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3300-6001-RC000

TECHNICAL REPORT

TASK MSC/STL A-20

APOLLO MISSION SA 501
PRELIMINARY MISSION PROFILE (U)

NAS9-2938

22 FEBRUARY 1965

(NASA-CR-103858) APOLLO MISSION SA 501 PRELIMINARY MISSION PROFILE (TRW Space Technology Labs.) 86 p

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3300-6001-RC000
Total Pages:

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APOLLO MISSION SA 501
PRELIMINARY MISSION PROFILE (U)

22 FEBRUARY 1965

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER

Contract No. NAS 9-2938
Phase II (Apollo)

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FOREWORD

This report, which defines the Preliminary Mission Profile for Apollo Mission SA-501, is submitted by TRW Space Technology Laboratories (STL) to the NASA Manned Spacecraft Center in partial response to Task MSC / STL A - 20 (Establishment of Reference Trajectory for Apollo Mission SA-501) of the Apollo Mission Trajectory Centrol Program (Contract No. NAS9-2938, Phase II). This report is presented in two volumes. Volume I summarizes the mission objectives, the system constraints, and the input data for mission simulation and describes the mission profile. It presents pertinent data in both tabular and graph forms. Volume II contains the trajectory listing of the mission profile, along with the necessary print key.

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ILLUSTRATIONS (Continued)

TABLES

1. INTRODUCTION AND SUMMARY

1.1 PURPOSE

The Preliminary Mission Profile defined in this report is designed for the unmanned Apollo Mission SA-501. It is a combined launch vehicle and spacecraft trajectory profile that is intended to satisfy the mission's primary spacecraft objective (to obtain data on the thermal protection system under lunar entry conditions; Reference 1) without violating any of the launch vehicle and spacecraft ground rules and constraints applicable to the mission. It also satisfies the single-SPS-burn mode previously agreed upon by MSC and MSFC.

1.2 SCOPE

In addition to the spacecraft mission requirements, this volume of the report summarizes the input data used in simulation of the profile. It describes the major phases of the mission, gives the trajectory analysis for applicable phases, and presents time history data for pertinent trajectory parameters. It also presents the spacecraft rise and set times as seen from 19 tracking stations and the times of spacecraft entry into and exit from the earth shadow.

Volume II of this report will contain the trajectory listing of the mission profile.

The computer simulations of both the launch vehicle and spacecraft trajectories were characterized by simple propulsion system models and open loop steering (constant attitude and attitude rate commands). These simulations do not consider spacecraft attitude during orbital coast operations and entry, RCS propellant consumption, or detailed tracking coverage. These items are currently under evaluation and will be reported in later documentation on this mission.

1.3 PROFILE SUMMARY

Apollo Mission SA-501, currently planned for the first quarter of 1967, will be the first launch of the Saturn V vehicle with an Apollo spacecraft. For mission simulation, launch is assumed to occur at

13:00 GMT, January 1, from launch complex 39A of the Merritt Island Launch Area. In addition to giving a daylight launch, this time selection results in almost a full day of sunlight near Hawaii for the Command Module (CM) recovery operation.

Major events of the mission are illustrated in Figure 1-1. The mission has been divided into seven major phases:

1. Saturn V ascent to orbit
2. Earth parking orbit
3. S-IVB second burn
4. Earth intersecting coast
5. Service Module Propulsion System (SPS) burn
6. Pre-entry sequence
7. Atmospheric entry

The Saturn V launch phase includes the burn of the S-IC stage, the burn of the S-II stage, and a partial burn of the S-IVB stage. Thrust termination for the latter occurs at a 100 n mi circular parking orbit. After approximately two revolutions in the earth parking orbit and while in the vicinity of Cape Kennedy, the S-IVB is restarted and burns to nominal fuel depletion. This burn injects the spacecraft into an orbit with an apogee altitude of 7,467 n mi and an inertial flight path angle at entry into the earth's atmosphere (defined as 400,000 feet) of -7.35 degrees. This earth-intersecting orbit will permit successful entry and recovery of the CM in case of an SPS failure.

Approximately 1-1/2 hours after apogee and while being tracked by Carnarvon, the SPS is ignited, accelerating the spacecraft so that an inertial entry velocity of 36,333 ft/sec and an inertial entry flight path angle of -7.35 degrees are achieved. Following SPS cutoff, a pre-entry sequence is initiated while the spacecraft is still under coverage of Carnarvon tracking. This coverage is lost approximately 4-1/2 minutes after SPS burnout and atmospheric entry occurs about 7 minutes later. The spacecraft then flies a Nominal Undershoot Entry Trajectory over a 2500 n mi range and lands approximately 750 n mi due north of the Hawaiian Islands.

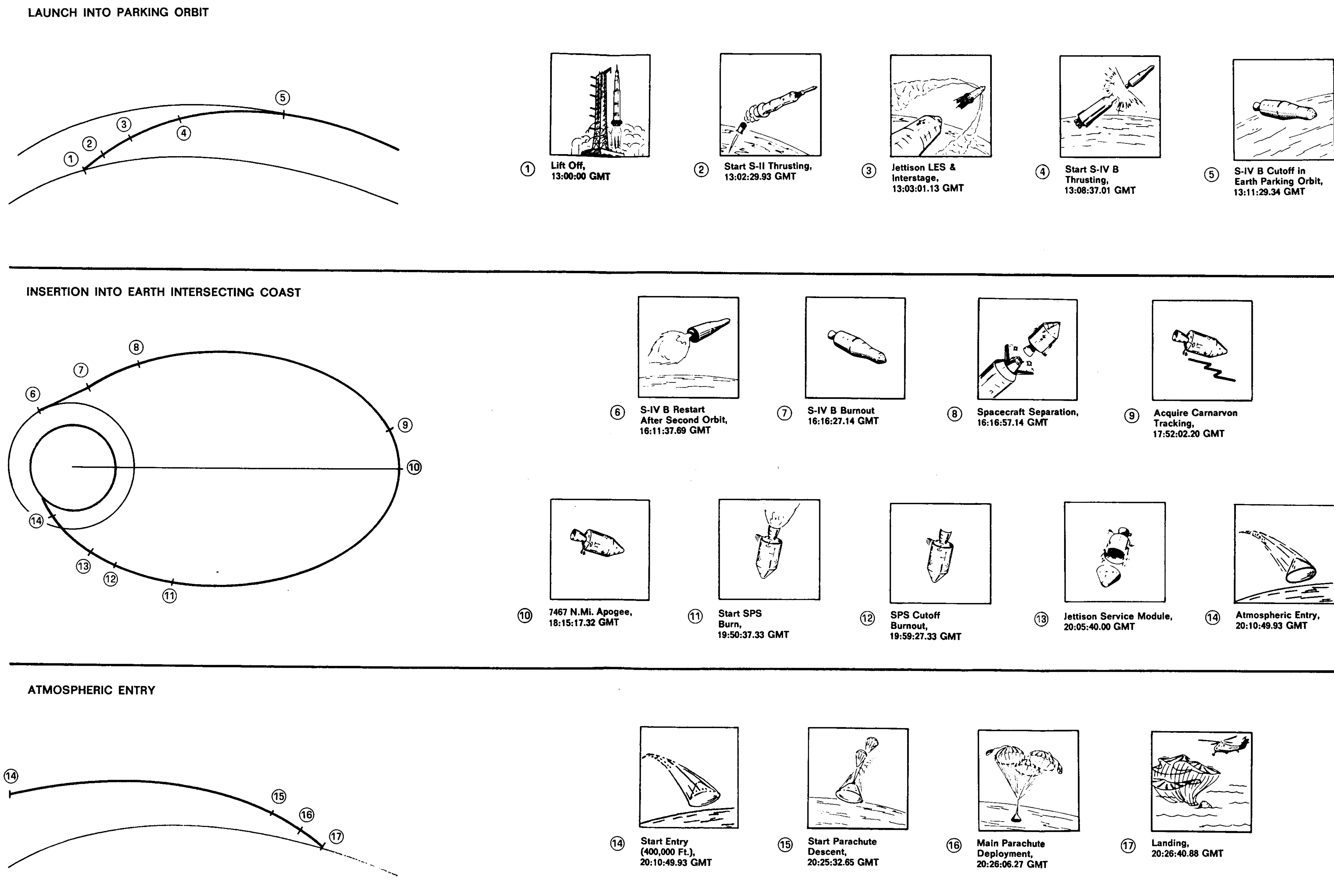

Figure 1-1. Mission Summary

2. SPACECRAFT MISSION REQUIREMENTS

2.1 SPACECRAFT TEST OBJECTIVES

The spacecraft test objectives presented here were taken from Reference 1.

2.1.1 First Order

a) Demonstrate satisfactory spacecraft performance at lunar return conditions during terminal transearth, entry, parachute-descent, and post-landing mission phases.

b) Demonstrate the structural integrity of the space vehicle (Saturn V/SLA-LEM-CSM).

2.1.2 Second Order

a) Evaluate CM heat shield performance at the Nominal Undershoot Entry, initiated at not less than the relative velocity corresponding to 36,333 ft/sec inertial velocity and an inclination of 40 degrees following a cold-soak to the transearth design temperature condition.

b) Determine Emergency Detection System open-loop performance.

c) Verify CM radiation shielding effectiveness.

d) Determine the structural and dynamic response of the CSM and adapter to the Saturn V launch environment.

2.1.3 Third Order

a) Determine the response of the LEM to the Saturn V launch environment.

b) Demonstrate normal mode separation of the Launch Escape System (LES) and the Boost Protective Cover (BPC) from the CSM.

c) Demonstrate (upon ground command) LES performance in event of launch vehicle failure prior to normal LES jettison.

d) Demonstrate maximum continuous SPS burn required (approximately 400 seconds to simulate lunar orbit insertion).

e) Demonstrate operation of the parachute recovery subsystem and recovery aids following entry at nominal design conditions.

f) Demonstrate operational radiation monitoring instrumentation in a radiation environment.

g) Demonstrate entry guidance at lunar return velocity.

2.2 MISSION CONSTRAINTS

The following mission constraints for this Preliminary Mission Profile have been compiled from data supplied by MSC and from Reference 1.

2.2.1 Launch Vehicle Systems Constraints

a) Launch azimuth of 72.0°.

b) The launch vehicle profile will be as close as possible to the profile of the nominal Lunar Orbital Rendezvous (LOR) mission.

c) Full S-IVB loading and full S-IVB burn are required.

d) A minimum of two orbits of the S-IVB/IU(Instrumentation Unit)/SC.

e) Tracking is required for both the pre-ignition sequence and the second S-IVB burn. This burn will occur over Eastern Test Range (ETR).

f) After S-IVB cutoff, the vehicle attitude will be maintained relative to the local vertical.

g) Guidance command angle rate limitation of 1 deg/sec in pitch and yaw.

h) Thirty-degree maximum command attitude in the yaw plane.

2.2.2 Spacecraft Systems Constraints

a) Total mission duration (launch to CM splash) not to exceed 12 hours (programmer limit).

b) Spacecraft orientation control as required to provide structural temperature gradients.

c) A continuous SPS burn of at least 400 seconds.

d) Initiation of SM/CM separation manuever no later than 5 minutes before reaching 400,000-foot altitude.

e) Nominal trim lift-to-drag ratio is 0.34.

f) Tracking is required for all SPS burns.

2.2.3 Trajectory Profile Constraints

a) A minimum of two revolutions in the 100 n mi parking orbit.

b) At least 4 hours of cold soak beyond earths' significant albedo (to simulate terminal transearth conditions).*

c) Free return of the spacecraft on an earth-intersecting trajectory following spacecraft/launch vehicle separation (to allow satisfactory recovery of the spacecraft in case of an SPS failure to fire).

d) CM entry into the earths' atmosphere (400,000-foot altitude) with an inertial velocity of 36,333 ft/sec and an inertial flight path angle of -7.35 degrees (measured from the local horizontal).

e) A 2500 n mi range from entry to landing (Nominal Undershoot Entry Trajectory).

f) Earth landing to occur in the Pacific Ocean clear of any major island group.

*In the selected mission profile, the time duration from S-IVB burnout to SPS ignition is only slightly greater than 3-1/2 hours.

3. SUMMARY OF INPUT DATA

The summary of input data in this section consists of data from References 2 and 3 and data agreed upon at a number of unpublished technical coordination meetings of MSC and STL personnel. This data includes all quantitative specifications on launch vehicle, spacecraft, and ground tracking stations, and is considered adequate for the present evaluation of the mission.

3.1 LAUNCH VEHICLE

Data on the Saturn V launch vehicle was based on material in Reference 2, and supplemented by an MSFC trajectory listing (dated 2 October 1964) for the SA-501 launch vehicle.

Weight and propulsion characteristics of the Saturn V launch vehicle are presented in Tables 3-1 and 3-2, respectively. Weights are given in a manner essentially equivalent to their chronological disposition in the trajectory simulation. It is understood that all jettison weights include propellant reserve allowances, if any. Propulsion data is used in a simple propulsion model that applies a constant propellant flow rate and a constant thrust, but with corrections for atmospheric pressure effects. The thrust history for the S-II stage is divided into three constant-thrust, constant-flow-rate phases to simulate the optimum thrust profile for this stage. These phases, listed in order of occurrence, are:

1) A short duration, nominal thrust, nominal specific impulse phase
2) A high thrust, low specific impulse phase
3) A low thrust, high specific impulse phase

The launch vehicle sequence of events used in the trajectory simulation is presented in Table 3-3. This sequence was derived from the above weight and propulsion data.

Table 3-1. Sequential Weight Statement

	Weight Losses (lb)	Event Weights (lb)
At Saturn V Liftoff		6,088,000
S-IC Propellant Consumed	4,192,421	
At Inboard Engine Cutoff*		1,895,579
S-IC Propellant Consumed	94,388	
At S-IC Burnout		1,801,191
S-IC at Burnout	394,145	
At S-II Ignition		1,407,046
S-IC/S-II Interstage**	9,869	
LES Jettison**	8,200	
S-II Propellant Consumed	929,998	
At S-II Burnout		458,979
S-II at Burnout	105,041	
At S-IVB Ignition		353,938
S-IVB Propellant Consumed	84,134	
At S-IVB Cutoff Into Parking Orbit		269,804
Loss in Parking Orbit	3,873	
At S-IVB Second Ignition		265,931
S-IVB Propellant Consumed	141,312	
At S-IVB Burnout		124,619
S-IVB at Burnout	39,619	
Payload at Injection		85,000

*S-IC inboard engine is cut off 4 sec prior to outboard engine cutoff.

**S-IC/S-II interstage and LES are jettisoned at 30 and 35 sec after S-IB burnout and jettison, respectively.

Table 3-2. Stage Propulsion Data

Stage	Vacuum Thrust (lb)	Sea Level Thrust (lb)	Propellant Flow Rate (lb/sec)
S-IC			
All Engines Firing	8,745,393	7,610,000	29,496.14
Only Four Outboard Engines Firing	6,996,314	6,088,000	23,596.91
S-II			
0 to 10.0 sec	1,035,000	N/A	2,441.040
10.0 to 238.319 sec	1,135,000	N/A	2,694.234
238.319 to 367.072 sec	960,000	N/A	2,255.799
S-IVB	207,000	N/A	488.206

Table 3-3. Time Sequence of Events

Event	Time from Liftoff (sec)
Liftoff	0
End Vertical Rise, Start Pitchover	12.000
Inboard Engine Cutoff	142.135
Outboard Engine Cutoff and S-IC Separation	146.135
S-II Ignition, Start High Pitch Rate Steering	149.935
Start Low Pitch Rate Steering	161.700
Jettison S-IC/S-II Interstage Adapter	176.135
Jettison Launch Escape System	181.135
S-II Burnout and Jettison, S-IVB Ignition	517.007
S-IVB Cutoff Into Orbit	689.340
S-IVB Restart	T + 0
S-IVB Burnout	T + 289.451

The Saturn V launch vehicle is illustrated in Figure 3-1, and the zero angle-of-attack drag force data is presented in Figure 3-2. An aerodynamic reference area of 855.3 square feet was used.

The static atmosphere model used in the trajectory simulation has two parts. Below an altitude of 35 km, the Patrick Atmosphere (Reference 4) is used, while between 35 km and 400,000 feet, the U.S. Standard Atmosphere, 1962 (Reference 5) is used. Both atmospheres are provided to the computer as tables of pressure and temperature versus geometric altitude. In changing from the Patrick to the U.S. Standard Atmosphere at an altitude of 114,830 feet, no attempt has been made to remove the discontinuity between the two models. Table 3-4 gives comparative atmospheric values at that altitude.

3.2 SPACECRAFT

Weight characteristics for the Apollo spacecraft were obtained from Reference 6. SPS thrust and propellant flowrate characteristics and CM entry aerodynamic data were obtained in unpublished technical coordination meetings with MSC personnel. The sequential weight statement for the spacecraft is presented in Table 3-5. Approximately 1400 pounds of usable SPS propellants are not consumed, which should provide more than adequate allowance for flight performance reserves.

The SPS was characterized by a vacuum thrust of 21,900 pounds and a vacuum specific impulse of 313.0 seconds. This results in a propellant flow rate of 69.968 lb/sec.

The aerodynamic trim drag coefficient data used for the CM entry trajectory is presented in Figure 3-3 and is based on an aerodynamic reference area of 129.36 square feet. The lift force is based on a constant 0.34 times the drag force. The entry trajectory is based upon the U.S. Standard Atmosphere, 1962, and a constant CM weight of 11,000 pounds.

3.3 GROUND STATIONS

The precise complement of stations, their ultimate locations, their operating characteristics, and such related data to be used for Apollo Mission SA-501 are currently not known. The data in Table 3-6, compiled from tracking site and equipment information supplied by MSC, is assumed to be applicable at this time.

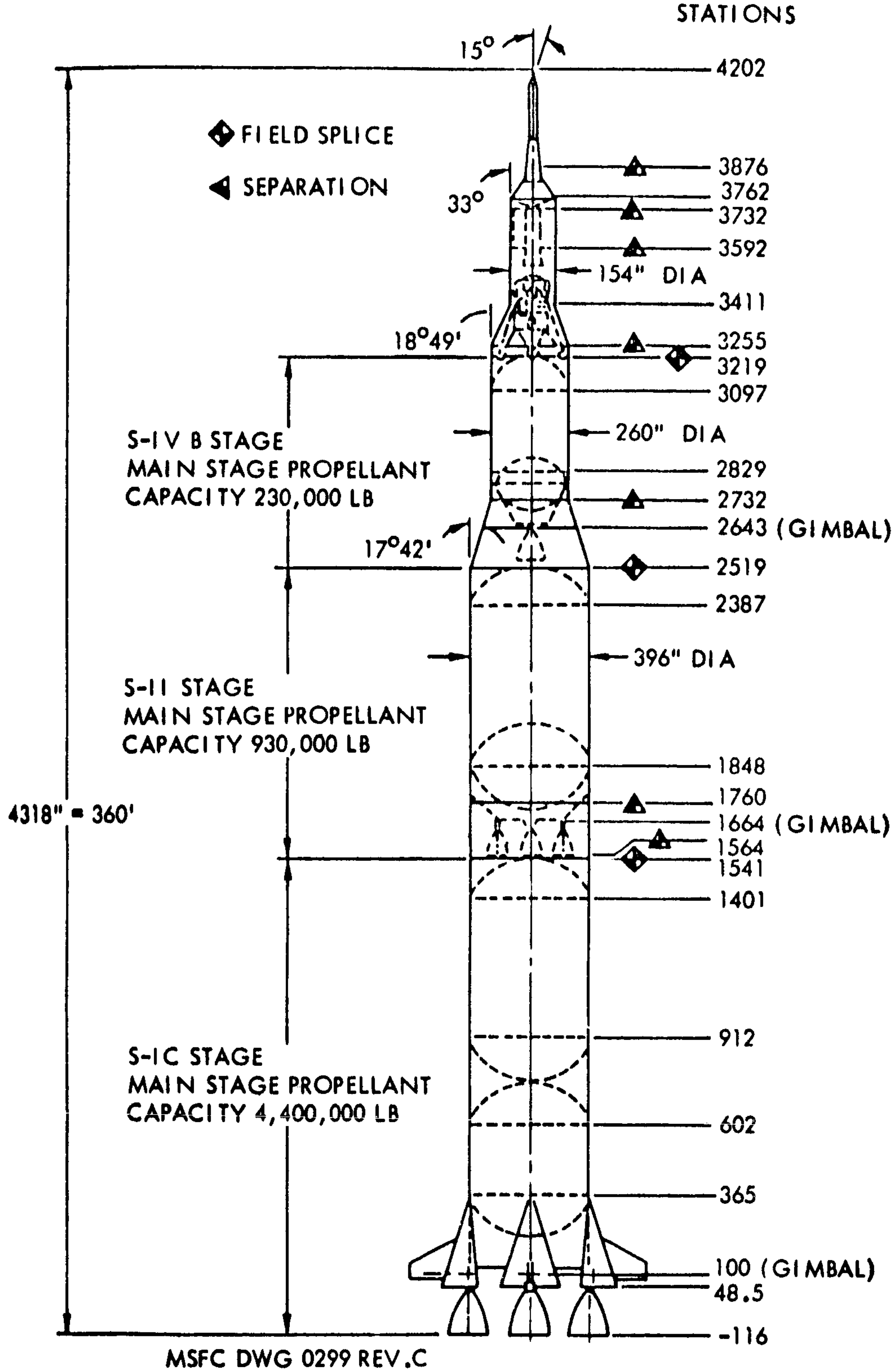

Figure 3-1. Saturn V Reference Dimensions

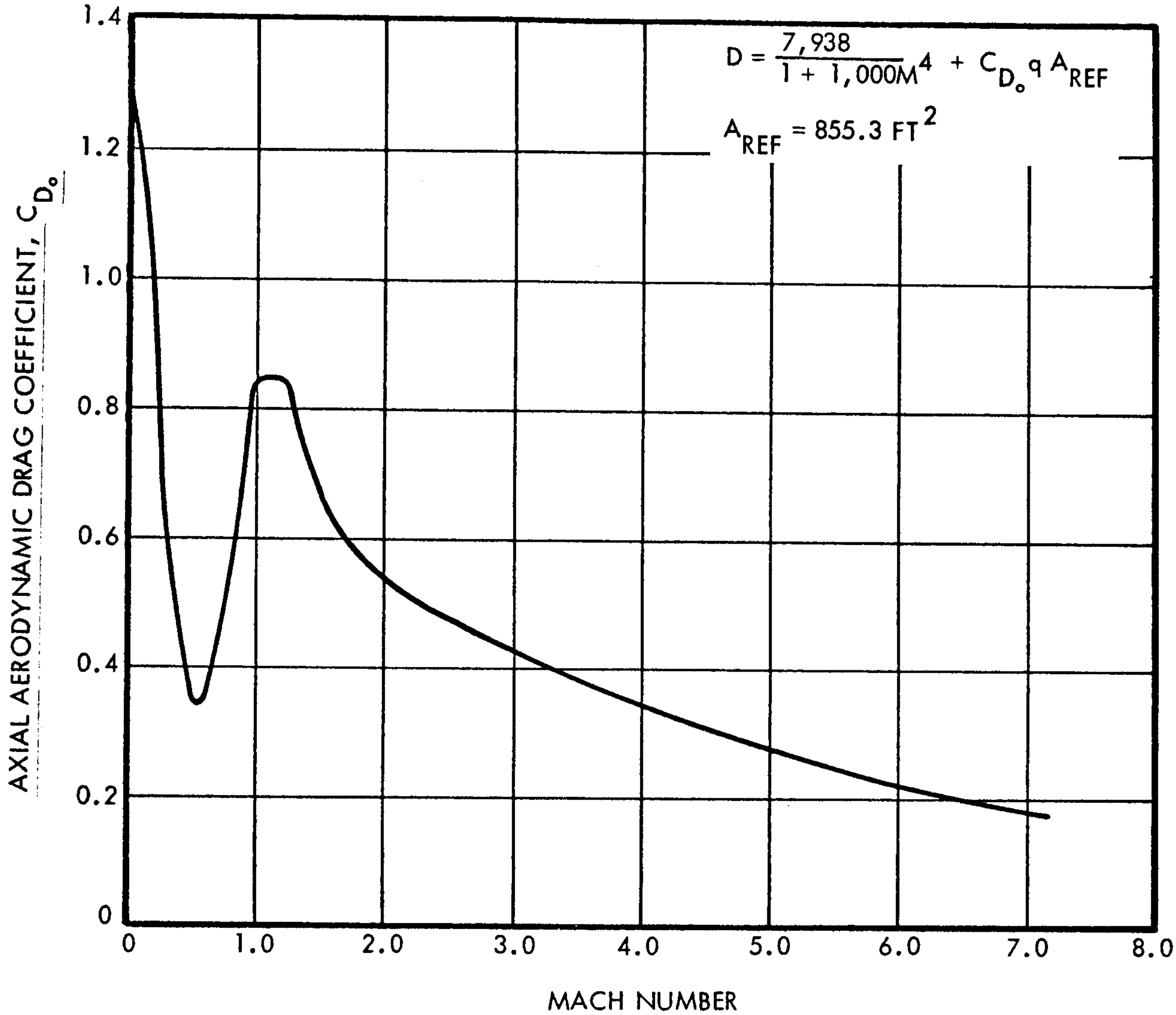

Figure 3-2. Saturn V Zero Angle of Attack Drag Coefficient

Table 3-4. Atmospheric Values at 35 km

	Patrick Atmosphere	U. S. Standard
Pressure (lb/in^2)	0.085922154	0.083418396
Temperature (^{o}R)	439.42235	425.72477
Speed of sound (ft/sec)	1027.6009	1011.4798
Density (slug/ft^3)	0.16403886 x 10^{-4}	0.1643758 x 10^{-4}

Table 3-5. Spacecraft Weight Data

	Weight Losses (lb)	Event Weights (lb)
At Liftoff		93,200
Launch Escape System	8,200	
At Injection Into Orbit		85,000
LEM Jettison	21,490	
Saturn Launch Adapter	3,800	
At SPS Ignition		59,710
SPS Propellant Consumed	37,083*	
At SPS Cutoff		22,627
SPS Propellant Remaining	1,427	
SPS Burnout	10,200	
Command Module		11,000

*Propellant consumption is based on a 530-second SPS burn time.

