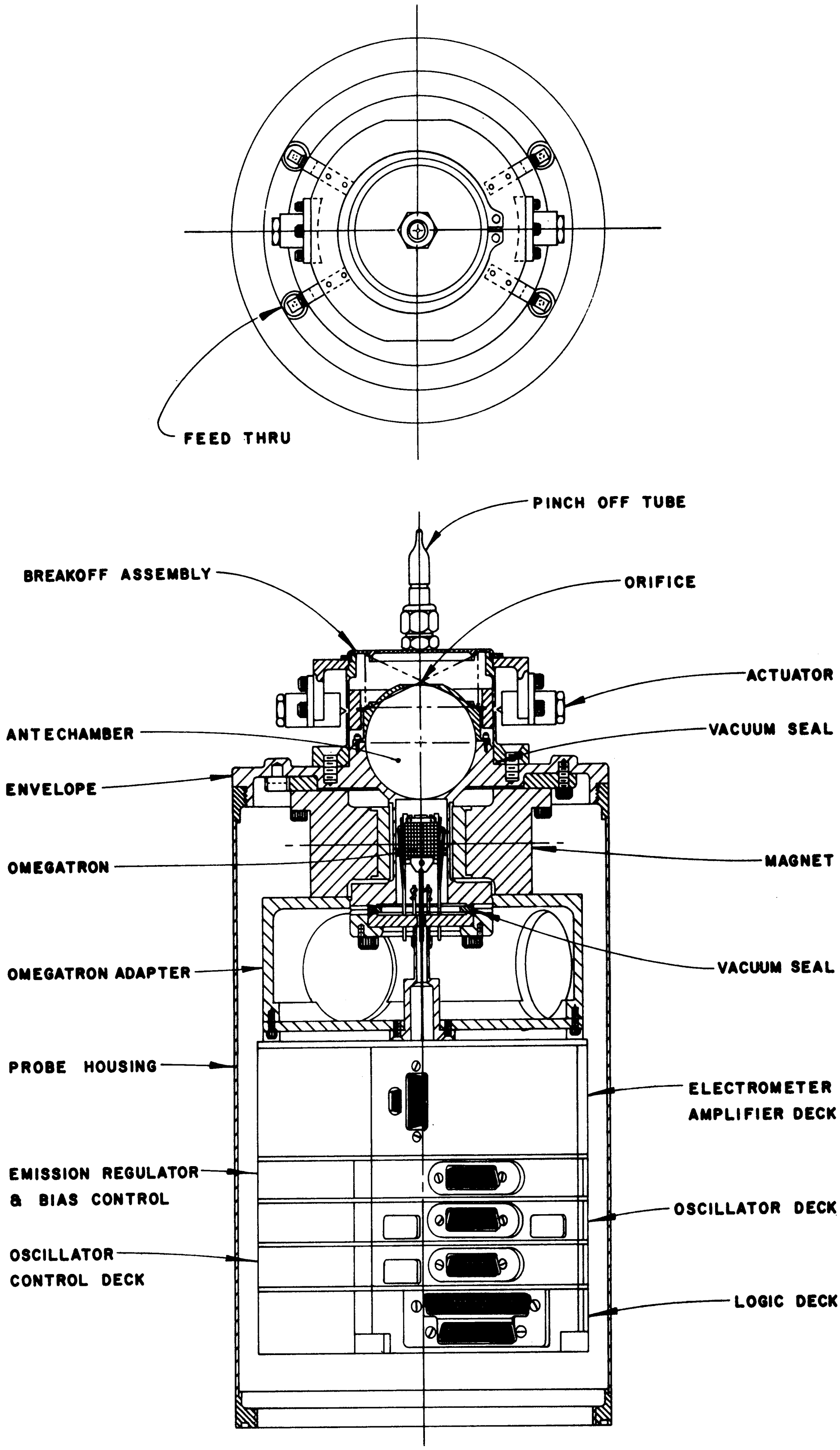

Figure 6. Omegatron II.

