[redacted]

UNCLASSIFIED

Classification changed to
UNCLASSIFIED by authority of
SCG-11, Rev. 1, 1/1/66, and
SCG-6, 8/27/64, as amended
Initials: [illegible] Date: 3/22/69
letter from R. L. Wagner
dated 3-11-69

STL'S BELLCOMM SUBCONTRACT FOR APOLLO STUDIES (U)

(NASA-CR-127534) STL'S BELLCOMM SUBCONTRACT FOR APOLLO STUDIES (Space Technology Labs., Inc.) 61 p

N79-71728

Unclas
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JUL 1972
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STL'S BELLCOMM SUBCONTRACT FOR APOLLO STUDIES (U)

Classification changed to UNCLASSIFIED by authority of SCG-11, Rev. 1, 1/1/66, and SCG-6, 8/27/64, as amended
Initials: JB Date: 3 22 69
letter dated 3-11-69 from R. L. Cooper

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8408-6031-TC-000
Page 1 of 60

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UNCLASSIFIED

CONTRACT TASK SUMMARY

- NINE MONTHS EFFORT - MISSION ANALYSIS & THREE LOR REF. TRAJECTORIES
- MISSION ANALYSES
  - POWERED FLIGHT OPTIMIZATION
    - S-V ASCENT TRAJECTORY
    - SM HYPERBOLIC DEBOOST
    - LEM ASCENT FROM MOON WITH PLANE CHANGE
    - SM TRANSEARTH INJECTION
  - LAUNCH WINDOW ANALYSIS
    - FREE RETURN GEOMETRY REQUIREMENTS
    - CONSTRAINED RETURN TO FIXED LANDING SITE
    - S-V AND SM VELOCITY REQUIREMENTS
    - EVENTS TIMING
    - LAUNCH WINDOW TRADEOFFS
  - LEM DESCENT TRAJECTORY SHAPING
  - RE-ENTRY STUDIES
  - RANGE SAFETY
  - SPACECRAFT VISIBILITY FROM MERCURY, AMR AND DSIF STATIONS
  - LUNAR ORBIT STABILITY

CONTRACT TASK SUMMARY (CONT'D)

- LUNAR ORBIT RENDEZVOUS REF. TRAJECTORY DATA PACKAGE (LOR RTDP)
  - MISSION PROFILE
  - SEQUENCE OF EVENTS
  - CONFIGURATION DATA AND TRAJECTORY CONSTRAINTS
  - REFERENCE TRAJECTORY DATA REDUCTION
  - TRAJECTORY RELATED INFORMATION
  - MISSION ANALYSIS SUMMARY
- THE INTEGRATED APOLLO REFERENCE TRAJECTORIES
  - COMPUTER PROGRAMS
    - SNS-TARGETING AND INTEGRATION OF TRANSLUNAR & TRANSEARTH TRAJ'S
    - MUNS-TARGETING AND INTEGRATION OF LUNAR OPERATIONS
  - ANALYTICALLY CONTINUOUS
  - BASED ON MINIMAL SET OF APOLLO SYSTEM DATA
    - COMPLETELY OPEN LOOP
    - SIMPLE PROPULSION MODELS
    - ALL POWERED FLIGHT SEGMENTS FULLY SIMULATED
    - NO ATTITUDE CONTROL SIMULATION
  - ALL SPECIFIED CONSTRAINTS SATISFIED

CONTRACT TASK SUMMARY (CONT'D)

- THE INTEGRATED APOLLO REFERENCE TRAJECTORIES
  - YAW STEERING EMPLOYED IN
    - SM DEBOOST
    - LEM ASCENT
    - SM RETURN
- CONTRACT DELIVERABLE ITEM REPORTS
  - LOR RTDP
  - LOR RTDP SIMULATION TECHNIQUES
  - MIDCOURSE SENSITIVITIES AND GUIDANCE ANALYSIS COEFFICIENTS
  - TRAJECTORY SENSITIVITY COEFFICIENTS
  - LAUNCH WINDOW AND OPPORTUNITY ANALYSIS
  - LEM ASCENT PLANE CHANGE AND SM MANEUVER ANALYSIS
  - LUNAR ORBIT STABILITY
  - MINUTES OF QUARTERLY BRIEFINGS
- FUTURE WORK
  - MISSION PARAMETER STUDY
  - PRELIMINARY ABORT ANALYSIS
  - ORBIT DETERMINATION STUDY

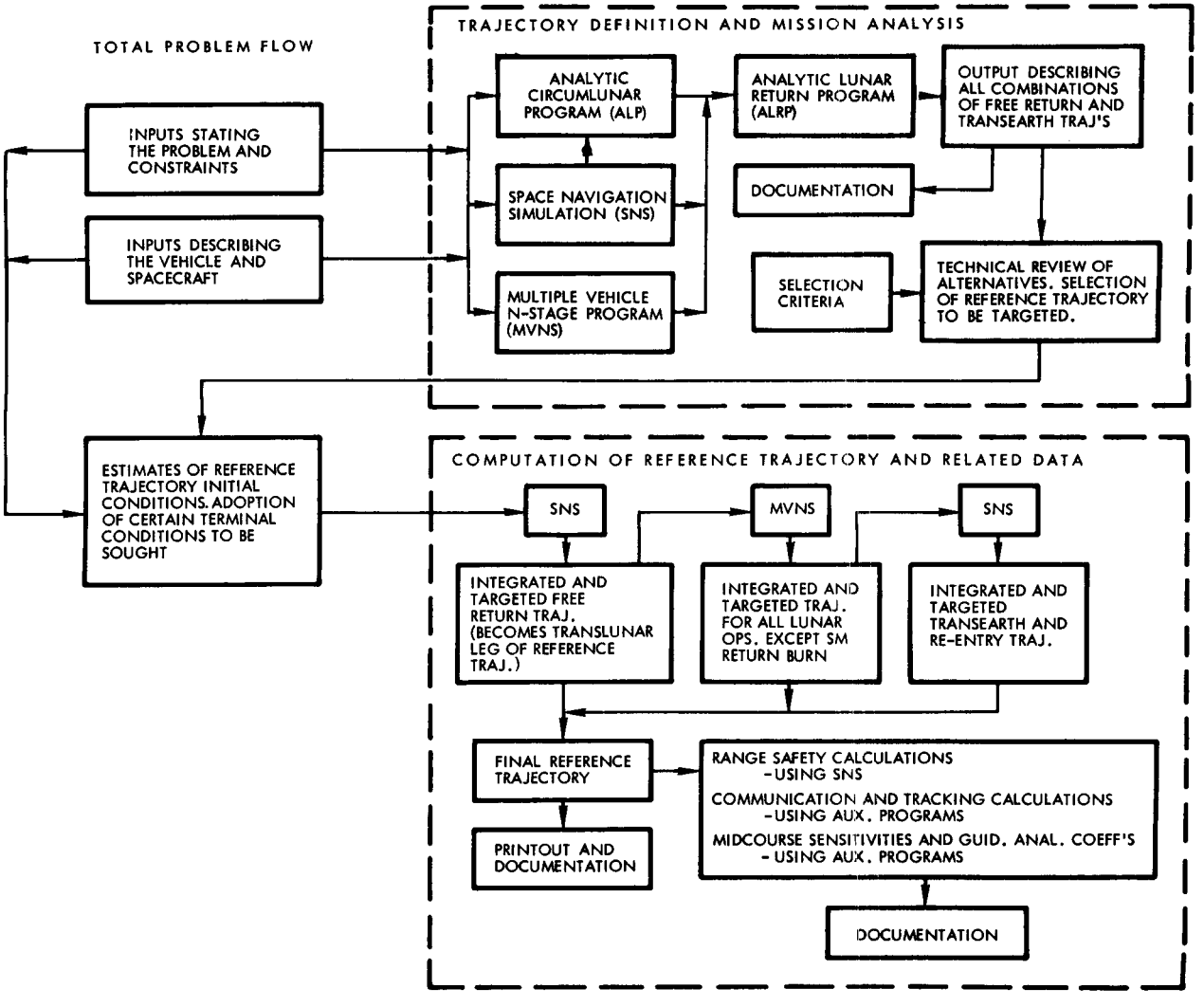
MAJOR TRAJECTORY CONSTRAINTS AND GROUND RULES

- LAUNCH ON JANUARY 28, 1963 – LAUNCH AZIMUTH ≤ 90 DEG.
- 100 N. MI. EARTH PARKING ORBIT – DURATION 1.5 TO 2.5 REVOLUTIONS
- FREE RETURN TRANSLUNAR TRAJECTORY WITHOUT MIDCOURSE
- PERICYNTHION ALTITUDE = 80 N. MI.
- LUNAR CIRCULAR ORBIT ALTITUDE = 80 N. MI.
- EQUIPERIOD LEM ORBIT – 50,000 FT. PERICYNTHION ALTITUDE
- LEM DESCENT TO LANDING SITE IN-PLANE
- VARIOUS LEM DESCENT TRAJECTORY CONSTRAINTS

MAJOR TRAJECTORY CONSTRAINTS & GROUND RULES (CONT'D)

- LANDING SITE AT LANSBERG CRATER (3°S, 28°W)
- LEM STAY TIME 4 TO 24 HOURS
- TWO BURN LEM ASCENT AND RENDEZVOUS
- RETURN TRAJECTORY WITHOUT MIDCOURSE
- EARTH LANDING AT SAN ANTONIO, TEXAS OR WOOMERA, AUSTRALIA
- RE-ENTRY RANGE 1200 TO 5000 N. MI.
- STEERABLE RE-ENTRY - 10 g's MAX. DECELERATION
- TOTAL MISSION DURATION ≤ 8 DAYS

TOTAL PROBLEM FLOW



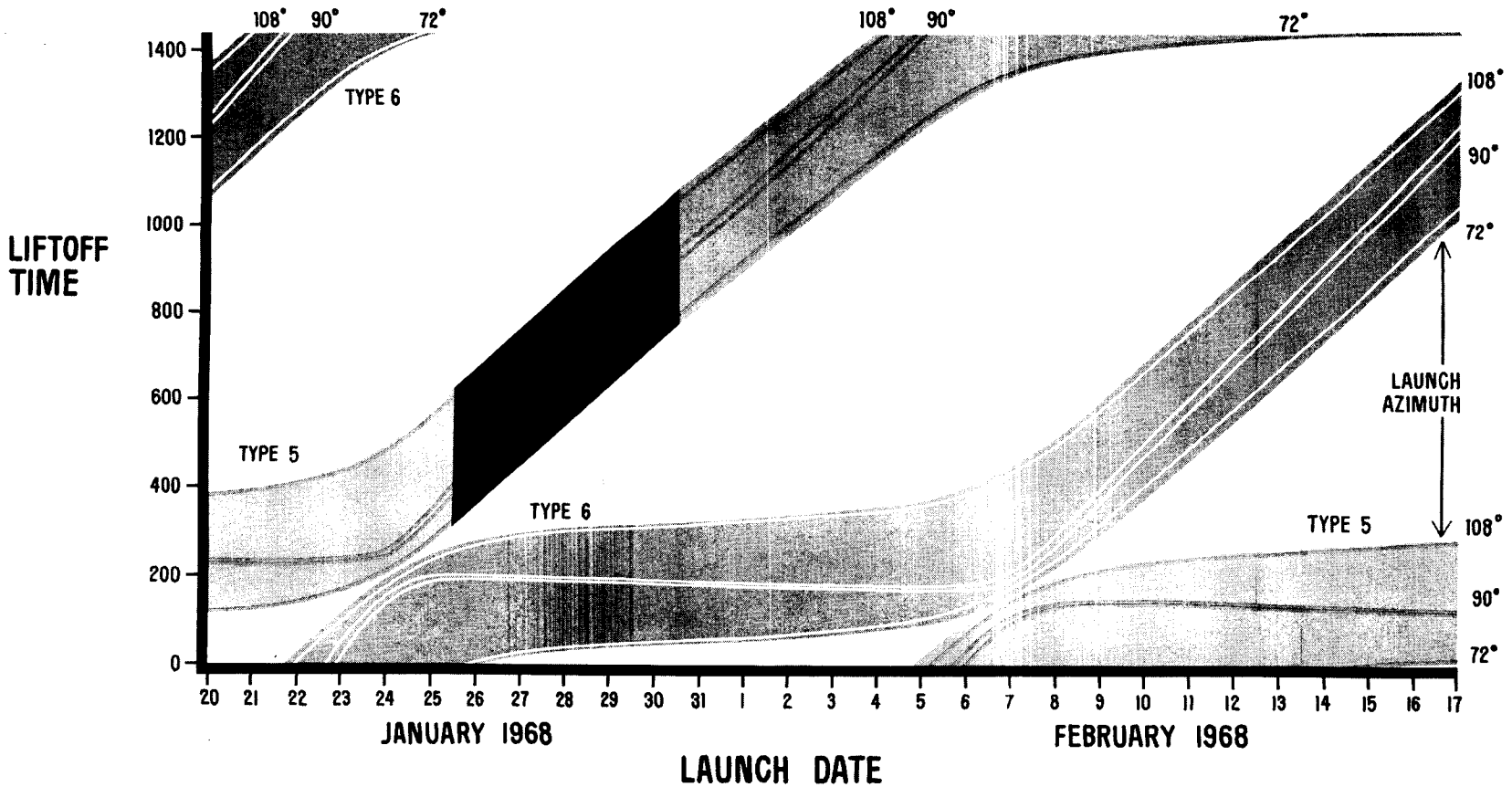
MISSION ANALYSIS - PROBLEMS CONSIDERED

- FREE CIRCUMLUNAR TRAJECTORIES
  - LAUNCH OPPORTUNITIES
  - TRIP TIMES & RETURN INCLINATIONS
  - LUNAR PHASE GEOMETRY - INCLINATION & NODE
  - GEOGRAPHIC RE-ENTRY POSITIONS

- CONSTRAINED LUNAR RETURN
  - DEBOOST VELOCITY TO ENTER A CORRECT ORBIT
  - VELOCITY PENALTY FOR EXCESSIVE STAY TIMES
  - LUNAR INJECTION VELOCITY TO RETURN TO SAN ANTONIO OR WOOMERA
  - POWERED FLIGHT OPTIMIZATIONS AT DEBOOST, LEM ASCENT & TRANSEARTH INJECTION