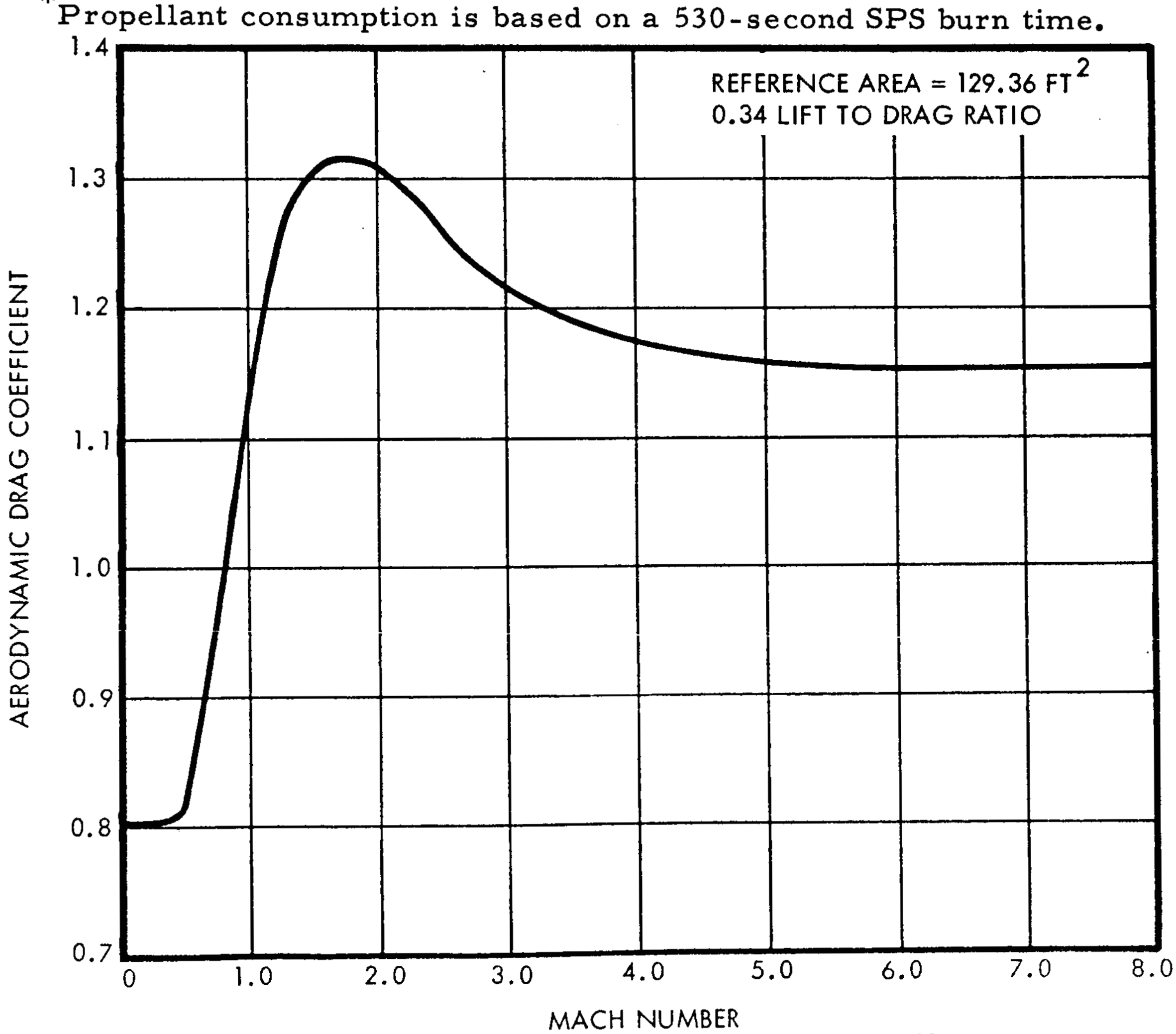

Figure 3-3. Command Module Trim Drag Coefficient

Table 3-6. Radar Tracking Station Sites and Equipment

No.	Station	Tracking Systems	Latitude	Longitude	Ellipsoid Height (ft)
1	Cape Kennedy, Florida	FPS-16, TPQ-18, USBS 30'	28°29'	-80°35'	46
2	Grand Bahama Island	FPS-16, TPQ-18	26°37'	-78°21'	46
3	San Salvador Island	FPS-16	24°07'	-74°30'	10
4	Grand Turk Island	TPQ-18	21°28'	-71°08'	82
5	Bermuda	FPS-16, FPQ-6, USBS 30'	32°21'	-64°39'	10
6	Antigua Island	FPQ-6, USBS 30'	17°09'	-61°48'	85
7	Grand Canary Islands	MPS-26, USBS 30'	27°44'	-15°36'	95
8	Ascension Island	TPQ-18, USBS 30'	-07°58'	-14°24'	469
9	Madrid, Spain	USBS 85'	40°25'	-03°40'	164
10	Pretoria, South Africa	MPS-25	-25°57'	28°22'	5,335
11	Carnarvon, Australia	FPQ-6, USBS 30'	-24°54'	113°43'	210
12	Canberra, Australia	USBS 85'	-35°19'	149°08'	164
13	Guam	USBS 30'	13°35'	144°56'	66
14	Hawaii	FPS-16, USBS 30'	22°08'	-159°40'	3,747
15	Pt. Arguello, California	FPS-16	34°35'	-120°34'	2,119
16	Goldstone, California	JPL 85'	35°23'	-116°51'	3,383
17	Guaymas, Mexico	USBS 30'	27°58'	-110°43'	59
18	White Sands, New Mexico	FPS-16	32°21'	-106°22'	164
19	Texas	USBS 30'	29°46'	-95°22'	46

The station coordinates given are based on a Fisher ellipsoid. This model is described by:

a = semimajor axis = 6378. 166 km

b = semiminor axis = 6356. 784 km

f = flattening = 1/298. 3

The altitude is referenced to the ellipsoid and includes geoidal separation.

3. 4 MISCELLANEOUS DATA

The following earth constants and conversion factors (Reference 7) have been used in the generation of the mission profile and are consistent with those presented in Reference 8.

3. 4. 1 Earth Constants

Rotational rate	$4.37526902 \times 10^{-3}$ rad/min
	$0.417807416 \times 10^{-2}$ deg/sec
	$0.729211504 \times 10^{-4}$ rad/sec
Equatorial radius	$2.092573819 \times 10^{7}$ ft
Average radius	2.0909841×10^{7} ft
Gravitational parameter (μ_e)	$5.53039344 \times 10^{-3}$ er^3/min^2
	$11.46782384 \times 10^{3}$ er^3/day^2
	3.986032×10^{5} km^3/sec^2
	$1.407653916 \times 10^{16}$ ft^3/sec^2
Coefficients of potential harmonics	
J term (second harmonic)	1.62345×10^{-3} nd
H term (third harmonic)	-0.575×10^{-5} nd
D term (fourth harmonic)	0.7875×10^{-5} nd
Earth flattening (f)	1/298. 3 nd

3.4.2 Miscellaneous Constants and Conversion Factors

Velocity of light in a vacuum	9.83571194×10^{8} ft/sec
Astronomical unit of length	$4.908103670 \times 10^{11}$ ft
Kilometers per foot	0.3048×10^{-3} km/ft
Kilometers per nautical mile	1.852 km/n mi
Feet per nautical mile	6076.115486 ft/n mi
Weight-to-mass ratio	32.17404856 lb/slug
Mass-to-weight ratio	0.031080950 slug/lb
Feet per earth equatorial radius	$2.092573819 \times 10^{7}$ ft/er
Nautical mile per earth equatorial radius	3443.93358 n mi/er

4. MISSION ANALYSIS AND DESCRIPTION

The mission profile for Apollo Mission SA-501 has been designed to meet the Test Objectives of Section 2.1 without violating the Mission Constraints of Section 2.2. To satisfy these objectives and constraints and determine values of the free variables, a certain amount of trajectory analysis was required. The results of this analysis, along with a description of the resulting mission profile, are given in this section.

In addition to the nominal mission profile, an alternate profile resulting from an SPS failure to burn is also described. These two profiles have been characterized by "SPS Burn" and "No SPS Burn" titles and are identical up to the SPS ignition.

In the selected profile, the time duration from S-IVB burnout to SPS ignition is slightly greater than 3-1/2 hours and therefore does not meet the 4-hour cold soak constraint (Section 2.2.3b).

4.1 SATURN V ASCENT TO PARKING ORBIT

Launch of Apollo Mission SA-501 will occur from Pad "A" of Launch Complex 39 during the first quarter of 1967. The geodetic coordinates are 28°38' 50.927" North latitude and 80°38' 08.071" West longitude. For the trajectory simulation, launch was assumed to occur at 13:00 hours GMT (08:00 hours EST) on 1 January 1967.

The launch profile is initiated with a 12-second vertical rise followed by a 0.3568-degree kick (an instantaneous rotation of the missile attitude and velocity vector) into a gravity turn trajectory with a 72-degree azimuth heading. Approximately 4 seconds prior to S-IC outboard engine cutoff, the center engine is cut off. Following a 3.8-second coast from S-IC cutoff and separation, the S-II is ignited and initiates a pitch-up at a 1 deg/sec rate. This high pitch rate steering is terminated approximately 11.5 seconds after ignition, and a low pitch rate steering of 0.1043 deg/sec down is initiated. Thirty seconds after S-IC cutoff and separation, the S-IC/S-II interstage adapter is jettisoned, and 5 seconds later, the LES is jettisoned.

The S-II burnout and separation and the S-IVB ignition all occur simultaneously in the simulation per Reference 2. The low pitch rate steering of 0.1043 deg/sec is maintained until S-IV B cutoff at circular orbit velocity.

The values of the kick angle, the duration of the high pitch rate steering, and the magnitude of the low pitch rate steering were determined by iteration techniques so that the S-IVB cutoff would occur at 100 n mi altitude with a zero-degree flight path angle and maximum injected weight (or concurrently, minimum S-IVB propellant consumption).

It should be noted that the injected weight of 269,804 pounds calculated in the above simulation is 366 pounds less than that presented in Reference 2. This amounts to 0.136 percent of the injected weight, or less than 1 second of S-IVB burning, and is well within the error to be expected due to non-nominal performance. These results are satisfactory for establishing the preliminary mission profile and the spacecraft launch environment.

4.2 EARTH PARKING ORBIT

The S-IVB cutoff, which occurs approximately 11.5 minutes after liftoff, injects the spacecraft into a 100 n mi circular parking orbit with an inclination of 32.588 degrees and an orbital period of 88.1 minutes. On the second orbit, approximately 169 minutes after S-IVB cutoff, the Point Arguello Tracking Site acquires the spacecraft at a 5.0-degree elevation angle from the horizon, in preparation for the S-IVB second burn ignition. This initial acquisition by Point Arguello marks the beginning of a period of continual tracking coverage over the continental United States.

4.3 S-IVB SECOND BURN

Eleven minutes after Point Arguello tracking acquisition, the spacecraft has passed over the Eastern coast and is approximately 240 n mi north of Cape Kennedy. At this point, the S-IVB is ignited and starts its second burn. This particular selection of ignition time was chosen for three reasons:

1) It is desirable to have a good period of tracking coverage prior to S-IVB ignition. The above selection allows 11 minutes of tracking coverage.

2) It is desirable to have a good period of tracking coverage following S-IVB burnout. This selection allows a 12-minute period of Antigua tracking coverage from burnout to the time that the spacecraft goes below a 5.0-degree tracking elevation angle.

3) For the earth intersecting coast profile selected, this timing places the CM splash point due north of the Hawaiian Islands. This appears to be a desirable landing point, for it places the impact position of the spent S-IVB stage and the SM near the middle of the Pacific Ocean and is a convenient position for operating the recovery force.

The S-IVB burns for a full 290 seconds, simulating a translunar injection. However, the pitch steering was determined so that the resulting orbit would remain near earth (less than 12,000 n mi altitude) and intersect the earth's atmosphere. The latter allows for a successful CM recovery if the SPS fails to fire.

At this date, there are no firm criteria on which to base the selection of an entry flight path angle for the no-SPS-burn condition. There appear to be two alternatives, however. The first would be to perform a high heat rate test of the CM if the SPS fails to burn. A large value of the entry flight path angle is required in this case since the entry velocity is considerably less than the desired value of 36,333 ft/sec. However, this alternative has an operational disadvantage in that the locations of atmospheric entry and CM splash from the no-SPS-burn case are considerably separated from those with an SPS burn, and two recovery teams would probably be needed to cover both landing locations.

The other alternative would be to select a no-SPS-burn entry condition in which the distance between the two landing sites would be minimized. This requirement would favor a shallow entry flight path angle in order to stretch the entry range to a maximum. The latter alternative was developed in this mission profile, and a flight path angle of -7.35 degrees (same as that required with an SPS burn) was selected. This results in a 363 n mi separation of the two CM splash points.

The effect of the S-IVB pitch rate on the initial pitch attitude* required to achieve entry flight path angles of -7.35, -10.0, -12.5, and -15.0 degrees is illustrated in Figure 4-1, Sheet 1. This illustration also shows the resulting apogee altitudes and entry latitudes. Figure 4-1, Sheet 2, shows the effect of S-IVB pitch rate on entry longitude, the time duration from liftoff to entry, and the entry velocities. Several interesting observations concerning pitch steering may be made from this data:

1) Large values of S-IVB pitch rate, both positive and negative, and greater in magnitude than 0.3 deg/sec, appear desirable since they place the atmospheric entry into the Pacific Ocean and clear of the Asian continent, and secondly, reduce the total mission duration time.

2) Conversely, values of S-IVB pitch rate less than 0.3 deg/sec in magnitude have very long mission durations, very poor locations of atmospheric entry location, and the highest entry velocities.

3) Negative pitch rates (counterclockwise and up) require negative (down) values of the initial pitch attitude. This is deemed undesirable because it will cause the altitude to decrease initially and is an undesirable thrusting attitude.

Based on the above observations, an S-IVB pitch rate of 0.5 deg/sec was selected for the second burn. This results in an initial pitch attitude of -122.4 degrees (up) for the entry flight path angle of -7.35 degrees.

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*For simulation purposes, the initial attitude is referenced to the inertial velocity vector.

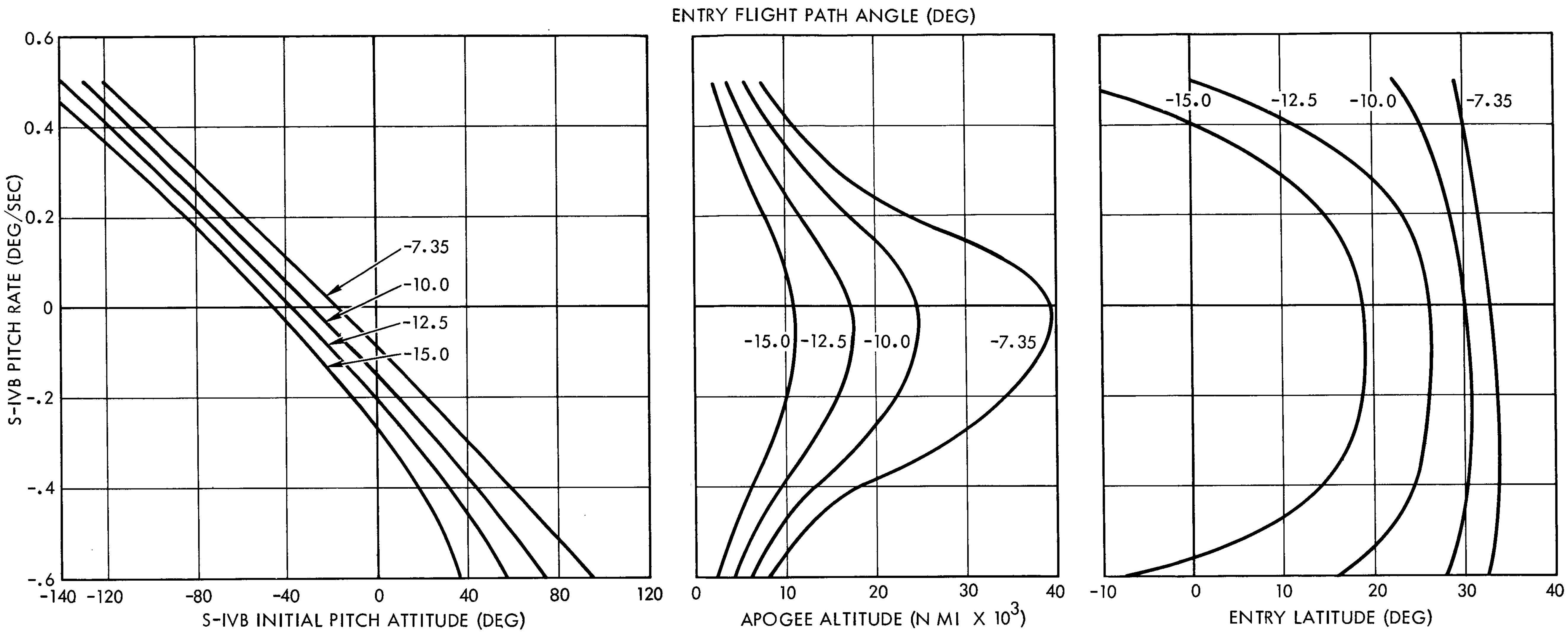


Figure 4-1. Effect of S-IVB Second Burn Steering on the Earth Intersecting Coast (Sheet 1)

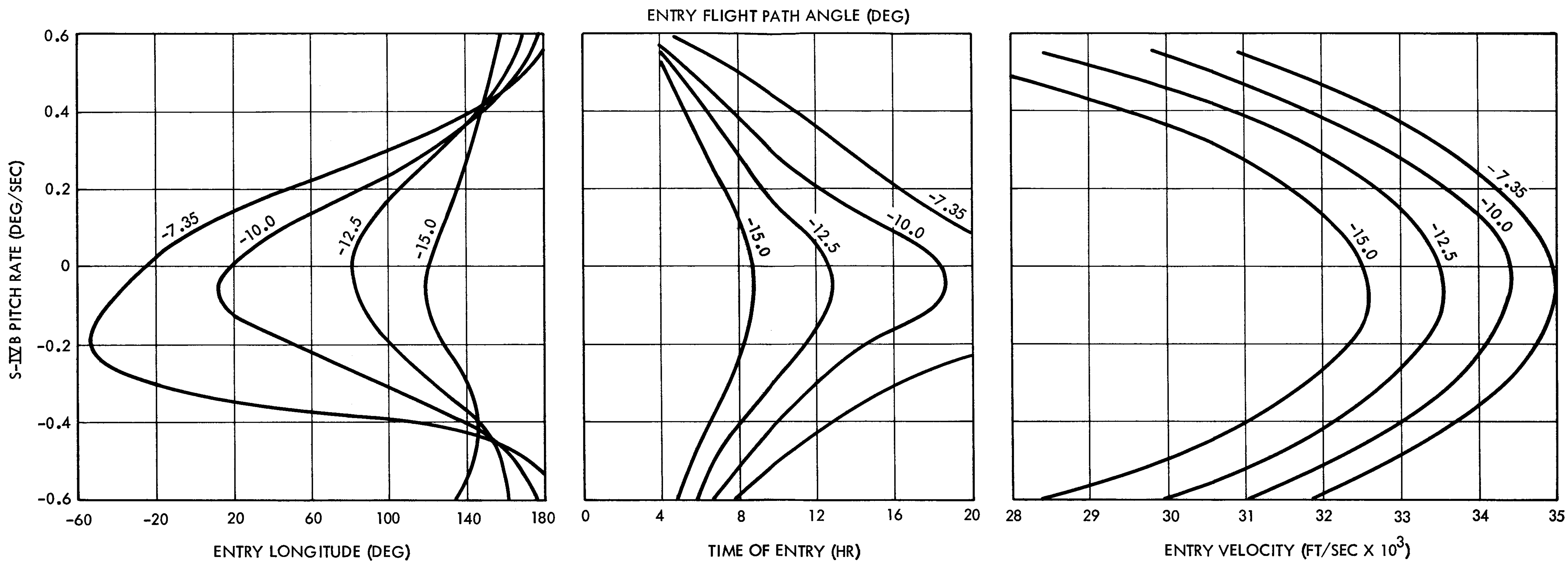


Figure 4-1. Effect of S-IVB Second Burn Steering on the Earth Intersecting Coast (Sheet 2)

Unfortunately, this selection does not meet the 4-hours cold-soak constraint of Section 2.2.3.b. The elapsed time from S-IVB burnout to SPS ignition is only 3 hours and 34 minutes with this profile.

4.4 EARTH INTERSECTING COAST

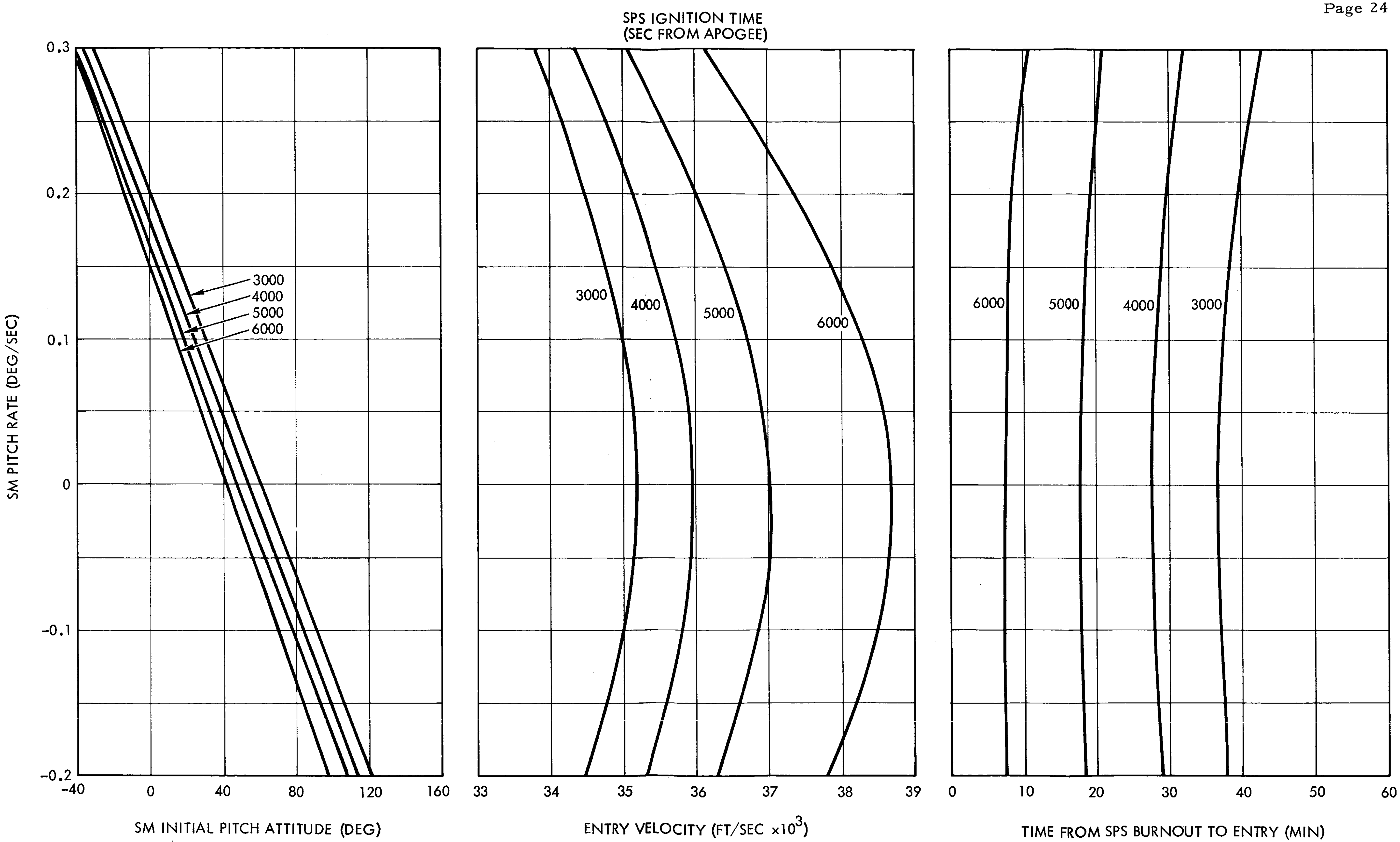
At final burnout, 3 hours and 16 minutes after liftoff, the S-IVB has injected the spacecraft into an orbit characterized by a 7,467 n mi apogee altitude and a -7.35-degree entry flight path angle. This orbit has a semimajor axis of 43,573,000 feet, an orbital eccentricity of 0.5226, and an orbital inclination of 32.6 degrees.

Although an exact coast duration from S-IVB burnout to S-IVB/CSM separation was not established in the launch vehicle constraint (2.2.1f), a 30-second coast period was assumed for this profile. Approximately 12 minutes after S-IVB burnout, the spacecraft goes below the 5-degree elevation angle from the Antigua tracking station. The ground tracking coverage over the continental United States before, during, and after the S-IVB burn should provide adequate ground tracking data for launch vehicle systems evaluation and spacecraft orbit determination.

Almost an hour and a half later, Carnarvon tracking observes the CSM at an elevation angle of 5.0 degrees and a range of 9500 n mi. Twenty-three minutes later (5 hours and 15 minutes after liftoff), the spacecraft reaches apogee. During the spacecraft descent from apogee, but prior to SPS ignition, the orbit state vector (position and velocity) and the target vector will be updated in the Apollo Guidance Computer (AGC) by Carnarvon tracking via the Up-Data-Link.

4.5 SPS BURN

The nominal mission plan calls for the SPS to accelerate the spacecraft in such a way that the desired values of velocity and flight path angle at atmospheric entry will be achieved. Figure 4-2 illustrates the effects of SPS pitch rate and SPS ignition time (measured from apogee) on the SPS initial pitch attitude that is required at ignition in order to achieve the -7.35-degree entry flight path angle. The corresponding values of the entry velocity and time duration from SPS burnout to atmospheric entry are also shown in this figure. This data indicates that the entry velocity achieved from the 530-second SPS burn continues to increase as the SPS ignition time is delayed.



