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DETAILED CREW PROCEDURES FOR POWERED FLIGHT EVALUATION OF THE TRANSLUNAR INJECTION MANEUVER

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Flight Analysis Branch

MISSION PLANNING AND ANALYSIS DIVISION

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PROJECT APOLLO

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DETAILED CREW PROCEDURES FOR POWERED FLIGHT EVALUATION OF THE TRANSLUNAR INJECTION MANEUVER

By Charles T. Hyle

SUMMARY

Detailed procedures to enable the lunar mission flight crew to perform an inflight evaluation of the translunar injection maneuver (TLI) have been defined. Preignition, powered flight, and overspeed evaluation procedures and techniques are discussed and presented in a detailed flow chart. Undesirable flight conditions which could be induced by S-IVB or spacecraft malfunctions are protected against through use of onboard displays and data provided by the ground. In addition to providing required crew safety, a maximum opportunity to obtain a lunar mission is afforded through these techniques.

INTRODUCTION

Just prior to and through the TLI maneuver, the flight crew will be required to evaluate the behavior of the S-IVB. Should anomalies develop before ignition or during the burn, the crew will evaluate the available data and either inhibit, shut down, or continue the burn. This report provides the necessary preignition and powered flight data and the associated rationale to enable the crew to make the proper decision. The proper decision is extremely important because it may determine whether an alternate lunar mission can be flown after a non-nominal TLI or whether the flight must be aborted.

Note that this document may be incorporated into data priority techniques documentation following approval or corrections by the Apollo Abort Working Group. Procedures during earh parking orbit are a part of other documentation and are not included here.

INFLIGHT EVALUATION OF THE TRANSLUNAR INJECTION MANEUVER

For clarity this section is divided into three parts, each providing details on the related portion in the crew procedures flow chart. (See flow chart 1.) The flow chart is a sequential summary of all necessary actions and limiting conditions from just prior to TLI through injection.

Preignition Evaluation and Procedures

Prior to lift-off of the S-V, the crew will be provided with information similar to that shown in table I and figures 1 through 5. If the launch occurs as planned, this information will be adequate for TLI, but more than likely it will require updating because most of the parameters vary with launch azimuth. The updates provided during earth parking orbit (pad data) will also contain data required for a possible abort maneuver at 90 minutes after TLI. (See ref. 1.)

About fifteen minutes from TLI, the crew optical alignment sight (COAS) will be mounted to provide a gross attitude check on the S-IVB instrumentation unit (IU) at ignition. The COAS will also be required for the 90 minute abort. (Unlike the midcourse data priority techniques, these techniques make no distinction for whether TLI is on the first or second opportunity.) After aligning the two spacecraft attitude reference frames - stabilization control system (SCS) to the inertial measurement unit, (IMU) - the crew waits for Saturn time base six (TB6). This is an internally computed signal which starts the remaining sequencing through TLI. The most current TB6 initiated sequence is shown in table II. Shortly after TB6, the crew will use the DSKY to call the CM computer (CMC) thrust monitor program, P47. At present, the time at which the S-IVB will be commanded to ignition attitude has not been specified. This attitude is expected to be -3.5° below the horizontal at ignition and in the plane of motion. Assuming the desired attitude is obtained prior to ignition, the gross attitude check can be made with the COAS by measuring the crew line of sight to the horizon, which should be about +7.5° with the COAS referenced as shown in figure 6. The maximum misalignment to avoid a low perigee is shown in figure 7.

Powered Flight Evaluation

At 90 percent thrust the next phase will begin and is signaled to the crew by the engine status light. Because TLI begins in a 100-n. mi. circular orbit and well out of the atmosphere, no trajectory problems are likely. As a result, malfunction effects which eventually require engine shut down are excessive rates or attitude deviations. Limiting values of ±10 deg/sec and ±45° in both pitch and yaw have been determined in references 2 and 3.

Unless TLI occurs on the first or second opportunity of the originally intended launch azimuth, the crew will need to modify the gimbal angle histories of figures 1 and 2 in the following manner. Knowing the launch azimuth, the crew can use figure 3 to produce the initial pitch gimbal angle. Then figures 1 and 2 can be used to plot a very close estimate of the nominal burn attitude. The attitude deviation limits for S-IVB shutdown should then placed on this crew chart as shown in figures 4 and 5. Under certain conditions it may be necessary to have the ground transmit some points for the crew to plot.

