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APOLLO MISSION SA-206A SPACECRAFT PRELIMINARY REFERENCE TRAJECTORY (U)

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Volume I

TRAJECTORY DESCRIPTION

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 Spacecraft Preliminary Reference Trajectory for Apollo Mission SA-206A, is submitted by TRW Systems to the NASA Manned Spacecraft Center in partial response to Task A-21 (Establishment of the Reference Trajectory for Apollo Mission SA-206A) of the Apollo Mission Trajectory Control Program (Contract No. NAS 9-2938, Phase II). This report is presented in three volumes. Volume I summarizes the mission objectives, the mission guidelines, and the input data for the mission simulation and provides a detailed description of the mission profile. Graphical and tabular time history data of spacecraft attitude, position, motion, and other pertinent trajectory data are also presented in Volume I. Volume II contains the trajectory listing of the mission profile, along with the trajectory print key. Detailed tracking time history data are presented graphically in Volume III and annotated for significant events.

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TABLES

1. INTRODUCTION AND SUMMARY

1.1 PURPOSE

The Spacecraft Preliminary Reference Trajectory defined in this document is designed for the unmanned Apollo Mission SA-206A. It is a combined launch vehicle and spacecraft trajectory profile that is intended to satisfy the mission's primary spacecraft objectives (Reference 1) without violating any of the launch vehicle and spacecraft constraints or the mission guidelines. Other than the removal of the long-duration cold-soak requirements, the basic trajectory profile is similar to that presented in the Preliminary Mission Profile, Reference 4. The purpose of this report is to improve upon and expand the scope of the trajectory profile presented in Reference 4 while complying with Reference 1.

1.2 SCOPE

This report is presented in three volumes. Volume I submits the spacecraft mission requirements, summarizes the input data used in the mission simulation, describes the major phases of the trajectory, and gives the trajectory analysis for applicable phases. It contains graphical and tabular time history data of the spacecraft attitude, position, and motion. Spacecraft separation characteristics and tracking station visibility data are also presented in this volume.

Volume II of this report contains the trajectory listing of the mission simulation.

Volume III presents detailed tracking time history data for the ground stations available for operation on this mission. These data consist of range, range rate, azimuth angle, elevation angle, and two spacecraft-to-MSFN station look angles and are presented as a function of time for each of the ground stations. The times of significant events are noted on these plots.

1.3 MISSION PROFILE SUMMARY

Apollo Mission SA-206A, currently planned for the second quarter of 1967, will be the first launch of a complete LEM spacecraft. For mission simulation purposes, the launch on an azimuth of 72° from true North is assumed to occur at 13:00 GMT, April 1, from Launch Complex 37B of the Kennedy Spaceflight Center.

Major events of the mission are illustrated in Figure 1-1. The mission has been divided into 14 major phases:

1. Saturn IB Ascent to Orbit
2. S-IVB/SLA/LEM Orbital Coast
3. Spacecraft Separation
4. Orbital Cold-Soak to First DPS Burn
5. First DPS Burn
6. Orbital Coast to Second DPS Burn
7. Second DPS Burn
8. Orbital Coast to FITH Abort Test
9. FITH Abort Test*
10. Orbital Coast to Second APS Burn
11. Second APS Burn
12. Orbital Cold-Soak to Third APS Burn
13. Third APS Burn
14. Final Orbital Coast

The Saturn IB launch phase includes the burn of the S-IB stage and the burn of the S-IVB stage. The dummy CSM is jettisoned by firing the LES jettison motor at a point where the dynamic pressure is less than one pound per square foot.

S-IVB cutoff occurs at an altitude of 85 nautical miles and a zero degree flight path angle, with the velocity necessary for an elliptical orbit insertion, having an apogee altitude of 120 nautical miles.

The spacecraft is separated from the S-IVB/SLA combination on the first orbit by the LEM-RCS thrusters while in sight of the Carnarvon tracking station.

The first DPS burn is performed on the third orbit after the spacecraft has been subjected to an attitude-hold cold-soak (+ X-axis normal to the ecliptic) for approximately 3 hours.

The second DPS burn and the FITH abort test are performed over the United States at the end of the third and fourth revolutions, respectively.

*This test includes a third DPS burn followed by a FITH abort simulation (LEM staging/first APS burn).

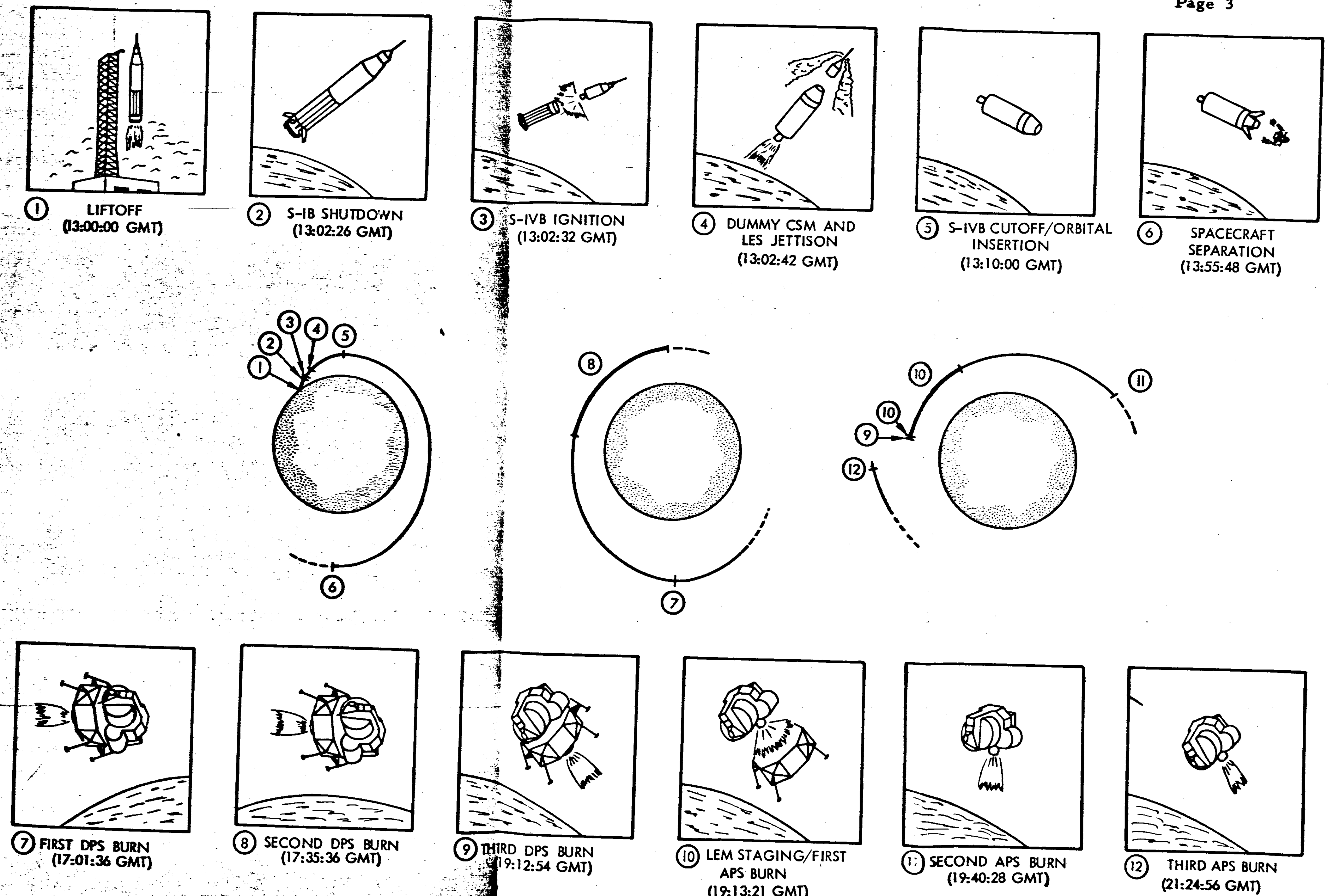


Figure 1-1. Mission Summary

Two short duration APS burns are then simulated, the first occuring 20 minutes after completion of the FITH abort test and the second one occuring approximately 2.5 hours after the first. During the 2.5-hour orbital coast between the short duration APS burns, the LEM ascent stage + X-axis is aligned normal to the ecliptic for the second time.

2. SPACECRAFT MISSION REQUIREMENTS

2.1 SPACECRAFT TEST OBJECTIVES

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

2.1.1 Primary

a) Verify LEM subsystems operation after launch vehicle boost and during and after LEM propulsion system operation.

b) Evaluate Flight Control Systems (Guidance and Navigation -- Stabilization and Control -- Reaction Control System) performance and operation at design inertias.

c) Demonstrate landing gear deployment and determine thermal distribution resulting from engine plume impingement.

d) Determine performance and operational characteristics of the Electrical Power System (EPS), Environmental Control System (ECS), and operational instrumentation subsystems in earth orbit.

e) Determine LEM communications subsystem performance, operation, and Manned Space Flight Net (MSFN) compatibility.

f) Evaluate DPS and APS propulsion subsystems operation following orbital soaks, including throttle and gimbal control, and demonstrate DPS and APS restart.

g) Demonstrate Fire-In-The-Hole (FITH) abort and evaluate the in-flight dynamics (staging characteristics), pressure distribution, and thermal distribution of the ascent/descent stages during staging.

h) Demonstrate LEM structural integrity, and determine ascent/descent stage interaction loads, LEM/SLA interaction loads, and dynamic loads on pressurant storage and ascent/descent stage engine propellant tanks.

i) Evaluate performance and operational characteristics of RCS in earth orbital environment.

j) Demonstrate ullage settling time for APS and DPS operation.

k) Determine vibration environment in critical equipment areas, including engine induced vibration environment during APS and DPS operation.

2.1.2 Secondary

a) Demonstrate DPS and APS operation at low propellant quantities.

b) Demonstrate operation of the LEM Mission Programmer (LMP).

2.2 MISSION PROFILE GUIDELINES

The following mission profile guidelines for this Preliminary Spacecraft Reference Trajectory have been compiled from data supplied by MSC and from References 1, 2, 4, and 7.

2.2.1 Launch Vehicle Systems

a) Launch azimuth of 72 degrees.

b) The Launch Escape Subsystem (Jettison motor) will be utilized to separate the dummy CSM from the S-IVB/SLA/LEM combination at a point where the dynamic pressure is less than one pound per square foot.

c) The S-IVB/SLA/LEM combination is to be inserted into an orbit with conditions similar to Mission 207, but optimized as to altitude and eccentricity for communications, ground control and ground monitoring aspects of the mission.

d) Guidance command angle rate limitation is to be one degree per second in pitch and yaw.

e) Approximately one orbit of S-IVB stabilization to provide for LEM subsystems checks, and to provide a stable S-IVB/SLA platform from which to separate the LEM.

2.2.2 Spacecraft Systems

a) Separation of LEM from S-IVB/SLA using LEM-RCS thrusters and deployment of landing gear during second orbit.

b) LEM attitude maneuver rate limitations (in the automatic mode) is to be 10 degrees per second in pitch and roll, and 5 degrees per second in yaw.

c) LEM orbital altitude is not to exceed 300 nautical miles (communications limitation).

d) The predicted orbital lifetime for the spent descent and ascent stages is not to exceed three months (also see Reference 19).

e) The coast times between propulsion tests should be used, as required, to optimize the ground coverage of the mission.

f) Backup ground command of S-IVB/LEM separation is recommended.

g) The third DPS burn and the first APS burn should have good, continuous ground coverage.

h) The FITH staging demonstration should be positioned so that at least three ground stations, with data record capability, can receive these data.

i) Orbital soaks are required prior to each APS and DPS burn. These soak periods are described below:

- Coast for approximately 4 hours with the LEM X-axis oriented perpendicular to the ecliptic (when not in the earth's shadow) prior to firing the descent stage engine.
- Coast, any orientation, for approximately 60 minutes between the first and second descent stage engine burns.
- Coast, any orientation, 20 $\pm$ 2 minutes between the first and second ascent stage engine burns. This time interval is critical since it is required to demonstrate APS restart under maximum heat soak back conditions.
- Coast for approximately 3 hours with the ascent stage X-axis oriented perpendicular to the ecliptic (when not in the earth's shadow) between the second and third ascent stage engine burns.

j) APS and DPS tests are required as follows:

- First DPS burn: 25 seconds at 10 percent thrust, followed by a rapid rise to full thrust and 7 seconds at 100 percent thrust.
- Second DPS burn: 25 seconds at 10 percent thrust, with a rapid rise to full thrust, then a 385-second continuous burn with the thrust decaying linearly from 100 percent to 90 percent. Decrease thrust from 90 percent to 45 percent and burn for 115 seconds. Then conduct random throttling between 10 percent and 50 percent thrust for 205 seconds.
- Third DPS burn/FITH staging/first APS burn: 25 seconds of DPS firing at 10 percent thrust, a rapid rise to full thrust, and 2 seconds at maximum thrust. FITH staging, followed by an APS burn with a duration to ensure propellant depletion after completion of the third APS burn.

- Second APS burn: 5 seconds.
- Third APS burn: 5 seconds.

3. SUMMARY OF INPUT DATA

The input data in this section were extracted from the references and also include data agreed upon at several technical coordination meetings between MSC and TRW personnel. These data include all quantitative specifications on the launch vehicle, spacecraft, and MSFN stations, and form the basis for the Spacecraft Preliminary Reference Trajectory in support of Apollo Mission SA-206A.

3.1 SATURN IB LAUNCH VEHICLE

Data necessary to adequately describe the launch vehicle were obtained from References 3, 4, 5, 7, 13 and 14 and supplemented by data from MSC/TRW technical coordination meetings. These launch vehicle data are included only for completeness and should not be used as official launch trajectory data or event times. The official launch vehicle data and launch trajectory will be published by the MSFC.

A brief weight statement of the Saturn IB launch vehicle is presented in Table 3-1. The weights are given in a manner essentially equivalent to their chronological disposition during the mission.

The propulsion characteristics are presented in Table 3-2. The operation of the S-IVB stage is divided into three constant-thrust, constant-flow-rate phases. These phases, listed in order of occurrence, are:

- A short duration, nominal thrust, nominal specific impulse phase.
- A high thrust, low specific impulse phase.
- A low thrust, high specific impulse phase.

The launch vehicle event timing criteria used in the trajectory generation are presented in Table 3-3.

The Saturn IB launch vehicle is illustrated in Figure 3-3, and the zero-lift drag coefficient (power-on and power-off) data are presented in Figure 3-4. An aerodynamic reference area of 360.24 square feet was used.

Two static atmosphere models are used in the ascent trajectory simulation. Below an altitude of 35 km (114,830 feet), the Patrick AFB atmosphere (Reference 10) is used, and between 35 km and 400,000 feet, the U. S. Standard Atmosphere of 1962 (Reference 11) is used. No attempt has been made to remove the small discontinuity between the two models at 35 km.

[redacted]

Table 3-1. Saturn IB Weight Statement

Event	Weight Losses (lb)	Event Weights (lb)
S-IB Ignition/Liftoff		1,297,088
S-IB Impulse Propellant	861,829	
S-IB Inboard Engines Cutoff		435,259
S-IB Outboard Engines Impulse and Thrust Decay Propellants	24,515	
S-IB Outboard Engines Cutoff		410,744
Spent S-IB	98,826	
S-IB/S-IVB Interstage Adapter	7,000	
S-IVB Engine Ignition		304,918
S-IVB Impulse Propellant	227,824	
Thermolag and Ullage Cases	235	
Dummy CSM/LES	9,540	
S-IVB Engine Cutoff		67,319
Spent S-IVB	25,535	
Consumable Propellants Remaining*	1,494	
Instrument Unit	4,150	
Spacecraft LEM Adapter	3,600	
Spacecraft (LEM-1) in Orbit		32,540

* Includes flight performance reserves.

Table 3-2. Saturn IB Propulsion Data

S-IB Stage

(See Figures 3-1 and 3-2 for thrust and propellant weight flow rate profiles, respectively).

S-IVB Stage

Programmed Mixture Ratio	5.0	5.5	4.7
Duration (sec)*	10.00	285.33	152.78
Thrust (lb)	205,000	230,000	190,000
Propellant Weight Flow Rate (lb/sec)	481.221	543.607	444.476
Specific Impulse (sec)	426.0	423.1	427.5

* Total burn duration of the S-IVB stage is 448.11 seconds.

Table 3-3. Saturn IB Event Timing Criteria

Event	Timing Criteria
Saturn IB Liftoff	t_o
Pitch Over/Begin Gravity Turn	t_o + 10 seconds
End Gravity Turn	t_1 - 2 seconds
S-IB Inboard Engines Cutoff	t_1
S-IB Outboard Engines Cutoff	t_2 (t_1 + 6 seconds)
S-IVB Ignition	t_3 (t_2 + 5.5 seconds)
Thermolag and Ullage Cases Jettison	t_3 + 10 seconds
Dummy CSM/LES Jettison*	t_3 + 10 seconds
S-IVB Cutoff	t_4

* Dynamic pressure equal to approximately 0.98 lb/ft^2.

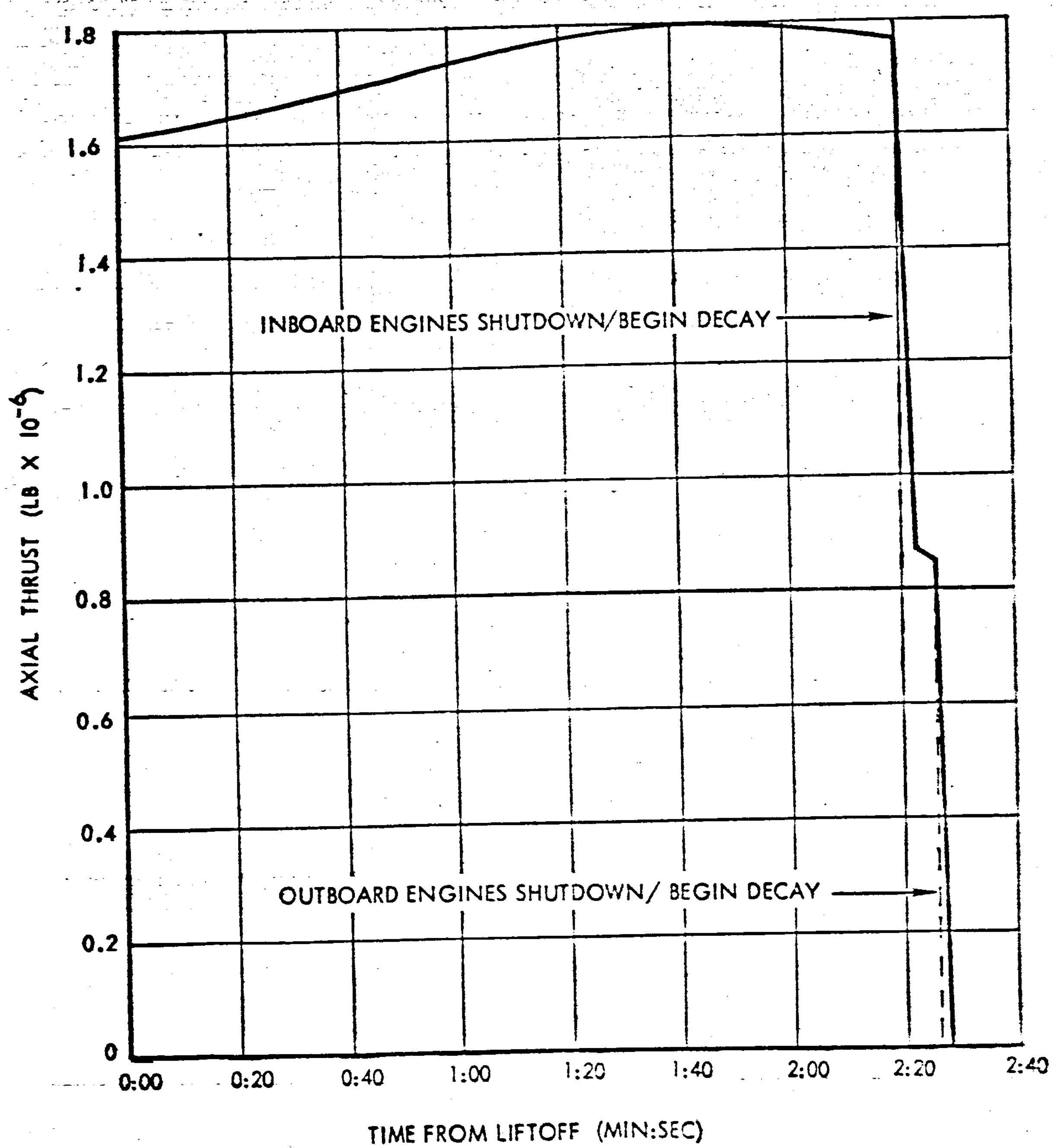


Figure 3-1. S-IB Thrust Profile

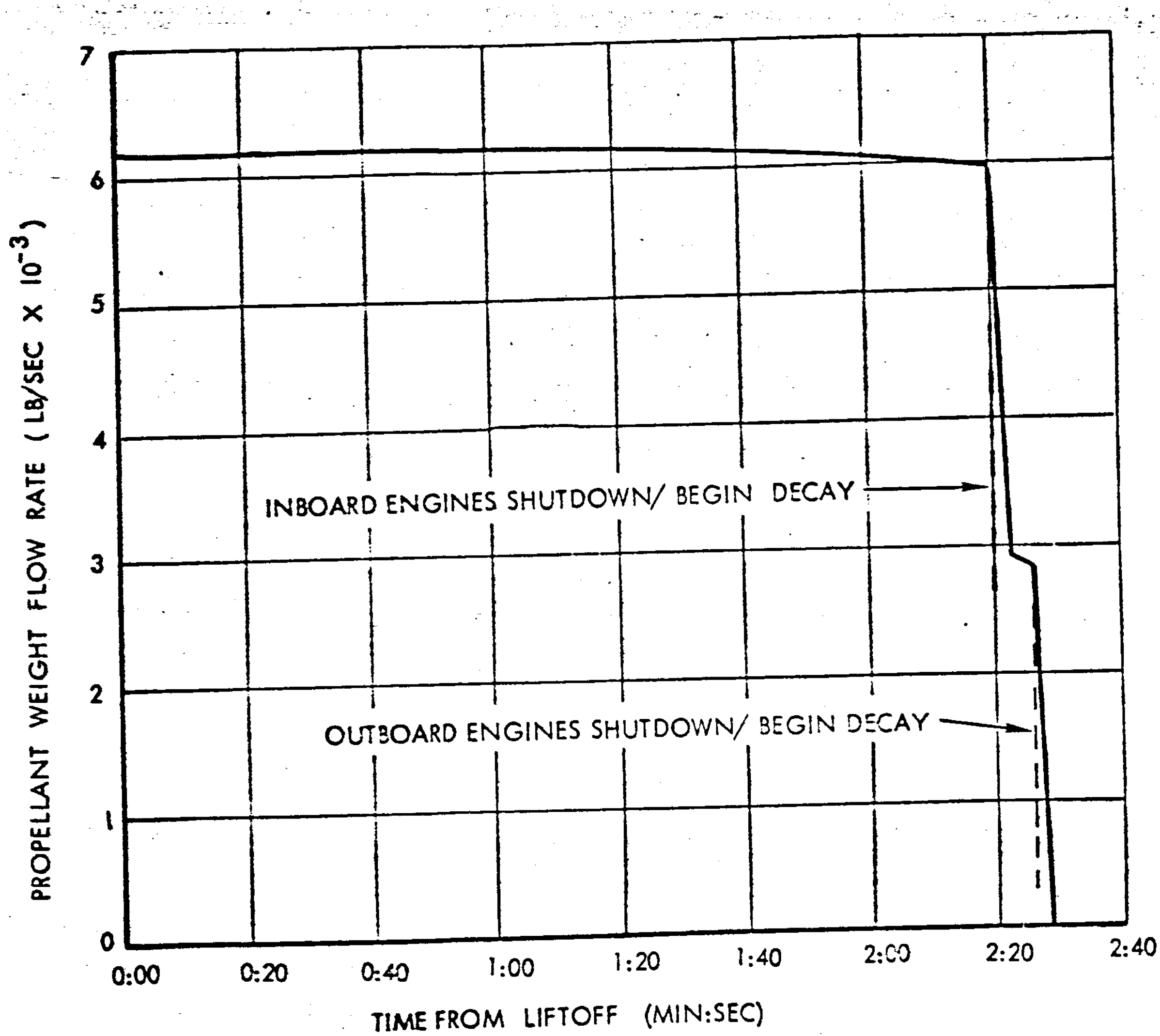
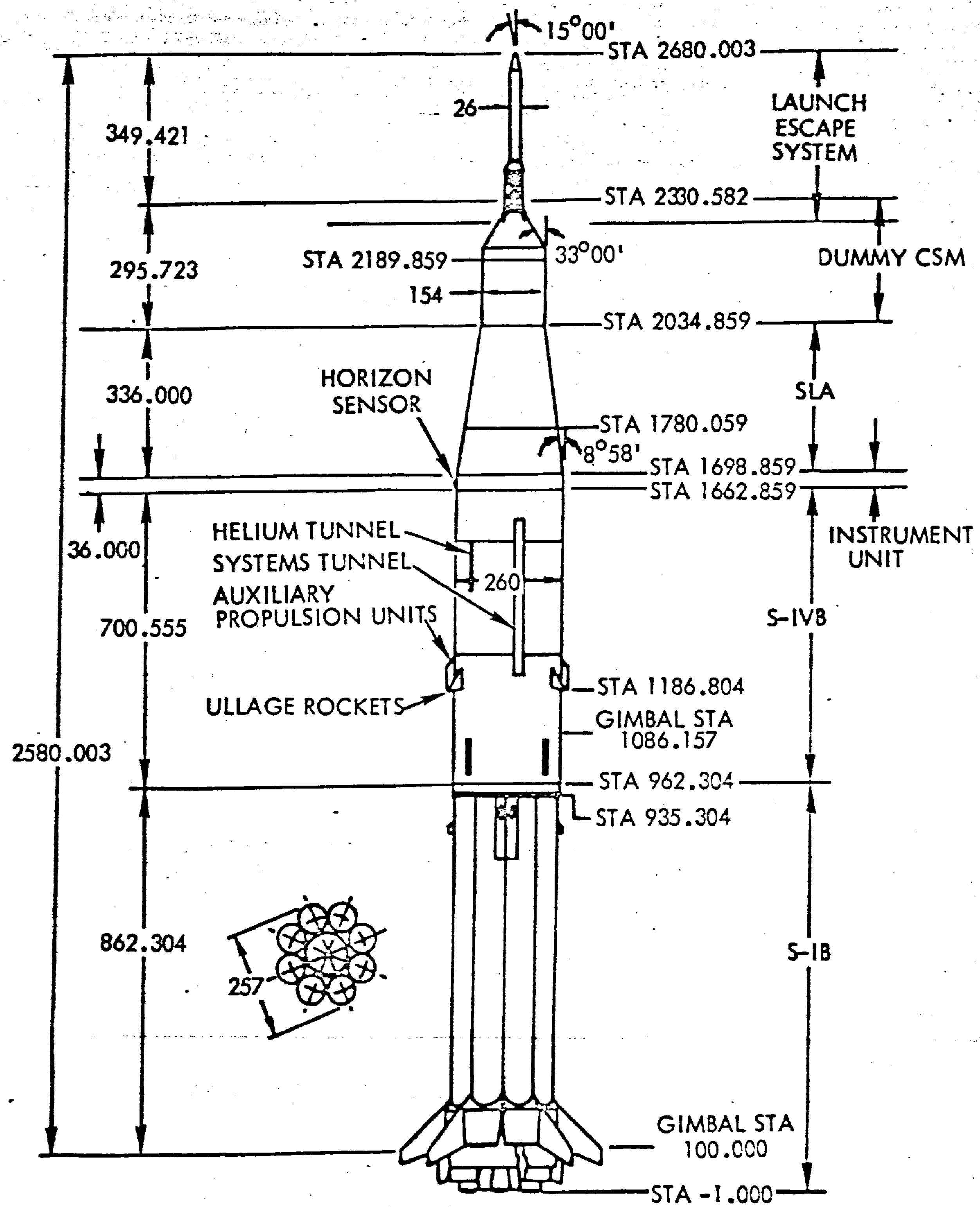


Figure 3-2. S-IB Propellant Weight Flow Rate Profile



NOTES:
1. ALL VEHICLE STATIONS AND DIMENSIONS ARE IN INCHES
2. SATURN REF: MSFC DWG 10M03544, REV. F

Figure 3-3. Saturn IB Launch Vehicle

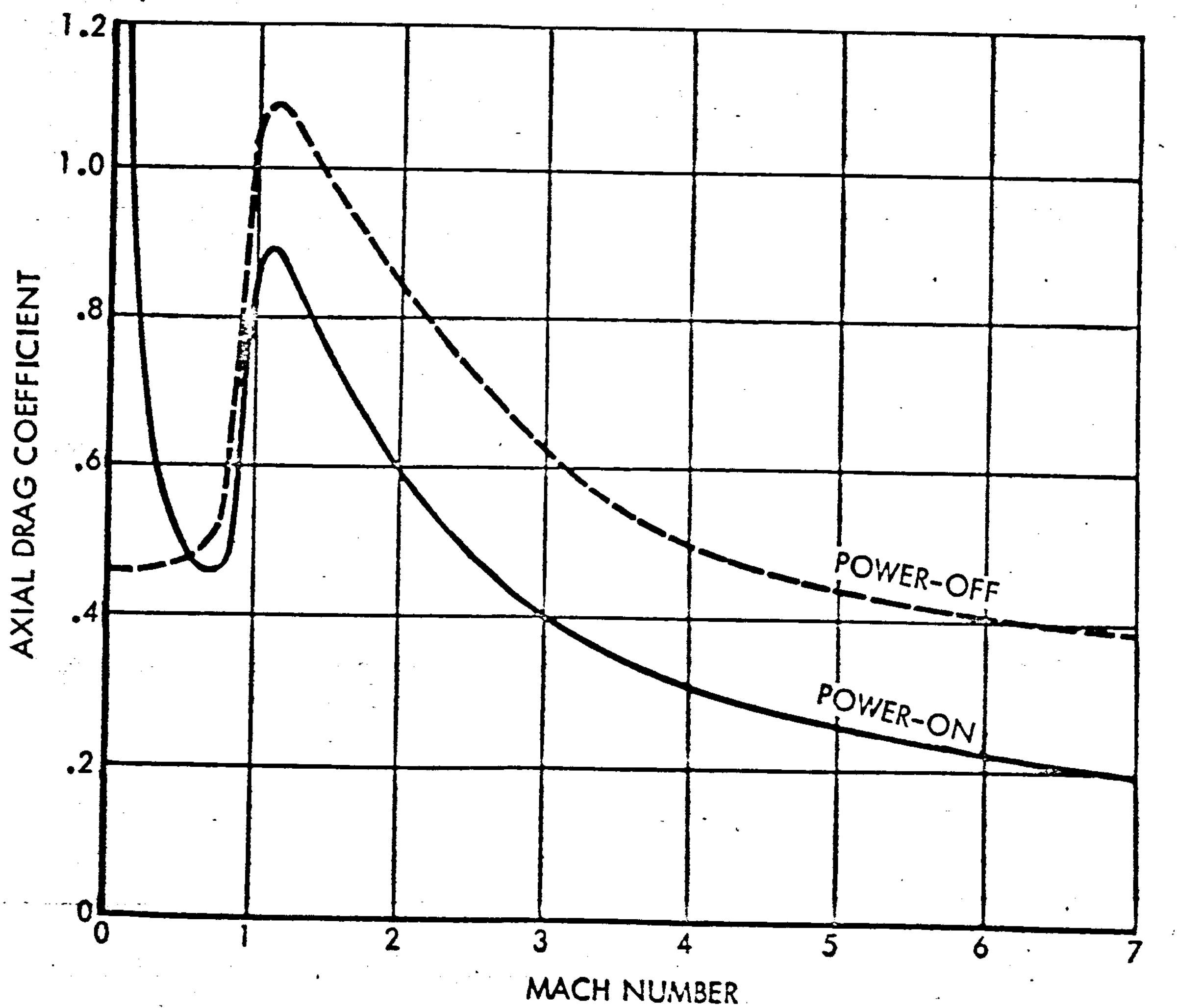


Figure 3-4. Saturn IB Zero-Lift Drag Coefficient (power-on and power-off)

3.2 SPACECRAFT (LEM-1)

The spacecraft weight breakdown was obtained from Reference 7 and is based on an inserted payload weight of 36,140 pounds. This 640-pound increase from the LEM control weight of 35,500 pounds is the expected increase in payload capability by insertion into the nominal elliptical orbit. Spacecraft propulsion characteristics and LEM-Reaction Control System (RCS) propellant expenditure criteria were obtained from References 6 and 7 and meetings with MSC personnel.

The spacecraft weight statement is presented in Table 3-4. Flight performance propellant reserves equal to one percent of the consumable propellants are assumed. The criteria for establishing the LEM-RCS propellant expenditures are presented in Table 3-5. The ascent stage propulsion system is characterized by a vacuum nominal thrust and propellant weight flow rate of 3,500 pounds and 11.45 pounds per second, respectively. The descent stage propulsion system data are presented in Figure 3-5. An illustration of the spacecraft is shown in Figure 3-6.

3.3 MSFN STATIONS

The MSFN stations that are planned to be available for support of this mission, their locations, and equipment available were obtained from Reference 18. These data are summarized in Table 3-6. Locations for three of the five Apollo tracking ships available for support of this mission are also indicated in Table 3-6. One ship has been placed near the western coast of Australia, one off the western coast of the continental United States, and the third near the western coast of Africa.

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

a = equatorial earth radius = 6378166.000 meters (exact)
b = polar earth radius = 6356784.284 meters
f = flattening = 1/298.30

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

3.4 EARTH CONSTANTS AND CONVERSION FACTORS

The following earth constants and conversion factors (Reference 15) have been used in the generation of the Spacecraft Preliminary Reference Trajectory.

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)	1/298.30 nd

3.4.2 Conversion Factors

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

Table 3-4. LEM-1 Weight Statement

	Weight (lb)		
LEM-1 in Orbit			32,540
Descent Stage		21,845	
Inert Weight[1]	4,623		
Usable DPS Propellants[2]	17,050		
DPS Performance Reserves[3]	172		
Ascent Stage		10,695	
Inert Weight[1]	5,104		
Usable APS Propellants[2]	4,965		
APS Performance Reserves[3]	50		
Usable RCS Propellants[4]	576		

1 Includes dry weight and trapped fluids.

2 Off-loaded by 133 pounds (full-tank capacity is 17,355 pounds).

3 Approximately one percent of propellants available.

4 From Reference 7.

Table 3-5. Criteria for LEM-RCS Propellant Expenditures

RCS Operation	Propellant Expenditure Criteria
Spacecraft Separation	1.25 lb/sec
Ullages Preceding	
1) DPS Operation	1.25 lb/sec
2) APS Operation	1.25 lb/sec
Attitude Holds (± 5 deg deadband)	
1) During LEM Coast	0.26 lb/hr
2) During Ascent Stage Coast	1.30 lb/hr
Attitude Holds (± 0.3 deg deadband)	
1) During DPS Burns	10.5 lb/burn
2) During APS Burns	0.15 lb/sec of burn
3) During FITH Staging	10 lb
Attitude Orientation Maneuver*	
1) LEM	17.6 lb/maneuver
2) Ascent Stage	4.1 lb/maneuver

*Attitude maneuver about all three axes.

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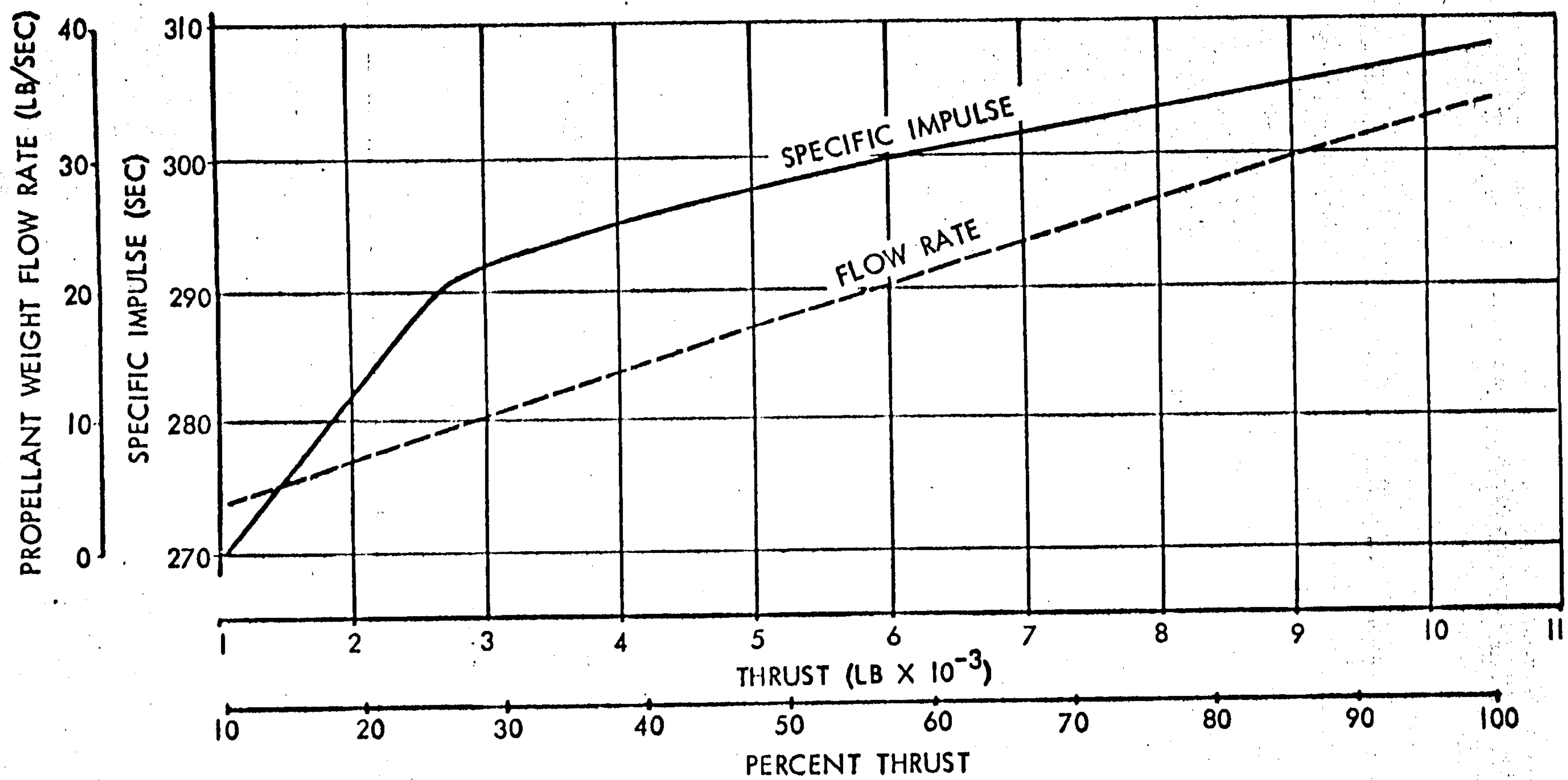

Figure 3-5. LEM-DPS Specific Impulse and Propellant Weight Flow Rate

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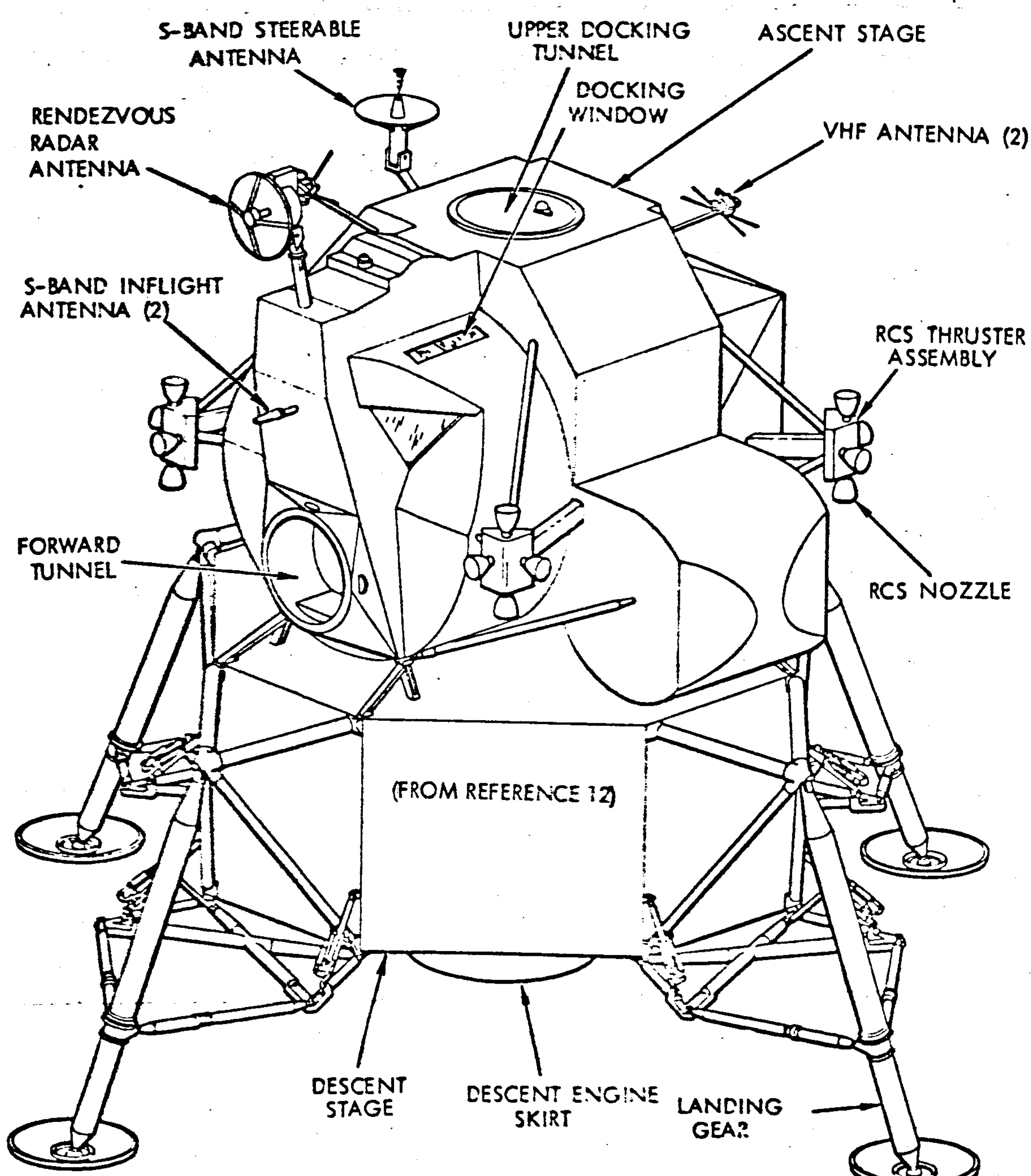


Figure 3-6. Spacecraft (LEM)

Table 3-6. MSFN Station Sites and Equipment

Identification	Station	Tracking Equipment	Latitude* (deg)	Longitude* (deg)	Altitude** (ft)
CNV	Cape Kennedy, Florida	FPS-16, TPQ-18, USBS 30'	28.481767	-80.576514	45.9
GBI	Grand Bahama Island	FPS-16, TPQ-18	26.615786	-78.347849	45.9
SSI	San Salvadore Island	FPS-16	24.118992	-74.504077	9.8
GTI	Grand Turk Island	TPQ-18	21.462908	-71.132043	82.0
BDA	Bermuda	FPS-16, FPQ-6, USBS 30'	32.347766	-64.653643	9.8
ANT	Antigua Island	FPQ-6, USBS 30'	17.143796	-61.792683	85.3
CYI	Grand Canary Island	MPS-26, USBS 30'	27.735522	-15.600000	95.1
ASC	Ascension Island	TPQ-18, USBS 30'	-7.972994	-14.401694	469.2
PRE	Pretoria, South Africa	MPS-25	-25.945553	28.361996	5,334.6
CRO	Carnarvon, Australia	FPQ-6, USBS 30'	-24.897356	113.716067	210.0
GUA	Guam	USBS 30'	13.583333	144.924999	65.6
HAW	Hawaii	FPS-16, USBS 30'	22.125267	-159.667619	3,746.7
CAL	Pt. Arguello, California	FPS-16	34.582902	-120.561149	2,119.4
GLD	Goldstone, California	JPL 85'	35.389638	-116.848776	3,382.5
GYM	Guaymas, Mexico	USBS 30'	27.958405	-110.720791	59.0
WHS	White Sands, New Mexico	FPS-16	32.358222	-106.369564	4,042.0
TEX	Texas	USBS 30'	29.758610	-95.363582	164.0
---	Ship No. 1	USBS	-31.0	113.0	0.0
---	Ship No. 2	USBS	31.0	-124.0	0.0
---	Ship No. 3	USBS	1.5	-14.0	0.0

* Minus coordinates are South latitudes and West longitudes.
** Altitude is above the Fischer reference ellipsoid.

3.5 SPACECRAFT AND REFERENCE COORDINATE SYSTEMS

The spacecraft attitude is measured by the pitch, yaw, and roll angles required to rotate from the reference system to the current spacecraft orientation. The reference coordinate systems are illustrated in Figure 3-7 and defined below.

Earth Referenced Rotating Coordinate System, XR-YR-ZR:

Right-handed, orthogonal system centered at the vehicle in which the positive $\hat{X}_r$ axis extends downrange in the direction of motion and lies in the the plane of the horizon, the positive $\hat{Y}_r$ axis extends upward along the geocentric radius vector, and the positive $\hat{Z}_r$ axis extends to the right in a direction orthogonal to the downrange direction.

Launch Site Inertial Coordinate System, XI-YI-ZI:

Right-handed, orthogonal system in which the origin coincides with the launch site, the positive $\hat{X}_i$ axis extends downrange in the direction of the launch azimuth and lies in the plane of the horizon, the positive $\hat{Y}_i$ axis extends upward along the geocentric radius vector at liftoff, and the positive $\hat{Z}_i$ axis extends to the right in a direction orthogonal to the launch azimuth.