NOTE: 530-seconds SPS Burn Duration

Figure 4-2. Effect of SM Steering on Entry

The selection of a 45-minute period from apogee to ignition appears to be a reasonable one based on the above data. This selection allows for an 11.3-minute period from SPS burnout to atmospheric entry. Resulting values of SPS pitch rate and initial pitch attitude* to satisfy the 36,333 ft/sec entry velocity and the -7.35-degree entry flight path angle were -0.292 deg/sec (counterclockwise) and +129.3 degrees (down), respectively.

4.6 PRE-ENTRY SEQUENCE

4.6.1 Pre-Entry Sequence (SPS Burn)

Almost 7 hours after liftoff, the SPS is cut off and an 11.3-minute coast to atmospheric entry is started. At 3.8 minutes after SPS cutoff, the spacecraft drops below a 5.0-degree Carnarvon tracking elevation angle. This profile assumes that 5 minutes prior to entry, CM/SM separation is initiated. The CM then assumes the proper entry attitude. Atmospheric entry occurs at a longitude of 155.64° East and a latitude of 23.40° North.

4.6.2 Pre-Entry Sequence (No SPS Burn)

The pre-entry sequence phase in case of SPS failure to burn is initiated at the nominal SPS ignition time, 45 minutes after apogee. Approximately 5.3 minutes of Carnarvon tracking at elevation angles greater than 5.0 degrees remain after this time, and atmospheric entry occurs 12.1 minutes after loss of Carnarvon tracking. Entry occurs at 170.85° East longitude and 28.95° North latitude with an inertial velocity of 31,592 ft/sec and an inertial flight path angle of -7.35 degrees. As before, CM/SM separation is assumed to occur 5 minutes prior to entry.

4.7 ATMOSPHERIC ENTRY

4.7.1 Atmospheric Entry (SPS Burn)

Seven hours and 18 minutes after liftoff, the CM initiates entry into the earth's atmosphere. The entry trajectory was simulated by using two values of the vertical lift-to-drag ratio. The maximum value 0.34 was used from entry to pullout (horizontal flight) while a lower value

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*Referenced to the inertial velocity vector.

was used from pullout to drogue chute deployment at 24,000 feet. A search iteration was performed on the latter lift-to-drag ratio in order to satisfy the 2500 n mi entry range requirement. The resulting lift-to-drag ratio of 0.2346 simulates the effect of the Apollo CM rolling back and forth to reduce the vertical lift component.

Horizontal pullout is achieved 76.3 seconds after entry, and the CM starts an upward drift at the reduced lift-to-drag ratio. The CM ascends to an altitude of 360,400 feet before it starts the final descent 5-1/2 minutes after atmospheric entry. Drogue chute deployment occurs 9 minutes later at an altitude of 24,000 feet. Following the main parachute deployment at an altitude of 11,000 feet, the CM performs a water landing almost 16 minutes after entry and almost 7-1/2 hours after liftoff. The splash point latitude and longitude are 32.46° North and 157.98° West, respectively. This position places the spacecraft approximately 750 n mi north of Hawaii.

4.7.2 Atmospheric Entry (No SPS Burn)

The entry trajectory profile for the no-SPS-burn condition has a sequencing of events identical to that presented above. The primary difference in the two profiles is that the entry velocity for the no-SPS-burn is 5740 ft/sec less than desired. By using maximum lift throughout this profile, a range of 1254 n mi from entry to landing can be achieved. The water landing occurs 11.4 minutes after entry and almost 7-1/2 hours after liftoff at 32.54° North latitude and 165.15° West longitude. This splash point is approximately 363 n mi from that estimated for the nominal, SPS-burn profile.

4.8 VACUUM IMPACT POINTS

Impact points for the S-IC, S-II, and S-IVB have been calculated, based upon a vacuum ballistic entry. No impact was available for the SM since burnout inserts the SM into an orbit with a perigee altitude of 10 n mi.

S-IC impact occurs at 30.16° North latitude and 74.59° West longitude while S-II impact occurs at 32.05° North latitude and 38.32° West longitude. The S-IVB impact following the second burn will occur at 31.48° North latitude and 176.90° West longitude.

5. NOMINAL TRAJECTORY DATA

This section contains trajectory parameter histories describing and illustrating the nominal mission profile. These data, presented here in tabular and graph forms, are based on the trajectory printout data in Volume II of this report. Data are presented for both the SPS burn profile and the no-SPS-burn profile.

Figures 5-1 and 5-2 present the earth ground track and the altitude-longitude history, respectively, for the entire mission profile. The time sequence of events for the mission is shown in Table 5-1.

For each of the mission's seven major phases, pertinent powered and and free flight trajectory parameters have been plotted as a function of time from liftoff. These graphs, along with related tabular data, have been grouped on the following pages according to mission phase, as follows:

1) Saturn V Ascent to Orbit (Table 5-2, Figures 5-3 through 5-8)

2) Earth Parking Orbit (Table 5-3, Figures 5-9 and 5-10)

3) Second S-IVB Burn (Table 5-4, Figures 5-11 through 5-14)

4) Earth Intersecting Coast (Table 5-5, Figures 5-15 and 5-16)

5) SPS Burn (Table 5-6, Figures 5-17 through 5-20)

6) Pre-entry Sequence (Tables 5-7 and 5-8, Figures 5-21 through 5-24)

7) Atmospheric Entry (Tables 5-9 and 5-10, Figures 5-25 through 5-36)

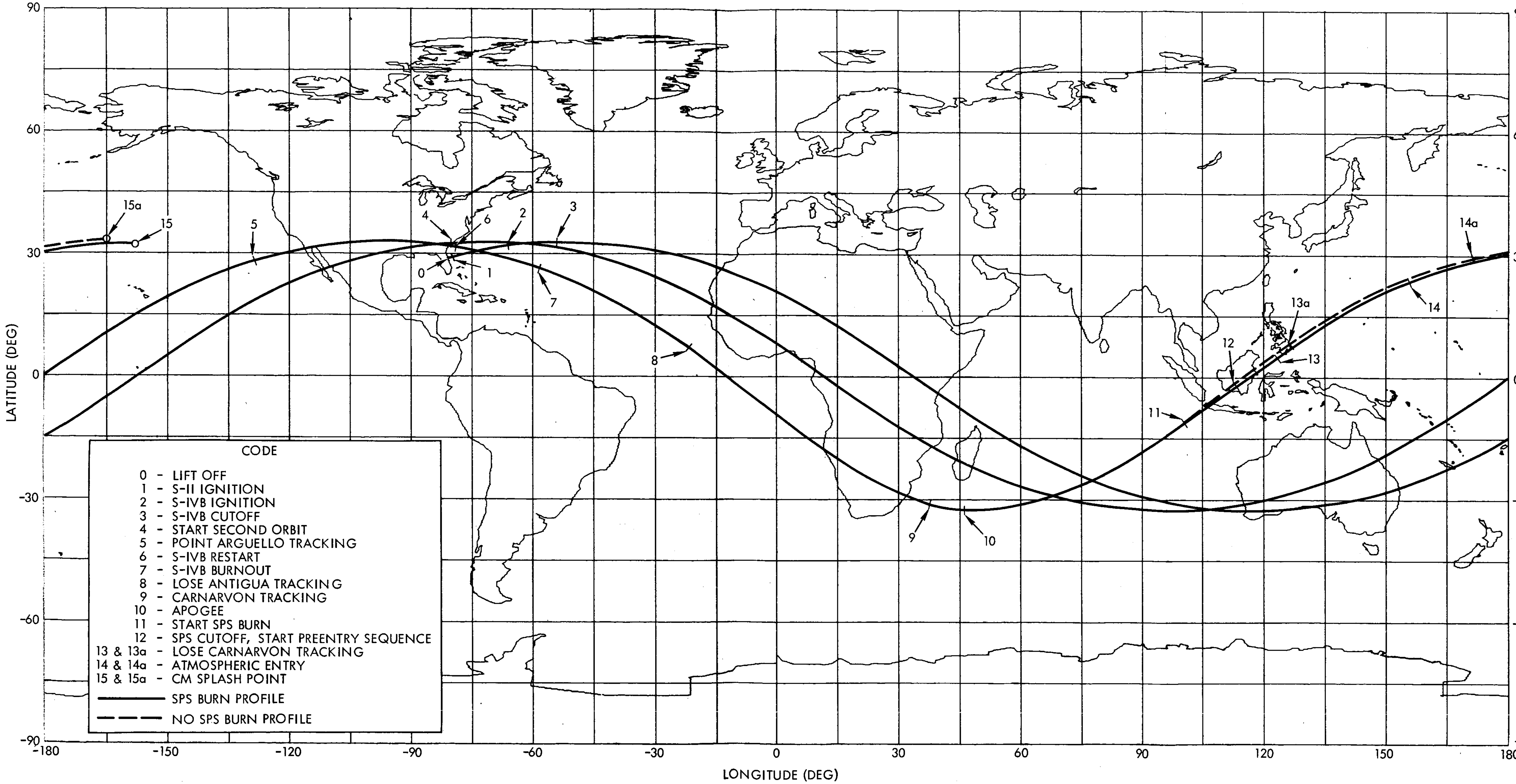

Figure 5-1. Earth Ground Track

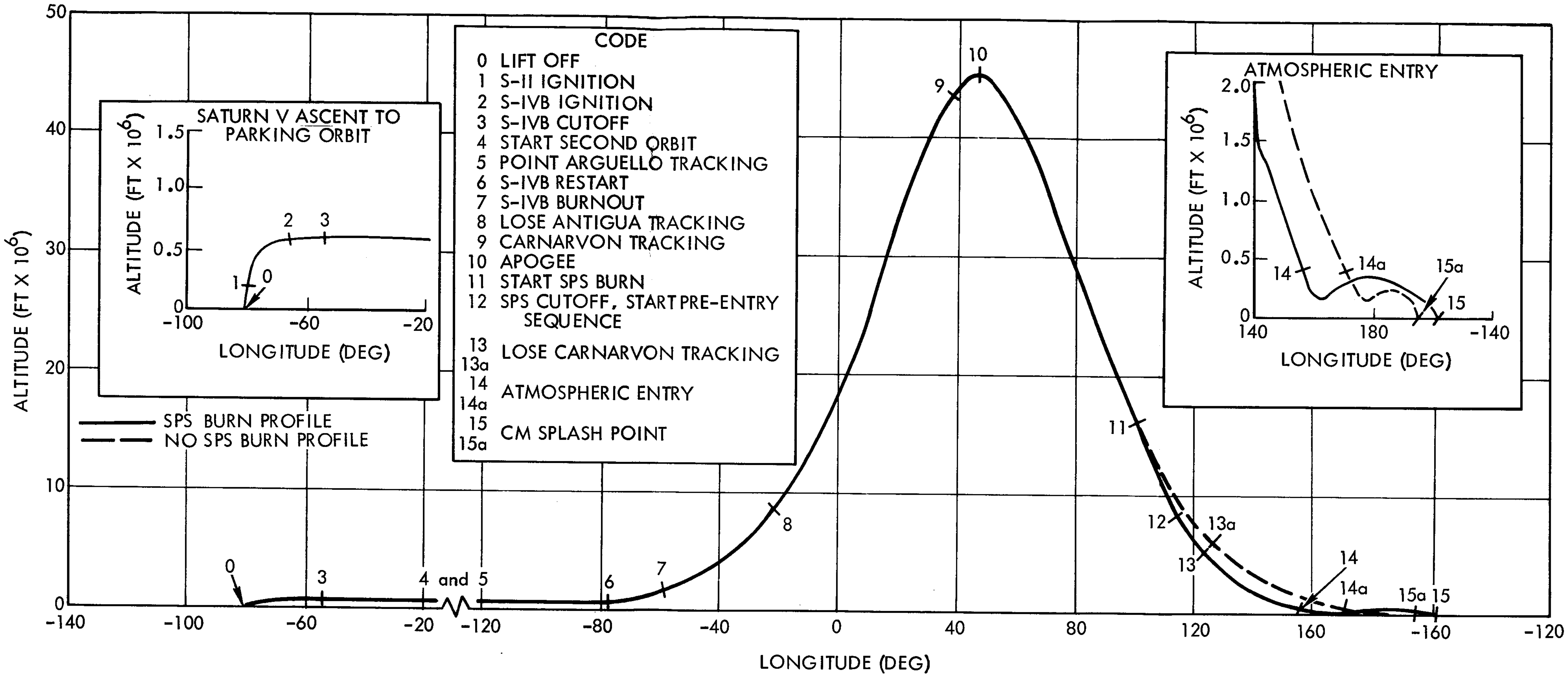

Figure 5-2. Altitude - Longitude History

Table 5-1. Time Sequence of Events

Phase Event	Time From Liftoff (hr:min:sec, GMT)
SPS Burn Profile	
Saturn V Ascent to Parking Orbit	
Liftoff	13:00:00
End Vertical Rise, Start Pitchover	13:00:12.00
S-IC Center Engine Cutoff	13:02:22.13
S-IC Outboard Engine Cutoff, S-IC Separation	13:02:26.13
S-II Ignition	13:02:29:93
S-IC/S-II Interstage Adapter Jettison	13:02:56.13
Launch Escape System Jettison	13:03:01.13
S-II Engine Cutoff, S-II Jettison, and S-IVB Ignition	13:08:37.01
S-IVB Engine Cutoff Into Earth Parking Orbit	13:11:29.34
Earth Parking Orbit	
Start of Earth Parking Orbit	13:11:29.34
Start of Second Orbit	~ 14:38:00
Acquisition of Point Arguello Tracking	16:00:37.69
End of Earth Parking Orbit	16:11:37.69
Second S-IVB Burn	
Start of S-IVB Second Burn	16:11:37.69
Burnout of S-IVB	16:16:27.14
Earth Intersecting Coast	
Start of Coast	16:16:27.14
Los Antigua Tracking	16:28:30.00
S-IVB Jettison	16:16:57.14
Acqure Carnarvon Tracking	17:52:02.20
Apogee of Coast (7,467 n mi Altitude)	18:15:17.32
Update Spacecraft State Vector (Position and Velocity)	19:36:00.00
End of Earth Intersecting Coast	19:50:37.33
SPS Burn	
Start of SPS Burn	19:50:37.33
SPS Cutoff	19:59:27.33
Pre-entry Sequence	
Start of Coast to Entry	19:59:27.33
Lose Carnarvon Tracking	20:03:15.28
SM Jettison and Assume Entry Attitude	20:05:40.00
400,000 ft Altitude	20:10:49.93
Atmospheric Entry	
Start of Entry Trajectory	20:10:49.93
Pullout to Horizontal Flight, Start Roll Maneuvering	20:12:06.29
Drogue Chute Deployment at 24,000 ft	20:25:32.65
Main Parachute Deployment at 11,000 ft	20:26:06.27
Earth Landing	20:26:40.88
No SPS Burn Profile*	
Pre-entry Sequence	
Start of Coast to Entry	19:50:37.33
Lose Carnarvon Tracking	20:05:56.73
SM Jettison and Assume Entry Attitude	20:12:00.00
400,000 ft	20:17:57.63
Atmospheric Entry	
Start of Entry Trajectory	20:17:57.63
Pullout to Horizontal Flight, Start Roll Maneuvering	20:19:22.23
Droge Chute Deployment at 24,000 ft	20:28:11.29
Main Chute Deployment at 11,000 ft	20:28:46.65
Earth Landing	20:29:22.94

*The event times are the same through the Earth Intersecting Coast phase.

Table 5-2. Saturn V Ascent to Orbit/Discrete Events Summary

Event	Time From Liftoff (sec)	Altitude (ft)	Latitude (deg)	Longitude (deg)	Inertial Velocity (ft/sec)	Flight Path Angle (deg)	Azimuth Angle (deg)
Liftoff	0.0	0	28.647	-80.636	1340	0.000	90.000
End Vertical Rise, Start Pitchover	12.00	638	28.647	-80.636	1345	4.754	89.977
S-IC Center Engine Cutoff	142.13	174,703	28.838	-79.965	8201	20.621	75.491
S-IC Outboard Engine Cutoff, S-IC Separation	146.13	186,443	28.860	-79.887	8642	20.108	75.372
S-II Ignition	149.93	197,548	28.881	-79.811	8601	19.440	75.413
S-IC/S-II Interstage Adapter Jettison	176.13	267,297	29.030	-79.263	9000	15.993	75.549
Launch Escape System Jettison	181.13	279,569	29.060	-79.154	9089	15.421	75.577
S-II Engine Cutoff, S-II Jettisoned, and S-IVB Ignition	517.01	596,852	31.700	-66.028	21,922	0.754	81.360
S-IVB Engine Cutoff Into Earth Parking Orbit	689.34	607,582	32.711	-53.987	25,581	0.000	88.044

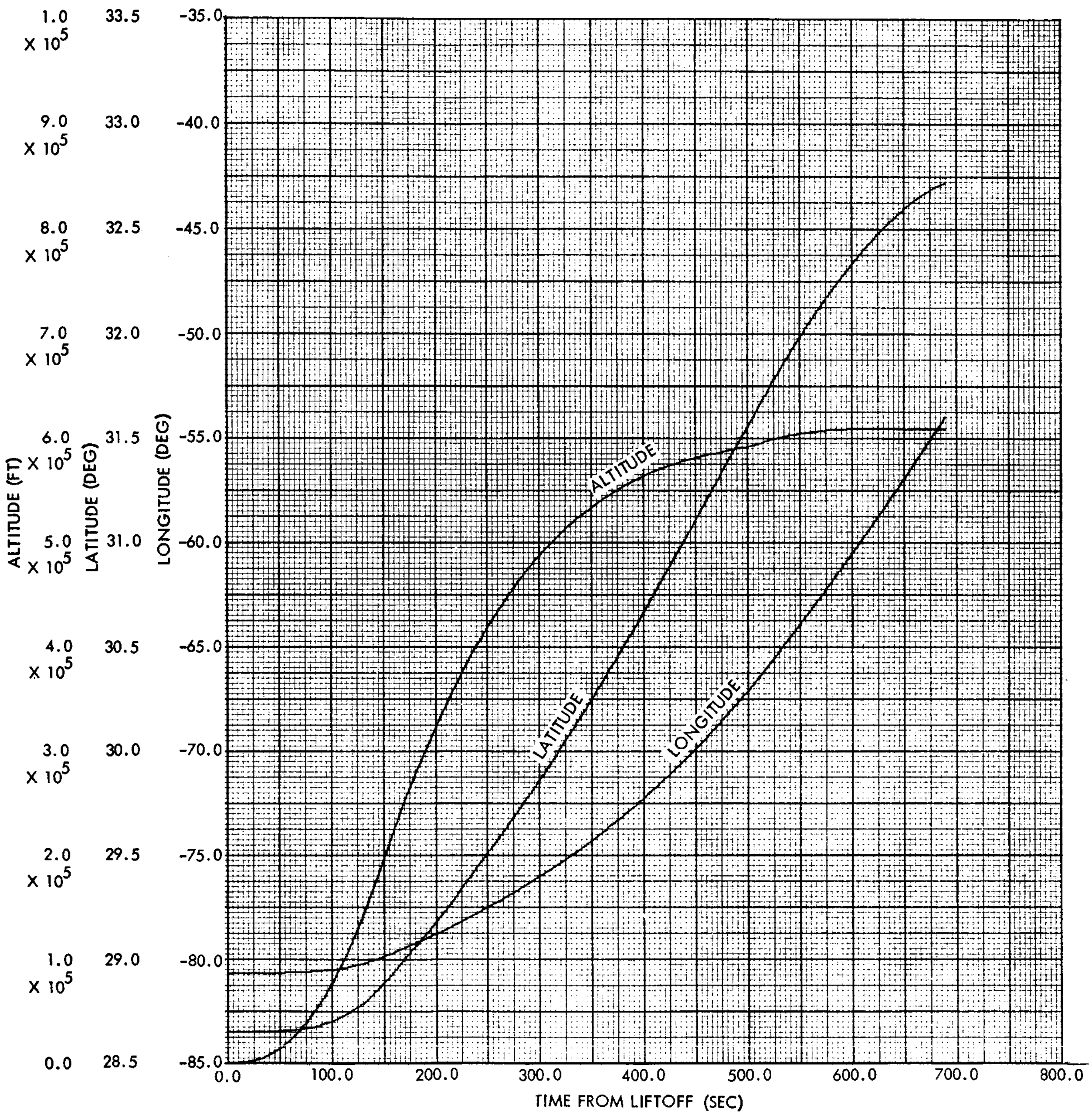

Figure 5-3. Saturn V Ascent to Orbit/Altitude, Latitude, and Longitude

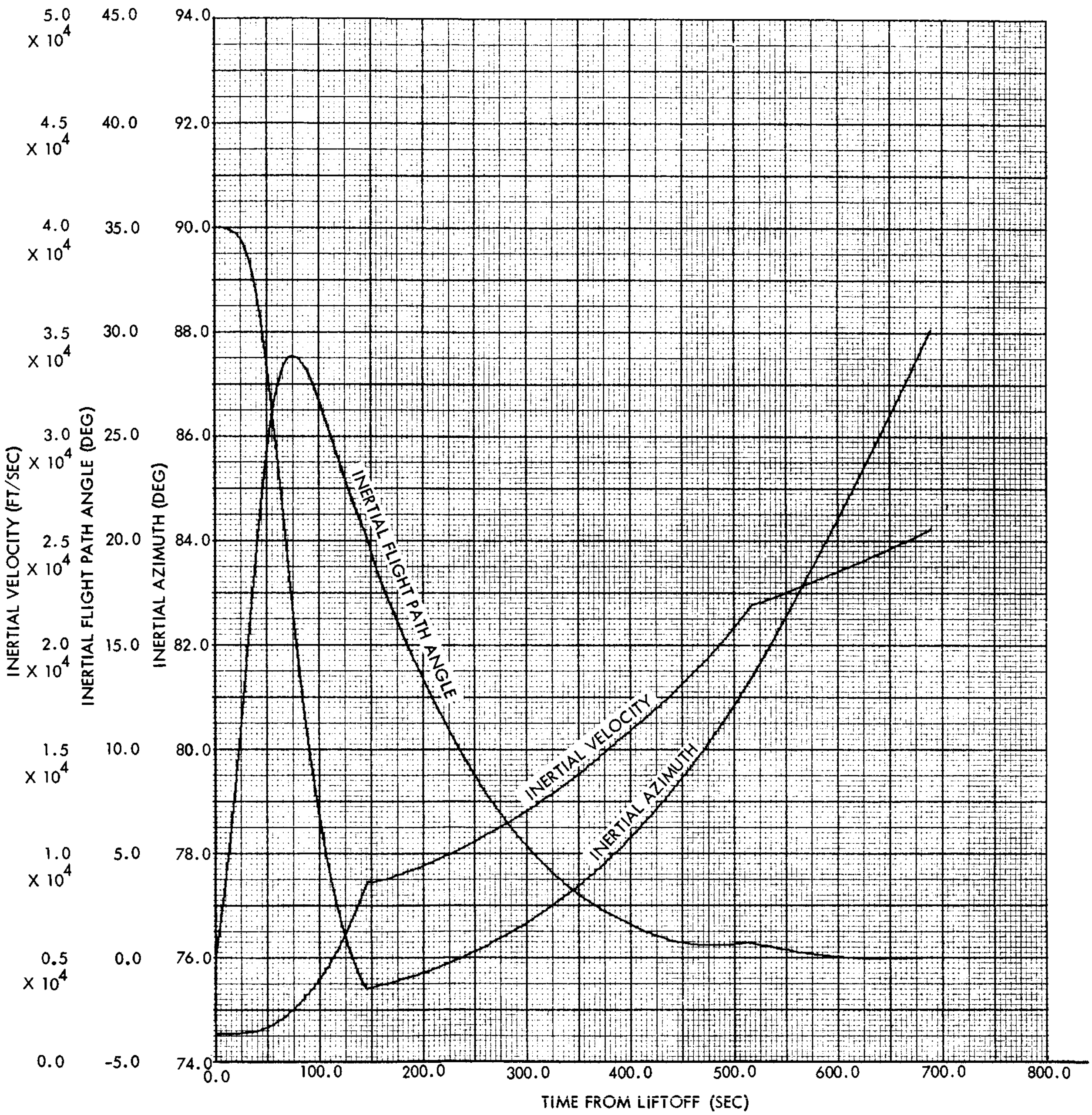

Figure 5-4. Saturn V Ascent to Orbit/Inertial Velocity, Flight Path Angle, and Azimuth

