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 18.53 THERMOSPHERE PROBE EXPERIMENT

Prepared on behalf of the project by

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ORA Project 07065

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ACKNOWLEDGMENTS

The launching of NASA 18.53 was one of a series conducted during an expedition to Puerto Rico. The launch facilities at Mar Chiquita were set up and operated by personnel from NASA, Wallops Station, under the direction of Mr. Robert Long. The launchings were coordinated with the Arecibo Ionosphere Observatory under the direction of Dr. H. C. Carlson.

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 NASA 18.53 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
Mahajan, K. K.	Scientist
Pharo, M. W., III	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

LIST OF ILLUSTRATIONS (Concluded)

1. INTRODUCTION

The results of the launching of NASA 18.53, 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. 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 18.53 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), an ion spectrometer, and two lunar sensors. A general description of the payload kinematics, the orientation analysis, and the techniques for the reduction and analysis of the data is given by Taeusch, Carignan, Niemann, and Nagy (1965) and by Carter (1968).

Because of a failure of the radar tracking, no velocity or positional data were acquired for this flight. The complete loss of trajectory data precluded an absolute determination of several parameters important in the reduction of the data. However, the raw atmospheric data acquired were of excellent quality and were reduced to the results presented herein by using an estimated trajectory. The trajectory estimates used in this reduction were based on the shape of the raw data obtained from the flight and on much previous experience with the performance of the TP in a Nike-Tomahawk sounding rocket.

The omegatron data were reduced at SPRL and are discussed in the present report. The ion spectrometer data and the electron temperature probe data were reduced at GSFC and are not discussed here.

2. GENERAL FLIGHT INFORMATION

The general flight information for NASA 18.53 is listed below. Table I gives the flight times and altitudes of significant events which occurred during the flight. As mentioned previously, all altitude parameters are estimated.

Launch Date:	17 March 1968
Launch Time:	07:30:01.110 GMT, 03:30:01.110 Local
Location:	Puerto Rico
	Latitude: 18°28'57.41" N
	Longitude: 66°26'20.06" W
Apogee Parameters:	
Altitude:	295.16 km (est.)
Horizontal Velocity:	389.36 m/sec (est.)
Flight Time:	266.00 sec (est.)
TP Motion:	
Tumble Period:	2.97 sec
Roll Rate:	181.7 deg/sec

TABLE I

TABLE OF EVENTS

(NASA 18.53)

Event	Flight Time (sec)	Altitude (km)
Lift-off	0	0
1st Stage Burnout	3.5 (est.)	1.3 (est.)
2nd Stage Ignition	12.0 (est.)	7.0 (est.)
2nd Stage Burnout	21.0 (est.)	20.0 (est.)
Despin	44.2 (est.)	73.2 (est.)
TP Ejection	46.2	77.0 (est.)
Omegatron Breakoff	78.6	136.7 (est.)
Omegatron Filament On, M28	81.2	141.1 (est.)
Peak Altitude	266.00 (est.)	295.16 (est.)
L.O.S.	508.0	--

3. LAUNCH VEHICLE

The NASA 18.53 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 92.6 in. long and weighed 167 lb, including despin and adapter modules, made the total vehicle 378.9 in. long with a gross lift-off weight of 2022 lb. The vehicle is illustrated in Figure 1.

The launch vehicle appeared to perform without any problems and reached an estimated summit altitude of about 295 km at about 266 sec of flight time.

ROCKET NO. 18.53

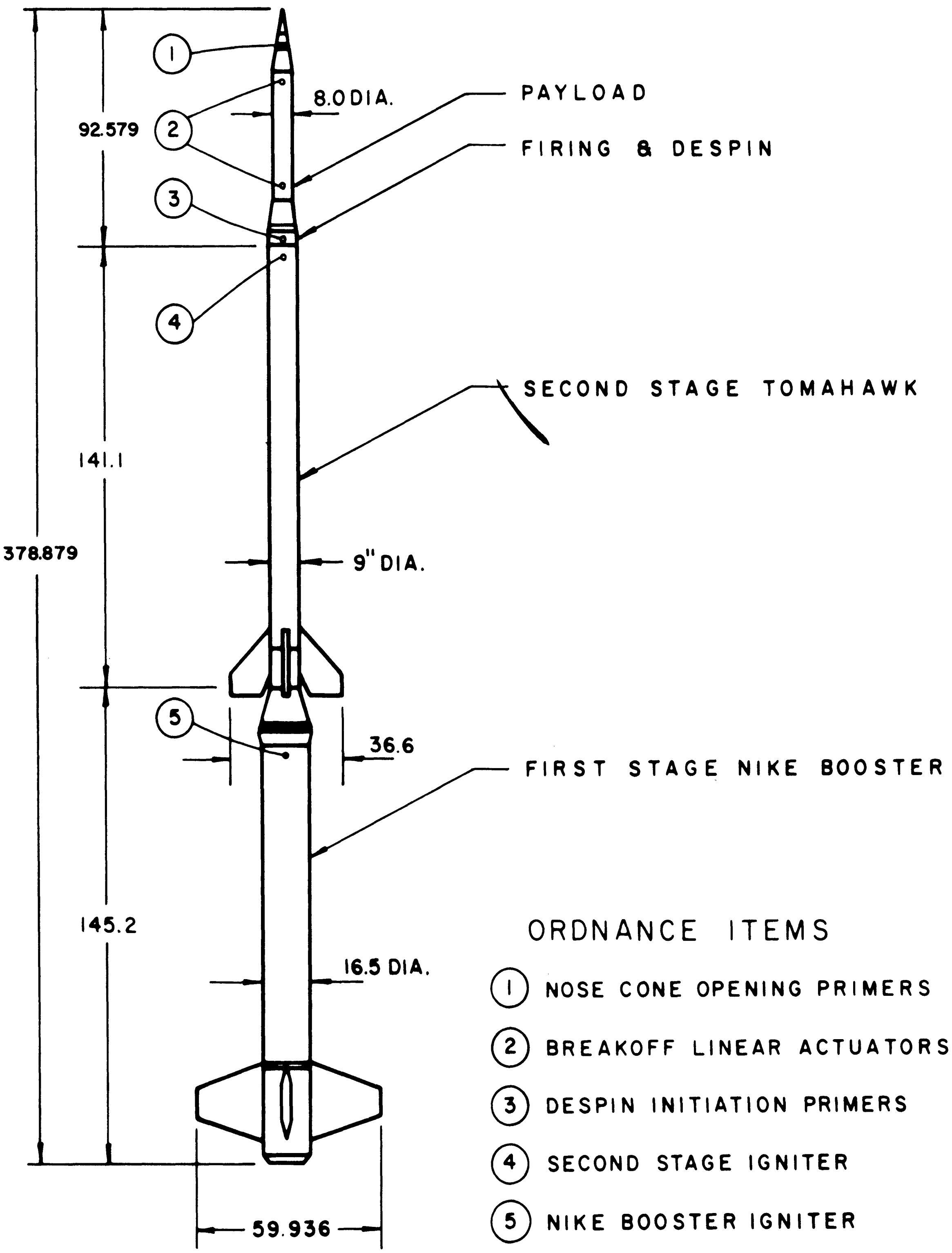

Figure 1. Nike-Tomahawk dimensions.

4. NOSE CONE

A diagram of the NASA 18.53 payload including the nose cone, the despin mechanism, and the adapter section is shown in Figure 2. An assembly drawing of the 8-in. nose cone is given in Figure 3.

The payload was despun at about 73 km altitude (44 sec after launch), and ejection began at about 77 km (46 sec after launch). The ejection system was designed for a tumble period of 4 sec by using a 2.5 lb Neg'ator* force and by limiting the travel of the plunger to 1.0 in. (Carter, 1968). The omegatron breakoff device was removed at about 137 km (79 sec after launch), and the omegatron filament was turned on approximately 2 sec later.

*Neg'ator is a trade name.

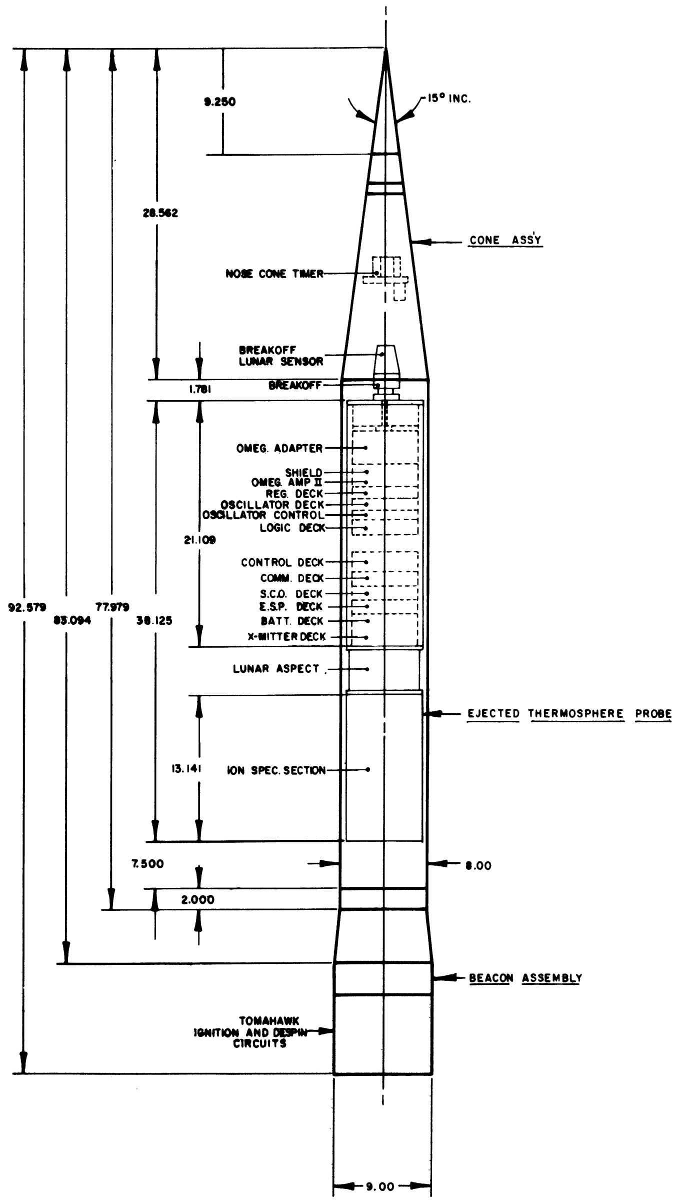

Figure 2. Thermosphere probe instrumentation design.