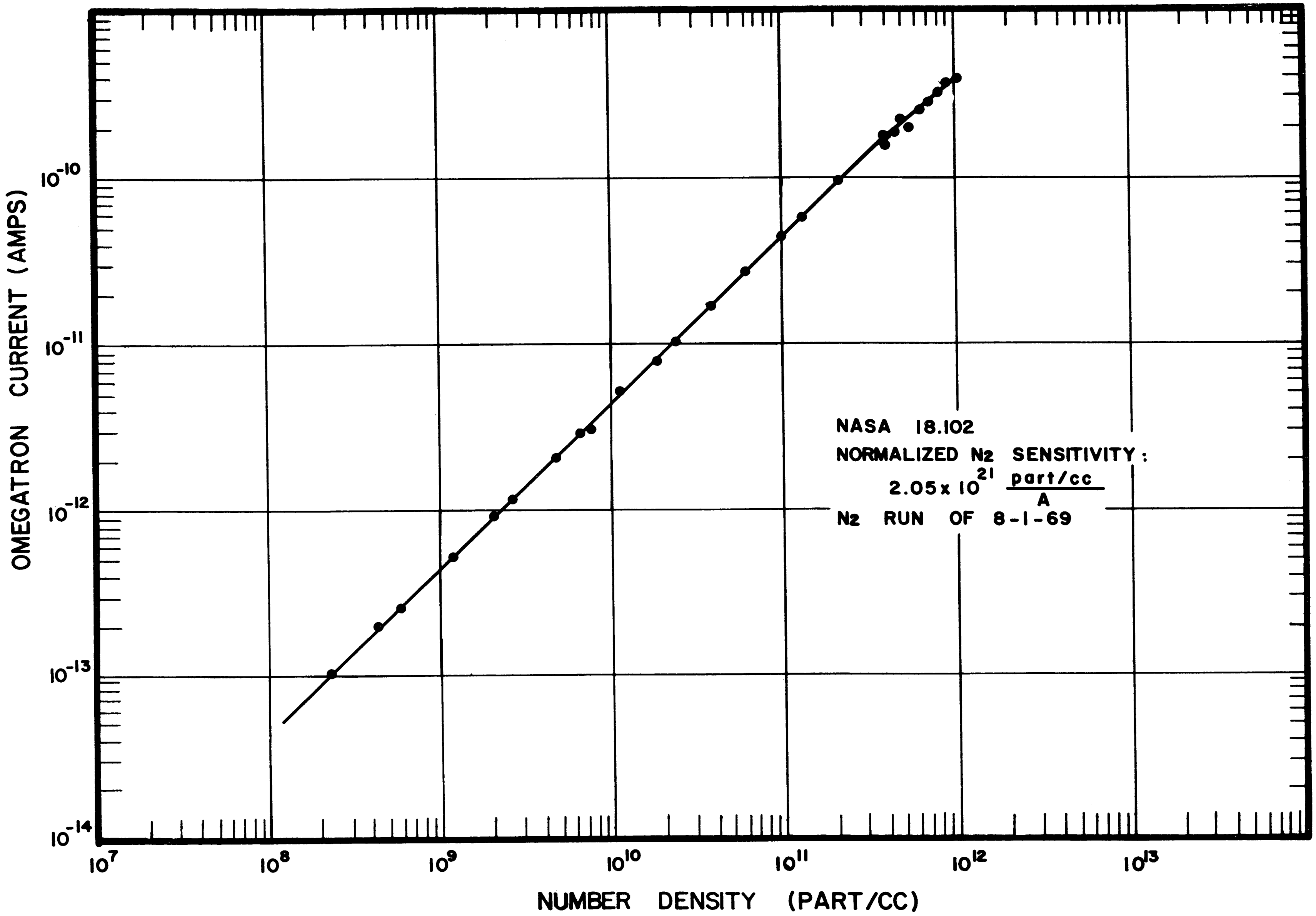

Figure 7. Final calibration of the omegatron.

TABLE II

OMEGATRON DATA

(NASA 18.102)

Omegatron Gauge Parameters	OM II
Beam Current:	2.13 μA
Electron Collector Bias:	68.36 V
Filament Bias:	- 90.70 V
Cage Bias:	- 0.20 V
Top Bias:	- 0.60 V
RF Amplitude:	4.0 V_{p-p}
RF Frequency:	144.2 kHz
Monitors	
Filament Voltage	
OFF:	0.00 V
ON:	3.64 V
Filament Emission	
OFF:	0.00 V
ON:	2.09 V
Thermistor Pressure ("zero" pressure)	
Filament OFF:	1.80 V
Filament ON:	1.62 V
RF Amplitude:	2.85 V
RF Frequency:	2.00 V
Calibration	
Normalized N_2 Sensitivity:	1.60×10^{-5} A/torr

TABLE II (Concluded)

Electrometer Amplifier, OM II

OUT/S

Range	Range Indicator	Range Resistor	Gain	Bias
1-1	0.55 V	1.00×10^{12}	-2.023	+ 1.57 V
1-2	0.86 V	1.00×10^{12}	-2.023	- 2.51 V
1-3	1.18 V	1.00×10^{12}	-1.017	- 3.04 V
1-4	1.48 V	1.00×10^{12}	-1.017	- 7.16 V
1-5	1.79 V	1.00×10^{12}	-1.017	-11.24 V
1-6	2.11 V	1.00×10^{12}	-1.017	-15.26 V
1-7	2.41 V	1.00×10^{12}	-1.017	-19.45 V
2-1	2.98 V	6.66×10^{10}	-2.023	+ 1.57 V
2-2	3.31 V	6.66×10^{10}	-2.023	- 2.51 V
2-3	3.62 V	6.66×10^{10}	-1.017	- 3.04 V
2-4	3.92 V	6.66×10^{10}	-1.017	- 7.16 V
2-5	4.22 V	6.66×10^{10}	-1.017	-11.24 V
2-6	4.52 V	6.66×10^{10}	-1.017	-15.26 V
2-7	4.81 V	6.66×10^{10}	-1.017	-19.45 V

OUT/D

Range	Range Indicator	Range Resistor	Gain	Bias
1	---	1.00×10^{12}	-0.2500	0.0 V
2	---	6.66×10^{10}	-0.2500	0.0 V

Miscellaneous

+28 Power current all on:	260 mA
Preflight gauge pressure (N_2):	$\leq 10^{-4}$ torr
Magnetic field strength:	2600 gauss

5.2. ELECTRON TEMPERATURE AND DENSITY PROBE

The electron temperature and density probe consists of a cylindrical Langmuir probe placed in the plasma, and an electronics unit which measures the current collected by the probe as it is swept through a series of ramp voltages. A typical Langmuir probe is shown in Figure 8. The probe, for this flight, is rhodium-plated stainless steel.

The electronics unit consists of a dc-dc converter, 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
2.0 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	80.1	V/sec
Low ΔV	23.9	V/sec
Period	125.2	msec

(d) Output

Voltage	- 0.62	V to +5.8 V
Resistance	2600	Ω
Bias Level	0.961	V

(e) System Calibration
Calibration occurs every 31.5 sec for a duration of 750 msec.