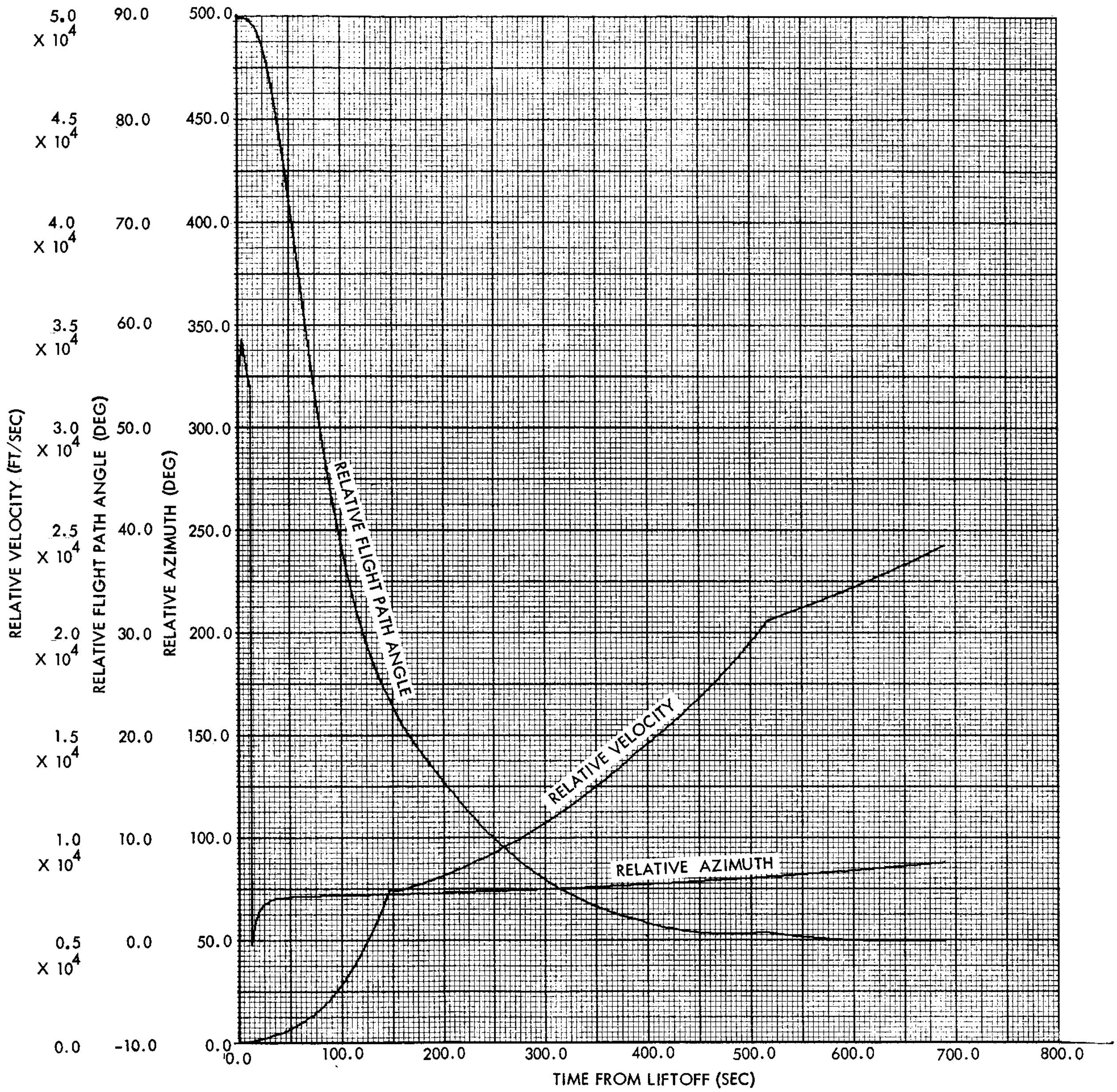

Figure 5-5. Saturn V Ascent to Orbit/Relative Velocity, Flight Path Angle, and Azimuth

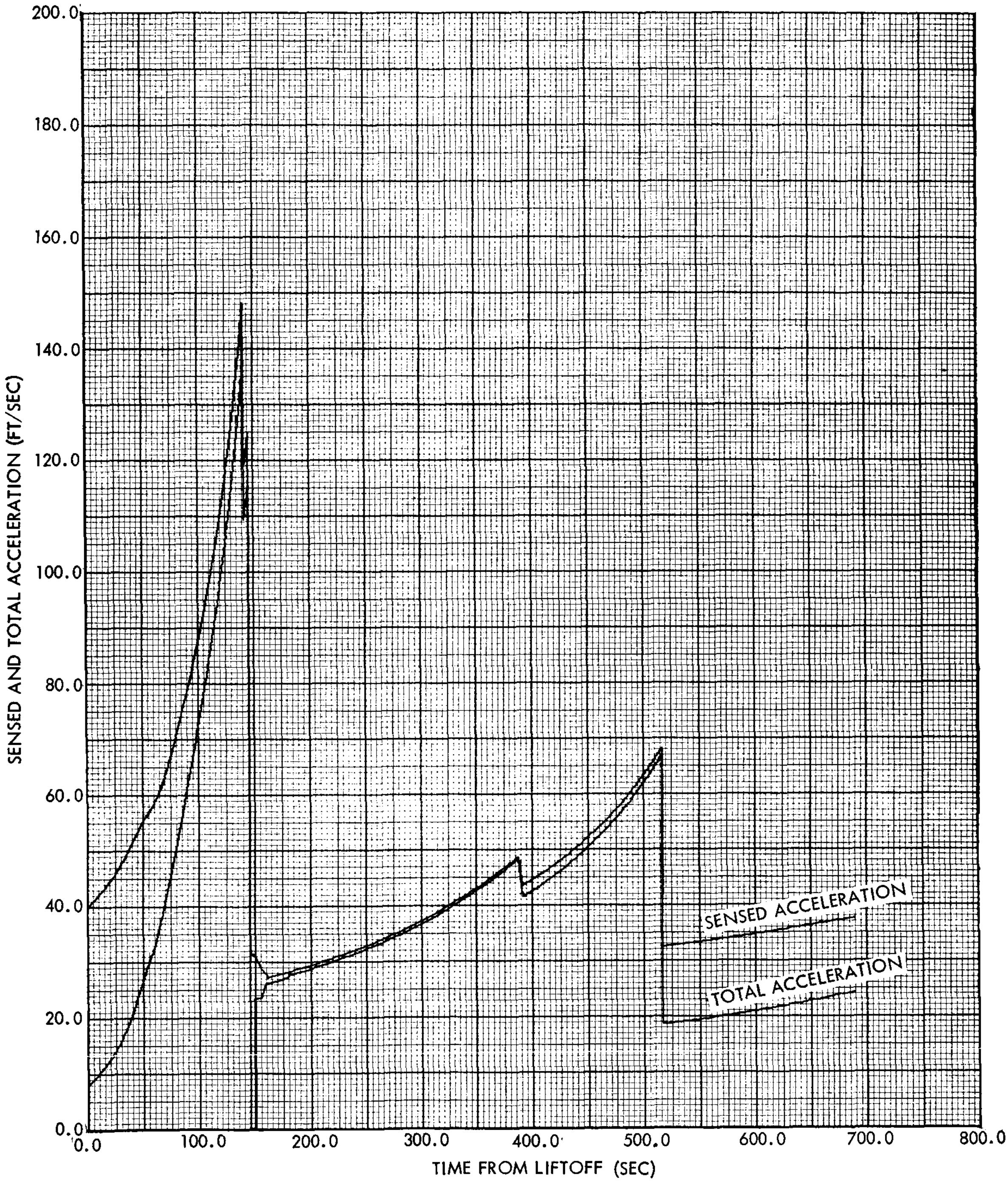

Figure 5-6. Saturn V Ascent to Orbit/Sensed and Total Acceleration

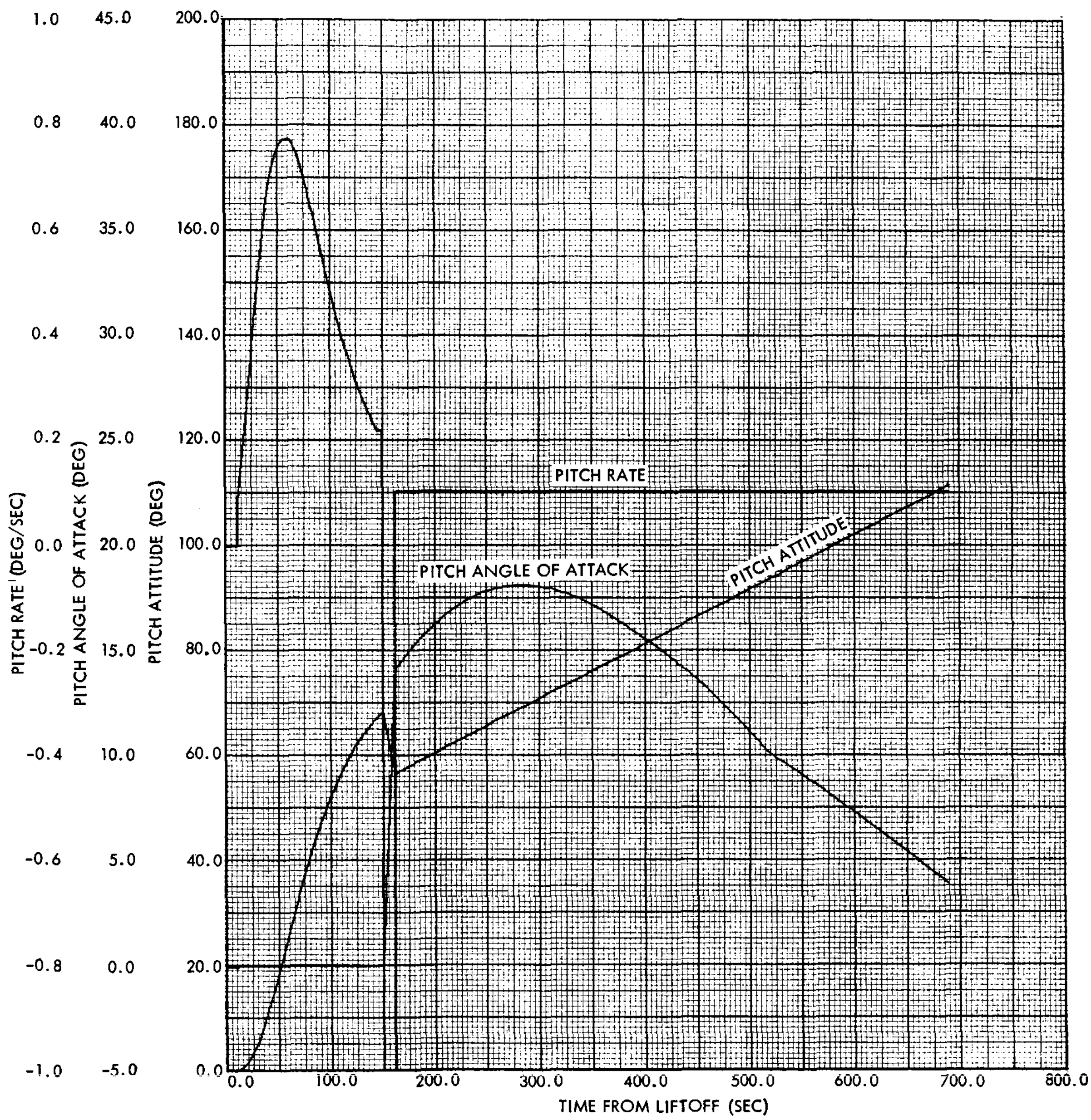

Figure 5-7. Saturn V Ascent to Orbit/Pitch Rate, Pitch Attitude, and Pitch Angle of Attack

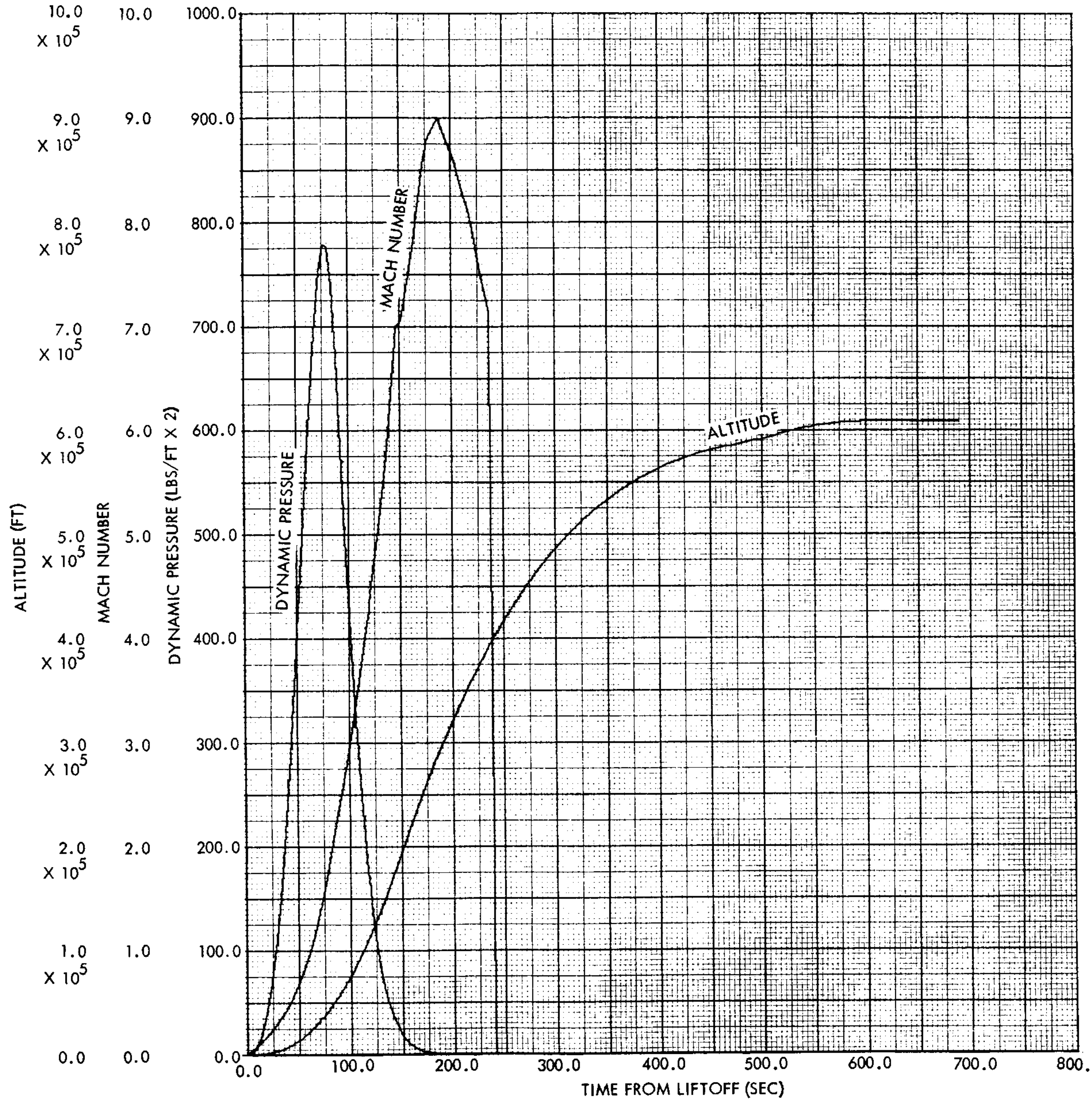

Figure 5-8. Saturn V Ascent to Orbit/Altitude, Mach Number, and Dynamic Pressure

Table 5-3. Earth Parking Orbit/Discrete Events Summary

Event	Time From Liftoff (sec)	Altitude (ft)	Latitude (deg)	Longitude (deg)	Inertial Velocity (ft/sec)	Flight Path Angle (deg)	Azimuth Angle (deg)
Start of Earth Parking Orbit	689	607,582	32.711	-53.987	25,581	0.000	88.044
Start of Second Orbit	5880	607,131	32.340	-82.811	25,581	0.001	84.463
Acquisition of Point Arguello Tracking	10,838	601,931	27.884	-128.350	25,584	0.005	72.127
End of Earth Parking Orbit	11,498	606,306	31.559	-79.106	25,582	-0.001	99.260

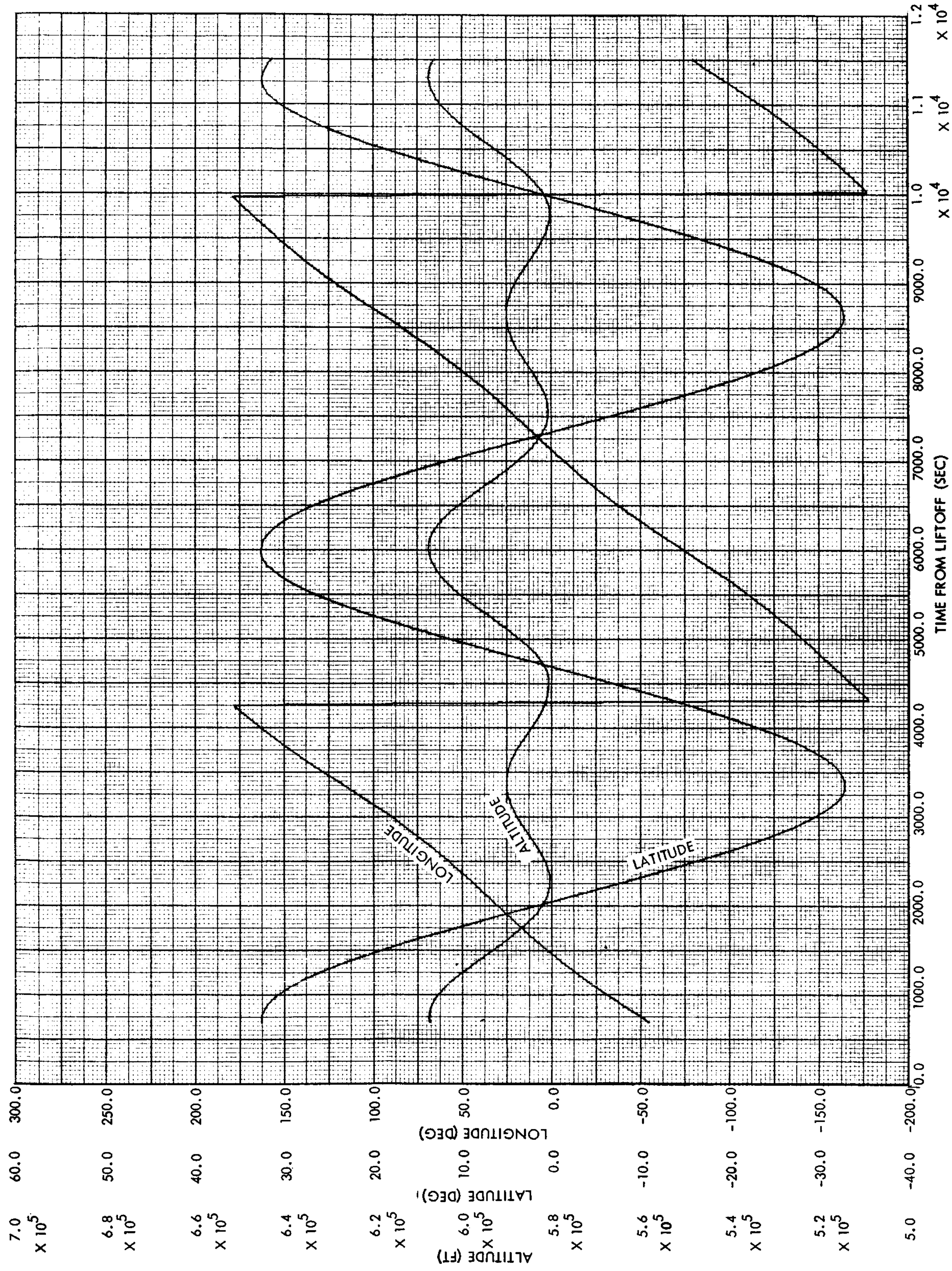

Figure 5-9. Earth Parking Orbit-Altitude, Latitude, and Longitude

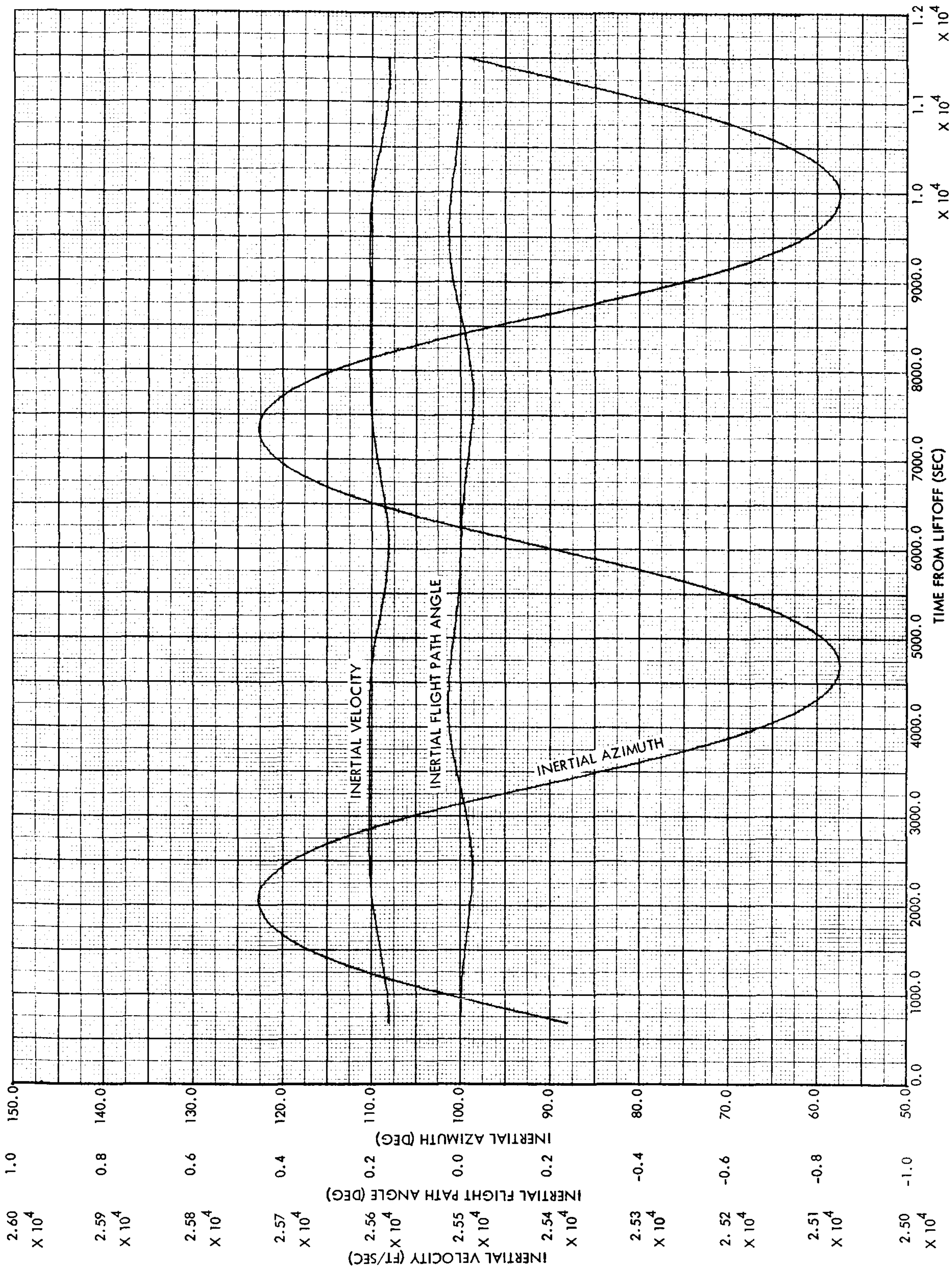

Figure 5-10. Earth Parking Orbit/Inertial Velocity, Flight Path Angle, and Azimuth

Table 5-4. Second S-IVB Burn/Discrete Events Summary

Event	Time From Liftoff (sec)	Altitude (ft)	Latitude (deg)	Longitude (deg)	Inertial Velocity (ft/sec)	Flight Path Angle (deg)	Azimuth Angle (deg)
Start of S-IVB Second Burn	11,498	606,306	31.559	-79.106	25,582	-0.001	99.260
Burnout of S-IVB	11,787	1,692,548	26.488	-58.450	30,371	13.447	109.944