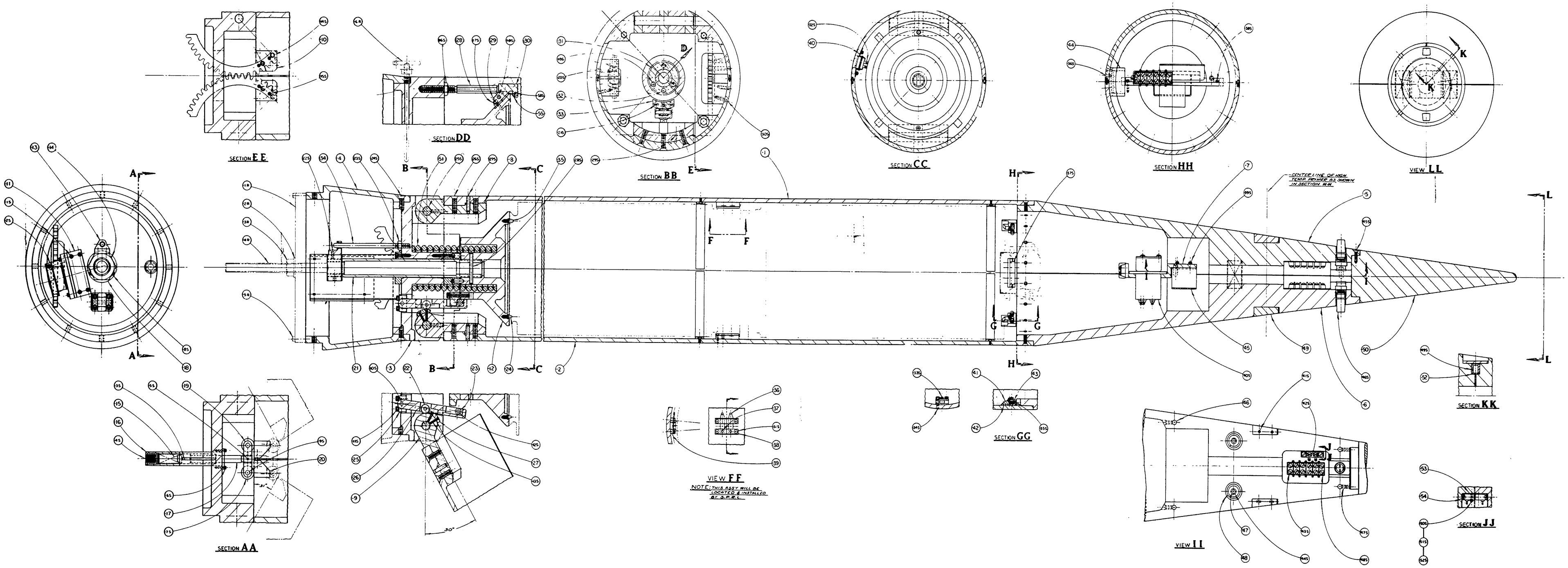

Figure 3. Assembly drawing, 8-in. nose cone.

5. THE THERMOSPHERE PROBE (TP)

The TP used for the NASA 18.53 payload was a cylinder 38.1 in. long and 7.25 in. in diameter and weighed 72.6 lb. The major instrumentation of this payload included an Omegatron II mass analyzer, an electron temperature probe, and an ion spectrometer experiment. Supporting instrumentation included a lunar aspect sensor for use in determining the attitude of the TP. The diagram in Figure 2 shows the location of instrumentation and supporting electronics in the nose cone. Figure 4 is the system block diagram.

5.1. OMEGATRON

The omegatron (OM II) used in the payload is a new design based on the standard omegatron described by Niemann and Kennedy (1966). The new design 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 5. The calibration of the NASA 18.53 omegatron, performed at SPRL during January 1968, is shown in Figure 6.

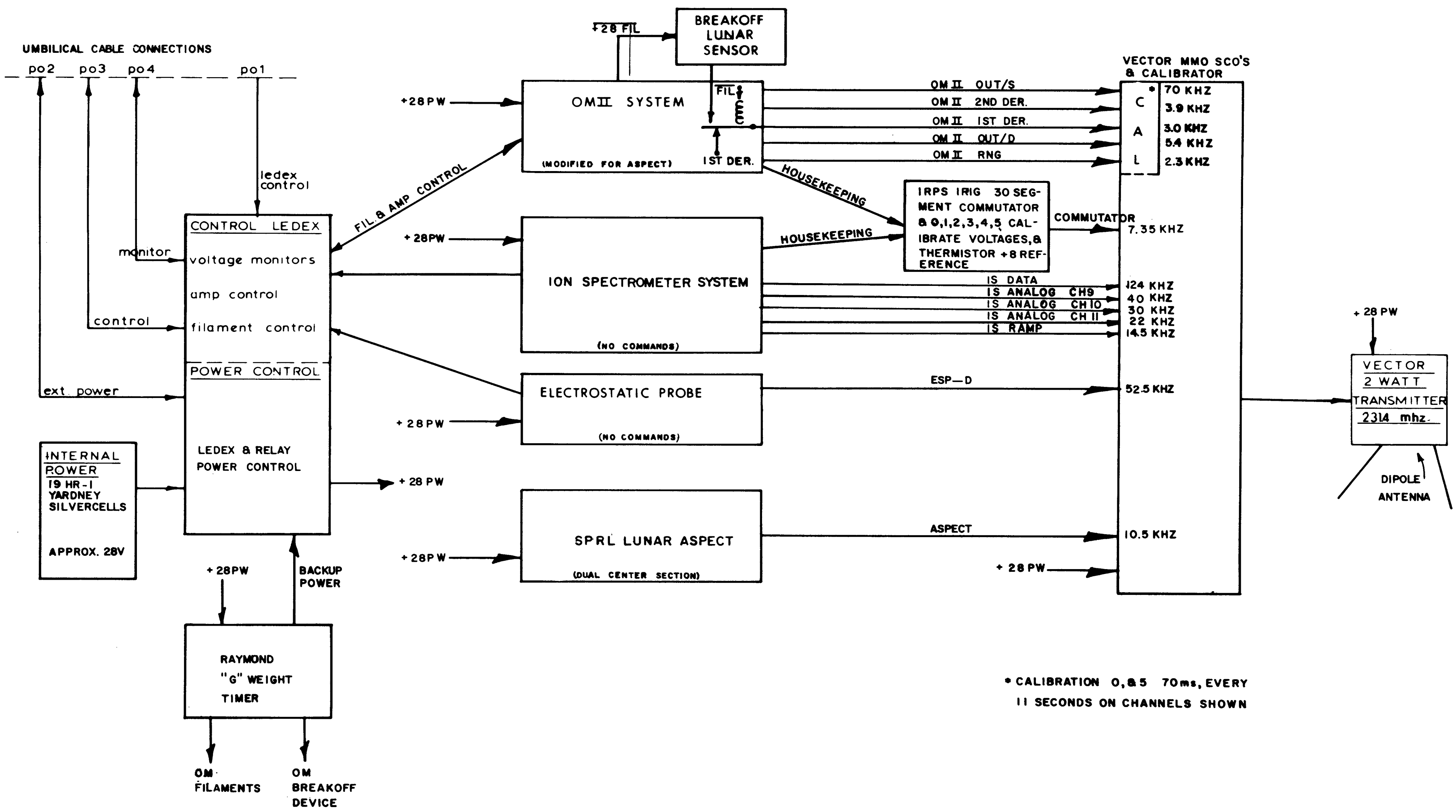

Figure 4. Thermosphere probe system block diagram.

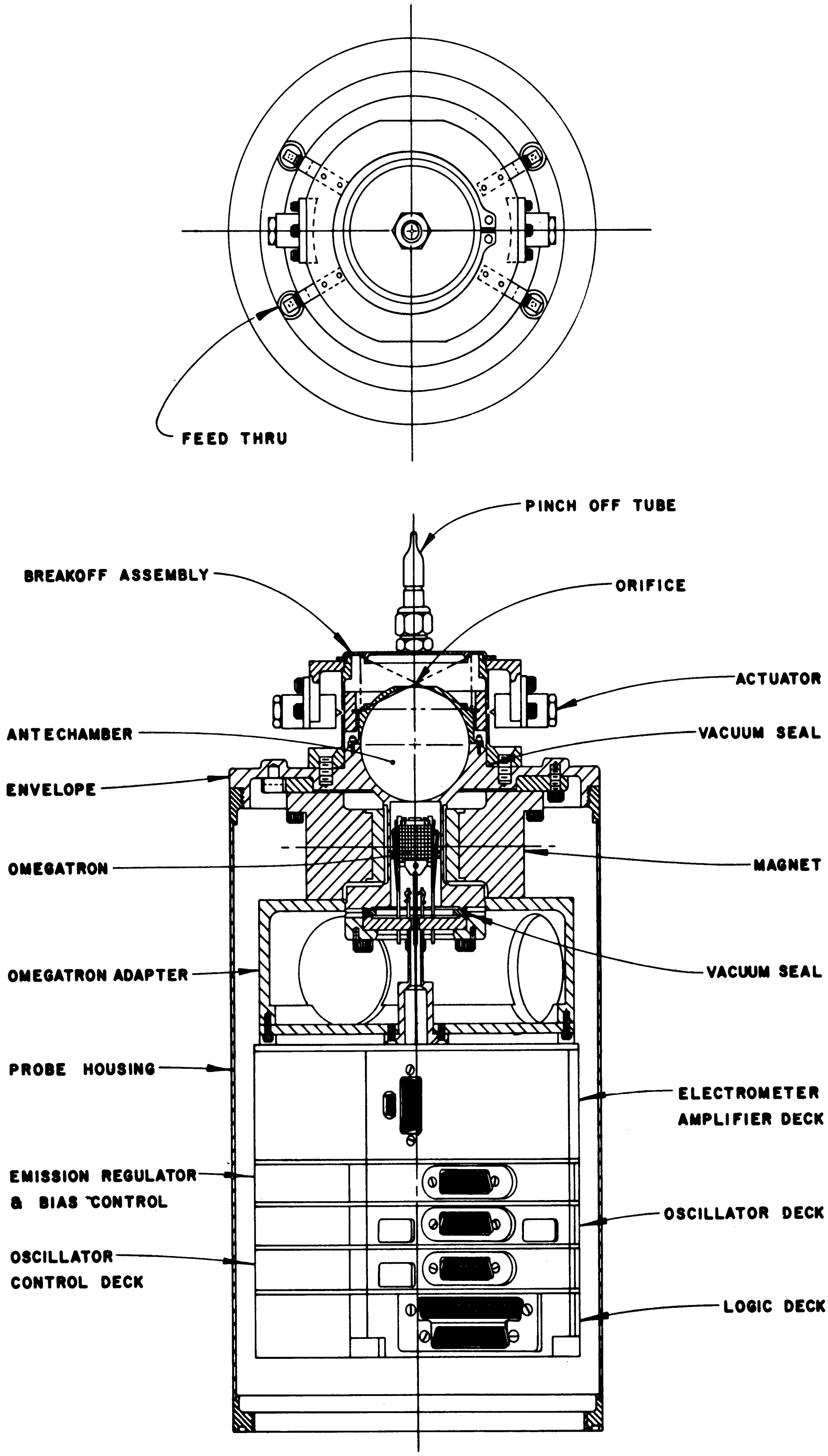

Figure 5. Omegatron II.