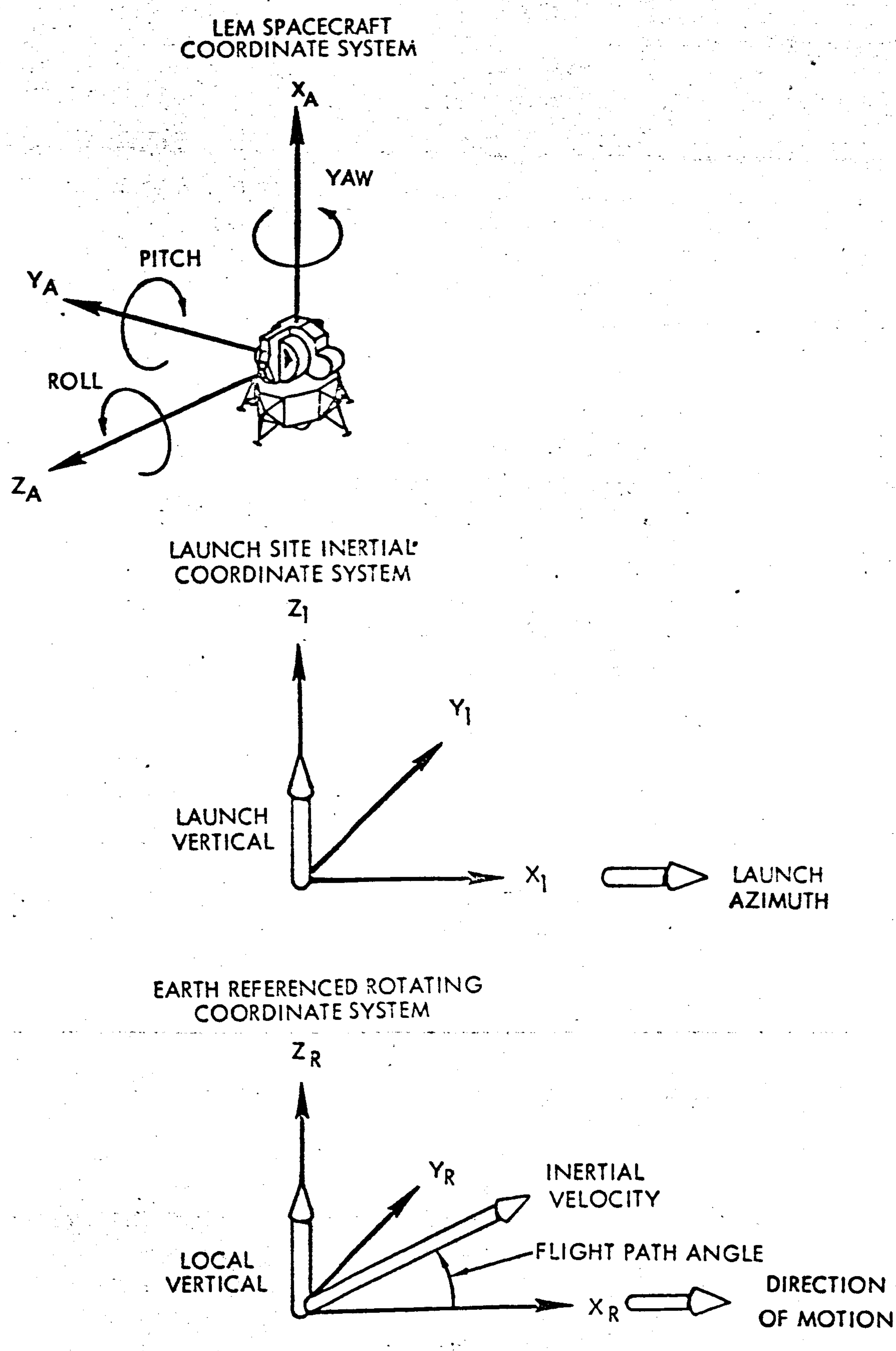


Figure 3-7. Spacecraft and Reference System Coordinates

4. MISSION ANALYSIS AND DESCRIPTION

The Spacecraft Preliminary Reference Trajectory for Apollo Mission SA-206A is designed to meet the test objectives of Section 2.1. The Mission Profile Guidelines of Section 2.2 are followed except for those officially changed by References 2 and 7. To satisfy these objectives and guidelines and to determine values of the free variables, a certain amount of trajectory analysis was performed. The results of this analysis, along with a description of the resulting mission profile, are given in this section.

4.1 SATURN IB ASCENT TO ORBIT

Launch of Apollo Mission SA-206A will occur from Launch Complex 37B of the Kennedy Spaceflight Center during the second quarter of 1967. The geodetic coordinates of the launch point are 28.531856 degrees North latitude and 80.564952 degrees West longitude. For the trajectory simulation, launch was assumed to occur at 13:00 hours GMT (08:00 hours EST) on 1 April 1967.

The Saturn IB ascent to orbit phase is initiated by a 10-second vertical rise followed by a 0.1522 degree kick (an instantaneous rotation of the vehicle attitude and velocity vector) into a 128-second gravity turn trajectory with a 72-degree azimuth heading. The inboard engines are shutdown approximately 6 seconds prior to S-IB engines cutoff. Following a 5.5-second coast from S-IB cutoff, the spent S-IB and the interstage adapter are jettisoned. In the simulation, S-IVB engine ignition also occurs at this time and a pitch rate of 0.9904 degree per second downward is initiated. This high pitch rate steering is terminated 9.00 seconds after ignition, and a low pitch rate of 0.0765 degree per second downward is initiated. Ten seconds after S-IVB engine ignition, the dummy CSM is jettisoned by using the LES jettison motor. This occurs at a point where the dynamic pressure is approximately 0.98 pound per square foot. Reference 17 states that the dummy CSM/LES is approximately 73 feet away from the thrusting S-IVB/LEM at the end of tower jettison motor thrusting. Also, the separation velocity remains positive and the separation distance keeps increasing. The thermolag and ullage cases are also jettisoned at this time. The low pitch rate steering is maintained until S-IVB engine cutoff at approximately 10 minutes after liftoff.

The value of the kick angle and the magnitudes of the two pitch rates were determined by iteration techniques so that the following conditions would exist at S-IVB engine cutoff:

1) Inertial velocity of 25,694.78 feet per second.
2) Inertial flight path angle of zero degrees.
3) Altitude of approximately 85 nautical miles.
4) S-IVB/SLA/LEM weight at insertion of 67,319 pounds.

Conditions 1), 2), and 3) result in S-IVB cutoff at an altitude of 85.6 nautical miles, a zero degree flight path angle, and the velocity necessary for an elliptical orbit insertion with an apogee altitude of 119.4 nautical miles.

The inserted weight from condition 4) is consistent with the launch vehicle capability as extracted from References 3, 7, and 14. Assuming a flight performance propellant reserve of 1,494 pounds at S-IVB cutoff, the allowable spacecraft weight is 32,540 pounds in orbit. Table 3-1 presents a more complete breakdown of the inserted weight.

4.2 S-IVB/SLA/LEM ORBITAL COAST

Ten seconds after orbital insertion, the S-IVB/SLA/LEM combination is maneuvered at a 0.5 degree per second rate until the S-IVB +X-axis lies in the plane of the local horizontal and the - Z-axis is along the geocentric radius vector. This attitude is maintained in order to provide a stable platform from which to separate the spacecraft. The duration of this orbital coast (insertion to spacecraft separation) is 45 minutes and 48.4 seconds.

4.3 SPACECRAFT SEPARATION

The spacecraft separation events consist of the Spacecraft LEM Adapter (SLA) petal deployment, separation of the spacecraft by firing the LEM-RCS +X thrusters for 12 seconds, a coast for 8 seconds, followed by deployment of the LEM landing gear.

The in-orbit position of this sequence of events is near apogee in the first orbit, rather than during the second orbit as suggested in Section 2.2. This selection allows continuous tracking coverage for the events from the Carnarvon ground station, which has ground command capability. Apollo tracking ship No. 1 has been located near the western coast of Australia in this profile to provide backup coverage for these events and for the subsequent first DPS burn.

Separation characteristics during the first several minutes after separation are illustrated in Figure 4-1. These data are based upon point mass simulations.

4.4 ORBITAL COLD-SOAK TO FIRST DPS BURN

Approximately 30 seconds after initiation of the LEM landing gear deployment the LEM is commanded to perform a 53.6-second maneuver to align the +X-axis (yaw axis) normal to the ecliptic and the +Z-axis (roll axis) toward the sun.* The sun's position relative to the earth is dependent upon both the launch date and time of day. The spacecraft orientation with respect to the earth, in this case, is also launch time and day dependent. The general attitude maneuver logic used to simulate the spacecraft attitude orientation is summarized in the Appendix. Following this attitude maneuver, the spacecraft is put into an attitude hold mode ($\pm$ 5 degrees deadband) and maintains this inertial attitude for approximately 2 hours and 57 minutes. In the simulation, the spacecraft attitude drifted approximately 0.1 degree, with no maneuvers, during this cold-soak (see Figure 5-23).

After this orbital coast in the attitude-hold mode, a spacecraft orientation maneuver to the desired DPS ignition attitude is initiated. This maneuver takes approximately 41.5 seconds. The spacecraft holds this attitude until the completion of the first DPS burn. The total time duration from spacecraft separation to the RCS ullage maneuver preceding the first DPS burn is approximately 3 hours and 5 minutes. The duration of this coast is slightly less than that suggested in the Mission Profile Guidelines. This selection was made to allow the first DPS burn to occur while the spacecraft is in sight of the Carnarvon tracking station, which has the necessary ground command capability.

*In the automatic mode, the spacecraft is capable of executing attitude rates up to 10 degrees per second in pitch and roll, and 5 degrees per second in yaw.

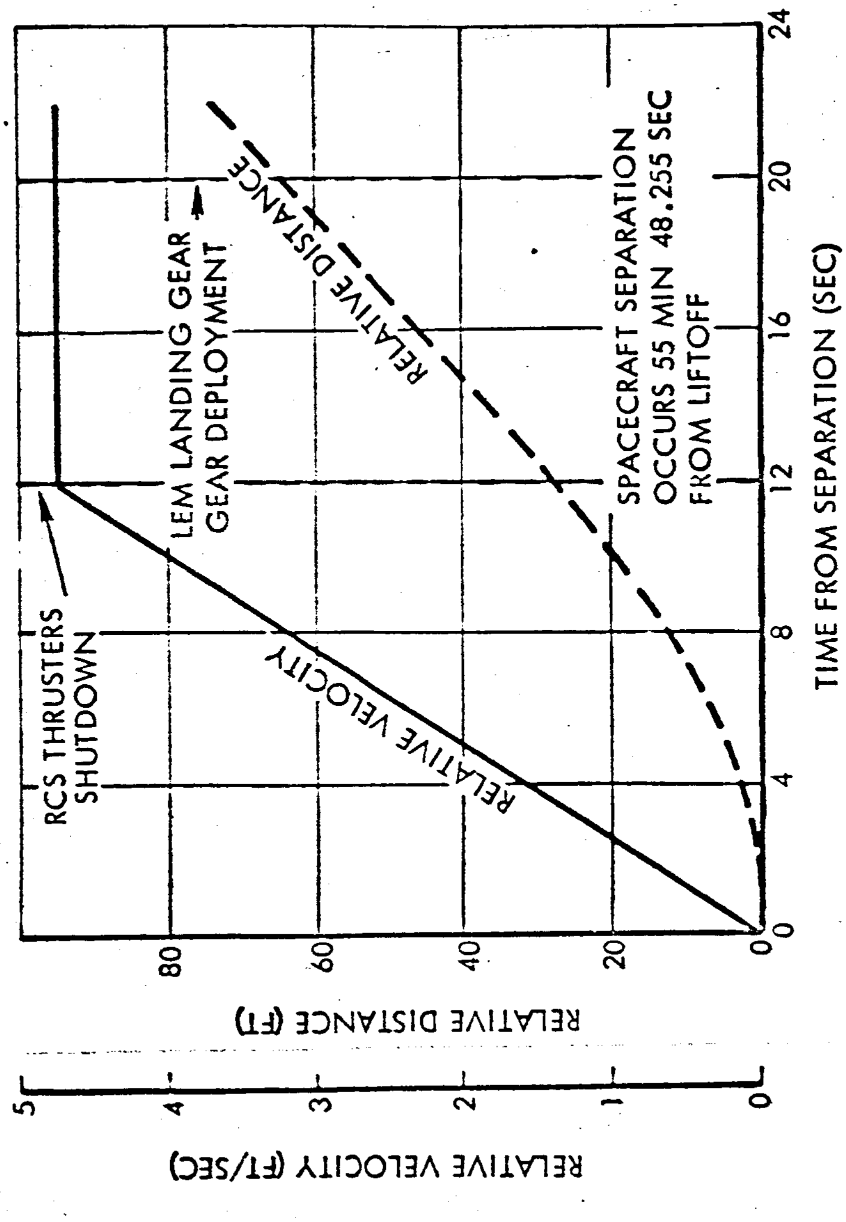


Figure 4-1a. S-IVB/LEM Relative Velocity and Distance to 22 Seconds

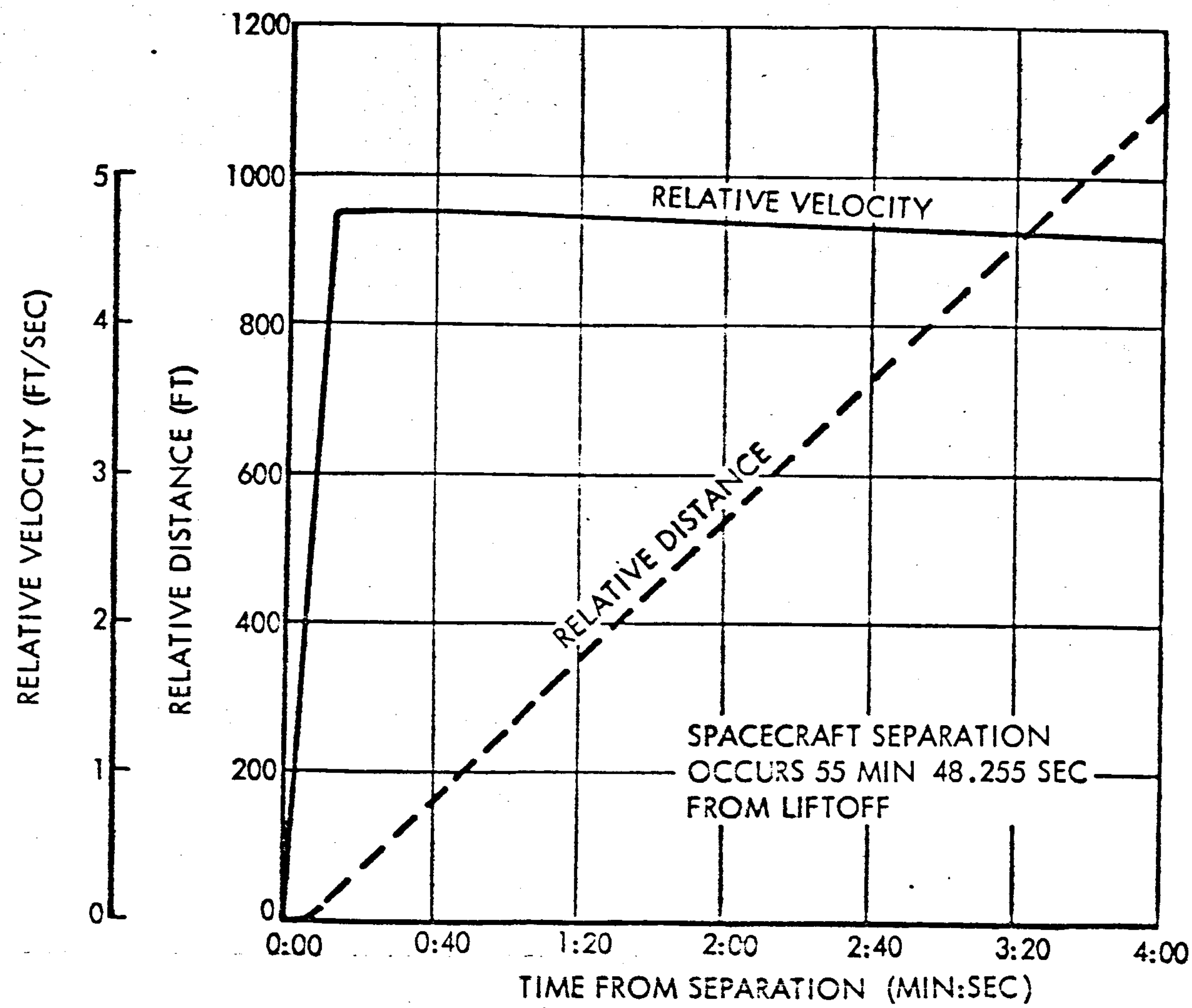


Figure 4-1b. S-IVB/LEM Relative Velocity and Distance to 240 Seconds

4.5 FIRST DPS BURN

The first DPS ignition is preceded by an 8-second RCS ullage maneuver. RCS ignition occurs 2 minutes after the Carnarvon tracking station acquires the spacecraft on the third orbit. The Apollo ship used to track the spacecraft separation events is also tracking during this event. The constant spacecraft inertial attitude during the ullage and the DPS burn (see Figure 5-27) increases the orbit perigee altitude by approximately 17 nautical miles.

The first DPS burn consists of 25 seconds at 10 percent thrust, followed immediately by 7 seconds at 100 percent thrust. Thrust and propellant weight flow rate profiles for this burn, and for the subsequent DPS burns, are shown in Figures 4-2 and 4-3, respectively.

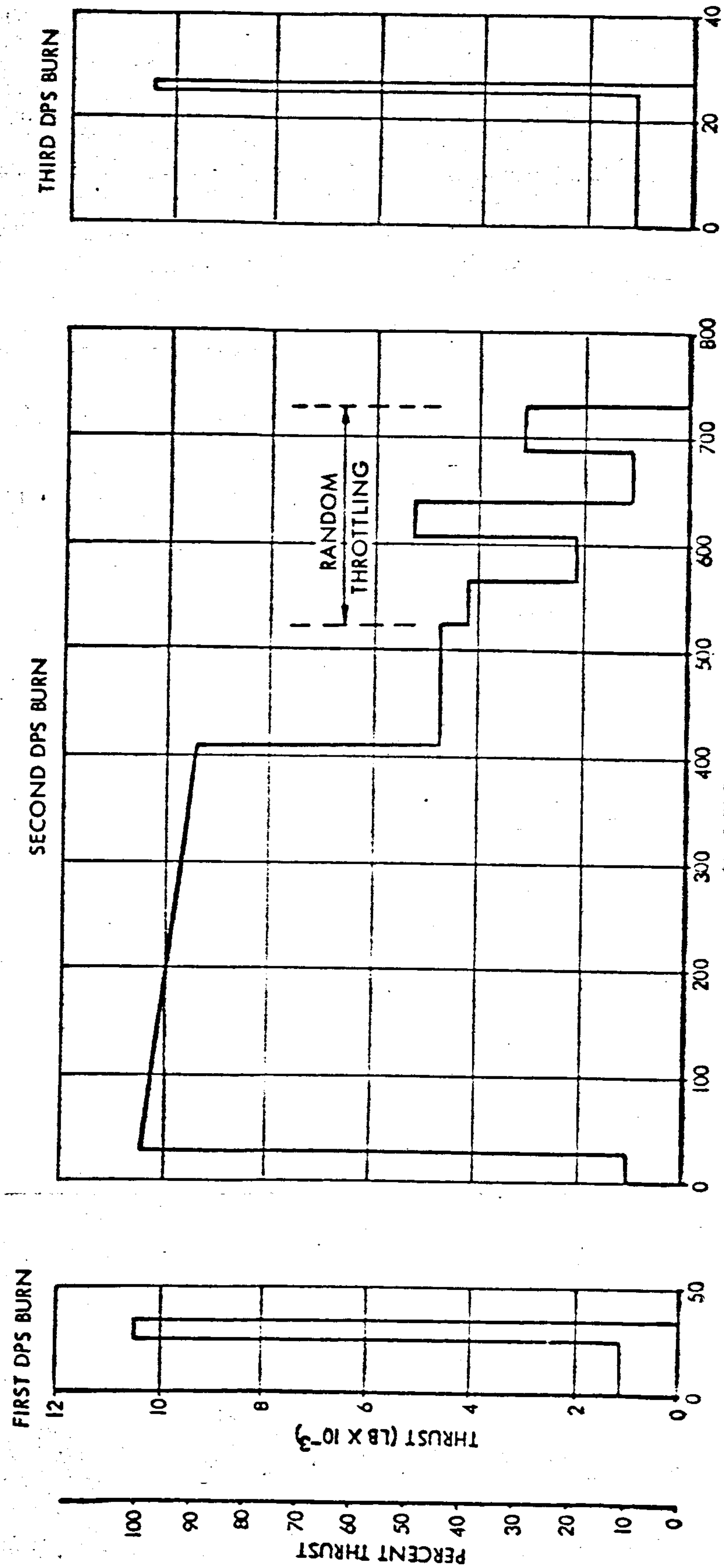
At DPS shutdown, the spacecraft is on an orbit characterized by perigee and apogee altitudes of 110.0 and 155.8 nautical miles, respectively. The resulting orbital period is 89.3 minutes.

4.6 ORBITAL COAST TO SECOND DPS BURN

The spacecraft coasts in orbit, with no attitude constraints, for approximately 28 minutes. The spacecraft is being tracked approximately 20 minutes during this coast. It is expected that certain RCS tests will be performed during this coast. No attempt has been made to simulate these various tests in this profile; however, a certain portion of the RCS propellants available have been allocated for this phase of the mission (see Table 5-5). After this coast, a maneuver is initiated to orient the spacecraft to a desired inertial attitude (see Figure 5-34). This maneuver takes approximately 39 seconds. The LEM holds this attitude to the second DPS burn ignition. The total time duration between the first DPS burn shutdown and the ullage maneuver preceding the second DPS burn is approximately 33 minutes and 20 seconds. This is slightly shorter than that suggested in the Mission Profile Guidelines, but it is necessary in order to achieve the tracking required for the second DPS burn.

4.7 SECOND DPS BURN

An 8-second RCS ullage maneuver precedes the second DPS ignition. RCS ignition occurs 2 minutes after Point Arguello tracking acquisition, and within sight of Apollo tracking ship No. 2 capable of ground-commanding


THIRD DPS BURN
SECOND DPS BURN
FIRST DPS BURN
RANDOM THROTTLING
TIME FROM IGNITION (SEC)
THRUST (LB X 10^-3)
PERCENT THRUST

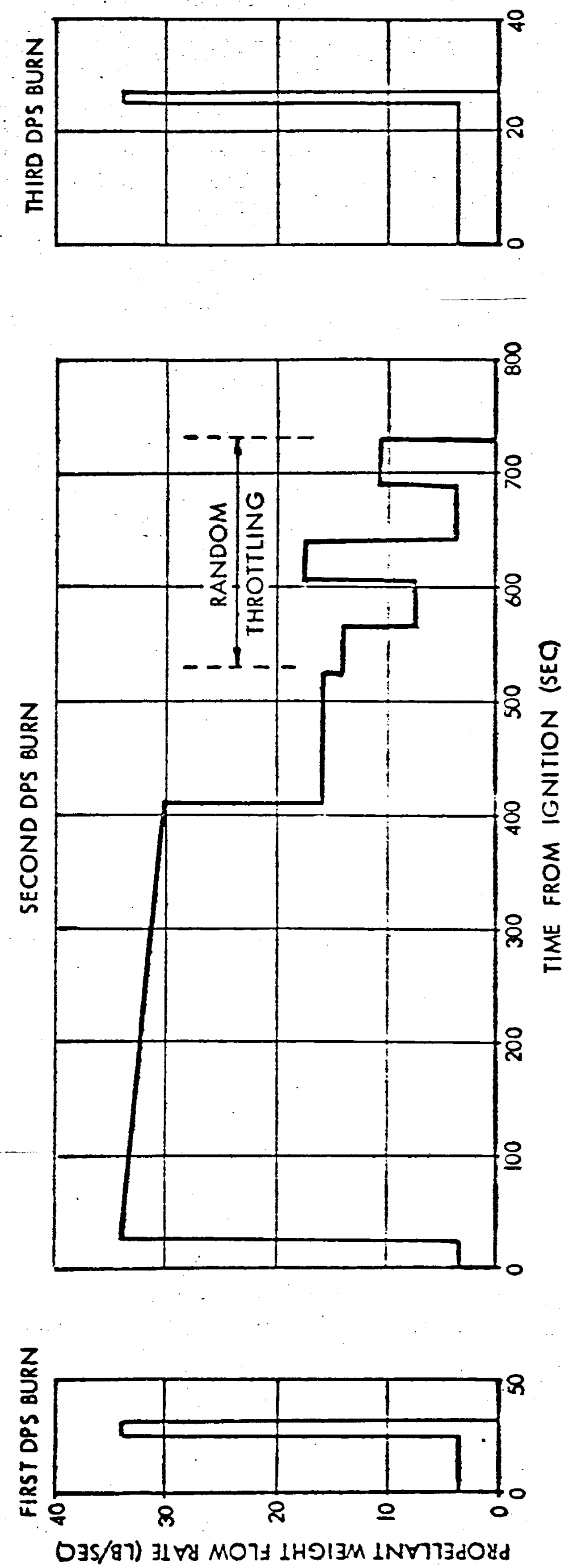


Figure 4-3. LEM-DPS Propellant Weight Flow Rate Profiles

the spacecraft, if necessary. The spacecraft is tracked continuously during the 730-second burn by 11 tracking stations across the continental United States and down the Eastern Test Range (ETR).

Most of the ΔV available from this burn (approximately 7,000 feet per second) is dissipated out of the orbit plane. This is done by selecting an inertial attitude at ignition (see Figure 5-34) and a spacecraft roll rate of 0.0166 degree per second, which places the LEM on an orbit with a perigee altitude of 140.9 nautical miles and an apogee altitude of 223.7 nautical miles. The period of this orbit is 91.1 minutes with an inclination of 31.425 degrees. This orbit increases the tracking duration of the ground stations on subsequent revolutions.

The thrust and propellant weight flow rate profiles for this burn are shown in Figures 4-2 and 4-3, respectively.

4.8 ORBITAL COAST TO FITH ABORT TEST

The LEM coasts in orbit with no attitude constraints for approximately 1 hour and 18 minutes. The spacecraft is being tracked approximately 30 minutes during this coast. It is expected that various tests of the RCS will be continued during this coast period. No attempt has been made to simulate these tests in this profile; however, a certain portion of the RCS propellants available have been allocated for this phase of the mission (see Table 5-5). After this coast, a 7-second orientation maneuver is initiated to achieve the desired inertial attitude for the FITH abort test. The LEM holds this attitude for 7 minutes and 12 seconds.

4.9 FITH ABORT TEST

An 8-second RCS ullage maneuver precedes this phase of the mission. RCS ignition occurs approximately 200 seconds after Point Arguello tracking acquisition. Apollo tracking ship No. 2 will provide the necessary ground command capability. The FITH abort test consists of a 27-second DPS (third) burn and a 0.5 second coast, followed immediately by LEM staging and a 432.6-second APS (first) burn.

The third DPS burn thrust and propellant weight flow rate profiles are presented in Figures 4-2 and 4-3, respectively. At shutdown, all of the DPS propellants available, except the one percent flight performance reserves, have been consumed.

LEM staging and the first APS ignition occur simultaneously. It is assumed that 1,183 pound-seconds of impulse will be delivered to each stage during LEM staging. Staging characteristics during the first several minutes after LEM staging are presented in Figures 4-4 and 4-5. These data are based upon point mass simulations. LEM staging occurs at a position in the orbit to allow simultaneous tracking of the event by the Apollo tracking ship, Point Arguello, Goldstone, Guaymas, and White Sands ground stations. Section 2. 2. 2 h) of the Mission Profile Guidelines suggests that this event be positioned so that at least three ground stations, with data record capability, can receive these data.

The spent descent stage is left on an orbit with a period of 91. 1 minutes and an inclination of 31. 438 degrees. The perigee altitude is 141. 0 nautical miles and the apogee altitude is 223. 1 nautical miles. The estimated descent stage maximum orbital lifetime is approximately 39 days (see Table 4-2).

The spacecraft ascent stage propulsion system is characterized by a vacuum thrust and propellant weight flow rate of 3,500 pounds and 11. 45 pounds per second, respectively. The duration of the first APS burn was chosen so that all the propellants available, except the one percent flight performance reserves, are consumed over the three suggested burns. This resulted in a 31. 4-second decrease from the duration suggested in Section 2. 2. 2 j).

As in the second DPS burn, most of the ΔV available from these burns (approximately 5,000 feet per second) is dissipated out of the orbit plane. A constant inertial attitude is held (see Figure 5-41) from the RCS ullage maneuver to three seconds after the APS ignition. The ascent stage is then rolled at a constant rate of 0. 0293 degree per second. The 3-second delay in the maneuver is to allow for hardware clearance. The above attitude and roll rate place the LEM ascent stage, at APS shutdown, on an orbit with a period of 92. 0 minutes and an inclination of 31. 375 degrees. The orbital perigee altitude is 135. 4 nautical miles and the apogee altitude is 275. 8 nautical miles.

4. 10 ORBITAL COAST TO SECOND APS BURN

The suggested 20-minute time duration of this coast to within $\pm$ 2 minutes is included in 2. 2. 2 i) of the Mission Profile Guidelines. Using

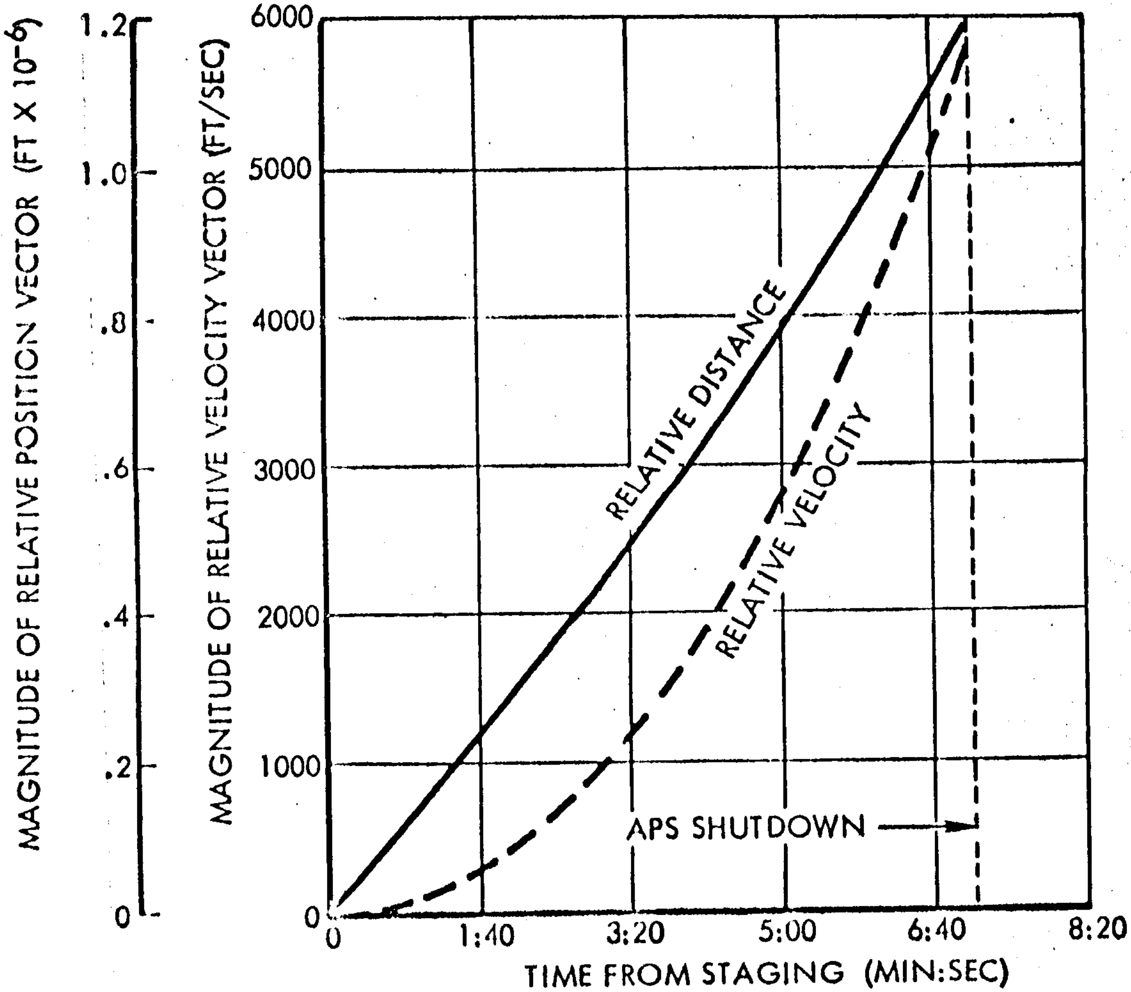


Figure 4-4a. Relative Velocity and Separation Distance Following LEM Staging to APS Shutdown

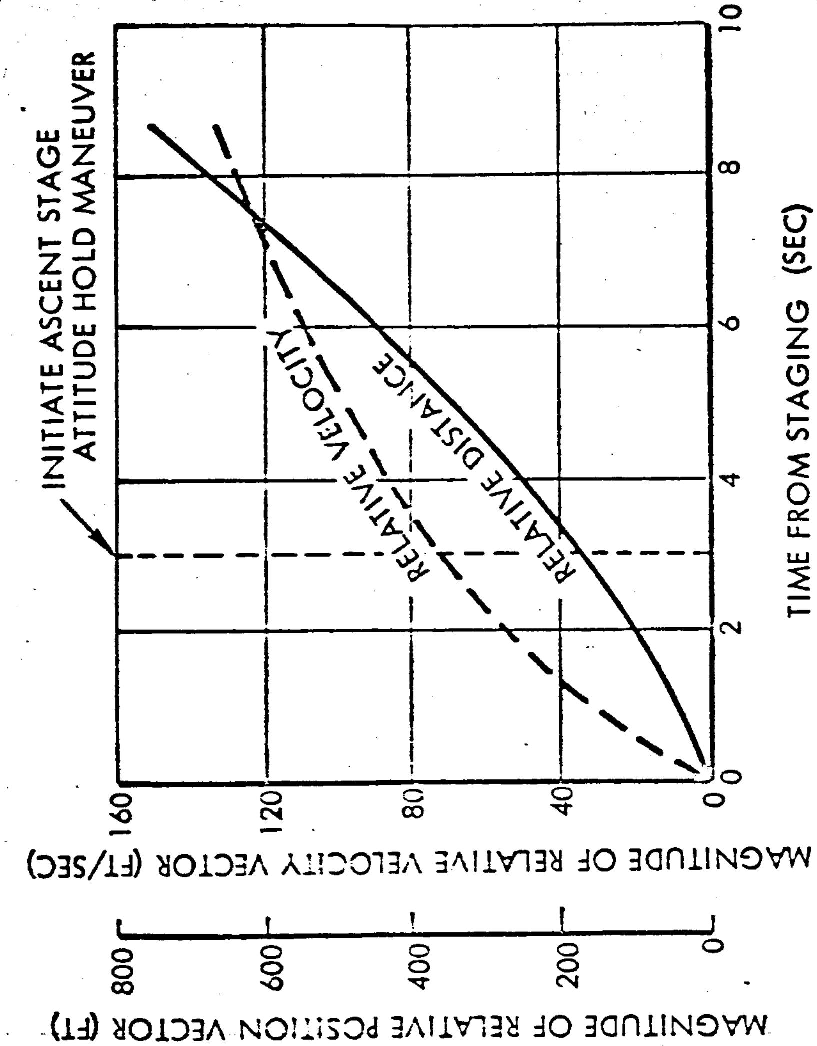


Figure 4-4b. Relative Velocity and Separation Distance Following LEM Staging to 8 seconds

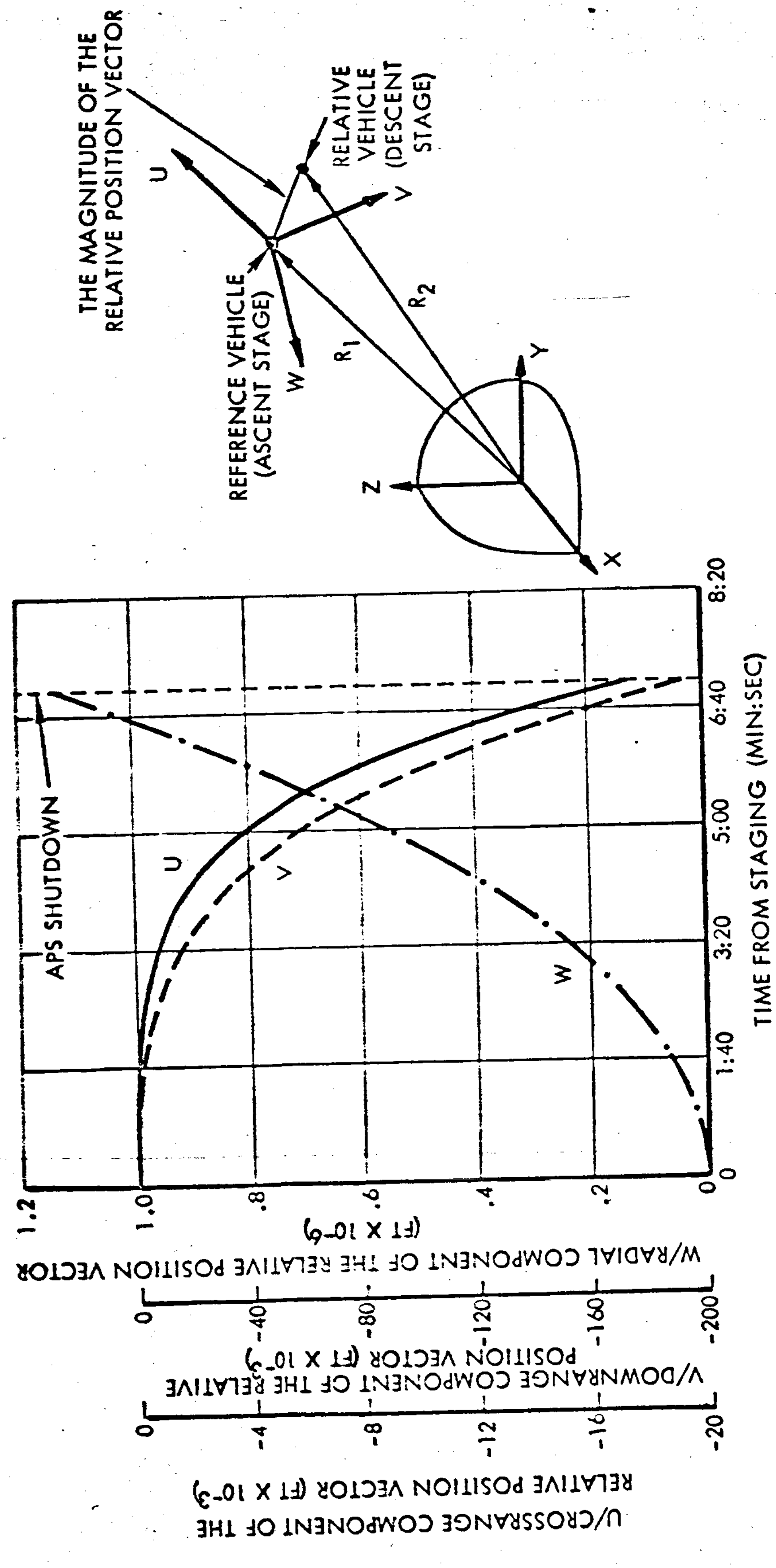


Figure 4-5a. Relative Position Coordinates Following LEM Staging to APS Shutdown

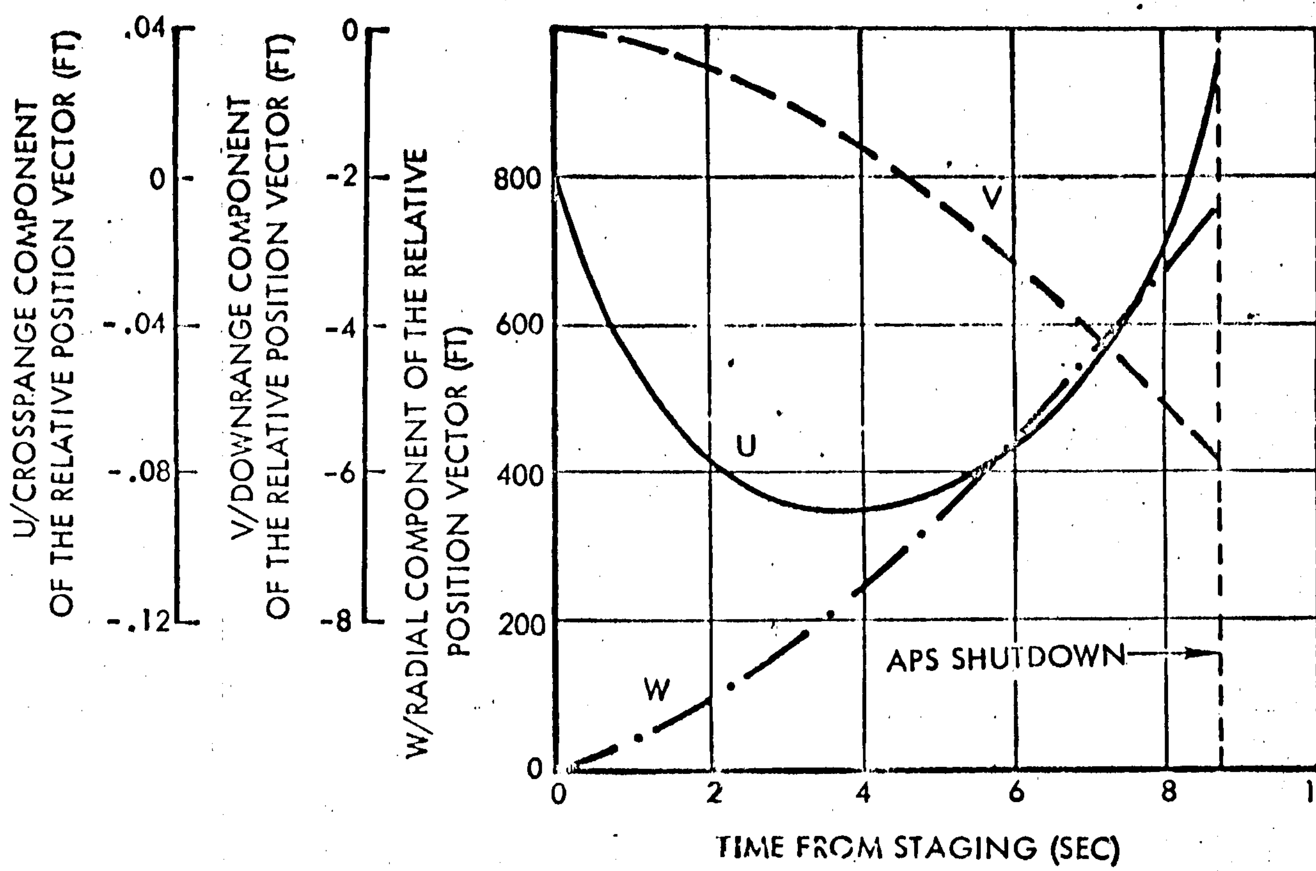


Figure 4-5b. Relative Position Coordinates Following LEM Staging to 8 seconds

this coast time, it becomes necessary to locate Apollo tracking ship No. 3 off the western coast of Africa. The primary function of this ship is to provide general tracking information, data recording and ground command capabilities in support of the second APS pre-burn and burn events.

No attempt has been made to simulate various RCS tests expected to be performed during this coast; however, a certain portion of the RCS propellants available have been allocated for this phase of the mission (see Table 5-5). The spacecraft is being tracked approximately 8 minutes during this coast.

After approximately 14 minutes and 40 seconds of this coast have elapsed, a 12-second spacecraft orientation maneuver is initiated to achieve, and hold, the desired pre-burn attitude (see Figure 5-48).

4.11 SECOND APS BURN

A 3-second RCS ullage maneuver precedes the second APS ignition. This event is initiated approximately 4 minutes after the Apollo tracking ship begins tracking the spacecraft.

The inertial attitude (see Figure 5-48) is held constant during the 5-second burn. This attitude was determined so as to decrease the orbital perigee altitude. This is done to decrease the expected orbital lifetime of the ascent stage. The post-burn perigee altitude is 115.8 nautical miles and the apogee altitude is 268.3 nautical miles. This orbit has a period of 91.5 minutes and an inclination of 31.2718 degrees.

4.12 ORBITAL COLD-SOAK TO THIRD APS BURN

Ten seconds after the second APS burn, an 18-second spacecraft maneuver is performed to align the +X-axis (yaw axis) normal to the ecliptic and the +Z-axis (roll axis) toward the sun. This attitude is held ($\pm$ 5 degrees deadband) for approximately 2 hours and 30 minutes. This coast duration is slightly shorter than that suggested in the Mission Profile Guidelines. The in-orbit position of the third APS burn achieved by the shortened coast allowed the burn to occur over MSFN stations with the necessary ground command and data record equipment. After the attitude-hold coast, an 8-second spacecraft orientation maneuver to the desired pre-burn attitude is initiated (see Figure 5-57).

In the simulation, the spacecraft attitude drifted approximately 0.1 degree, with no maneuvers, during the orbital cold-soak (see Figure 5-53).

4.13 THIRD APS BURN

Two minutes after the Point Arguello tracking site acquires the spacecraft, a 3-second RCS ullage maneuver is performed and is immediately followed by a 5-second APS burn. All the available propellants are consumed by the APS during this burn, with the exception of a one percent flight performance reserve.

The initial inertial pitch attitude held during this APS burn (see Figure 5-57) was chosen to further decrease the orbit perigee altitude.