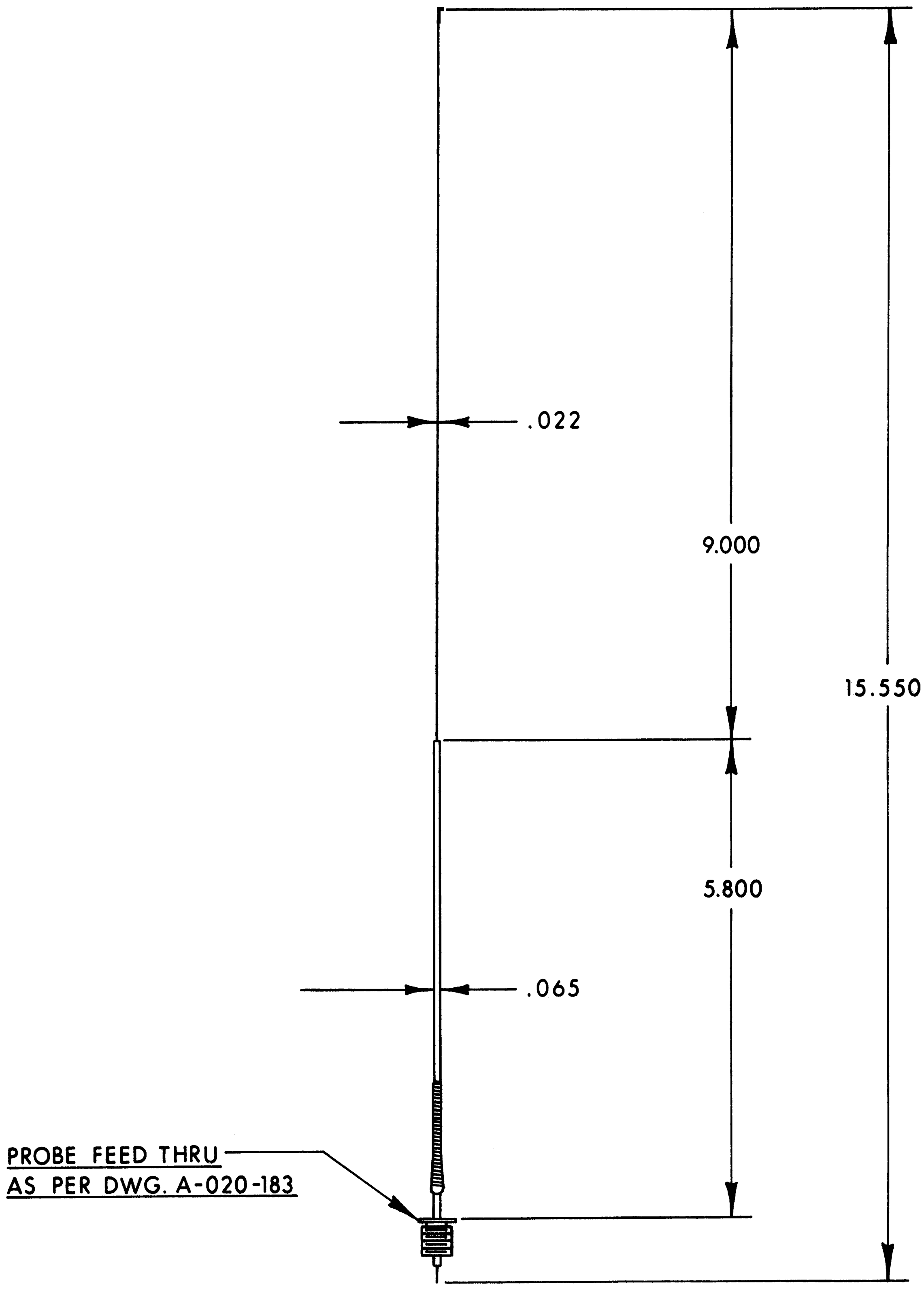

Figure 8. Electron temperature and density probe.

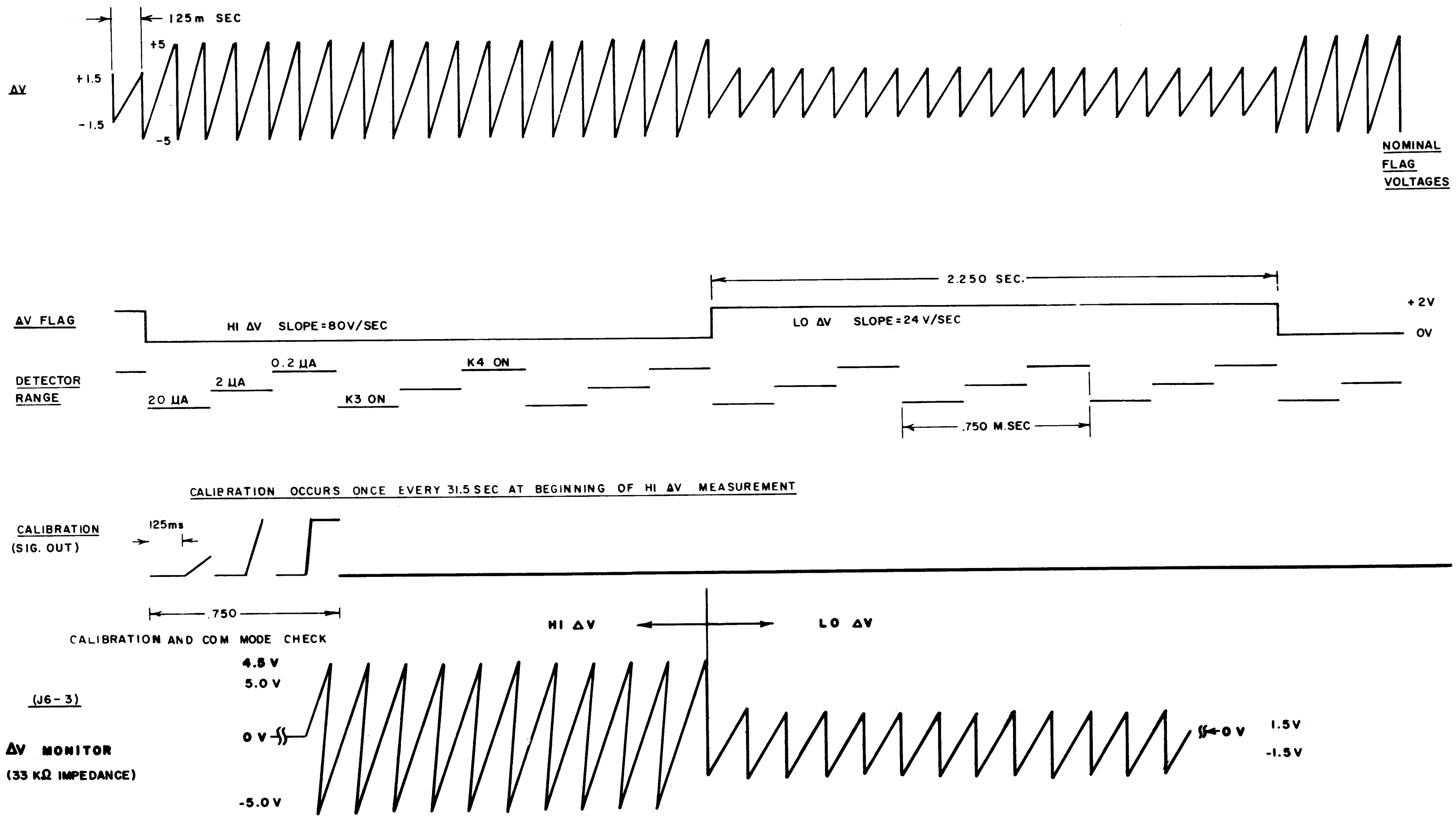

Figure 9. Electron temperature and density probe.

5.3. SUPPORT MEASUREMENTS AND INSTRUMENTATION

5.3.1. Aspect Determination System

The NASA 18.102 TP utilized two solar sensors. One system, located in the center of the TP body, was made by Adcole Corporation. This system was identical to the ones used on previous daytime flights and functioned satisfactorily throughout the flight. The other system was made at SPRL and was located at the opposite end of the TP from the omegatron. This was the first such instrument to be flown and the results showed close agreement with the Adcole sensor results. 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 versus altitude in Figure 10.