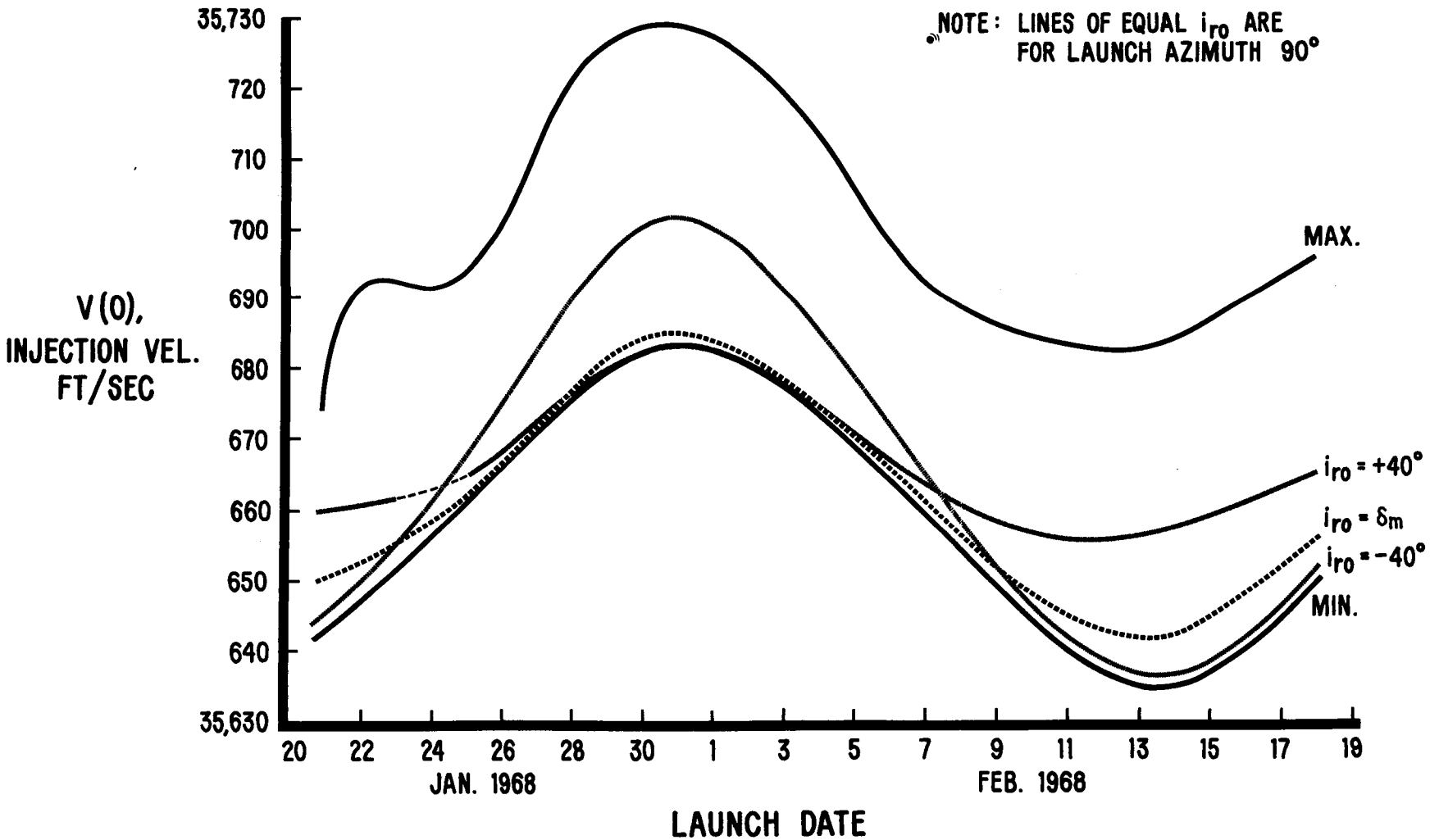
- RE-ENTRY

LAUNCH WINDOW FOR THE LUNAR MONTH



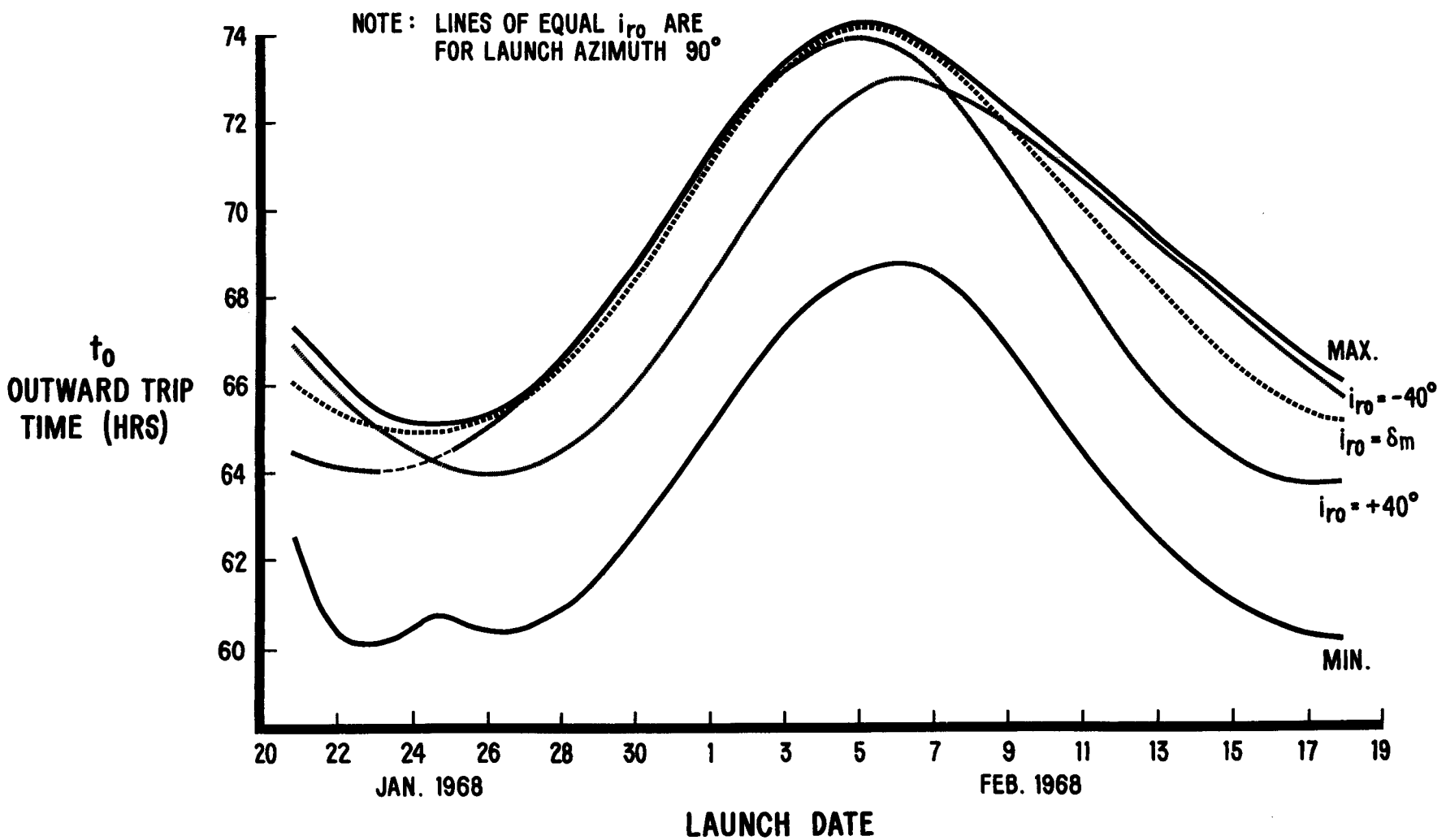
VARIATION IN INJECTION VELOCITY

TYPE 6 TRAJECTORIES



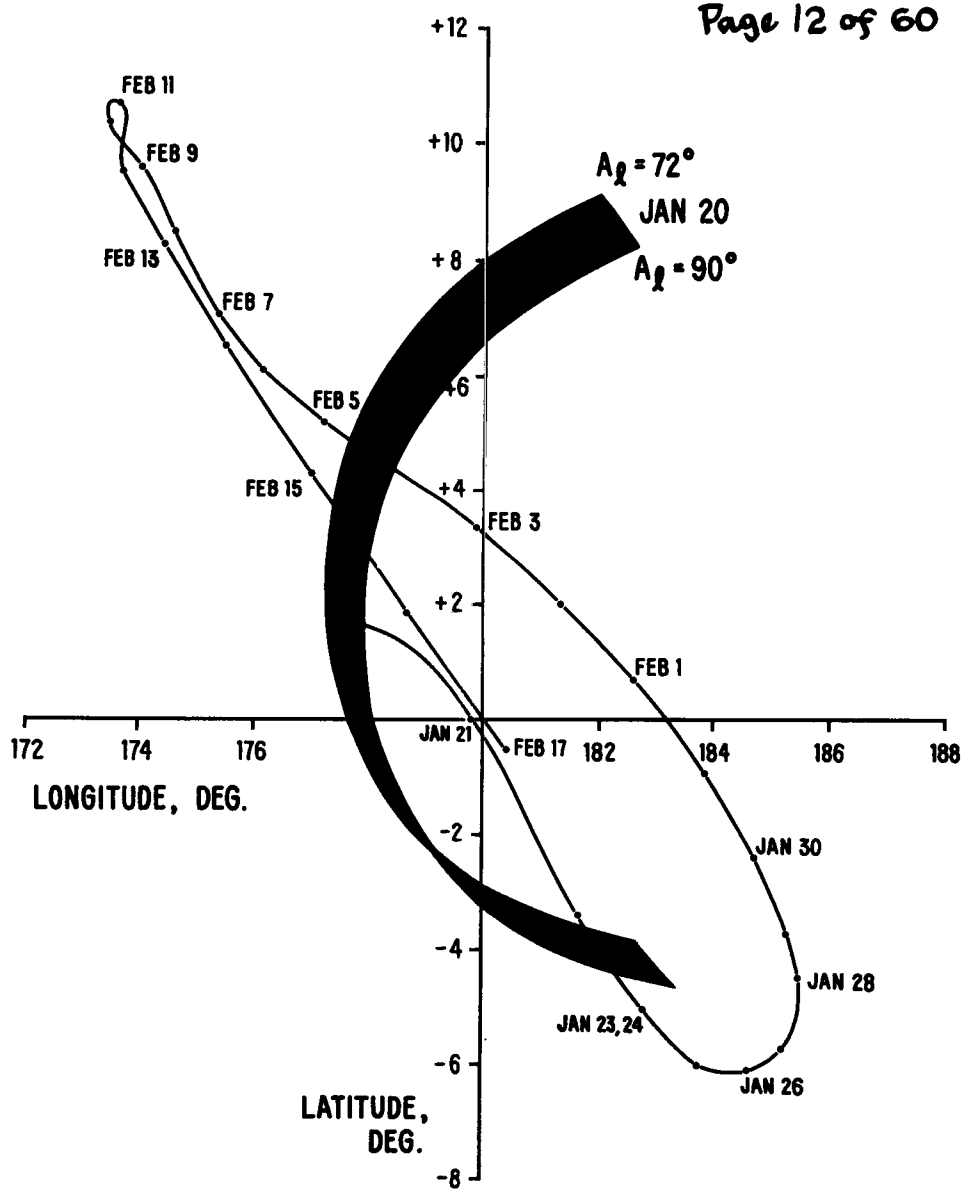
OUTWARD TRIP TIME VARIATION

TYPE 6 TRAJECTORIES



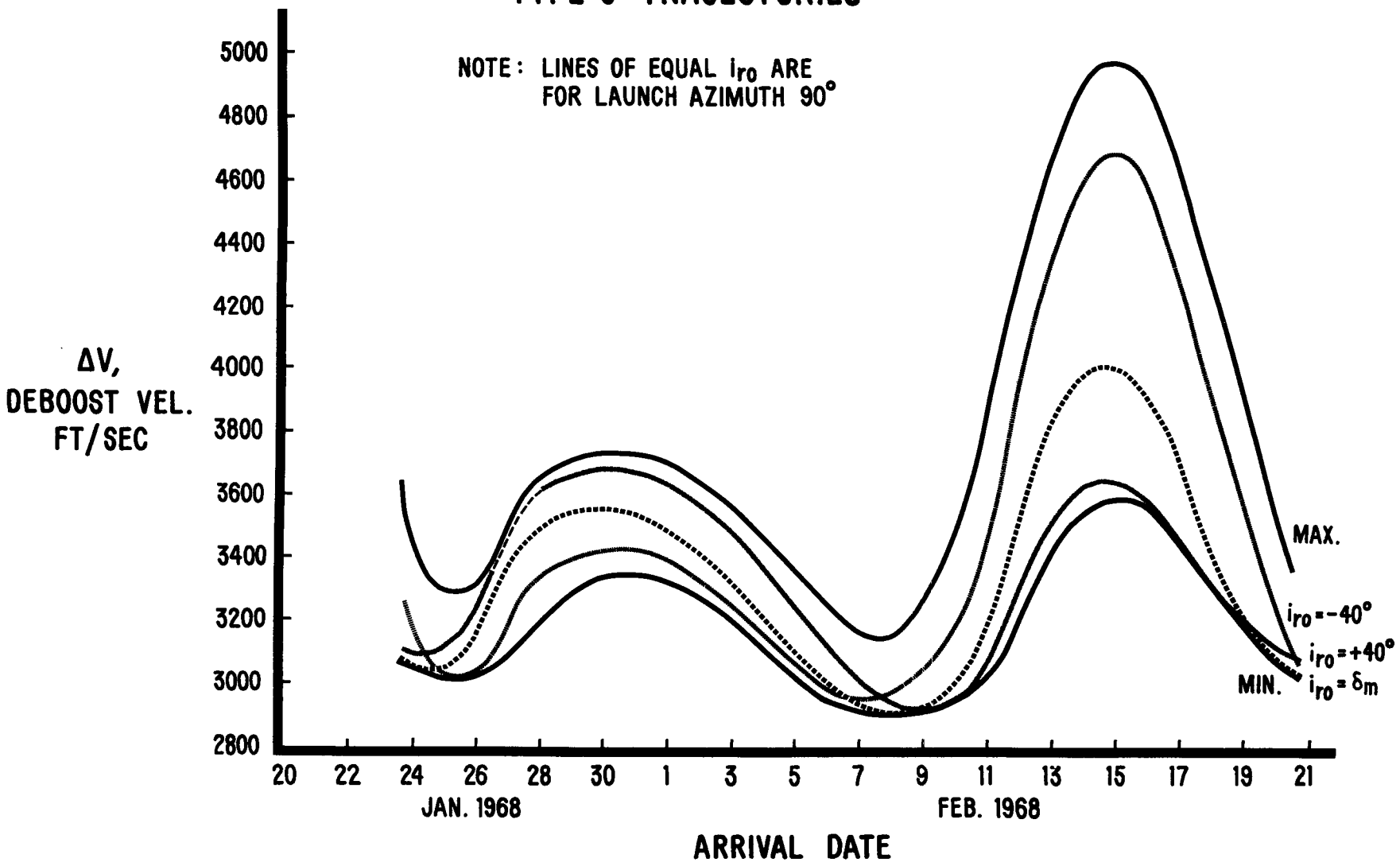
LOCUS OF PERICYNTHION POINTS

TYPE 6 TRAJECTORIES



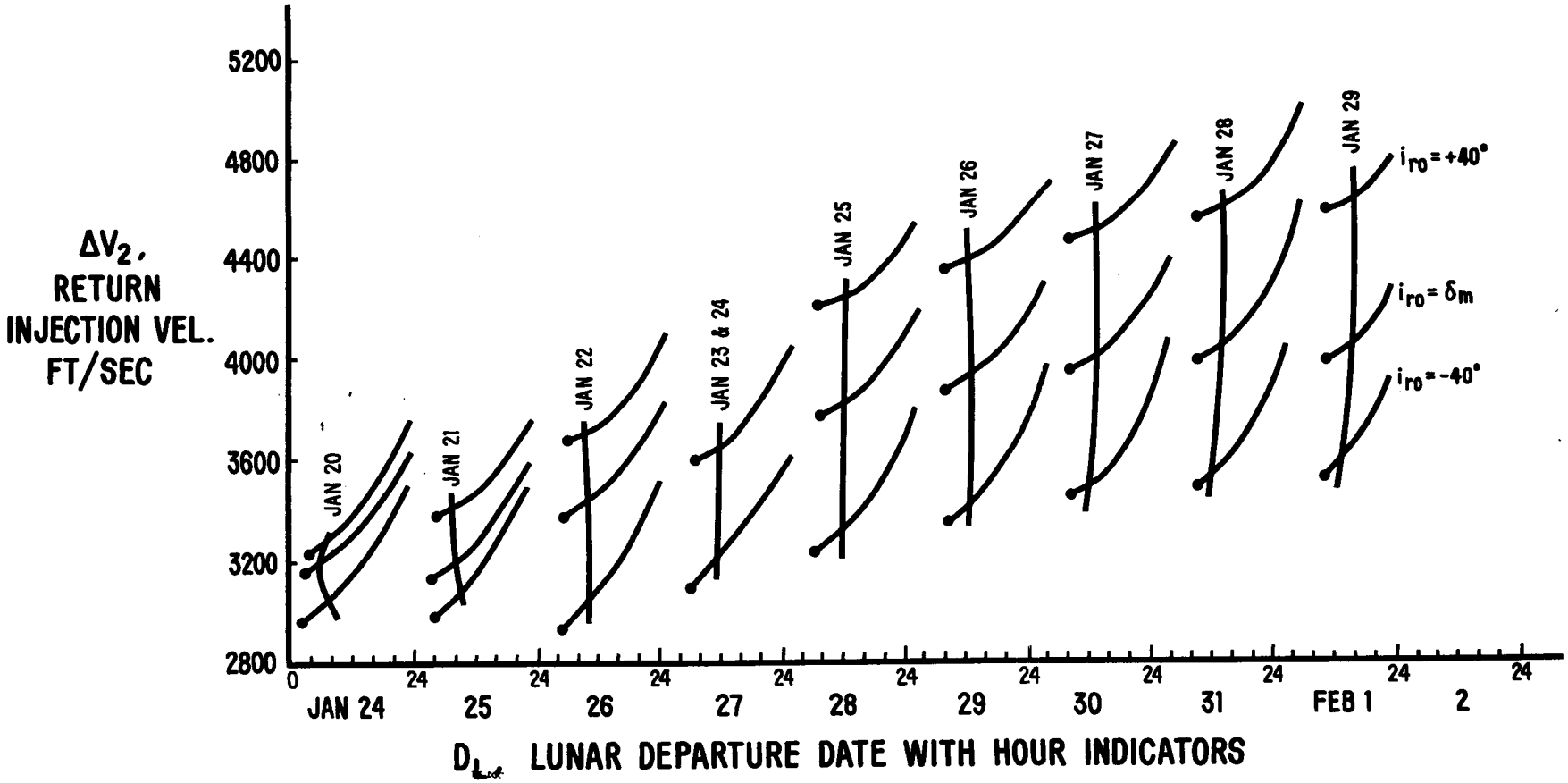
DEBOOST VELOCITY REQUIRED VS. ARRIVAL DATE

TYPE 6 TRAJECTORIES



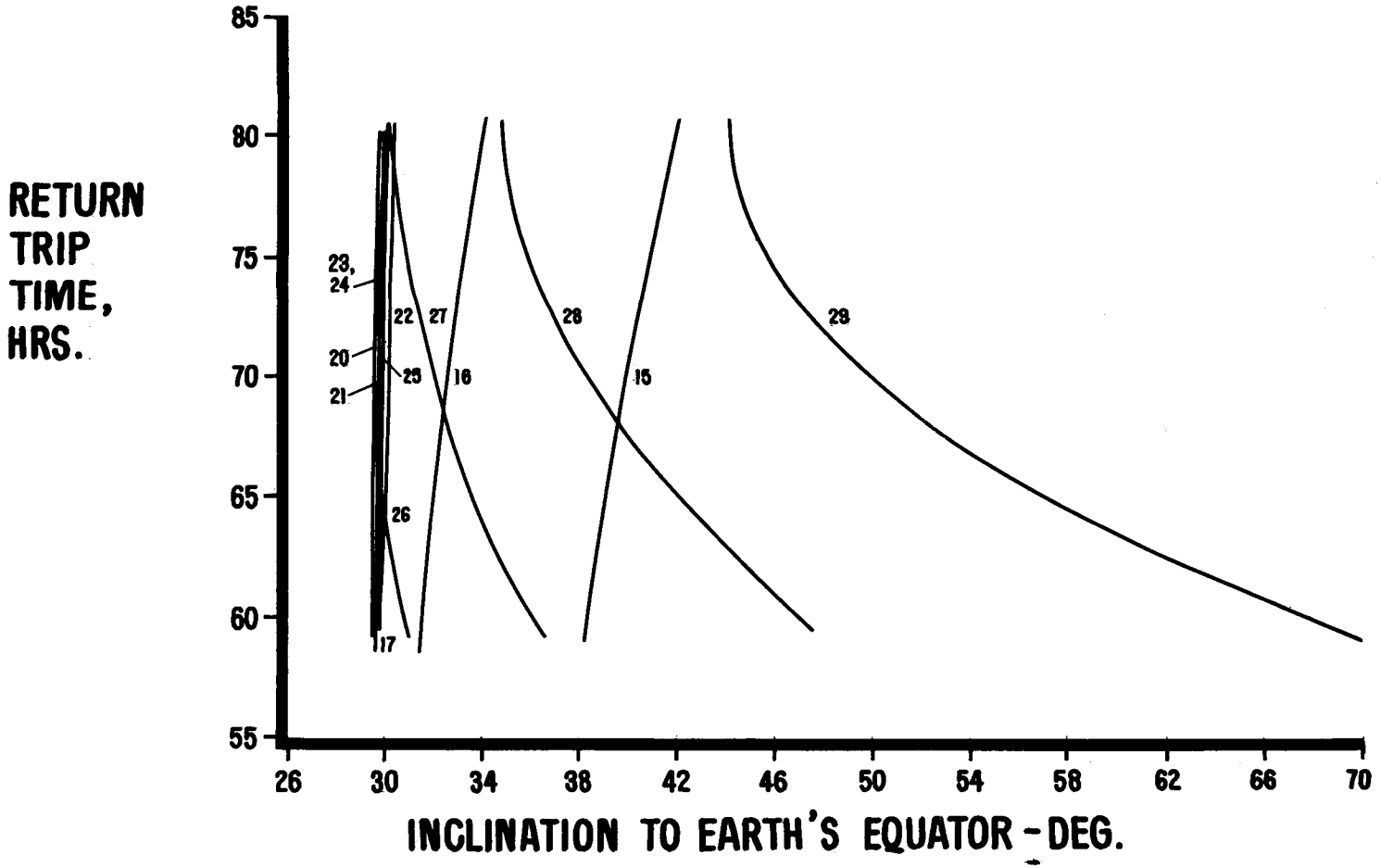
VELOCITY REQUIRED TO RETURN TO SAN ANTONIO FROM THE FIXED LUNAR ORBIT

RESULTING FROM A TYPE 6 OUTBOUND TRAJECTORY



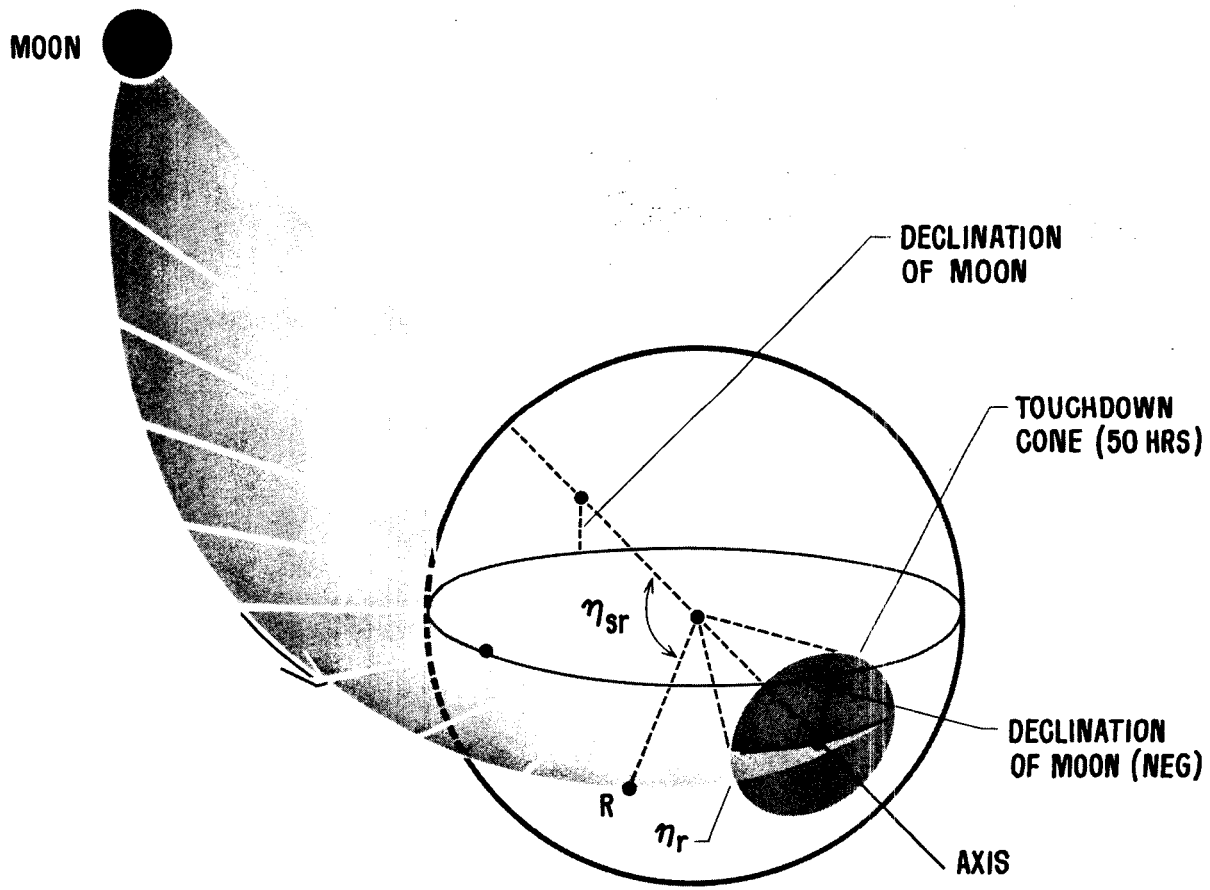
INCLINATION OF THE ORBIT TO THE EARTH'S EQUATOR

AS A FUNCTION OF TRIP TIME FOR TYPE 6 CASES RETURNING TO SAN ANTONIO



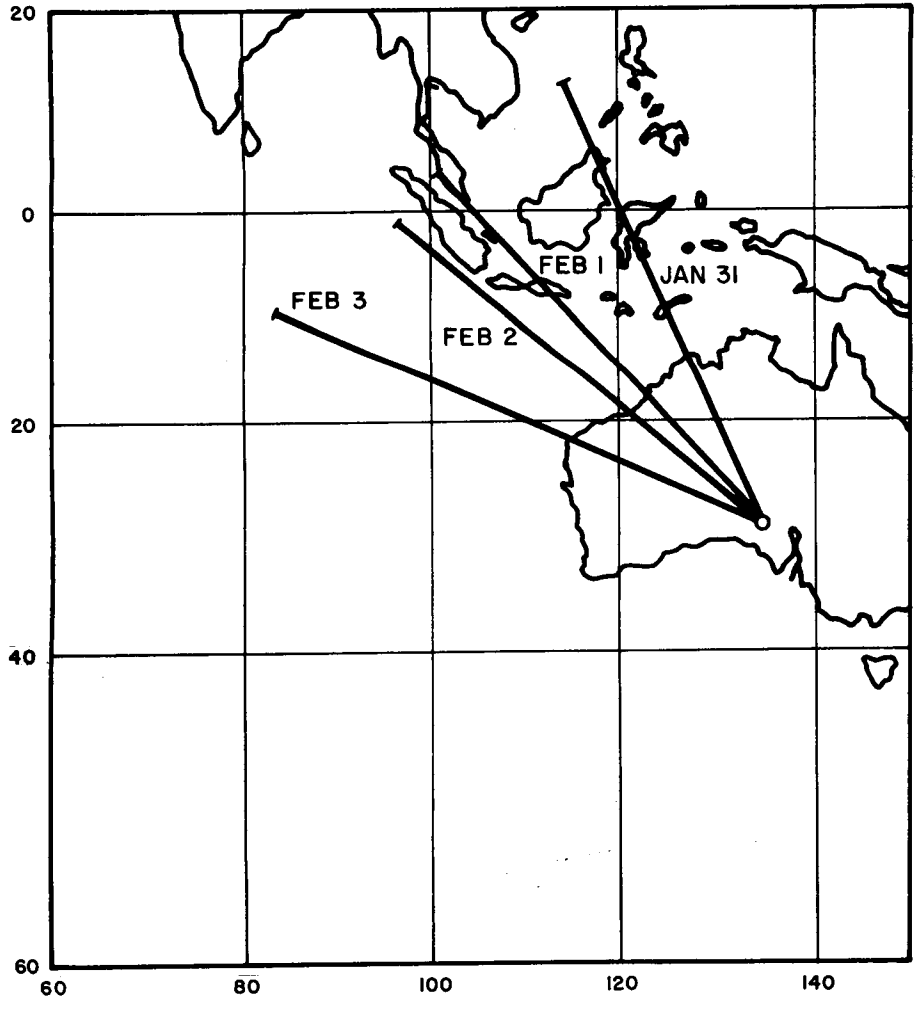
RESTRICTION IN TOUCHDOWN LATITUDE

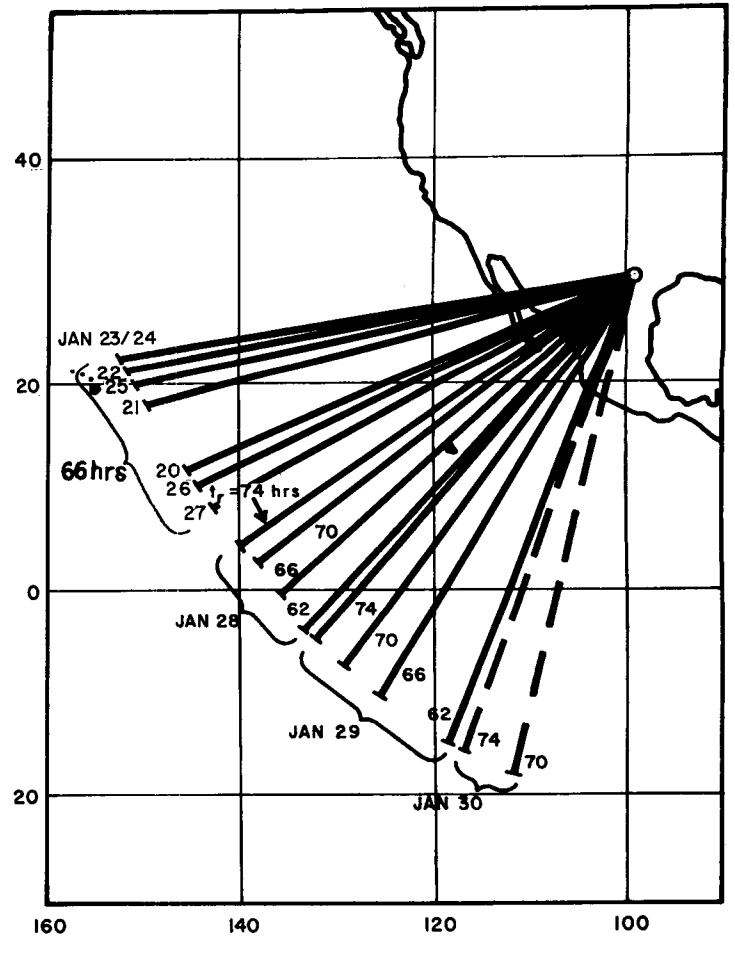
DUE TO THE DECLINATION OF THE MOON



(NON-ROTATING EARTH)