At APS shutdown, the spent LEM ascent stage is on an orbit characterized by a perigee altitude of 109.7 nautical miles and an apogee altitude of 284.8 nautical miles. The orbital period is 91.7 minutes. The estimated ascent stage maximum orbital lifetime is approximately 27 days (see Table 4-2).

4.14 FINAL ORBITAL COAST

The objectives of the mission are essentially completed at this point in the mission; however, if the capability exists, additional tests of the RCS system will be performed during this coast. Again, no attempt has been made to simulate these various tests in this profile. A certain portion of the RCS propellants available have been allocated for this phase of the mission. An allowance of approximately 4.5 hours is shown in this profile.

4.15 ORBITAL LIFETIME ESTIMATES

The approximate orbital lifetimes of various LEM-1 configurations have been estimated and are presented herein in the form of days to impact.

The three basic spacecraft configurations considered are outlined below:

<u>Configuration 1</u>
The LEM-1 on the nominal orbit after separation from the S-IVB/SLA, but before any major propulsion tests.

<u>Configuration 2</u>
The spent LEM-1 descent stage on the nominal orbit at the instant of spacecraft separation.

Configuration 3

The spent LEM-1 ascent stage on the nominal orbit after the third APS burn has been accomplished.

Ballistic coefficients, W/C_DA (weight divided by the orbital drag coefficient and the frontal area), were calculated for each of the configurations. An orbital drag coefficient of 2.0 has been assumed. Various views of each configuration were studied in order to arrive at the minimum and the maximum frontal area that each configuration could exhibit normal to the velocity vector. Table 4-1. presents the results of this analysis.

Table 4-1. Ballistic Coefficients

Configuration/Area	Weight (lb)	Frontal Area (ft^2)	W/C_DA (lb/ft^2)
1/*	32,540	200	81
2/minimum	4,795	80	30
2/maximum	4,795	200	12
3/minimum	5,289	125	21
3/maximum	5,289	190	14

*The frontal area of the LEM-1 spacecraft does not appreciably change when studied from various views; therefore, only one frontal area is given.

These ballistic coefficients, along with the applicable orbital characteristics from the nominal trajectory and from Reference 16 were used to calculate the orbital lifetime estimates presented in Table 4-2.

Table 4-2. Orbital Lifetime Estimates

Configuration	Orbital Lifetime (days) Minimum	Orbital Lifetime (days) Maximum
1	6 (See Table 4-1.)	
2	16	39
3	18	27

[redacted]

It should be noted that even if the orbital lifetime estimates presented above are in error by so much as 100 percent, they will still fall well within the 3-month limit for orbital lifetime suggested in the Mission Profile Guidelines section of this report. Furthermore, Reference 19 states that "special preventive measures are not required for the LEM on Apollo Mission SA-206A".

5. NOMINAL TRAJECTORY DATA

This section contains trajectory parameter histories describing and illustrating the nominal mission profile. These data, presented in tabular and graphic forms, are based upon the trajectory printout data in Volume II of this document.

5.1 MISSION PROFILE DATA

The time sequence of events for the entire mission is shown in Table 5-1. Figure 5-1 presents the earth ground track for the entire mission. Figures 5-2 and 5-3 present the earth ground track for the two propulsion system tests that occur over the United States. Orbital characteristics for the spacecraft coast phases are presented in Table 5-2.

Earth shadow information (daylight - darkness) is illustrated in Figure 5-1 and presented in tabular form in Table 5-3. A time history of the spacecraft body attitude rates is presented in Table 5-4.

Table 5-5 presents the LEM-RCS propellant expenditures based on the information from Reference 6, using the criteria established in Table 3-5.

5.2 TRAJECTORY PHASE DATA

Discrete events summaries and time history illustrations of the launch vehicle and spacecraft position, motion, and attitude are presented for each of the fourteen major phases of the mission as follows:

Mission Phase	Table	Figures
Saturn IB Ascent to Orbit	5-6	5-4 through 5-11
S-IVB/SLA/LEM Orbital Coast	5-7	5-12 through 5-15
Spacecraft Separation	5-8	5-16 through 5-20
Orbital Cold-Soak to First DPS Burn	5-9	5-21 through 5-24
First DPS Burn	5-10	5-25 through 5-29
Orbital Coast to Second DPS Burn	5-11	5-30 through 5-31
Second DPS Burn	5-12	5-32 through 5-36
Orbital Coast to FITH Abort Test	5-13	5-37 through 5-38
FITH Abort Test*	5-14	5-39 through 5-43
Orbital Coast to Second APS Burn	5-15	5-44 through 5-45

* The FITH Abort Test phase consists of the third DPS burn, LEM staging, and the first APS burn.

Mission Phase	Table	Figures
Second APS Burn	5-16	5-46 through 5-50
Orbital Cold-Soak to Third APS Burn	5-17	5-51 through 5-54
Third APS Burn	5-18	5-55 through 5-59
Final Orbital Coast	5-19	5-60 through 5-61

The attitude angles presented in the figures above are referenced to a launch-centered inertial coordinate system and an earth-referenced rotating system. These coordinate systems and the spacecraft axis system are illustrated in Figure 3-7.

Table 5-1. Time Sequence of Events

Phase Event	Time from Liftoff (hr:min:sec)
Saturn IB Ascent to Orbit	
Liftoff/Begin Vertical Rise	0:00:00.00
Pitch-Over/Initiate Gravity Turn	0:00:10.00
End Gravity Turn	0:02:18.00
S-IB Inboard Engines Shutdown	0:02:20.25
S-IB Outboard Engines Shutdown/Coast	0:02:26.25
S-IVB Ignition	0:02:31.75
Jettison Thermolag, Ullage Cases, and Dummy CSM	0:02:41.75
S-IVB Shutdown into Elliptical Earth Orbit	0:09:59.85
S-IVB/SLA/LEM Orbital Coast	
Start of Orbital Coast	0:09:59.85
Maneuver to Align S-IVB X-Axis Along Orbit Path	0:10:09.85
S-IVB X-Axis Aligned Along Orbit Path	0:10:50.64
Carnarvon Tracking Acquisition	0:53:46.26
SLA Petal Deployment	0:55:46.26
Spacecraft Separation	
SLA Petal Deployment	0:55:46.26
LEM Separation/RCS Ignition	0:55:48.26
RCS Shutdown	0:56:00.26
LEM Landing Gear Deployment	0:56:08.26
Orbital Cold Soak to First DPS Burn	
LEM Landing Gear Deployment	0:56:08.26
Maneuver to Align LEM +Z-Axis Toward The Sun	0:56:38.26
Maneuver to Required Pre-Burn Inertial Attitude	3:54:28.26
Carnarvon Tracking Acquisition	3:59:27.93
RCS Ullage Maneuver	4:01:27.93
First DPS Burn	
RCS Ullage Maneuver	4:01:27.93
First DPS Ignition	4:01:35.93
DPS Shutdown	4:02:07.93
Orbital Coast to Second DPS Burn	
DPS Shutdown	4:02:07.93
Maneuver to Required Pre-Burn Inertial Attitude	4:30:07.93
Point Arguello Tracking Acquisition	4:33:28.24
RCS Ullage Maneuver	4:35:28.24

Table 5-1. Time Sequence of Events (Continued)

Phase Event	Time from Liftoff (hr:min:sec)
Second DPS Burn	
RCS Ullage Maneuver	4:35:28.24
Second DPS Ignition	4:35:36.24
DPS Shutdown	4:47:46.24
Orbital Coast to FITH Abort Test	
DPS Shutdown	4:47:46.24
Maneuver to Required Pre-Burn Inertial Attitude	6:06:06.24
Point Arguello Tracking Acquisition	6:09:25.77
RCS Ullage Maneuver	6:12:45.77
FITH Abort Test	
RCS Ullage Maneuver	6:12:45.77
Third DPS Ignition	6:12:53.77
DPS Shutdown/Coast	6:13:20.77
LEM Staging/First APS Ignition	6:13:21.27
APS Shutdown	6:20:24.87
Orbital Coast to Second APS Burn	
APS Shutdown	6:20:24.87
Maneuver to Required Pre-Burn Inertial Attitude	6:35:04.87
Ship No. 3 Tracking Acquisition	6:36:29.25
RCS Ullage Maneuver	6:40:24.87
Second APS Burn	
RCS Ullage Maneuver	6:40:24.87
Second APS Ignition	6:40:27.87
APS Shutdown	6:40:32.87
Orbital Cold-Soak to Third APS Burn	
APS Shutdown	6:40:32.87
Maneuver to Align +Z-Axis Toward The Sun	6:40:42.87
Maneuver to Required Pre-Burn Inertial Attitude	9:10:32.87
Point Arguello Tracking Acquisition	9:22:53.33
RCS Ullage Maneuver	9:24:53.33
Third APS Burn	
RCS Ullage Maneuver	9:24:53.33
Third APS Ignition	9:24:56.33
APS Shutdown	9:25:01.33
Final Orbital Coast	
APS Shutdown	9:25:01.33
End of Mission Profile	14:00:00.00

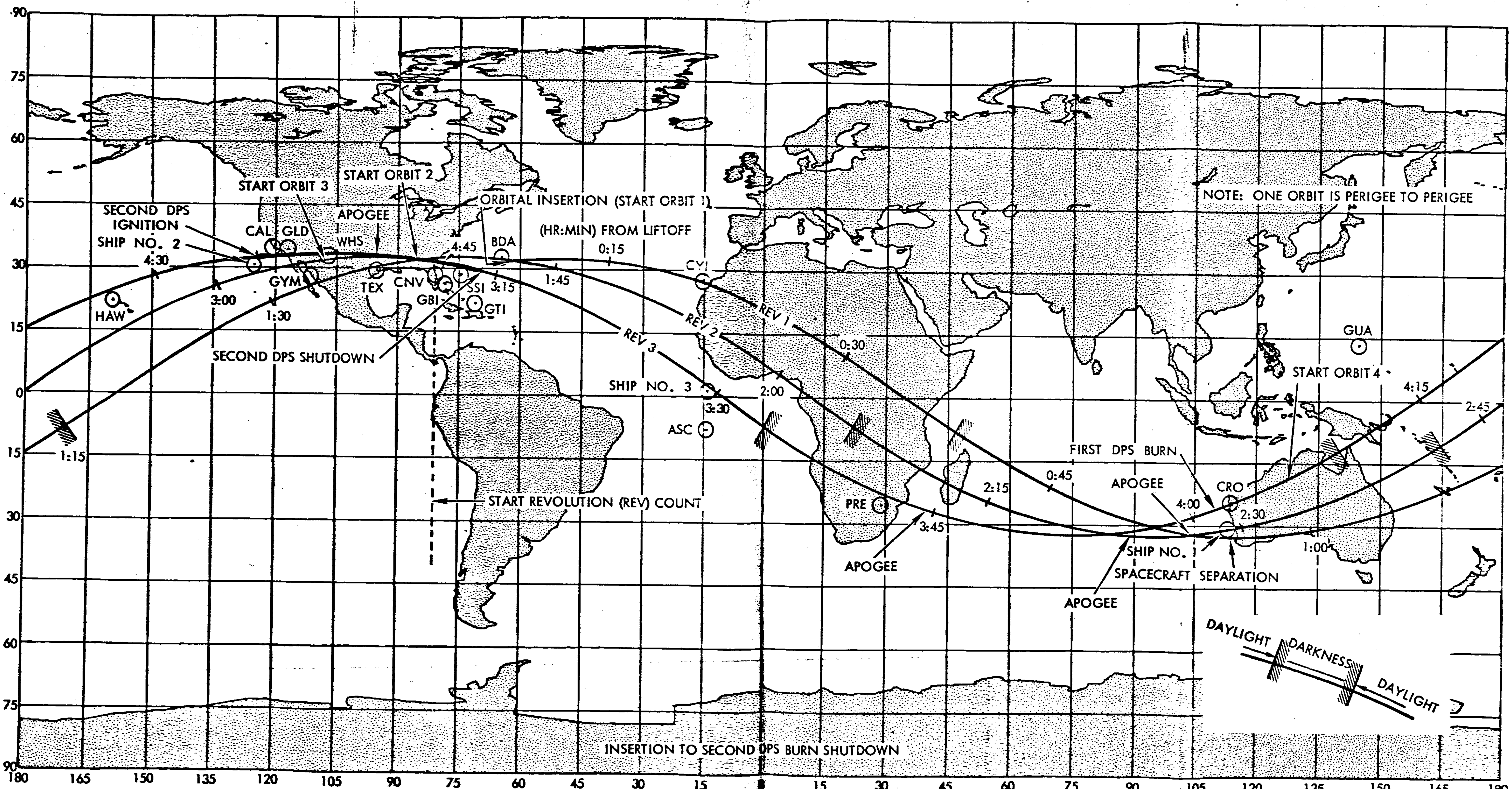


Figure 5-1. Earth Ground Track/Enti
Mission Profile

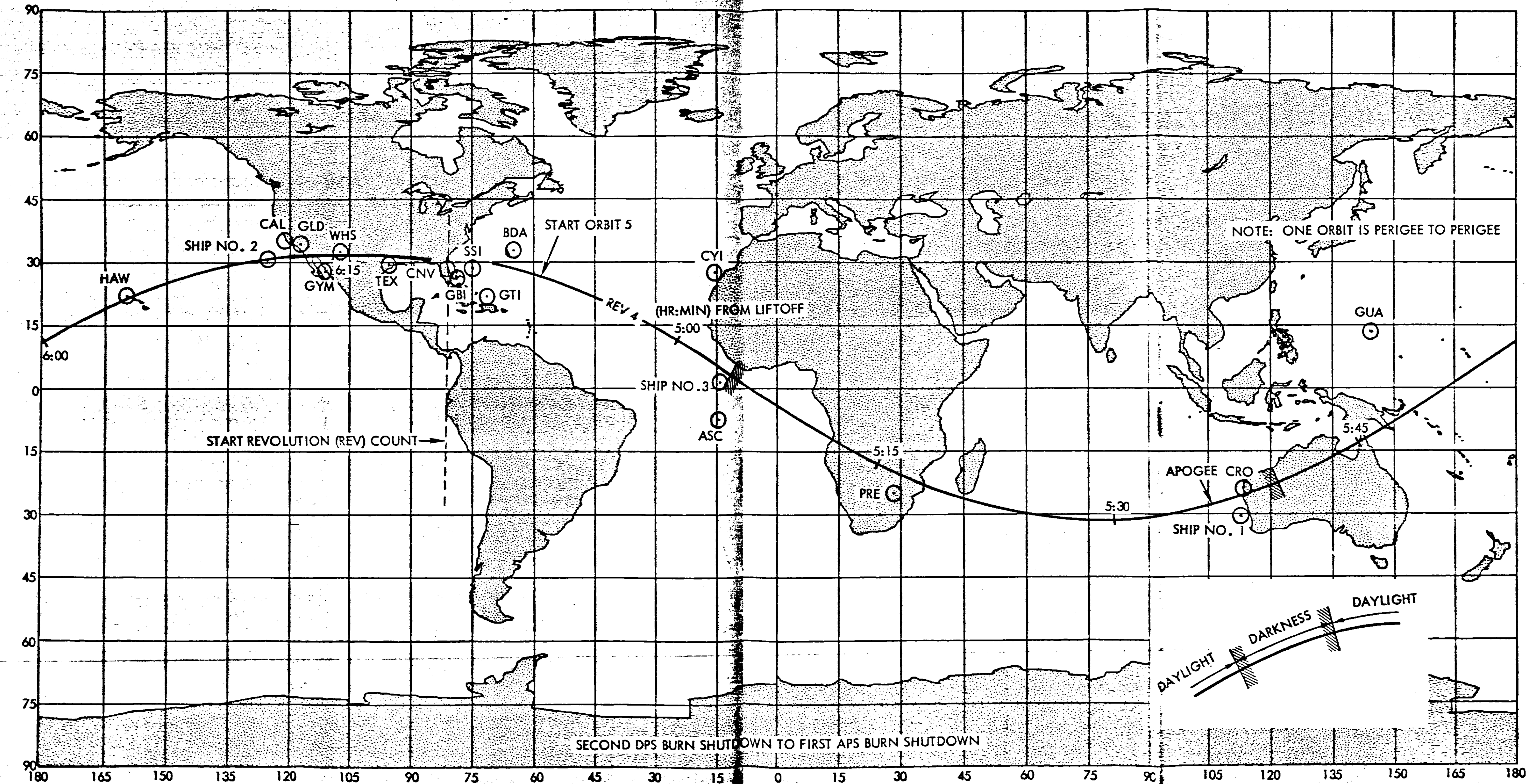


Figure 5-1. Earth Ground Track/Entire Mission Profile (Continued)

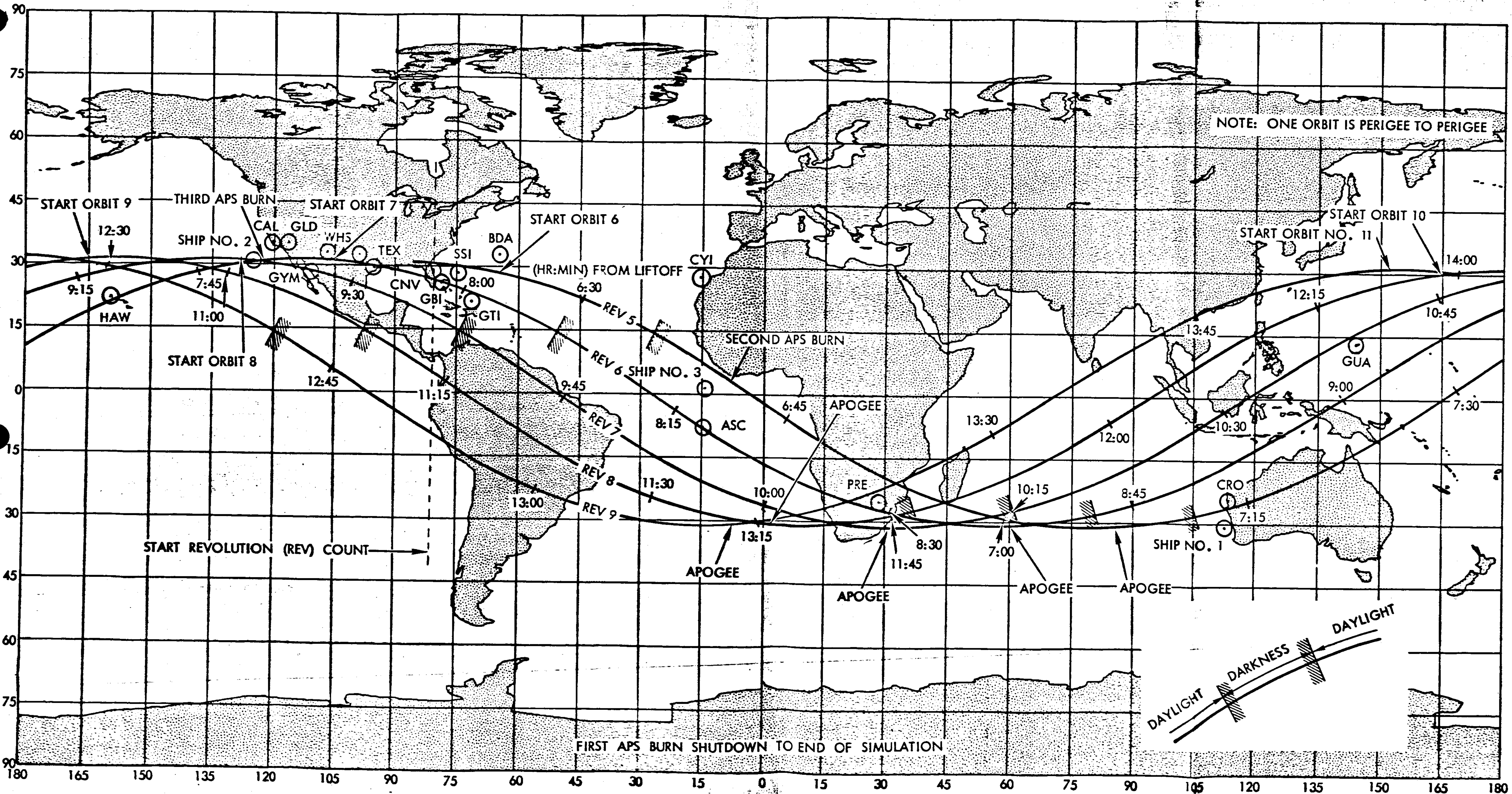


Figure 5-1. Earth Ground Track/Entire Mission Profile (Continued)

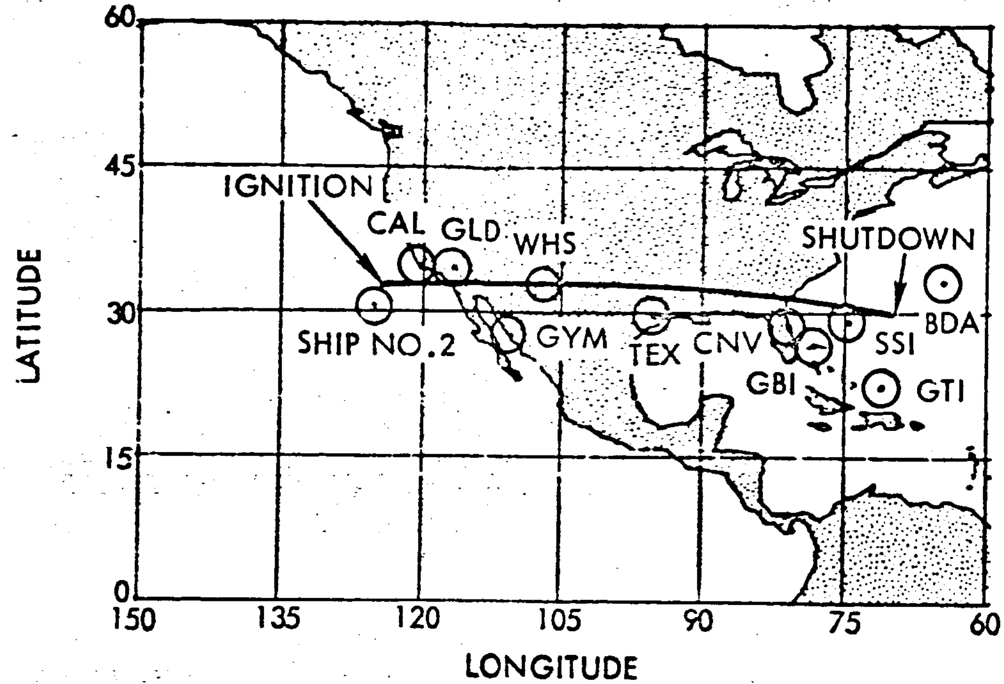


Figure 5-2. Earth Ground Track/Second DPS Burn

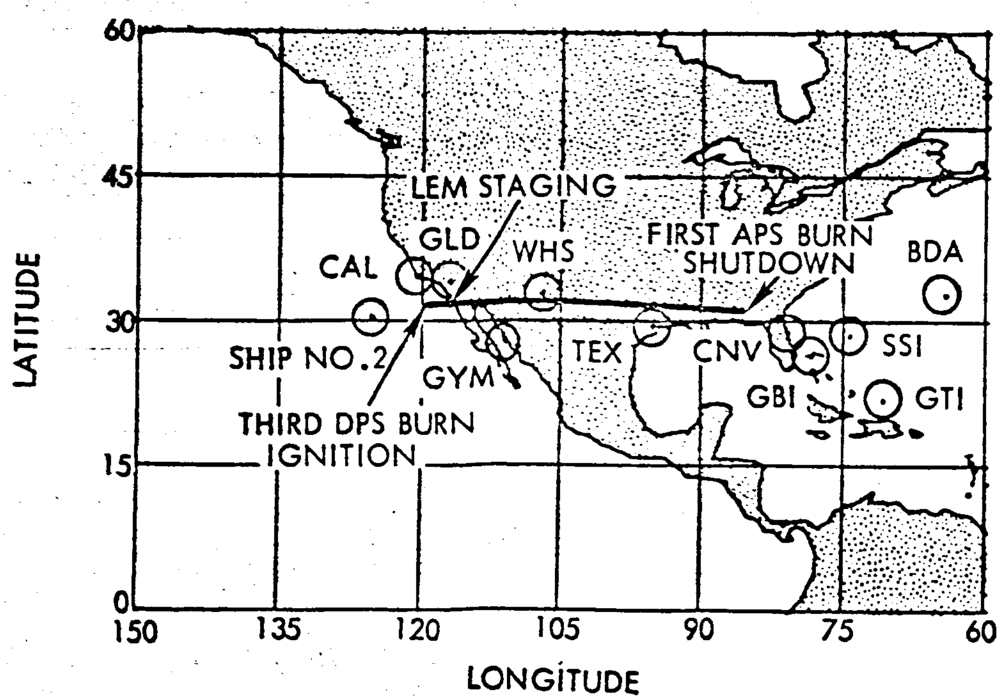


Figure 5-3. Earth Ground Track/FITH Abort Test

Table 5-2. Orbital Characteristics of the Spacecraft Coast Phases

Coast Following:	Coast Duration (hr:min:sec)	Semi-Major Axis (ft)	Eccentricity (nd)	Inclination (deg)	Orbital Period (min)	Perigee (n mi)	Apogee (n mi)
Orbital Insertion*	0:45:48	21,525,680	0.004779	32.474	88.149	85.5	119.4
Spacecraft Separation	3:05:28	21,532,980	0.003392	32.473	88.194	91.7	115.7
First DPS Burn	0:33:20	21,710,490	0.006405	32.488	89.286	110.0	155.8
Second DPS Burn	1:25:00	22,010,550	0.011435	31.425	91.144	140.9	223.7
FITH Abort Test	0:20:00	22,152,030	0.019247	31.235	92.024	135.4	275.8
Second APS Burn	2:44:20	22,069,490	0.020992	31.272	91.510	115.8	268.3
Third APS Burn**	4:34:59	22,101,190	0.024072	31.236	91.707	109.7	284.8

*S-IVB/SLA/LEM combination.
**Mission is assumed to end 14 hours after liftoff.

Table 5-3. Earth Shadow Data

Entrance Into Earth's Shadow (Time From Liftoff)		Exit From Earth's Shadow (Time From Liftoff)		Time In Earth's Shadow
Hrs	Min	Hrs	Min	Min
0	38	1	14	36
2	6	2	43	37
3	34	4	11	37
5	3	5	40	37
6	35	7	11	36
8	6	8	43	37
9	37	10	14	37
11	9	11	45	36
12	39	13	17	38

Table 5-4. Spacecraft Body Attitude Rate History

Time from Liftoff (hr:min:sec)	Pitch Rate (deg/sec)	Yaw Rate (deg/sec)	Roll Rate (deg/sec)
Spacecraft Separation			
0:55:48.26	0.0	0.0	0.0
Orbital Cold-Soak to First DPS Burn			
0:56:08.26	0.0	0.0	0.0
0:56:38.26	0.0	-5.0	0.0
0:56:45.06	0.0	0.0	10.0
0:56:56.61	0.0	-5.0	0.0
0:57:31.88	0.0	0.0	0.0
3:54:28.26	0.0	5.0	0.0
3:54:32.16	0.0	0.0	10.0
3:54:41.90	0.0	-5.0	0.0
3:55:09.78	0.0	0.0	0.0
Orbital Soak to Second DPS Burn			
4:02:07.93	0.0	0.0	0.0
4:30:07.93	0.0	5.0	0.0
4:30:08.10	0.0	0.0	10.0
4:30:16.97	0.0	5.0	0.0
4:30:46.51	0.0	0.0	0.0
Second DPS Burn			
4:35:36.24	0.0	0.0	0.0166
4:47:46.24	0.0	0.0	0.0166
Orbital Coast to FITH Abort Test			
4:47:46.24	0.0	0.0	0.0
6:06:06.24	0.0	-5.0	0.0
6:06:06.92	-10.0	0.0	0.0
6:06:07.50	0.0	5.0	0.0
6:06:13.23	0.0	0.0	0.0
FITH Abort Test			
6:12:45.77	0.0	0.0	0.0
6:13:24.27	0.0	0.0	0.0293
6:20:24.87	0.0	0.0	0.0293
Orbital Coast to Second APS Burn			
6:20:24.87	0.0	0.0	0.0
6:35:04.87	0.0	-5.0	0.0
6:35:06.94	0.0	0.0	-10.0
6:35:15.93	0.0	5.0	0.0
6:35:16.76	0.0	0.0	0.0
Orbital Cold-Soak to Third APS Burn			
6:40:32.87	0.0	0.0	0.0
6:40:42.87	0.0	5.0	0.0
6:40:50.72	0.0	0.0	10.0
6:40:55.83	0.0	-5.0	0.0
6:41:01.13	0.0	0.0	0.0
9:10:32.87	0.0	-5.0	0.0
9:10:34.80	0.0	0.0	-10.0
9:10:38.64	0.0	-5.0	0.0
9:10:41.30	0.0	0.0	0.0

Table 5-5. LEM-RCS Propellant Expenditures*

Maneuver	RCS Propellant Expenditure (lb)**
Spacecraft Separation	15.00
Ullages Preceding	
1) DPS Operation	30.00
2) APS Operation	7.50
Attitude Holds (±5 deg Deadband)	
1) During LEM Coast	0.76
2) During Ascent Stage Coast	3.90
Attitude Holds (±0.3 deg Deadband)	
1) During DPS Burns	31.50
2) During APS Burns	64.18
3) During FITH Staging	10.00
Three Axis Attitude Orientation	
1) LEM	70.40
2) Ascent Stage	8.20
RCS Tests***	
1) Coast Between First and Second DPS Burns	18.84
2) Coast Between Second and Third DPS Burns	91.22
3) Coast Between First and Second APS Burns	44.89
4) Coast After Third APS Burn	44.89
Total =	441.28
Usable Propellant Remaining**** =	134.72

*No allowances were made for RCS contingency operations.
**Based on the criteria from Table 3-5 and from mission profile.
***Reference 6.
****Based on an RCS usable propellant loading of 576 pounds.

Table 5-6. Saturn IB Ascent to Orbit/Discrete Events Summary

Event	Time From Liftoff (hr:min:sec)	Altitude* (ft)	Geodetic Latitude** (deg)	Longitude** (deg)	Inertial Velocity (ft/sec)	Inertial Flight Path Angle (deg)	Inertial Azimuth Angle (deg)
Liftoff/Begin Vertical Rise	0:00:00.0	-9	28.532	-80.565	1,342	0.00	90.00
Pitch-Over/Initiate Gravity Turn	0:00:10.0	419	28.532	-80.565	1,344	3.82	89.99
End Gravity Turn	0:02:18.0	175,567	28.657	-80.130	6,684	29.95	76.29
S-IB Inboard Engines Shutdown	0:02:20.2	183,197	28.666	-80.100	6,935	29.75	76.16
S-IB Outboard Engines Shutdown/Coast	0:02:26.2	204,284	28.690	-80.012	7,310	29.01	75.98
S-IVB Ignition	0:02:31.7	223,581	28.714	-79.929	7,305	28.00	76.00
Jettison Thermolag, Ullage Cases, and Dummy CSM	0:02:41.7	257,046	28.757	-79.775	7,378	26.14	76.00
S-IVB Shutdown into Elliptical Earth Orbit	0:09:59.9	516,621	31.965	-62.846	25,695	0.00	83.01

*Altitude above the Fischer ellipsoid.
**Minus coordinates indicate West longitudes and South latitudes.

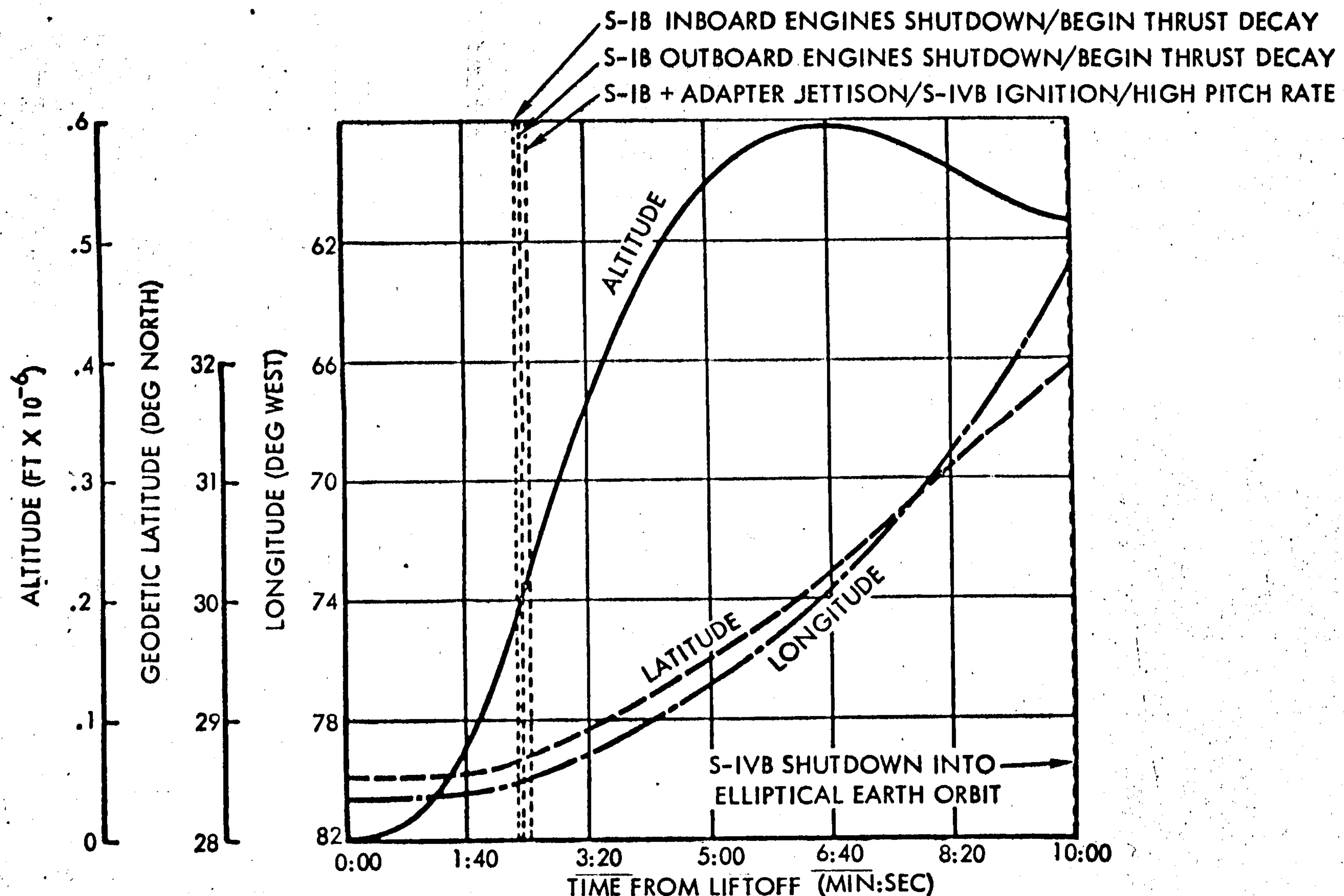


Figure 5-4. Saturn IB Ascent to Orbit/Altitude, Latitude, and Longitude

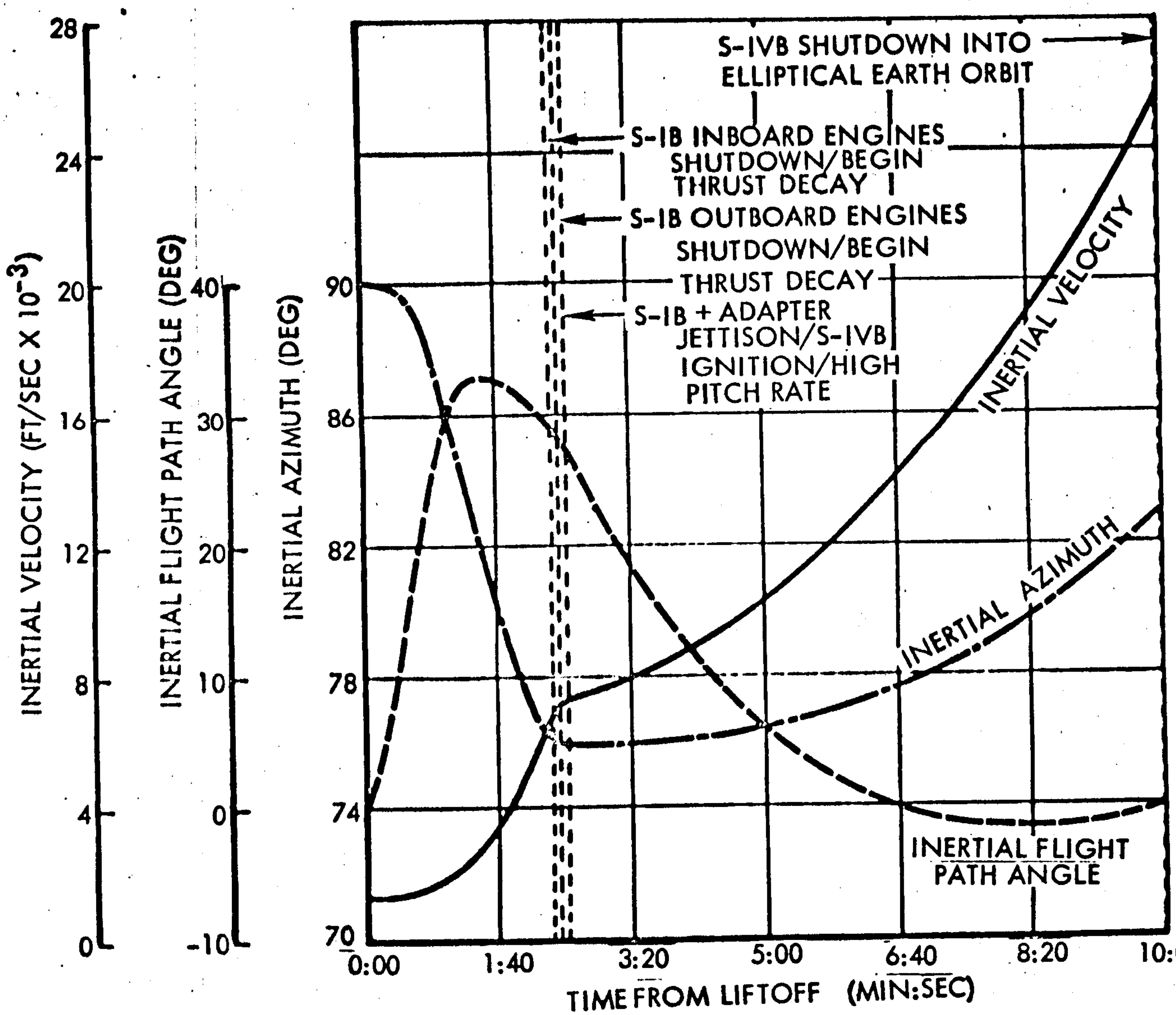


Figure 5-5. Saturn IB Ascent to Orbit/Inertial Velocity, Flight Path Angle, and Azimuth

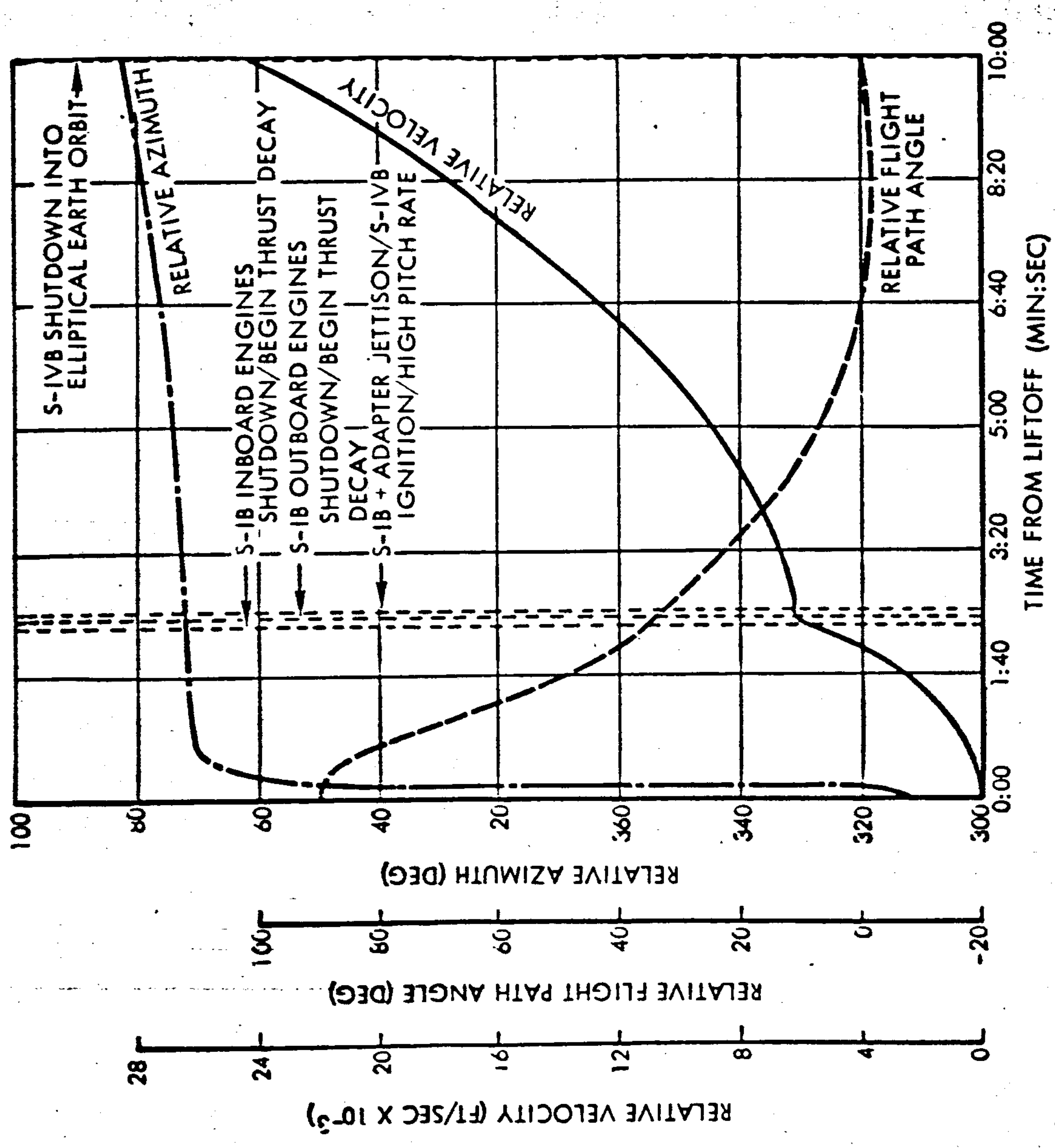


Figure 5-6. Saturn IB Ascent to Orbit/Relative Velocity, Flight Path Angle, and Azimuth