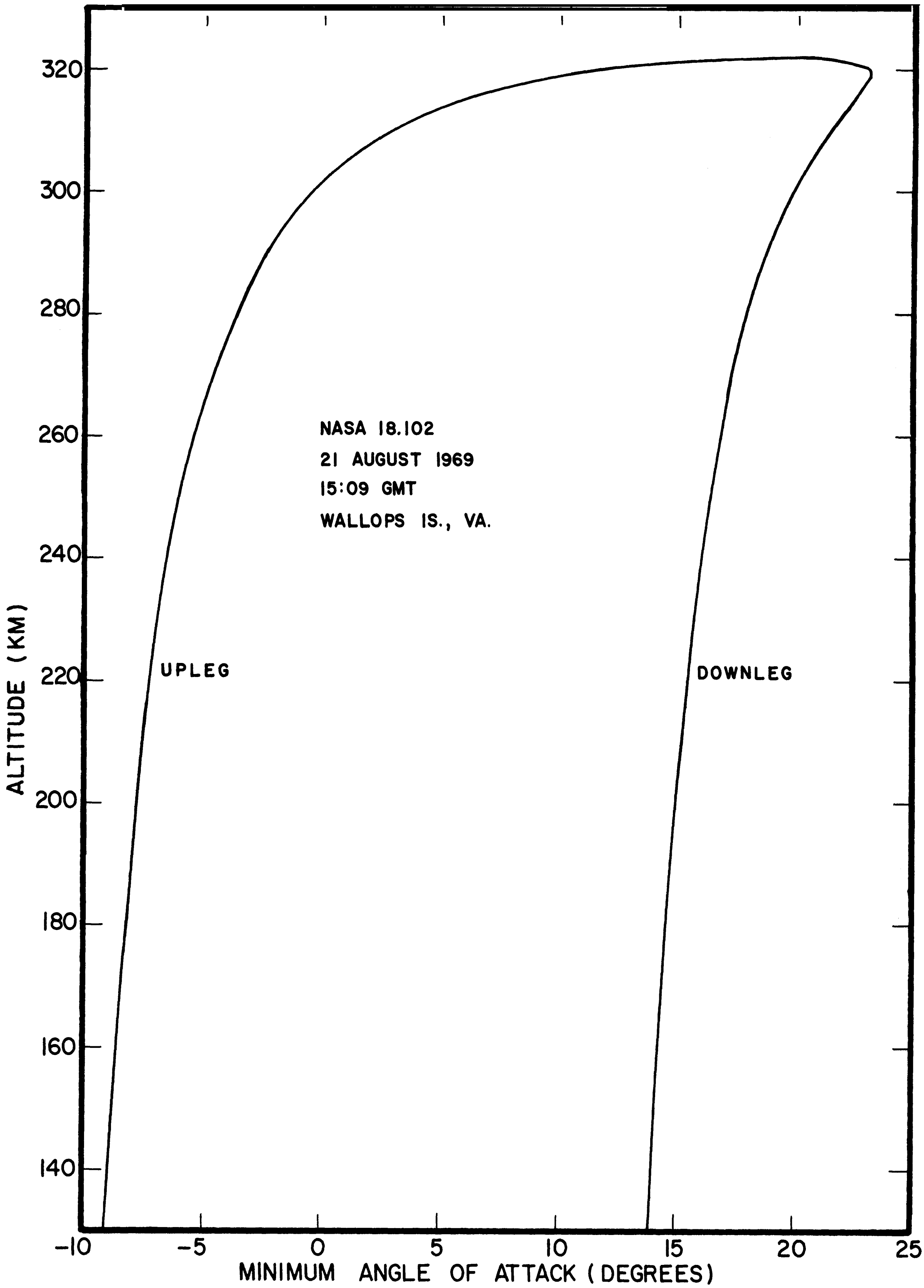

Figure 10. Minimum angle of attack vs. altitude.

5.3.2. Telemetry

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

Transmitter: Driver TRPT-251RAO-1, Serial No. 2372
Power Amplifier TRFP-2VA, Serial No. 382
Mixer Amplifier MMA-12, Serial No. 11989
Subcarrier channels (SCO Type MMO-11)

IRIG Band	Serial No.	Center Frequency		Function	Low Pass Filter Used
18	16714	70	kHz	OUT/S	450 Hz CD
17	7837	52.5	kHz	ETDP	790 Hz CD
16	19098	40	kHz	2nd Der	600 Hz CD
15	16346	30	kHz	1st Der	450 Hz CD
14	16245	22	kHz	OUT/D	110 Hz CD
13	15263	14.5	kHz	Aspect-Adcole	450 Hz CA
12	18717	10.5	kHz	Aspect-SPRL	330 Hz CA
11	444	7.35	kHz	Commutator	120 Hz CD
10	12552	5.4	kHz	OM Range	80 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 sixteen-segment commutator which ran at one rps. The commutator assignments were as follows:

COMMUTATOR FORMAT FOR NASA 18.102

Segment Number	Segment Assignment
0	0 V Calibration
1	5 V Calibration
2	5 V Calibration
3	RF Frequency
4	RF Amplitude
5	Automatic Frequency Control Lock
6	DC Frequency Control
7	Beam Current
8	Filament Voltage
9	Thermistor—Amplifier Temperature
10	Thermistor—Gauge Temperature
11	Thermistor—Transmitter Temperature
12	Internal Pressure Monitor
13	Battery Voltage Monitor
14	Omegatron Range
15	OUT/D

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 MPS-19, FPS-16, and Spandar 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.