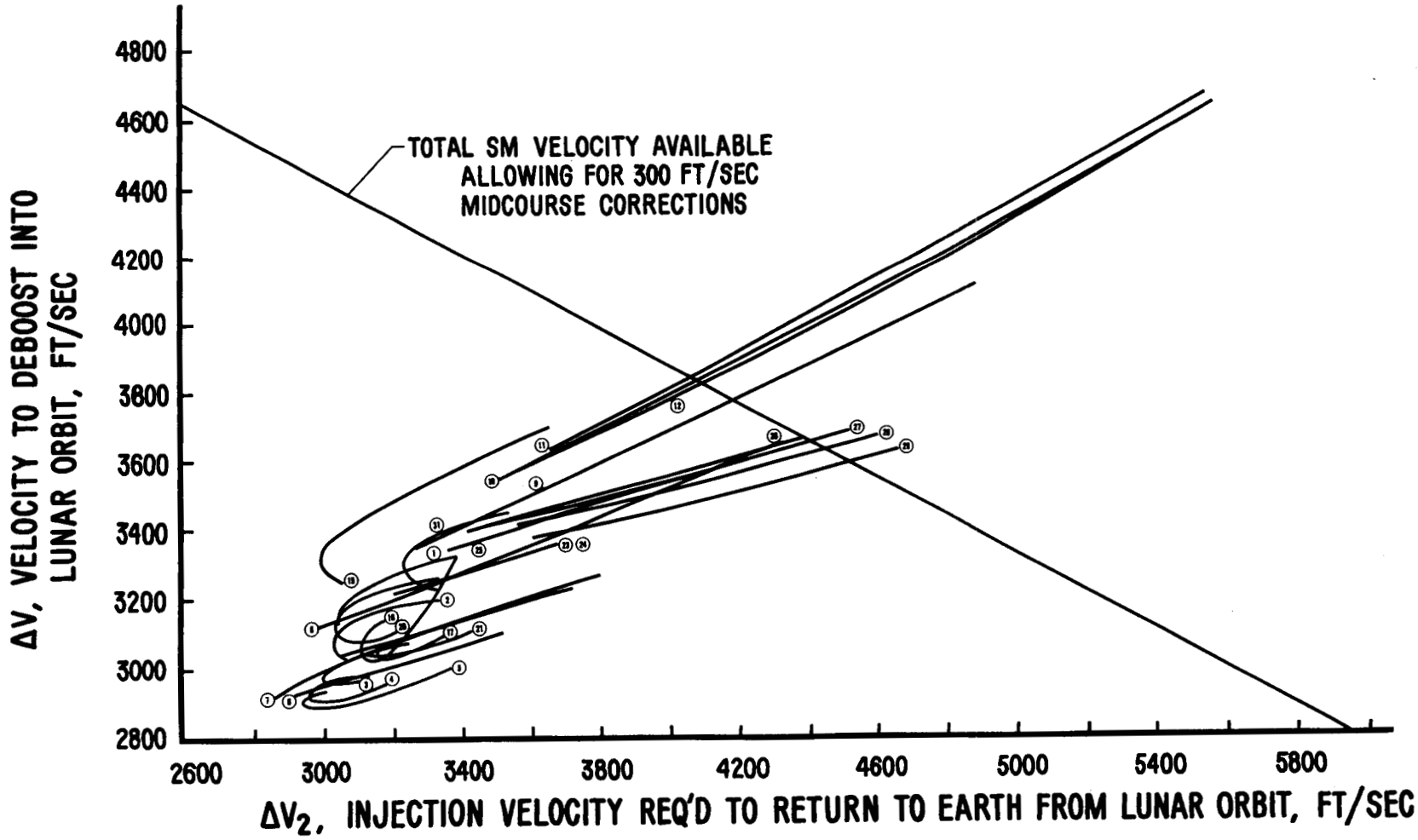
RETURN RE-ENTRY POINTS





MINIMUM TOTAL SERVICE MODULE VELOCITY

REQUIRED FOR TYPE 6 TRAJECTORIES DURING THE LUNAR MONTH



SPACECRAFT MANEUVER OPTIMIZ'N STUDIES

SERVICE MODULE MANEUVERS

- HYPERBOLIC DEBOOST
- TRANSEARTH INJECTION

LEM MANEUVERS

- LEM ASCENT TO RENDEZVOUS

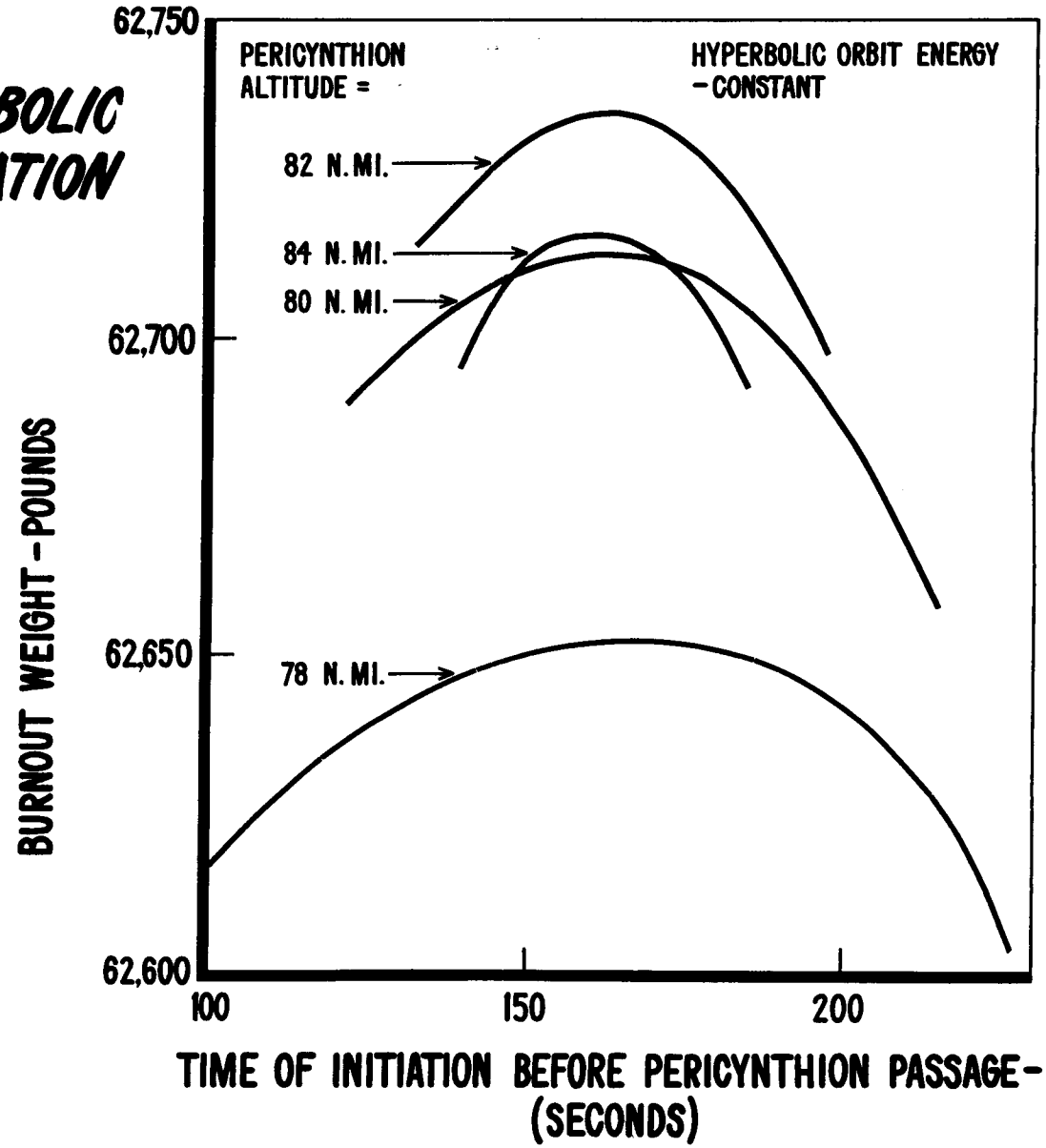
CO-PLANAR HYPERBOLIC DEBOOST OPTIMIZATION

CONTROL PARAMETERS

- INITIAL PITCH ATTITUDE
- PITCH RATE
- ENERGY AT CUT-OFF
- INITIATION TIME
- PERICYNTHION ALTITUDE

BURNOUT CONSTRAINTS

- ALTITUDE
- FLIGHT PATH ANGLE
- VELOCITY



PERICYNTHION ALTITUDE OPTIMIZATION

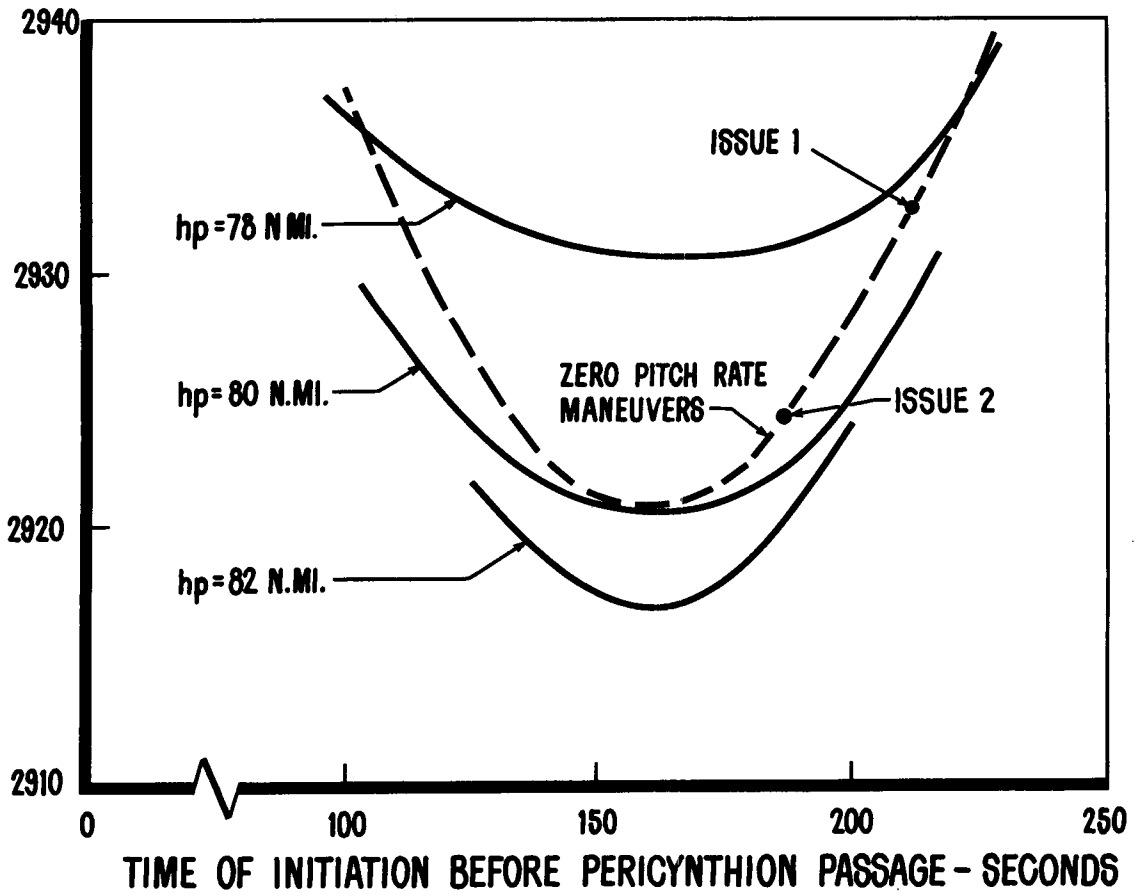
USING CONSTANT BODY ATTITUDE STEERING

CONTROL PARAMETERS

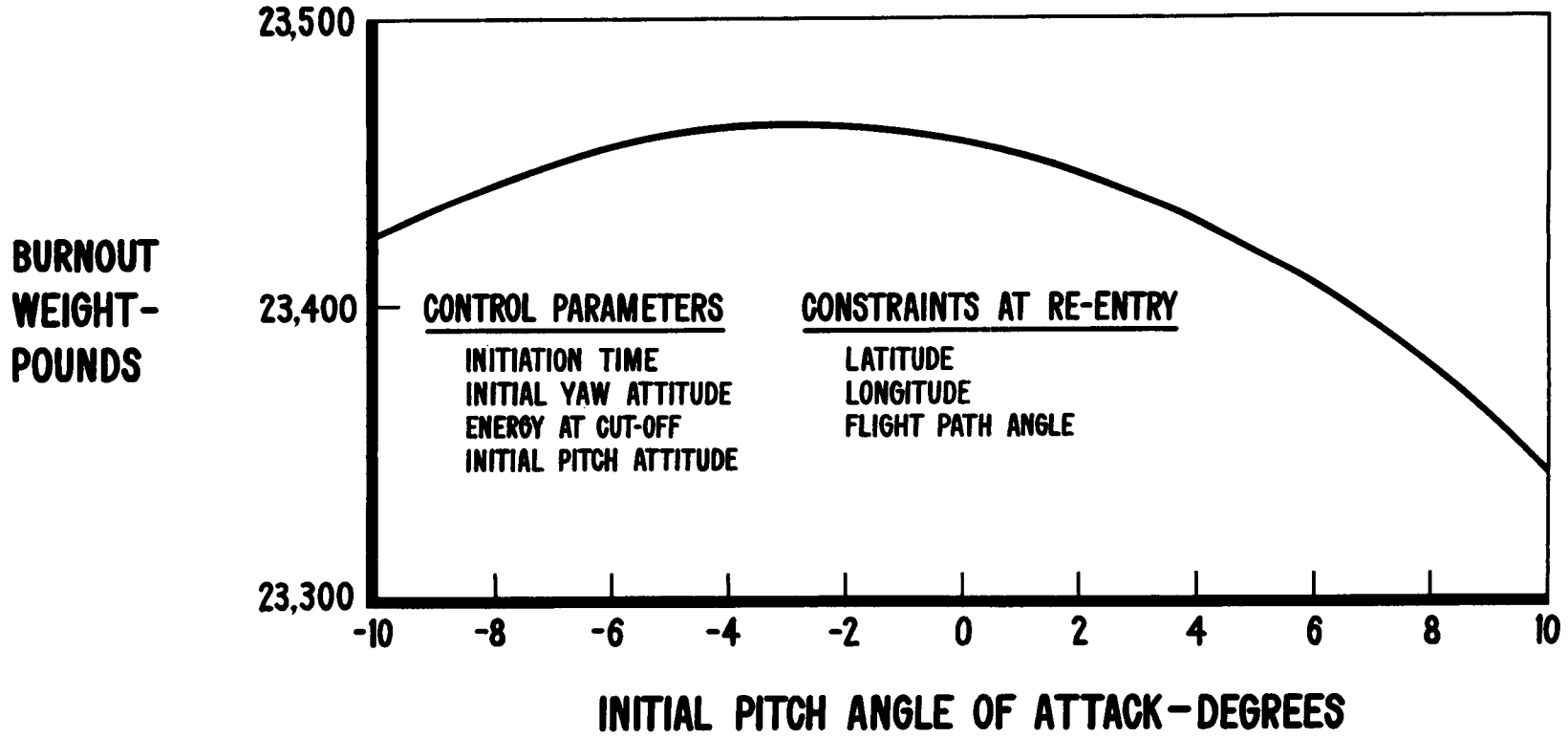
- INITIAL PITCH ATTITUDE
- ENERGY AT CUTOFF
- INITIATION TIME
- PERICYNTHION ALTITUDE

BURNOUT CONSTRAINTS

- ALTITUDE
- FLIGHT PATH ANGLE
- VELOCITY



TRANSEARTH INJECTION OPTIMIZATION
(ISSUE 2)



OPTIMIZATION OF LEM ASCENT WITH PLANE CHANGE

Ground Rules

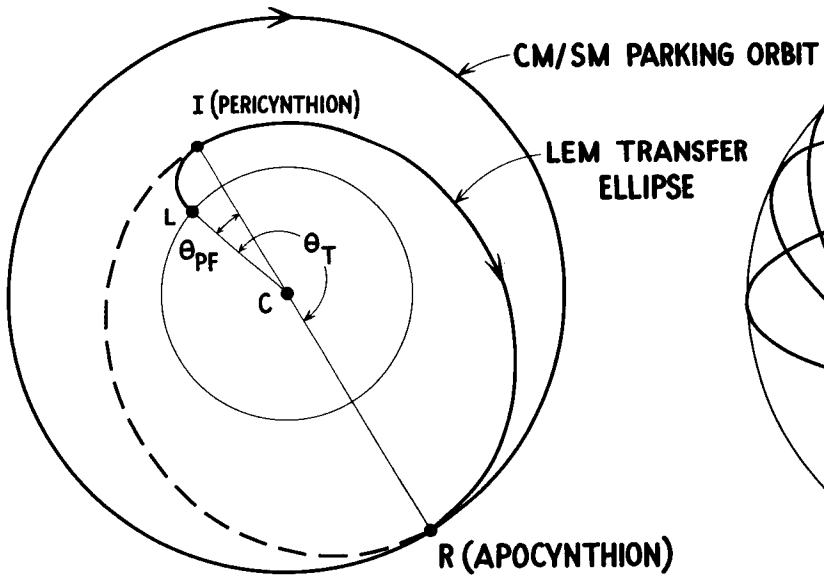
1. MANEUVER PERFORMED WITH TWO BURNS
2. PERICYNTHION ALTITUDE OF TRANSFER ORBIT ≥ 50,000 FT.