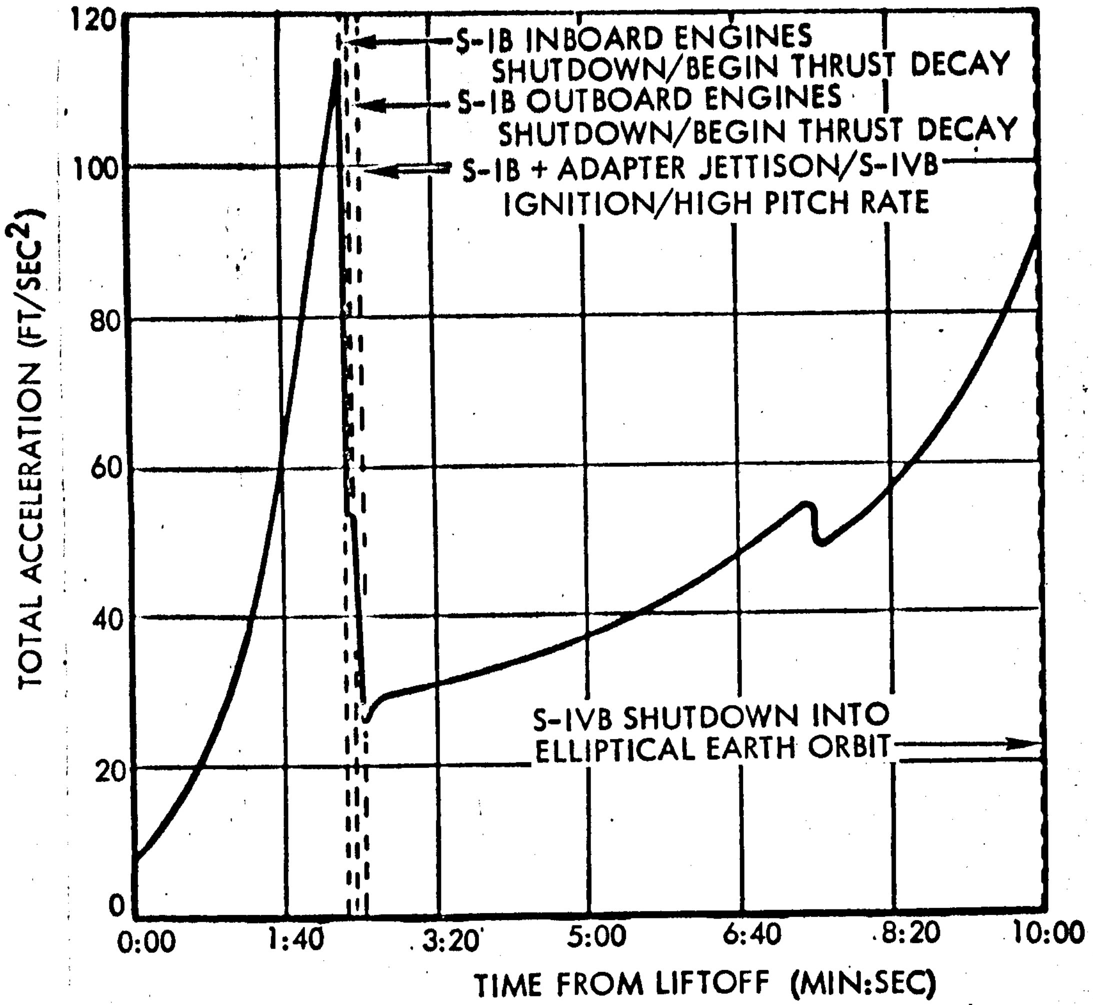
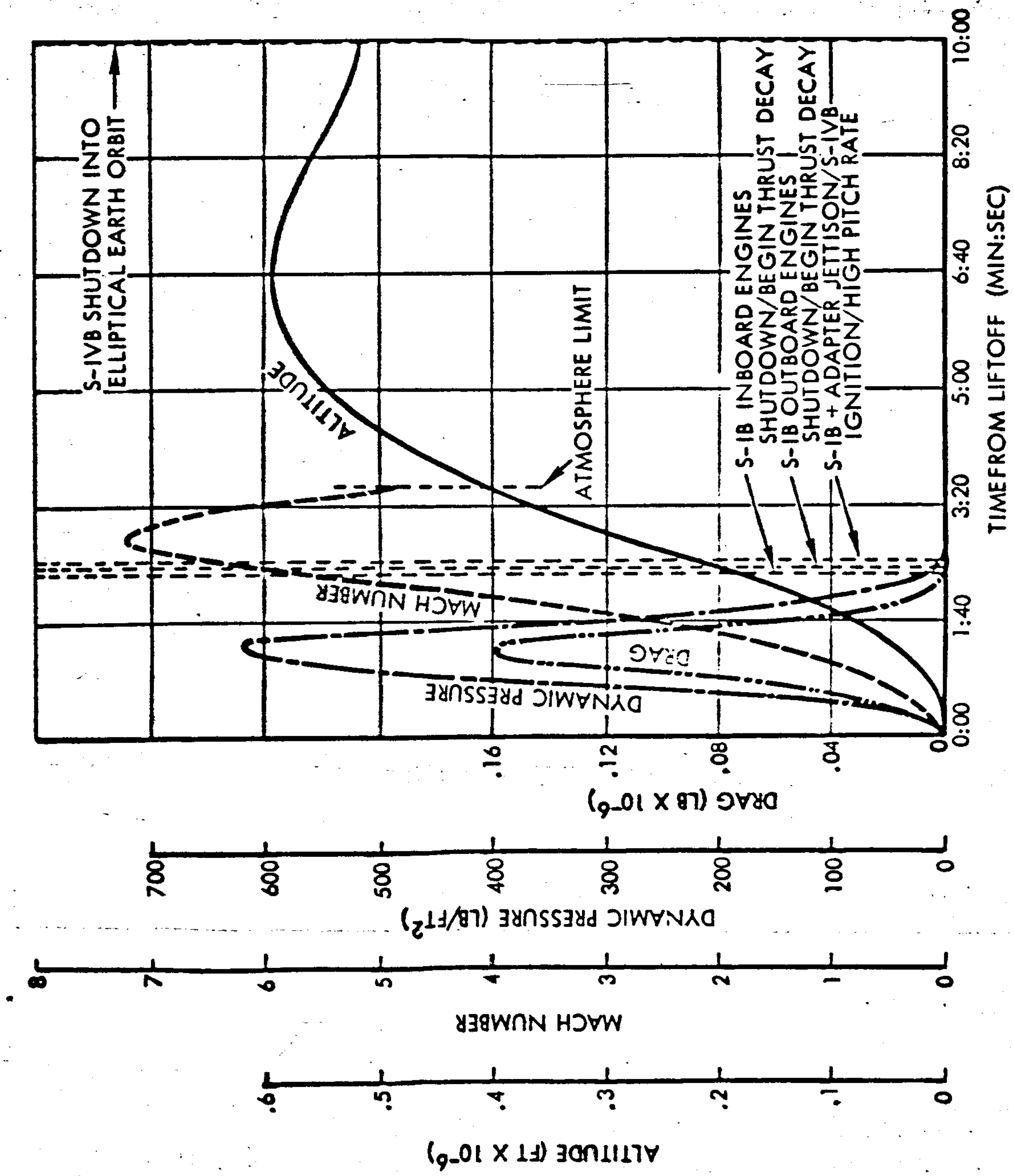


Figure 5-7. Saturn IB Ascent to Orbit/Total Acceleration


S-IVB SHUTDOWN INTO ELLIPTICAL EARTH ORBIT
ATMOSPHERE LIMIT
ALTITUDE
MACH NUMBER
DRAG
DYNAMIC PRESSURE
S-IB INBOARD ENGINES SHUTDOWN/BEGIN THRUST DECAY
S-IB OUTBOARD ENGINES SHUTDOWN/BEGIN THRUST DECAY
S-IB + ADAPTER JETTISON/S-IVB IGNITION/HIGH PITCH RATE
TIME FROM LIFTOFF (MIN:SEC)
0:00
1:40
3:20
5:00
6:40
8:20
10:00
DRAG (LB X 10^{-6})
0
.04
.08
.12
.16
DYNAMIC PRESSURE (LB/FT^2)
0
100
200
300
400
500
600
700
MACH NUMBER
0
1
2
3
4
5
6
7
8
ALTITUDE (FT X 10^{-6})
0
.1
.2
.3
.4
.5
.6

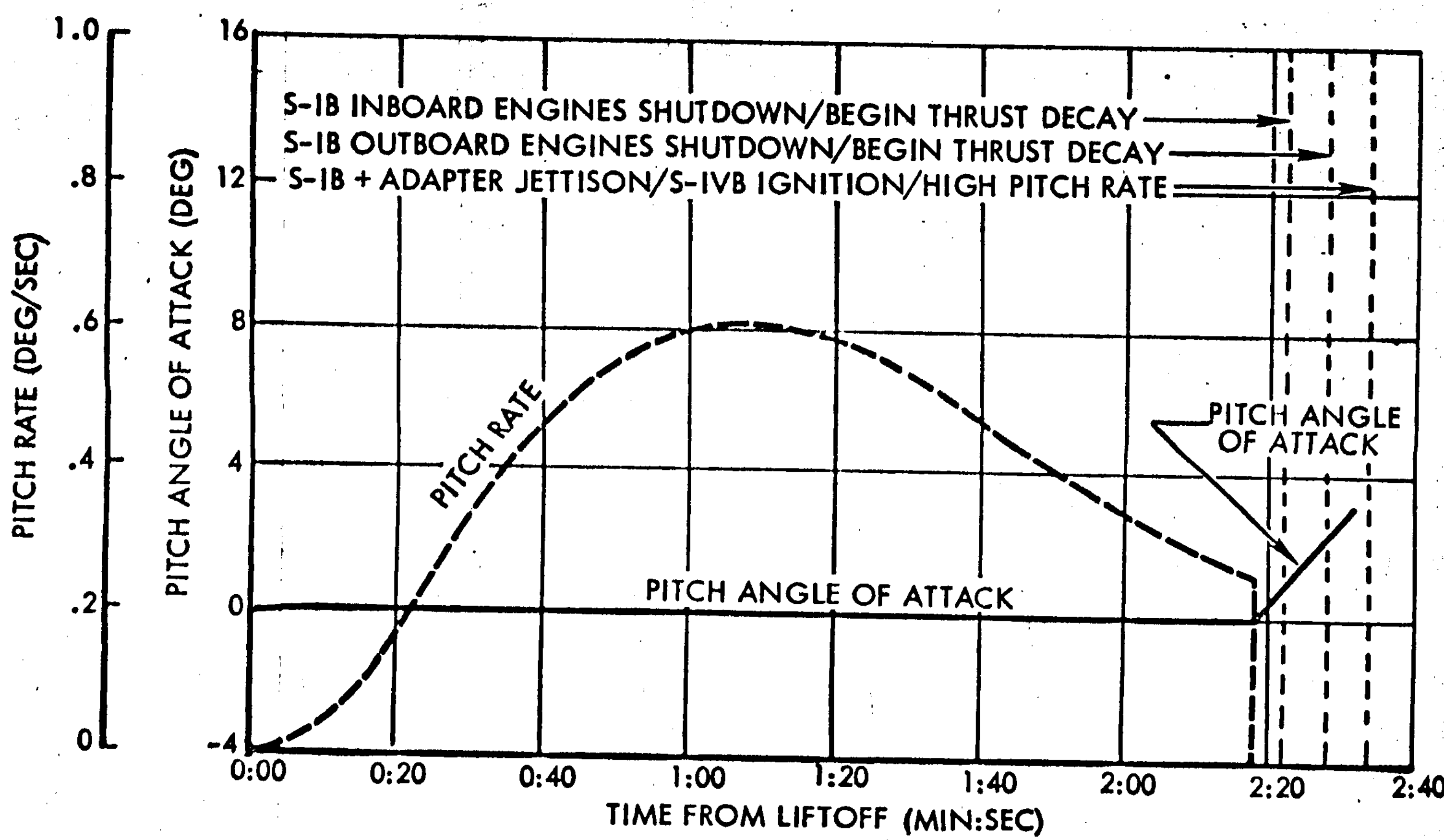


Figure 5-9. Saturn IB Ascent to Orbit/Pitch Rate, and Pitch Angle of Attack

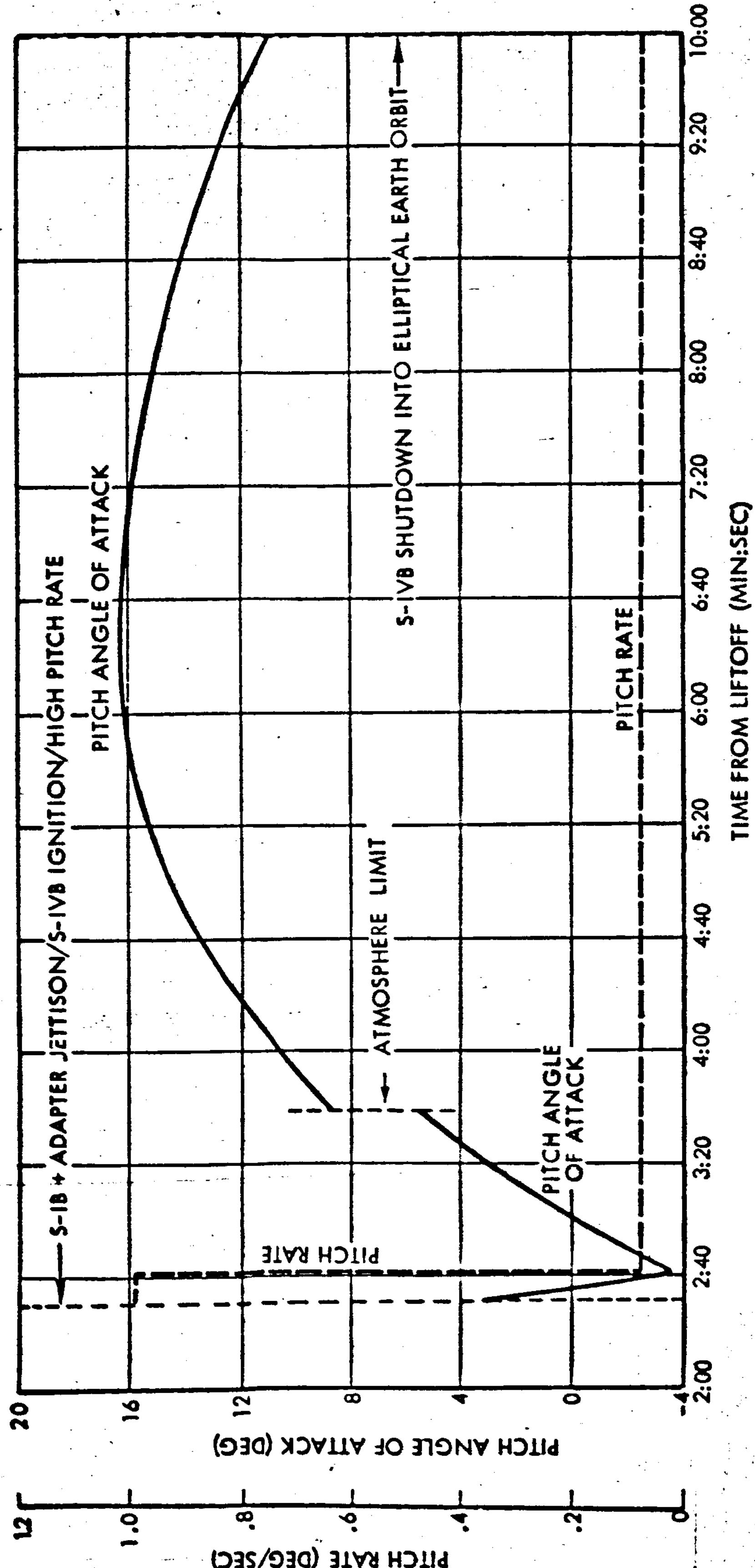


Figure 5-9. Saturn IB Ascent to Orbit/Pitch Rate, and Pitch Angle of Attack (Continued)

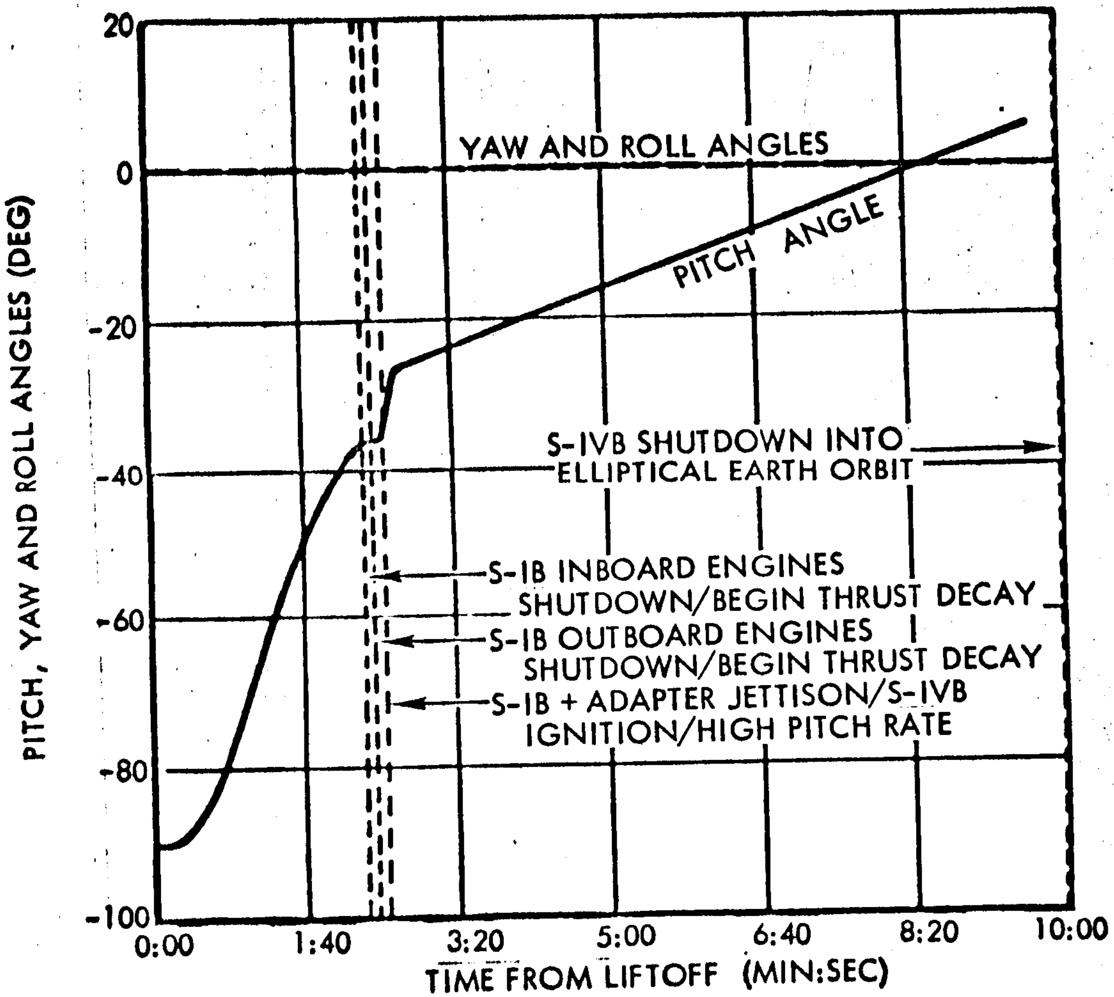


Figure 5-10. Saturn IB Ascent to Orbit/Vehicle Attitude (Launch Site Inertial)

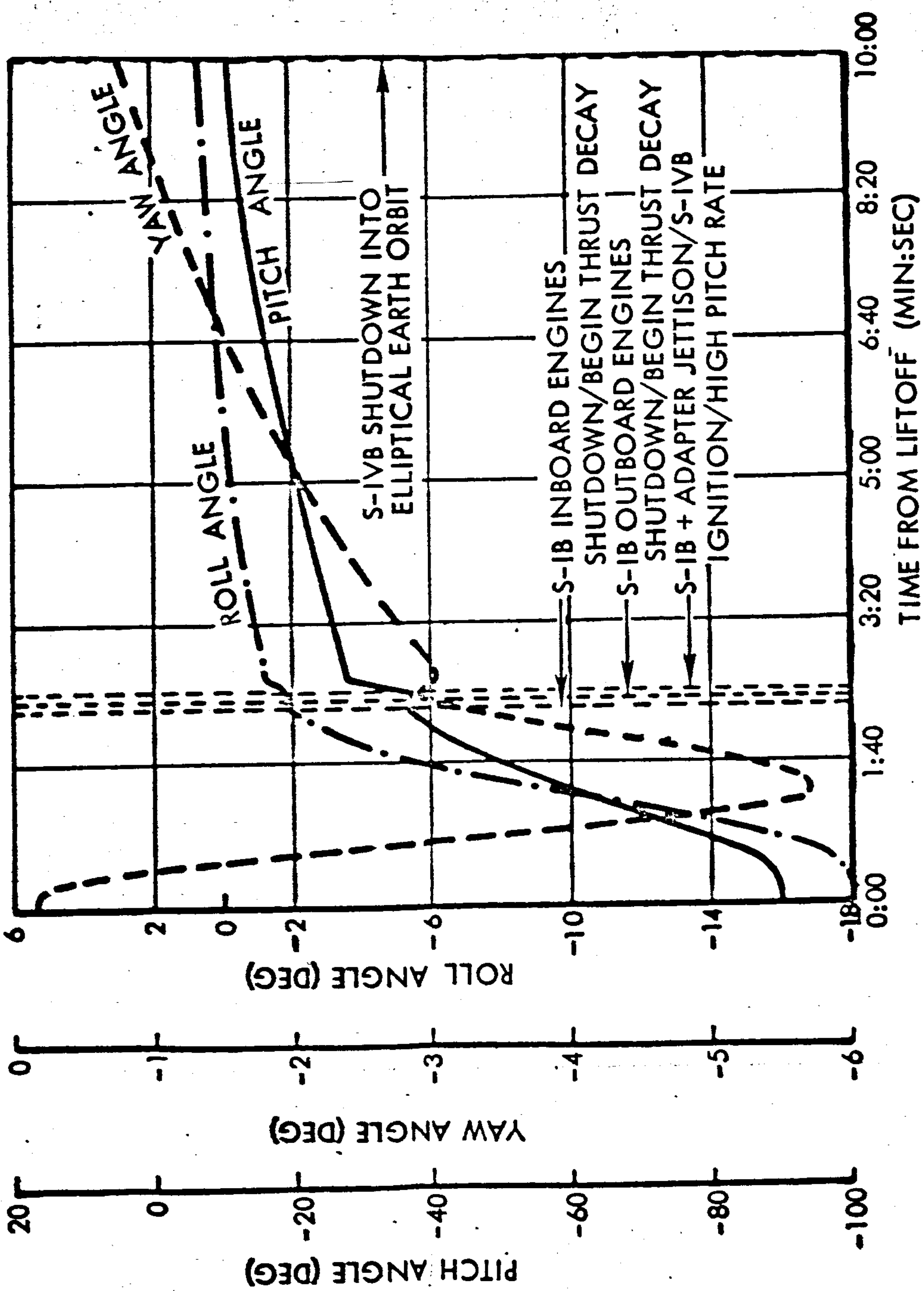


Figure 5-11. Saturn IB Ascent to Orbit/Vehicle Attitude (Earth Referenced Rotating)

Table 5-7. S-IVB/SLA/LEM Orbital Coast/Discrete Events Summary

Event	Time From Liftoff (hr:min:sec)	Altitude* (ft)	Geodetic Latitude** (deg)	Longitude** (deg)	Inertial Velocity (ft/sec)	Inertial Flight Path Angle (deg)	Inertial Azimuth Angle (deg)
Start of Orbital Coast	0:09:59.9	516,621	31.965	-62.846	25,695	0.00	83.01
Maneuver to Align S-IVB X-Axis Along Orbit Path	0:10:09.9	516,721	32.047	-62.084	25,695	0.00	83.43
S-IVB X-Axis Aligned Along Orbit Path	0:10:50.6	517,216	32.326	-58.965	25,694	0.02	85.18
Carnarvon Tracking Acquisition	0:53:46.3	699,504	-31.859	104.970	25,477	0.00	97.51
SLA Petal Deployment	0:55:46.3	699,277	-32.566	114.000	25,478	-0.03	92.43

*Altitude above the Fischer ellipsoid.
**Minus coordinates indicate West longitudes and South latitudes.

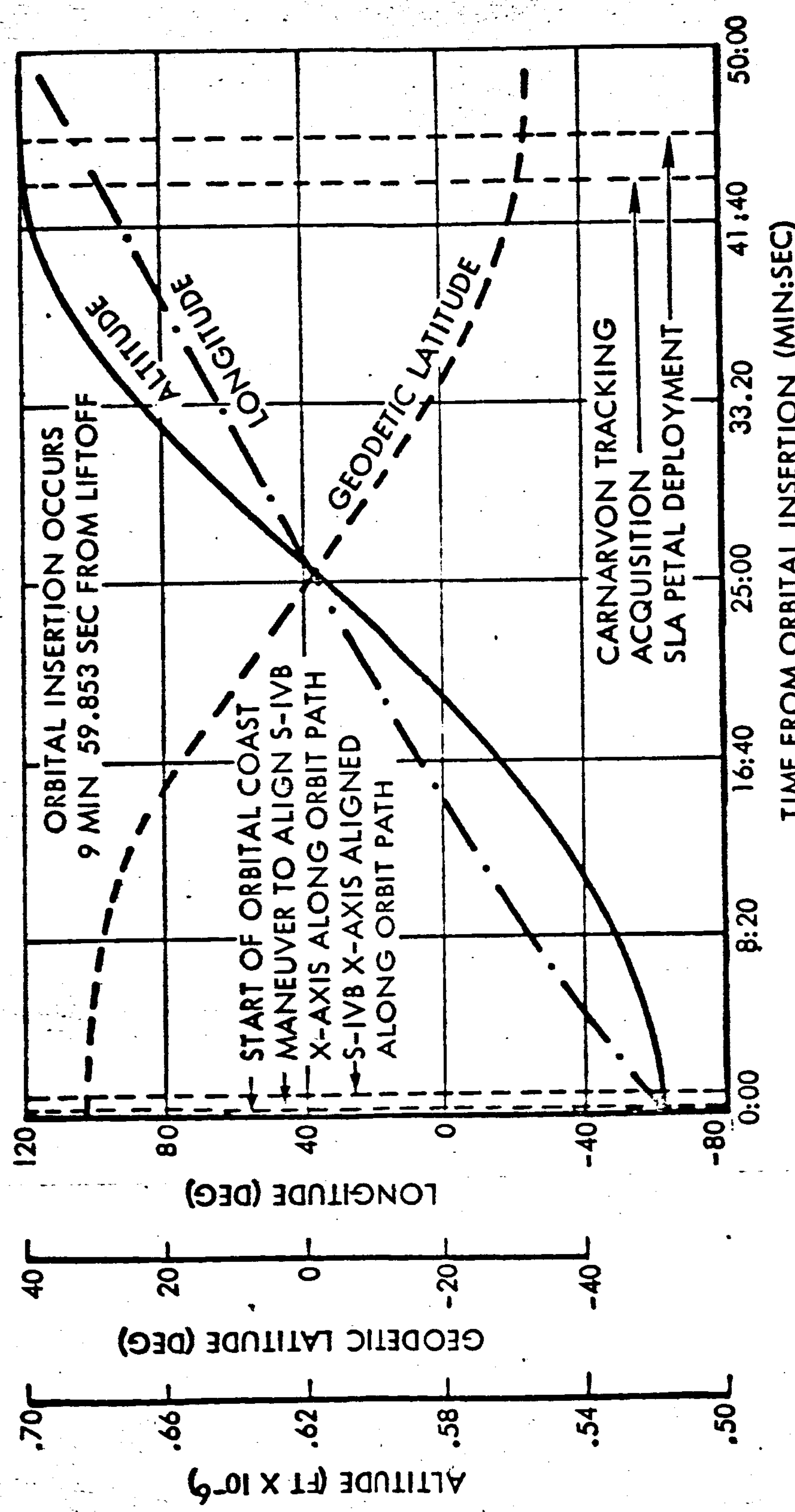


Figure 5-12. S-IVB/SLA/LEM Orbital Coast/Altitude, Latitude, and Longitude

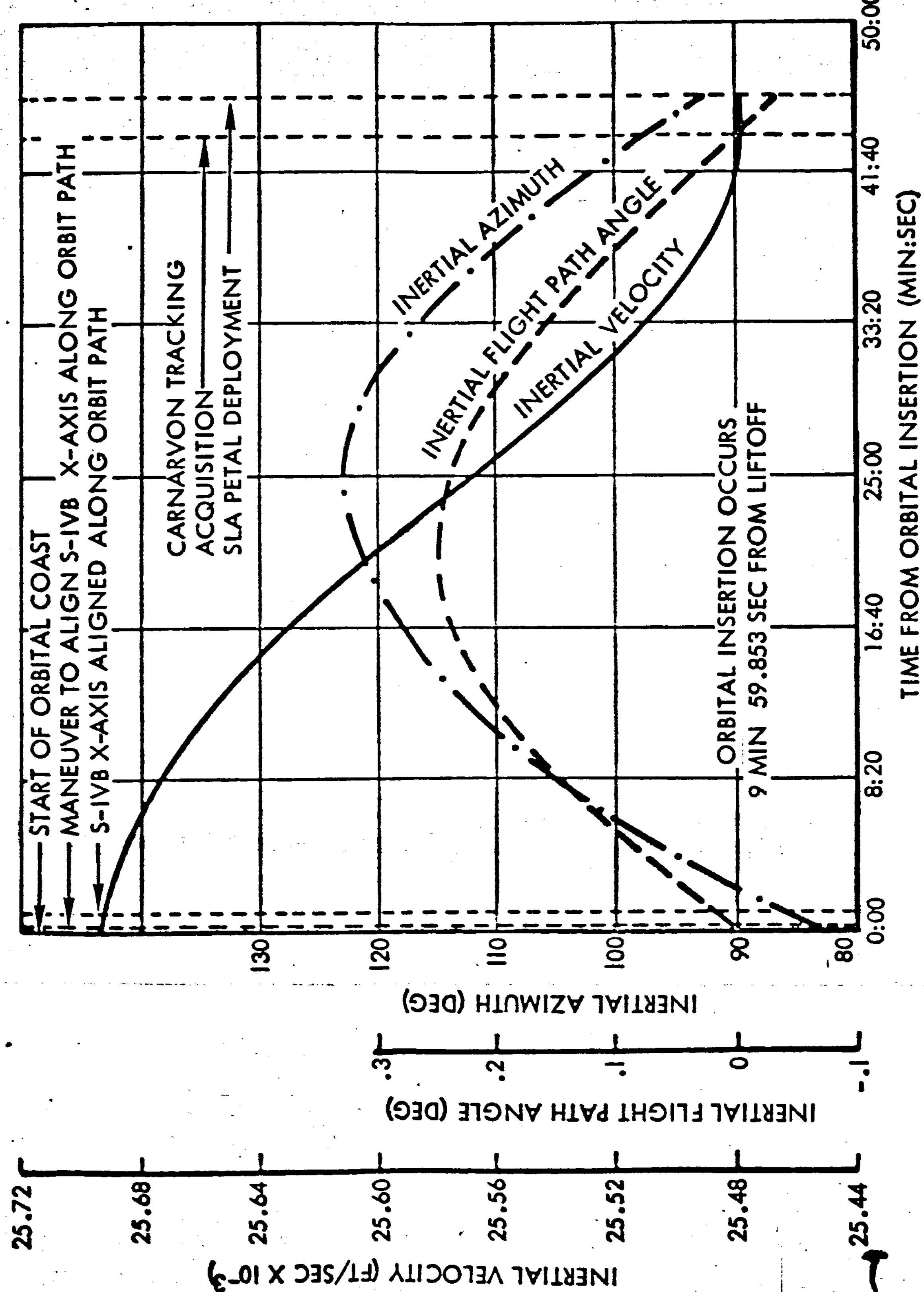


Figure 5-13. S-IVB/SLA/LEM Orbital Coast/Inertial Velocity, Flight Path Angle and Azimuth

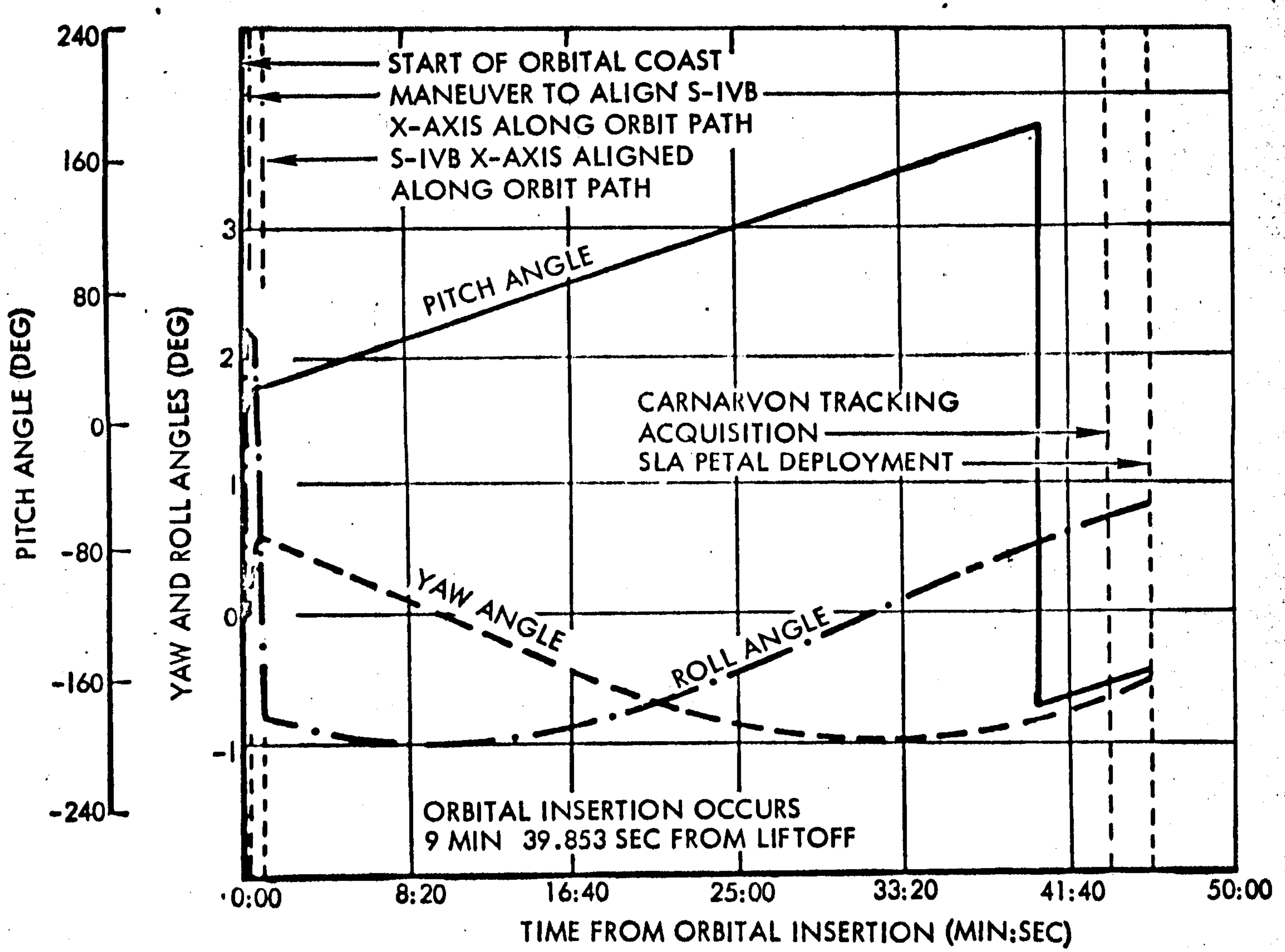


Figure 5-14. S-IVB/SLA/LEM Orbital Coast/Vehicle Attitude (Launch Site Inertial)

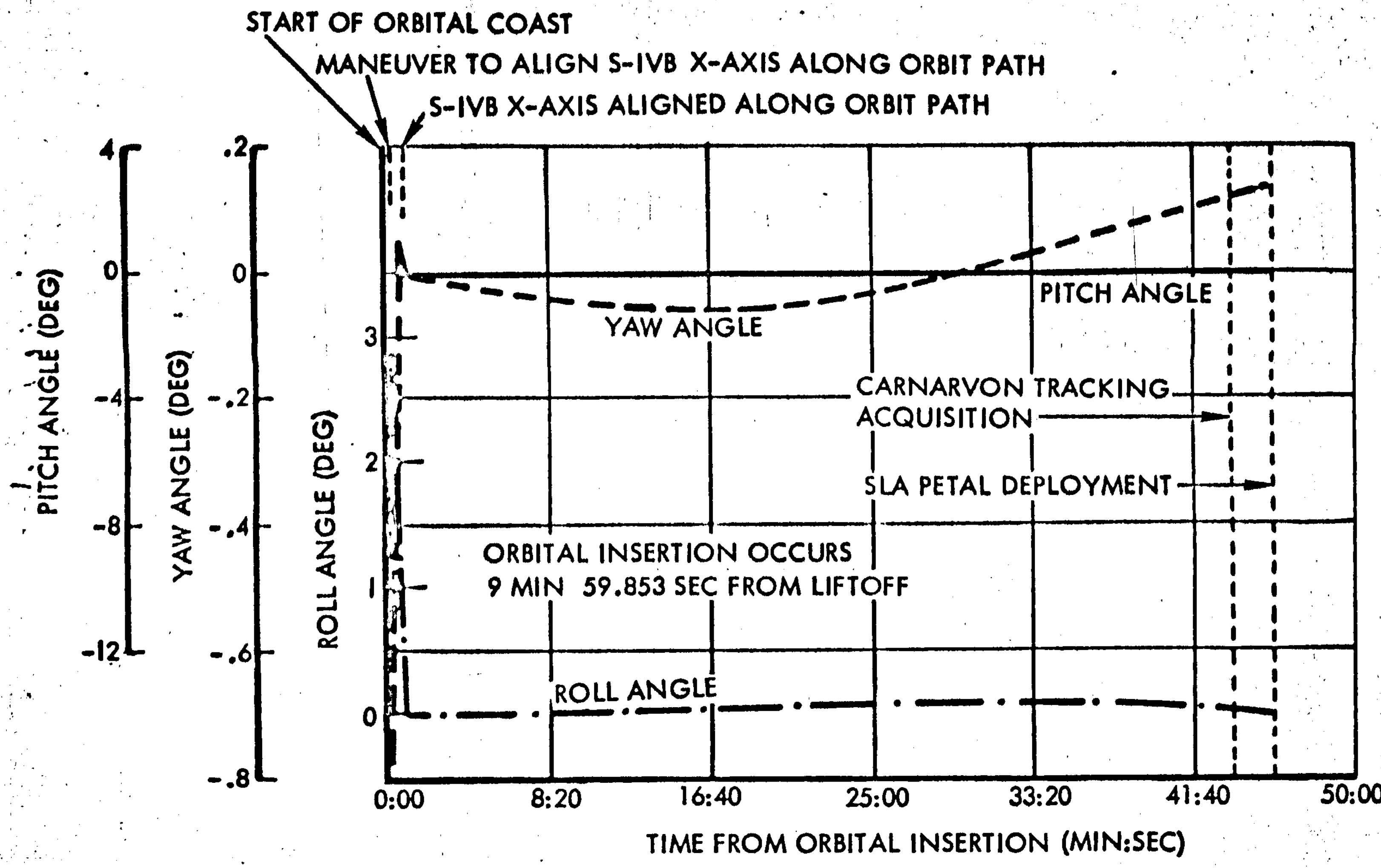


Figure 5-15. S-IVB/SLA/LEM Orbital Coast/Vehicle Attitude (Earth Referenced Rotating)

Table 5-8. Spacecraft Separation/Discrete Events Summary

Event	Time From Liftoff (hr:min:sec)	Altitude * (ft)	Geodetic Latitude** (deg)	Longitude** (deg)	Inertial Velocity (ft/sec)	Inertial Flight Path Angle (deg)	Inertial Azimuth Angle (deg)
SLA Petal Deployment	0:55:46.3	699,277	-32.566	114.000	25,478	-0.03	92.43
LEM Separation/RCS Ignition	0:55:48.3	699,251	-32.571	114.152	25,478	-0.04	92.35
RCS Shutdown	0:56:00.3	699,087	-32.601	115.062	25,483	-0.04	91.83
LEM Landing Gear Deployment	0:56:08.3	698,964	-32.617	115.669	25,483	-0.04	91.49

*Altitude above the Fischer ellipsoid.
**Minus coordinates indicate West longitudes and South latitudes.

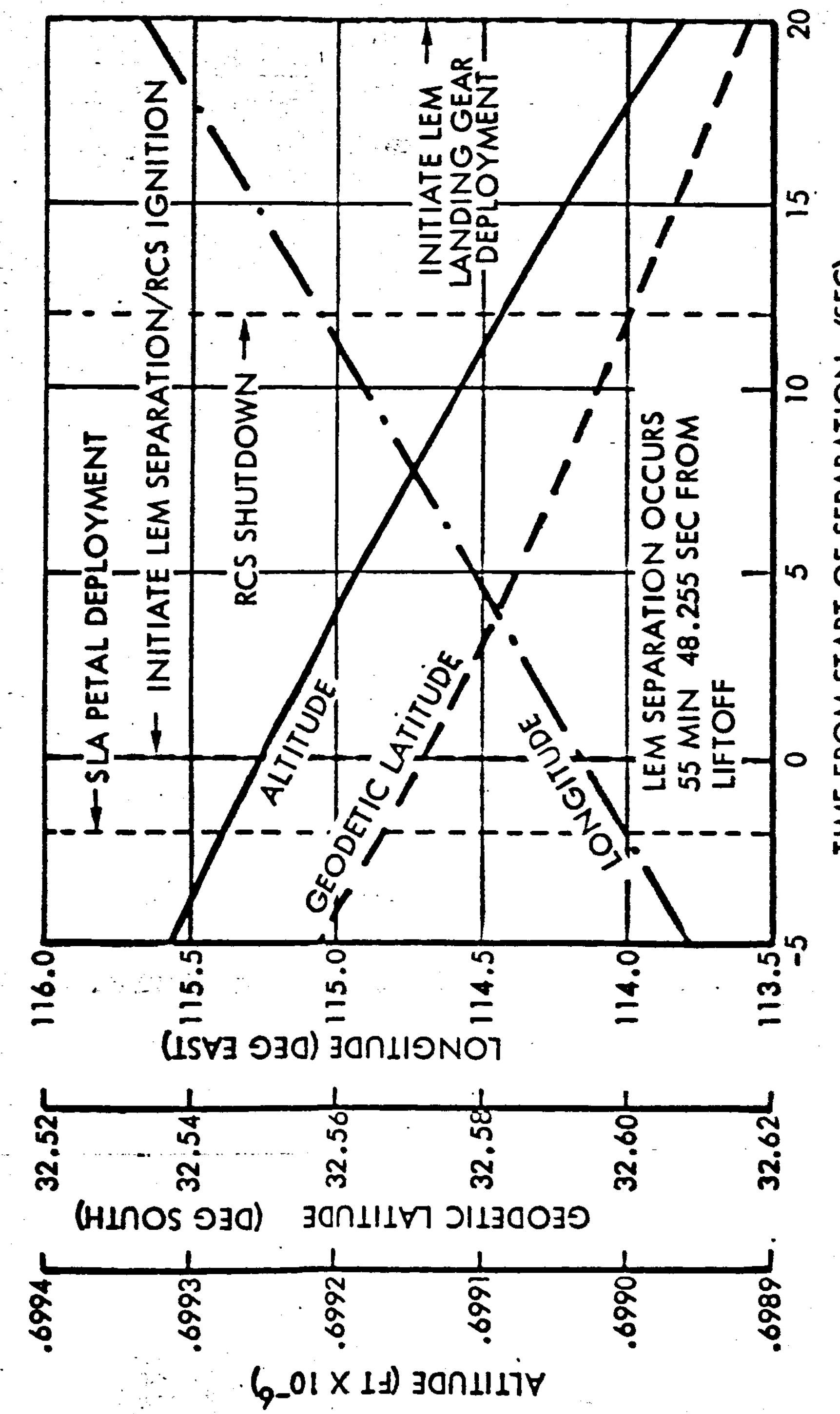


Figure 5-16. Spacecraft Separation/Altitude, Latitude, and Longitude

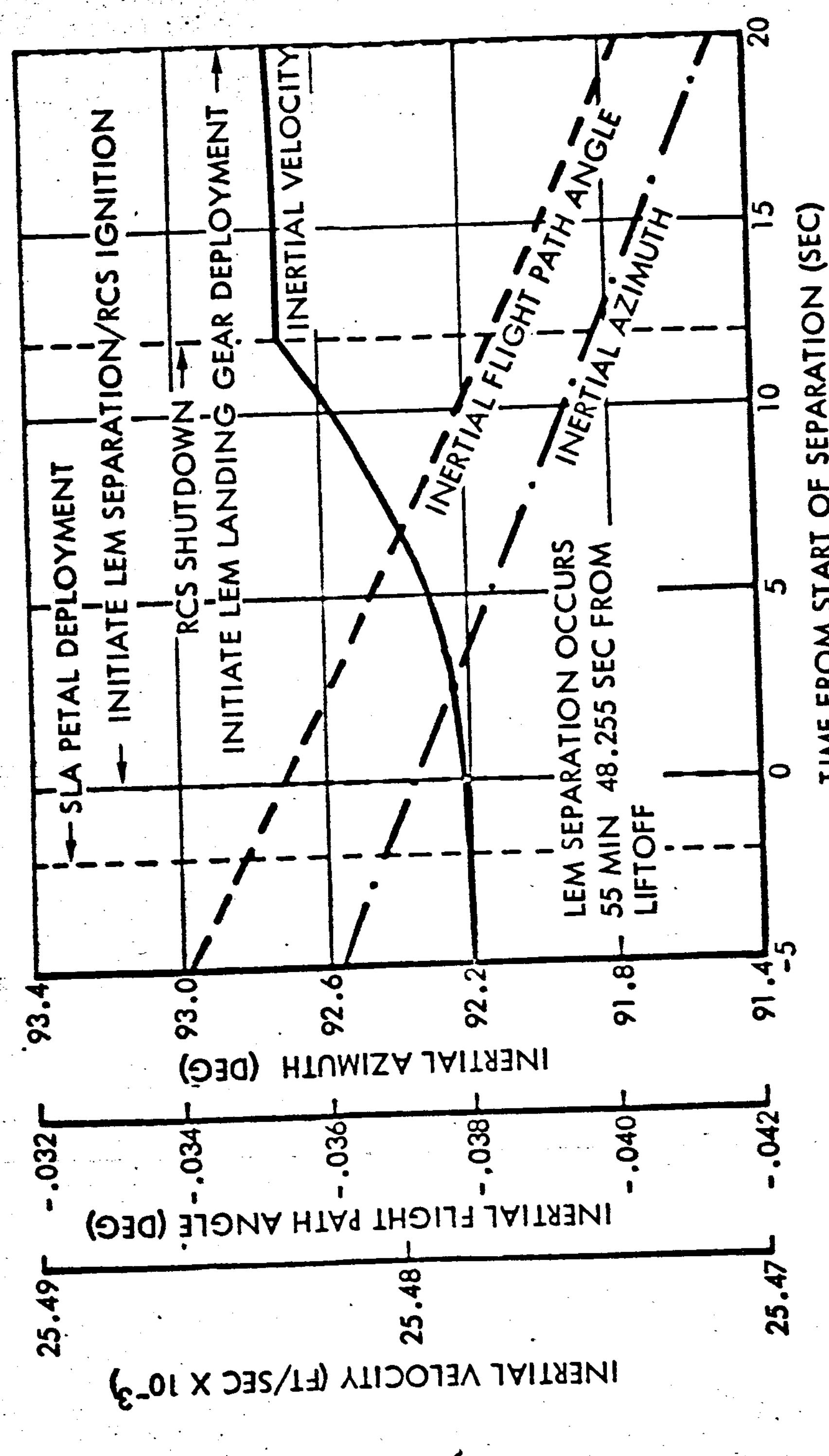


Figure 5-17. Spacecraft Separation/Inertial Velocity, Flight Path Angle, and Azimuth