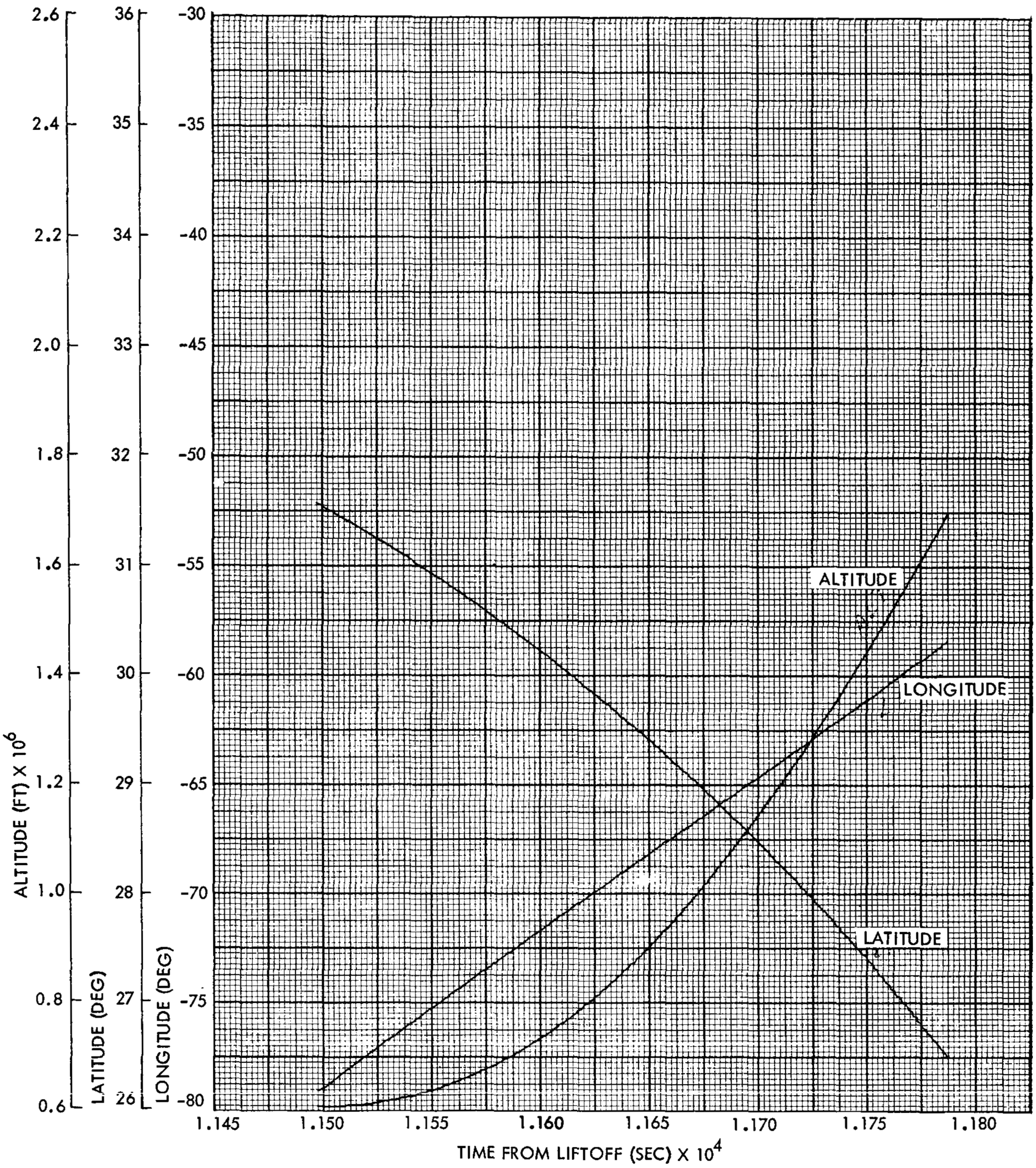

Figure 5-11. Second S-IVB Burn/Altitude, Latitude, and Longitude

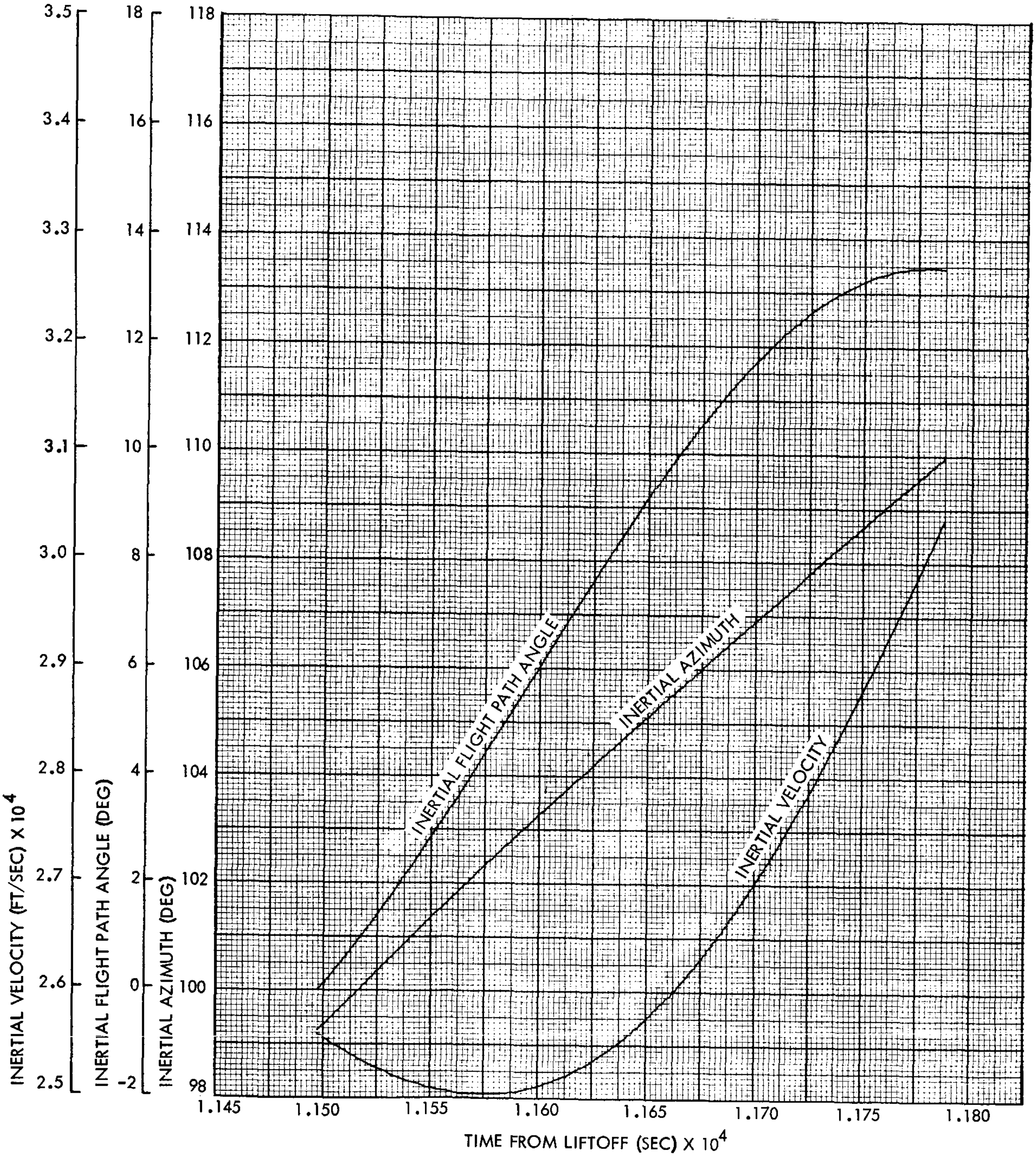

Figure 5-12. Second S-IVB Burn/Inertial Velocity, Flight Path Angle, and Azimuth

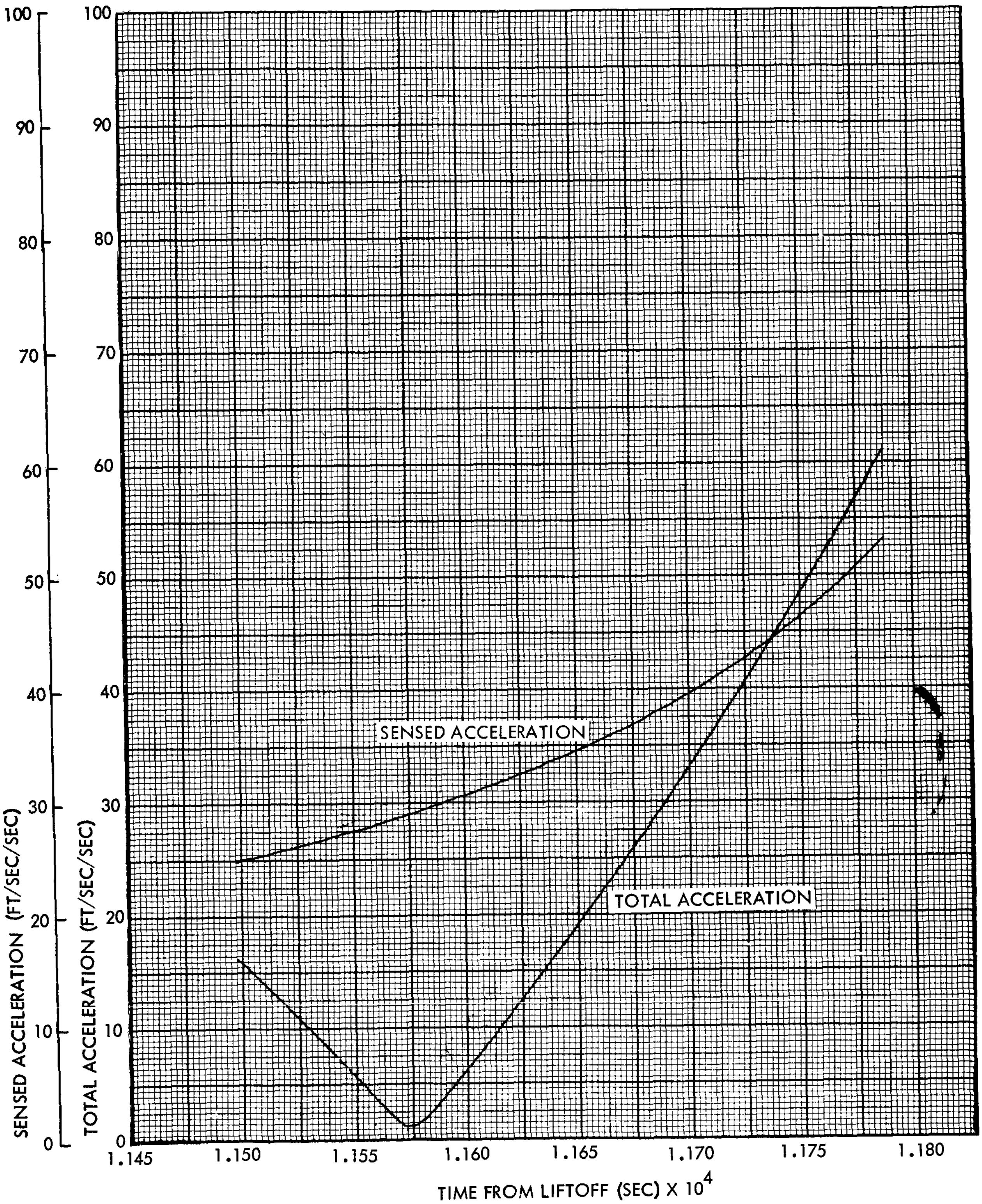

Figure 5-13. Second S-IVB Burn/Sensed and Total Acceleration

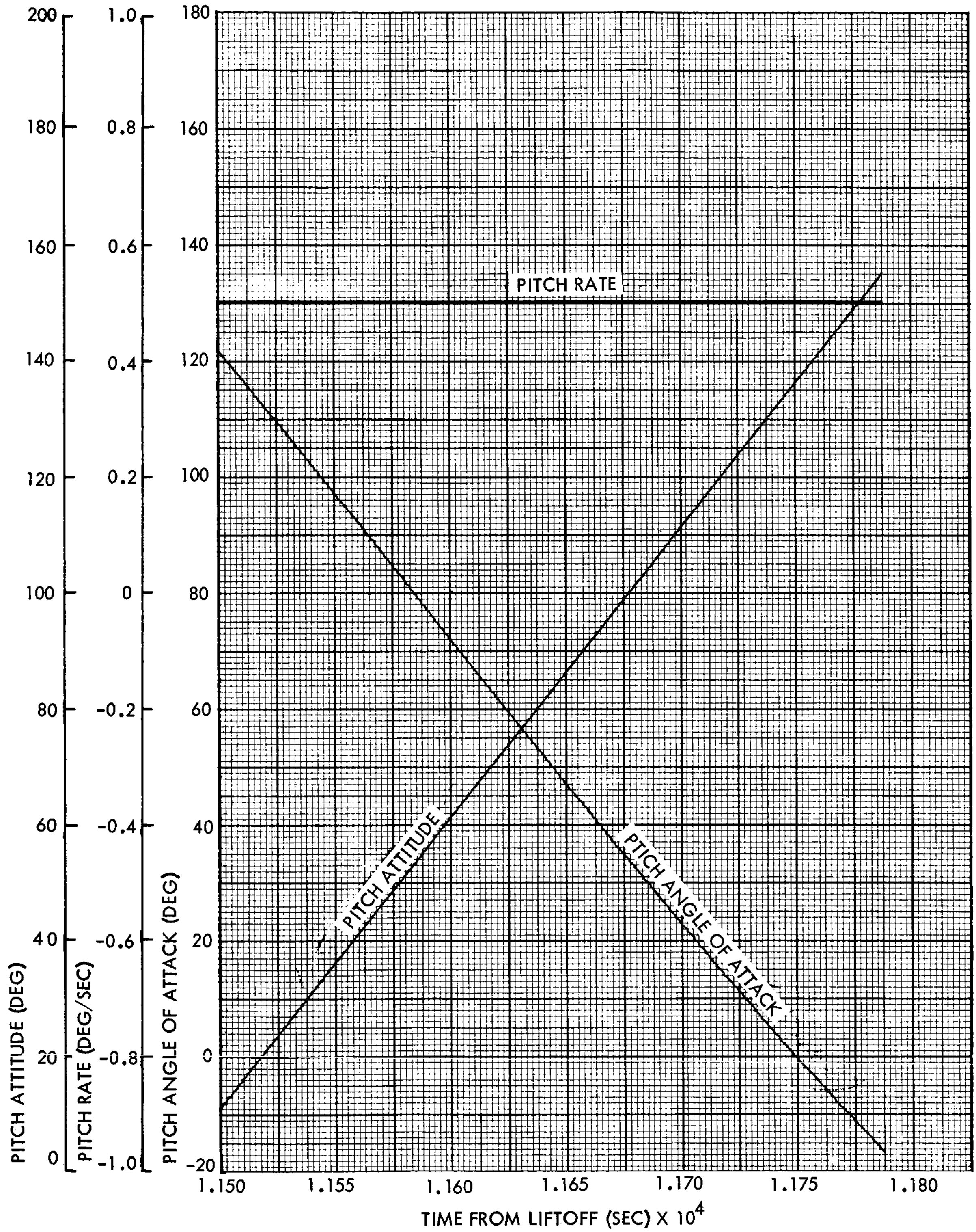

Figure 5-14. Second S-IVB Burn/Pitch Attitude, Pitch Rate, and Pitch Angle of Attack

Table 5-5. Earth Intersection Coast/Discrete Events Summary

Event	Time From Liftoff (sec)	Altitude (ft)	Latitude (deg)	Longitude (deg)	Inertial Velocity (ft/sec)	Flight Path Angle (deg)	Azimuth Angle (deg)
Start of Coast	11,787	1,692,548	26.488	-58.450	30,371	13.447	109.944
S-IVB Jettison	11,817	2,390,000	24.	-52.	29,800	15.	113.
Lose Antigua Tracking	12,510	8,600,000	7.	-22.	25,000	26.	122.
Acquire Carnarvon Tracking	17,522	43,731,244	-31.076	37.648	10,595	12.843	100.937
Apogee of Coast (7467 n mi Altitude)	18,917	45,368,525	-32.625	46.236	10,075	0.000	93.333
Update Spacecraft State Vector (Position and Velocity)	23,760	24,689,430	-20.838	85.943	17,148	-31.365	64.232
End of Earth Intersecting Coast	24,637	16,092,420	-11.334	100.370	20,914	-30.386	59.189

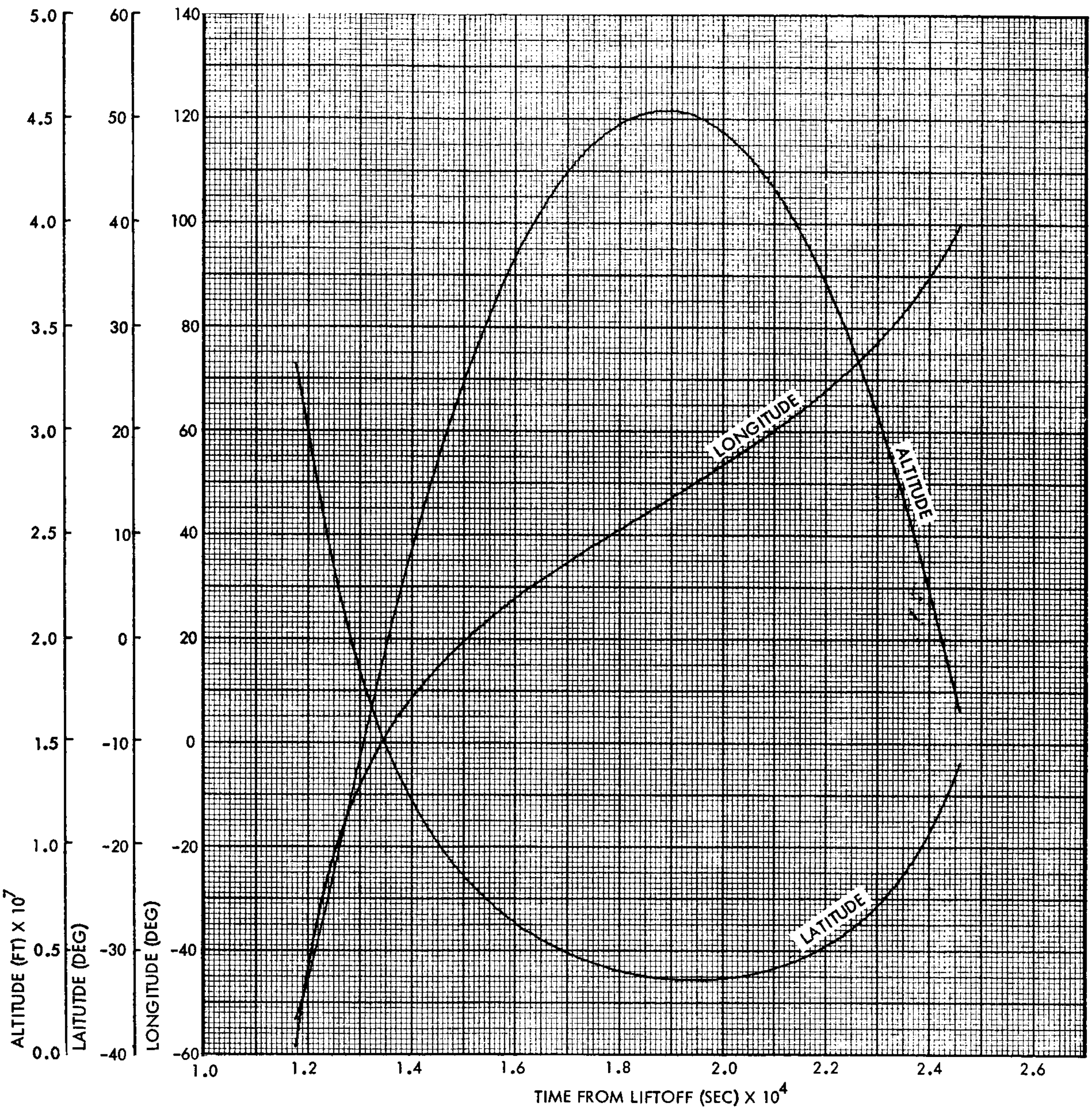

Figure 5-15. Earth Intersecting Coast/Altitude, Latitude, and Longitude

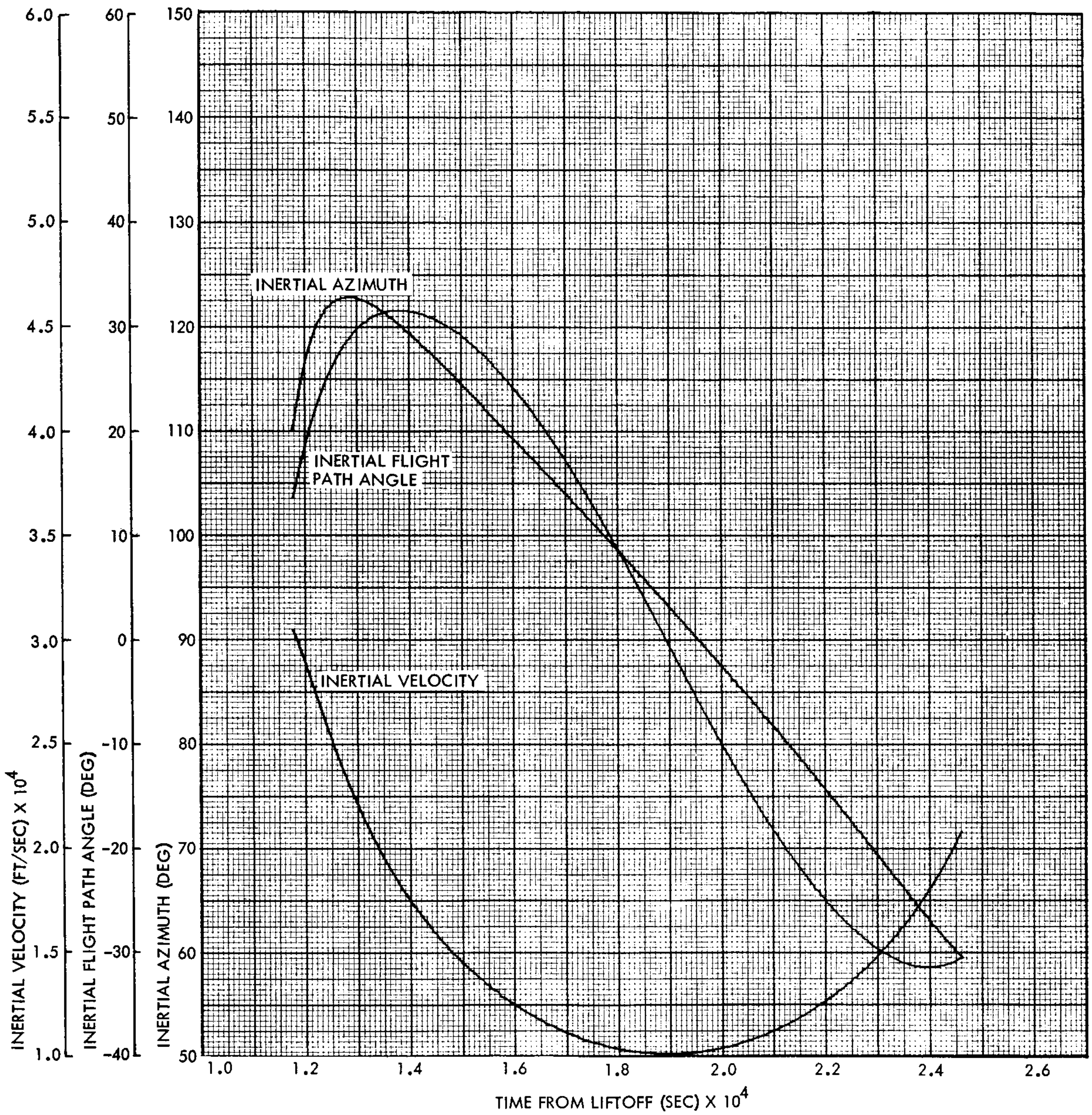

Figure 5-16. Earth Intersecting Coast/Inertial Velocity, Flight Path Angle, and Azimuth

Table 5-6. SPS Burn/Discrete Events Summary

Event	Time From Liftoff (sec)	Altitude (ft)	Latitude (deg)	Longitude (deg)	Inertial Velocity (ft/sec)	Flight Path Angle (deg)	Azimuth Angle (deg)
Start of SPS Burn	24,637	16,092,420	-11.334	100.370	20,914	-30.386	59.189
SPS Engine Cutoff	25,167	8,595,689	-1.822	113.453	30,868	-32.546	57.430