Much mention has been made recently over the large attitude excursions that the Saturn propellant utilization (PU) system caused during the AS-501 mission. Best estimates to date indicate that this system will cause an attitude change of about 2°, which is considered negligible. An expanded version of the PU effect may be seen in figure 8, which was taken from reference 4. Current planning to retarget the S-IVB in the event of low propellant at TLI will produce additional changes to expected gimbal angle histories. Should this occur the ground-to-crew update described above will be used to provide the new nominal gimbal angle histories.

As shown in the detailed flow chart, the powered flight evaluation consists primarily of having the crew monitor rates, attitudes, and DSKY output in that order. Because of the redundant information available in the spacecraft additional logic is provided to insure that there are two positive indications of a malfunction. There is a redundant rate gyro package and an S-IVB rate light to provide rates. In addition to the IMU, the gyro display coupler (GDC), and an uncaged rate gyro package provide three vehicle attitude references. Having three systems each for rates and attitudes is convenient for determining if one system is malfunctioning.

As shown in the flow chart, the DSKY parameters are included primarily for crew information on the progress of the burn. Selected parameters such as inertial velocity, V_I, altitude rate, $\dot{h}$, altitude, h, and perigee, h_p, are checked against nominal values at specific burn times.

Non-nominal values will simply provide an indication to the crew that they may be required to perform a shutdown on the attitude limits. Typical variations due to platform drifts are shown for histories of V_I, $\dot{h}$, and perigee in figures 9 through 11. As discussed below, crew backup of the TLI Saturn guidance cutoff will require the V_I parameter. CMC program 47 is the thrust monitor program used during TLI and is obtained by DSKY input of "verb 37, enter 47 enter." "Verb 16, noun 62 enter" calls V_I, h, and h. "Verb 82 enter" provides the orbital parameters.

Crew Backup of the S-IVB Guidance Cutoff

Depending on the launch azimuth and the earth-moon geometry at a specific time, the required plane change during TLI may be essentially zero. Also, to ensure adequate propellant loading, a flight geometry reserve (FGR) is defined for the largest possible plane change requirements. Therefore, TLI could occur at a time when up to 9101 lb of excess propellant would be left after completion of TLI. If, for some reason, the S-IVB guidance cutoff signal was not acknowledged, an additional burn time of 18.9 seconds could occur unless the crew took some action. This extra burn time does not include the FPR which could conceivably be available for an overspeed. If the S-IVB continued thrusting the 18.9 seconds, more than 1000 fps would be added prior to a low-level-sensor, fuel-depletion cutoff. This information was obtained from reference 4 and does not reflect current weight data. As shown in the previously unpublished results of a Lunar Mission Analysis Branch midcourse processor test - figure 12 - even short delay times, such as three hours, practically eliminates a lunar mission involving the LM. That is ΔV MCC cost is more than available. Although most other launch opportunities will result in a small TLI ΔV increase following depletion shutdowns, the fact remains that a crew backup to the S-IVB cutoff is required.

One logical choice for enabling the crew to perform this cutoff backup is the entry monitoring system (EMS) ΔV counter. The second technique, as shown in the flow charts, uses the DSKY display of inertial velocity. The last few seconds of a typical TLI showing an EMS ΔV and V_I change is given in figure 13. Because of inherent errors in the EMS, a bias must be included in any TLI backup cutoff value. Using an accuracy of 1.3 percent for the EMS means a typical bias of about 137 fps is required. Because the rate of change of velocity is about 50 ft/sec^2 at the end of TLI, the nearest consistent velocity increment to be read in the V_I DSKY register would be about 150 fps. Therefore, a bias of 150 fps will be added to the expected TLI cutoff V_I. The variation of TLI cutoff velocity across a launch window for first and second opportunity taken from reference 5 is shown in figure 14. It can be seen that these nominal variations will definitely require an update to the pad data of table I if launch does occur on time. As shown in the detailed flow chart, the crew may begin preparation for the backup action about 30 to 40 seconds prior to nominal cutoff.

Use of the previously described backup values does not eliminate all problems however, as can be seen again in figure 12. Since a 3-second overspeed can occur, a 150-fps TLI velocity increase may result. This means that even a midcourse at 3 hours after TLI costs about 500 fps, which may eliminate the lunar landing. Even if the EMS inaccuracy did not exist, reducing the required time delay for backup cutoff to 1 second still leaves a very high midcourse requirement. Since a proper shutdown by the S-IVB is more probable than a backup shutdown, it is more advisable to use the equivalent 3-second delay than risk an early shutdown with a 1-second delay.