TABLE II

OMEGATRON DATA

(NASA 18.53)

Omegatron Gauge Parameters	OM II
Beam Current:	2.00 μA
Electron Collector Bias:	74.59 V
Filament Bias:	-91.55 V
Cage Bias:	- 0.20 V
Top Bias:	- 0.59 V
RF Amplitude, Mass 28:	4.20 V_{p-p}
RF Frequency, Mass 28:	141.54 kHz
Monitors	
Filament	
OFF:	0.12 V
ON:	3.46 V
Beam	
OFF:	0.65 V
ON:	4.38 V
Thermistor Pressure (zero pressure)	
Filament OFF:	1.83 V
Filament ON:	1.74 V
Bias:	3.89 V
RF:	3.87 V
Calibration	
Normalized N_2 Sensitivity:	2.54×10^{-5} A/torr

TABLE II (Concluded)

Electrometer Amplifier, OM II

OUT/S, Gain: -1.000

Range	Range Indicator	Range Resistor	Mass 28 ZPV	Offset
1-1	0.87 V	9.63×10^{11} Ω	3.02 V	+ 3.0034
1-2	1.17 V	9.63×10^{11} Ω	3.02 V	- 0.9795
1-3	1.46 V	9.63×10^{11} Ω	3.02 V	- 4.9540
1-4	1.77 V	9.63×10^{11} Ω	3.02 V	- 8.9266
1-5	2.06 V	9.63×10^{11} Ω	3.02 V	-12.9055
1-6	2.35 V	9.63×10^{11} Ω	3.02 V	-16.8208
1-7	2.65 V	9.63×10^{11} Ω	3.02 V	-20.8445
2-1	2.90 V	6.67×10^{10} Ω	3.01 V	+ 3.0034
2-2	3.14 V	6.67×10^{10} Ω	3.01 V	- 0.9795
2-3	3.47 V	6.67×10^{10} Ω	3.01 V	- 4.9540
2-4	3.78 V	6.67×10^{10} Ω	3.01 V	- 8.9266
2-5	4.09 V	6.67×10^{10} Ω	3.01 V	-12.9055
2-6	4.38 V	6.67×10^{10} Ω	3.01 V	-16.8208
2-7	4.66 V	6.67×10^{10} Ω	3.01 V	-20.8445

OUT/D, Gain: -0.25015

Range	Range Indicator	Range Resistor	Mass 28 ZPV	Offset
1	0.87 V	9.63×10^{11} Ω	0.017 V	- 0.0150
2	2.88 V	6.67×10^{10} Ω	0.014 V	- 0.0150

Miscellaneous

+28 power current all on:	460 mA
Preflight gauge pressure (N_2):	3×10^{-4} torr
Magnetic field strength:	2600 gauss

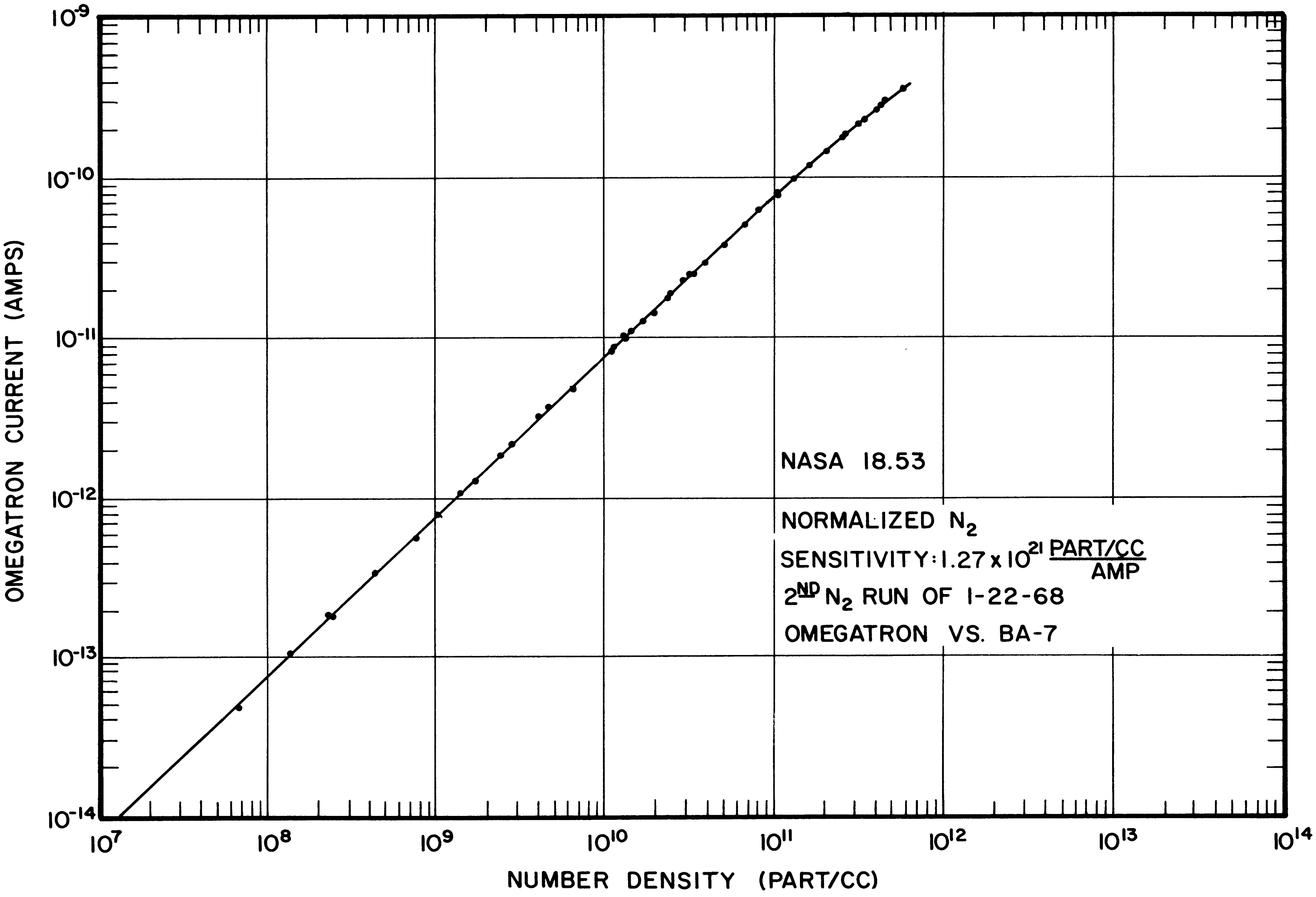

Figure 6. Final calibration of the omegatron.

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. A typical probe is shown in Figure 7. Probe 1, for this payload, was stainless steel and probe 2 was a platinum-iridium alloy.

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 8. The pertinent system parameters follow.

(a) Input Power

2.26 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 V/sec
Low ΔV	24 V/sec
Period	125 msec

(d) Output

Voltage	-0.68 V to + 5.8 V
Resistance	2600 Ω
Bias Level	1.0 V

(e) System Calibration

Occurrence of calibration every 31.5 sec for a duration of 750 m sec.

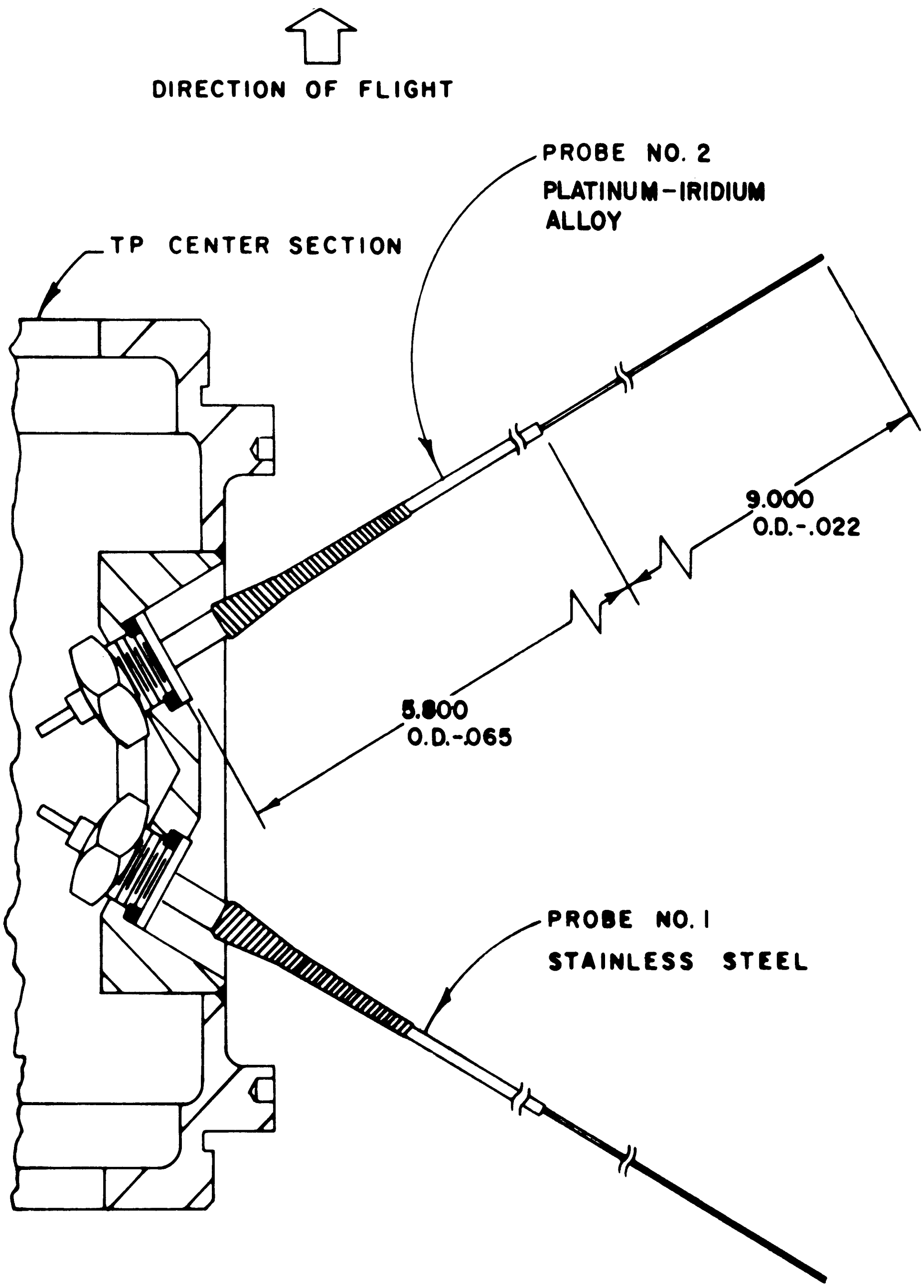

Figure 7. ETDP mounting configuration.