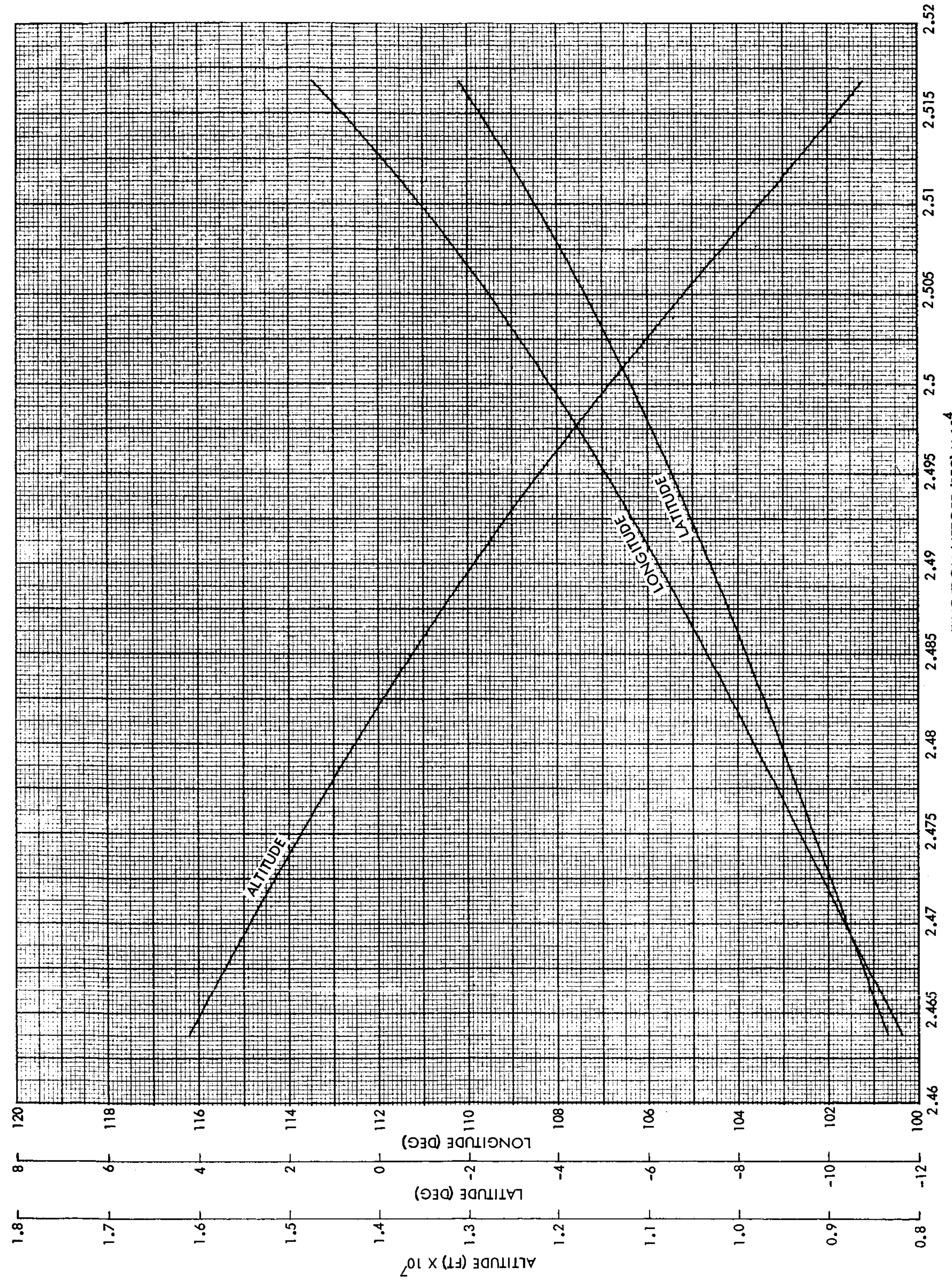

Figure 5-17. SPS Burn/Altitude, Latitude, and Longitude

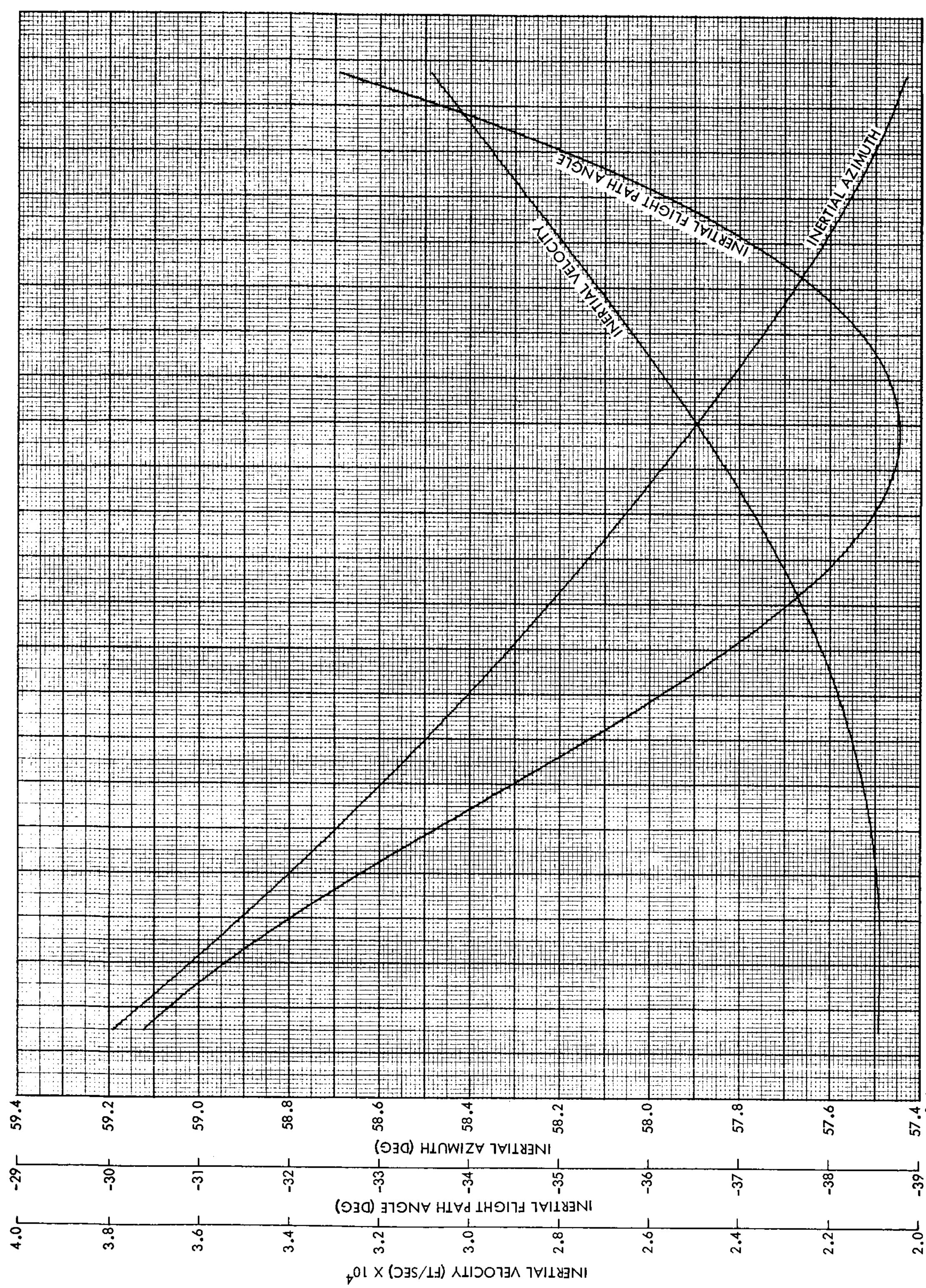

Figure 5-18. SPS Burn/Inertial Velocity, Flight Path Angle, and Azimuth

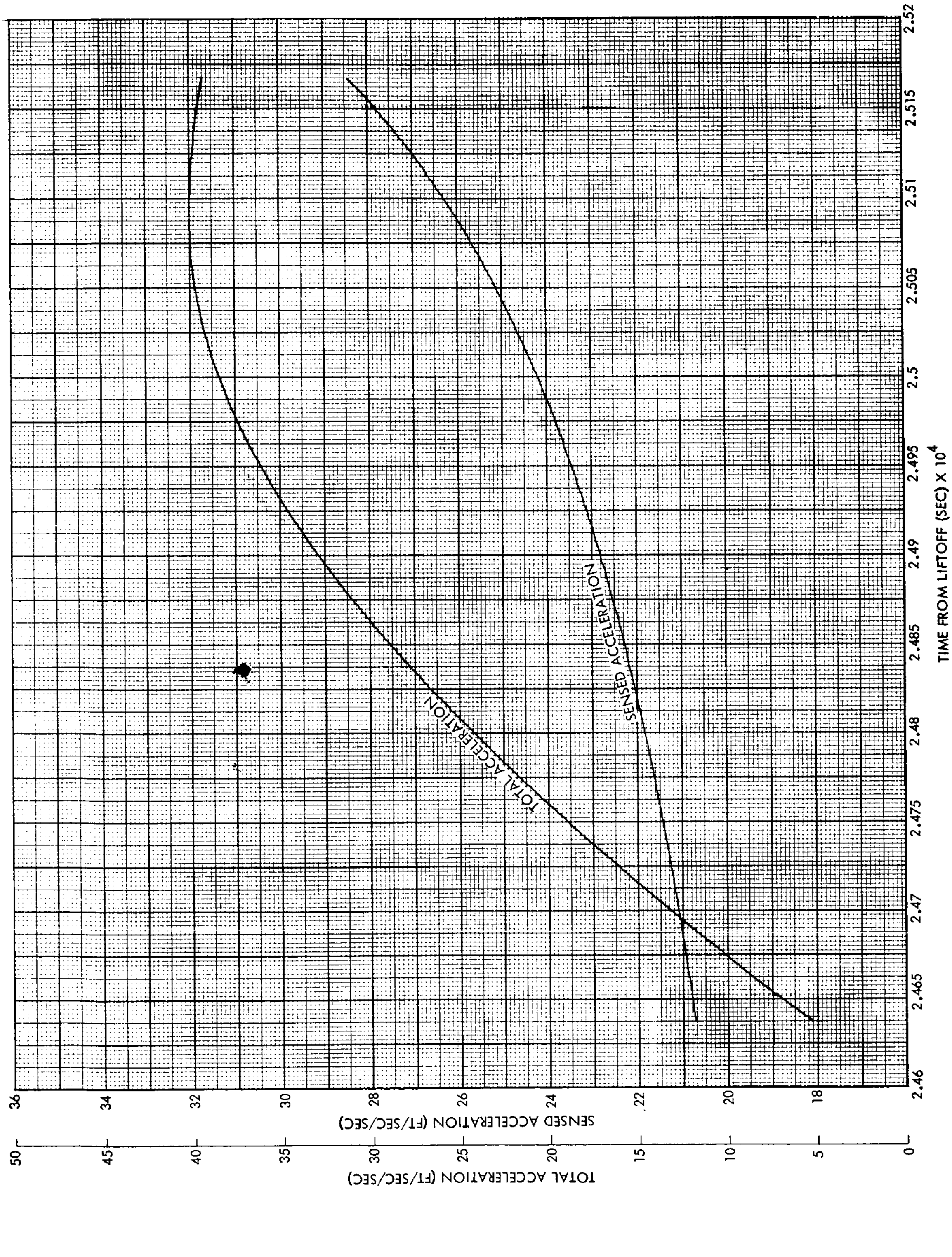

Figure 5-19. SPS Burn/Sensed and Total Acceleration

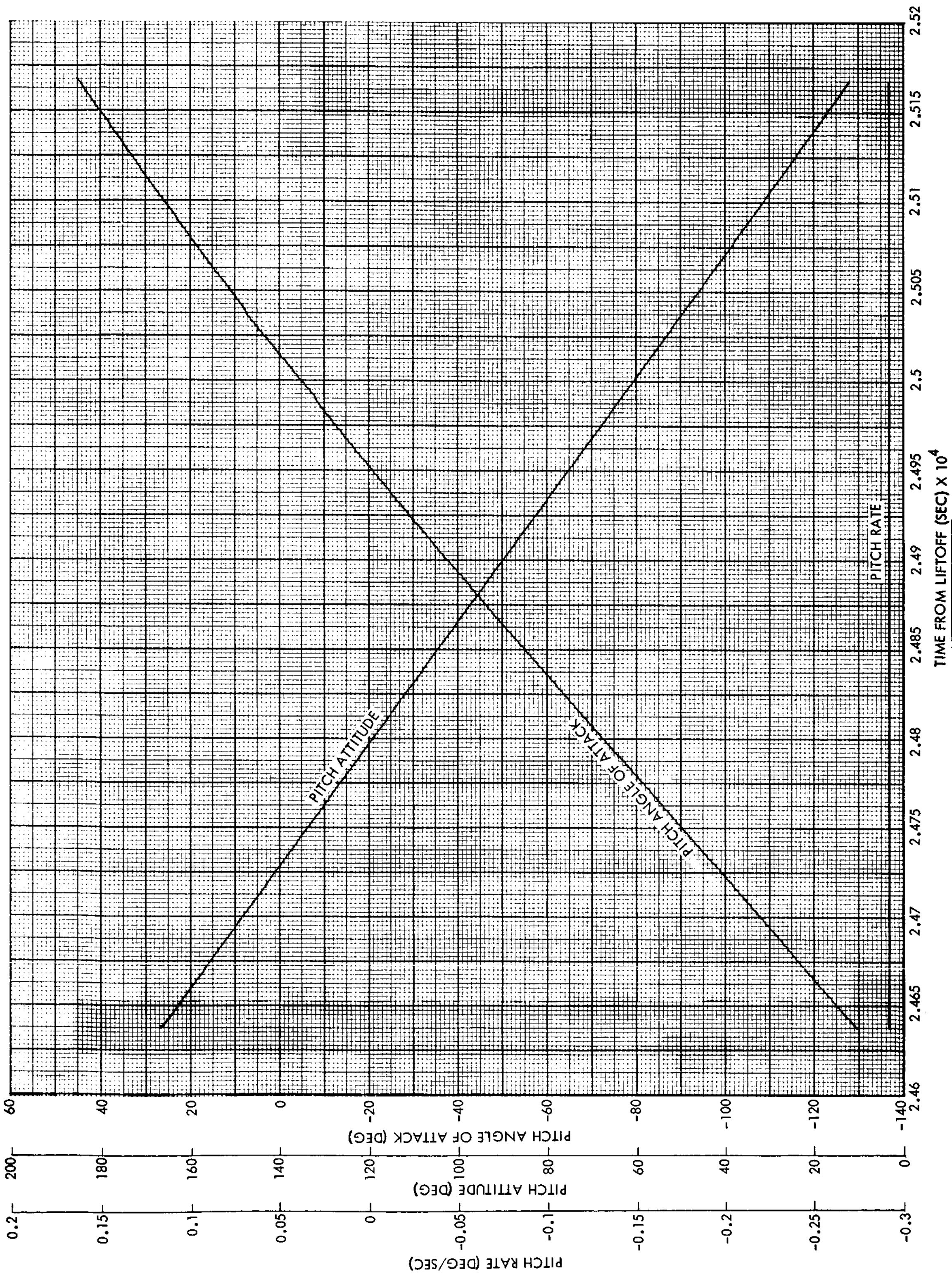

Figure 5-20. SPS Burn/Pitch Attitude, Pitch Rate, and Pitch Angle of Attack

Table 5-7. Pre-entry Sequence/Discrete Events Summary

Event	Time From Liftoff (sec)	Altitude (ft)	Latitude (deg)	Longitude (deg)	Inertial Velocity (ft/sec)	Flight Path Angle (deg)	Azimuth Angle (deg)
Start of Coast to Entry	25,167	8,595,689	-1.822	133.453	30,868	-32.546	57.430
Lose Carnarvon Tracking	25,359	5,033,034	5.284	123.585	32,921	-25,991	57.765
Jettison SM and Assume Entry Attitude	25,540	3,098,863	10.697	131.777	34,224	-20.882	58.985
400,000 ft Altitude	25,850	400,000	23.398	155.637	36,333	-7.350	66.481

Table 5-8. Pre-entry Sequence (No SPS Burn)/Discrete Events Summary

Event	Time From Liftoff (sec)	Altitude (ft)	Latitude (deg)	Longitude (deg)	Inertial Velocity (ft/sec)	Flight Path Angle (deg)	Azimuth Angle (deg)
Start of Coast to Entry	24,637	16,092,420	-11.334	100.370	20,914	-30.386	59.189
Lose Carnarvon Tracking	25,557	6,124,552	7.497	126.444	26,793	-22.885	58.156
Jettison SM and Assume Entry Attitude	25,920	2,670,529	18.495	144.424	29,505	-16.374	62.582
400,000 ft Altitude	26,278	400,000	28.950	170.851	31,592	-7.350	74.008

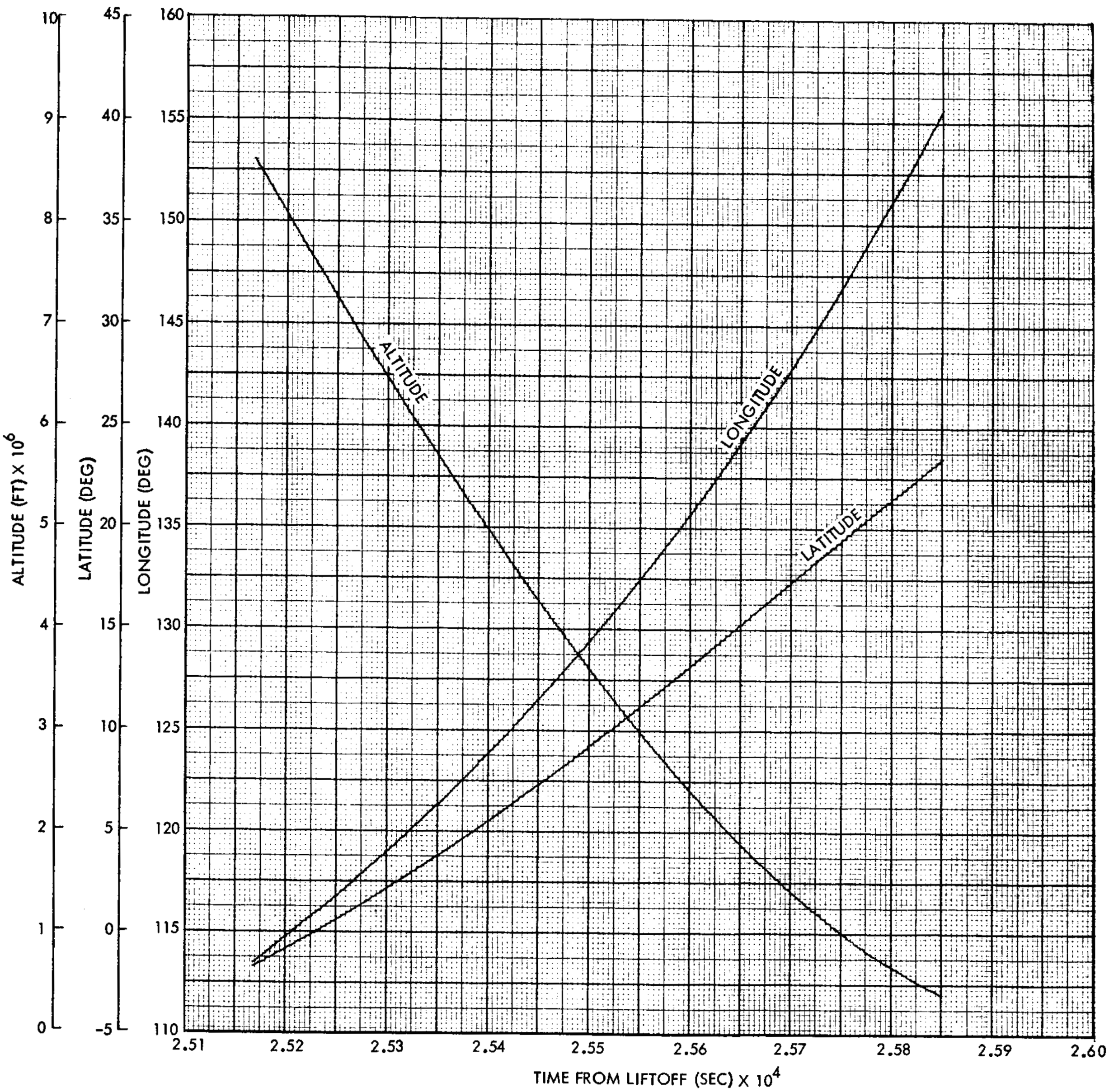

Figure 5-21. Pre-entry Sequence/Altitude, Latitude, and Longitude

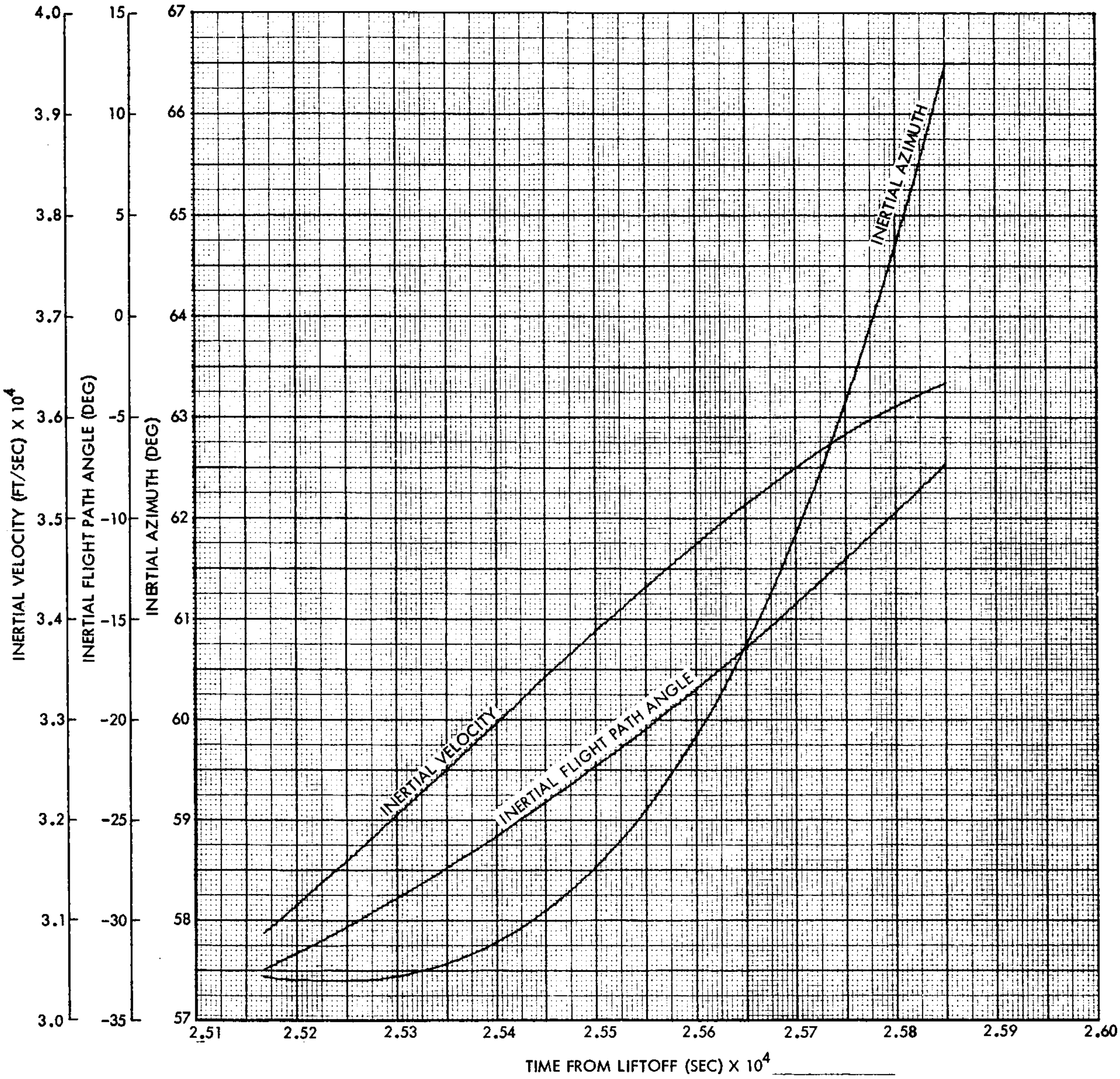

Figure 5-22. Pre-entry Sequence/Inertial Velocity, Flight Path Angle, and Azimuth

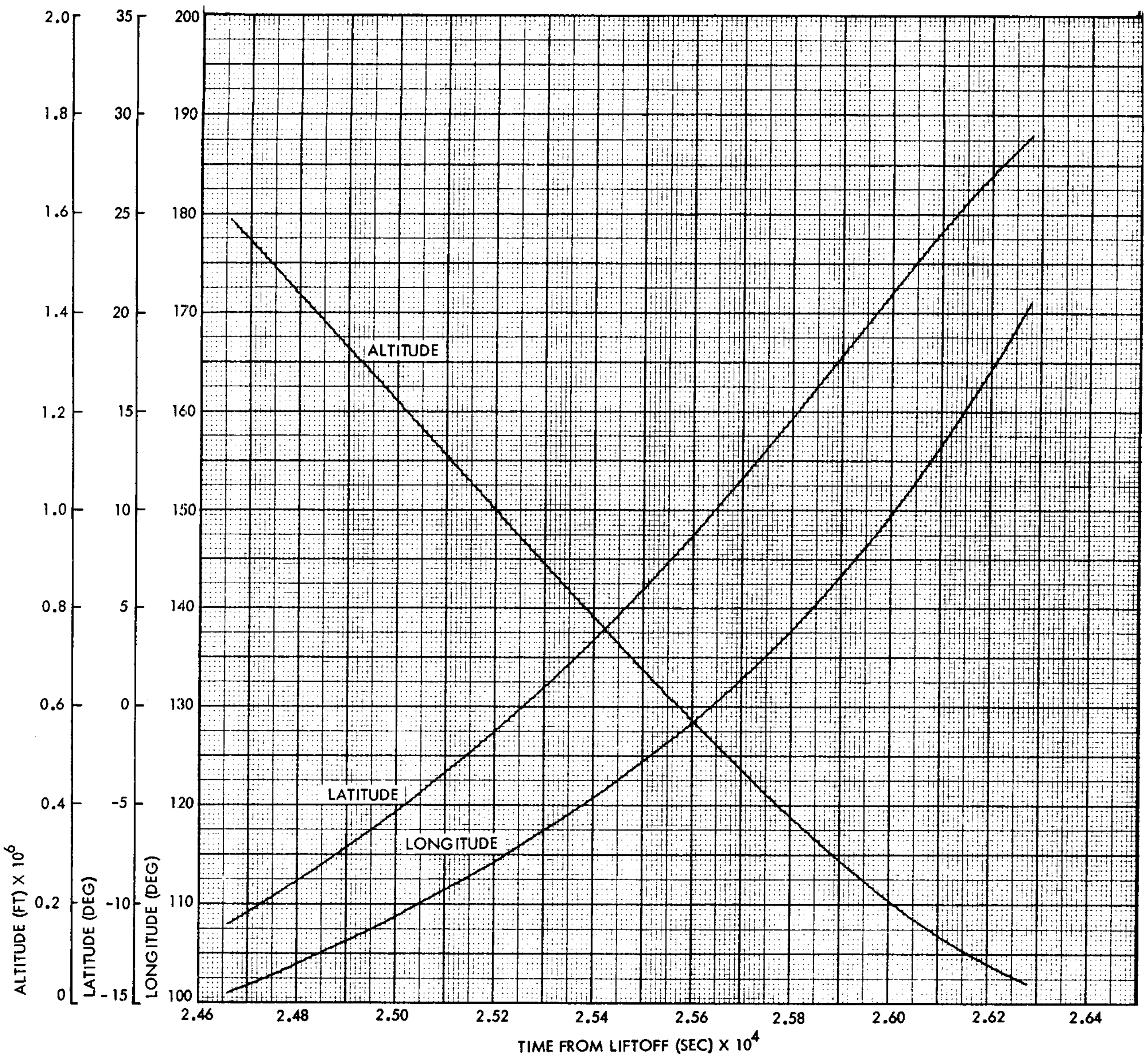

Figure 5-23. Pre-entry Sequency (No SPS Burn)/Altitude, Latitude, and Longitude

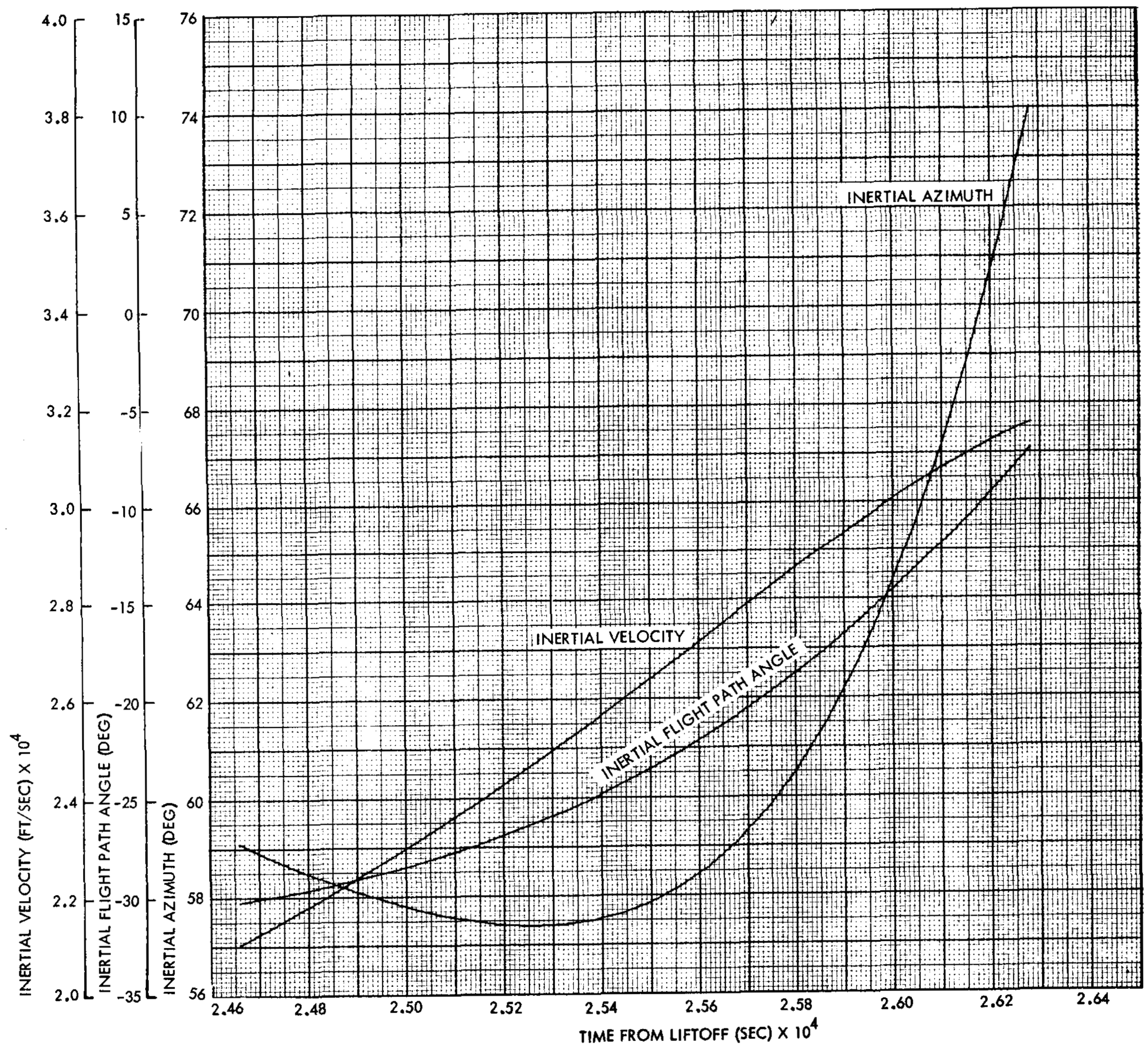

Figure 5-24. Pre-entry Sequence (No SPS Burn)/Inertial Velocity, Flight Path Angle, and Azimuth