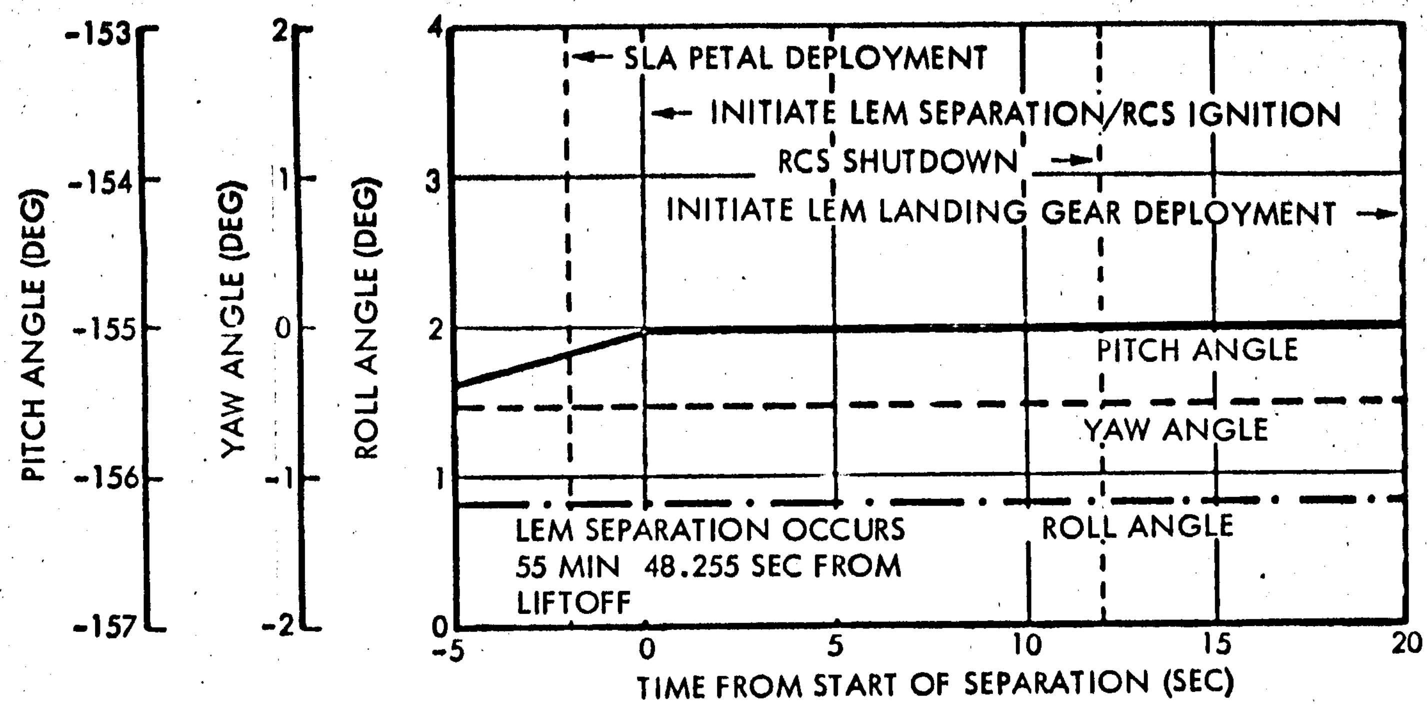


Figure 5-18. Spacecraft Separation/Spacecraft Attitude (Launch Site Inertial)

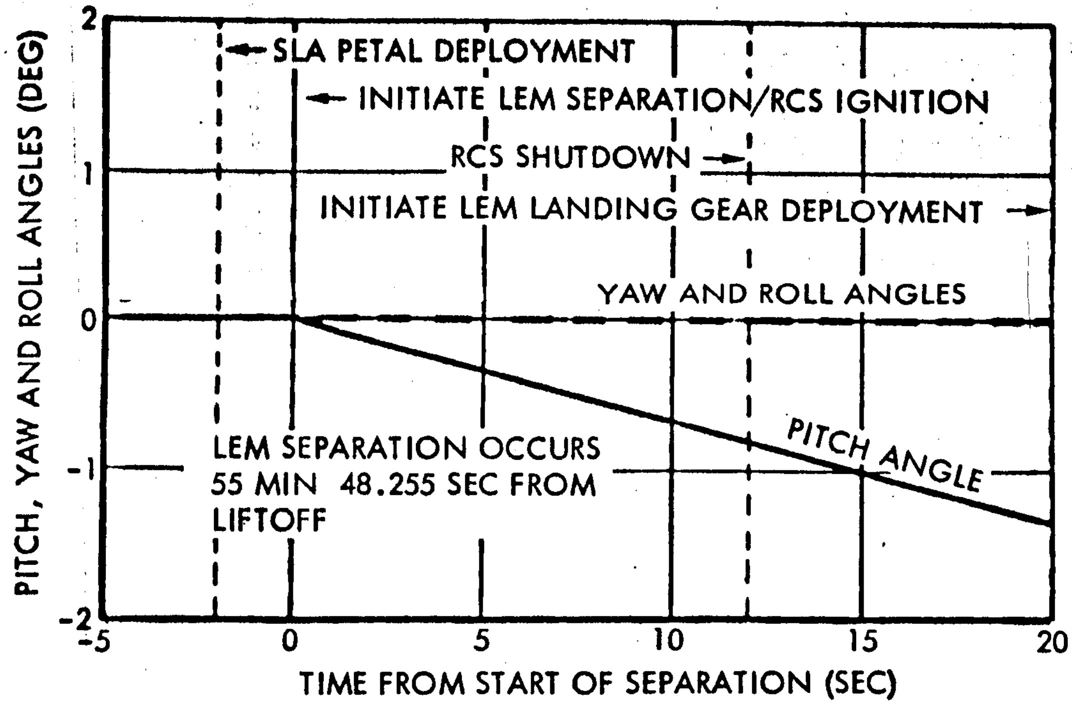


Figure 5-19. Spacecraft Separation/Spacecraft Attitude (Earth Referenced Rotating)

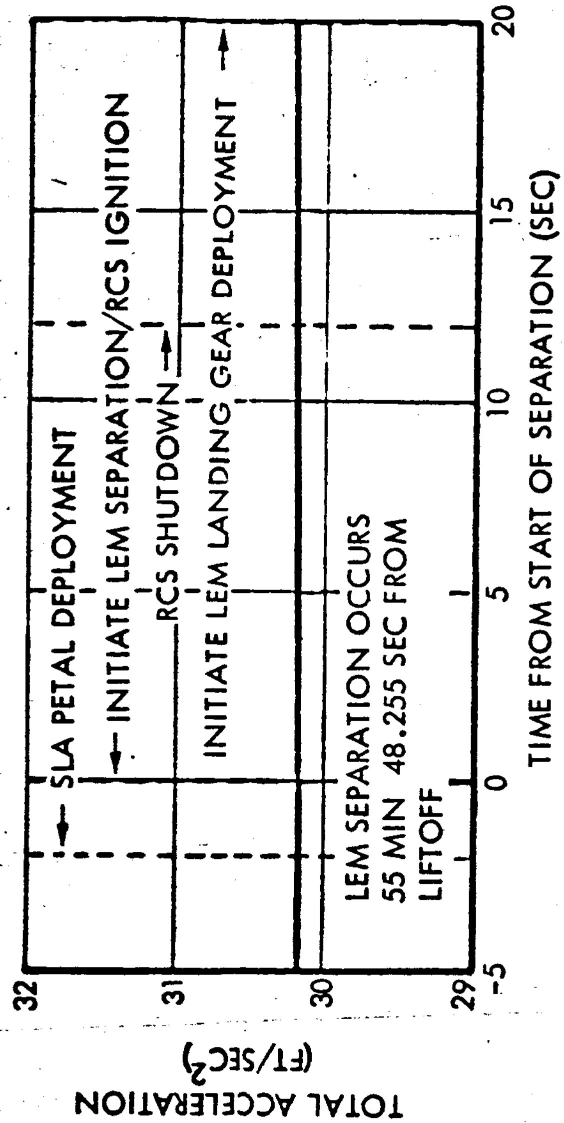


Figure 5-20. Spacecraft Separation/Total Acceleration

Table 5-9. Orbital Cold-Soak to First DPS Burn/Discrete Events Summary

Event	Time From Liftoff (hr:min:sec)	Altitude* (ft)	Geodetic Latitude** (deg)	Longitude** (deg)	Inertial Velocity (ft/sec)	Inertial Flight Path Angle (deg)	Inertial Azimuth Angle (deg)
LEM Landing Gear Deployment	0:56:08.3	698,964	-32.617	115.669	25,483	-0.04	91.49
Maneuver to Align LEM +Z-Axis Toward the Sun	0:56:38.3	698,413	-32.647	117.946	25,484	-0.05	90.19
Maneuver to Required Pre-Burn Inertial Attitude	3:54:28.3	695,793	-32.365	81.219	25,487	-0.07	85.48
Carnarvon Tracking Acquisition	3:59:27.9	678,257	-28.623	103.098	25,505	-0.13	73.65
RCS Ullage Maneuver	4:01:27.9	668,008	-26.050	111.269	25,516	-0.15	69.67

*Altitude above the Fischer ellipsoid.
**Minus coordinates indicate West longitudes and South latitudes.

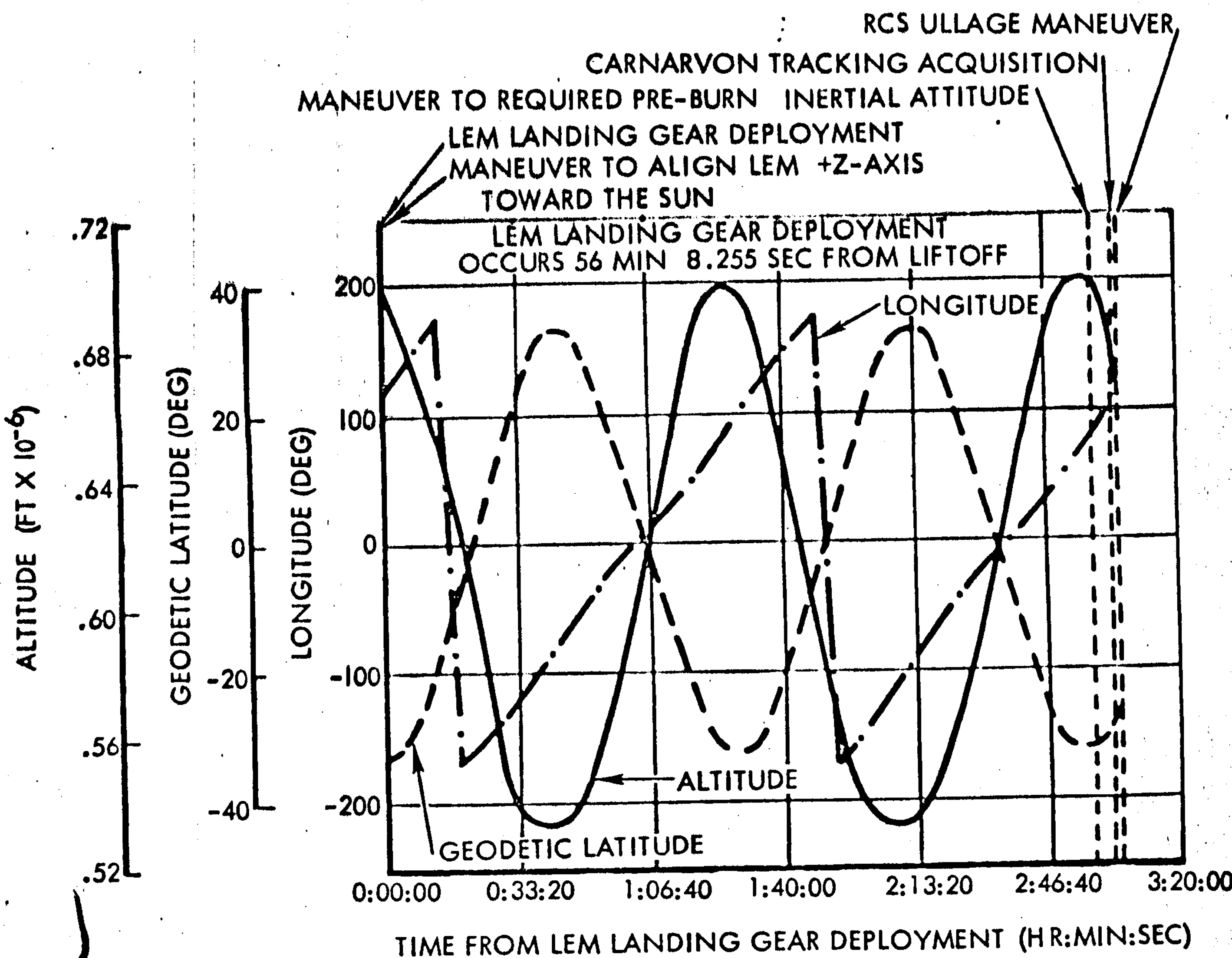


Figure 5-21. Orbital Cold-Soak to First DPS Burn/Altitude, Latitude, and Longitude

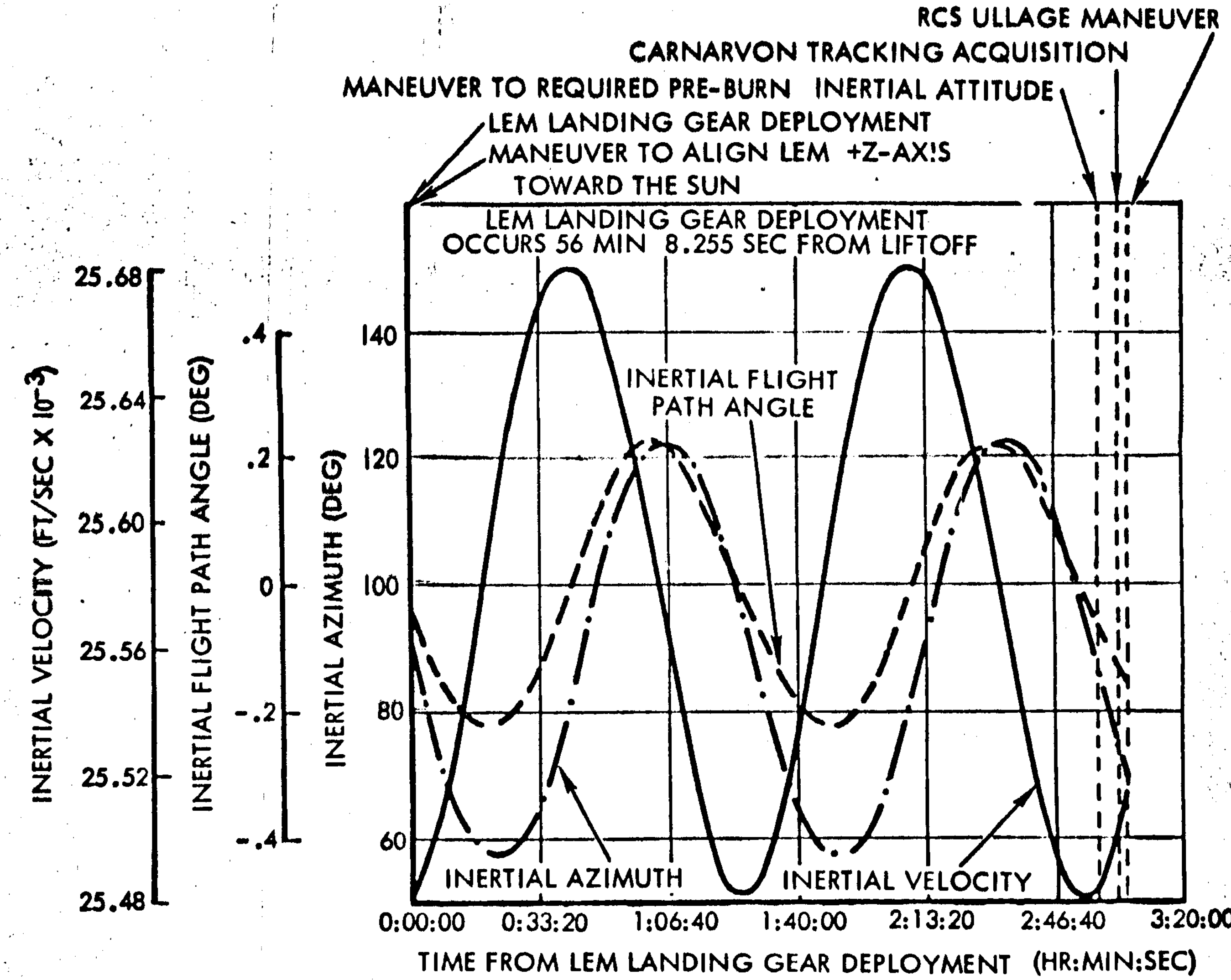


Figure 5-22. Orbital Cold-Soak to First DPS Burn/Inertial Velocity, Flight Path Angle, and Azimuth

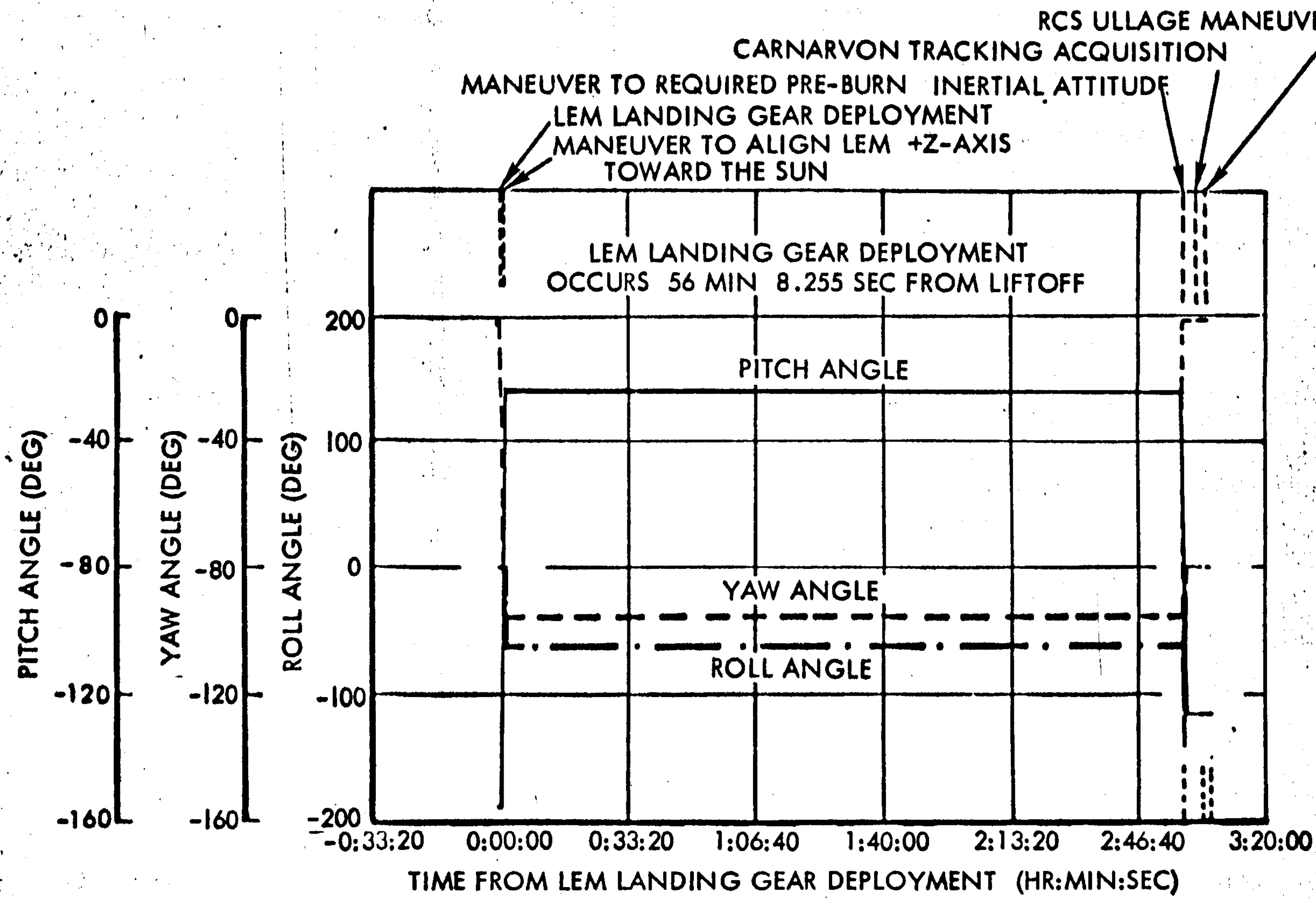


Figure 5-23. Orbital Cold-Soak to First DPS Burn/Spacecraft Attitude (Launch Site Inertial)

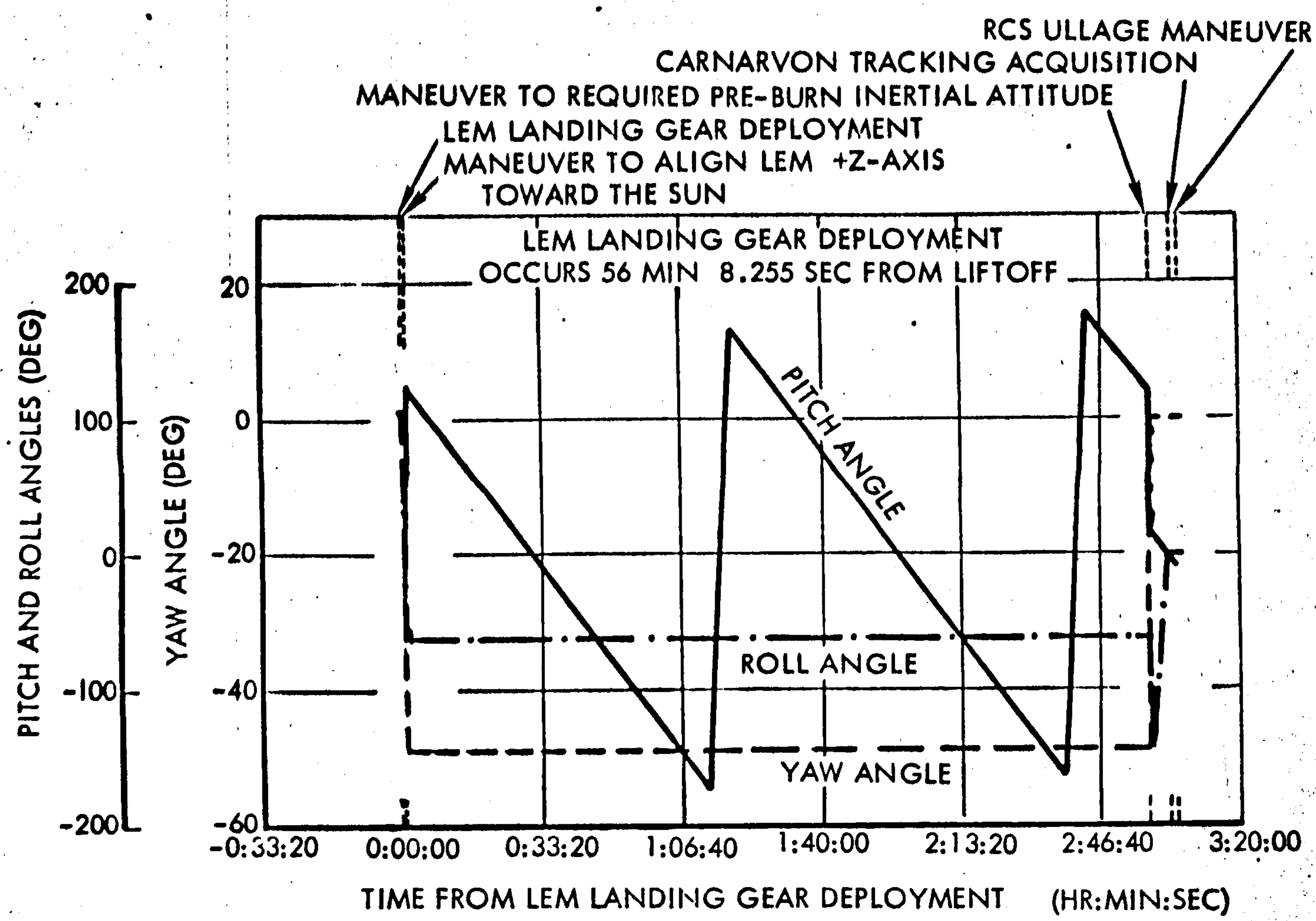


Figure 5-24. Orbital Cold-Soak to First DPS Burn/Spacecraft Attitude (Earth Referenced Rotating)

Table 5-10. First DPS Burn/Discrete Events Summary

Event	Time From Liftoff (hr:min:sec)	Altitude* (ft)	Geodetic Latitude ** (deg)	Longitude** (deg)	Inertial Velocity (ft/sec)	Inertial Flight Path Angle (deg)	Inertial Azimuth Angle (deg)
RCS Ullage Maneuver	4:01:27.9	668,008	-26.050	111.269	25,516	-0.15	69.67
First DPS Ignition	4:01:35.9	667,274	-25.860	111.799	25,519	-0.15	69.42
DPS Shutdown	4:02:07.9	664,457	-25.077	113.906	25,619	-0.11	68.46

*Altitude above the Fischer ellipsoid.
**Minus coordinates indicate West longitudes and South latitudes.

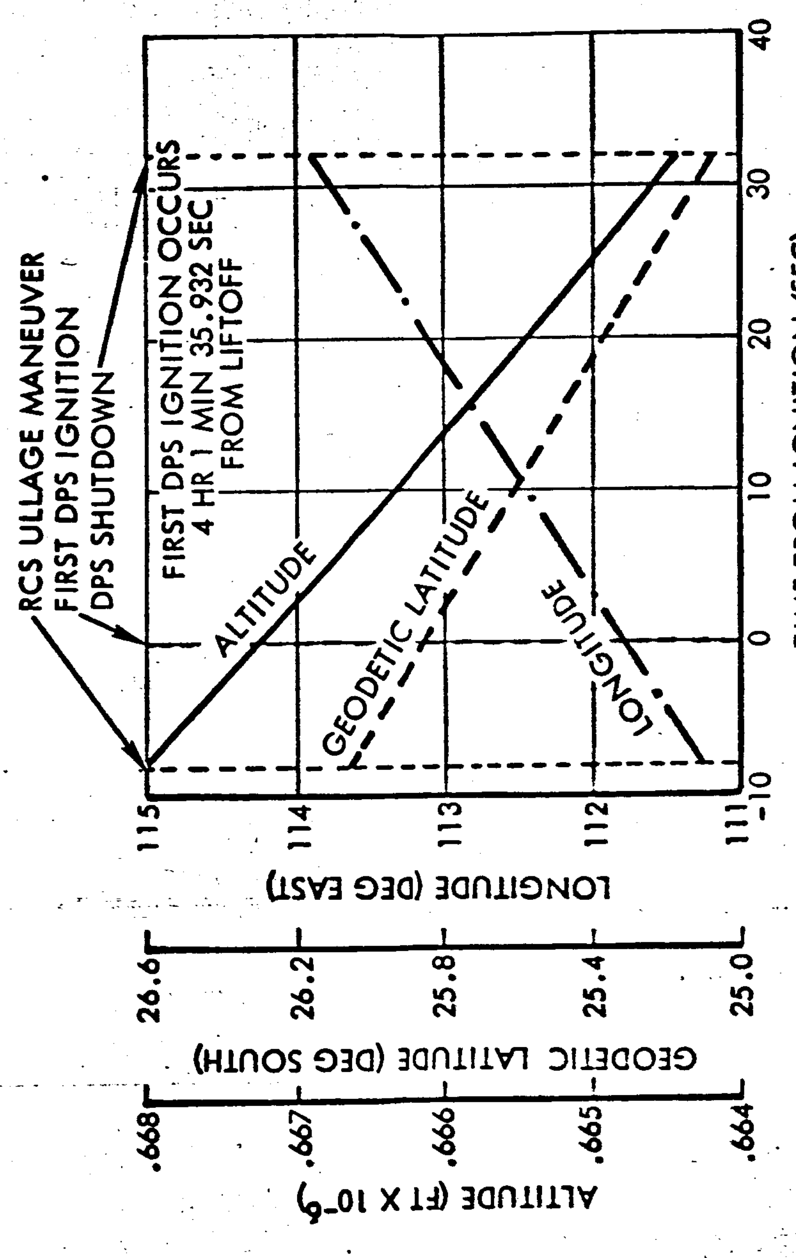


Figure 5-25. First DPS Burn/Altitude, Latitude, and Longitude

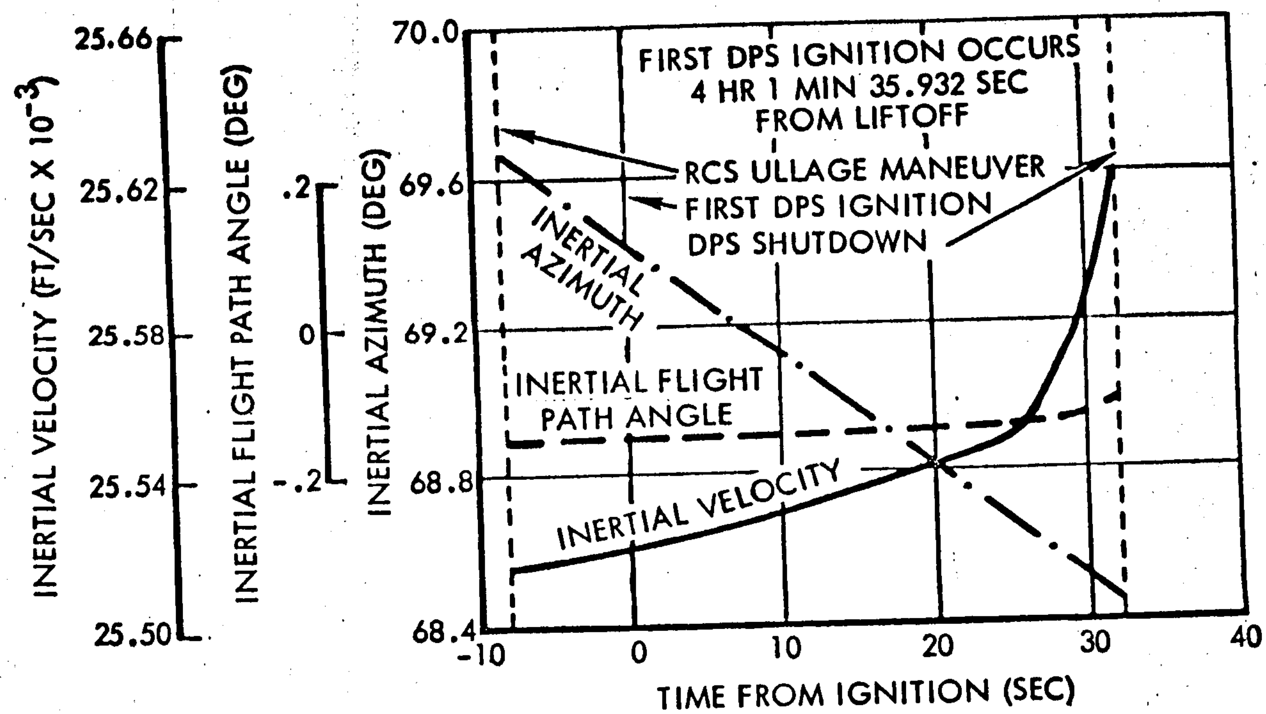


Figure 5-26. First DPS Burn/Inertial Velocity, Flight Path Angle, and Azimuth

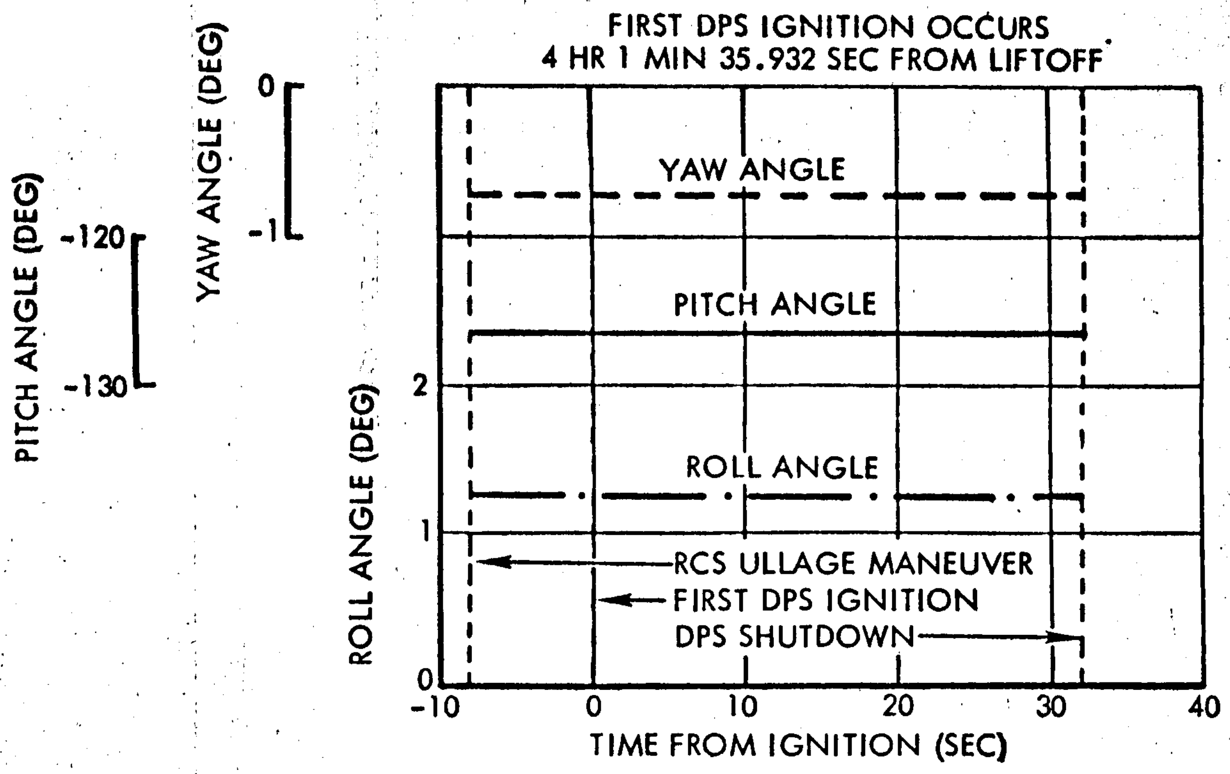


Figure 5-27. First DPS Burn/Spacecraft Attitude (Launch Site Inertial)

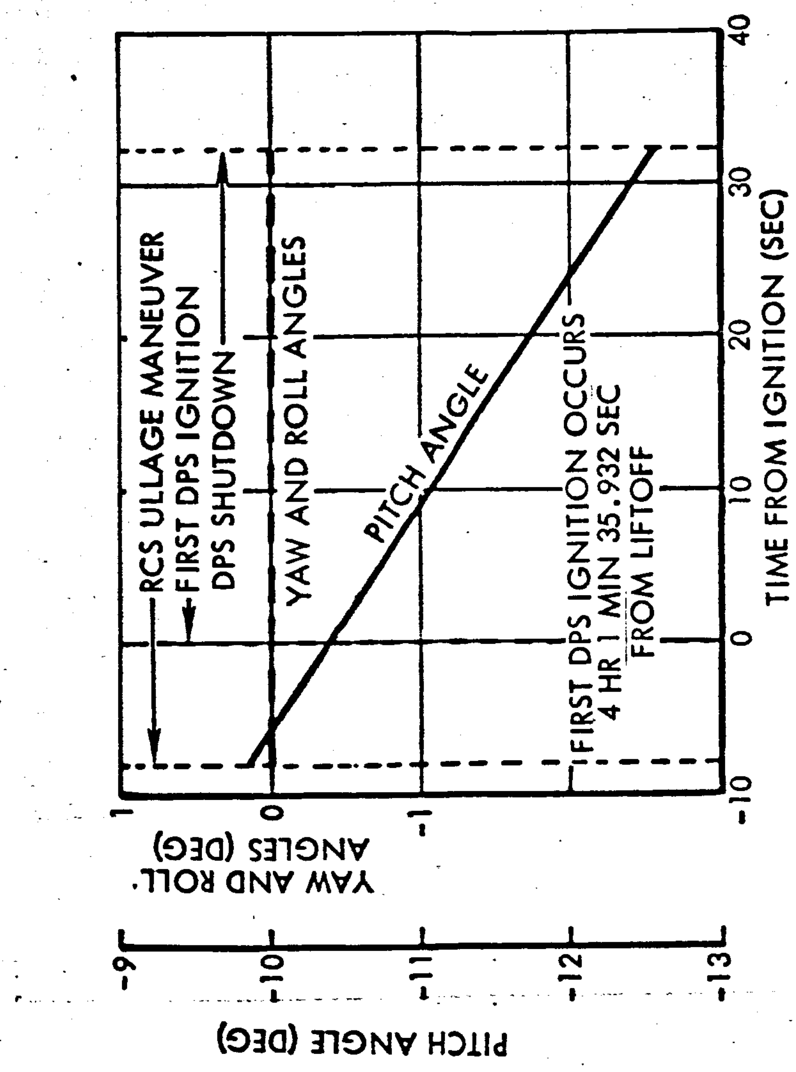


Figure 5-28. First DPS Burn/Spacecraft Attitude (Earth Referenced Rotating)

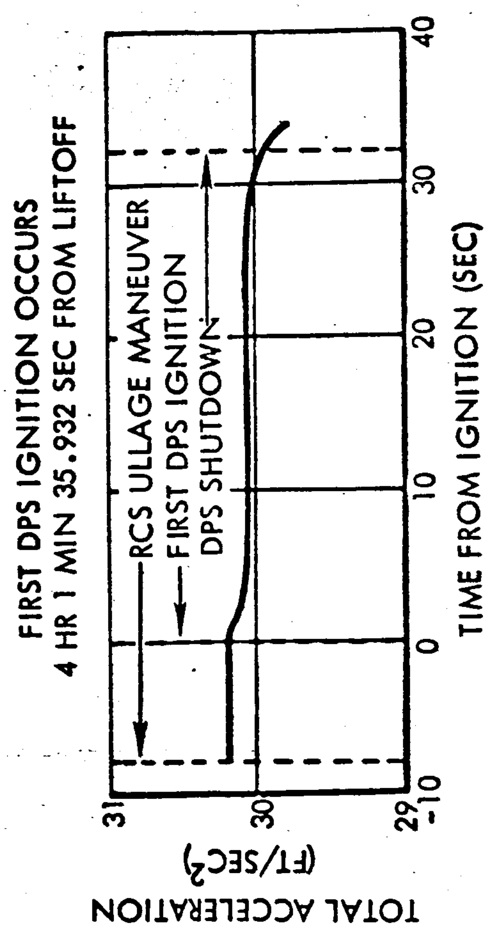


Figure 5-29. First DPS Burn/Total Acceleration

Table 5-11. Orbital Coast to Second DPS Burn/Discrete Events Summary

Event	Time From Liftoff (hr:min:sec)	Altitude* (ft)	Geodetic Latitude** (deg)	Longitude** (deg)	Inertial Velocity (ft/sec)	Inertial Flight Path Angle (deg)	Inertial Azimuth Angle (deg)
DPS Shutdown	4:02:07.9	664,457	-25.077	113.906	25,619	-0.11	68.46
Maneuver to Required Pre-Burn Inertial Attitude	4:30:07.9	788,523	28.562	-148.167	25,475	0.32	73.53
Point Arguello Tracking Acquisition	4:33:28.2	819,882	31.542	-133.852	25,441	0.31	81.14
RCS Ullage Maneuver	4:35:28.2	837,093	32.439	-124.942	25,421	0.30	86.12

*Altitude above the Fischer ellipsoid.
**Minus coordinates indicate West longitudes and South latitudes.

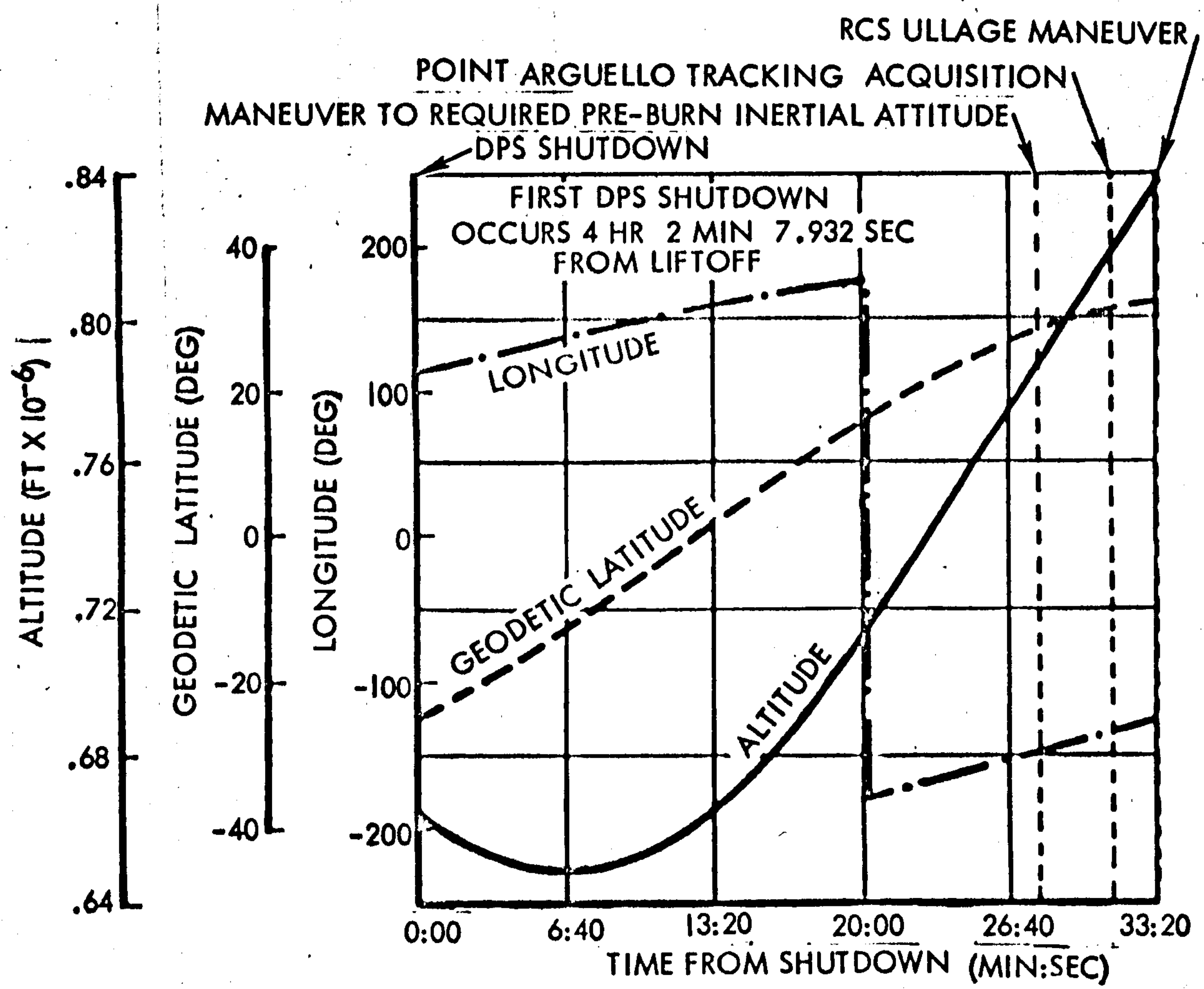


Figure 5-30. Orbital Coast to Second DPS Burn/Altitude, Latitude, and Longitude

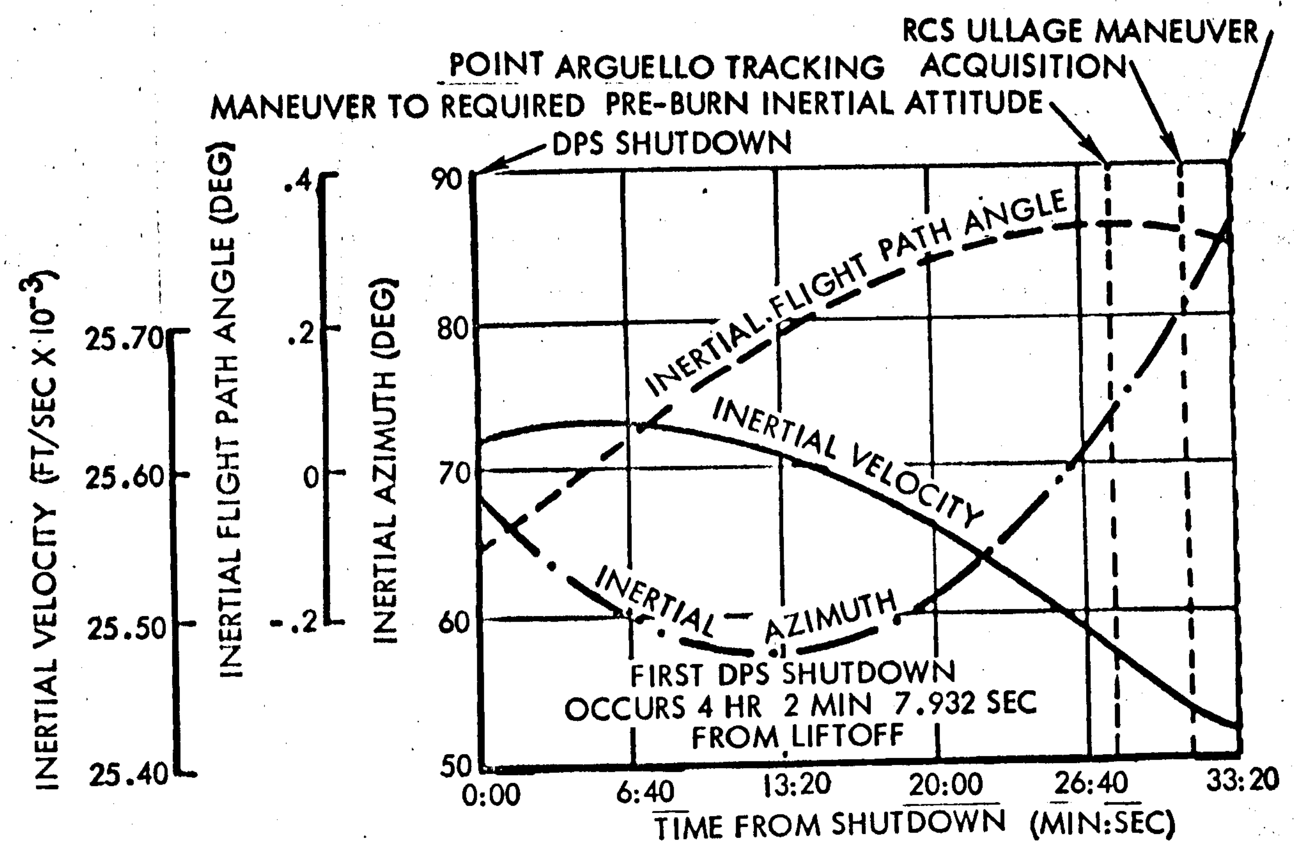


Figure 5-31. Orbital Coast to Second DPS Burn/Inertial Velocity, Flight Path Angle, and Azimuth

Table 5-12. Second DPS Burn/Discrete Events Summary

Event	Time From Liftoff (hr:min:sec)	Altitude* (ft)	Geodetic Latitude** (deg)	Longitude** (deg)	Inertial Velocity (ft/sec)	Inertial Flight Path Angle (deg)	Inertial Azimuth Angle (deg)
RCS Ullage Maneuver	4:35:28.2	837,093	32.439	-124.942	25,421	0.30	86.12
Second DPS Ignition	4:35:36.2	838,185	32.474	-124.343	25,420	0.30	86.45
DPS Shutdown	4:47:46.2	854,673	29.821	-70.051	25,575	-0.12	100.90

*Altitude above the Fischer ellipsoid.
**Minus coordinates indicate West longitudes and South latitudes.