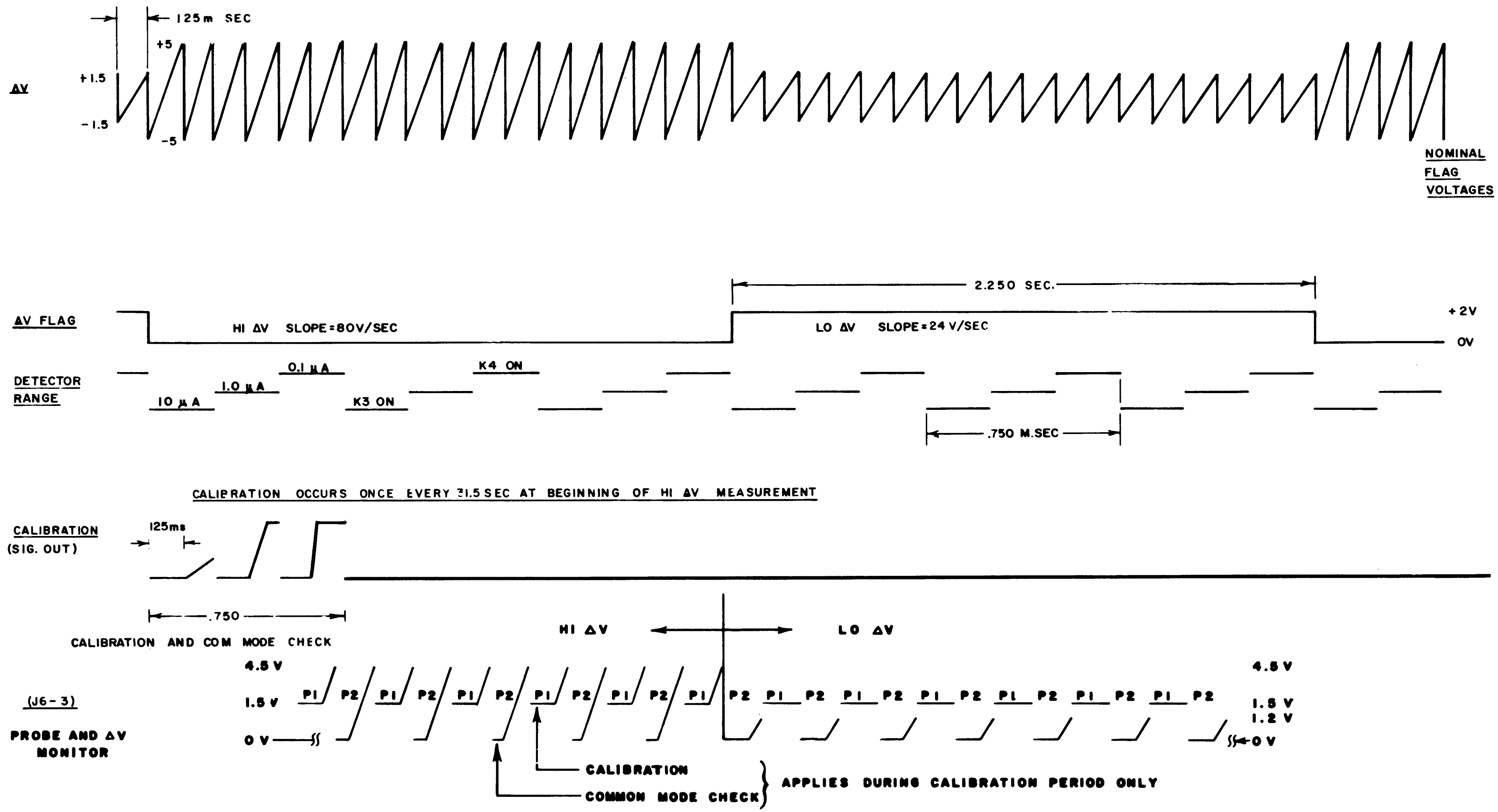

Figure 8. ETDP system timing and output format.

5.3. SUPPORT MEASUREMENTS AND INSTRUMENTATION

5.3.1. Aspect Determination System

The NASA 18.53 TP utilized two lunar sensor systems. One system, a new design, which was located in the center of the TP body, functioned satisfactorily throughout the flight. The other was the standard design identical to those used on previous nighttime shots with the difference that it was located on the omegatron breakoff device because of the lack of space at either end of the probe. Consequently, the standard system functioned only between ejection and breakoff and was used as a check on the new aspect system. The attitude of the TP was determined by using the method of referencing the moon vector and the estimated velocity vector (Carter, 1968). The resulting minimum angle of attack is plotted versus altitude in Figure 9.

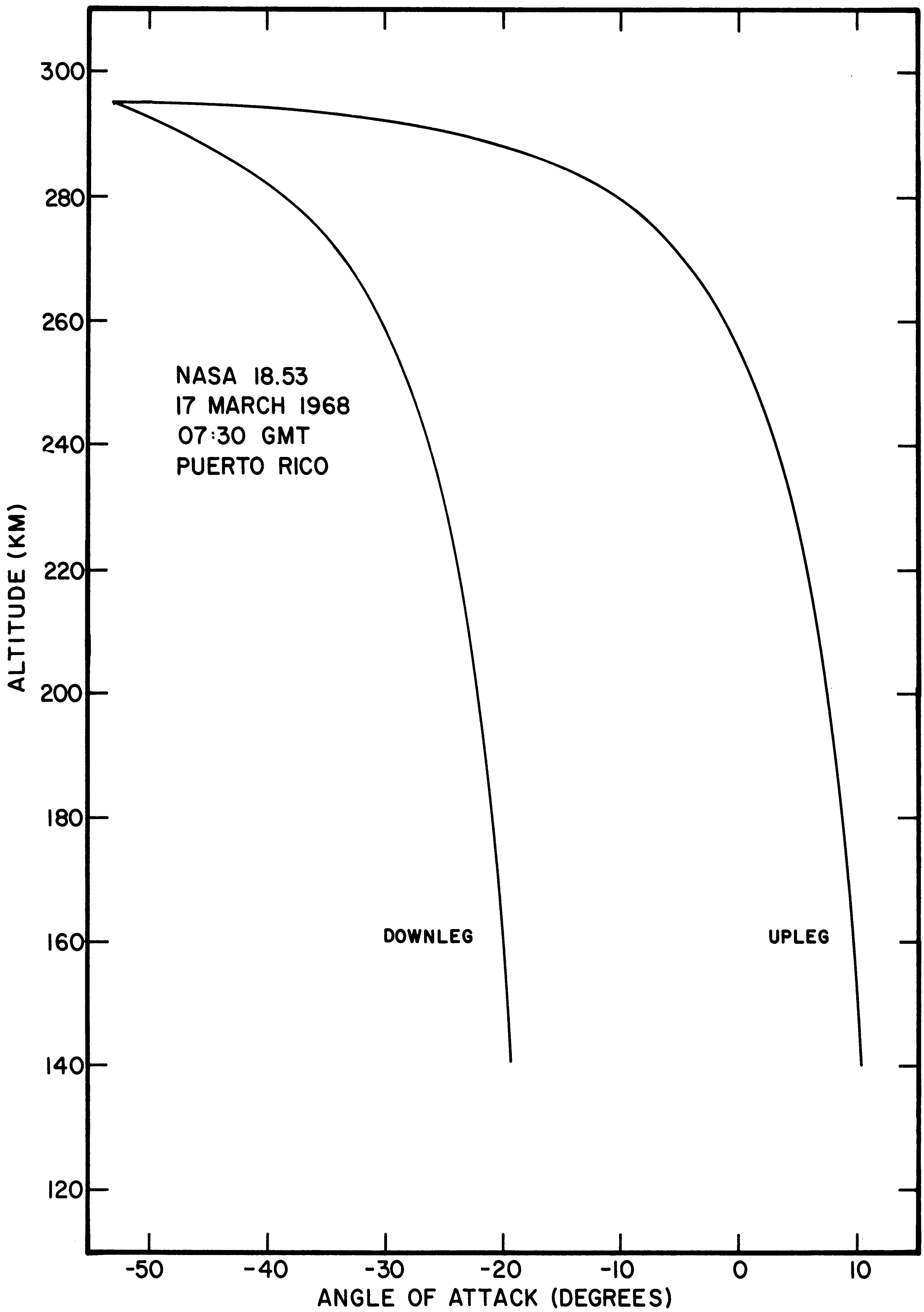

Figure 9. Minimum angle of attack vs. altitude.

5.3.2. Telemetry

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

Transmitter: Driver TRPT-251RBO, Serial No. 512
Power Amplifier TRFP-2V, Serial No. 672

Subcarrier Channels (SCO Type TS58)

IRIG Band	Serial No.	Center Frequency	Function	Low Pass Filter Used
20	6083	124 kHz	IS Digital	2500 Hz CA
18	4747	70 kHz	OM OUT/S	450 Hz CD
17	5926	52.5 kHz	ESP-D	790 Hz CD
16	7400	40 kHz	IS Analog 1	790 Hz CA
15	6769	30 kHz	IS Analog 2	450 Hz CA
14	4331	22 kHz	IS Analog 3	330 Hz CA
13	6032	14.5 kHz	IS Ramp	220 Hz CA
12	7277	10.5 kHz	Aspect	450 Hz CA
11	6010	7.35 kHz	Commutator	120 Hz CD
10	4160	5.4 kHz	OM OUT/D	80 Hz CD
9	5936	3.9 kHz	OM 2nd Der	60 Hz CD
8	5039	3.0 kHz	OM 1st Der	45 Hz CD
7	4573	2.3 kHz	OM Range	35 Hz CD

Instrumentation power requirements totaled approximately 40 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 18.53

Segment Number		Segment Assignment
1		OUT/D
2		Filament Monitor
3		Emission Current Monitor
4		Bias Voltage Monitor
5		RF Voltage Monitor
6		Comparator Ramp Monitor
7		Sweep Voltage Monitor (Ion Spectrometer)
8		Internal Pressure Monitor
9		Thermistor-Gauge Temperature
10		Thermistor-Amplifier Temperature
11		Thermistor-Transmitter Temperature
12		Battery Voltage Monitor
13	Ion Spectrometer	Sweep Voltage Monitor
14	Ion Spectrometer	+14 Power Supply Voltage
15	Ion Spectrometer	RF Amplitude
16	Ion Spectrometer	G15 Monitor
17	Ion Spectrometer	Sweep Voltage Monitor
18	Ion Spectrometer	Thermistor 1
19	Ion Spectrometer	Thermistor 2
20	Ion Spectrometer	+10 Power Supply Voltage
21	Ion Spectrometer	-10 Power Supply Voltage
22	Ion Spectrometer	+ 3 Power Supply Voltage
23	Ion Spectrometer	Sweep Voltage Monitor
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 at the launch site by a mobile telemetry receiving station. 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 the housekeeping data were reduced by computer techniques from the magnetic tapes.