Table 5-9. Atmospheric Entry/Discrete Events Summary

Event	Time From Liftoff (sec)	Altitude (ft)	Latitude (deg)	Longitude (deg)	Inertial Velocity (ft/sec)	Flight Path Angle (deg)	Azimuth Angle (deg)
Start of Entry Trajectory	25,850	400,000	23.398	155.637	36,333	-7.350	66.481
Pull Out to Horizontal Flight, Start Roll Maneuvering	25,926	170,362	26.126	162.702	29,798	0.000	69.753
Drogue Chute Development	26,733	24,000	32.467	-157.996	1,478	-17.004	90.363
Main Parachute, Deployment	26,766	11,000	32.466	-157.985	1,421	-14.162	90.391
Earth Landing	26,801	0	32.465	-157.976	1,391	-12.111	90.450

Table 5-10. Atmospheric Entry (No SPS Burn)/Discrete Events Summary

Event	Time From Liftoff (sec)	Altitude (ft)	(Latitude) (deg)	Longitude (deg)	Inertial Velocity (ft/sec)	Flight Path Angle (deg)	Azimuth Angle (deg)
Start of Entry Trajectory	26, 278	400,000	28.950	170.851	31, 592	-7.350	74.008
Pull Out to Horizontal Flight, Start Roll Maneuvering	26, 362	157, 728	30.641	178.235	24, 143	0.000	78.017
Drogue Chute Deployment	26, 891	24,000	32.538	-165.177	1509	-15.763	90.040
Main Chute Deployment	26, 926	11,000	32.538	-165.161	1448	-13.217	90.167
Earth Landing	26, 963	0	32.538	-165.148	1415	-11.362	90.281