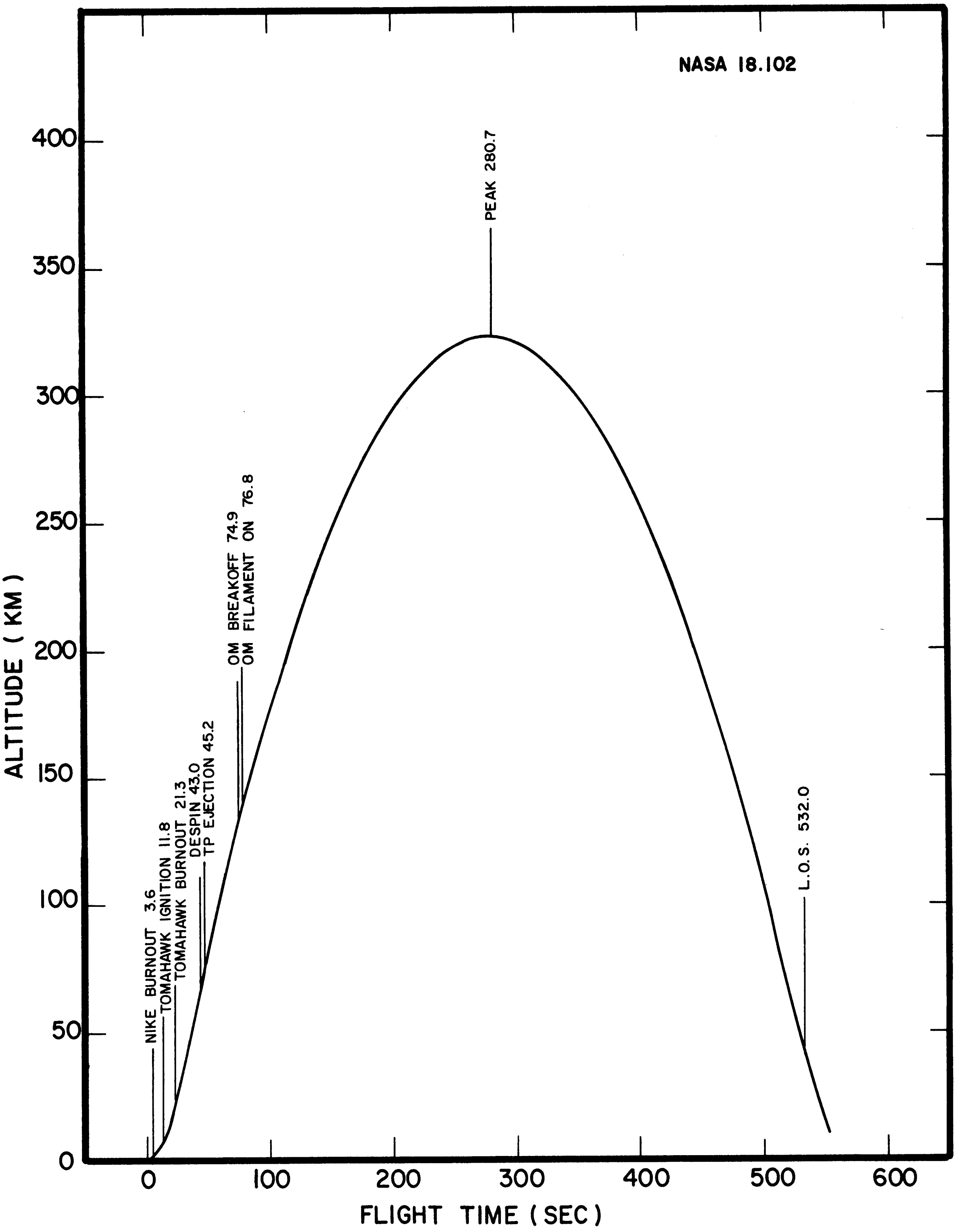

Figure 11. Sequence of events.

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 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, is shown versus altitude in Figure 13. 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 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.

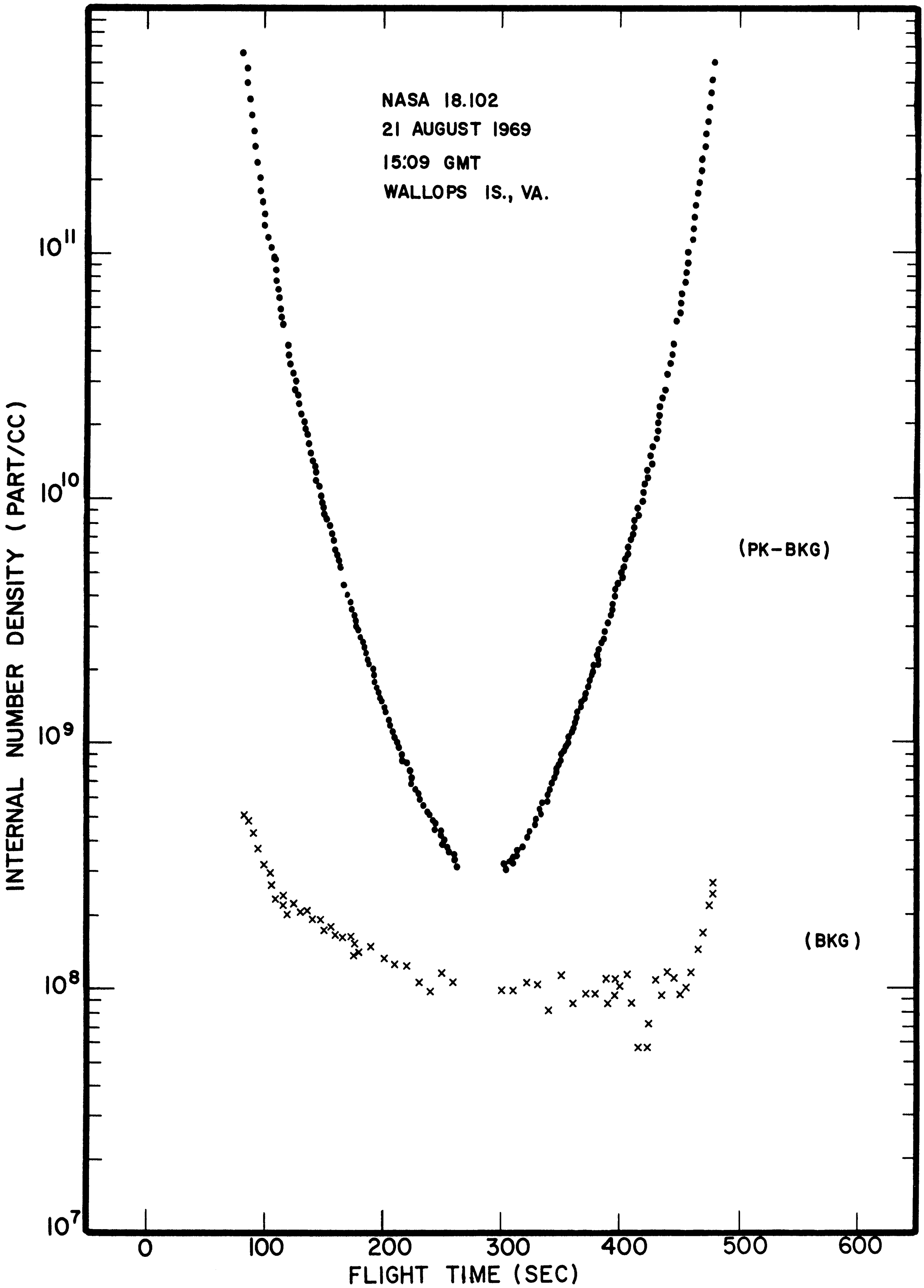

Figure 12. Omegatron current vs. flight time.