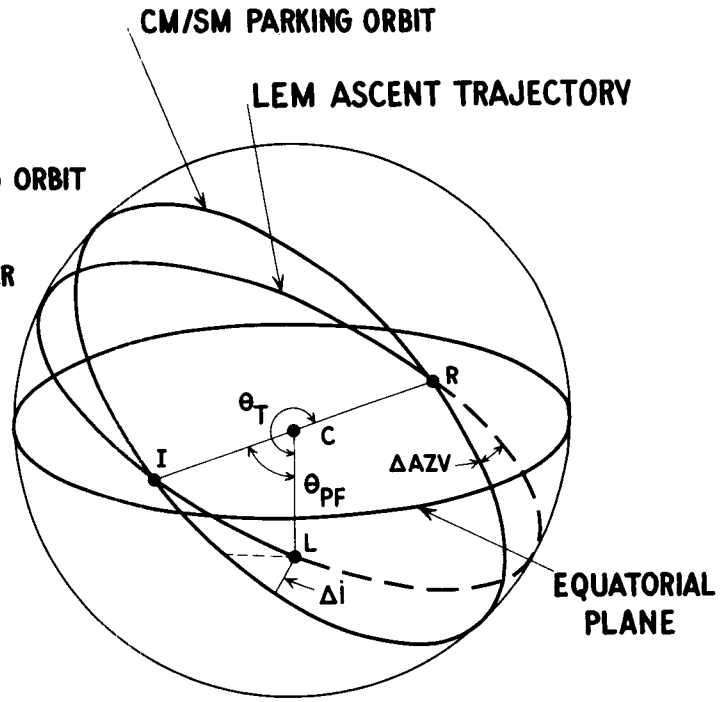
Types of Maneuvers

1. MINIMUM ENERGY TRANSFER- INJECTION AT PERICYNTHION
2. MINIMUM ENERGY TRANSFER- NON-PERICYNTHION INJECTION
3. HIGHER ENERGY TRANSFER- INJECTION AT PERICYNTHION

FIXED MANEUVER ANGLE ASCENTS

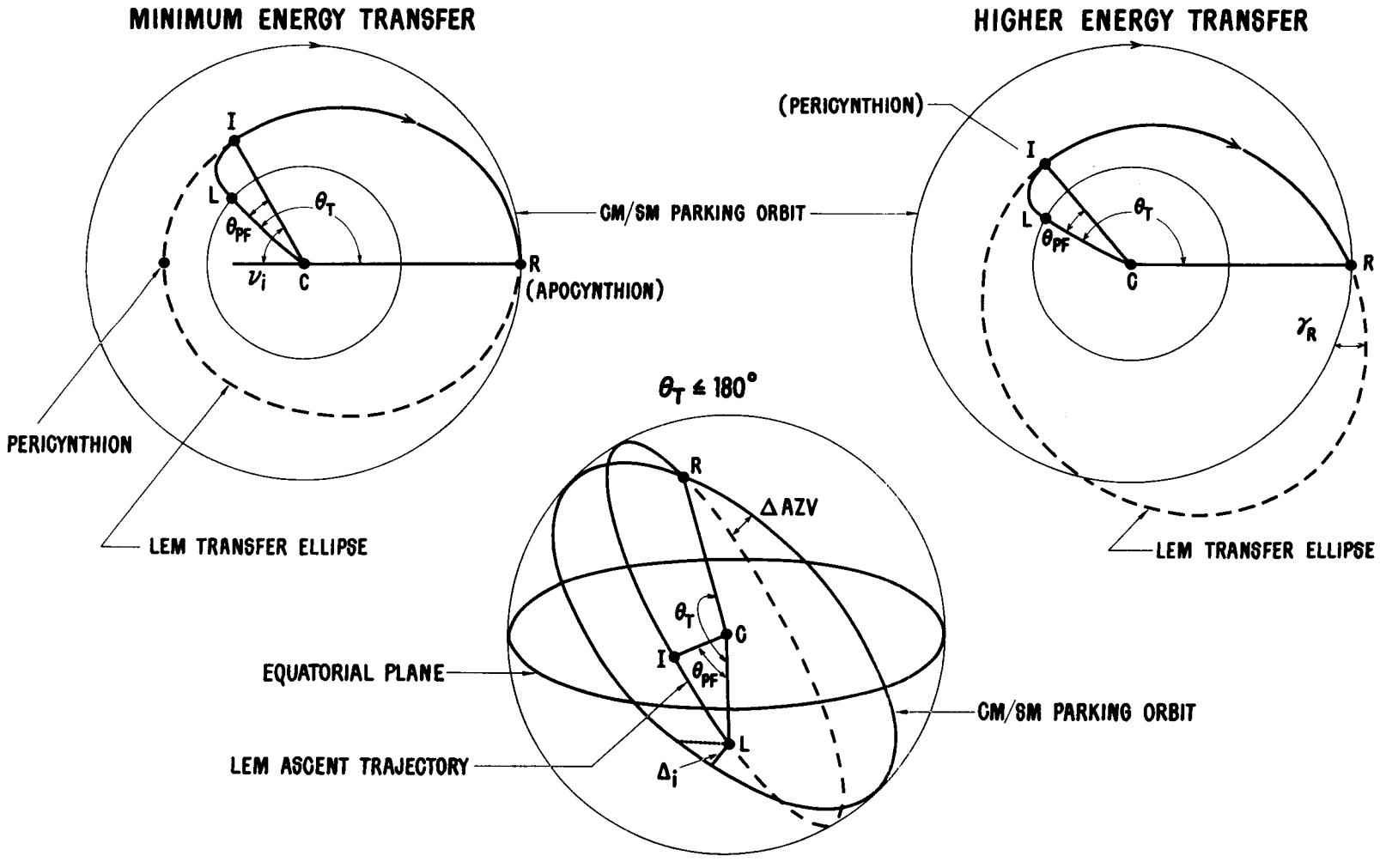
(MINIMUM ENERGY TRANSFER - INJECTION AT PERICYNTHION)



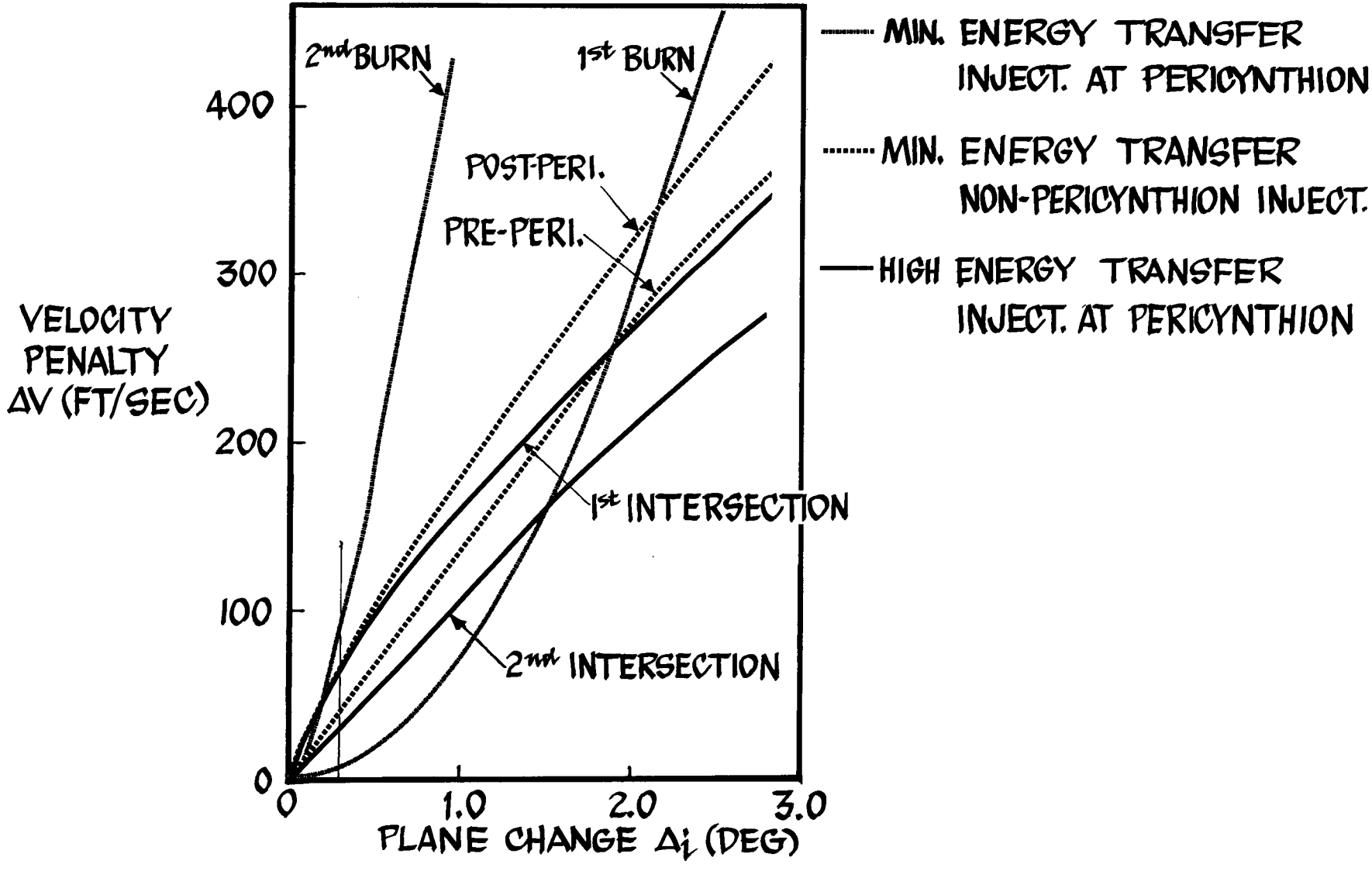


$$\theta_T = 180^\circ + \theta_{PF}$$

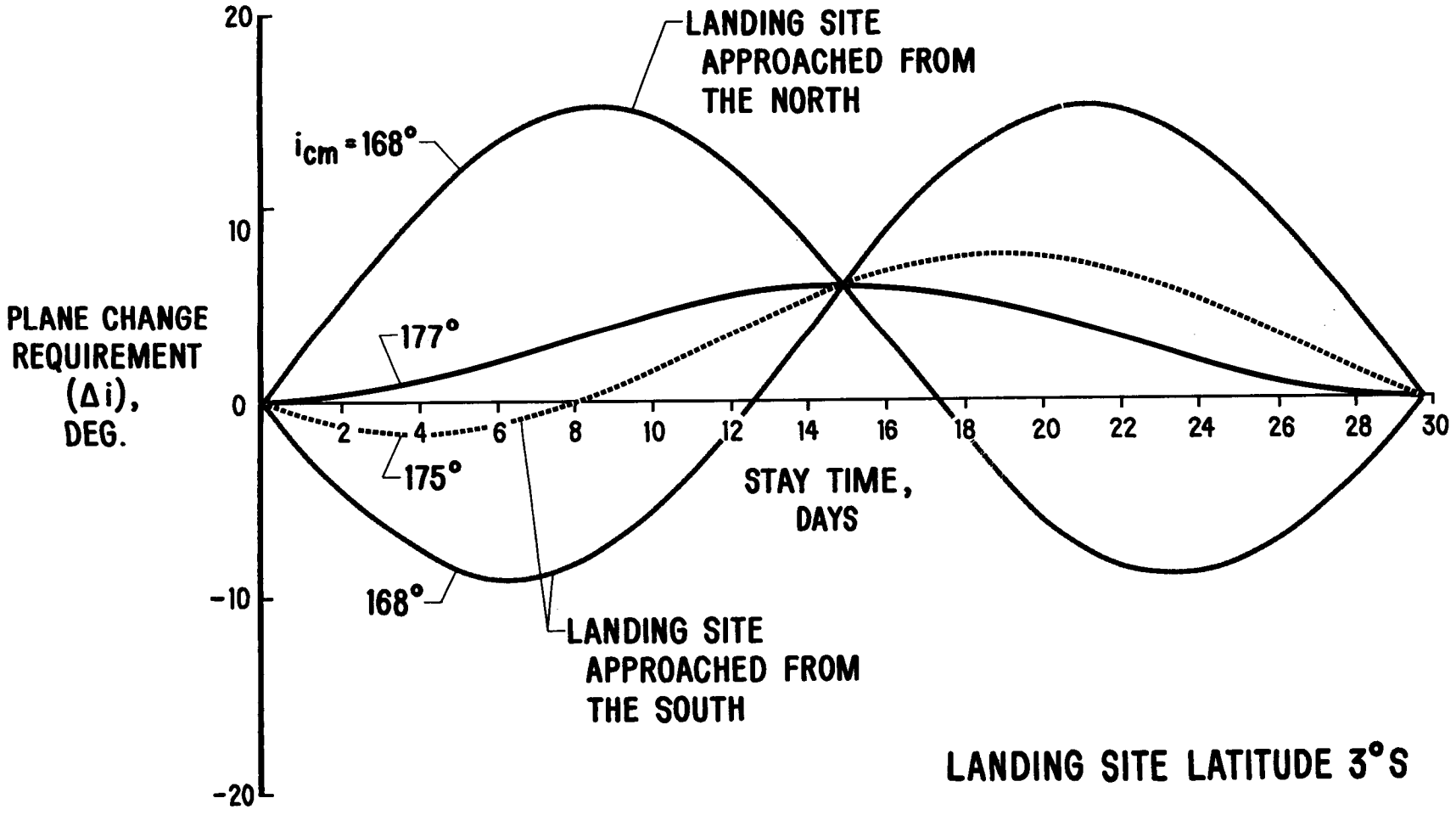
VARIABLE MANEUVER ANGLE ASCENTS



COMPARISON OF ASCENT METHODS

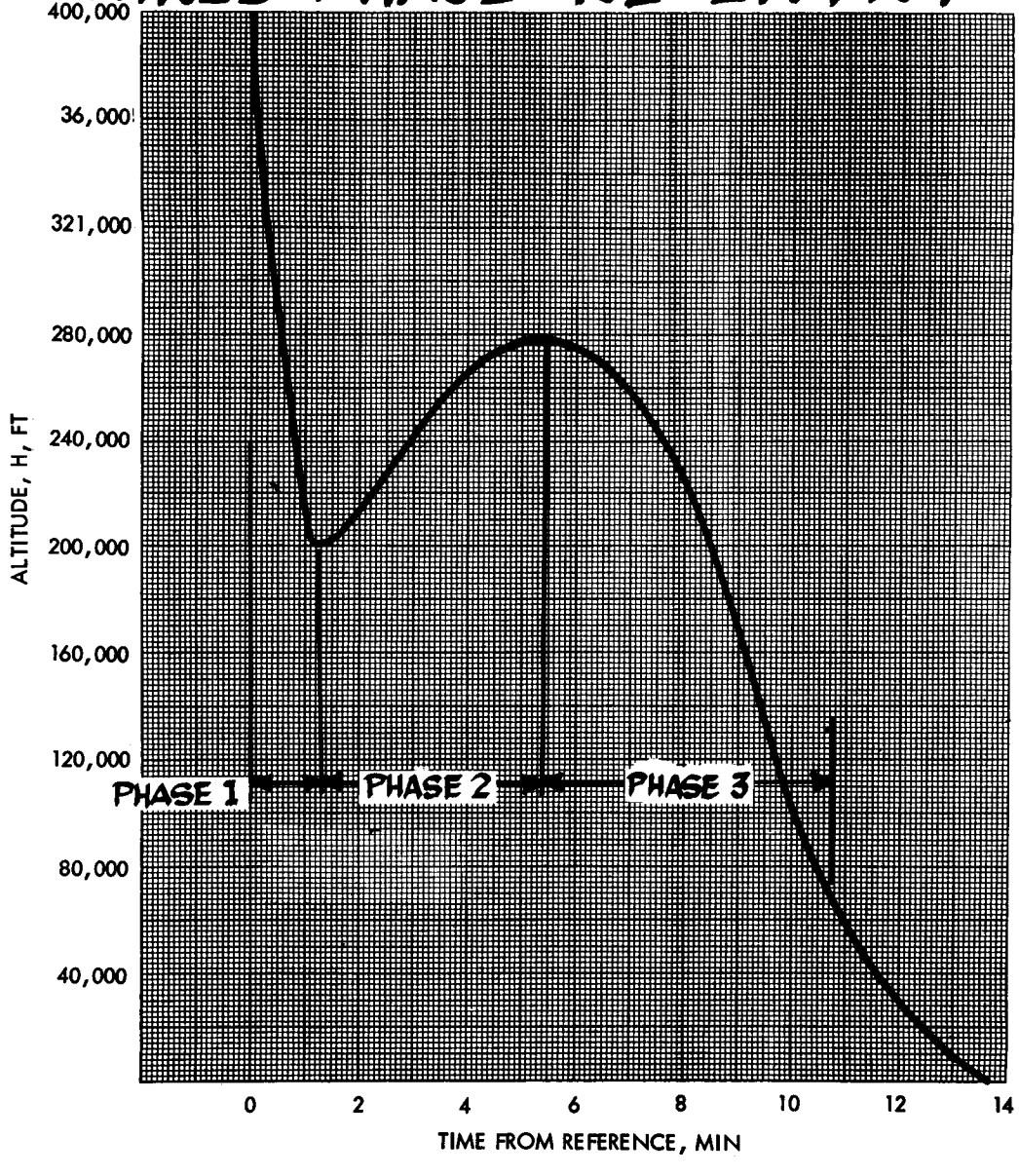


EFFECT OF MOON'S ROTATION

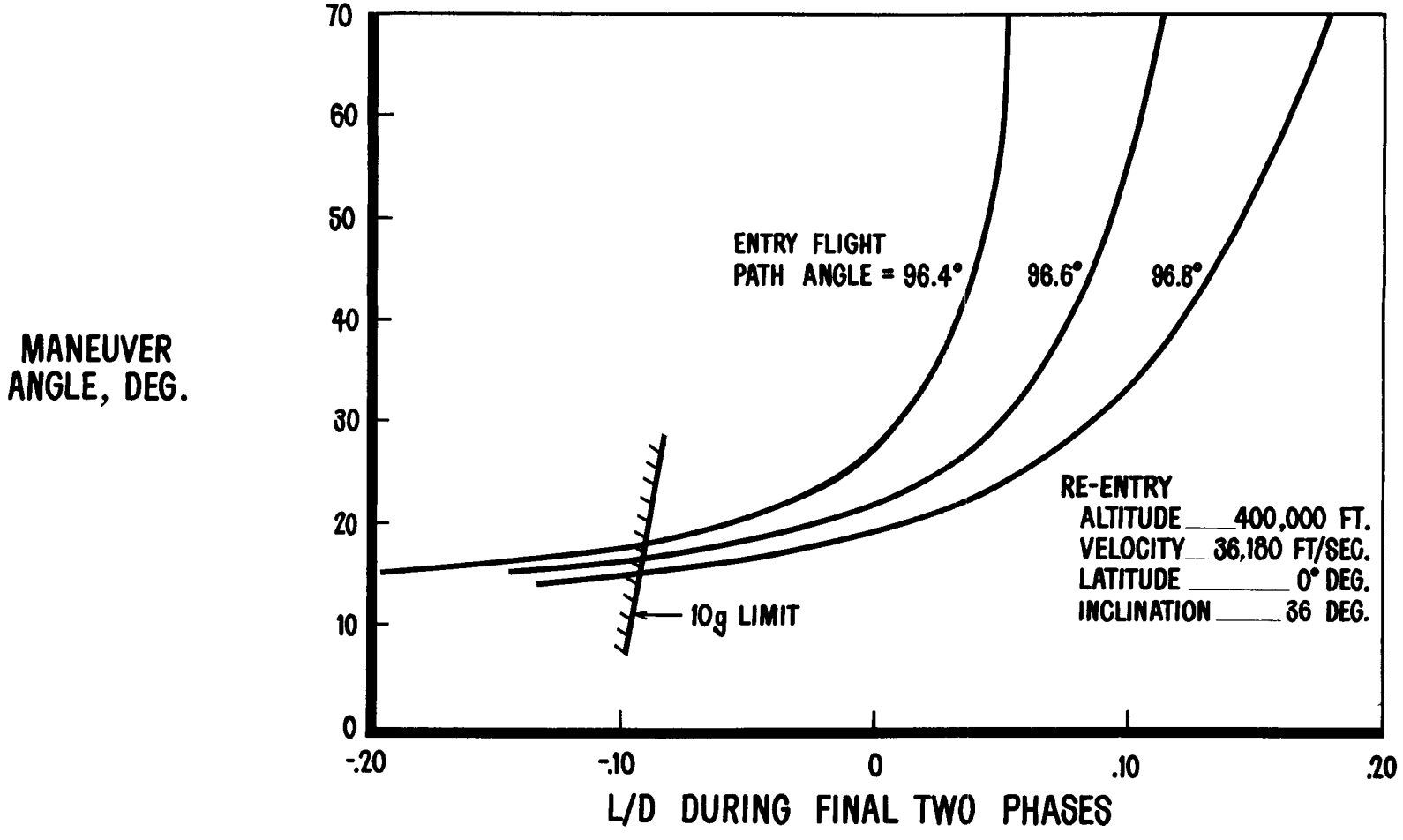


LANDING SITE LATITUDE 3°S

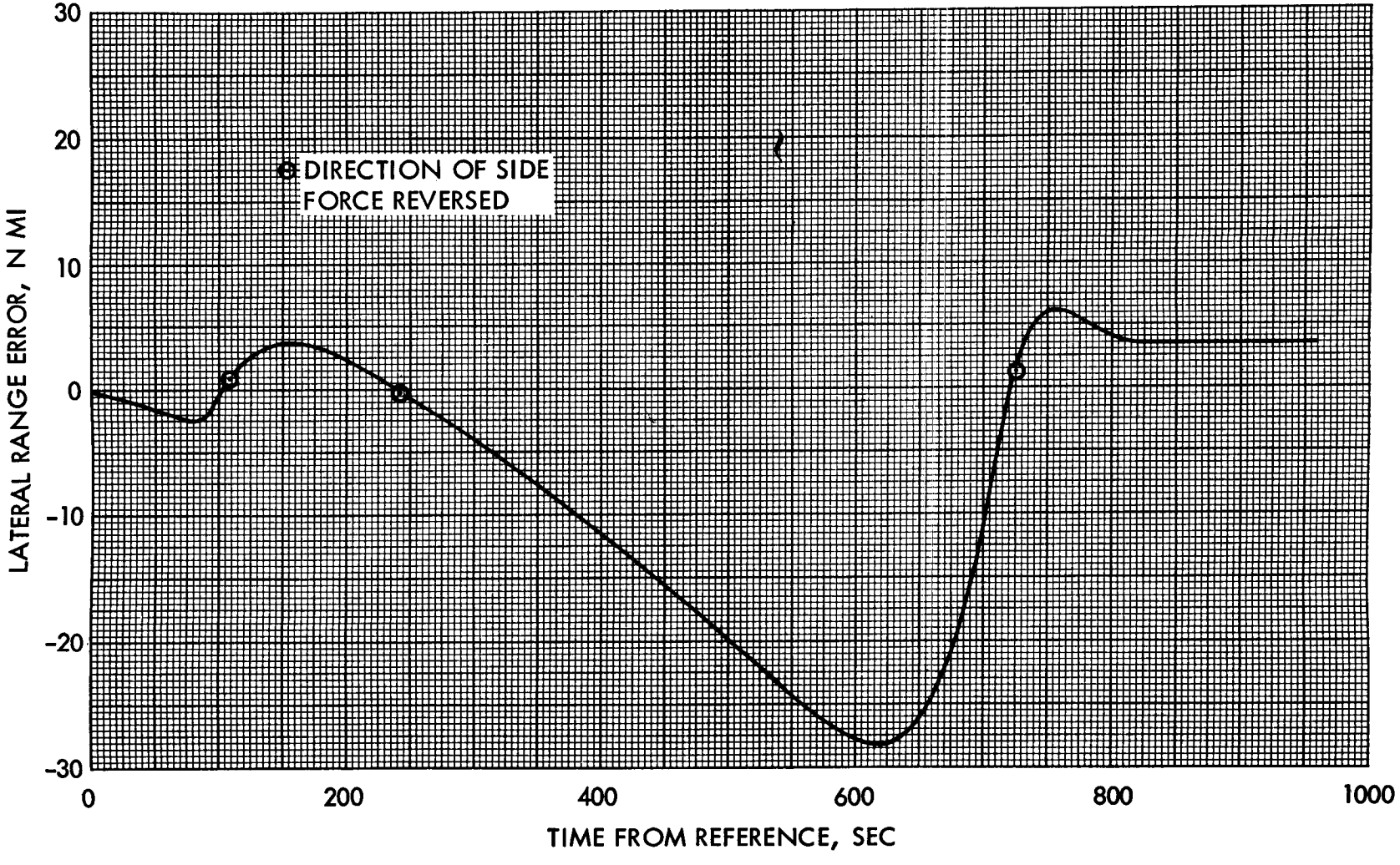
THREE PHASE RE-ENTRY



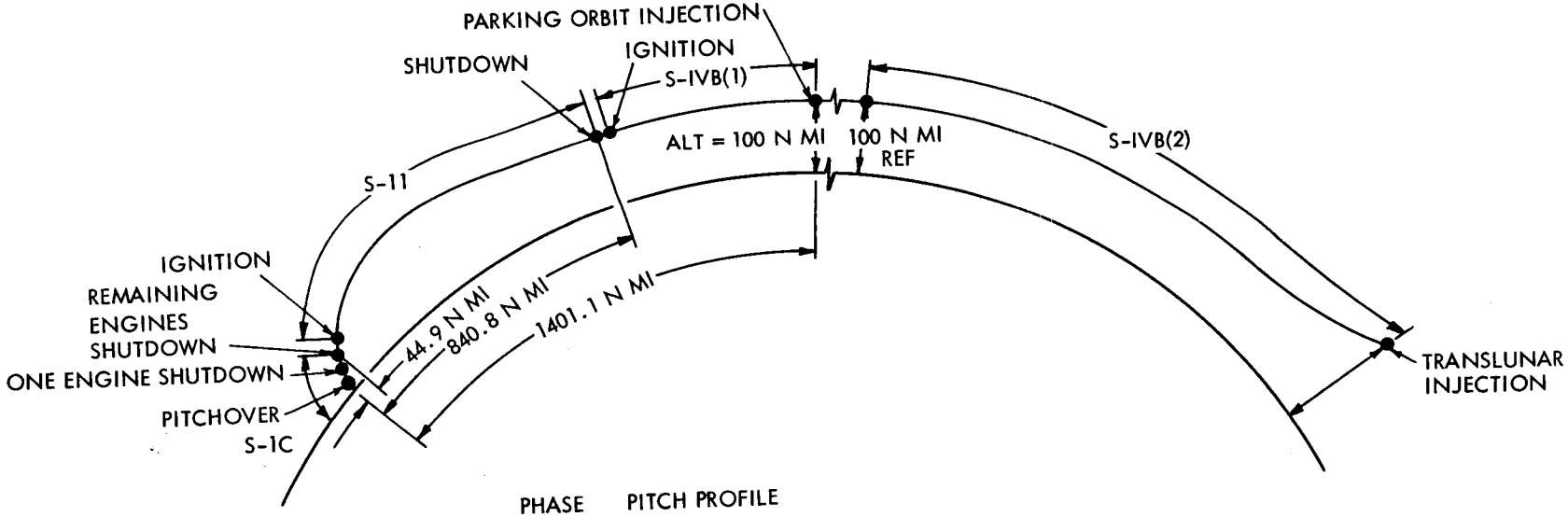
VARIATION OF RE-ENTRY MANEUVER ANGLE
WITH L/D AND ENTRY FLIGHT PATH ANGLE



RE-ENTRY SIDE FORCE MGT.