6.1. TRAJECTORY AND ASPECT

The reduction of TP data involves the use of a mass point trajectory program fitted to radar tracking data (Parker, 1962, and Carter, 1968). The program, which requires input parameters normally available from radar tracking, provides an accurate reconstruction of the flight path of the TP. Because of the failure of the radar tracking systems, most of these input parameters were not available. The information necessary to provide a trajectory consists of starting longitude, starting latitude, flight azimuth, time of peak altitude, peak altitude, and horizontal velocity. All but the first two of these parameters were unknown and had to be estimated.

An estimate for the time of peak altitude was perhaps the easiest to obtain. Examination of Δn_i versus time (Figure 13, and more exactly, Figure 10) indicated that the peak altitude occurs about 270 sec into the flight; however, angle of attack considerations might shift this value from the true time of peak altitude. Typically, the TP has a low angle of attack on the upleg and a higher value on the downleg, with rapidly changing values over the peak of the trajectory. If we remove the effect of angle of attack on Δn_i by using an assumed angle of attack variation similar to that of past flights over the peak, the peak shifts backward in time to about 266 sec (Figure 10). A confirmation of this value was obtained by examining a plot of gauge density at $\alpha = 90$ deg versus time. Since this plot of density versus time is for a constant α, the peak exhibited is very close to the true peak and occurs at 266 sec, as found previously. This value for the time of peak was considered reliable. The remaining parameters are much more difficult to obtain and are more uncertain.

The peak altitude was determined with some degree of confidence from considerations of the past performance of the Nike-Tomahawk launch vehicle (see Figure 11). Based on the history of vehicle performance and given a peak altitude time of 266 sec into the flight, the expected peak altitude for NASA 18.53 would be about 290 km. Data from the electron temperature probe experiment suggested the possibility of a peak altitude of 295 km. Thus the range of values from 290 to 295 km was used to attempt a reconstruction of the 18.53 trajectory.

From previous flights the range of horizontal velocities achieved was approximately 275 to 575 m/sec. This was the range of values considered possible in the case of the NASA 18.53 flight reduction procedure.

The standard reduction of TP data proceeds in three steps. First, a trajectory is determined; then an aspect solution is obtained from the trajectory and the aspect sensor data; and finally, to this information is added the time history of the internal density of the omegatron gauge. The result is a profile of the ambient density versus altitude. For NASA 18.53, after a trajectory was obtained, an aspect solution was attempted. The initial solutions were poor; improvements were made by changing the azimuth of the trajectory. For this series of flights the nominal launch azimuth was 325 deg. However, during the course of this analysis it was necessary to choose a trajectory azimuth of 330 deg in order to obtain self-consistency between the resulting trajectory and aspect solutions.

After a satisfactory aspect solution was obtained, an ambient density profile was calculated. If the shape of this profile was totally unreasonable, then the trajectory input parameters were revised and the procedure was repeated. This iterative approach was carried out many times. Because of the presence of three unknowns, convergence was slow. However, ambient densities eventually showed some promise; that is, upleg and downleg densities (excluding the usual geometry and thermal corrections) exhibited some degree of consistency. From this point on, minor variations were made in the peak altitude and horizontal velocity for improving the shape of the density profile.

This procedure was followed until the trajectory, the aspect solution, and the time history of the internal density of the omegatron combined to yield a compatible upleg and downleg density profile with respect to altitude. The final results, described in Sections 6.2 and 6.3 of the present report, including the atmospheric N_2 density and temperature profiles, were derived from the foregoing analysis utilizing the established trajectory and aspect solutions.

A tabulation of the final estimates of the trajectory parameters and angle of attack is given in Table III. A plot of angle of attack has already been given in Figure 9. Figure 12 shows the occurrence of significant events during the flight.

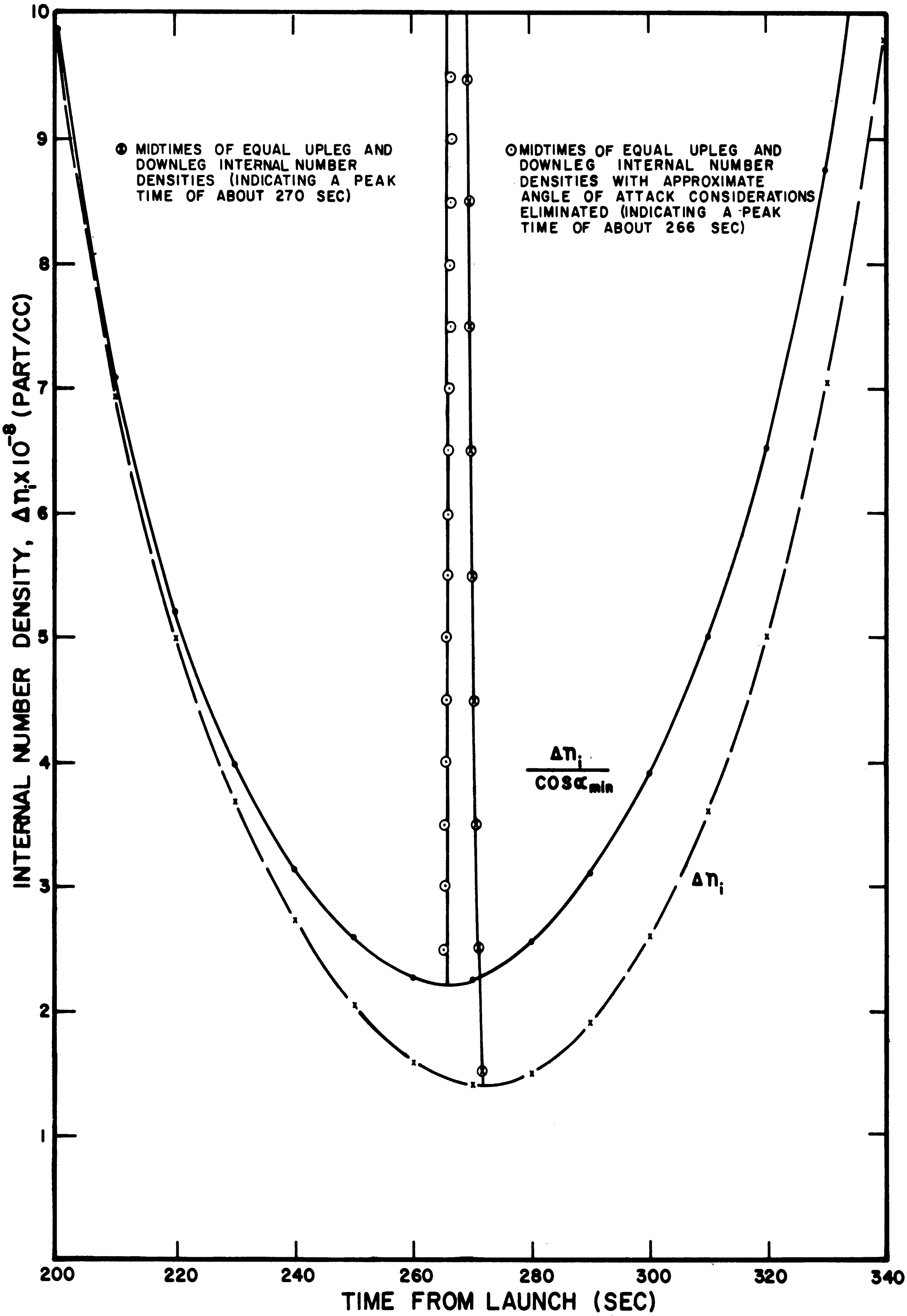

Figure 10. Determination of the time of peak altitude.

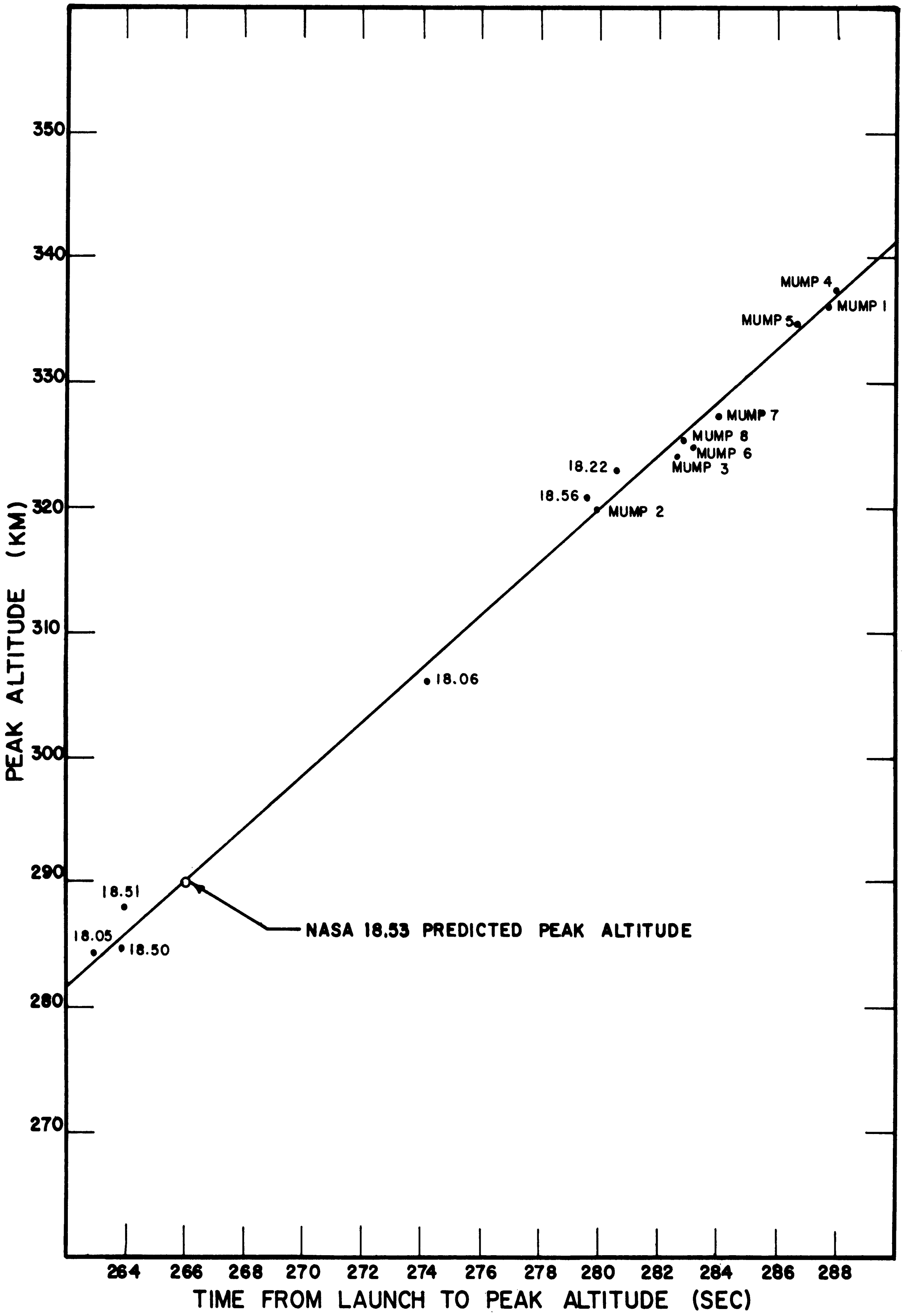

Figure 11. History of Nike-Tomahawk peak altitude vs. peak time from launch.