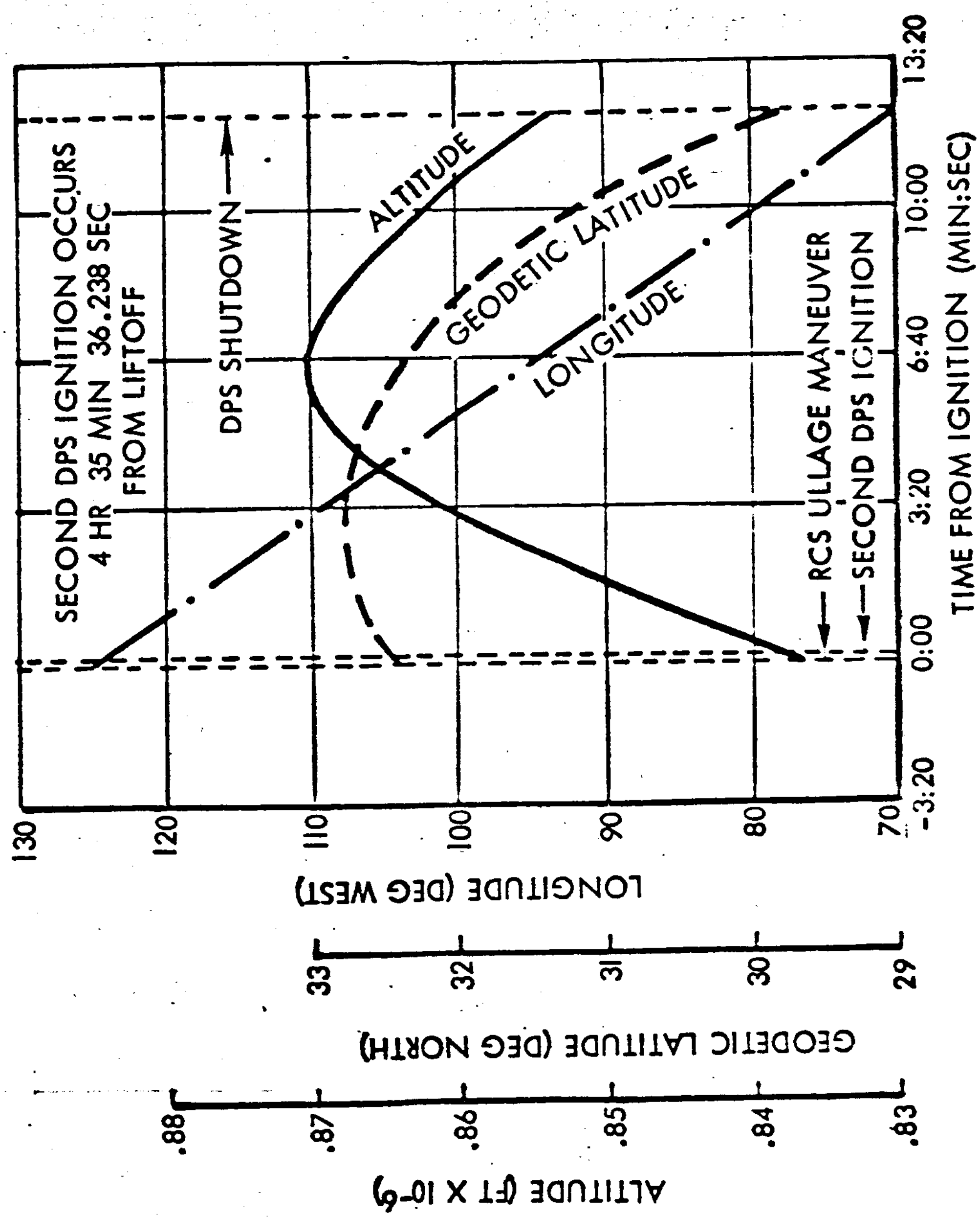


Figure 5-32. Second DPS Burn/Altitude, Latitude, and Longitude

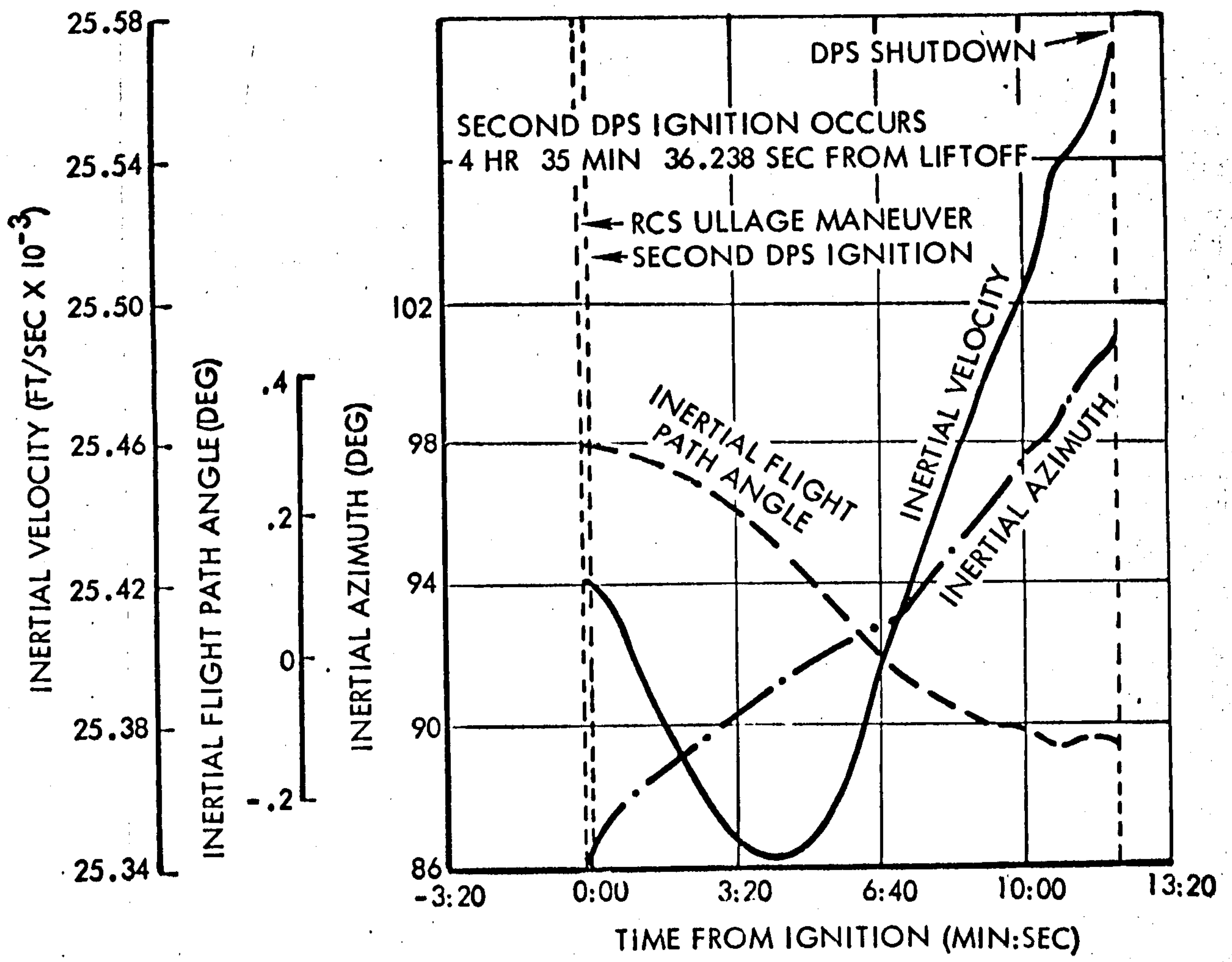


Figure 5-33. Second DPS Burn/Inertial Velocity, Flight Path Angle, and Azimuth

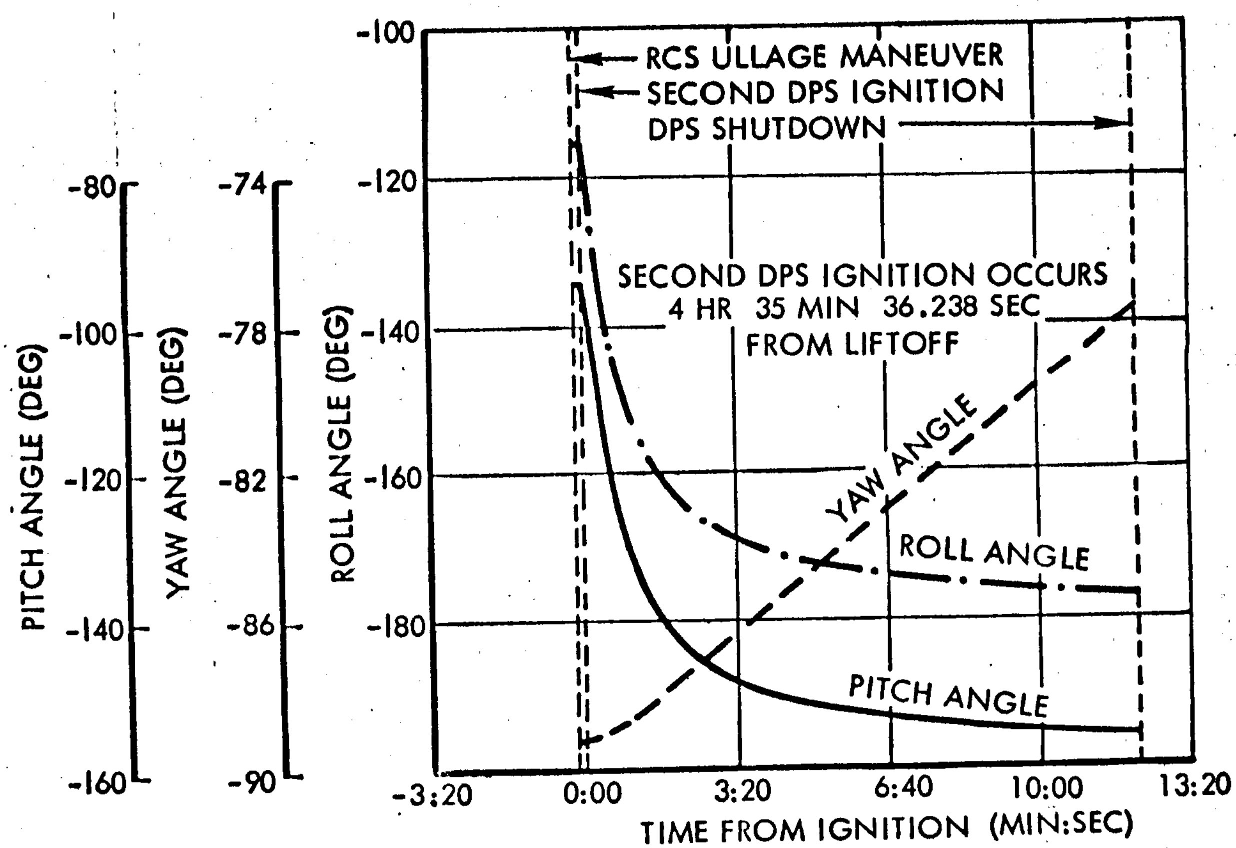


Figure 5-34. Second DPS Burn/Spacecraft Attitude (Launch Site Inertial)

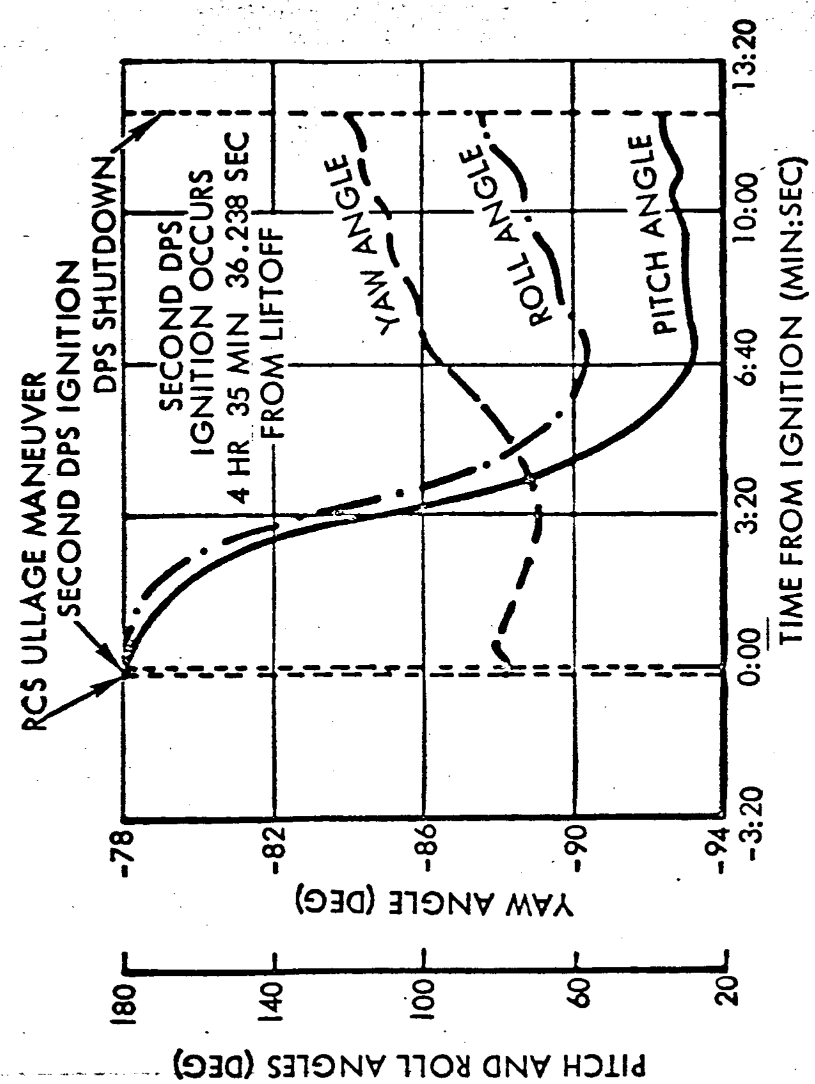


Figure 5-35. Second DPS Burn/Spacecraft Attitude (Earth Referenced Rotating)

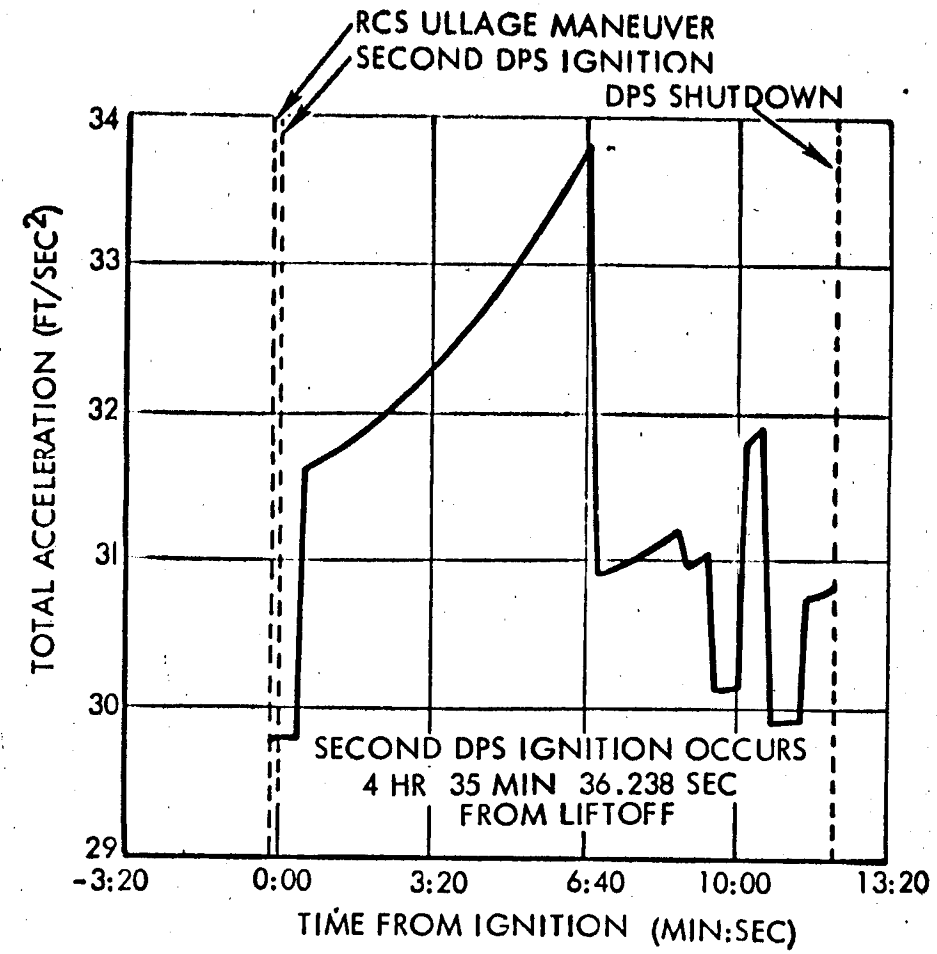


Figure 5-36. Second DPS Burn/Total Acceleration

Table 5-13. Orbital Coast to FITH Abort Test/Discrete Events Summary

Event	Time From Liftoff (hr:min:sec)	Altitude* (ft)	Geodetic Latitude** (deg)	Longitude** (deg)	Inertial Velocity (ft/sec)	Inertial Flight Path Angle (deg)	Inertial Azimuth Angle (deg)
DPS Shutdown	4:47:46.2	854,673	29.821	-70.051	25,575	-0.12	100.90
Maneuver to Required Pre-Burn Inertial Attitude	6:06:06.2	975,412	26.277	-147.929	25,433	-0.56	71.87
Point Arguello Tracking Acquisition	6:09:25.8	932,789	29.690	-134.197	25,484	-0.48	78.72
RCS Ullage Maneuver	6:12:45.8	896,935	31.423	-119.622	25,527	-0.37	86.57

*Altitude above the Fischer ellipsoid.
**Minus coordinates indicate West longitudes and South latitudes.

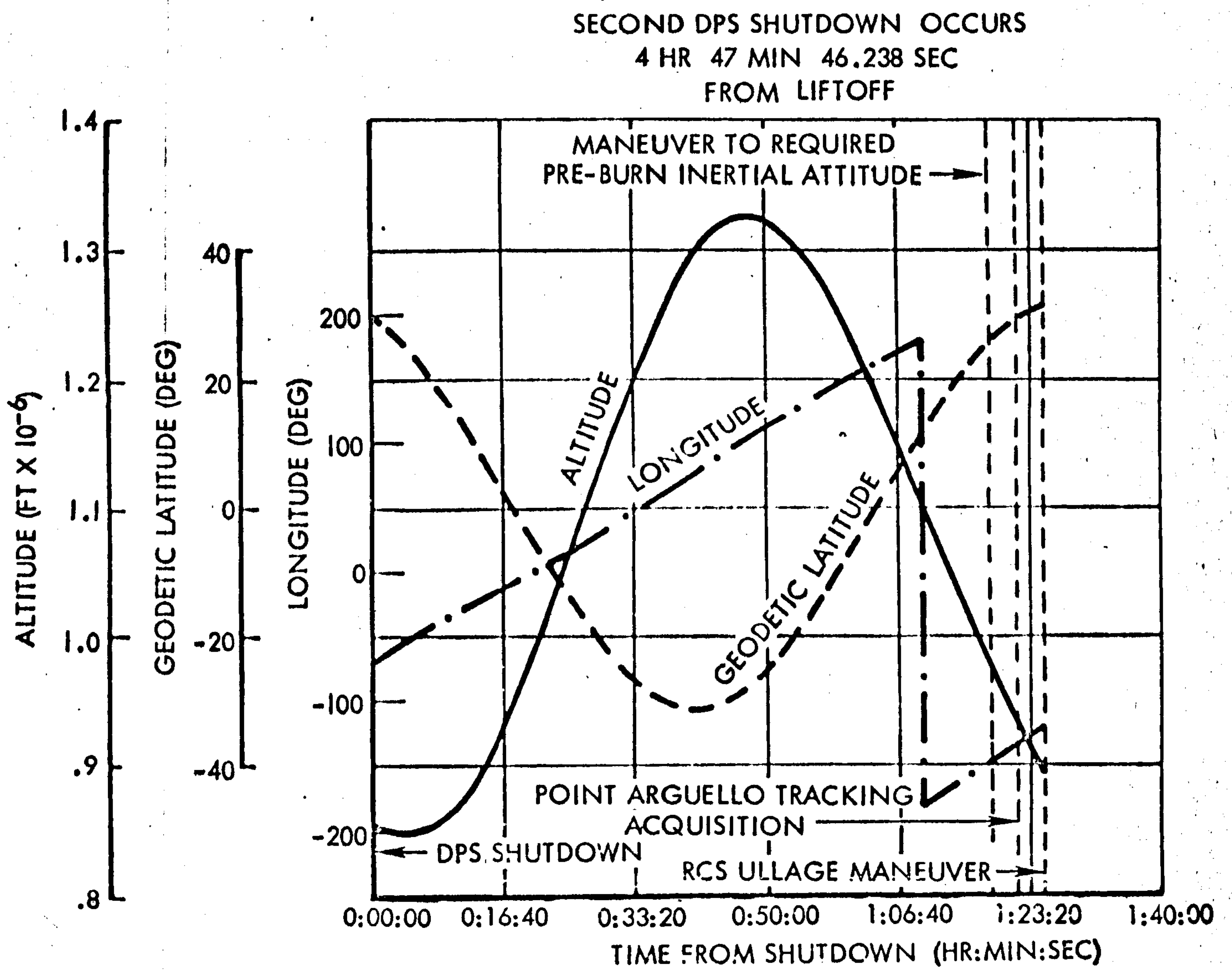


Figure 5-37. Orbital Coast to FITH Abort Test/Altitude, Latitude, and Longitude

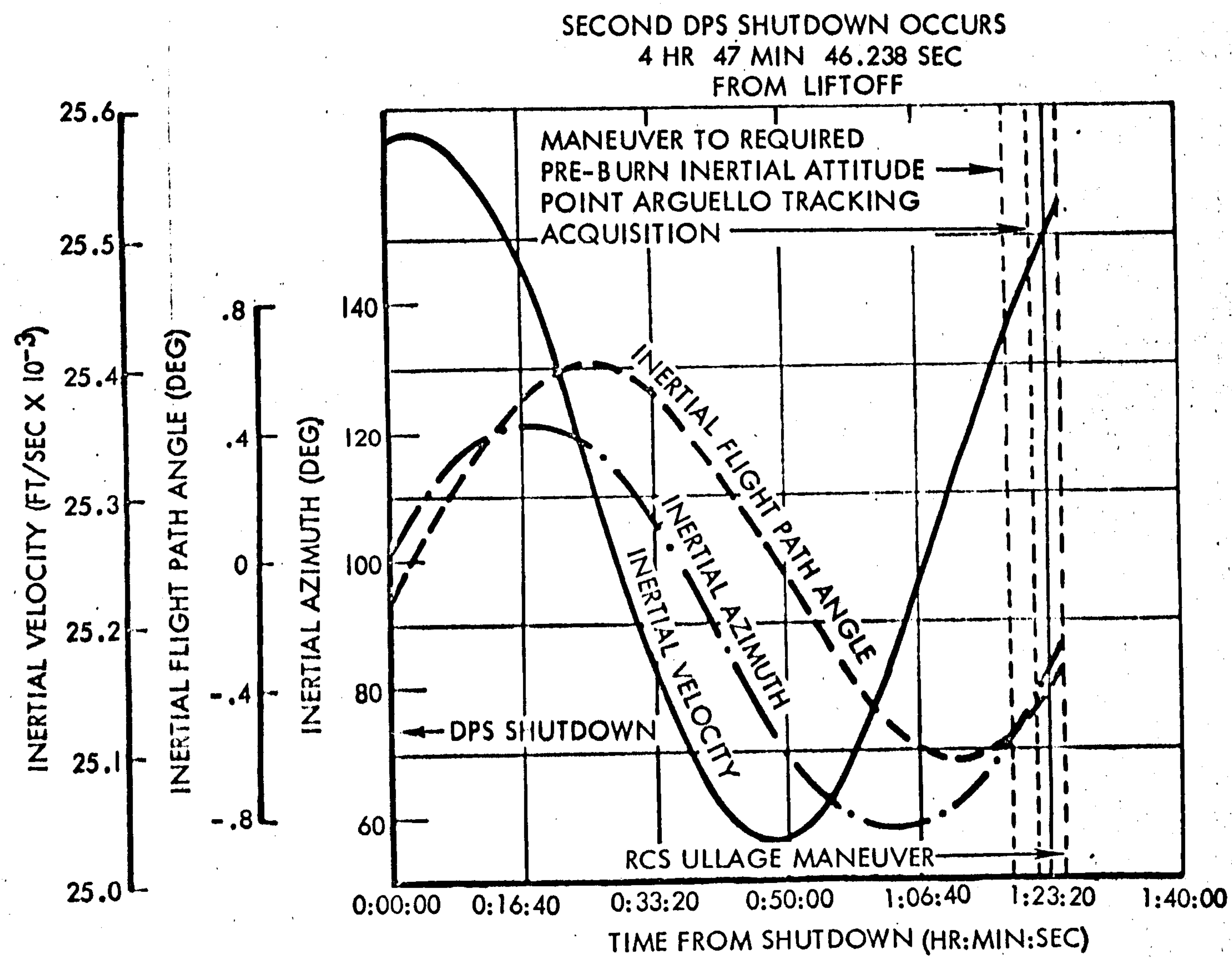


Figure 5-38. Orbital Coast to FITH Abort Test/Inertial Velocity, Flight Path Angle, and Azimuth

Table 5-14. FITH Abort Test/Discrete Events Summary

Event	Time From Liftoff (hr:min:sec)	Altitude* (ft)	Geodetic Latitude** (deg)	Longitude** (deg)	Inertial Velocity (ft/sec)	Inertial Flight Path Angle (deg)	Inertial Azimuth Angle (deg)
RCS Ullage Maneuver	6:12:45.8	896,935	31.423	-119.622	25,527	-0.37	86.57
Third DPS Ignition	6:12:53.8	895,669	31.454	-119.029	25,528	-0.36	86.88
DPS Shutdown/Coast	6:13:20.8	891,500	31.536	-117.023	25,533	-0.35	87.76
LEM Staging/First APS Ignition	6:13:21.3	891,425	31.539	-116.986	25,534	-0.35	87.78
APS Shutdown	6:20:24.9	839,355	31.375	-85.341	25,674	-0.34	91.47

*Altitude above the Fischer ellipsoid.
**Minus coordinates indicate West longitudes and South latitudes.

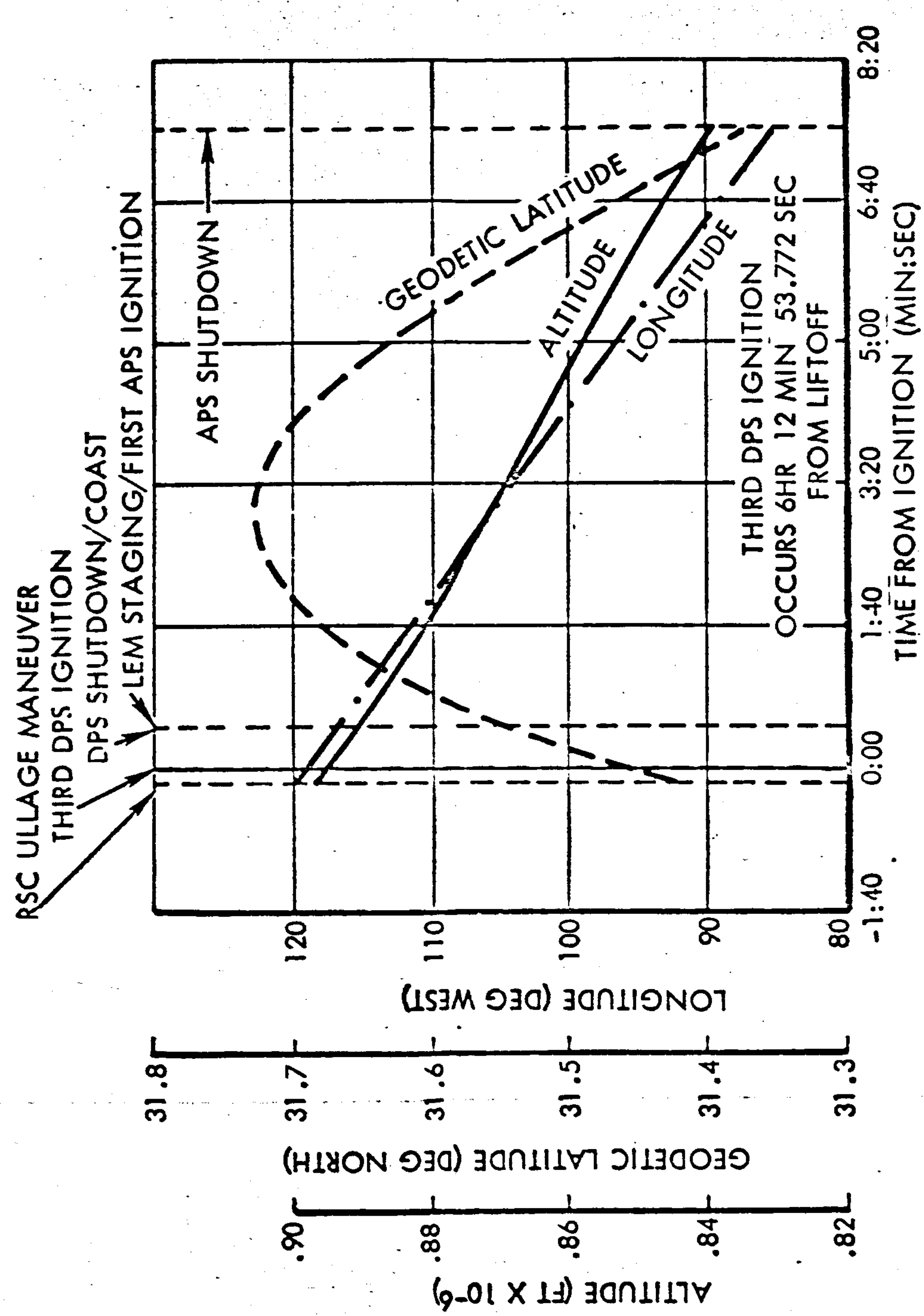


Figure 5-39. FITH Abort Test/Altitude, Latitude, and Longitude

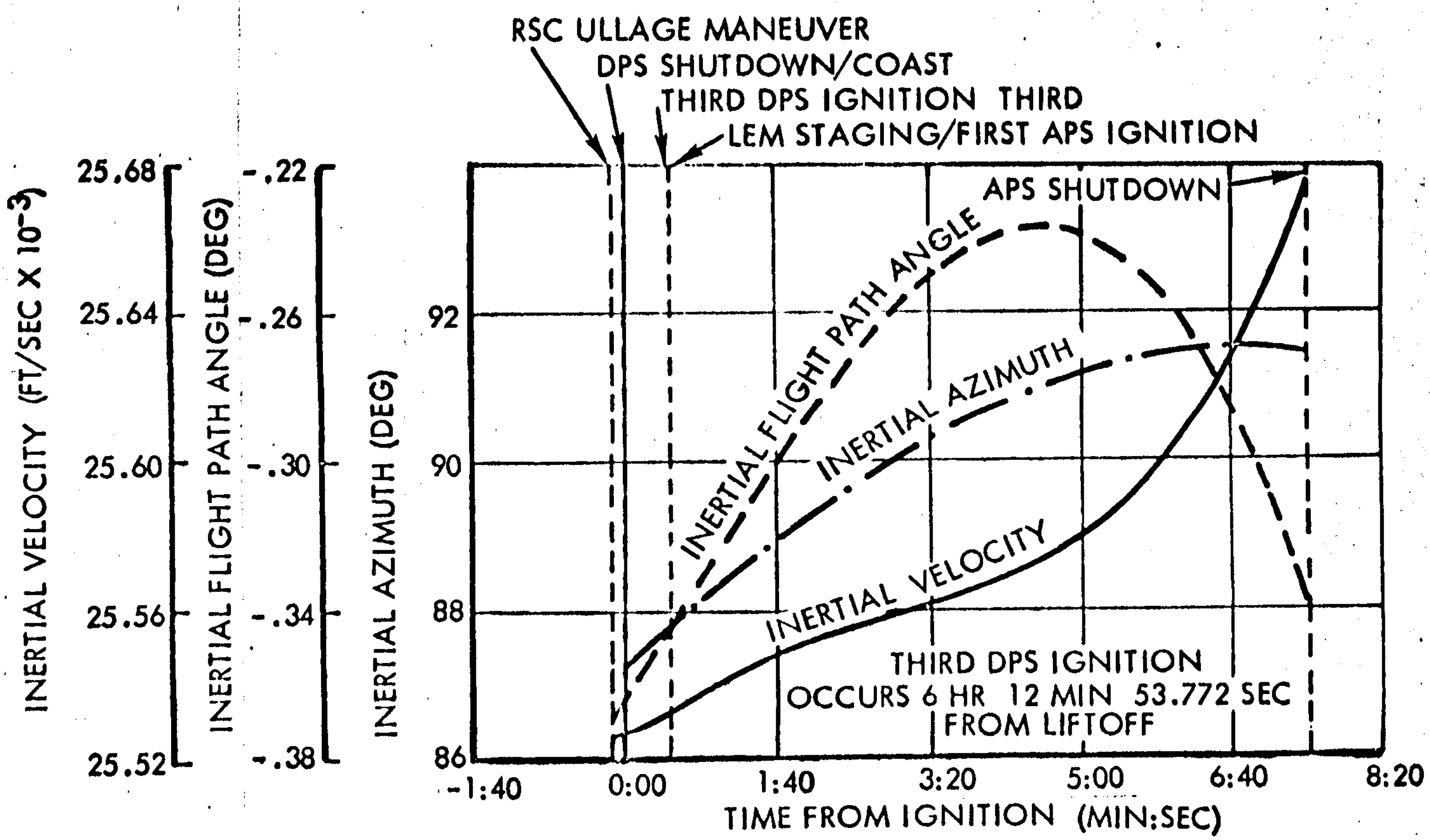


Figure 5-40. FITH Abort Test/Inertial Velocity, Flight Path Angle, and Azimuth

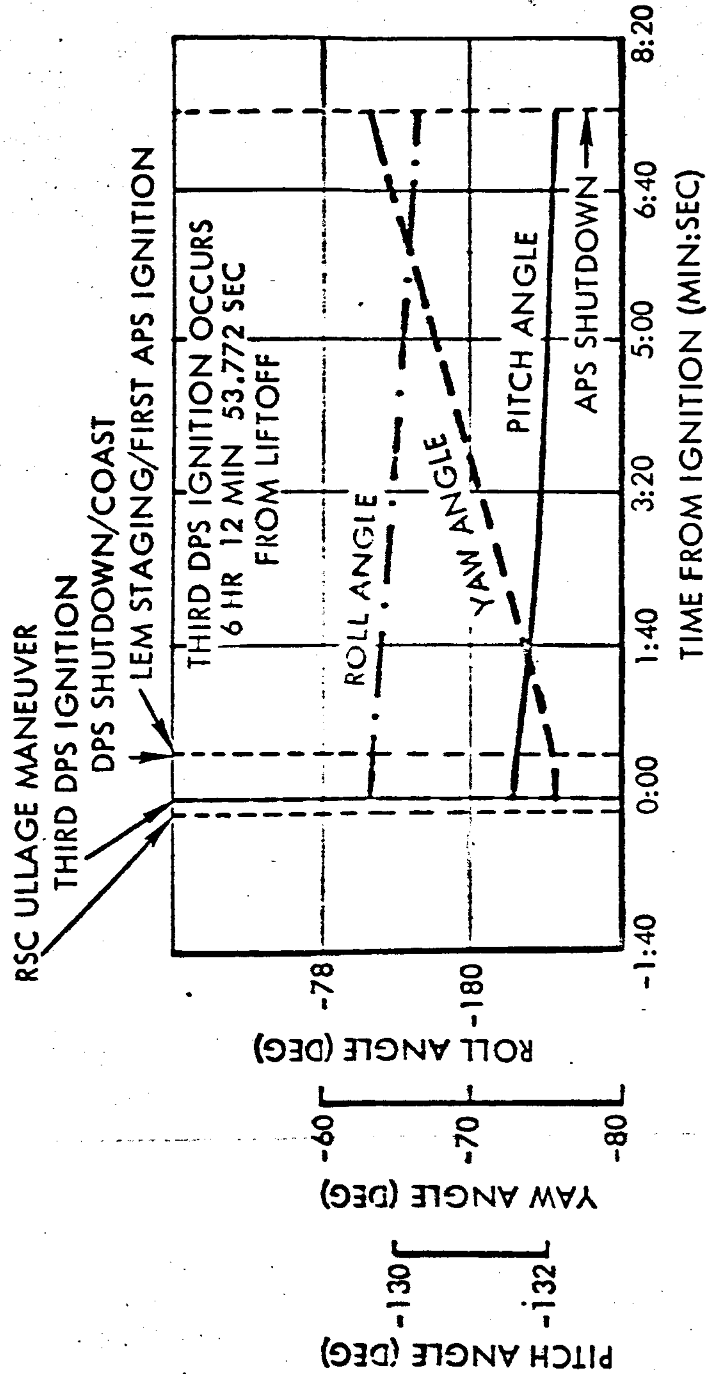


Figure 5-41. FITH Abort Test/Spacecraft Attitude (Launch Site Inertial)

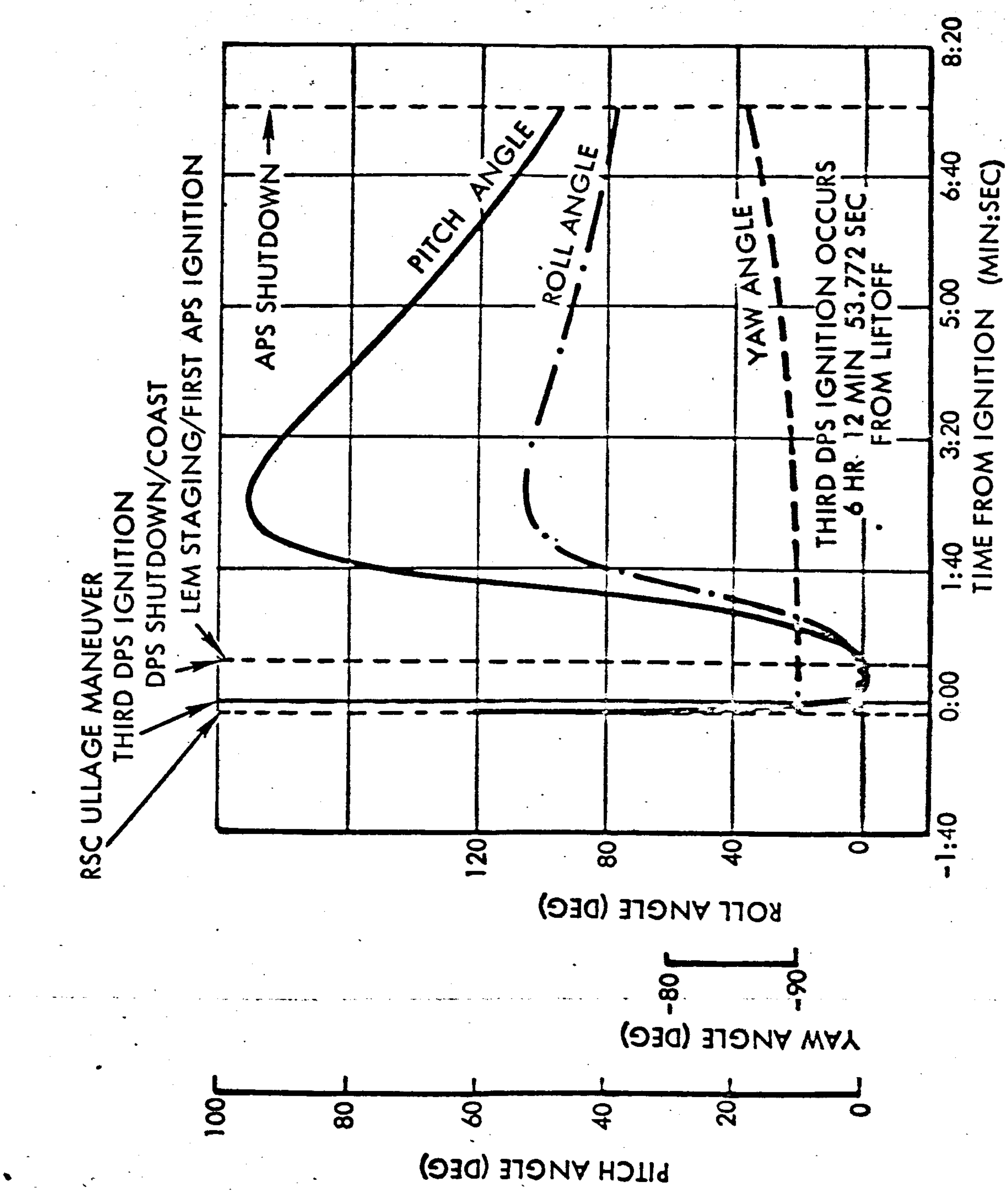


Figure 5-42. FITH Abort Test /Spacecraft Attitude (Earth Referenced Rotating)

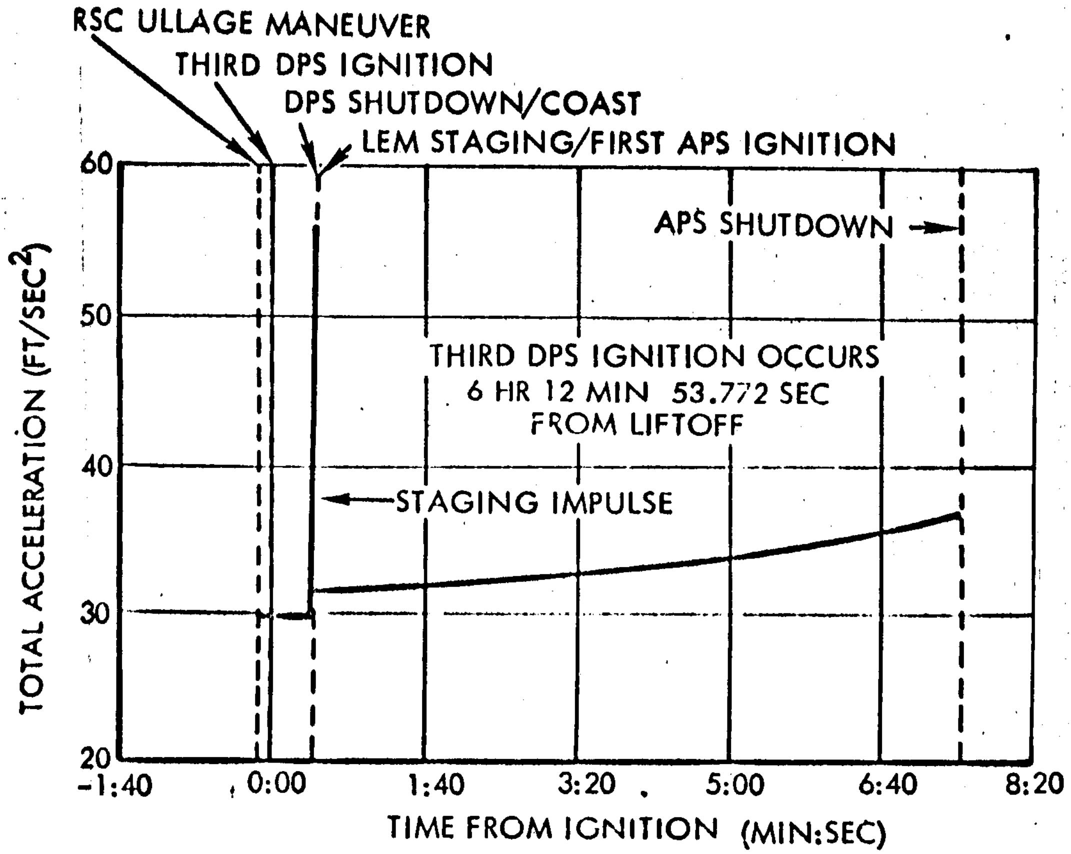


Figure 5-43. FITH Abort Test/Total Acceleration

Table 5-15. Orbital Coast to Second APS Burn/Discrete Events Summary

Event	Time From Liftoff (hr:min:sec)	Altitude* (ft)	Geodetic Latitude** (deg)	Longitude** (deg)	Inertial Velocity (ft/sec)	Inertial Flight Path Angle (deg)	Inertial Azimuth Angle (deg)
APS Shutdown	6:20:24.9	839,355	31.375	-85.341	25,674	-0.34	91.47
Maneuver to Required Pre-Burn Inertial Attitude	6:35:04.9	902,834	14.186	-26.375	25,592	0.70	118.20
Ship No. 3 Tracking Acquisition	6:36:29.2	929,061	11.443	-21.640	25,560	0.77	119.32
RCS Ullage Maneuver	6:40:24.9	1,016,990	3.439	-8.930	25,458	0.94	121.10

*Altitude above the Fischer ellipsoid.
**Minus coordinates indicate West longitudes and South latitudes.