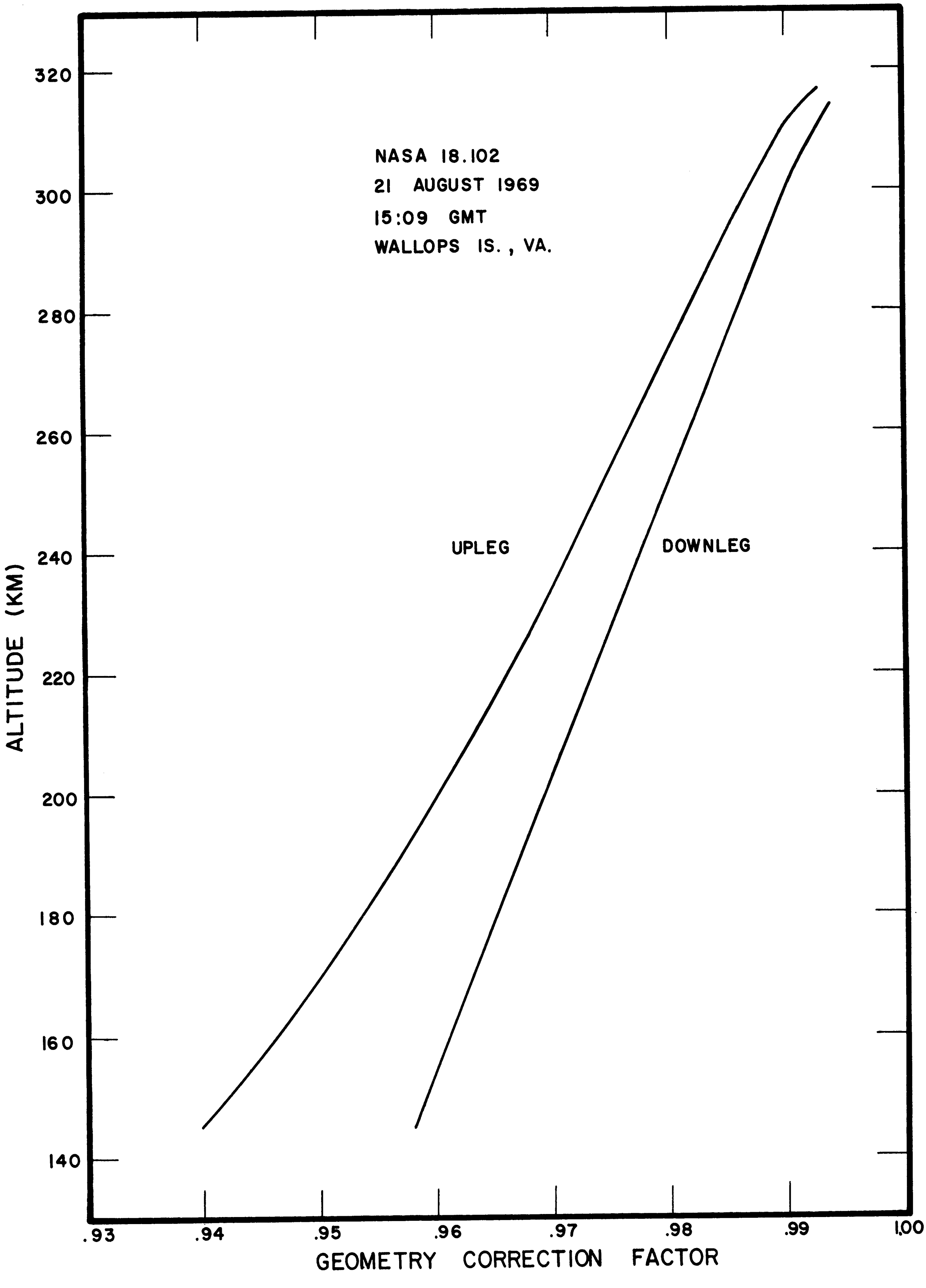

Figure 13. $K(S_o,\alpha)$ vs. altitude.

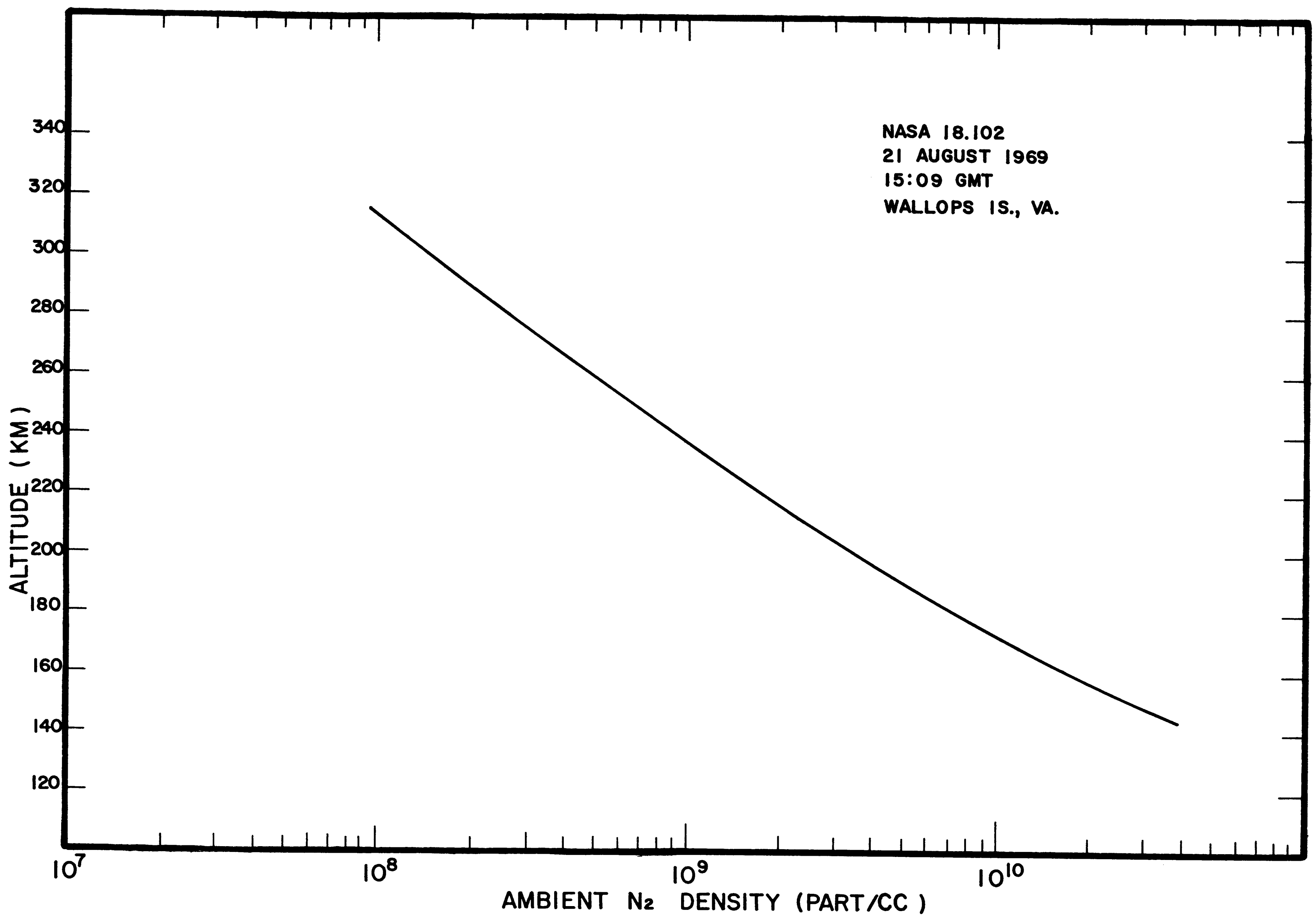

Figure 14. Ambient N_2 density vs. altitude.