TABLE III

TRAJECTORY PARAMETERS

NASA 18.53

Time (sec from launch)	Altitude (km)	Total Velocity (m/sec)	Angle of Attack (deg)
60	103.36	1918.51	11.61
70	121.69	1826.02	11.07
80	139.07	1734.26	10.48
90	155.51	1643.23	9.82
100	171.02	1552.95	9.10
110	185.60	1463.43	8.29
120	199.26	1374.71	7.38
130	212.00	1286.84	6.36
140	223.81	1199.91	5.19
150	234.72	1114.00	3.84
160	244.71	1029.28	2.29
170	253.79	945.96	0.46
180	261.97	864.34	- 1.70
190	269.25	784.83	- 4.30
200	275.62	708.06	- 7.44
210	281.09	634.91	-11.30
220	285.67	566.69	-16.07
230	289.34	505.33	-21.97
240	292.12	453.52	-29.13
250	294.01	414.81	-37.36
260	295.00	393.03	-45.71
270	295.09	391.00	-52.10
280	294.30	409.01	-54.24
290	292.60	444.65	-52.19
300	290.01	494.16	-48.12
310	286.53	553.86	-43.76
320	282.14	620.89	-39.80
330	276.86	693.18	-36.40
340	270.68	769.32	-33.53
350	263.60	848.34	-31.12
360	255.61	929.59	-29.08
370	246.72	1012.60	-27.33
380	236.92	1097.06	-25.84
390	226.21	1182.75	-24.54
400	214.59	1269.49	-23.41
410	202.05	1357.19	-22.41
420	188.59	1445.74	-21.52
430	174.21	1535.11	-20.73
440	158.90	1625.25	-20.02
450	142.65	1716.14	-19.38
460	125.47	1807.76	-18.80
470	107.35	1900.11	-18.27
480	88.28	1993.19	-17.78

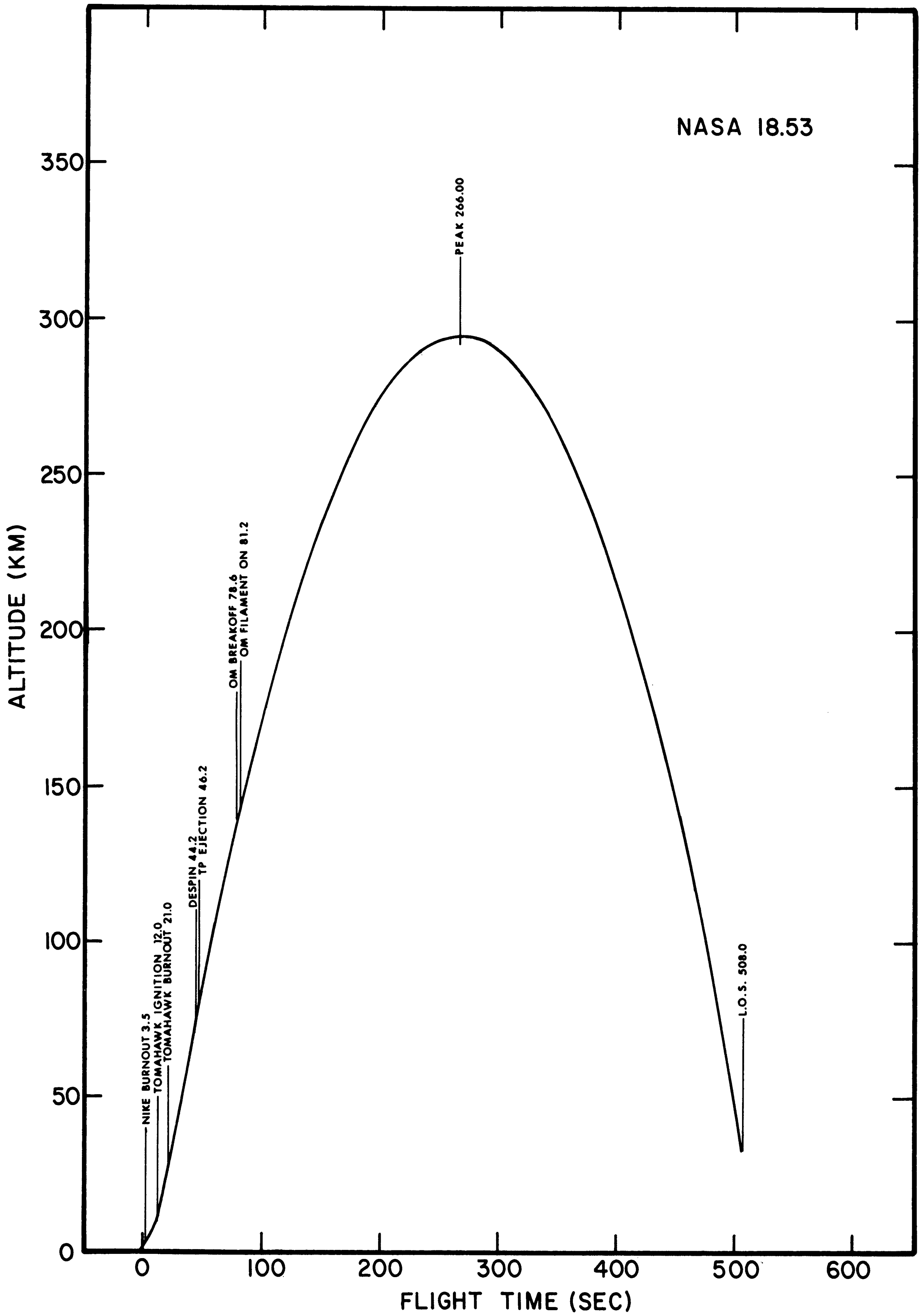

Figure 12. Sequence of events.

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., (1965a, 1965b), 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, $A \times \Delta I$, 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.

The internal gauge number density shown in Figure 13 (Δn_i) is the difference between the maximum (peak) omegatron gauge current and the minimum (background) gauge current converted (by the gauge sensitivity factor) to density units. 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. The gauge sensitivity is determined from calibration data obtained by standard techniques.

The most probable thermal speed of the particles inside the gauge, u_i, is computed by using the measured gauge wall temperature. Both V, the vehicle velocity with respect to the earth, and α_{min} are obtained from the estimated trajectory. The geometry correction factor, $K(S_o, \alpha)$, is determined from empirical and theoretical studies and is shown versus altitude in Figure 14.

The resulting ambient N_2 number density is shown in Figure 15 and is tabulated in Table IV.

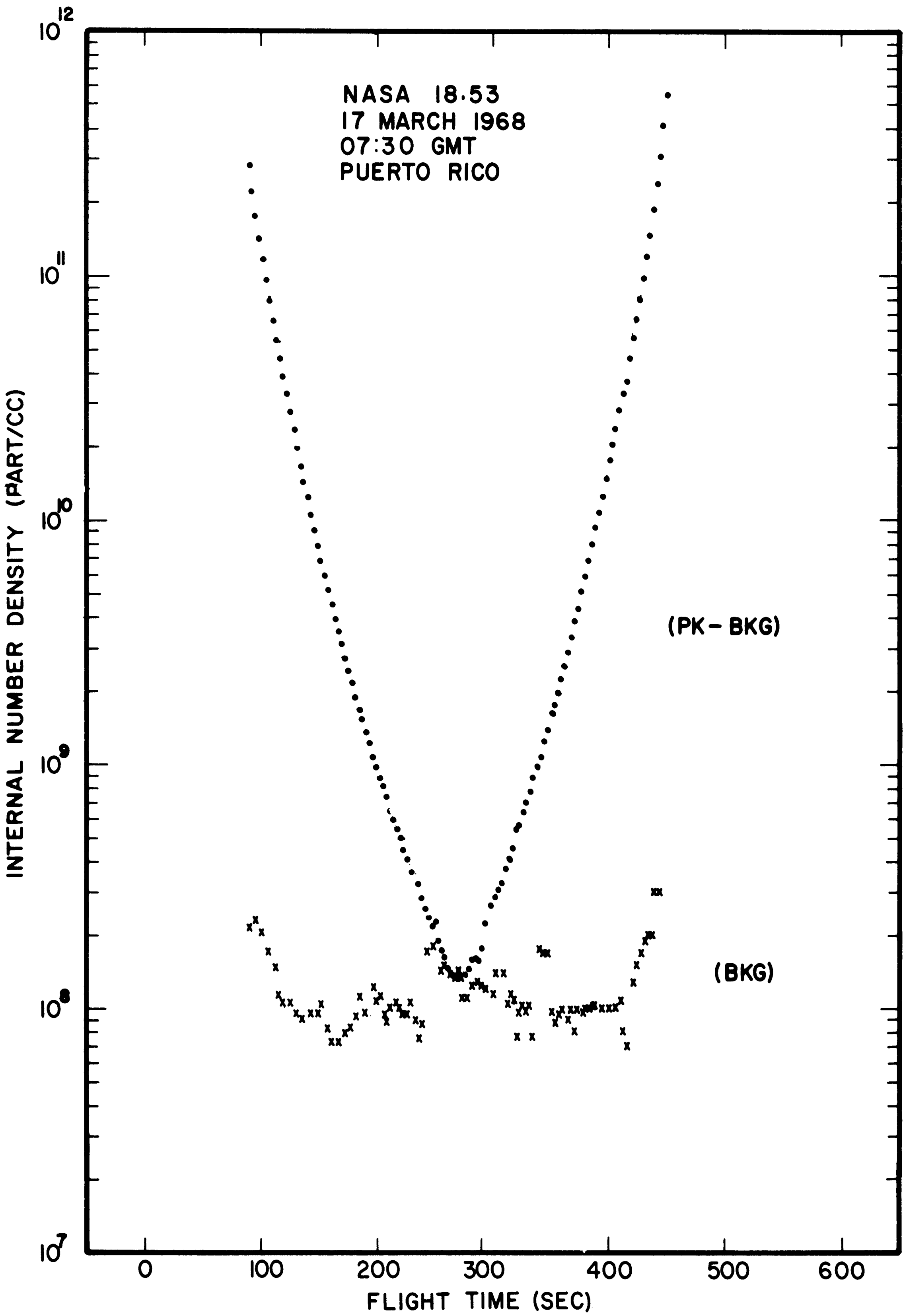

Figure 13. Omegatron current vs. flight time.