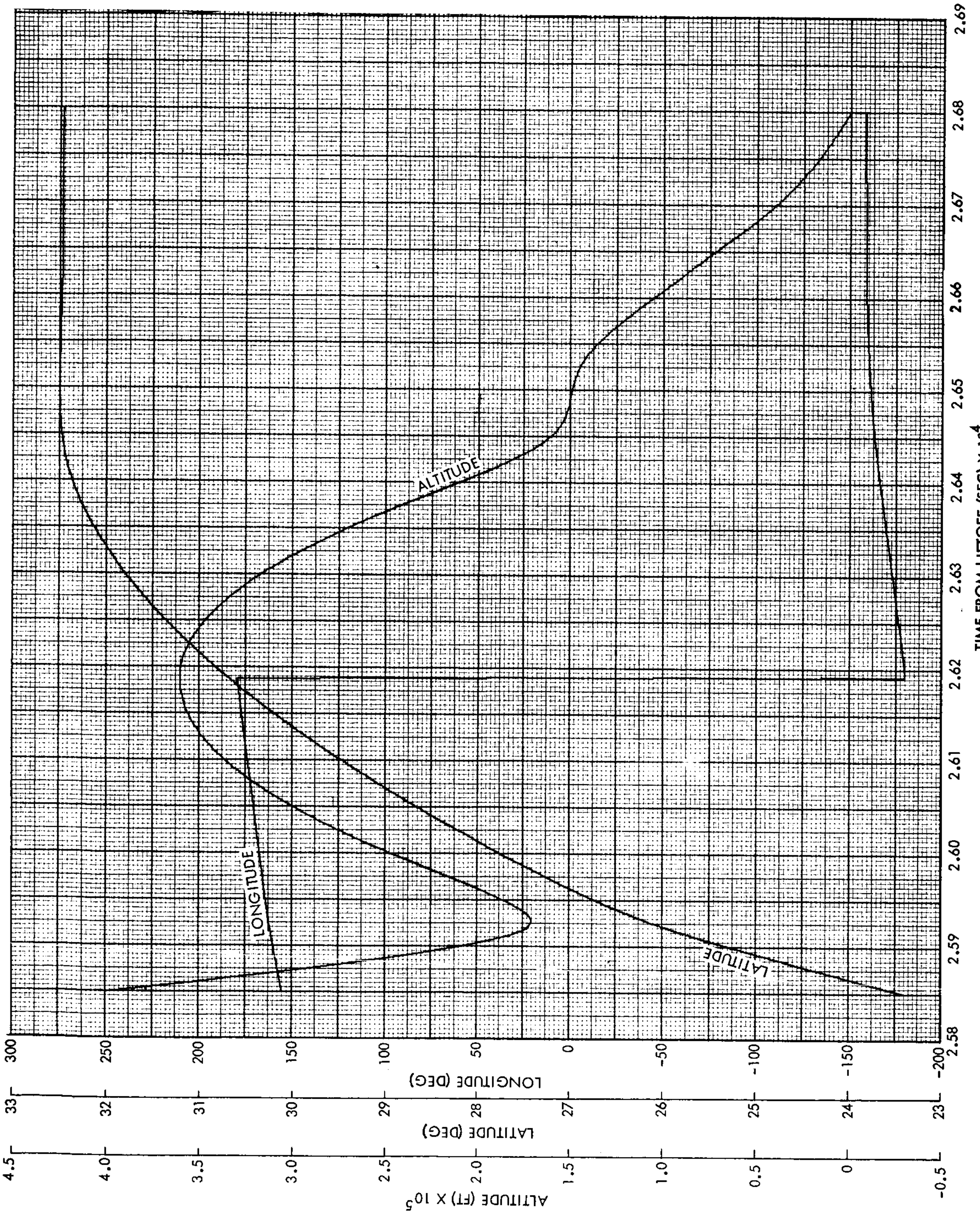

Figure 5-25. Atmospheric Entry/Altitude, Latitude, and Longitude

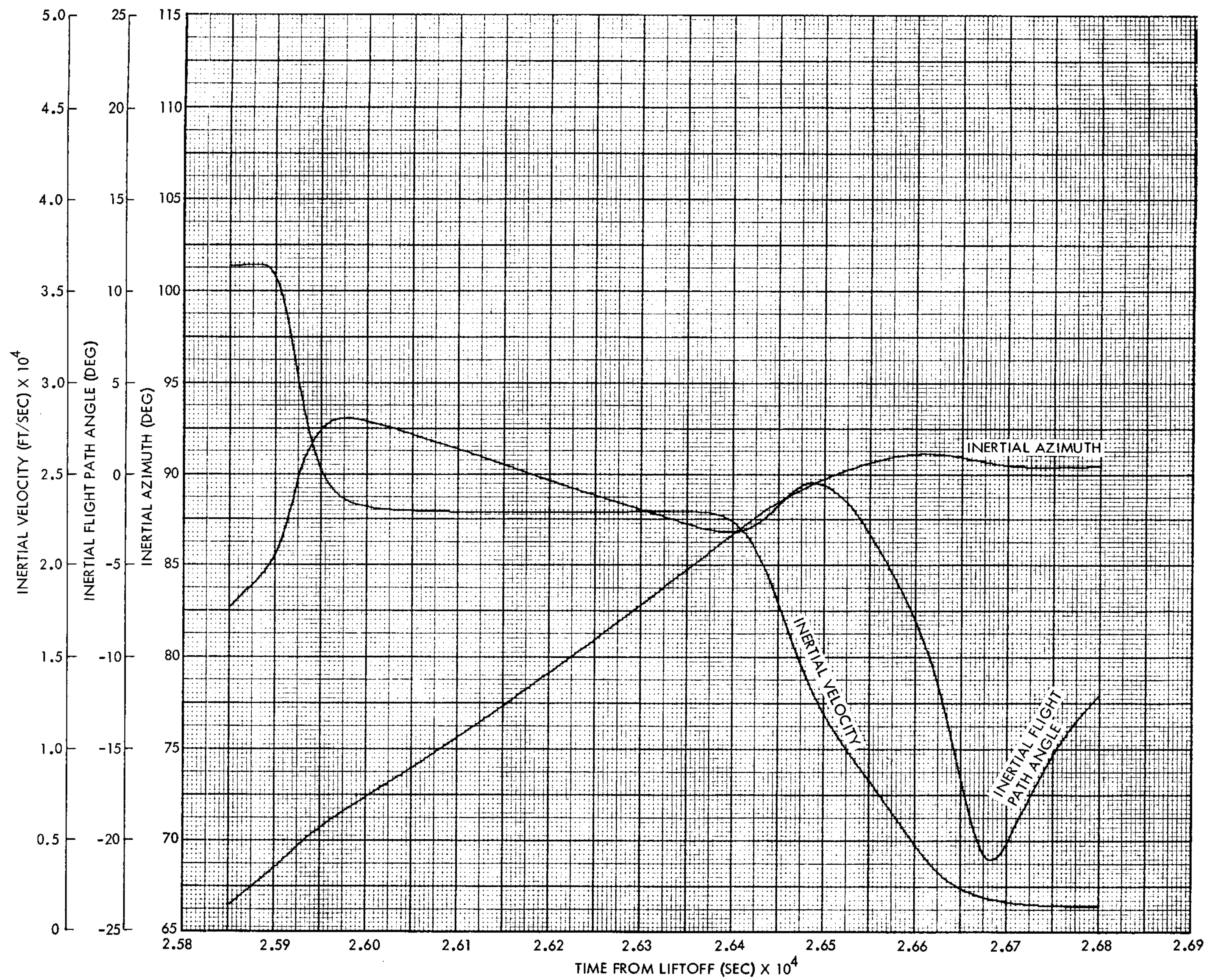

Figure 5-26. Atmospheric Entry/Inertial Velocity, Flight Path Angle, and Azimuth

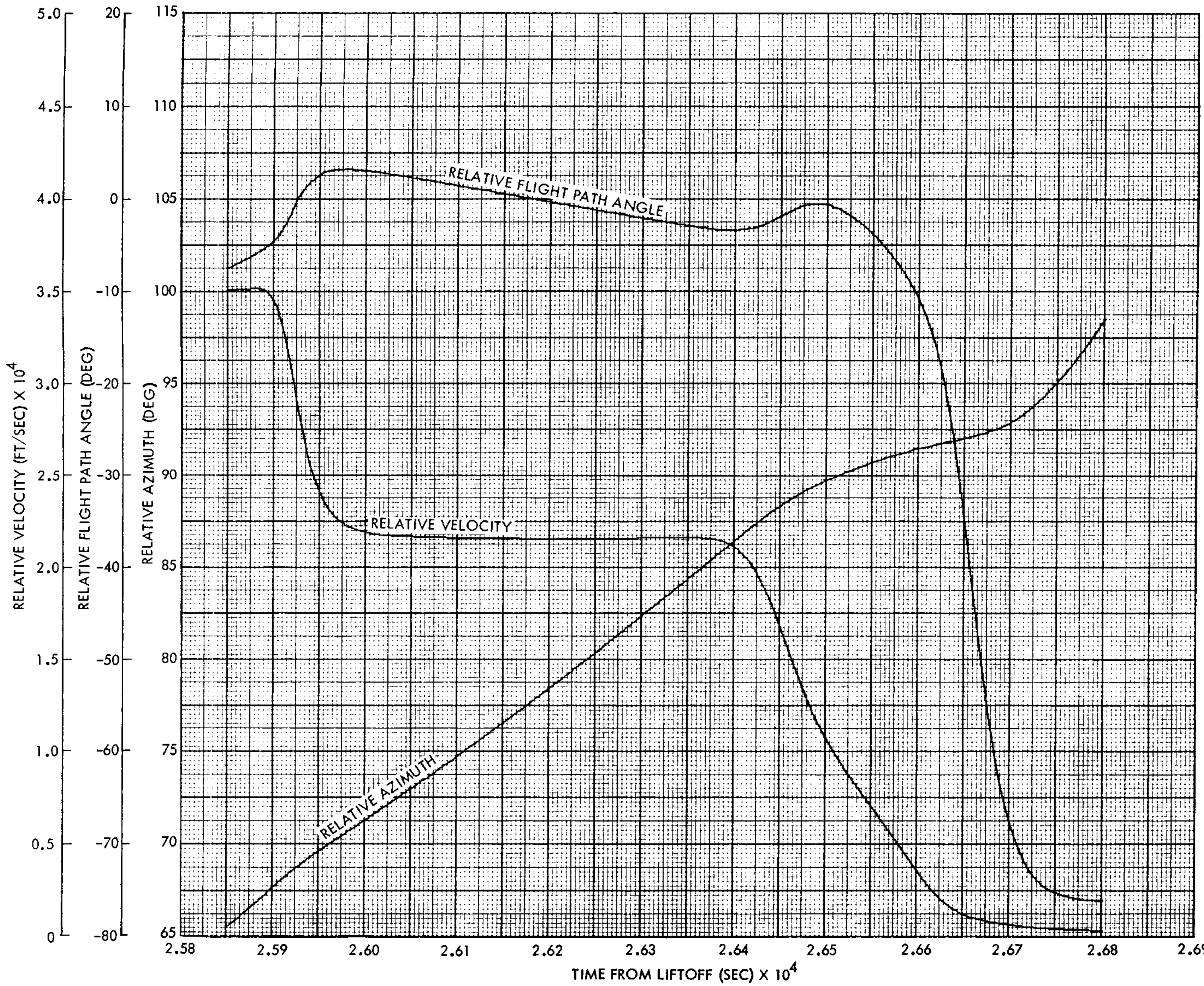

Figure 5-27. Atmospheric Entry/Relative Velocity, Flight Path Angle, and Azimuth

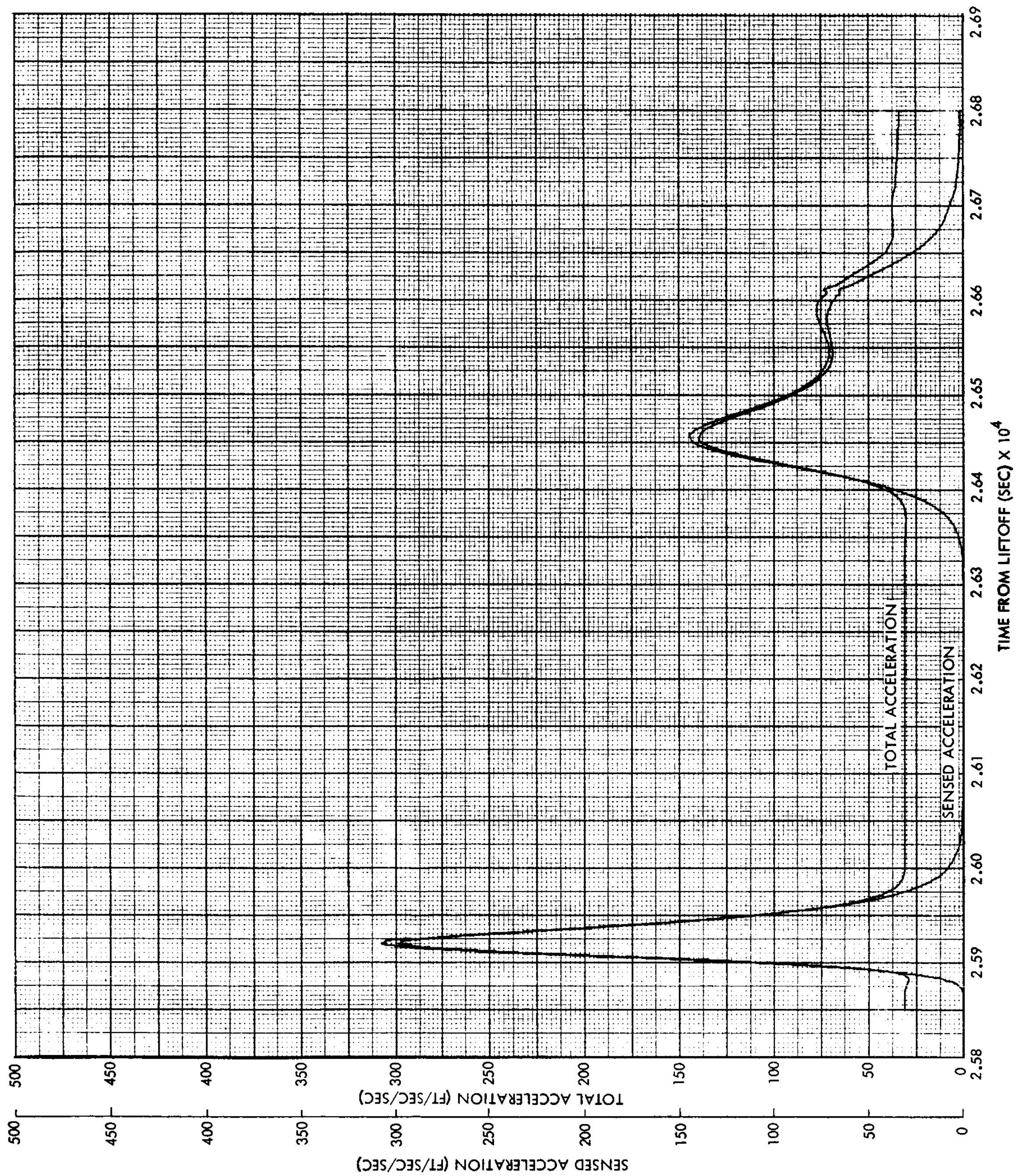

Figure 5-28. Atmospheric Entry/Sensed and Total Acceleration

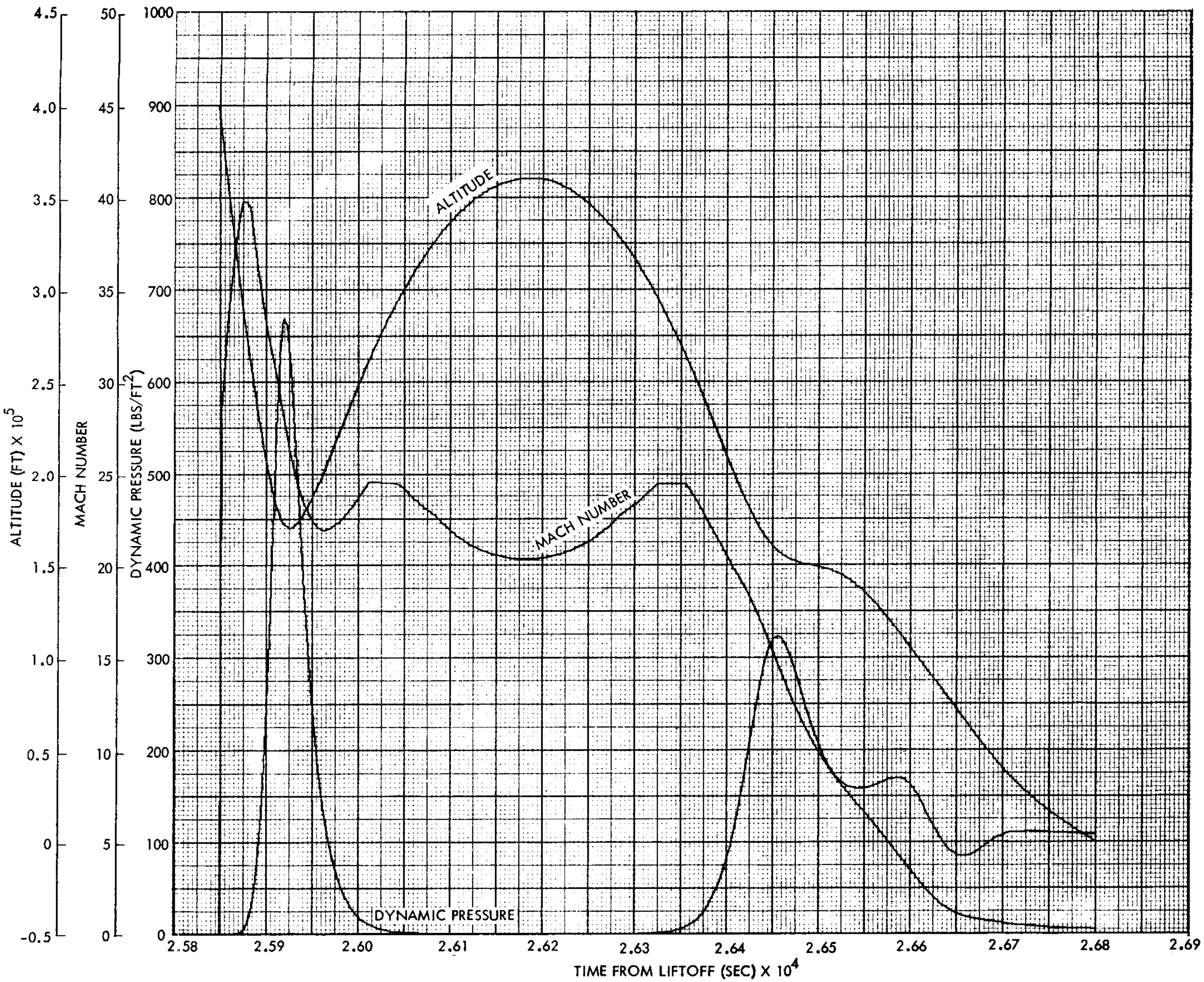

Figure 5-29. Atmospheric Entry/Altitude, Dynamic Pressure, and Mach Number

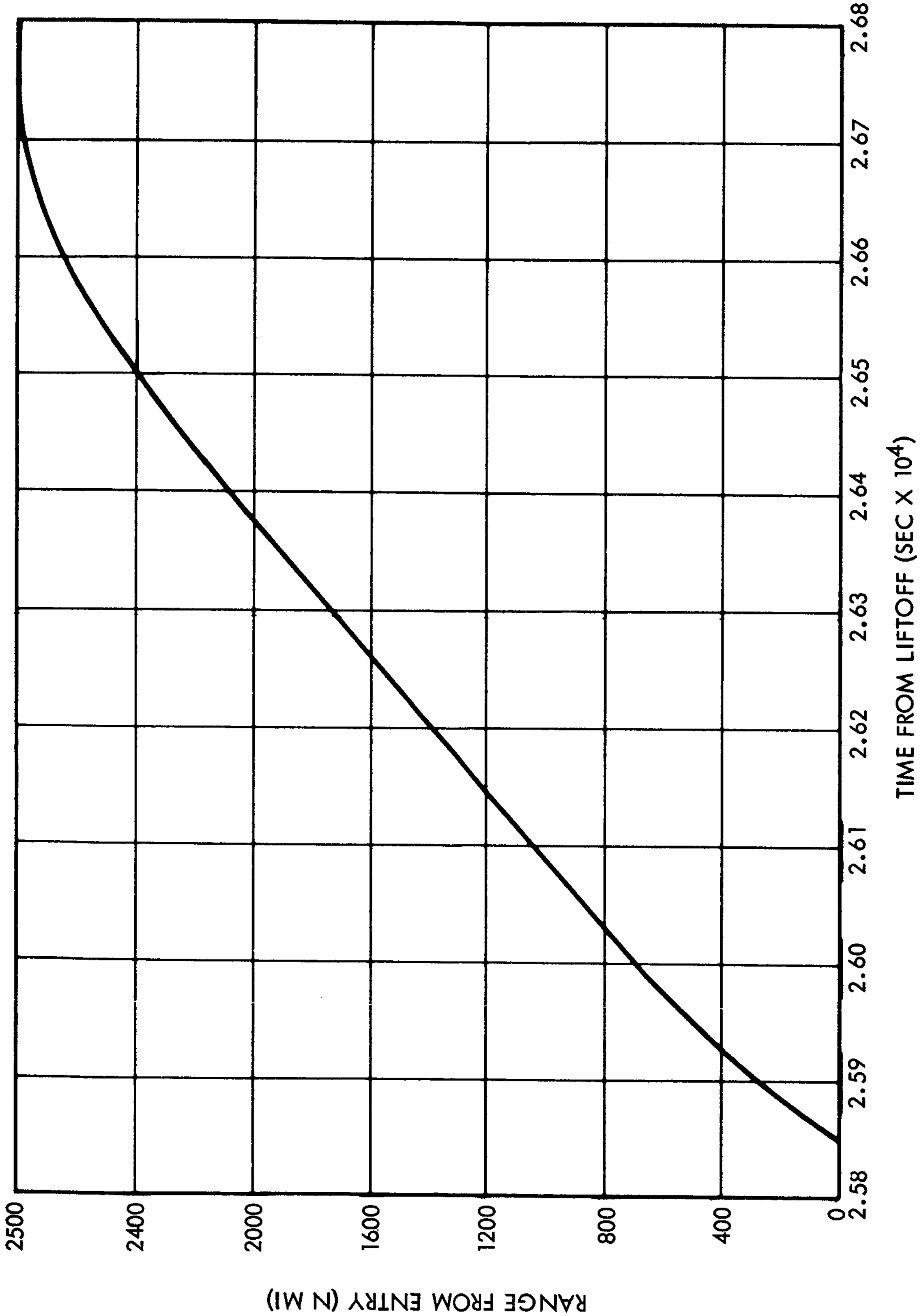

Figure 5-30. Atmospheric Entry/Range From Entry

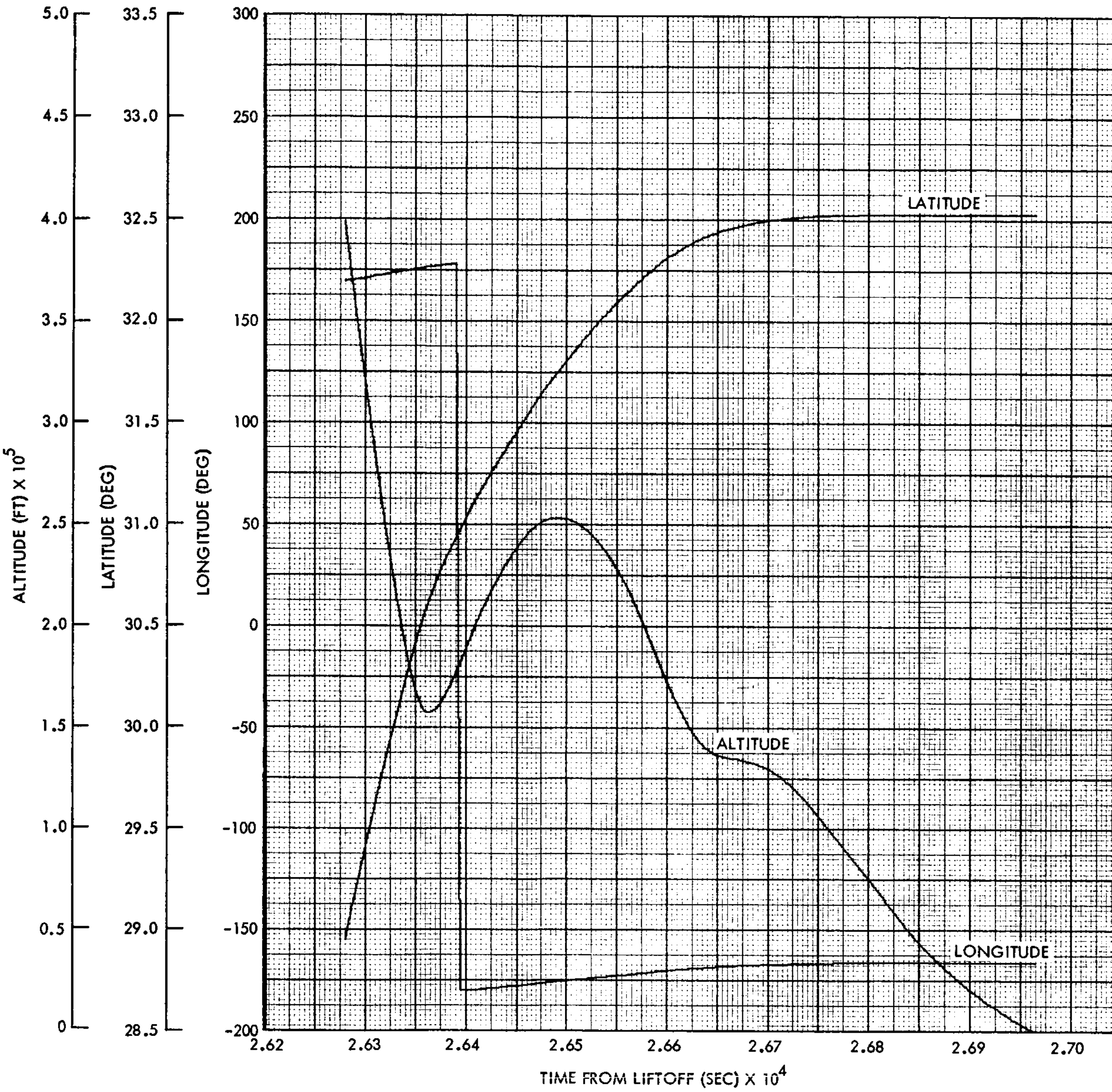

Figure 5-31. Atmospheric Entry (No SPS Burn)/Altitude, Latitude, and Longitude

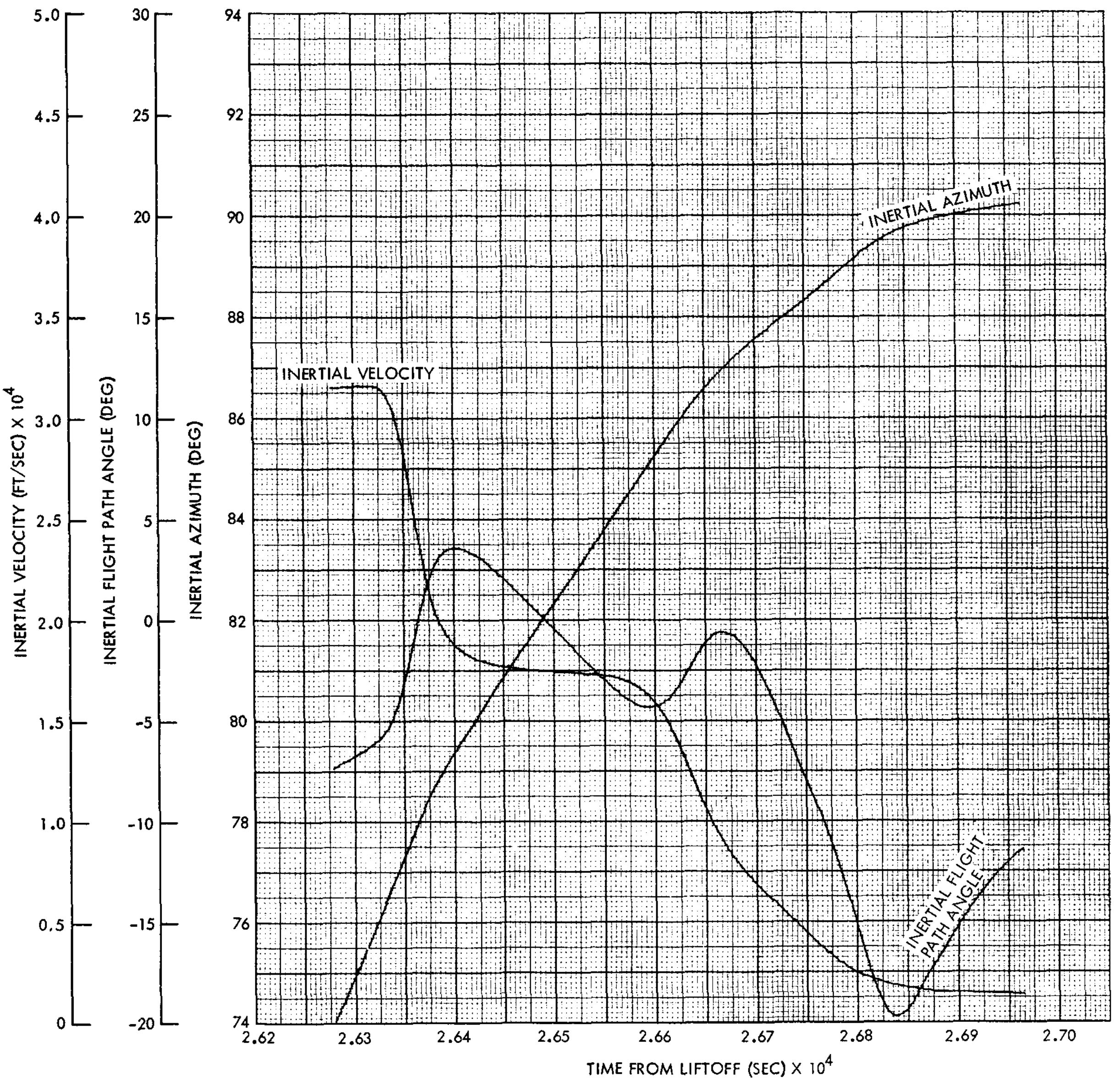

Figure 5-32. Atmospheric Entry (No SPS Burn)/Inertial Velocity, Flight Path Angle, and Azimuth

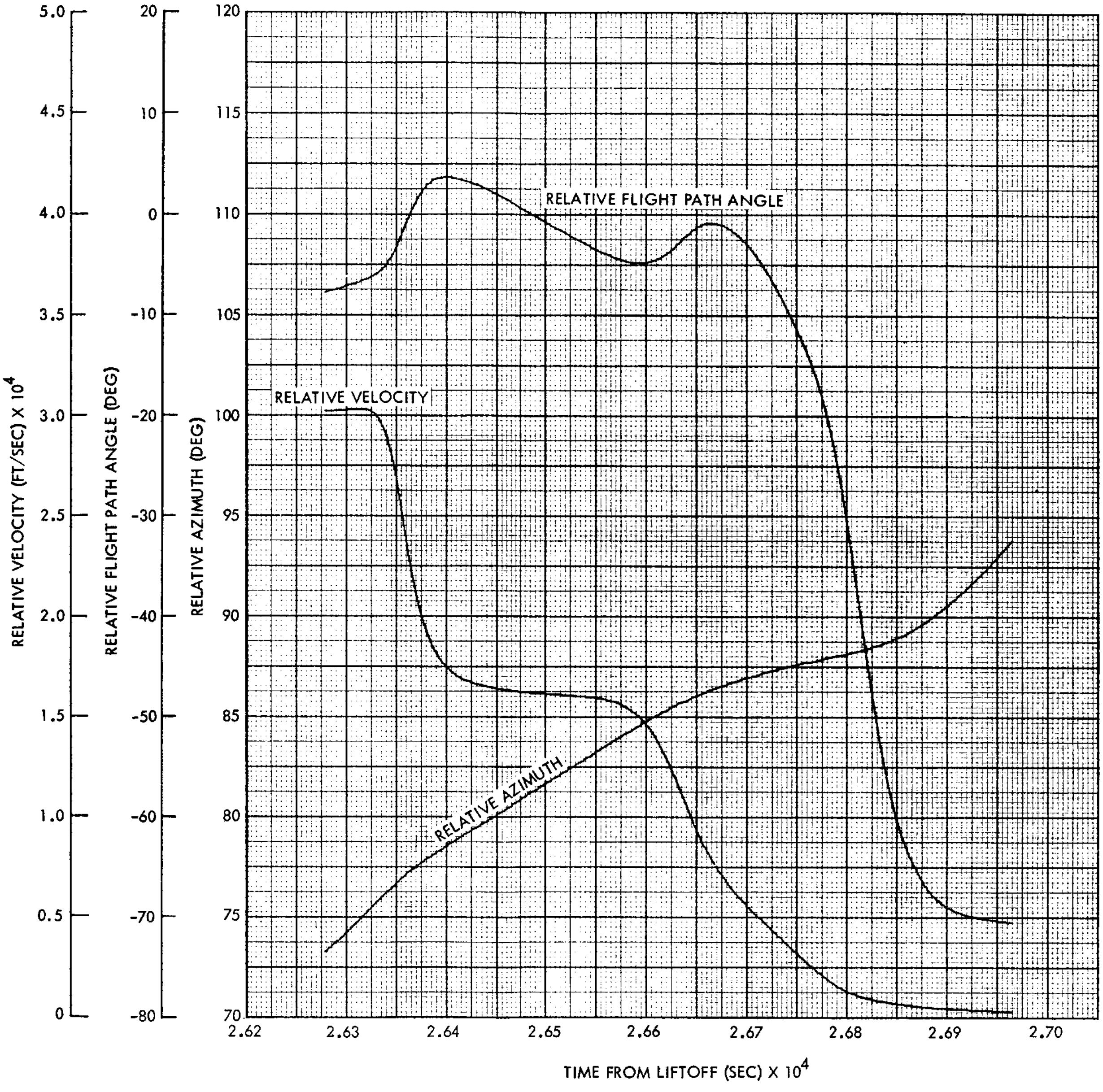

Figure 5-33. Atmospheric Entry (No SPS Burn)/Relative Velocity, Flight Path Angle, and Azimuth

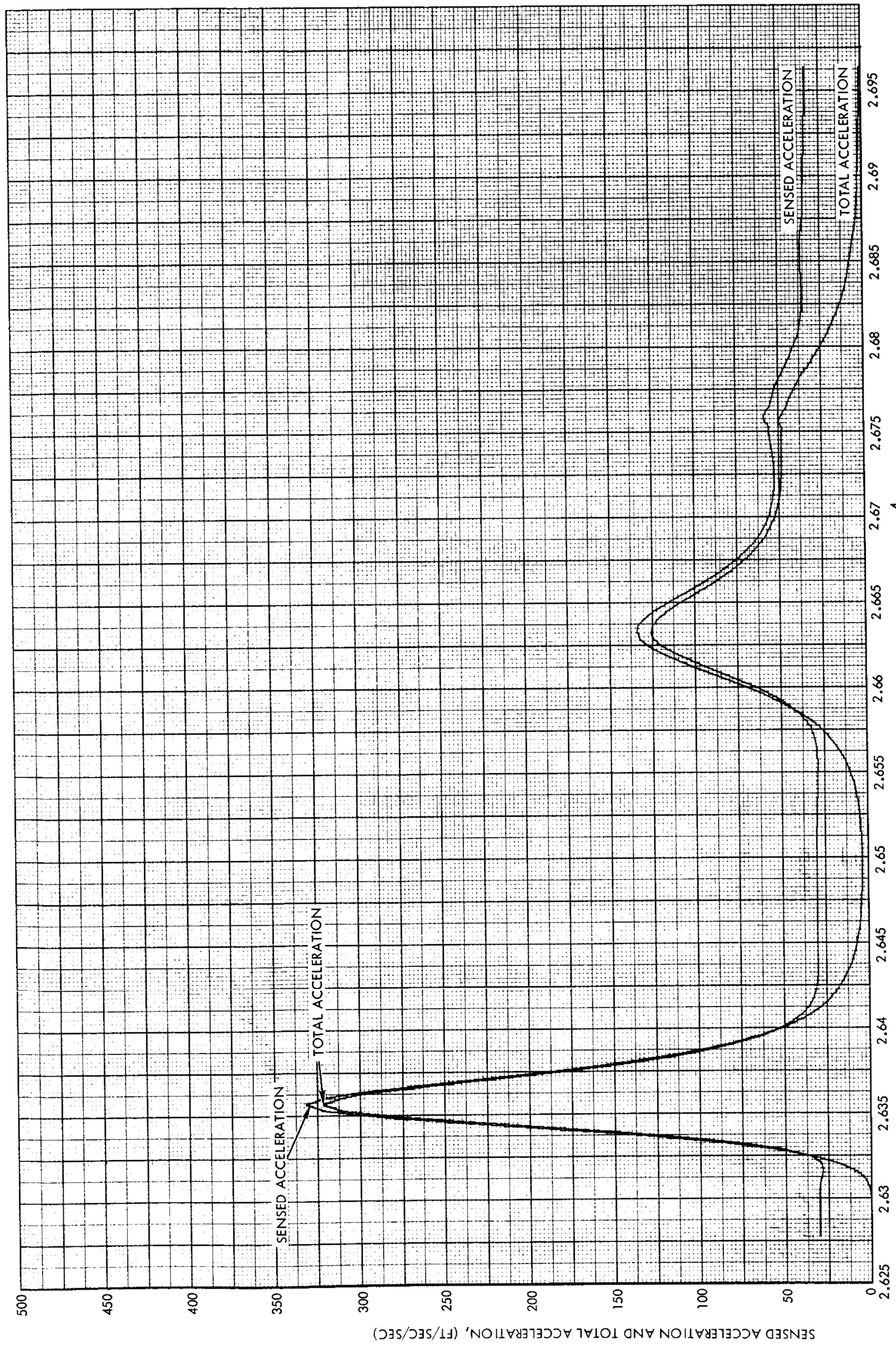

Figure 5-34. Atmospheric Entry (No SPS Burn)/Sensed and Total Acceleration

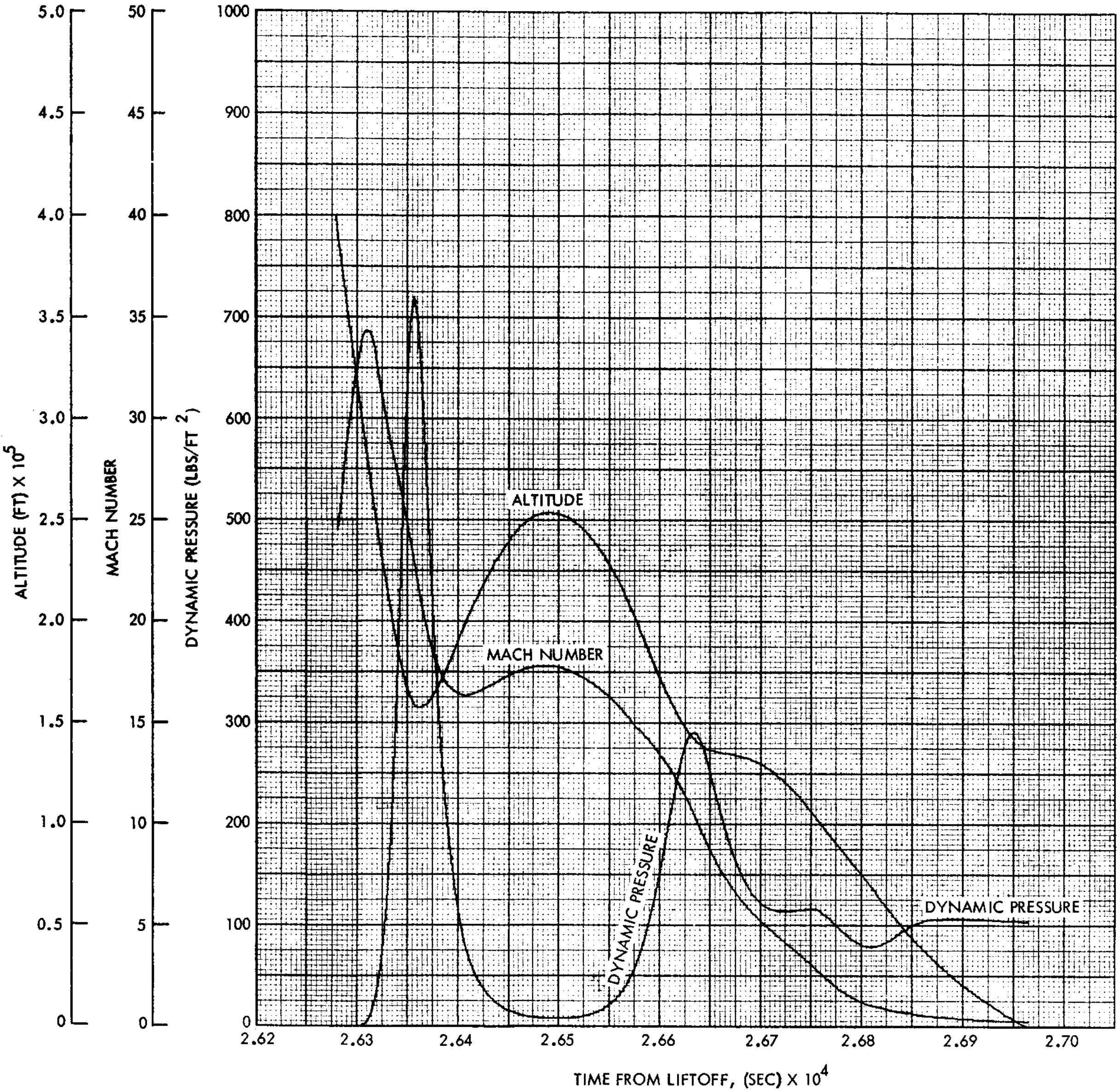

Figure 5-35. Atmospheric Entry (No SPS Burn)/Altitude, Dynamic Pressure, and Mach Number

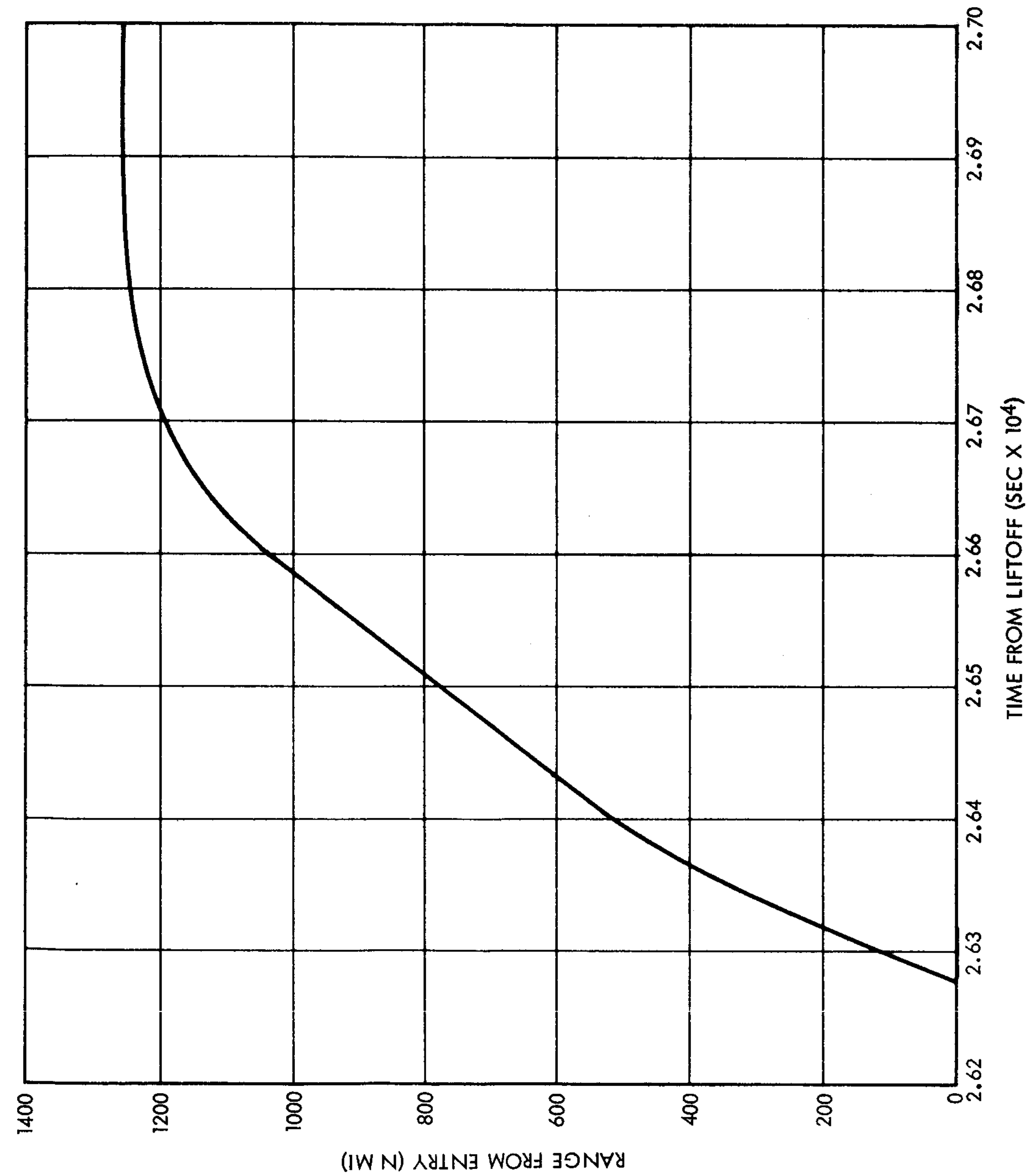

Figure 5-36. Atmospheric Entry (No SPS Burn)/Range From Entry

6. TRACKING AND COMMUNICATIONS DATA

Spacecraft visibility periods for the tracking stations presented in Table 3-6 are illustrated in Figure 6-1. Spacecraft visibility is defined as a tracking elevation angle greater than 5.0 degrees. Figure 6-1 also illustrates the time periods when the spacecraft is in the earths' shadow.

It is expected that at least one injection tracking ship and one entry tracking ship will be available for this mission. Visibility data is not presented for these stations because their placement for this mission has not been established.

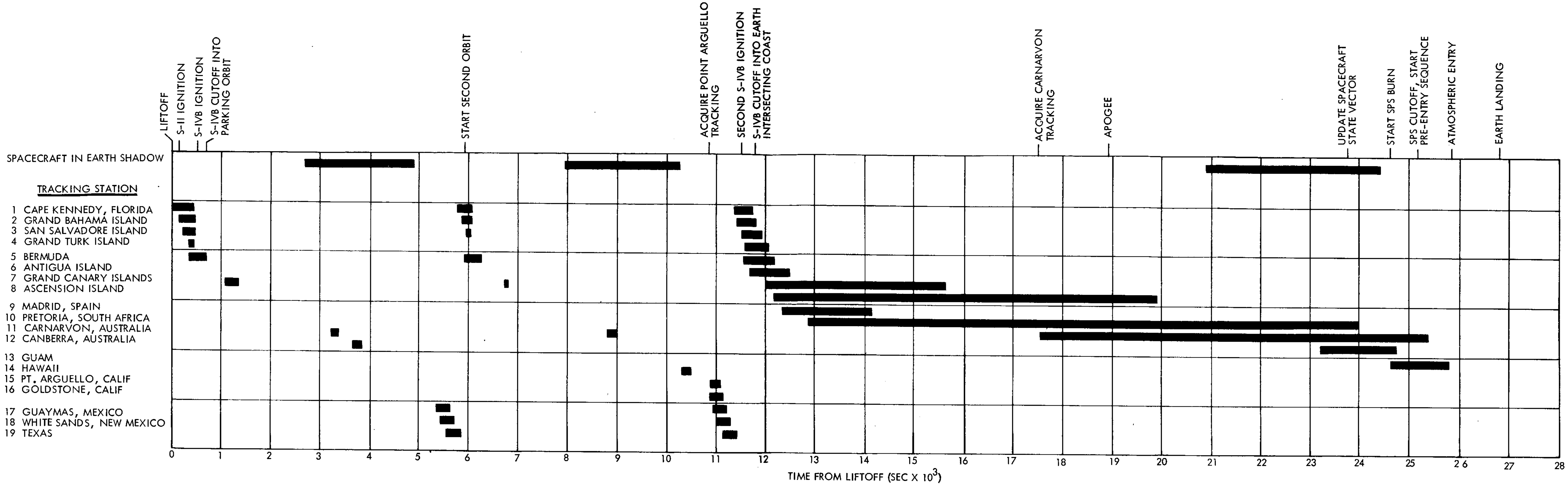

Figure 6-1. Tracking Visibility and Earth Shadow Data

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