THE SATURN V POWERED FLIGHT PROFILE



PHASE	PITCH PROFILE
S-IC	PITCHOVER FOLLOWED BY GRAVITY TURN
SS-II	BODY AXIS RE-ORIENTATION FOLLOWED BY OPTIMIZED PITCH RATE (CONSTANT - SAME AS S-IVB (1)
S-IVB(1)	OPTIMIZED PITCH RATE (CONSTANT - SAME AS S-II)
S-IVB(2)	BODY AXIS RE-ORIENTATION FOLLOWED BY OPTIMIZED PITCH RATE (CONSTANT - DIFFERENT THAN S-II AND S-IVB (1)

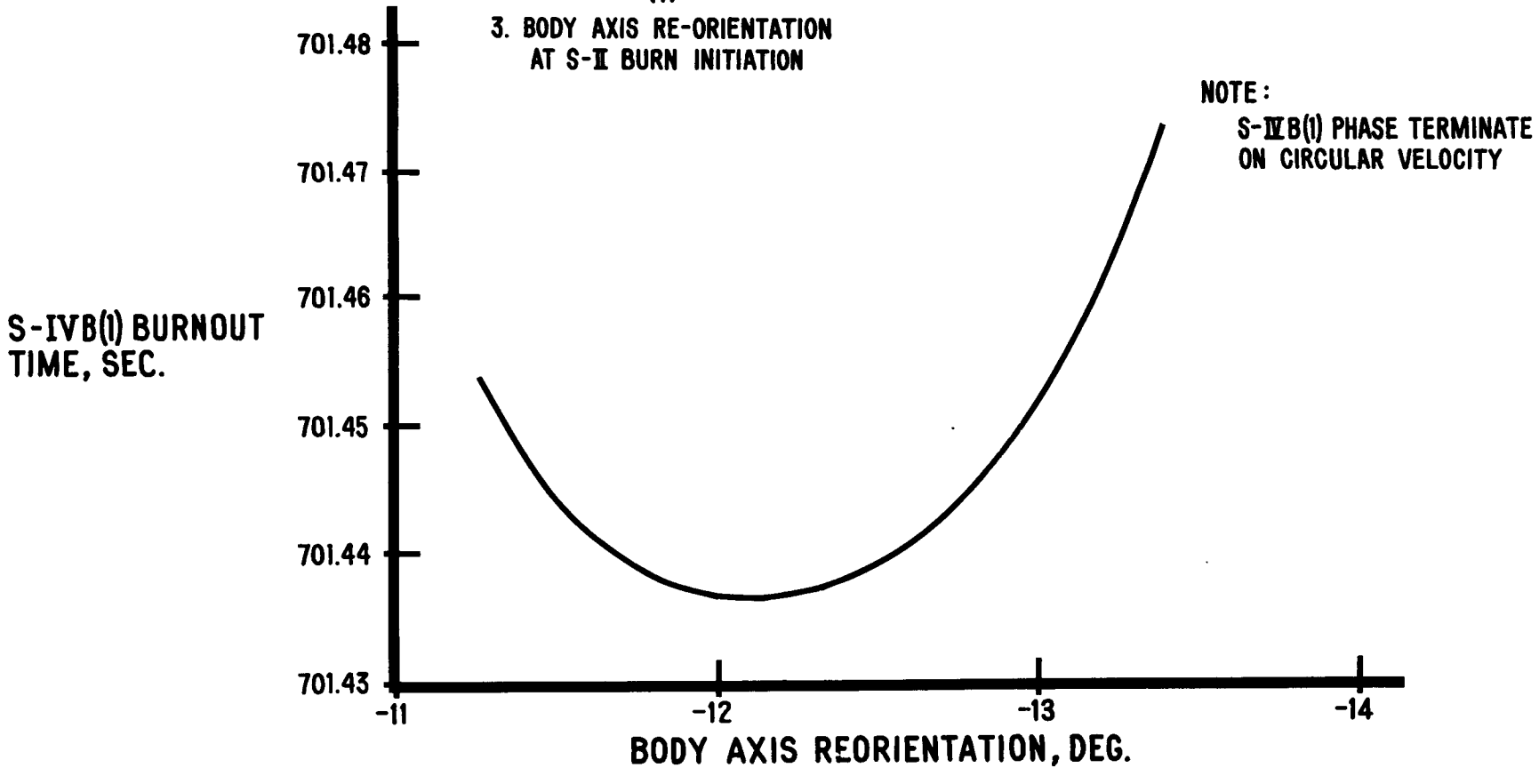
OPTIMIZATION OF S-V TRAJECTORY TO PARKING ORBIT INJECTION

OPTIMIZING PARAMETERS

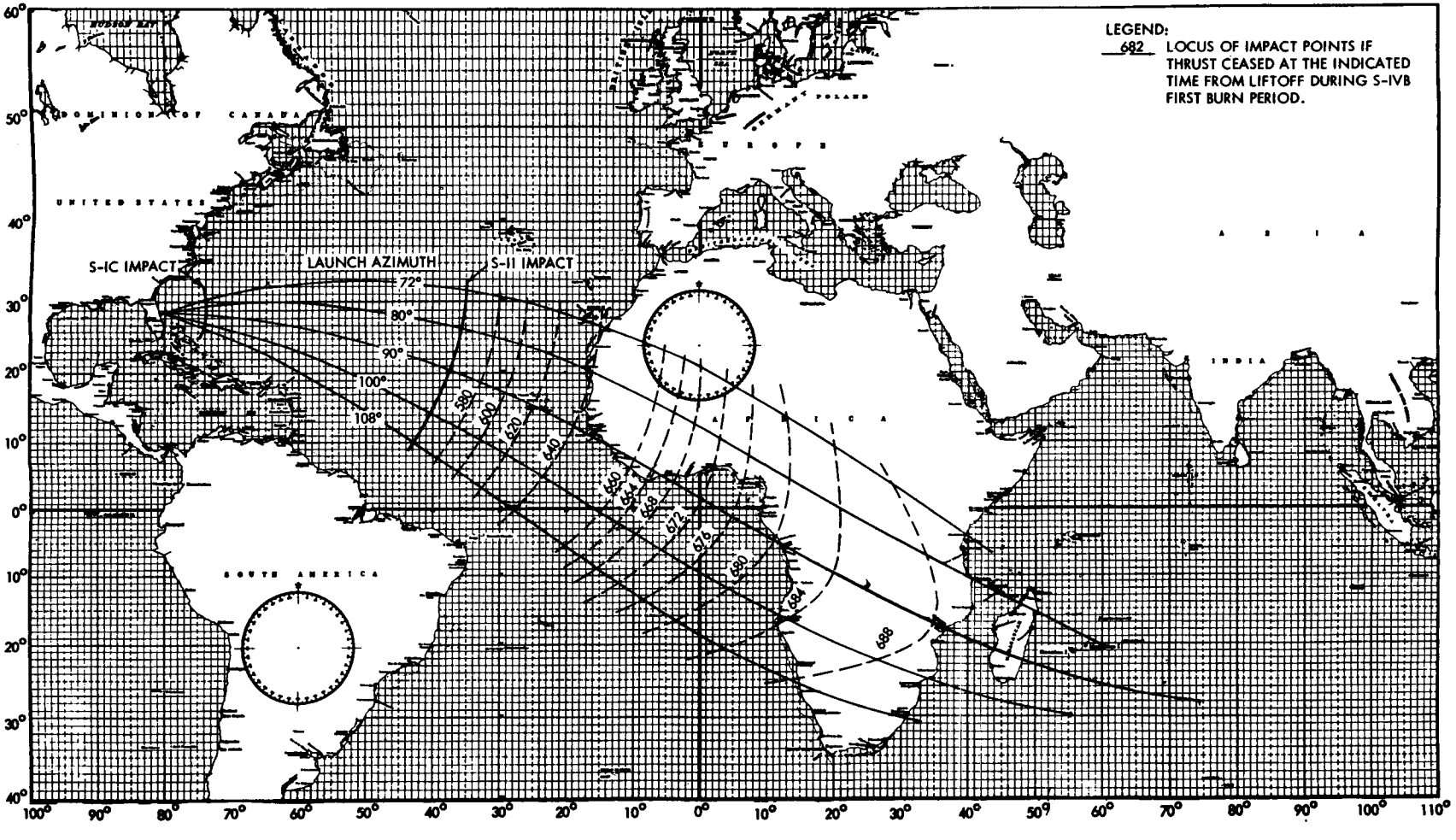
1. KICK ANGLE, S-IC
2. PITCH TURNING RATES
   a. S-II
   b. S-IVB(1)
   } SAME RATES
3. BODY AXIS RE-ORIENTATION AT S-II BURN INITIATION