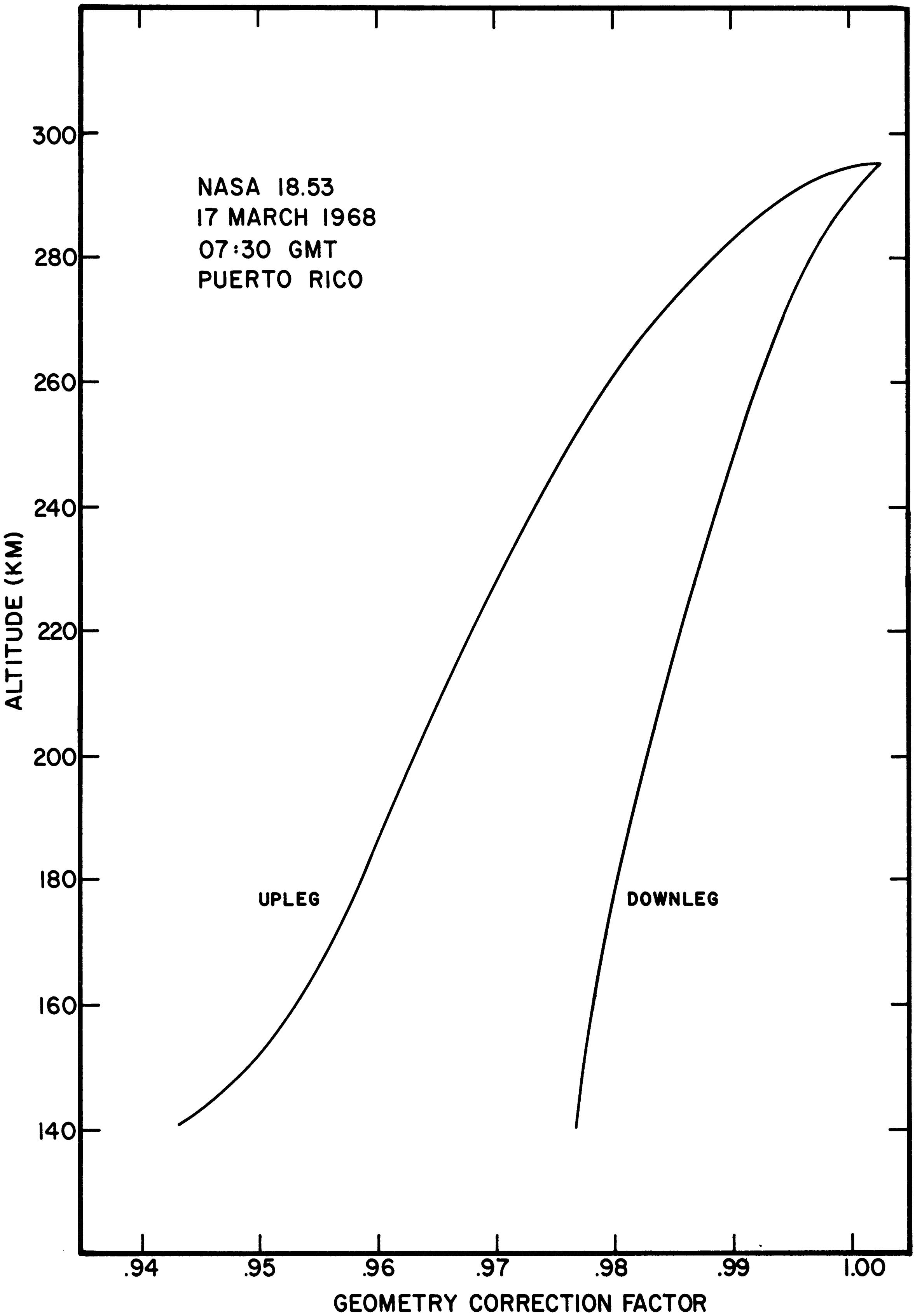

Figure 14. $K(S_o,\alpha)$ vs. altitude.

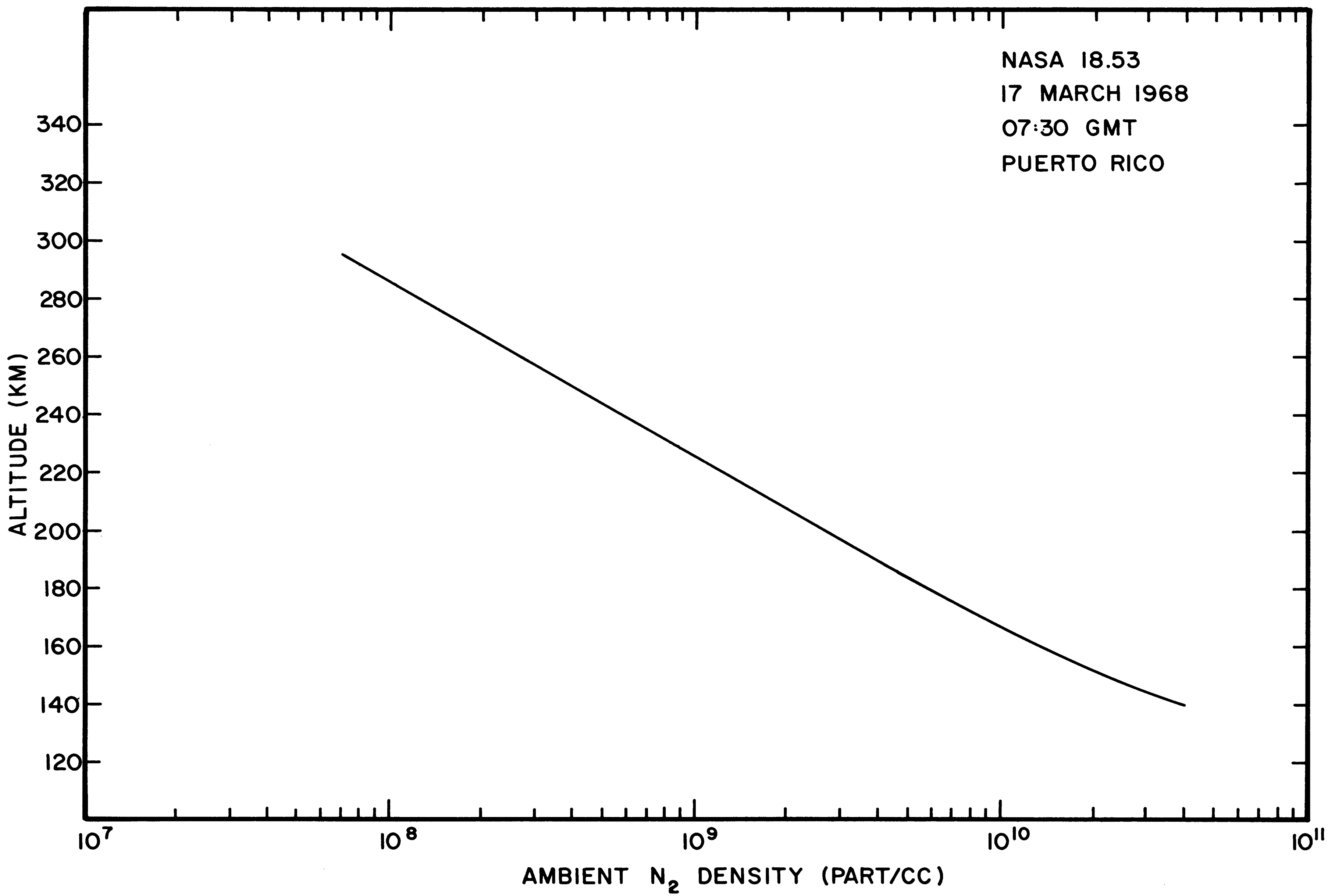

Figure 15. Ambient N_2 density vs. altitude.

TABLE IV

N_2 AMBIENT DENSITY DATA

NASA 18.53
17 March 1968
07:30 GMT
03:30 Local
Puerto Rico

Altitude* (km)	Temperature* (°K)	Density* (part/cc)
140	655	3.76×10^{10}
145	699	2.79
150	730	2.15
155	753	1.68
160	768	1.34
165	781	1.08×10^{10}
170	790	8.70×10^{9}
175	796	7.07
180	798	5.78
185	799	4.76
190	799	3.92
195	799	3.23
200	799	2.67
205	799	2.21
210	799	1.83
215	799	1.50
220	799	1.24
225	799	1.01×10^{9}
230	799	8.43×10^{8}
235	799	6.94
240	799	5.73
245	799	4.73
250	799	3.91
255	799	3.22
260	799	2.65
265	799	2.18
270	799	1.79
275	799	1.48
280	799	1.23
285	799	1.00×10^{8}
290	799	8.33×10^{7}
295	799	6.91×10^{7}

*All the listed information is subject to the qualification that it was derived from an estimated trajectory and aspect solution (see Section 6.1).

Fit parameters:

$T_\infty = 797°K$
$T_o = 651°K$
$P_b = 5.84 \times 10^{-6}$ torr
$\sigma = 8.52 \times 10^{-2}$

6.3. TEMPERATURE

The ambient temperature shown in Figure 16 and tabulated in Table IV 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_0), 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.