TABLE III

N_2 AMBIENT DENSITY DATA

NASA 18.102
21 August 1969
15:09 GMT
11:09 EDT
Wallops Island, Virginia

Altitude (km)	Temperature (°K)	Density (part/cc)
145	685	4.18×10^{10}
150	717	3.19
155	746	2.48
160	776	1.93
165	801	1.54
170	822	1.23×10^{10}
175	841	9.97×10^{9}
180	859	8.13
185	875	6.67
190	891	5.49
195	906	4.55
200	919	3.77
205	932	3.16
210	944	2.64
215	954	2.22
220	964	1.86
225	974	1.57
230	983	1.33
235	992	1.14×10^{9}
240	999	9.62×10^{8}
245	1006	8.20
250	1013	7.00
255	1019	6.00
260	1026	5.15
265	1031	4.41
270	1036	3.79
275	1041	3.26
280	1045	2.81
285	1049	2.42
290	1053	2.09
295	1056	1.81
300	1060	1.56
305	1063	1.35
310	1066	1.17
315	1070	1.01×10^{8}

Fit Parameters:

T_∞ = 1105 °K
T_o = 822 °K at 170 km
P_b = 1.038×10^{-8} torr
σ = 1.4286×10^{-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.

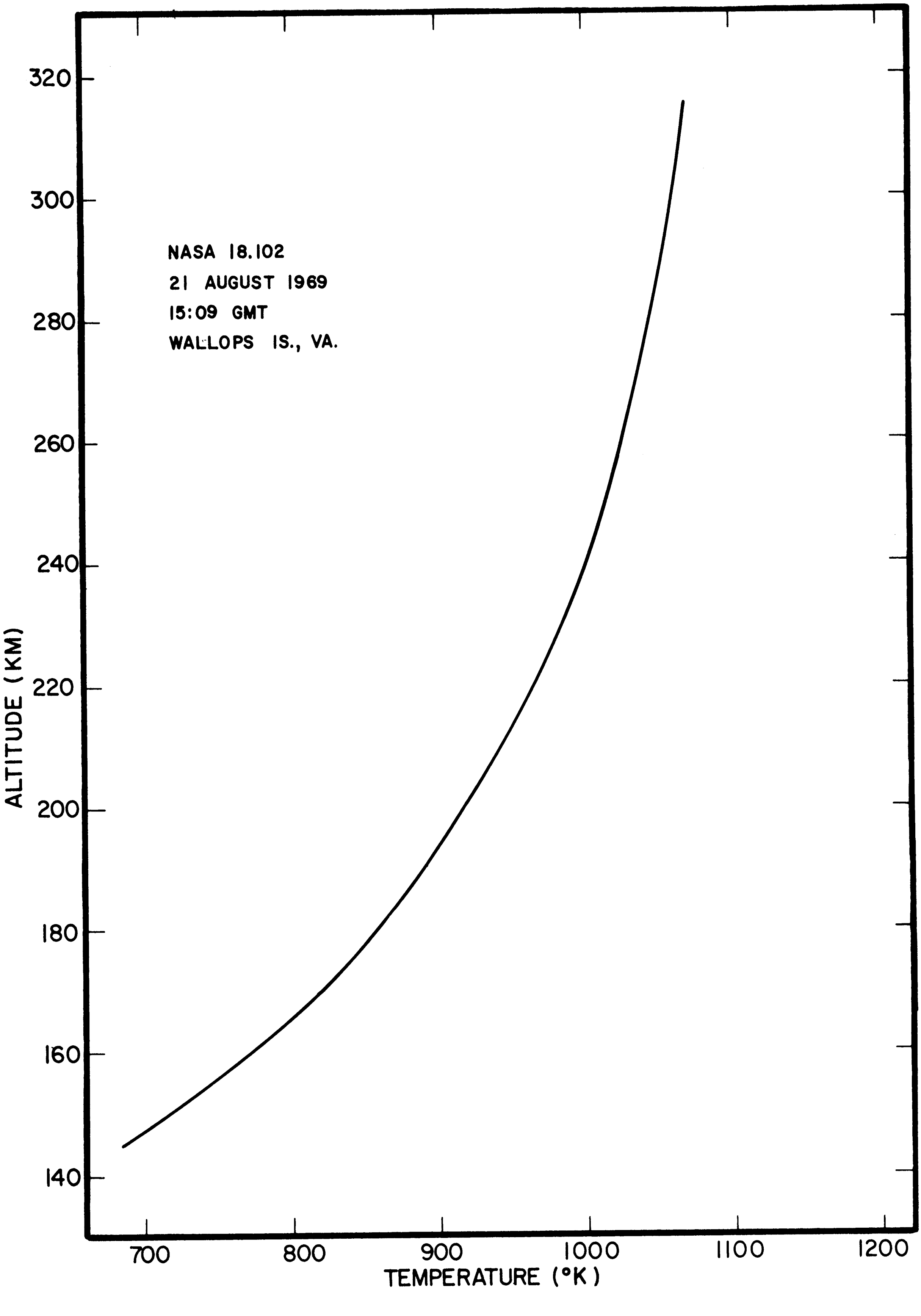

Figure 15. Neutral particle temperature vs. altitude.