DESIRED TERMINAL CONDITIONS

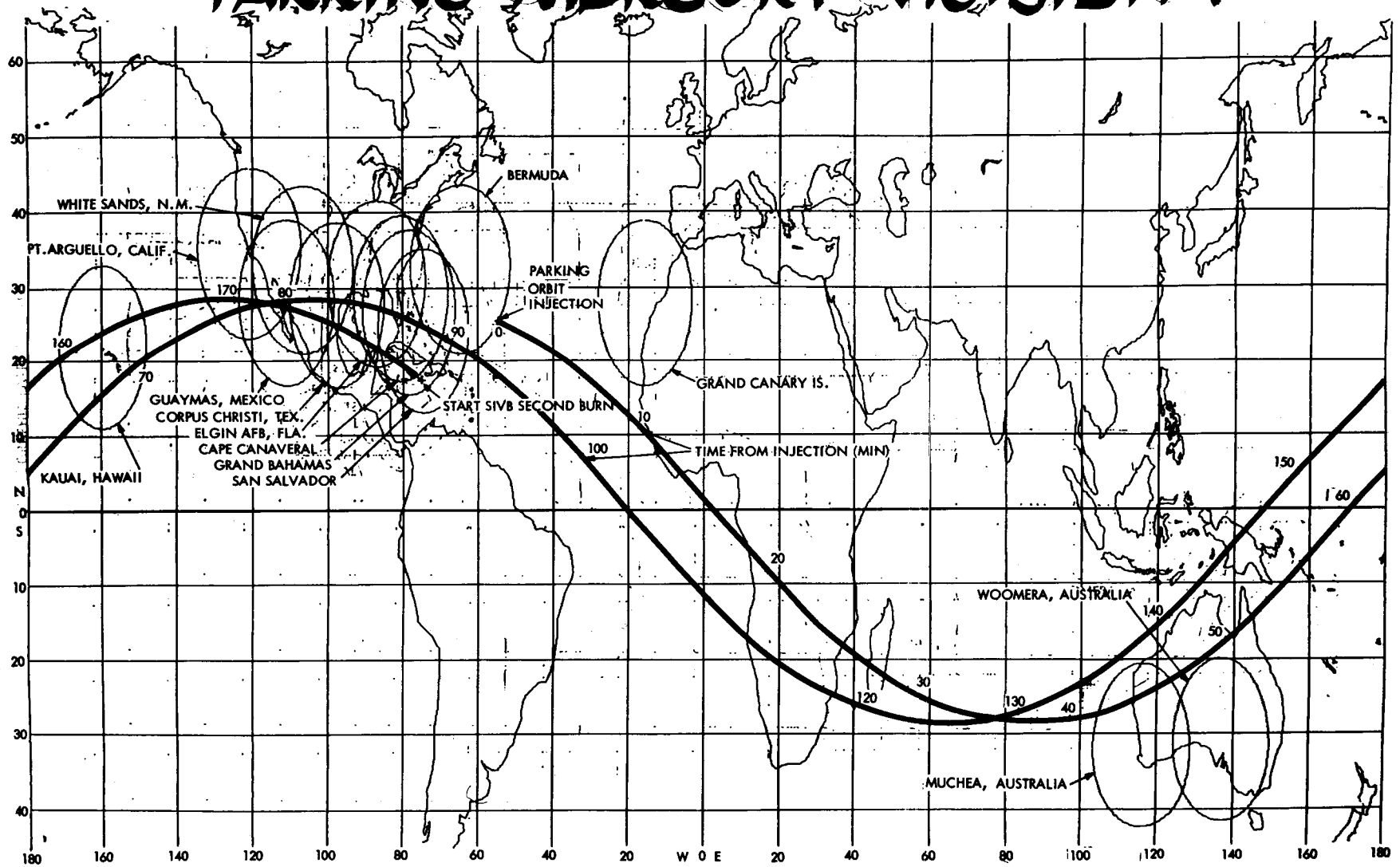
1. ALTITUDE - 100 N.MI.
2. FLIGHT PATH ANGLE - 0 DEG
3. MAXIMUM BURNOUT WEIGHT



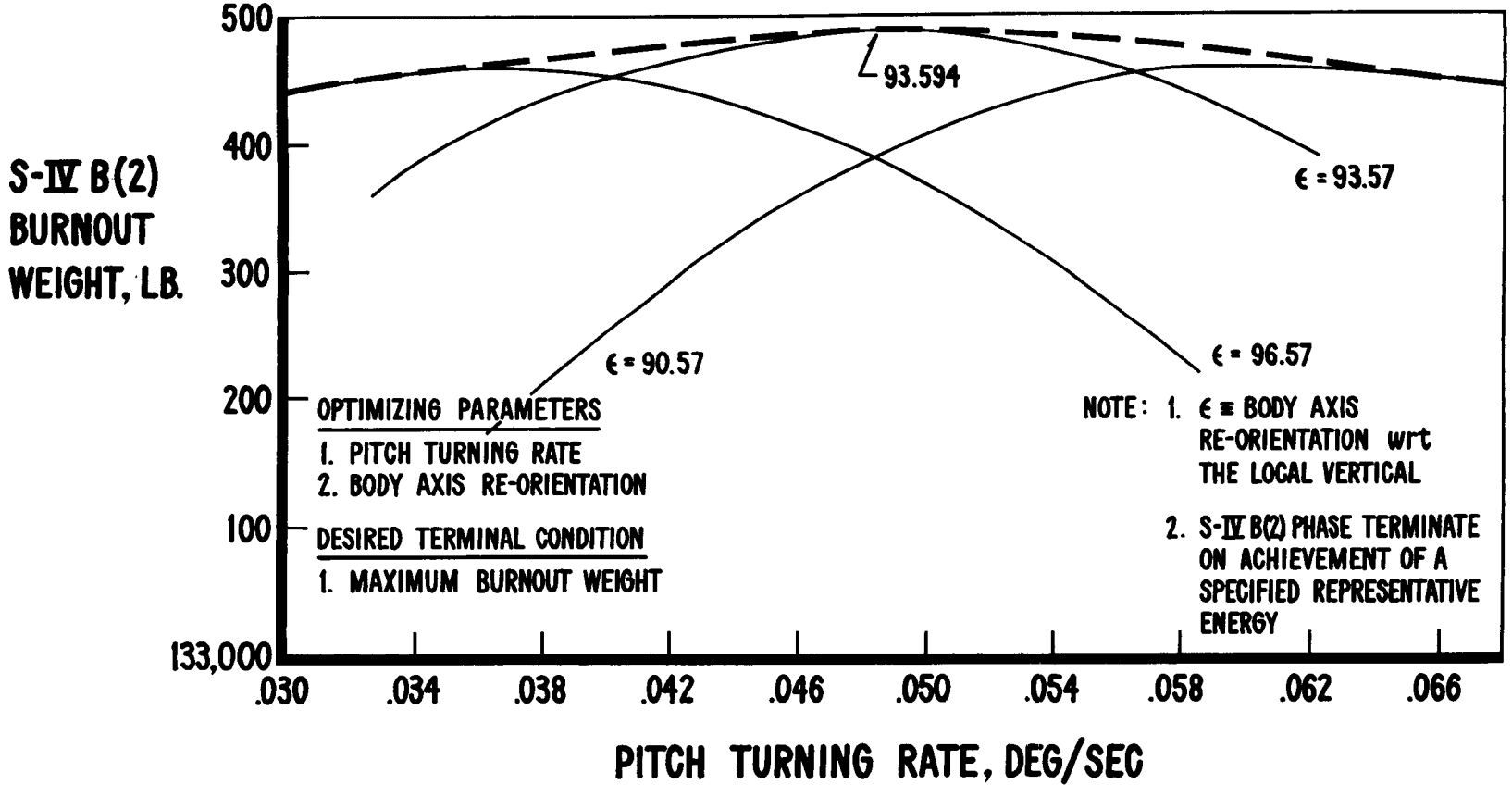
IMPACT POINT TRACES



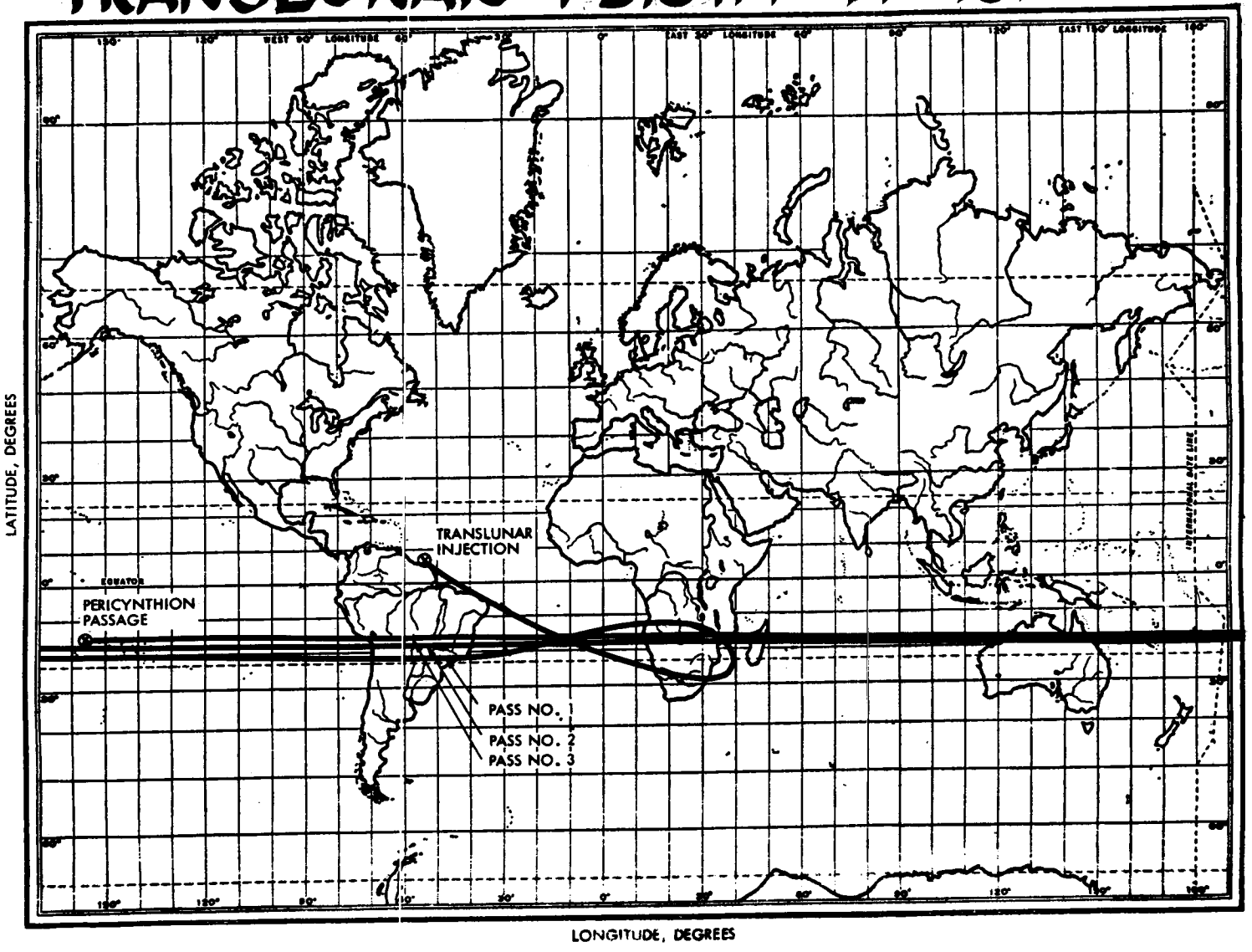
PARKING MERCURY VISIBILITY



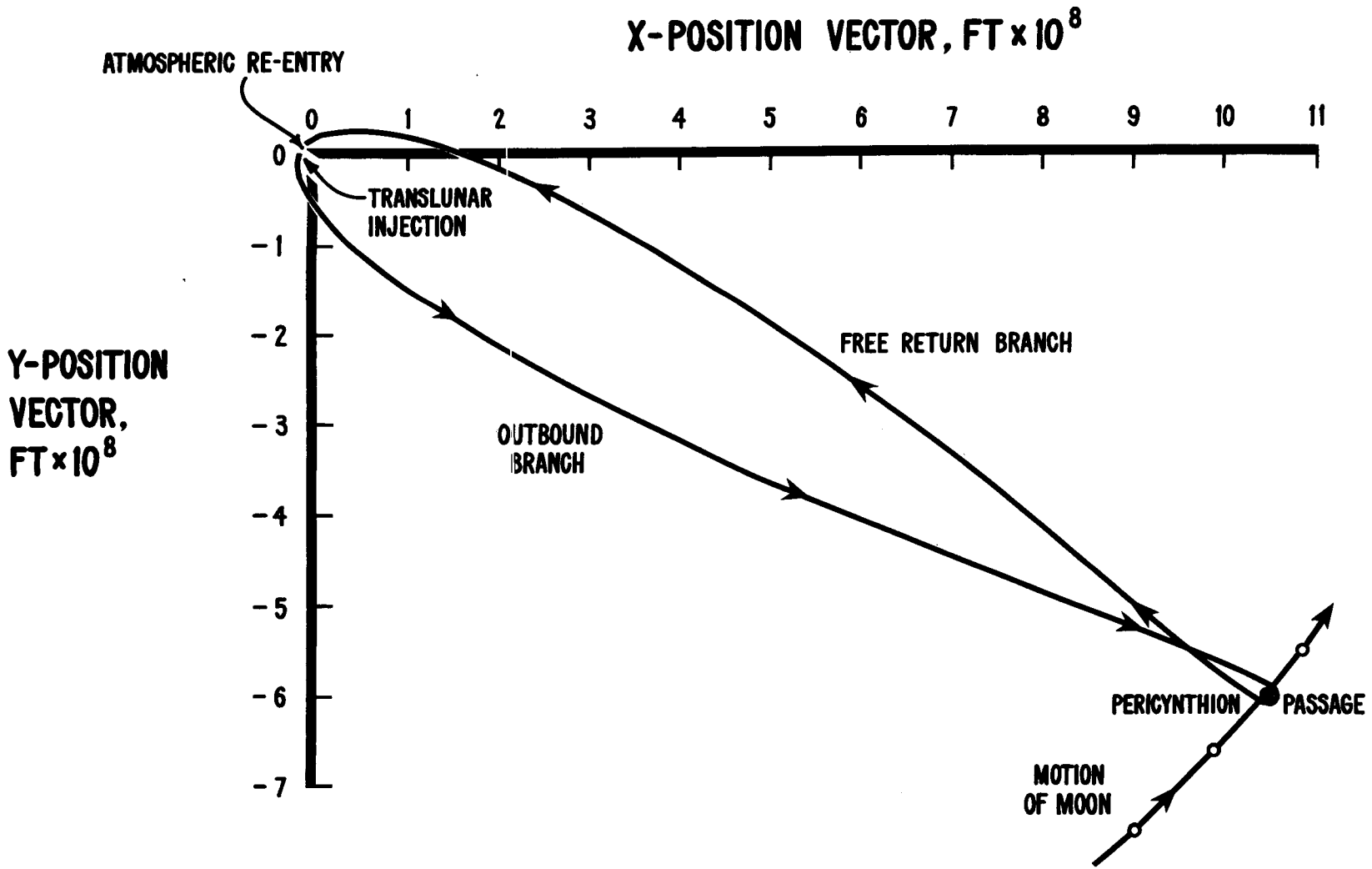
OPTIMIZATION OF S-IVB SECOND BURN PHASE



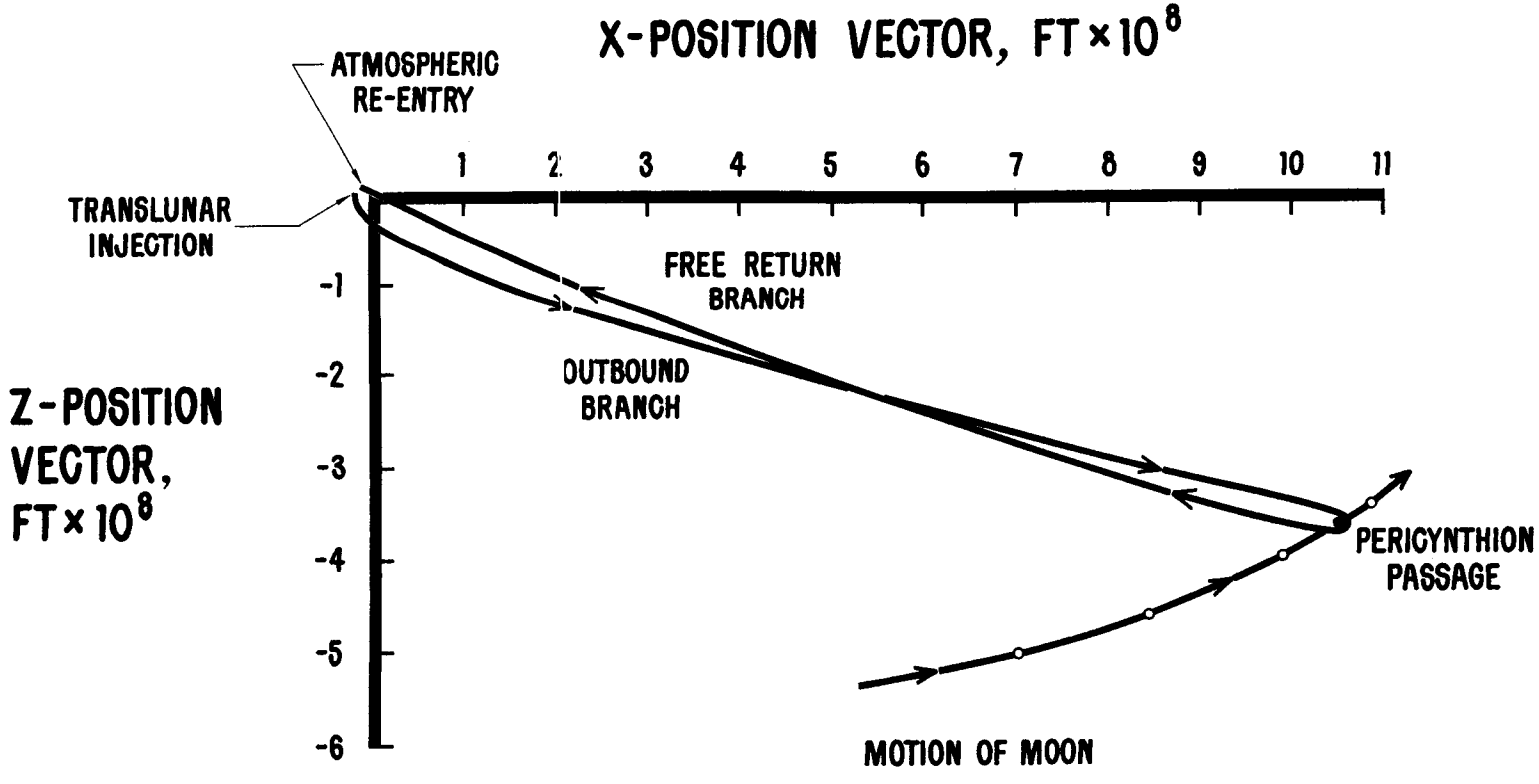
TRANSLUNAR FLIGHT TRACK



COORDINATE PLANE FREE RETURN TRAJECTORY



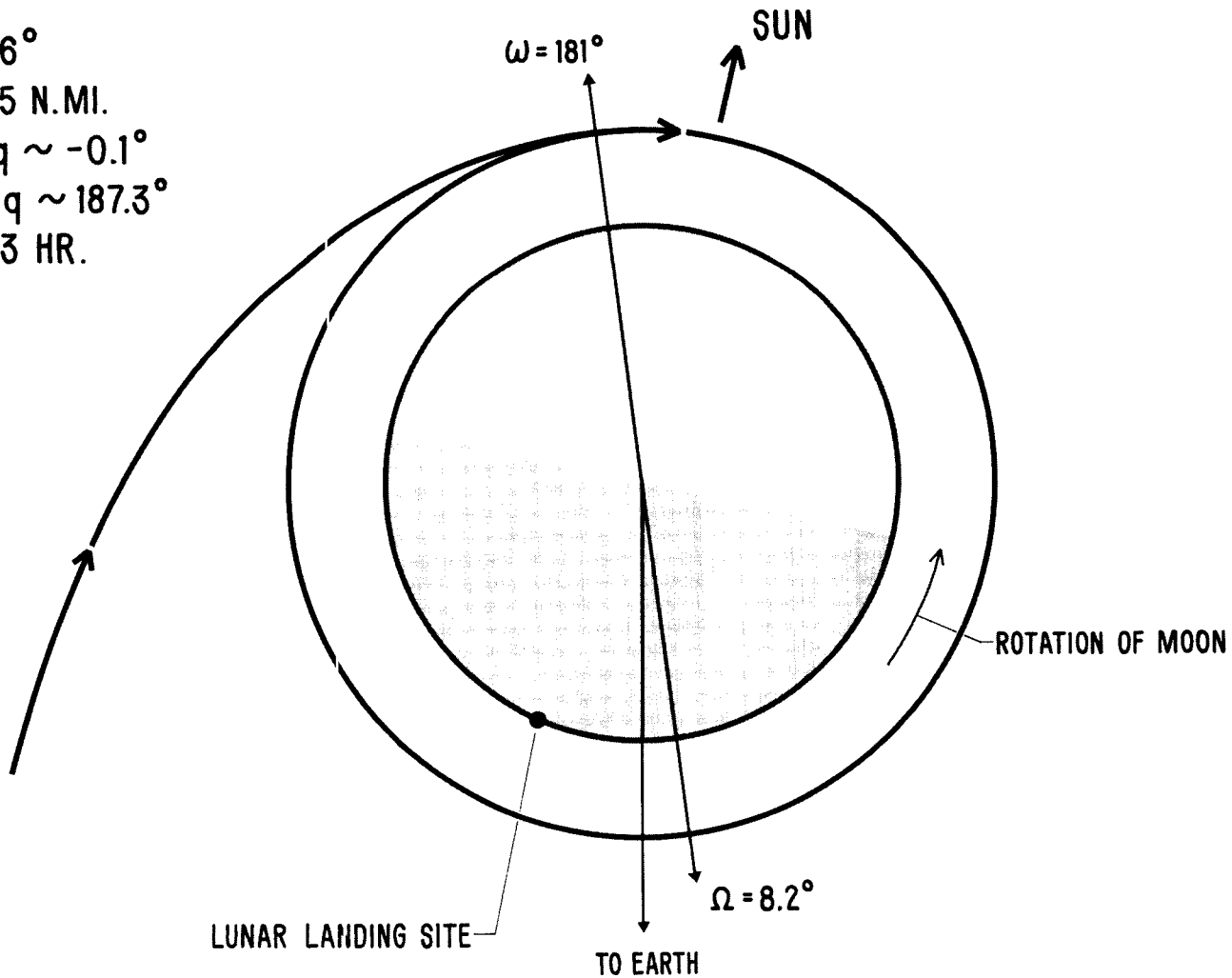
COORDINATE PLANE FREE RETURN TRAJECTORY



GEOMETRY OF THE LUNAR APPROACH HYPERBOLA

VIEW FROM LUNAR NORTH POLE (SCHEMATIC)

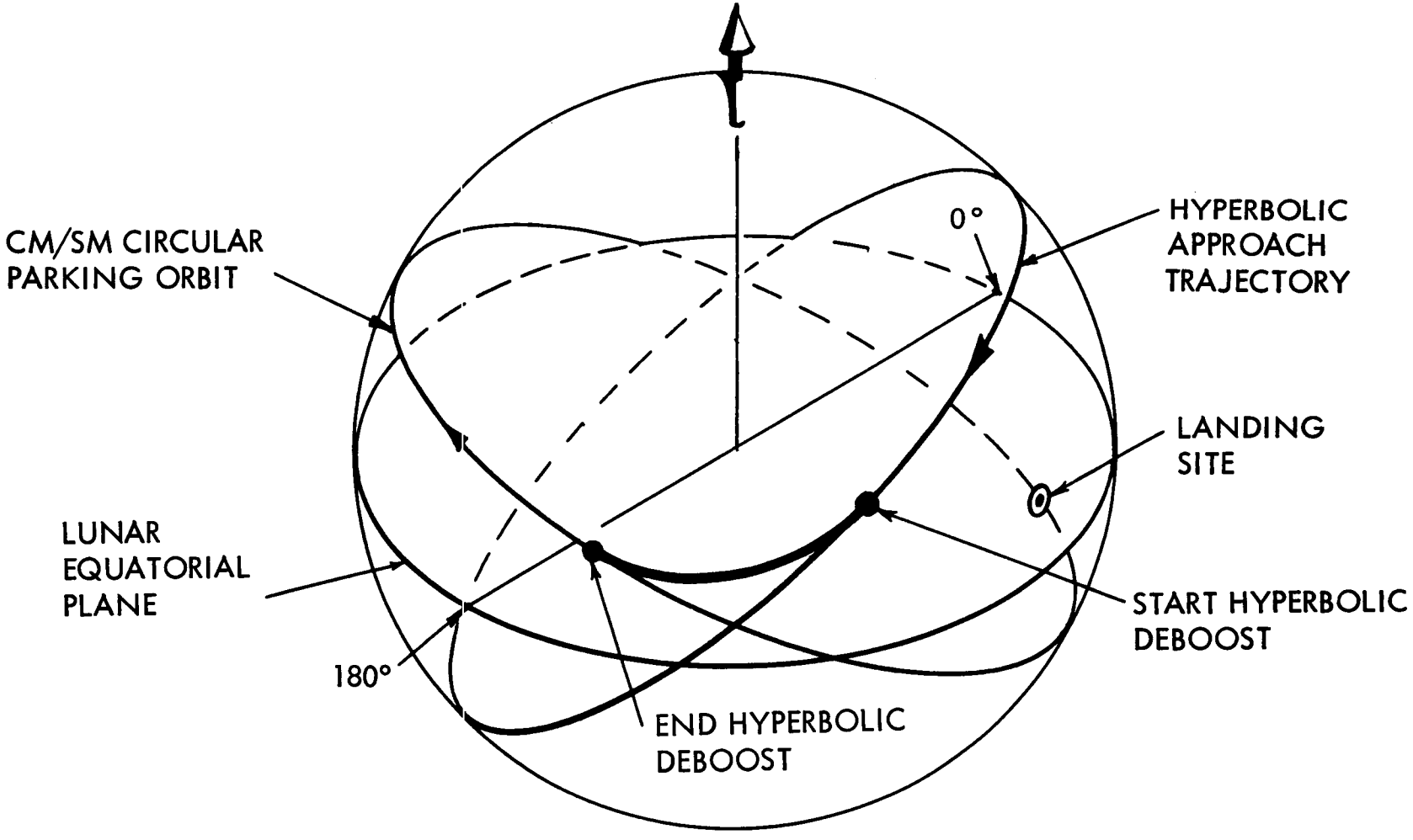
$I_S \sim 171.6°$
$q \sim 79.5$ N.MI.
LAT. OF $q \sim -0.1°$
LONG. OF $q \sim 187.3°$
$T_F \sim 65.3$ HR.



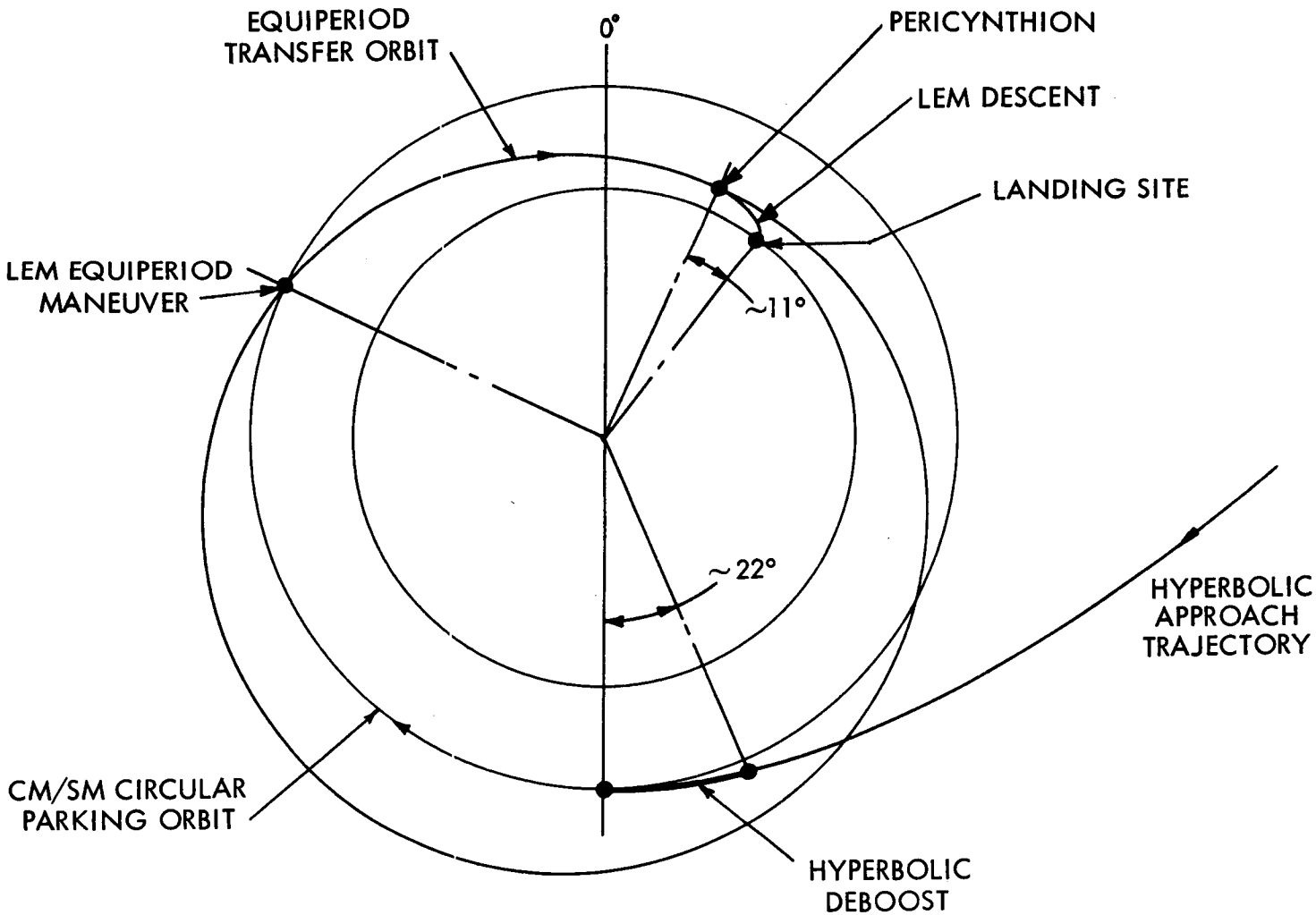
FREE RETURN PHASE OF OUTBOUND TRAJECTORY

- INCLINATION OF TRANSEARTH ORBIT ~ 29.2 DEGREES
- LATITUDE OF RE-ENTRY ~ 18.93° N
- LONGITUDE OF RE-ENTRY ~ 350.37° E
- RE-ENTRY FLIGHT PATH ANGLE ~ -6.04 DEGREES
- TOTAL TIME OF FLIGHT TO RE-ENTRY ~ 5 DAYS 18 HOURS 0.9 MINUTES FOR OUTBOUND AND FREE RETURN LEGS

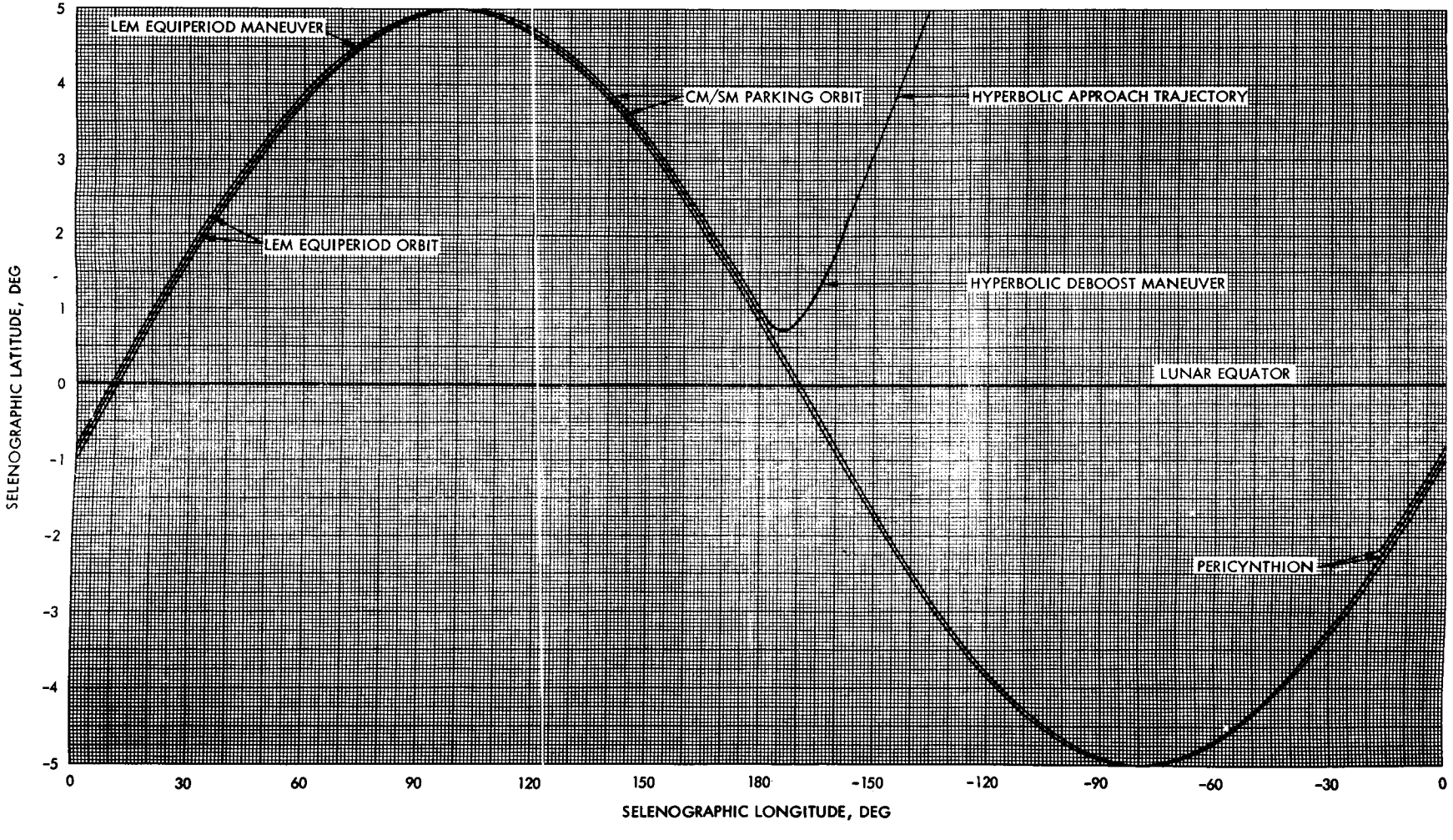
HYPERBOLIC DEBOOST



LEM DESCENT PROFILE (PROJECTED INTO CM/SM ORBITAL PLANE)