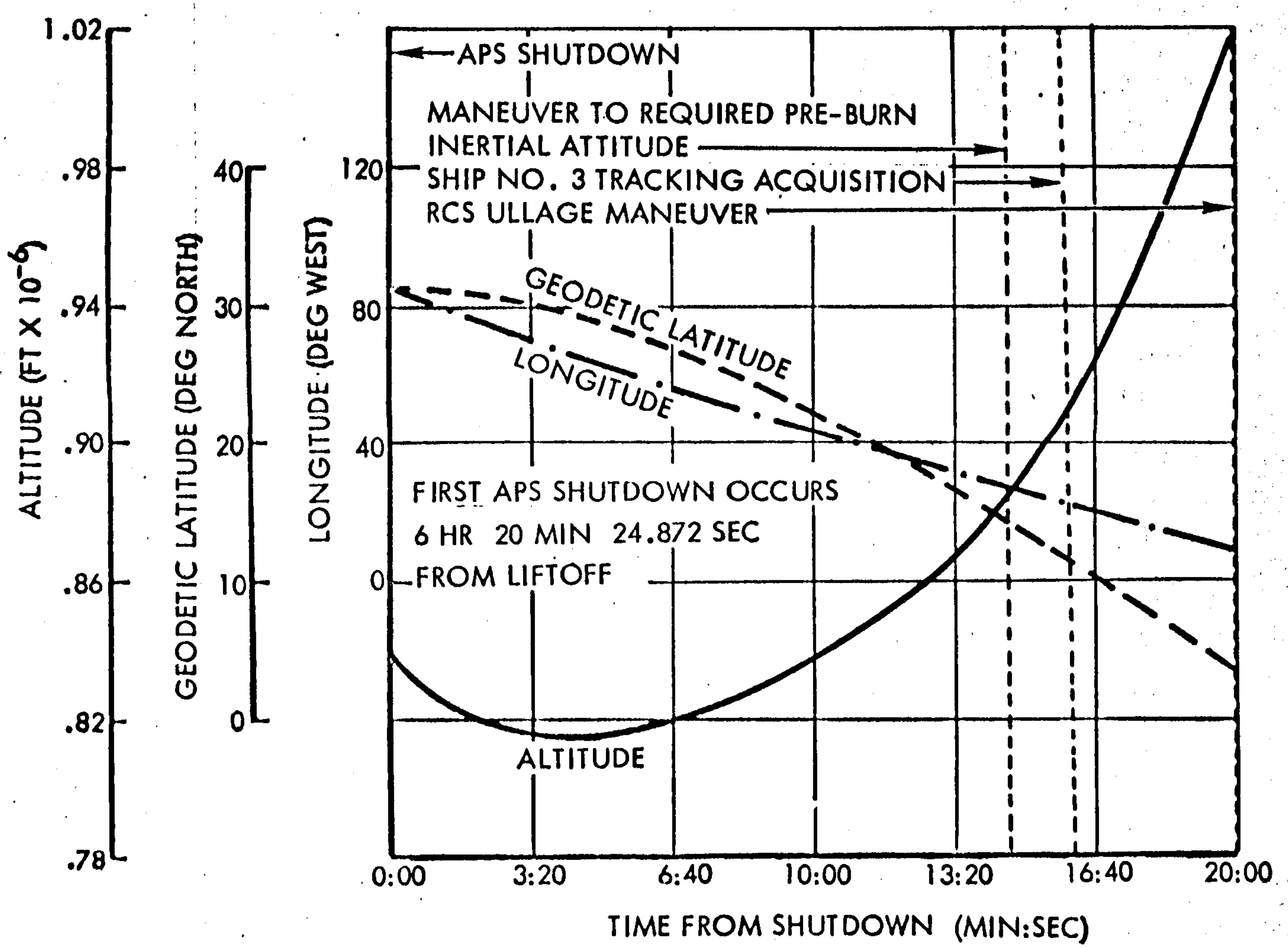


Figure 5-44. Orbital Coast to Second APS Burn/Altitude, Latitude, and Longitude

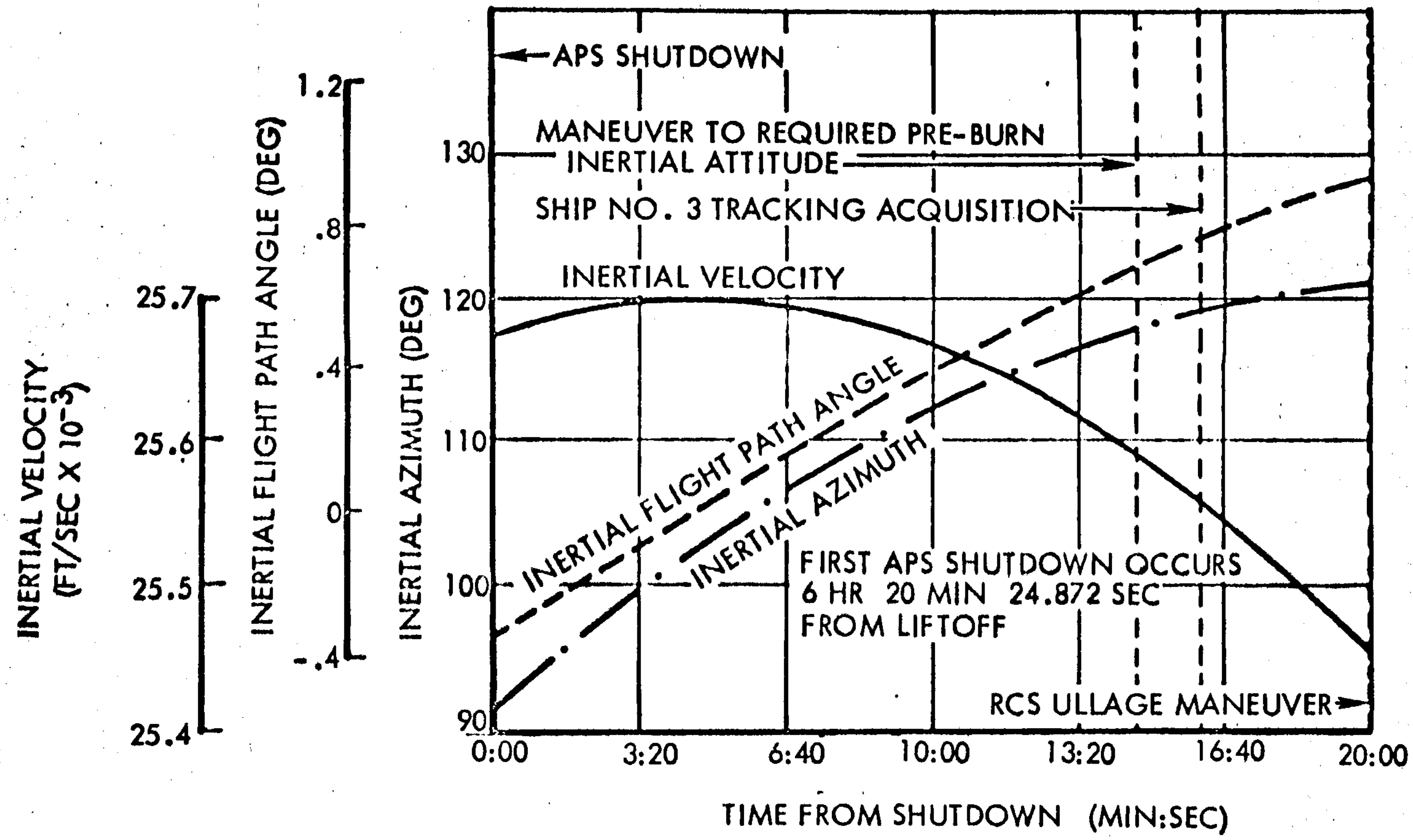


Figure 5-45. Orbital Coast to Second APS Burn/Inertial Velocity, Flight Path Angle, and Azimuth

Table 5-16. Second APS Burn/Discrete Events Summary

Event	Time From Liftoff (hr:min:sec)	Altitude* (ft)	Geodetic Latitude** (deg)	Longitude** (deg)	Inertial Velocity (ft/sec)	Inertial Flight Path Angle (deg)	Inertial Azimuth Angle (deg)
RCS Ullage Maneuver	6:40:24.9	1,016.990	3.439	-8.930	25,458	0.94	121.10
Second APS Ignition	6:40:27.9	1,018,239	3.335	-8.771	25,453	0.96	121.11
APS Shutdown	6:40:32,9	1,020,563	3.163	-8.508	25,397	1.16	121.13

*Altitude above the Fischer ellipsoid.
**Minus coordinates indicate West longitudes and South latitudes.

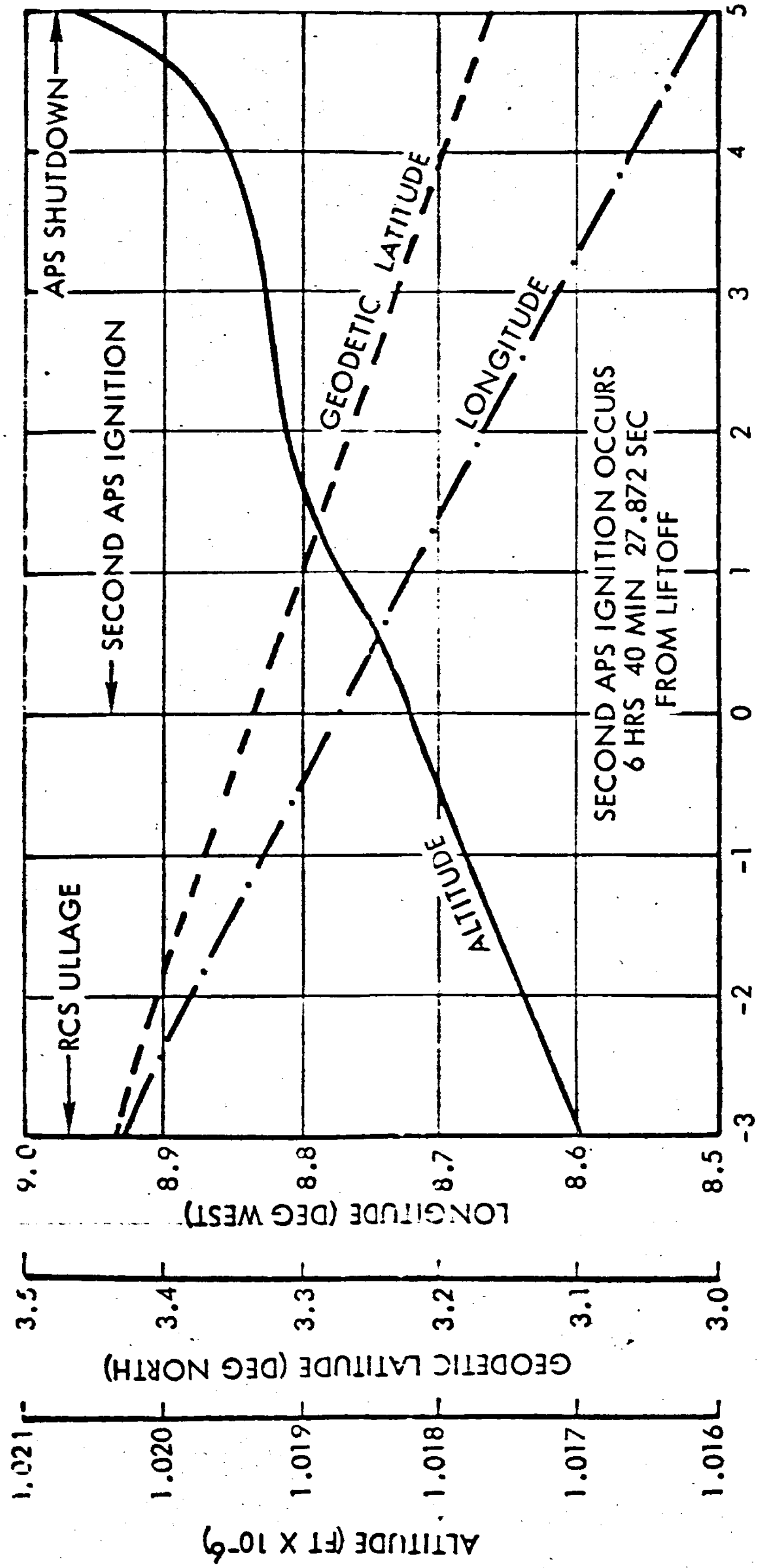


Figure 5-46. Second APS Burn/Altitude, Latitude, and Longitude

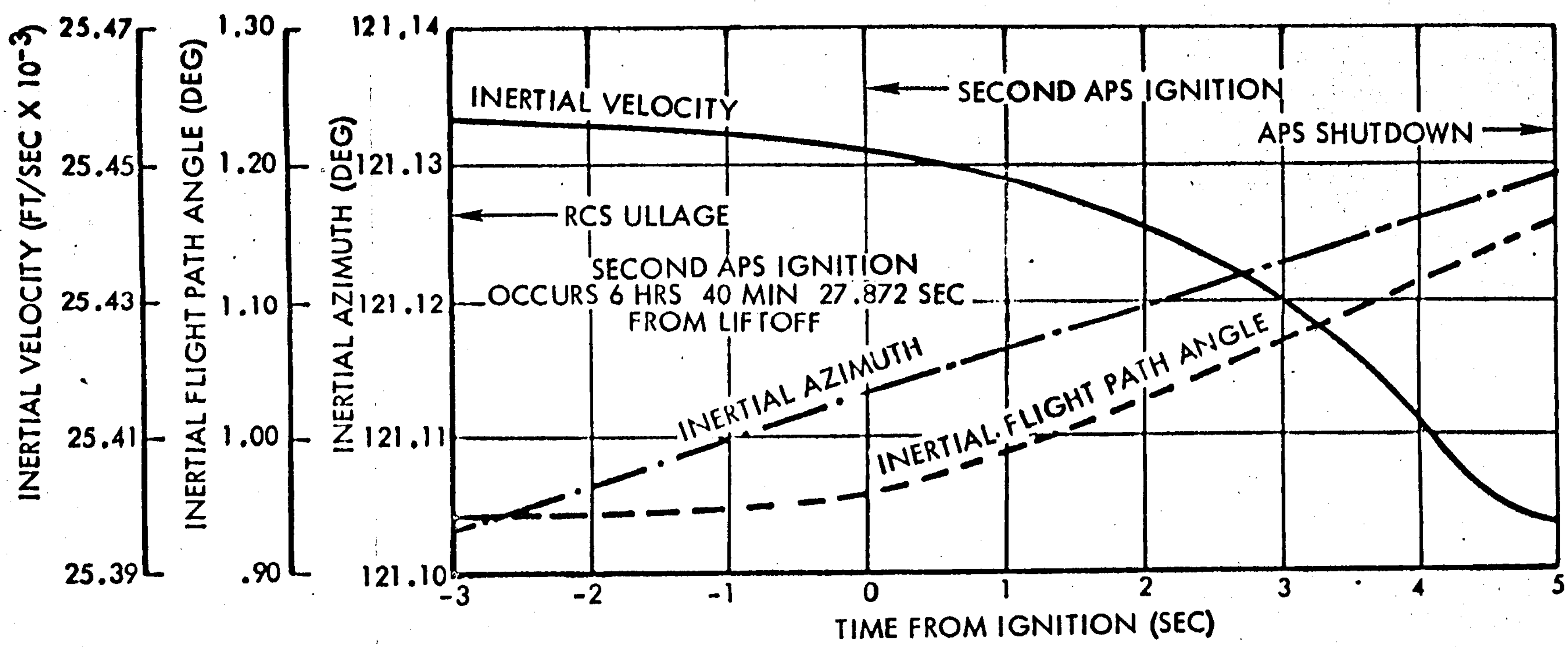


Figure 5-47. Second APS Burn/Inertial Velocity, Flight Path Angle, and Azimuth

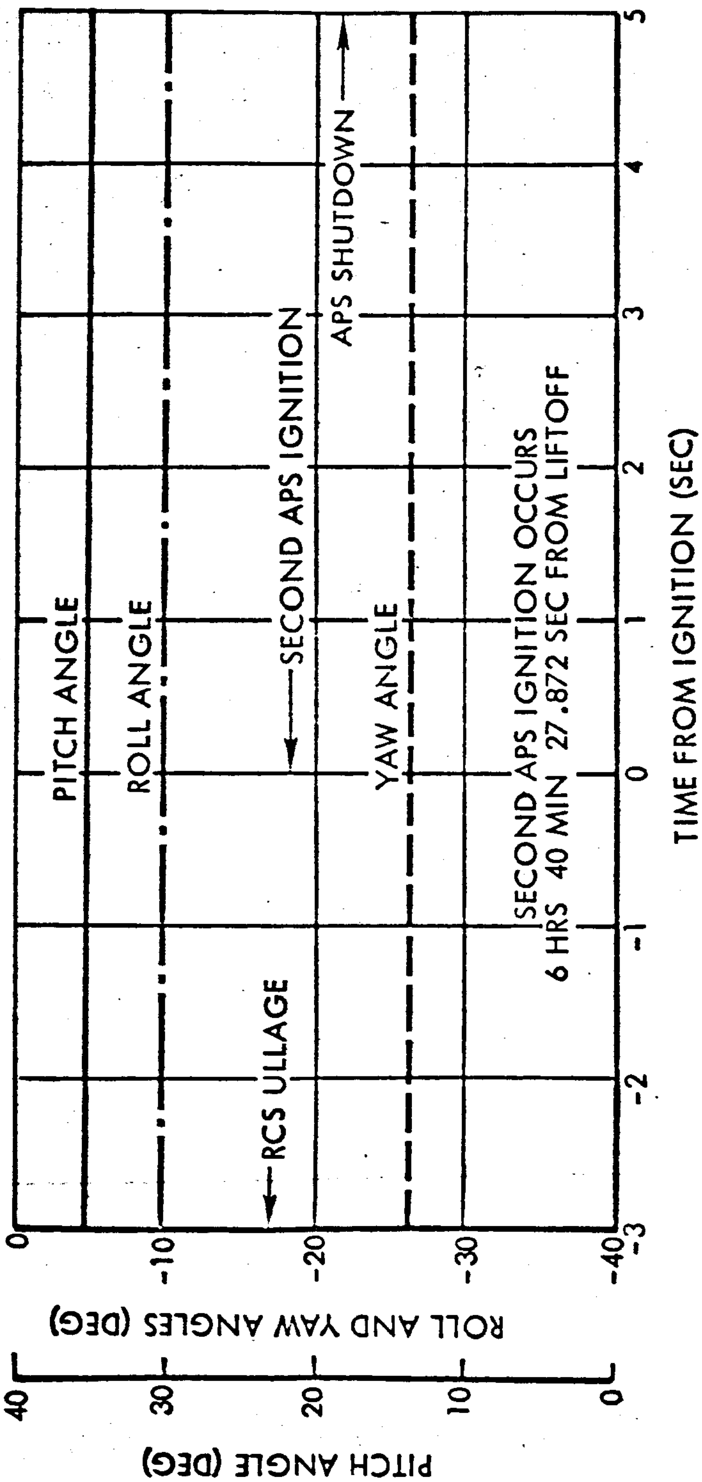


Figure 5-48. Second APS Burn/Spacecraft Attitude (Launch Site Inertial)

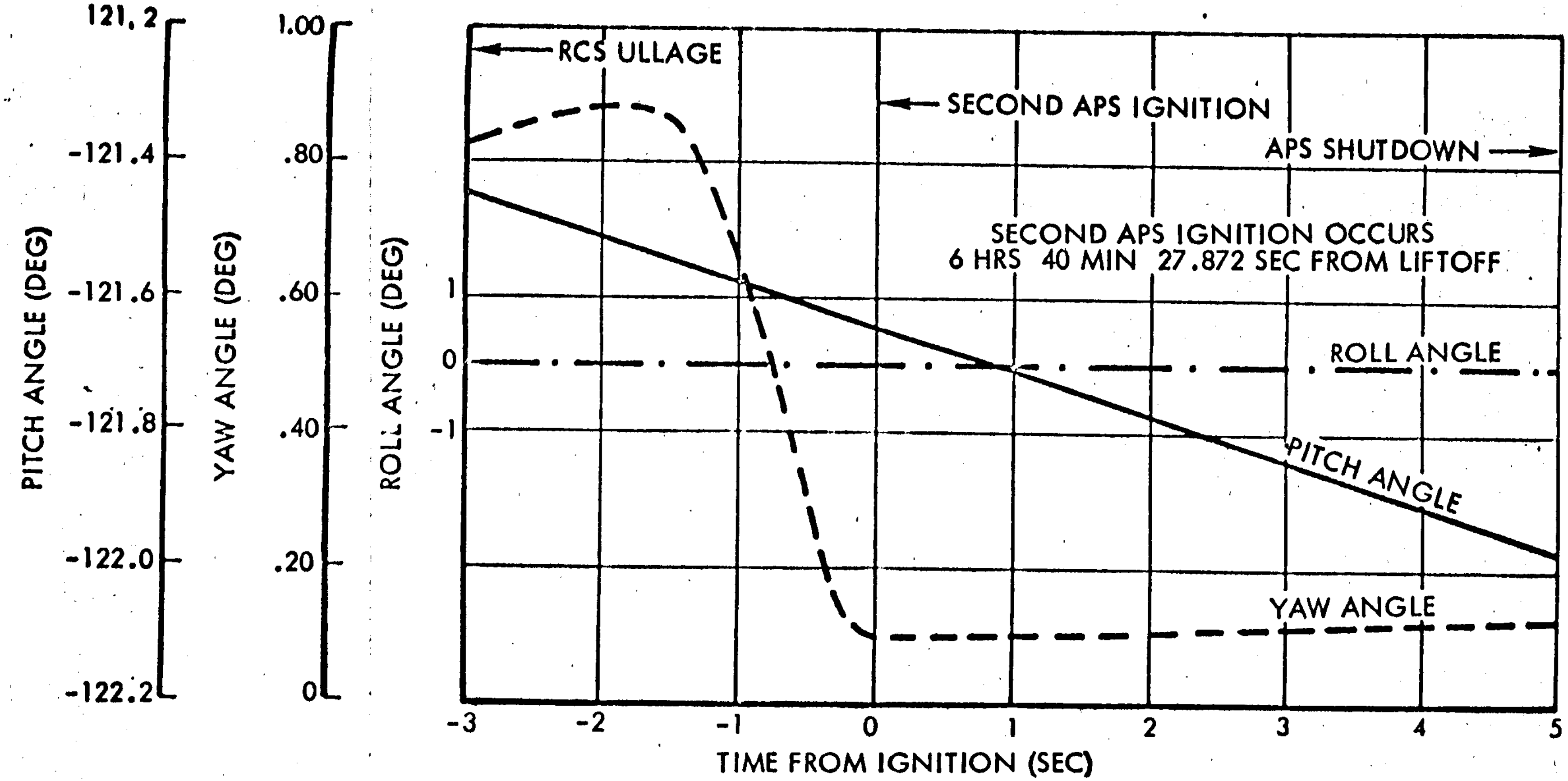


Figure 5-49. Second APS Burn/Spacecraft Attitude (Earth Referenced Rotating)

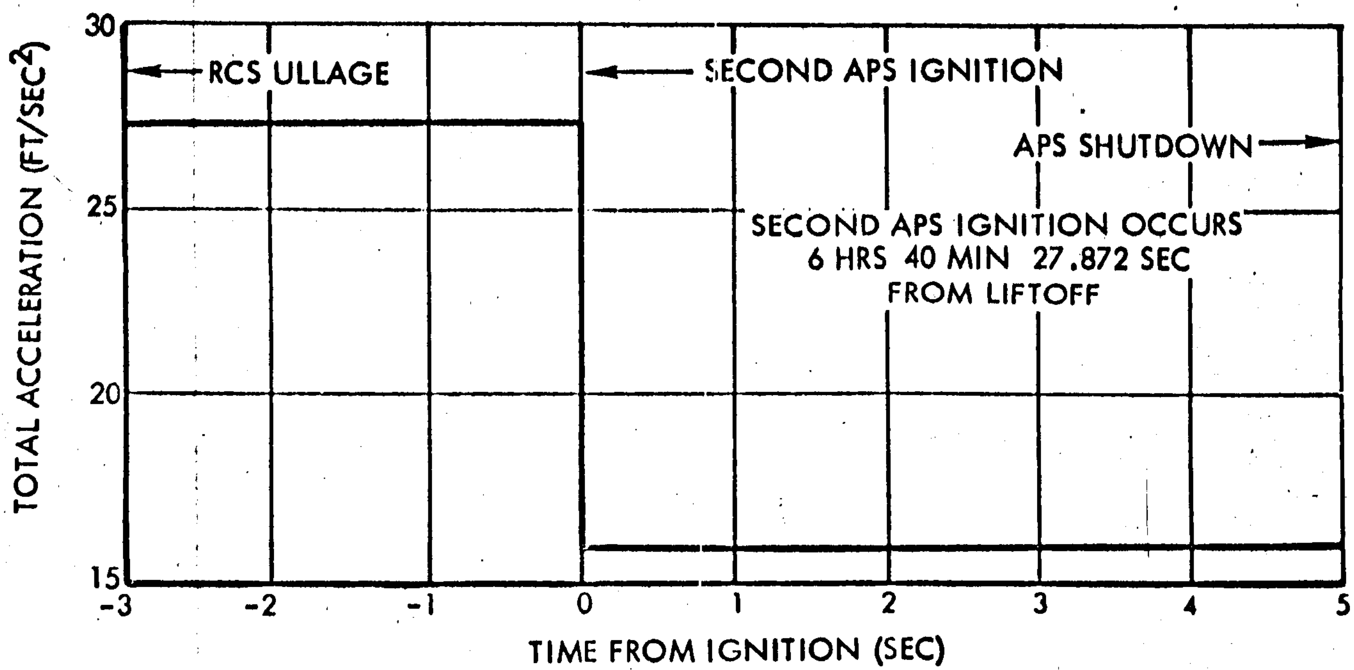


Figure 5-50. Second APS Burn/Total Acceleration

Table 5-17. Orbital Cold-Soak to Third APS Burn/Discrete Events Summary

Event	Time From Liftoff (hr:min:sec)	Altitude* (ft)	Geodetic Latitude** (deg)	Longitude** (deg)	Inertial Velocity (ft/sec)	Inertial Flight Path Angle (deg)	Inertial Azimuth Angle (deg)
APS Shutdown	6:40:32.9	1,020,563	3.163	-8.508	25,397	1.16	121.13
Maneuver to Align + Z-Axis Toward the Sun	6:40:42.9	1,025,663	2.818	-7.982	25,391	1.16	121.16
Maneuver to Required Pre-Burn Inertial Attitude	9:10:32.9	852,081	20.350	175.760	25,597	-0.96	65.65
Point Arguello Tracking Acquisition	9:22:53.3	678,061	31.378	-132.144	25,806	-0.08	91.38
RCS Ullage Maneuver	9:24:53.3	677,727	30.822	-123.081	25,806	0.09	96.32

*Altitude above the Fischer ellipsoid.
**Minus coordinates indicate West longitudes and South latitudes.

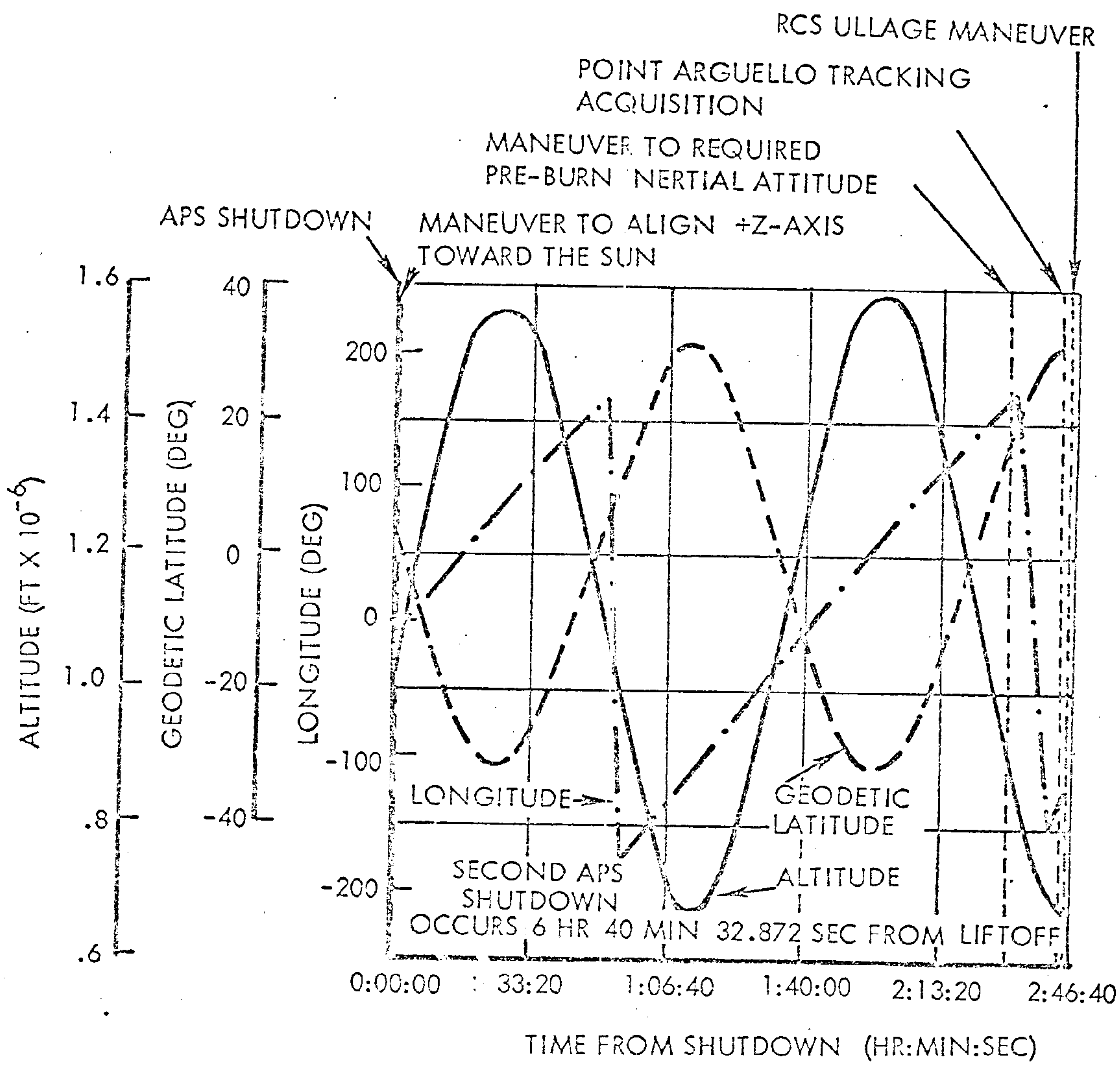


Figure 5-51. Orbital Cold-Soak to Third APS Burn/Altitude, Latitude, and Longitude

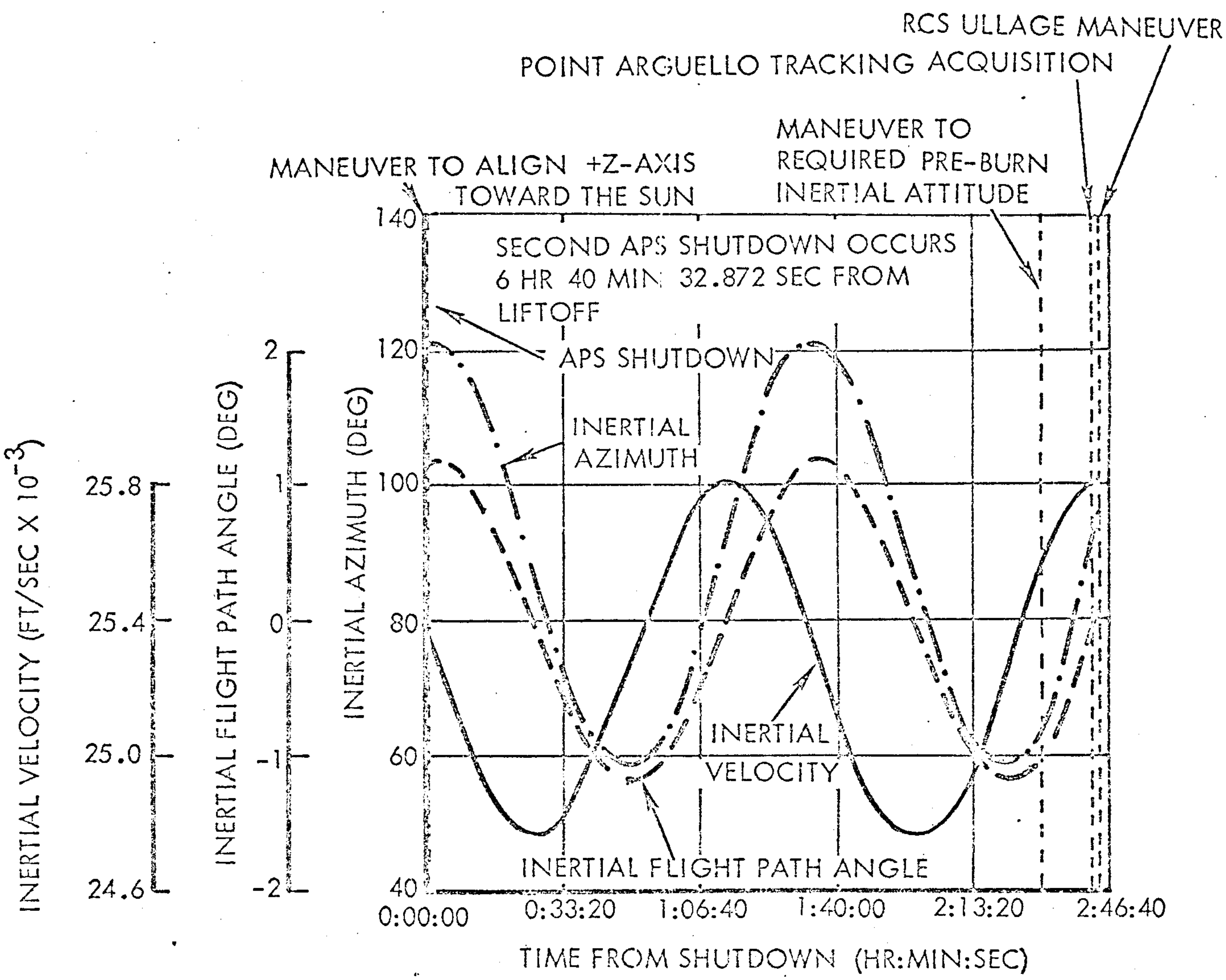


Figure 5-52. Orbital Cold-Soak to Third APS Burn/Inertial Velocity, Flight Path Angle, and Azimuth

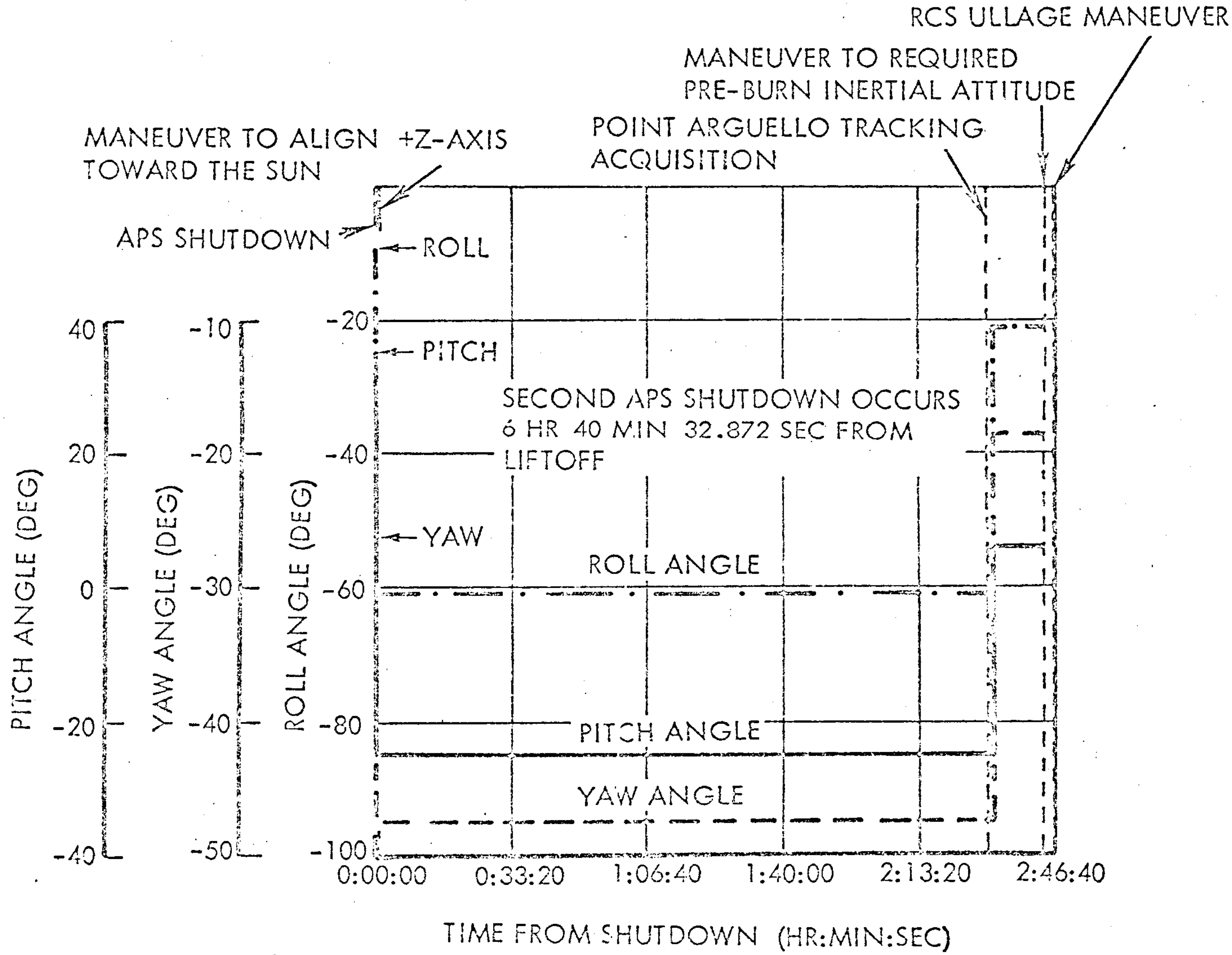


Figure 5-53. Orbital Cold-Soak to Third APS Burn/Spacecraft Attitude (Launch Site Inertial)

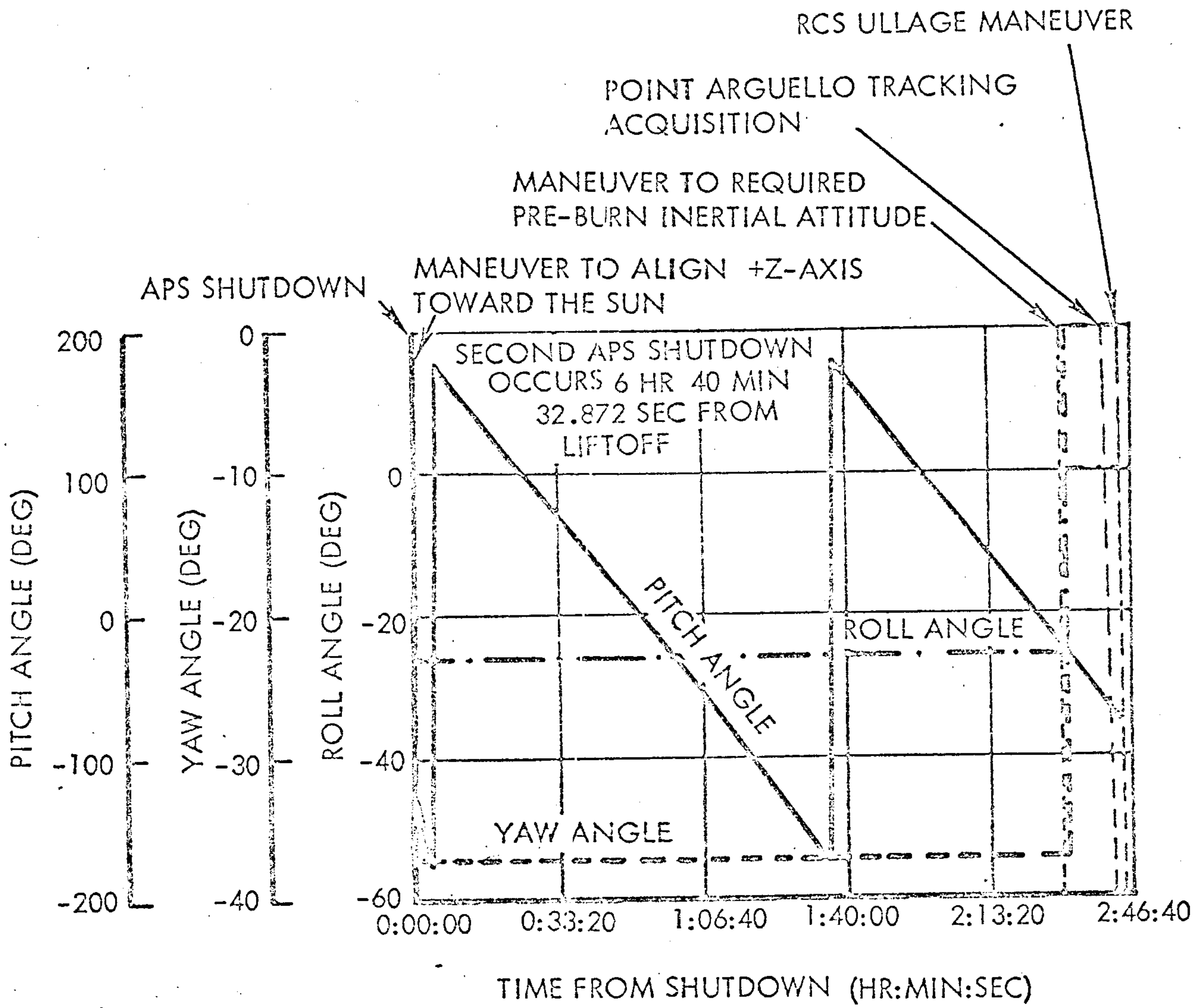


Figure 5-54. Orbital Cold-Soak to Third APS Burn/Spacecraft Attitude (Earth Referenced Rotating)

Table 5-18. Third APS Burn/Discrete Events Summary

Event	Time From Liftoff (hr:min:sec)	Altitude* (ft)	Geodetic Latitude** (deg)	Longitude** (deg)	Inertial Velocity (ft/sec)	Inertial Flight Path Angle (deg)	Inertial Azimuth Angle (deg)
RCS Ullage Maneuver	9:24:53.3	677,727	30.822	-123.081	25,806	0.09	96.32
Third APS Ignition	9:24:56.3	677,837	30.800	-122.856	25,808	0.11	96.44
APS Shutdown	9:25:01.3	678,302	30.760	-122.481	25,833	0.34	96.64

*Altitude above the Fischer ellipsoid.
**Minus coordinates indicate West longitudes and South latitudes.