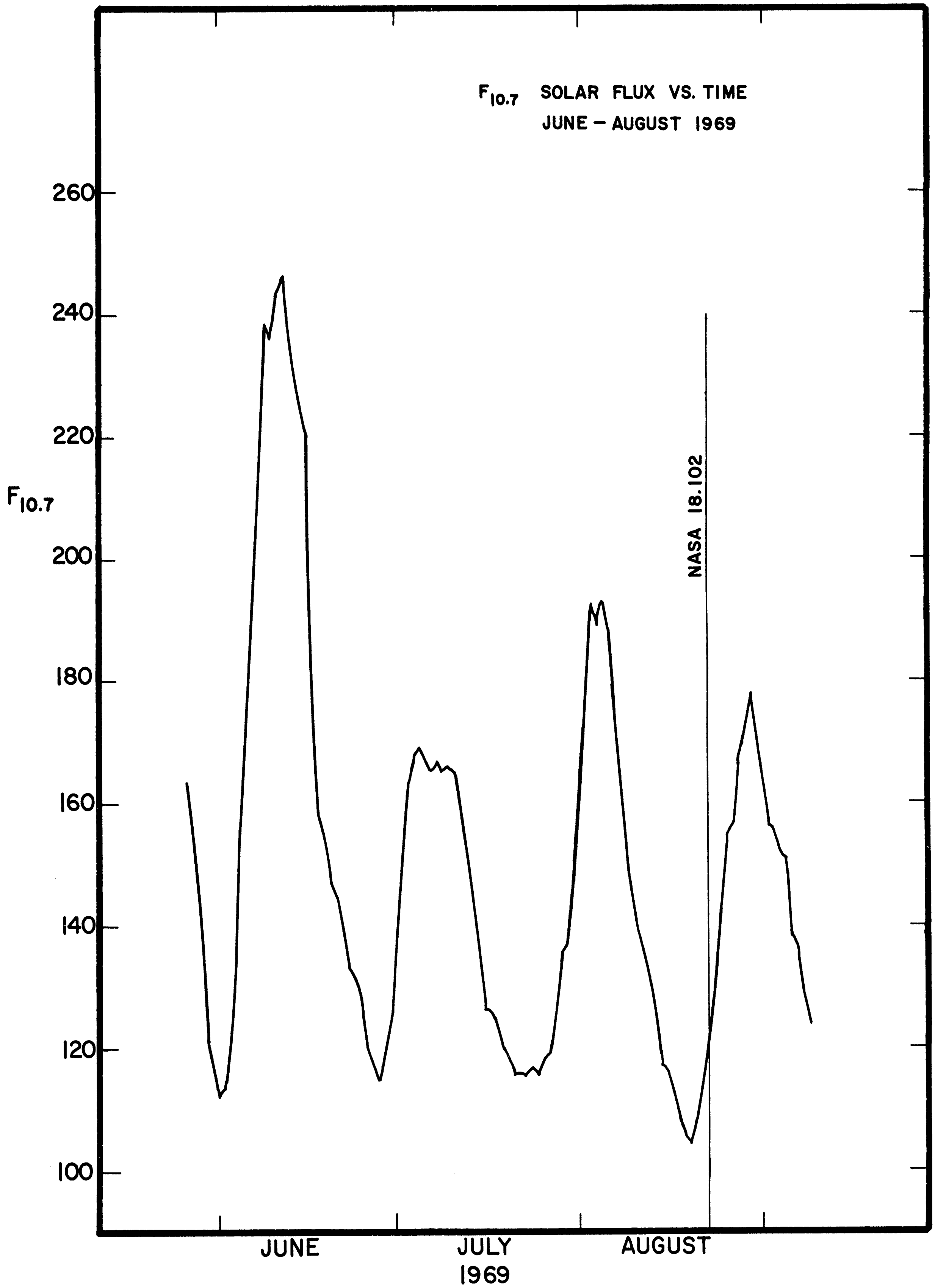

Figure 16. Solar flux at 10.7 cm wavelength.

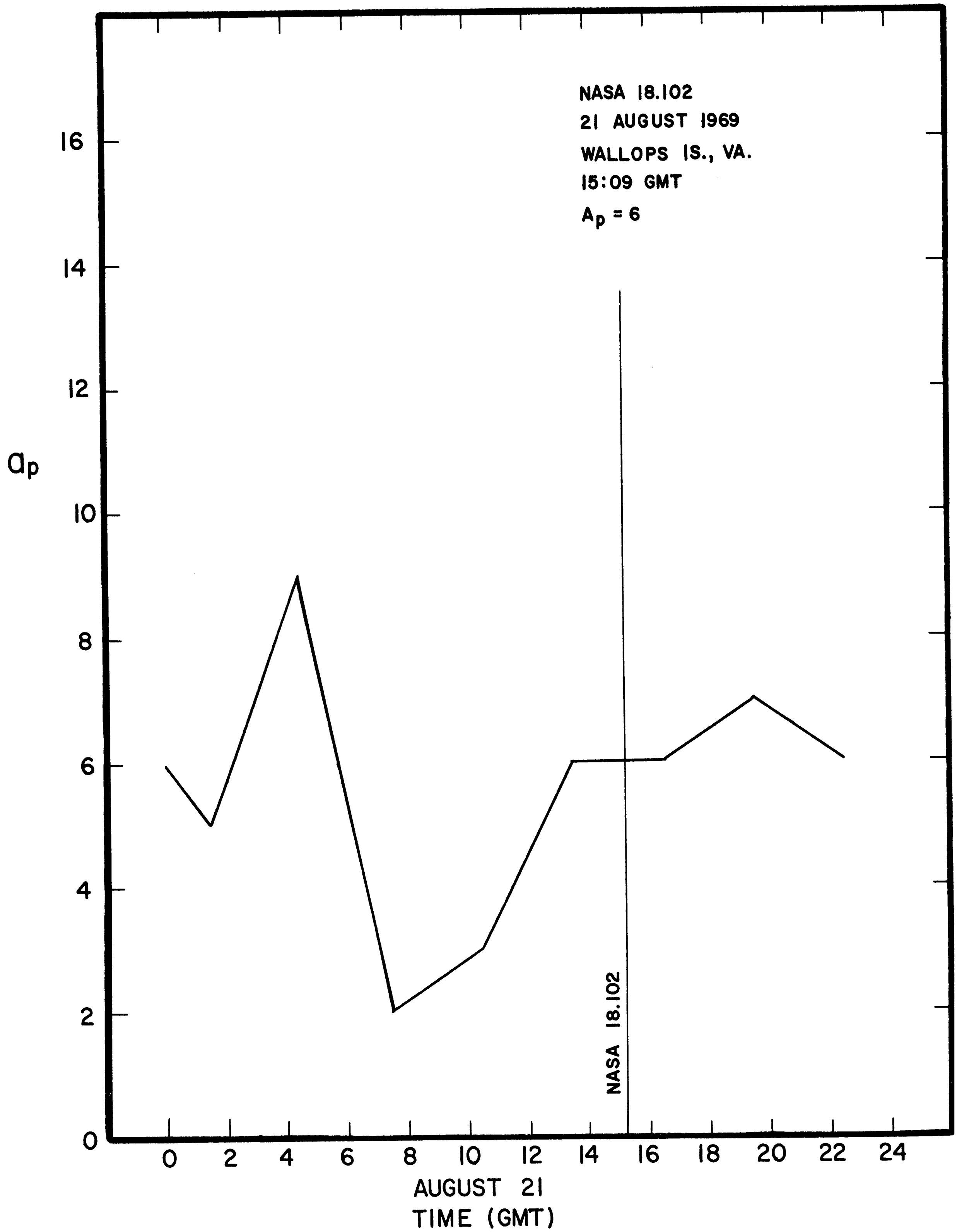

Figure 17. Three-hour geomagnetic activity index (a_p).

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