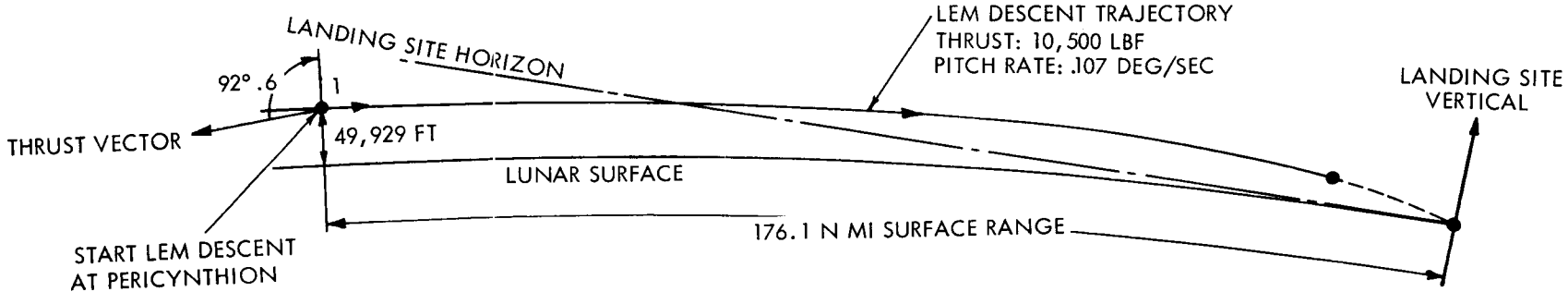


DEBOOST LUNAR GROUND TRACK



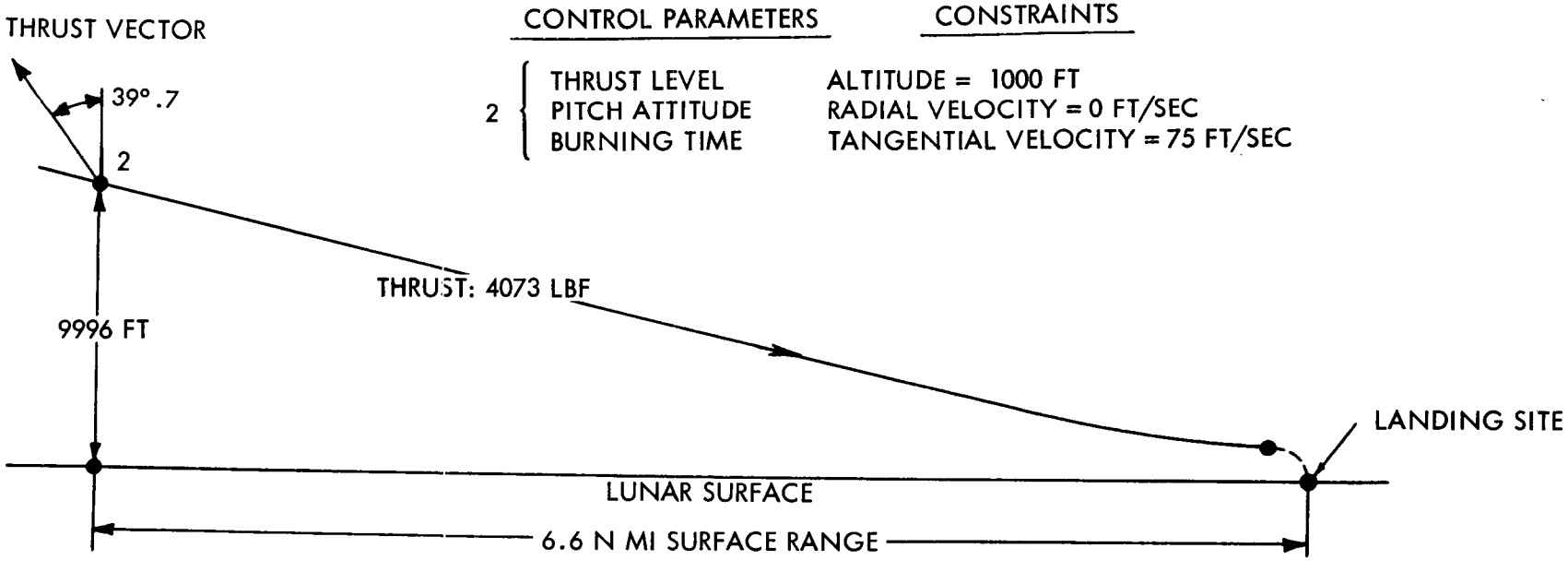
LEM DESCENT
(MAXIMUM THRUST PHASE)

	CONTROL PARAMETERS	CONSTRAINTS
1	INITIAL PITCH ATTITUDE PITCH RATE BURNING TIME	ALTITUDE = 10,000 FT LOCAL EPSILON = 70° TOTAL RELATIVE VELOCITY = 700 FT/SEC



LEM DESCENT
(CONSTANT THRUST ATTITUDE PHASE)

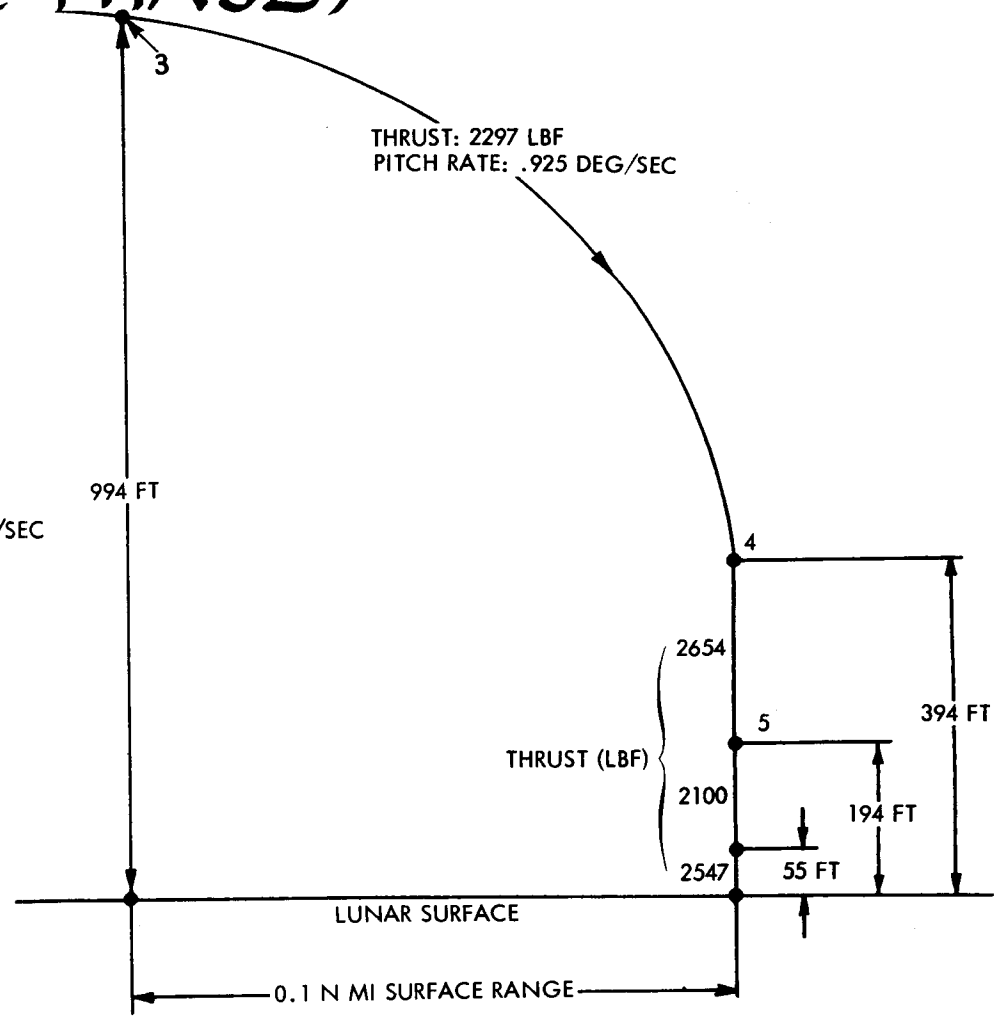
CONTROL PARAMETERS	CONSTRAINTS
2 { THRUST LEVEL, PITCH ATTITUDE, BURNING TIME	ALTITUDE = 1000 FT RADIAL VELOCITY = 0 FT/SEC TANGENTIAL VELOCITY = 75 FT/SEC



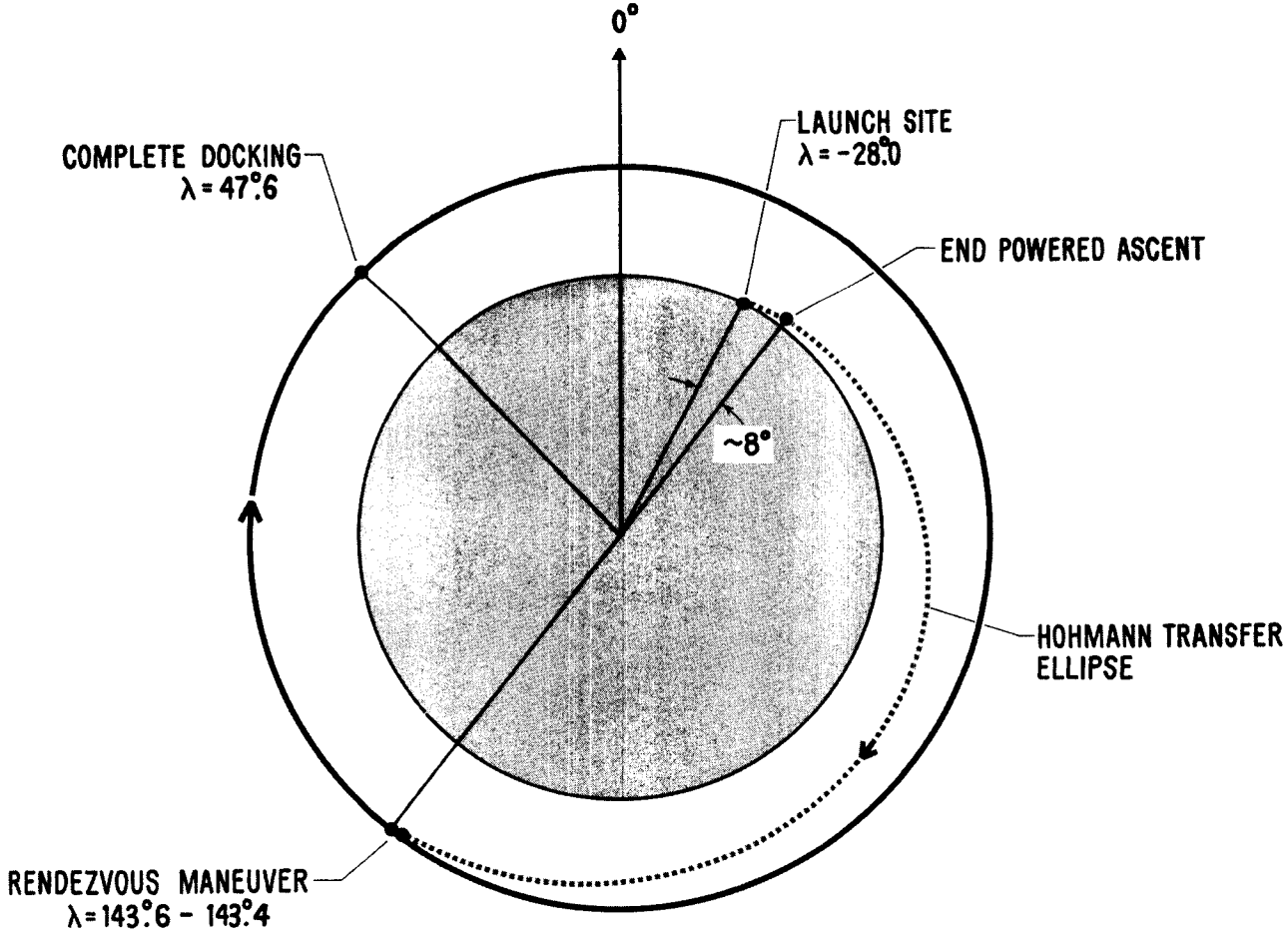
LEM DESCENT
(TERMINAL PHASE)

	CONTROL PARAMETERS	CONSTRAINTS
3	THRUST LEVEL PITCH RATE BURNING TIME	ALTITUDE = 400 FT LOCAL EPSILON = 0 DEG TANGENTIAL VELOCITY = 0 FT/SEC
4	THRUST LEVEL BURNING TIME	ALTITUDE = 200 FT RADIAL VELOCITY = 0 FT/SEC
5	BURNING TIME THRUST LEVEL	ALTITUDE = 0 FT RADIAL VELOCITY = 0 FT

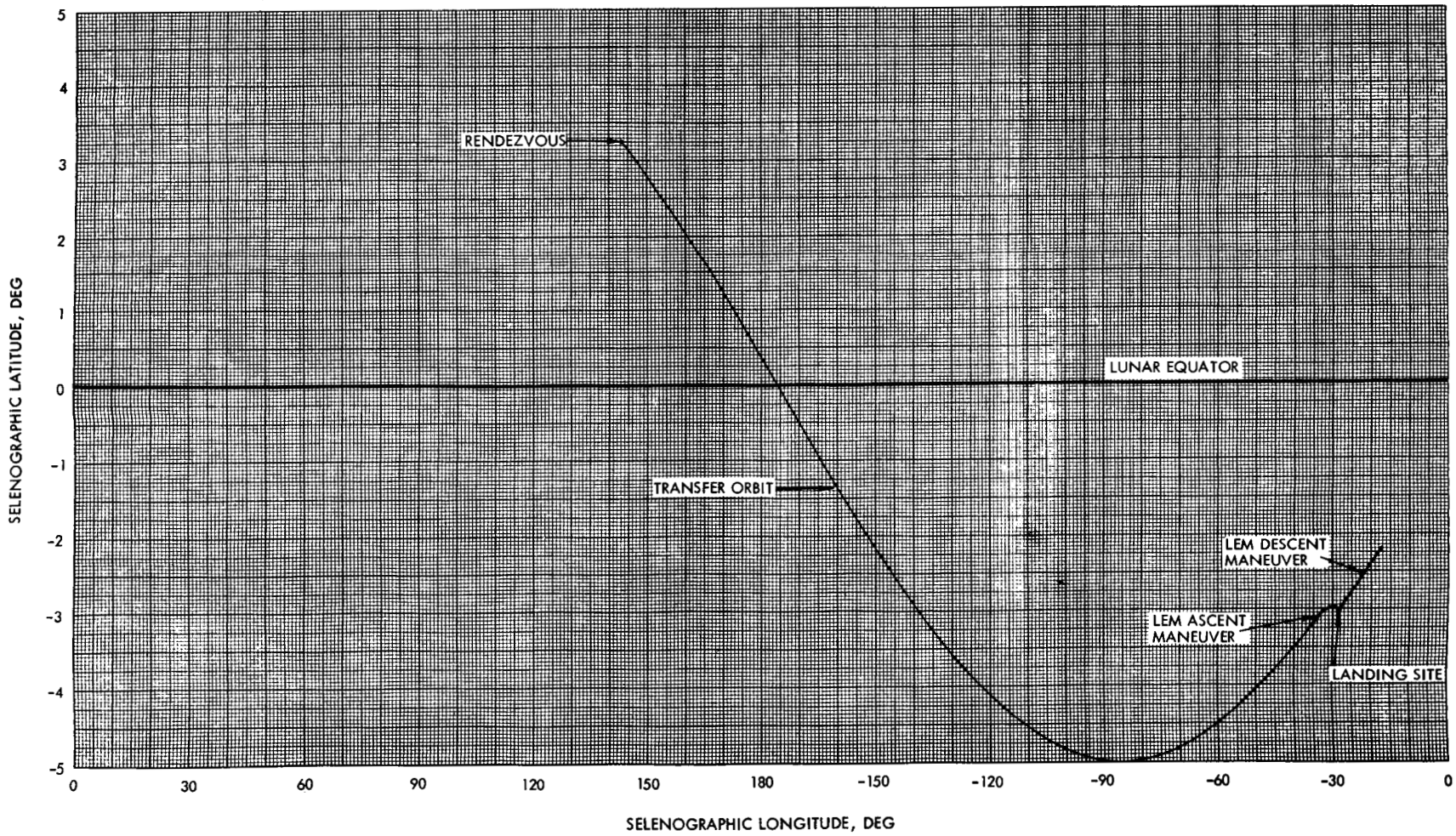
CUTOFF AT 40 SEC



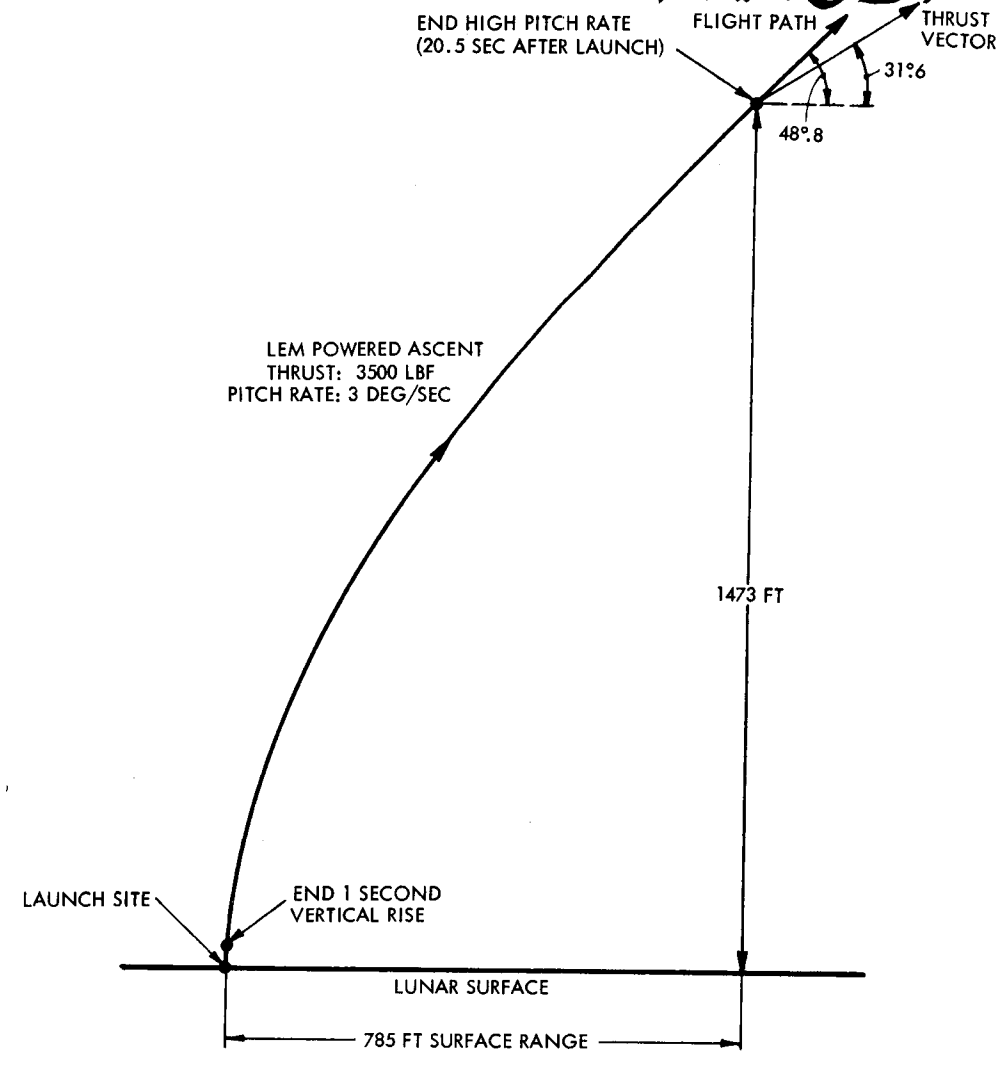
LEM ASCENT TO RENDEZVOUS



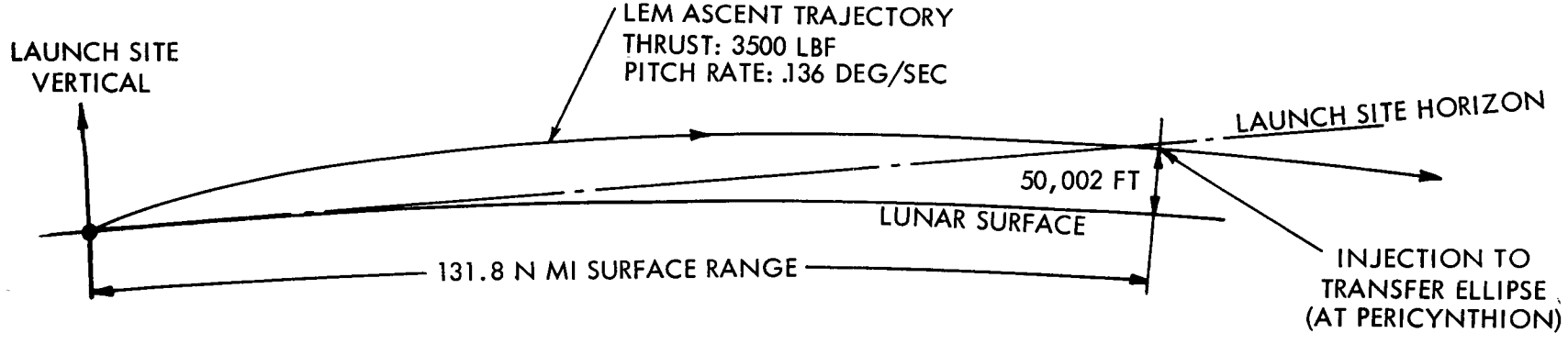
LEM ASCENT LUNAR GROUND TRACK



LEM ASCENT
(HIGH PITCH RATE PHASE)