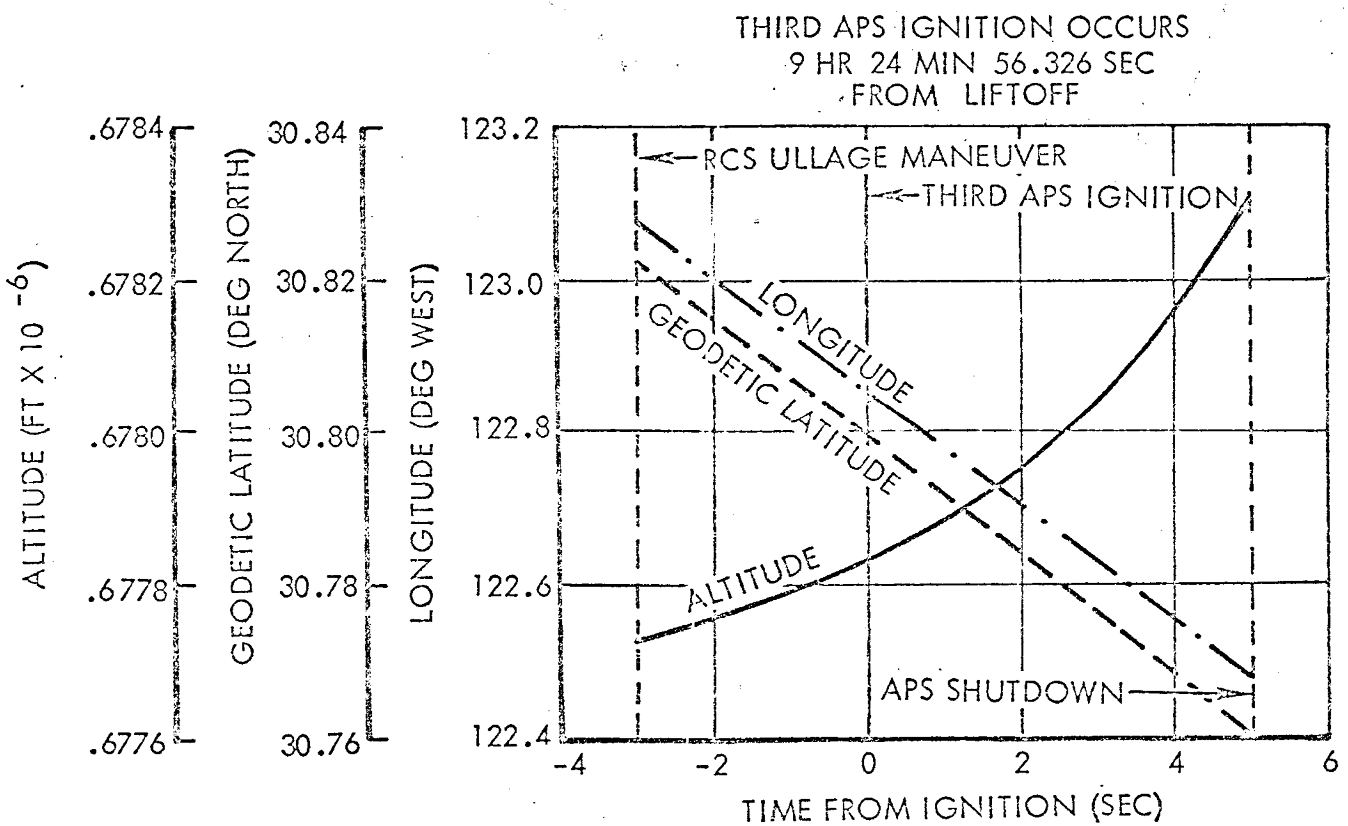


Figure 5-55. Third APS Burn/Altitude, Latitude and Longitude

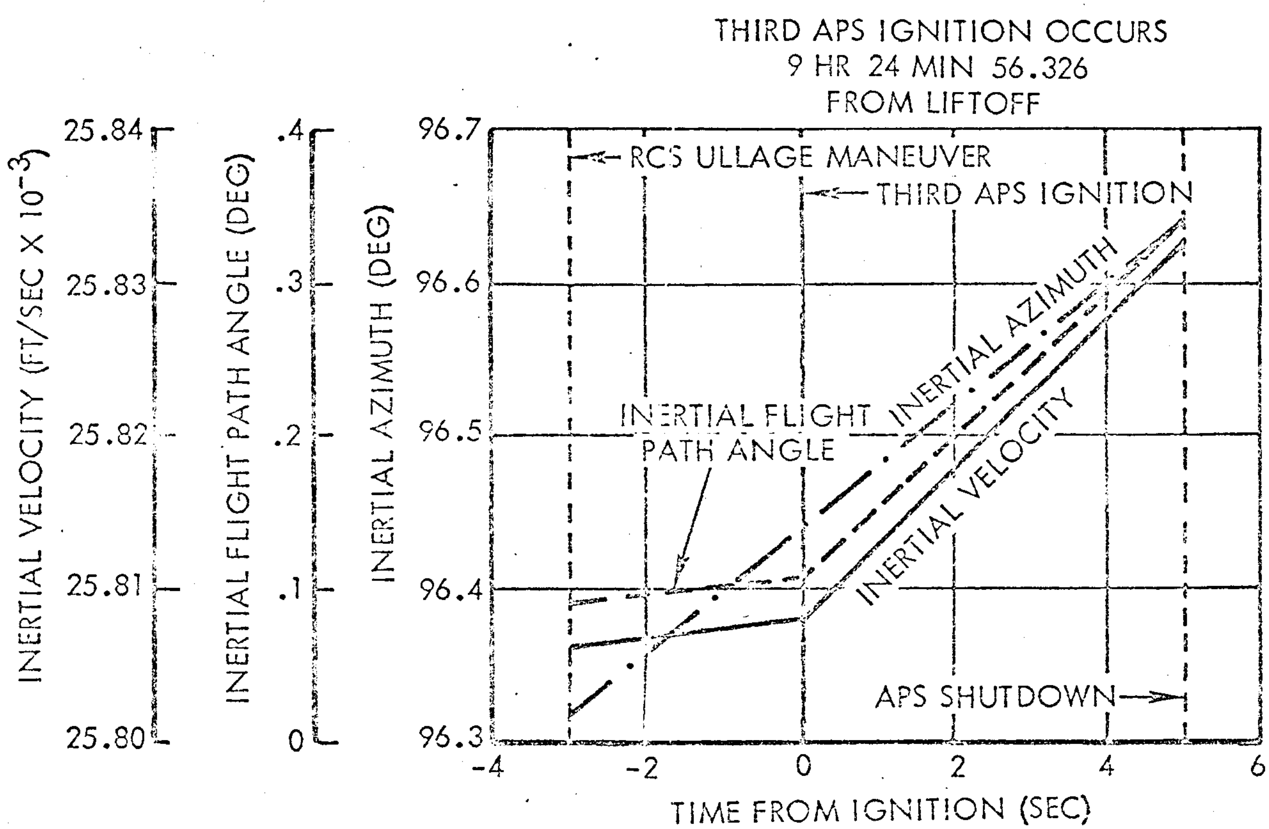


Figure 5-56. Third APS Burn/Inertial Velocity, Flight Path Angle, and Azimuth

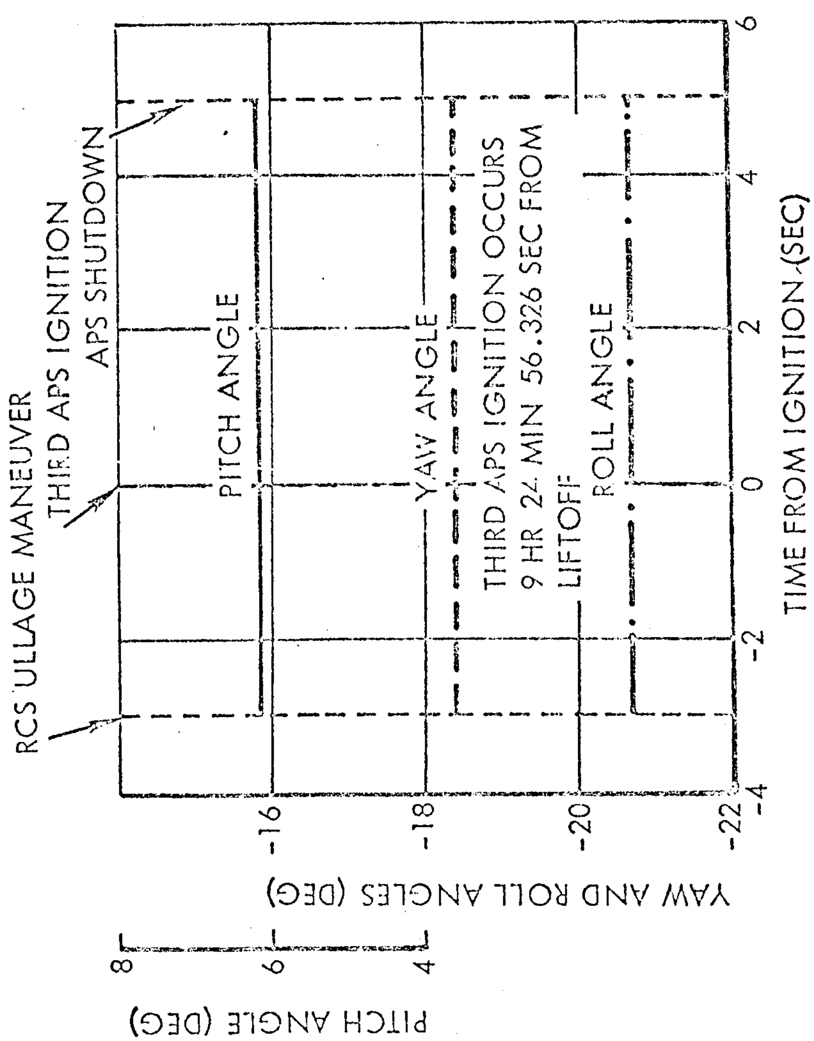


Figure 5-57. Third APS Burn/Spacecraft Attitude (Launch Site Inertial)

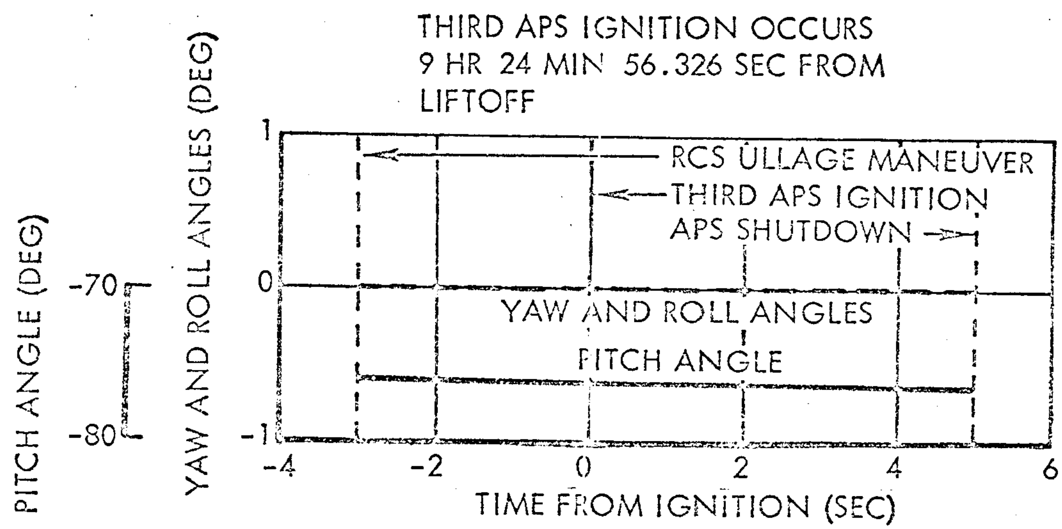


Figure 5-58. Third APS Burn/Spacecraft Attitude (Earth Referenced Rotating)

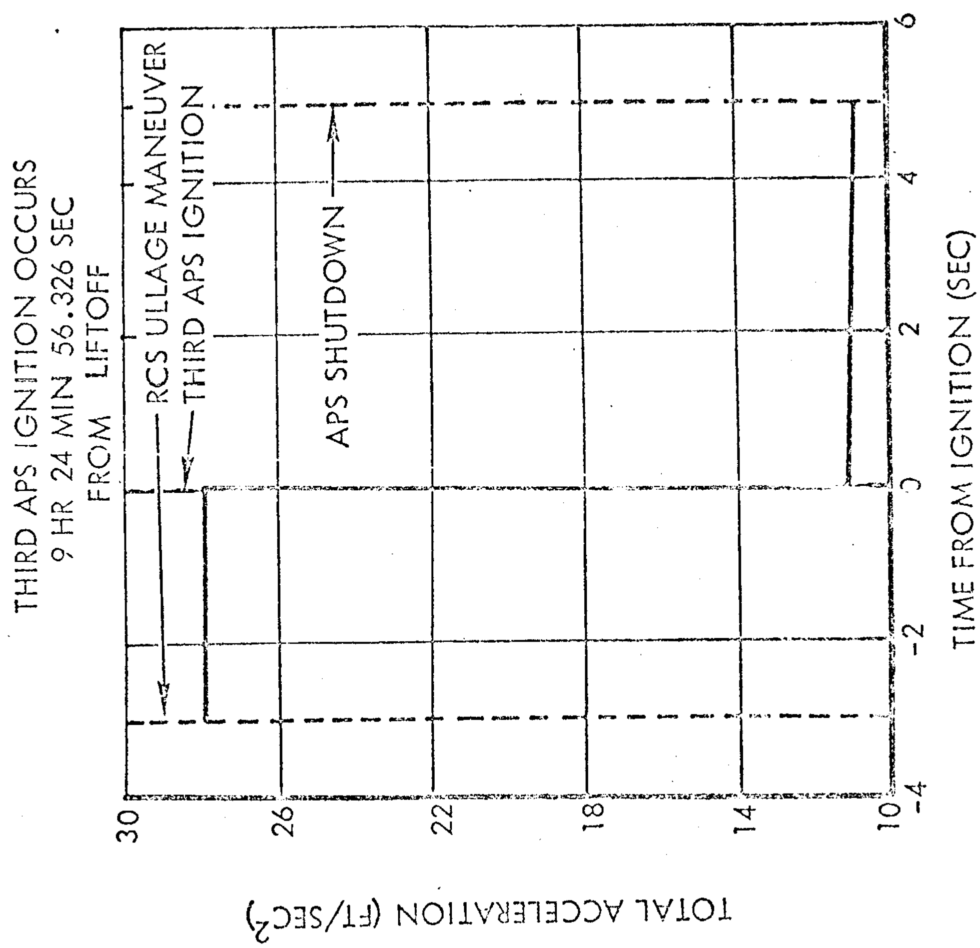


Figure 5-59. Third APS Burn/Total Acceleration

Table 5-19. Final Orbital Coast/Discrete Events Summary

Event	Time From Liftoff (hr:min:sec)	Altitude* (ft)	Geodetic Latitude** (deg)	Longitude** (deg)	Inertial Velocity (ft/sec)	Inertial Flight Path Angle (deg)	Inertial Azimuth Angle (deg)
APS Shutdown	9:25:01.3	678,302	30.760	-122.481	25,833	0.34	96.64
End of Mission Profile	14:00:00.0	677,720	30.523	169.413	25,833	0.34	97.75

*Altitude above the Fischer ellipsoid.
Minus coordinates indicate West longitudes and South latitudes.

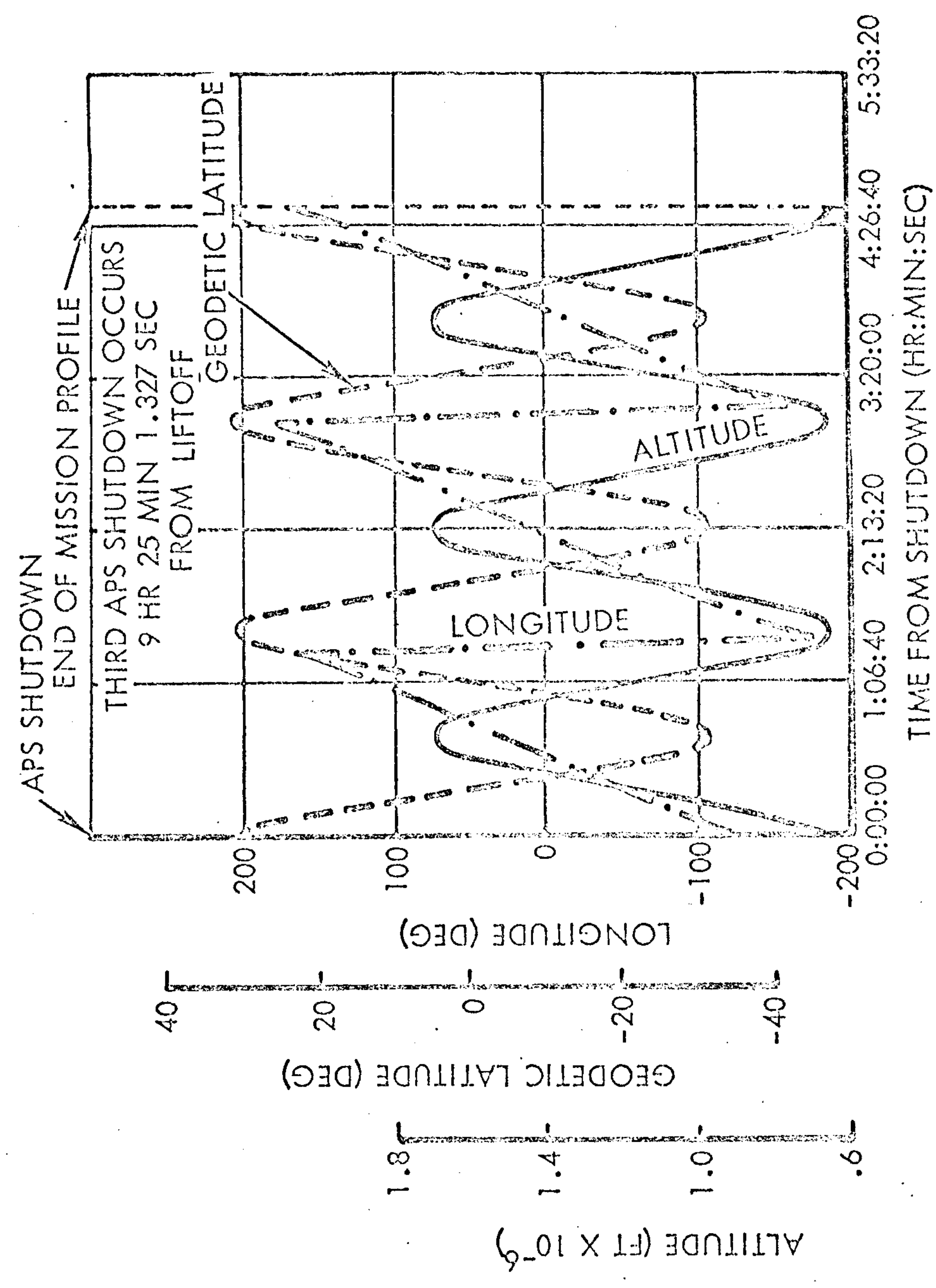


Figure 5-60. Final Orbital Coast/Altitude, Latitude, and Longitude

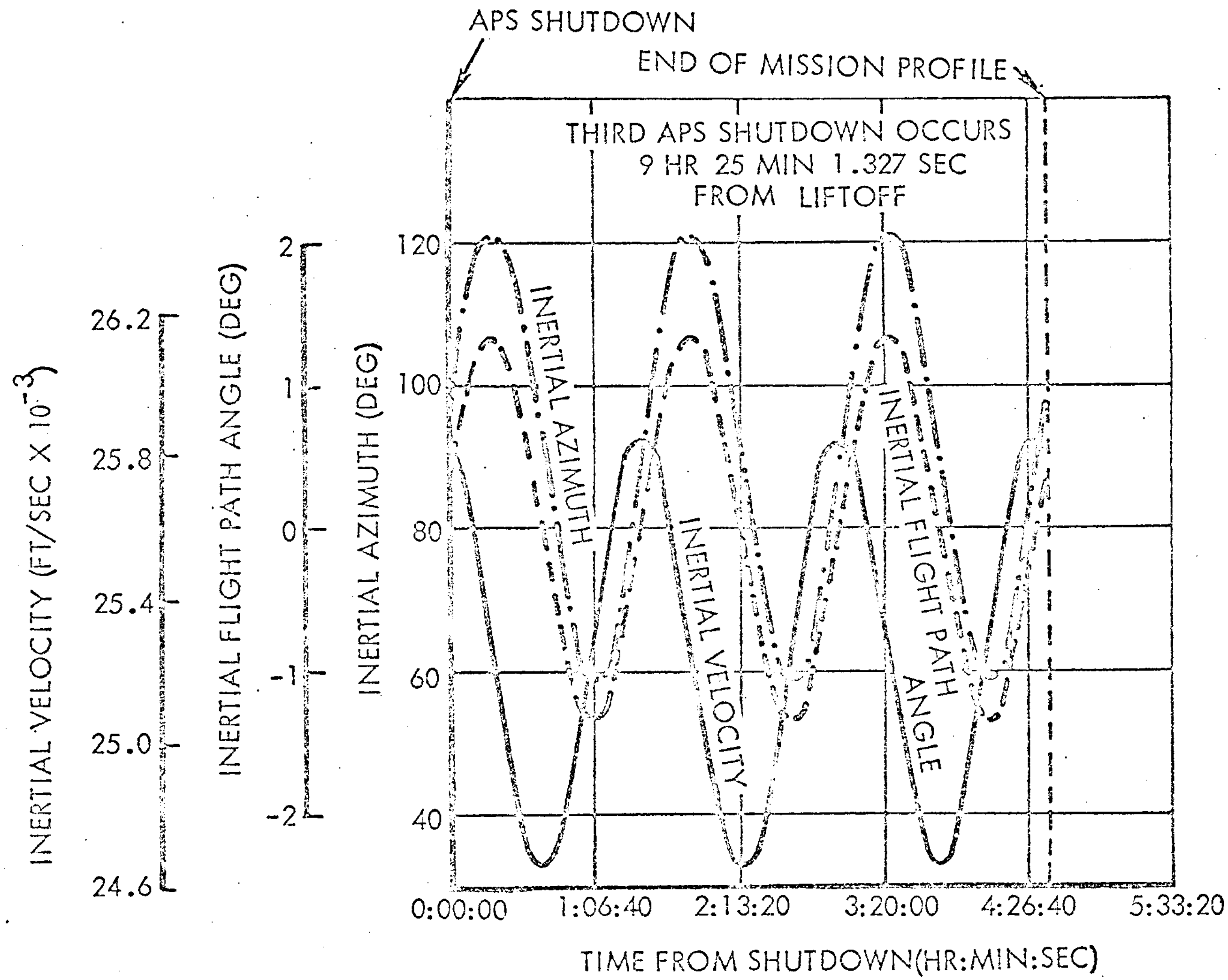


Figure 5-61. Final Orbital Coast/Inertial Velocity, Flight Path Angle, and Azimuth

6. TRACKING AND COMMUNICATIONS DATA

Spacecraft visibility periods for the MSFN stations presented in Table 3-6 are listed in Table 6-1. Table 6-2 presents the intervals of the mission which are not seen by any of the tracking stations (communications void). The surface tracking coverage, during the ascent to orbit, spacecraft separation and staging, and all the APS and DPS burns, is shown in Figure 6-1. Spacecraft visiblity is defined as a tracking elevation angle greater than 5.0 degrees as measured from the station local horizontal.

Volume III presents detailed tracking time history data for the ground stations available for operation on this mission. These data consist of range, range rate, azimuth angle, elevation angle, and two spacecraft-to-radar look angles, and are presented as a function of time for each of the ground stations. Significant events are noted in this data.

Table 6-1. Surface Tracking Coverage

Tracking Station	Acquisition of Signal-Time from Liftoff (hr:min:sec)	Loss of Signal-Time from Liftoff (hr:min:sec)	Visibility Duration (min:sec)
Grand Turk	0:05:47.251	0:07:36.155	1:48.904
Cape Kennedy	0:00:19.332	0:07:56.850	7:37.518
Grand Bahama	0:01:55.066	0:08:16.833	6:21.767
San Salvador	0:03:10.837	0:08:34.194	5:23.357
Bermuda	0:05:57.792	0:11:51.464	5:53.672
Grand Canary	0:18:11.446	0:22:48.459	4:37.013
Carnarvon	0:53:46.255	0:57:26.467	3:40.211
Ship No. 1	0:52:48.850	0:58:14.320	5:25.470
Guaymas Mex.	1:30:02.811	1:34:32.386	4:29.575
White Sands	1:31:36.161	1:35:31.470	3:55.310
Texas	1:33:24.034	1:37.57.064	4:33.030
Cape Kennedy	1:36:56.104	1:40:57.147	4:01.043
San Salvador	1:39:55.908	1:40:15.058	0:19.150
Grand Bahama	1:37:45.816	1:41:04.236	3:18.419
Bermuda	1:40:10.280	1:44:47.569	4:37.289
Grand Canary	1:52:49.890	1:53:16.695	0:26.805
Carnarvon	2:26:49.787	2:31:07.915	4:18.128
Ship No. 1	2:25:49.235	2:31:15.095	5:25.859
Hawaii	2:52:51.470	2:55:22.402	2:30.932
Ship No. 2	3:00:13.931	3:04:43.612	4:29.681
Pt. Arguello	3:01:29.179	3:05:23.050	3:53.871
Goldstone	3:02:18.832	3:06:09.431	3:50.599
Guaymas Mex.	3:03:08.545	3:07:16.433	4:07.888
White Sands	3:04:03.940	3:08:37.138	4:33.199
Texas	3:06:31.995	3:10:51.530	4:19.534
Cape Kennedy	3:09:56.585	3:14:11.884	4:15.299
Grand Bahama	3:10:41.574	3:14:36.187	3:54.613
San Salvador	3:12:06.545	3:15:13.213	3:06.668
Grand Turk	3:13:51.382	3:15:18.672	1:27.290
Bermuda	3:13:09.569	3:17:23.260	4:13.691
Ascension Is.	3:29:52.307	3:32:17.357	2:25.050
Ship No. 3	3:27:15.925	3:32:18.010	5:02.085

Table 6-1. Surface Tracking Coverage (Continued)

Tracking Station	Acquisition of Signal- Time from Liftoff (hr:min:sec)	Loss of Signal- Time from Liftoff (hr:min:sec)	Visibility Duration (min:sec)
Pretoria	3:39:53.816	3:45:05.434	5:11.618
Ship No. 1	3:59:03.035	4:03:38.476	4:35.441
Carnarvon	3:59:27.932	4:04:45.257	5:17.325
Hawaii	4:24:13.836	4:29:52.525	5:38.690
Ship No. 2	4:32:39.315	4:38:44.995	6:05.680
Pt. Arguello	4:33:28.239	4:39:35.237	6:06.999
Goldstone	4:34:17.826	4:40:23.267	6:05.441
Guaymas Mex.	4:35:52.021	4:41:28.259	5:36.238
White Sands	4:36:30.704	4:42:44.528	6:13.823
Texas	4:39:03.227	4:45:06.936	6:03.710
Cape Kennedy	4:42:25.312	4:48:29.985	6:04.673
Grand Bahama	4:43:08.439	4:48:54.293	5:45.854
San Salvador	4:44:24.118	4:49:38.932	5:14.814
Grand Turk	4:45:45.770	4:50:07.605	4:21.835
Bermuda	4:45:48.858	4:51:47.203	5:58:345
Antigua	4:49:07.508	4:51:54.875	2:47.368
Ascension Is.	5:03:29.420	5:06:20.425	2:51.005
Ship No. 3	5:00:23.808	5:06:49.171	6:25.364
Pretoria	5:13:10.388	5:20:16.475	7:06.087
Ship No. 1	5:32:17.219	5:40:24.411	8:07.191
Carnarvon	5:32:50.370	5:41:16.890	8:26.519
Hawaii	5:59:23.175	6:06:27.794	7:04.619
Ship No. 2	6:08:26.660	6:14:55.900	6:29.240
Pt. Arguello	6:09:25.772	6:15:40.107	6:14.335
Goldstone	6:10:18.916	6:16:26.178	6:07.262
Guaymas Mex.	6:11:41.628	6:17:39.046	5:57.418
White Sands	6:12:31.502	6:18:48.977	6:17.474
Texas	6:15:06.373	6:21:11.454	6:05.081
Cape Kennedy	6:18:32.619	6:24:29.362	5:56.743
Grand Bahama	6:19:14.850	6:24:52.706	5:37.856
San Salvador	6:20:31.369	6:25:34.841	5:03.471
Grand Turk	6:21:57.695	6:25:59.271	4:01.575
Bermuda	6:22:00.441	6:27:49.612	5:49.171

Table 6-1. Surface Tracking Coverage (Continued)

Tracking Station	Acquisition of Signal-Time from Liftoff (hr:min:sec)	Loss of Signal-Time from Liftoff (hr:min:sec)	Visibility Duration (min:sec)
Antigua	6:25:39.362	6:27:26.348	1:46.986
Ascension Is.	6:39:48.361	6:42:17.625	2:29.264
Ship No. 3	6:36:29.247	6:43:03.953	6:34.705
Pretoria	6:49:02.437	6:57:07.692	8:05.255
Ship No. 1	7:08:26.337	7:17:35.094	9:08.757
Carnarvon	7:09:02.751	7:18:22.595	9:19:844
Hawaii	7:36:32.552	7:42:44.092	6:11.541
Ship No. 2	7:45:32.055	7:50:58.900	5:26.845
Pt. Arguello	7:46:34.339	7:51:41.945	5:07.606
Goldstone	7:47:27.257	7:52:25.581	4:58.324
Guaymas Mex.	7:48:43.802	7:53:47.183	5:03.381
White Sands	7:49:31.813	7:54:51.806	5:19.992
Texas	7:52:03.342	7:57:25.773	5:22.430
Cape Kennedy	7:55:19.021	8:00:50.061	5:31.041
Grand Bahama	7:55:58.510	8:01:31.662	5:33.152
San Salvador	7:57:01.447	8:02:37.268	5:35.821
Bermuda	7:59:46.024	8:02:22.799	2:36.775
Grand Turk	7:58:02.963	8:03:36.527	5:33.564
Antigua	8:00:29.239	8:06:16.884	5:47.645
Ship No. 3	8:13:07.508	8:19:22.094	6:14.586
Ascension Is.	8:13:33.696	8:21:28.000	7:54.304
Pretoria	8:25:00.845	8:34:11.435	9:10.591
Ship No. 1	8:46:11.636	8:52:16.953	6:05.317
Carnarvon	8:46:09.943	8:54:12.567	8:02.624
Guam	8:59:58.421	9:05:24.385	5:25:964
Hawaii	9:13:55.813	9:18:28.917	4:33.104
Pt. Arguello	9:22:53.326	9:27:50.943	4:57.617
Ship No. 2	9:22:02.780	9:27:26.010	5:23.230
Goldstone	9:23:47.814	9:28:27.798	4:39.984
Guaymas Mex.	9:25:06.053	9:30:38.120	5:32.066
White Sands	9:25:59.381	9:31:03.035	5:03.655
Texas	9:28:25.464	9:33:43.115	5:17.651
Cape Kennedy	9:32:19.286	9:36:19.038	3:59.752

Table 6-1. Surface Tracking Coverage (Continued)

Tracking Station	Acquisition of Signal-Time from Liftoff (hr:min:sec)	Loss of Signal-Time from Liftoff (hr:min:sec)	Visibility Duration (min:sec)
Grand Bahama	9:32:44.112	9:37:17.198	4:33.085
San Salvador	9:33:38.448	9:38:38.312	4:59.865
Grand Turk	9:34:27.827	9:39:56.449	5:28.622
Antigua	9:37:02.602	9:42:37.024	5:34.422
Ascension Is.	9:51:06.807	9:57:46.241	6:39.434
Pretoria	10:02:02.787	10:11:38.407	9:35.620
Guam	10:36:20.887	10:42:33.092	6:12.205
Hawaii	10:52:35.449	10:54:20.597	1:45.148
Pt. Arguello	11:00:03.130	11:03:26.429	3:23.299
Goldstone	11:01:43.499	11:03:09.532	1:26.033
Ship No. 2	10:58:44.630	11:03:56.334	5:11.705
White Sands	11:04:57.811	11:05:01.281	0:03.471
Guaymas Mex.	11:01:53.223	11:07:02.201	5:08.978
Pretoria	11:39:21.014	11:48:59.782	9:38.768
Hawaii	12:28:41.494	12:32:42.412	4:00.918
Pretoria	13:16:32.296	13:25:55.831	9:23.535

Table 6-2. Communications Void Intervals

Void Begins - Time from Liftoff (hr:min:sec)	Void Ends - Time from Liftoff (hr:min:sec)	Void Duration (min:sec)
0:00:00.000	0:00:19.332	0:19.332
0:11:51.464	0:18:11.446	6:19.982
0:22:48.459	0:53:46.255	30:57.796
0:58:14.320	1:30:02.811	31:48.491
1:44:47.569	1:52:49.890	8:02.321
1:53:16.695	2:26:49.787	33:33.092
2:31:15.095	2:52:51.470	21:36.375
2:55:22.402	3:00:13.931	4:51.529
3:17:23.260	3:29:52.307	12:29.047
3:32:18.010	3:39:53.816	7:35.806
3:45:05.434	3:59:03.035	13:57.601
4:04:45.257	4:24:13.836	19:28.579
4:29:52.525	4:32:39.315	2:46.790
4:51:54.875	5:03:29.420	11:34.545
5:06:49.171	5:13:10.388	6:21.217
5:20:16.475	5:32:17.219	12:00.744
5:41:16.890	5:59:23.175	18:06.285
6:06:27.794	6:08:26.660	1:58.866
6:27:26.348	6:39:48.361	12:22.013
6:43:03.953	6:49:02.437	5:58.484
6:57:07.692	7:08:26.337	11:18.645
7:18:22.595	7:36:32.552	18:09.957
7:42:44.092	7:45:32.055	2:47.963
8:06:16.884	8:13:07.508	6:50.624
8:34:11.435	8:46:11.636	12:00.201
8:54:12.567	8:59:58.421	5:45.854
9:05:24.385	9:13:55.813	8:31.428
9:18:28.917	9:22:53.326	4:24.409
9:42:37.024	9:51:06.807	8:29.783
9:57:46.241	10:02:02.787	4:16.546
10:11:38.407	10:36:20.887	24:42.480

Table 6-2. Communications Void Intervals (Continued)

Void Begins - Time from Liftoff (hr:min:sec)	Void Ends - Time from Liftoff (hr:min:sec)	Void Duration (min:sec)
10:42:33.092	10:52:35.449	10:02.357
10:54:20.597	11:00:03.130	5:42.533
11:03:56.334	11:04:57.811	1:01.477
11:07:02.201	11:39:21.014	32:18.813
11:48:59.782	12:28:41.494	19:41.712
12:32:42.412	13:16:32.296	43:49.884
13:25:55.831	14:00:00.000	34:04.169
	Total Void Time	512:07.729
	Percent of Mission	61.44

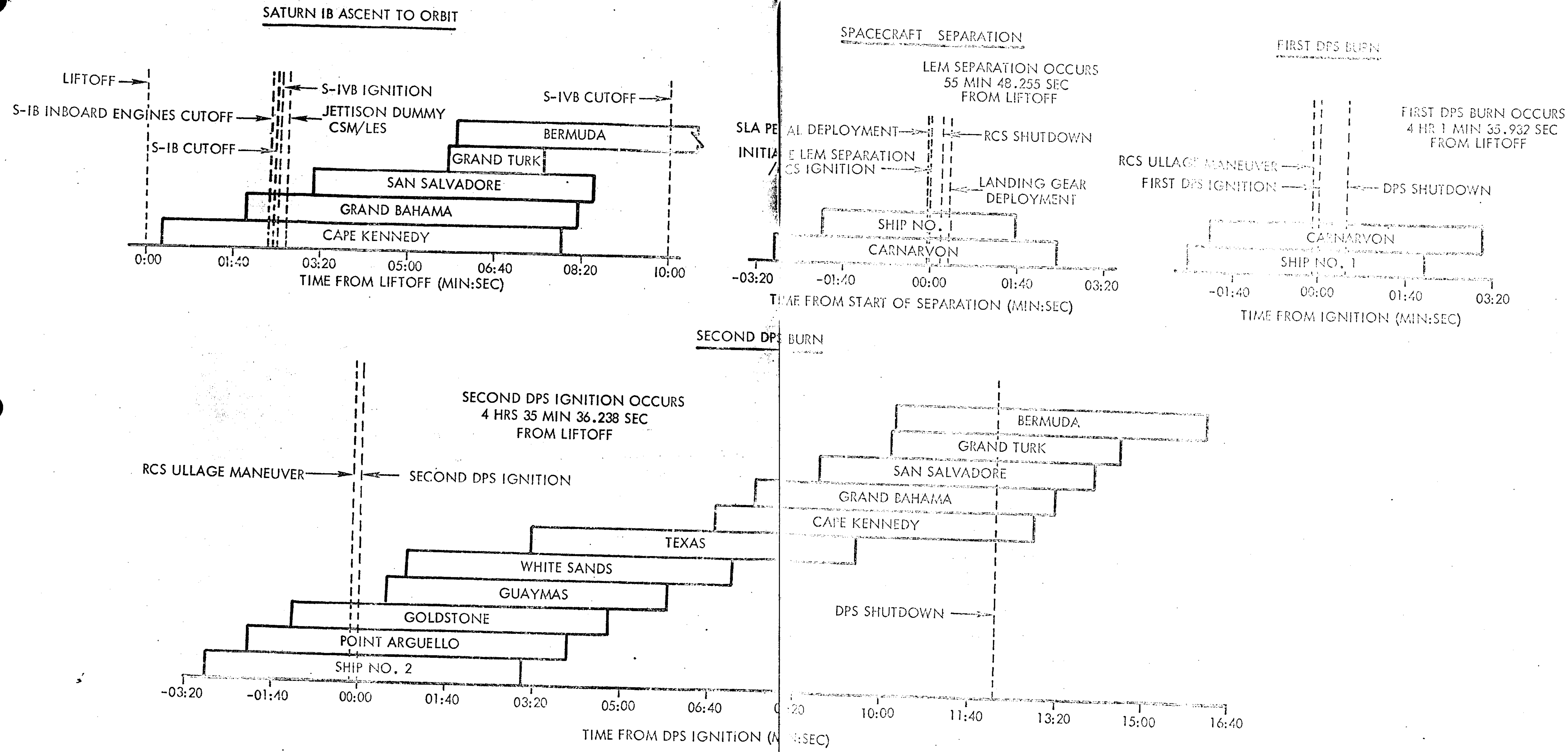


Figure 6-1. MSFN Tracking Summary

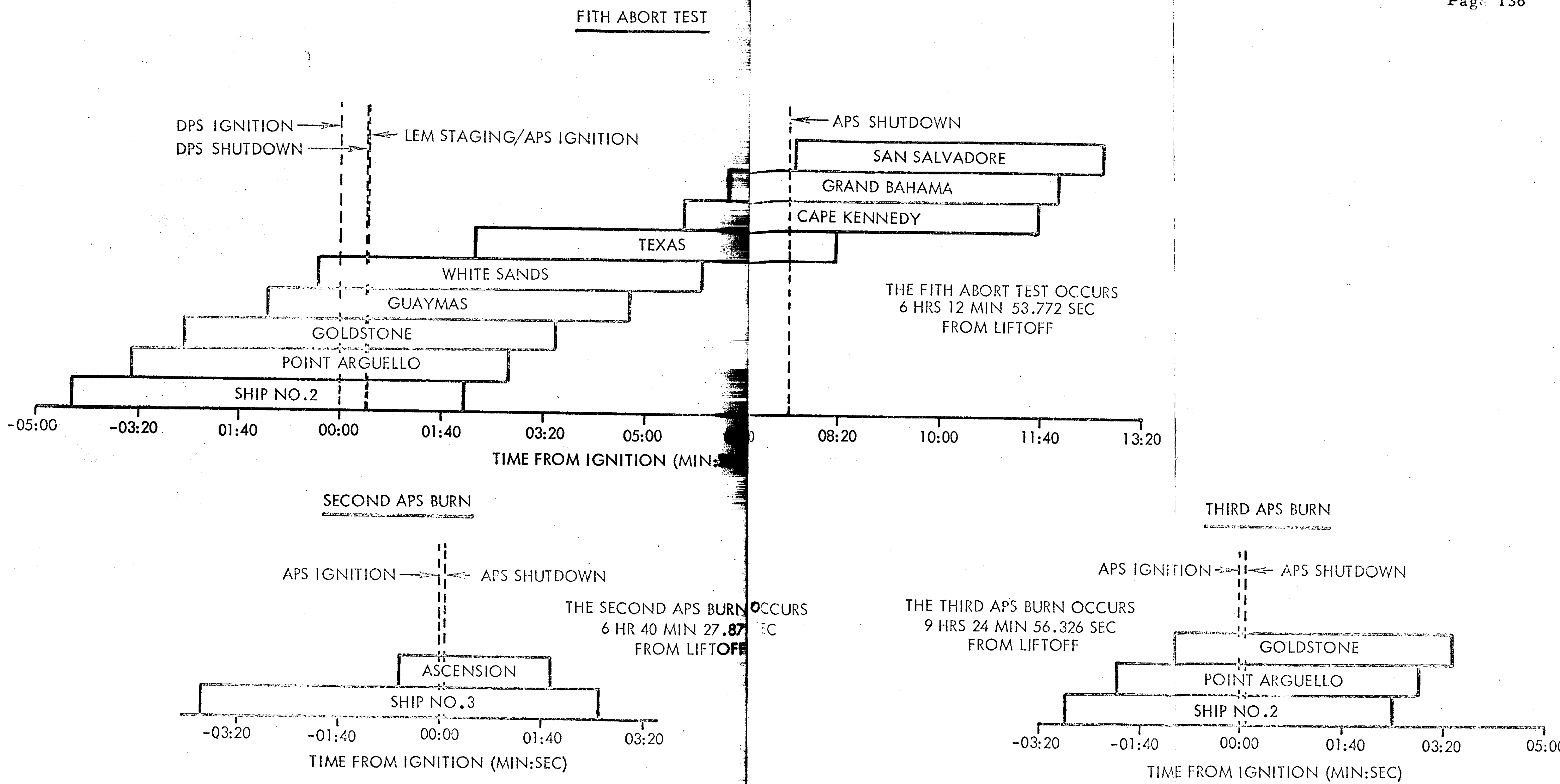


Figure 6-1. MSFN Tracking Summary (Continue

7. SUMMARY OF TECHNICAL ACHIEVEMENT

This report contains no innovations or improvements involving new technology, approaches, methods, or patentable ideas as defined in the contract's "New Technology and Property Rights in Inventions" clause.

APPENDIX

OPEN-LOOP MANEUVER LOGIC

The purpose of this appendix is to indicate the open-loop type logic used to simulate the spacecraft attitude change maneuvers in inertial space. This logic is similar to that expected to be used by the Apollo spacecraft. The reorientation will consist of a roll maneuver followed by a pitch or yaw maneuver and, if necessary, another roll maneuver. The magnitude and direction of the maneuvers are based upon Euler angles measured from the current attitude orientation to the desired attitude orientation.

Figure(A-1) shows the Euler angle transformation required to change from one inertial attitude to another. These Euler angles are computed using the knowledge of the unit vectors which describe current and desired orientation of the spacecraft roll, yaw, and pitch axes. The components of these unit vectors are measured in the Greenwich inertial coordinate system at the time of launch. Also calculated is the time required to perform the maneuver using the given spacecraft rotational rates.

The Euler angles are defined as follows:

ϕ = the azimuth angle measured in the plane formed by the Y and Z body axes measured from the +Z body axis to the vector $\vec{N}$ in the direction of the -Y body axis.

θ = the polar angle measured from the initial roll axis (X_o) to the final roll axis (X_f).

ψ = the azimuth angle measured in the new plane formed by the Y and Z body axes after the ϕ and θ rotations and is measured from $\vec{N}$ to the final Z body axis (Z_f).

The logic uses the Euler angles to compute the maneuver angles, $\alpha_{roll(1)}$, α_{yaw}, α_{pitch}, and $\alpha_{roll(2)}$. The first maneuver is a roll to the closest pitch or yaw axis ($|\alpha_{roll(1)}| \leq 45$ degrees). The second maneuver is a pitch or yaw of $\pm\theta$ degrees. The third maneuver, $\alpha_{roll(2)}$, is the final roll and is dependent on the first two maneuvers.

The maneuver angles are defined as follows:

$\alpha_{roll(1)}$ = the first roll the spacecraft has to perform to reorient its attitude.

$\left\{ \begin{matrix} \alpha_{pitch} \\ \text{or} \\ \alpha_{yaw} \end{matrix} \right\}$ = the second maneuver the spacecraft has to perform to reorient its attitude (by definition one of the two angles is always zero).

$\alpha_{roll(2)}$ = the third maneuver (second roll) the spacecraft has to perform to reorient its attitude.

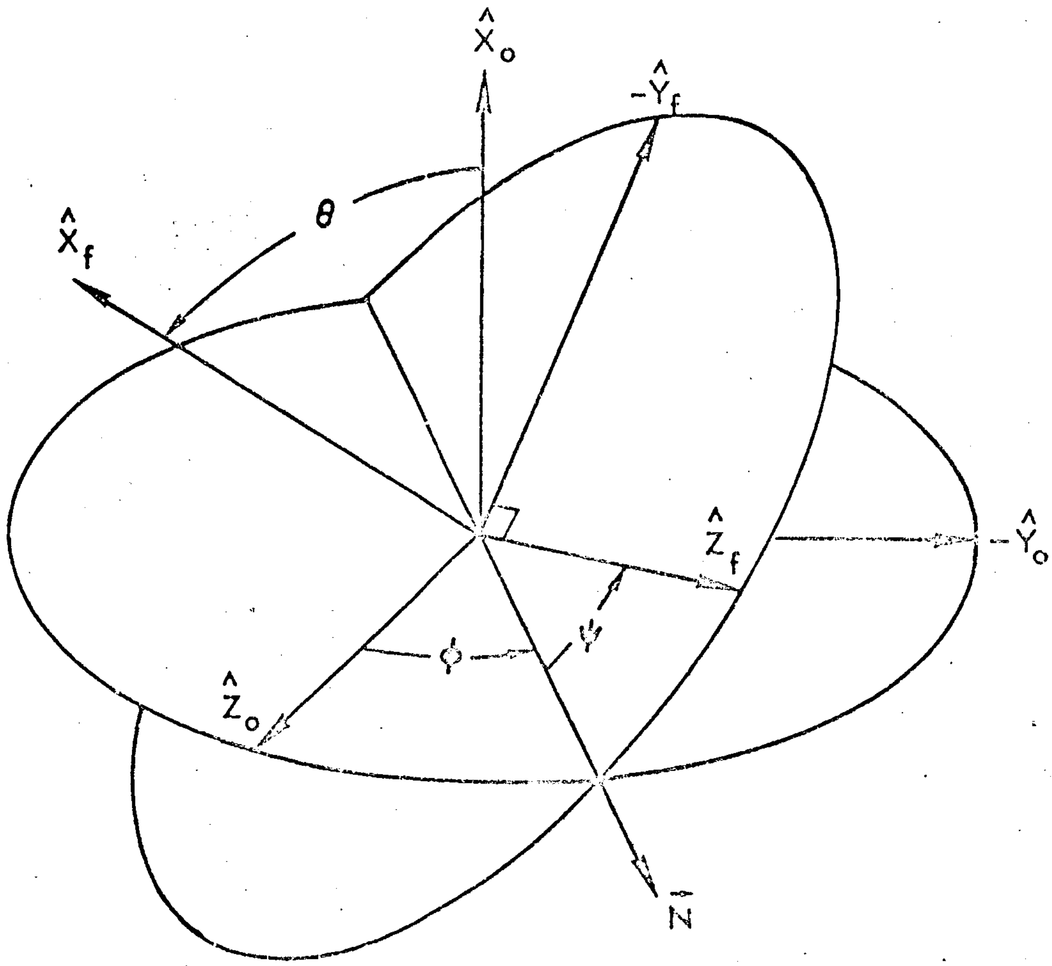


Figure A-1. Euler Angle Transformation

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ABBREVIATIONS

APS	Ascent Propulsion System
CSM	Command and Service Module
DPS	Descent Propulsion System
ECS	Environmental Control System
EPS	Electrical Power System
EST	Eastern Standard Time
ETR	Eastern Test Range
FITH	Fire-In-The-Hole
GMT	Greenwich Mean Time
LEM	Lunar Excursion Module
LES	Launch Escape System
LMP	LEM Mission Programmer
MSC	Manned Spacecraft Center
MSFC	Marshall Space Flight Center
MSFN	Manned Space Flight Net
RCS	Reaction Control System
SLA	Spacecraft LEM Adapter
deg	degrees
er	earth equatorial radius
ft	feet
hr	hours
km	kilometers
lb	pounds
min	minutes
n mi	nautical miles
rad	radians
sec	seconds