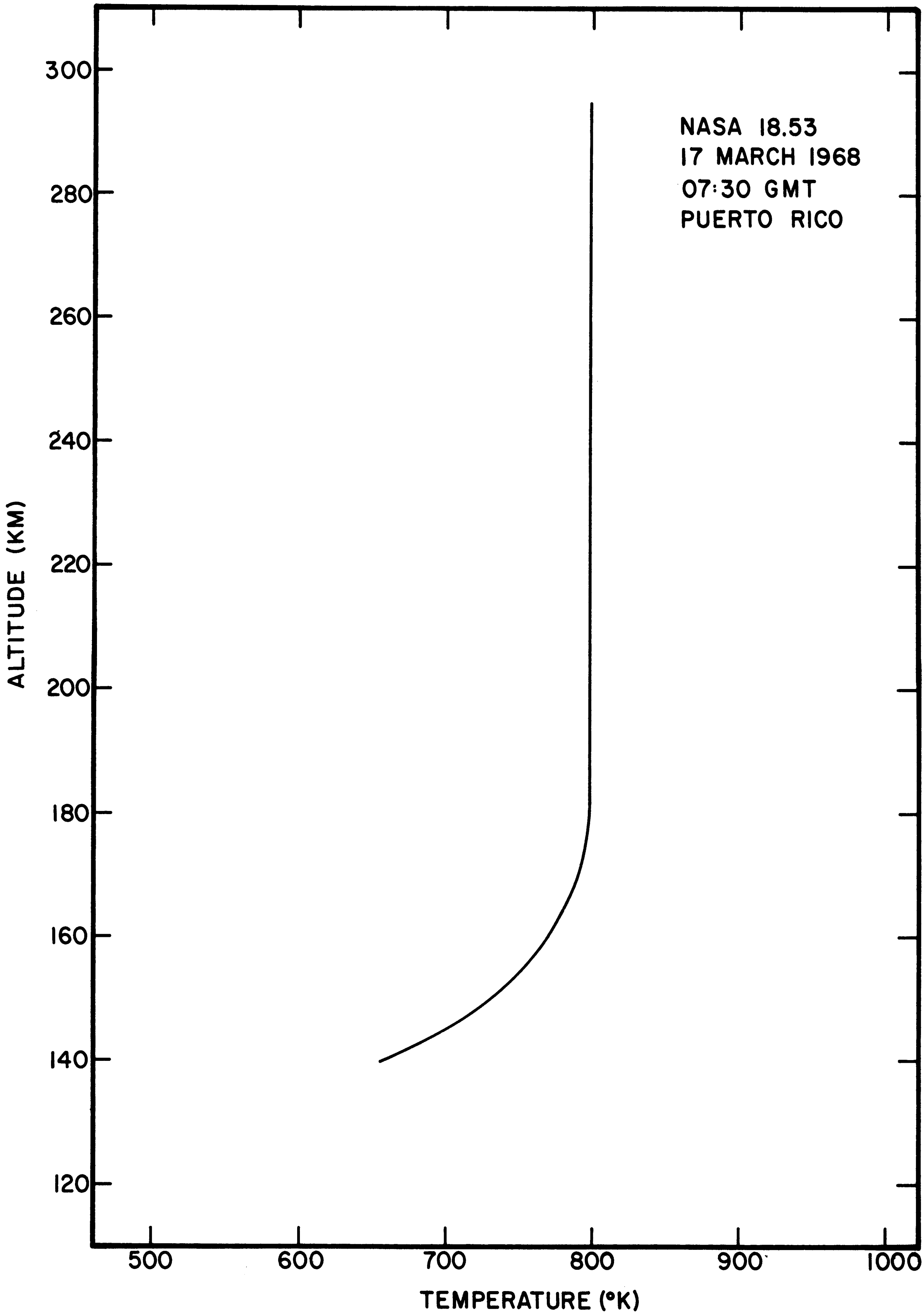

Figure 16. Neutral particle temperature vs. altitude.

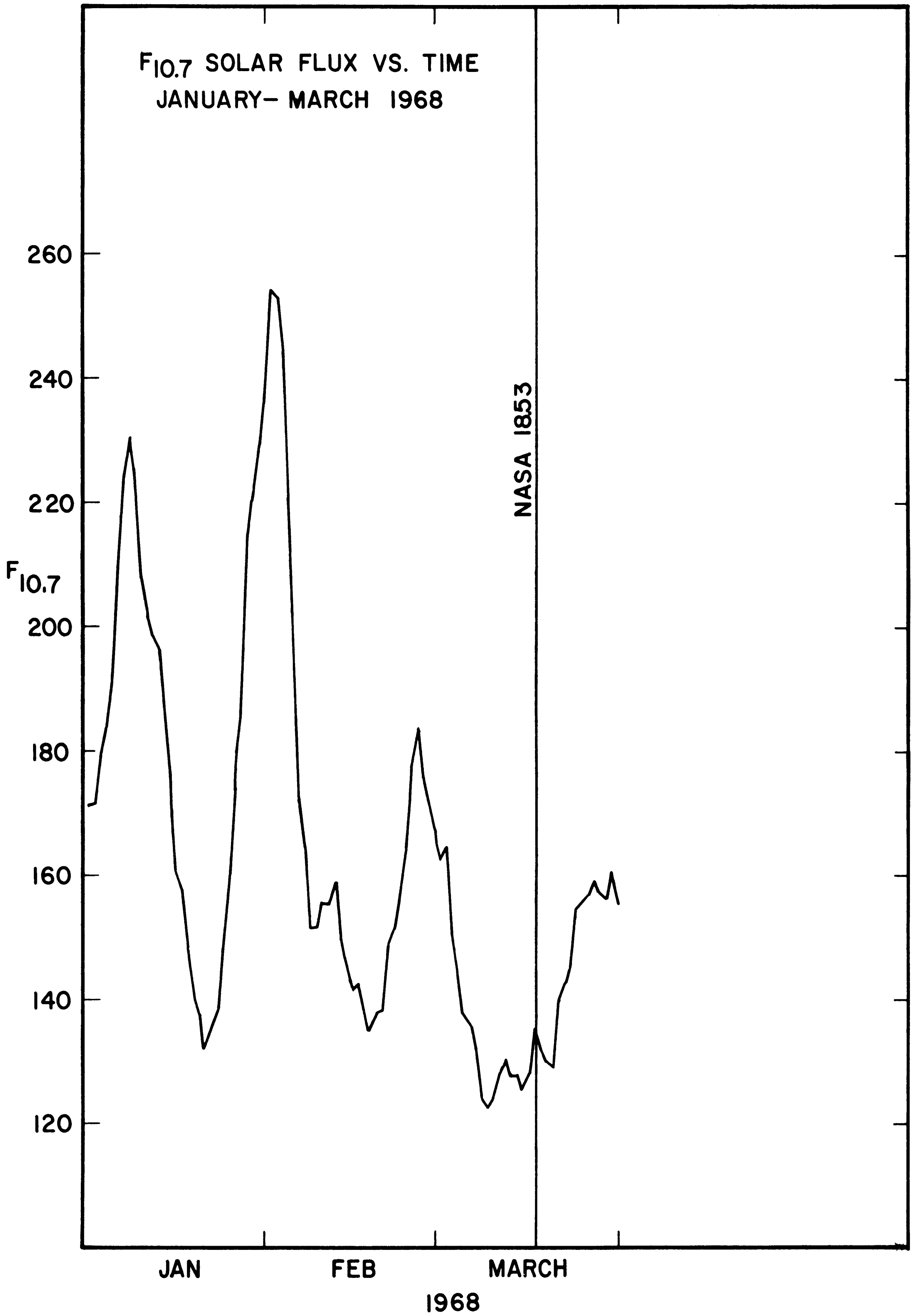

Figure 17. Solar flux at 10.7 cm wavelength.

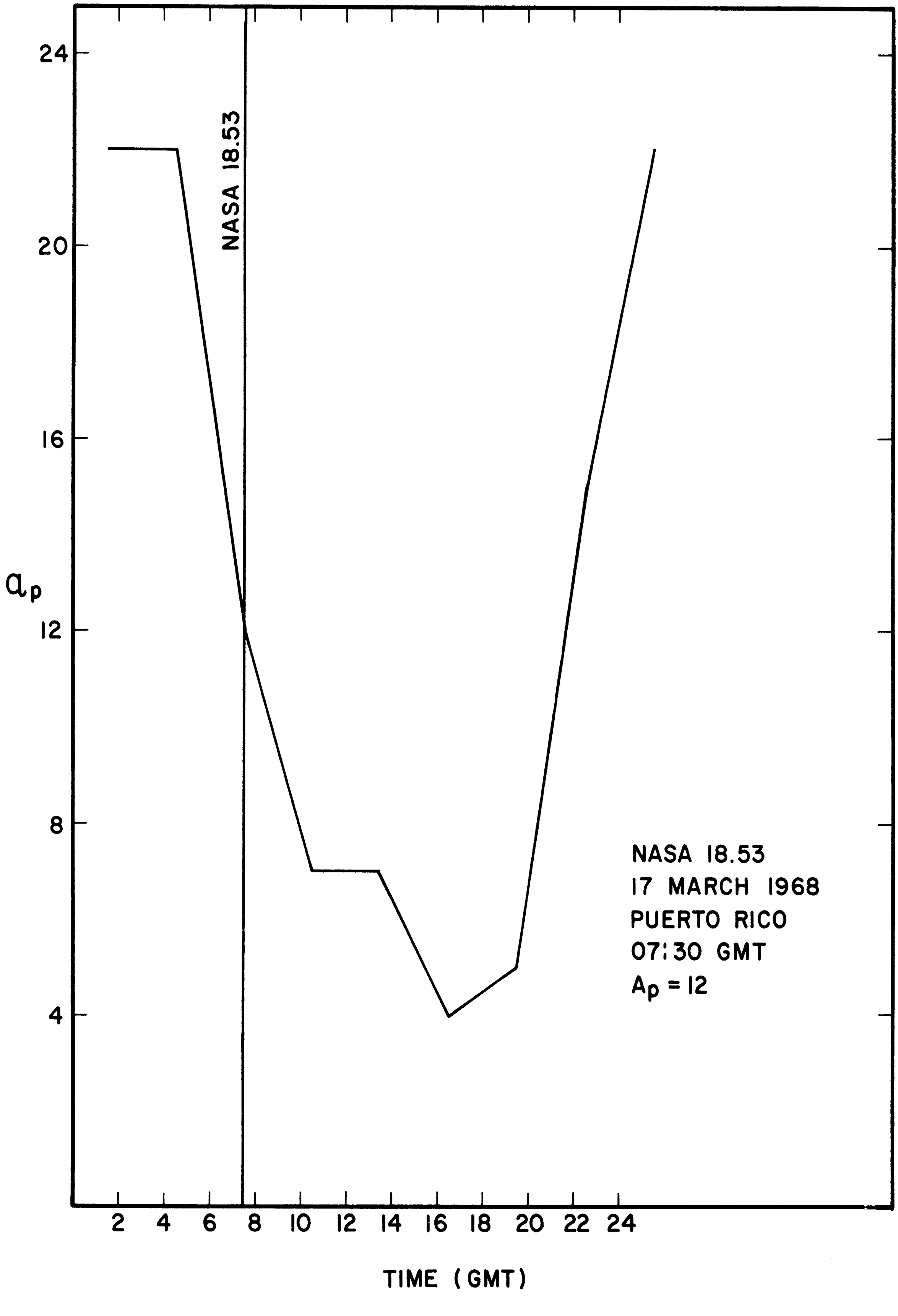

Figure 18. Three-hour geomagnetic activity index (a_p).

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