LEM ASCENT
(LOW PITCH RATE PHASE)



RETURN PHASE

- 130 MINUTES AFTER RENDEZVOUS ARE ALLOWED BEFORE ANY RETURN ATTEMPT IS MADE
- BURN DELTA VELOCITY OF 3720 FT/SEC.
- BURN OPTIMIZED FOR MAXIMUM INJECTED WEIGHT
- TIME OF FLIGHT ~ 63.6 HOURS
- RETURN INCLINATION OF 43.38 DEGREES
- RE-ENTRY AT 400,000 FT. WITH FLIGHT PATH ANGLE OF - 6.° 40
- LAND AT SAN ANTONIO, TEXAS
- G LIMIT SATISFIED AT RE-ENTRY

GEOMETRY OF THE LUNAR OUTBOUND ORBIT

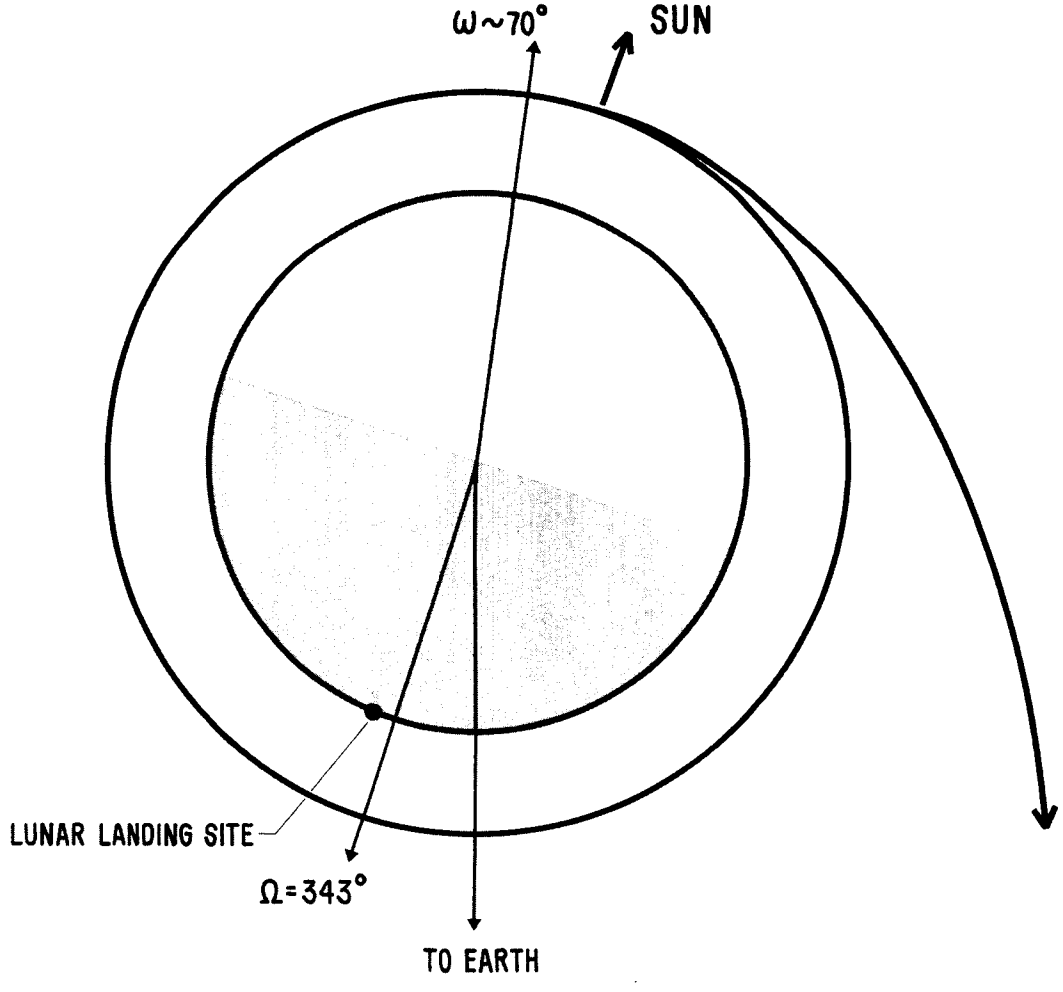
VIEW FROM LUNAR NORTH POLE (SCHEMATIC) AFTER INJECTION BURN

$I_S \sim 172.4°$

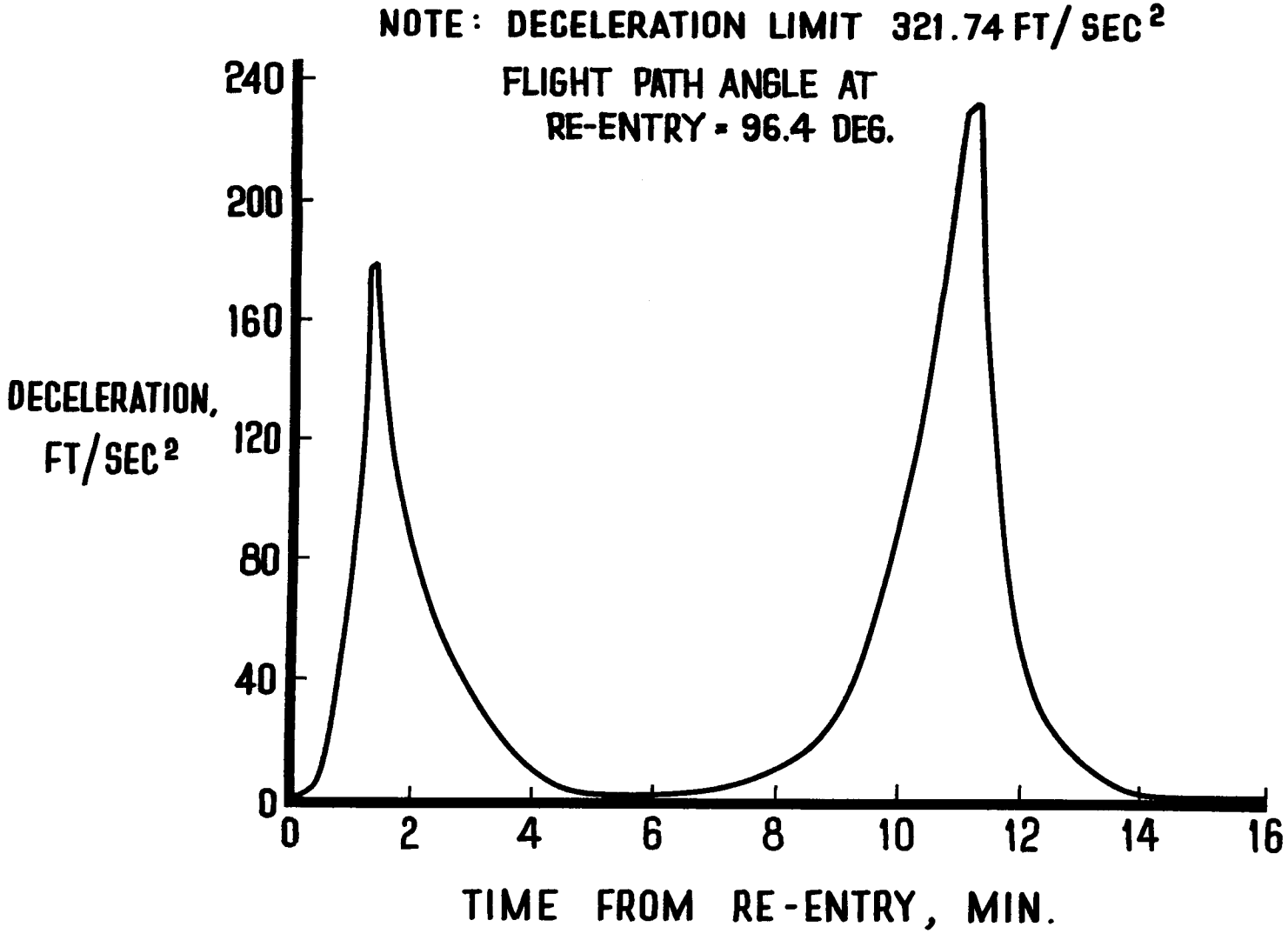
$q \sim 79.5$ N MI

$e \sim 1.7064$

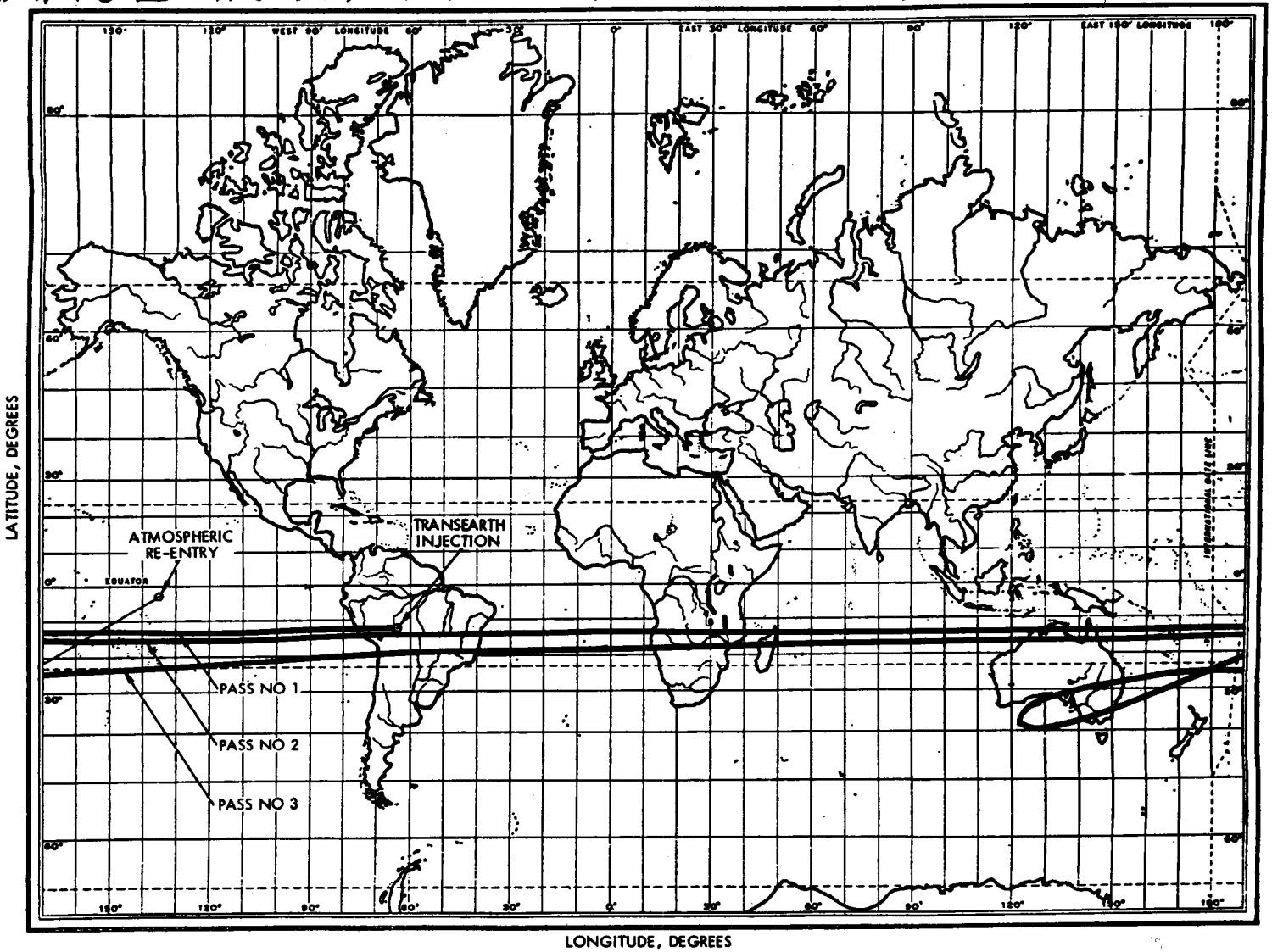
$T_F \sim 63.6$ HR



RE-ENTRY PHASE RELATIVE DECELERATION



TRANSEARTH FLIGHT GROUND TRACK



LAUNCH PHASE

	Issue 2	Issue 1
LAUNCH DATE	28 JAN 1968	3 FEB 1968
	3 HR 13 MIN 53 SEC	2 HR 54 MIN 53 SEC
SATURN CONFIGURATION		
S-IC		
ISP	264.9 LBF/LBM/SEC	263.6 LBF/LBM/SEC
S-II		
INITIATION ATTITUDE	12.125 DEG	12.281 DEG
PITCH RATE	0.101216 DEG/SEC.	0.101437 DEG/SEC
S-IVB(1)		
PITCH RATE	0.101216 DEG/SEC	0.101437 DEG/SEC
PARKING ORBIT INJECTION	701.4 SEC	703.5 SEC
PARKING ORBIT DURATION	2.065 REVS	2.277 REVS
S-IVB(2)		
INITIATION	93.594 DEG	93.570 DEG.
PITCH RATE	0.048348 DEG/SEC	0.048309 DEG/SEC.

TRANSLUNAR PHASE (FREE RETURN)

	Issue 2	Issue 1
INJECTION CONDITIONS		
ALTITUDE	158.6 N MI	157.7 N MI
VELOCITY	35673.3 FT/SEC	35675.3 FT/SEC
β	83.40 DEG.	83.44 DEG
LUNAR CONDITIONS		
TIME OF FLIGHT TO CLOSEST APPROACH	65.30 HR	73.57 HR
LUNAR INCLINATION	171.57 DEG	171.48 DEG
DISTANCE OF CLOSEST APPROACH	79.55 N.MI	78.60 N MI
RE-ENTRY CONDITIONS		
TOTAL FLIGHT TIME	5 DAYS 18.0 HR	6 DAYS 3.4 HR
RETURN INCLINATION	29.2 DEG	20.2 DEG
LATITUDE	8.93 N	12.93 S
LONGITUDE	350.37 E	271.15 E
FLIGHT PATH ANGLE	-6.04 DEG.	-6.59 DEG

LOR PHASE

CONFIDENTIAL

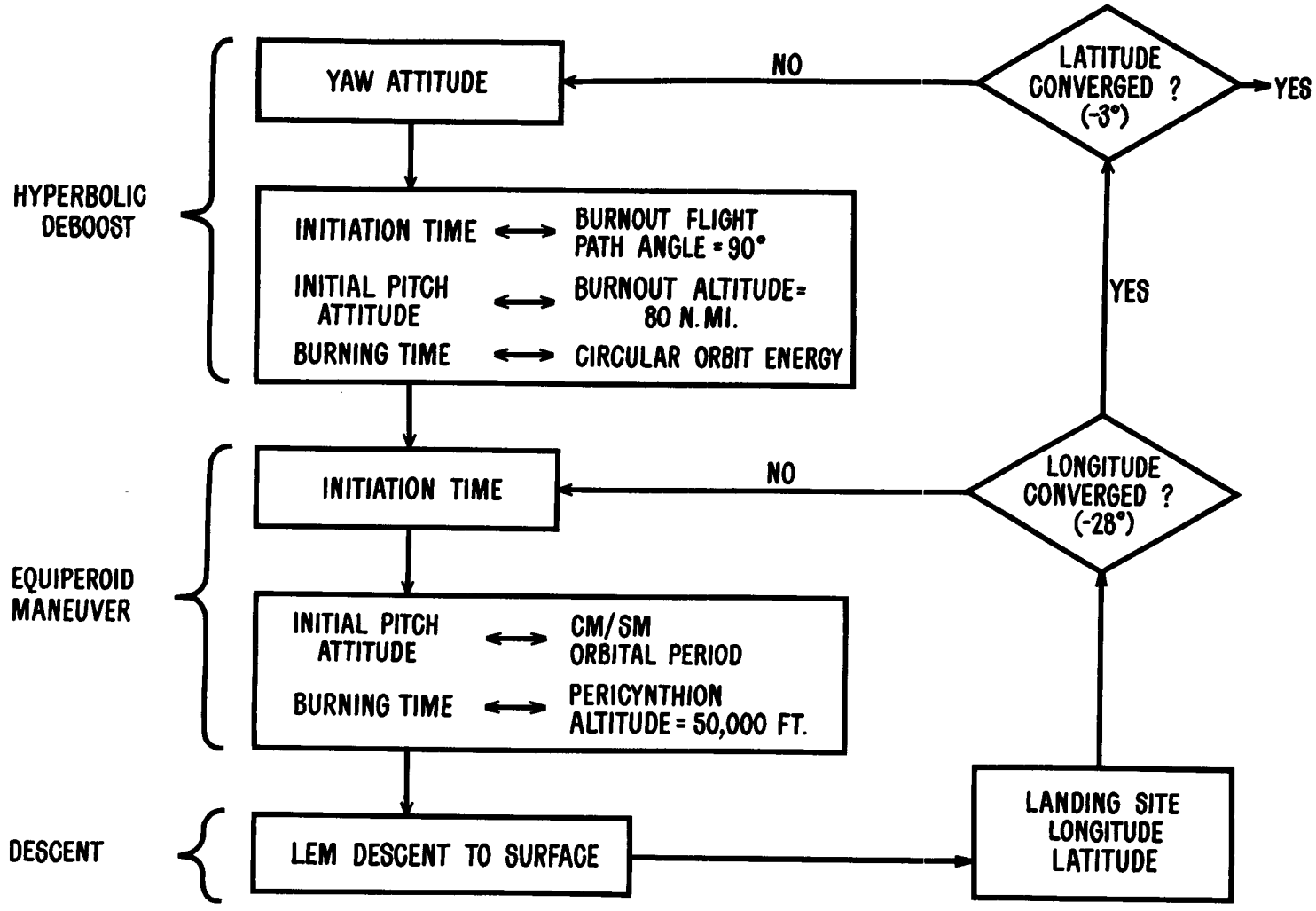
	Issue 2	Issue 1
HYPERBOLIC DEBOOST		
PERICYNTHION VELOCITY	8346 FT/SEC	8244 FT/SEC
PLANE CHANGE	~14.0 DEG	~5.0 DEG
DELTA VELOCITY	3443 FT/SEC	3026 FT/SEC
SPECIFIC IMPULSE	323 SEC	315 SEC
CIRCULAR ORBIT		
INCLINATION	175.01 DEG	174.85 DEG
ASCENDING NODE	191.56 DEG	299.06 DEG
LEM ASCENT		
SPECIFIC IMPULSE	307 SEC	325 SEC
THRUST	3500 LBF	3000 LBF
PROPELLANT FLOW RATE	11.40 LBM/SEC	9.23 LBM/SEC
PLANE CHANGE	0.3 DEG	0.3 DEG
DELTA VELOCITY	5969.1 FT/SEC	6022.4 FT/SEC
BURNOUT WEIGHT	4639 LBM	4773 LBM
MANEUVER ANGLE	~8 DEG	~10 DEG

THIS DOCUMENT CONTAINS INFORMATION AFFECTING THE NATIONAL DEFENSE OF THE UNITED STATES WITHIN THE MEANING OF THE ESPIONAGE LAWS, TITLE 18 U.S.C. SECS. 793 AND 794. ITS TRANSMISSION OR THE REVELATION OF ITS CONTENTS IN ANY MANNER TO AN UNAUTHORIZED PERSON IS PROHIBITED BY LAW.

RETURN PHASE

	Issue 2	Issue 1
RETURN BURN		
DELTA VELOCITY	3720 FT/SEC	3113 FT/SEC
BURNOUT WT.	23413 LB	26332 LB
RETURN TIME	63.6 HRS.	67.8 HRS
RETURN INCLINATION	43.38 DEG.	37.64 DEG.
RE-ENTRY		
LANDING SITE	SAN ANTONIO, TEX.	WOOMERA, AUSTRALIA

DESCENT TARGETING LOGIC



ASCENT TARGETING LOGIC

	CONTROL PARAMETERS	CONSTRAINTS AT CUTOFF
ASCENT TO HOHMANN TRANSFER ELLIPSE	LAUNCH AZIMUTH	OUT OF PLANE COORDINATE** = 0 ± 50 FT
	HIGH PITCH RATE BURNING TIME	ALTITUDE = 50,000 FT
	LOW PITCH RATE	FLIGHT PATH ANGLE = 90°
	YAW RATE	OUT OF PLANE VELOCITY = 0 ± .10 FT/SEC
	CUTOFF ON CIRCULAR ORBIT ENERGY	

	CONTROL PARAMETERS	CONSTRAINTS AT RENDEZVOUS
ASCENT TO HOHMANN TRANSFER ELLIPSE	LIFTOFF TIME	TANGENTIAL COORDINATE = 0 ± 200 FT
	BURNING TIME INCREMENT FOR TRANSFER ENERGY	RADIAL COORDINATE = 0 ± 200 FT
RENDEZVOUS MANEUVER*	BURNING TIME	TANGENTIAL VELOCITY = 0 ± 1 FT/SEC
	PITCH ATTITUDE	RADIAL VELOCITY = 0 ± 1 FT/SEC
	YAW ATTITUDE	OUT OF PLANE VELOCITY = 0 ± .10 FT/SEC

* INITIATED AT APOCYNTHION OF HOHMANN TRANSFER ELLIPSE

** RELATIVE COORDINATE SYSTEM