The SII/S-IVB switch should be used for the backup cutoff as opposed to the rotational hand controller to prevent a possible inadvertent separation.

CONCLUSIONS

Detailed procedures to enable the lunar mission flight crew to perform an inflight evaluation of the TLI maneuver have been defined. Preignition, powered flight, and overspeed evaluation procedures and techniques are discussed and tied together in a detailed flow chart. Undesirable flight conditions which could be induced by S-IVB or spacecraft malfunctions are protected against through use of onboard displays and data provided by the ground. In addition to providing required crew safety, maximum opportunity to obtain a lunar mission is afforded through these techniques. Pending possible changes by a MSC/MSFC retargeting group and review by the Apollo Abort Working Group, these procedures will be incorporated in the Missions F and G earth parking orbit and translunar injection techniques documentation.

TABLE I.- PAD MESSAGE FOR TRANSLUNAR INJECTION[a]

[First and second launch opportunity]

Parameter	Description
	(a) Translunar injection monitor
TB6	Predicted time of time base six
T_b	Predicted time span of maneuver referenced to 90% thrust
P, Y, R	IMU gimbal angles at ignition
ΔV	Predicted EMS velocity at injection
ΔV_B	EMS ΔV for cutoff backup
V	Predicted inertial velocity displayed by the DSKY at injection
V_B	Inertial velocity for cutoff backup
P, Y, R_{co}	IMU gimbal angles at injection
	(b) TLI cutoff-plus-90-minute abort
GETI	Ground elapsed time of abort maneuver ingition, hr:min:sec
ΔV_c	Change in velocity magnitude, fps
ϕ_L	Latitude of resultant landing point, + north
λ_L	Longitude of resultant landing point, + east
T_{FF}	Transit time from GETI to 400 000-ft altitude
V_{EI}	Inertial velocity at 400 000-ft altitude
γ_{EI}	Inertial flight-path angle at 400 000 ft altitude
P, Y, R	IMU gimbal angles at SPS ignition attitude

[a]These parameters are also provided preflight as well as in earth parking orbit.

TABLE II.- SATURN LAUNCH VEHICLE SEQUENTIAL ITEMS

RELATED TO S-IVB SECOND BURN (TLI)

LV digital computer	Event
TB6 - 9 sec	LV digital computer check for TLI inhibit from spacecraft
	(TB6 will be attempted one revolution later.)
TB6	LV digital computer passes vector convergence test and initiates restart preparations.
TB6 + 45 sec	S-IVB control system hydraulic pump starts.
TB6 + 50 sec	S-IVB propellant chilldown pumps start.
TB6 + 85 sec	LV digital computer check for TLI inhibit from spacecraft.
	(Functions accomplished in TB6 for control systems and propellant systems are reconfigured to coast.)
TB6 + 86 sec	S-IVB propellant tanks repressurization is initiated. Spacecraft indicators of tank pressure will increase.
TB6 + 346 sec	Ullage engines fire. Spacecraft indicator is turned on.
TB6 + X	Maneuver to restart attitude is initiated.
TB6 + 379 sec	LV digital computer starts continual checks for TLI inhibit from spacecraft.
	(Spacecraft indicator of S-II dual plane separation lamp lights.)
TB6 + 440 sec	Last LV digital computer check for TLI inhibit from spacecraft.
	(Functions issued in TB6 will be recycled to coast mode if required. TB6 will be attempted one revolution later but without use of the O_2 H_2 burner. S-II lamp is turned off.)

TABLE II.- SATURN LAUNCH VEHICLE SEQUENTIAL ITEMS

RELATED TO S-IVB SECOND BURN (TLI) - Concluded

LV digital computer	Event
TB6 + 450 sec	S-IVB engine starts.
TB6 + 460.2 sec	Shut off APS.
TB6 + 460.4 sec	J2 at 90% thrust
TB6 + 463.0 sec	Activate PU system
TB6 + 466.4 sec	Initiate IGM guidance
TB6 + X ($\approx 503 < x < 533$)	Final mixture ratio shift.
TB7	J2 thrust cutoff, TB6 + 330 typical translunar injection.

NOTE: The times shown above are representative and may change with future LV digital computer programs or SLV requirements revisions.

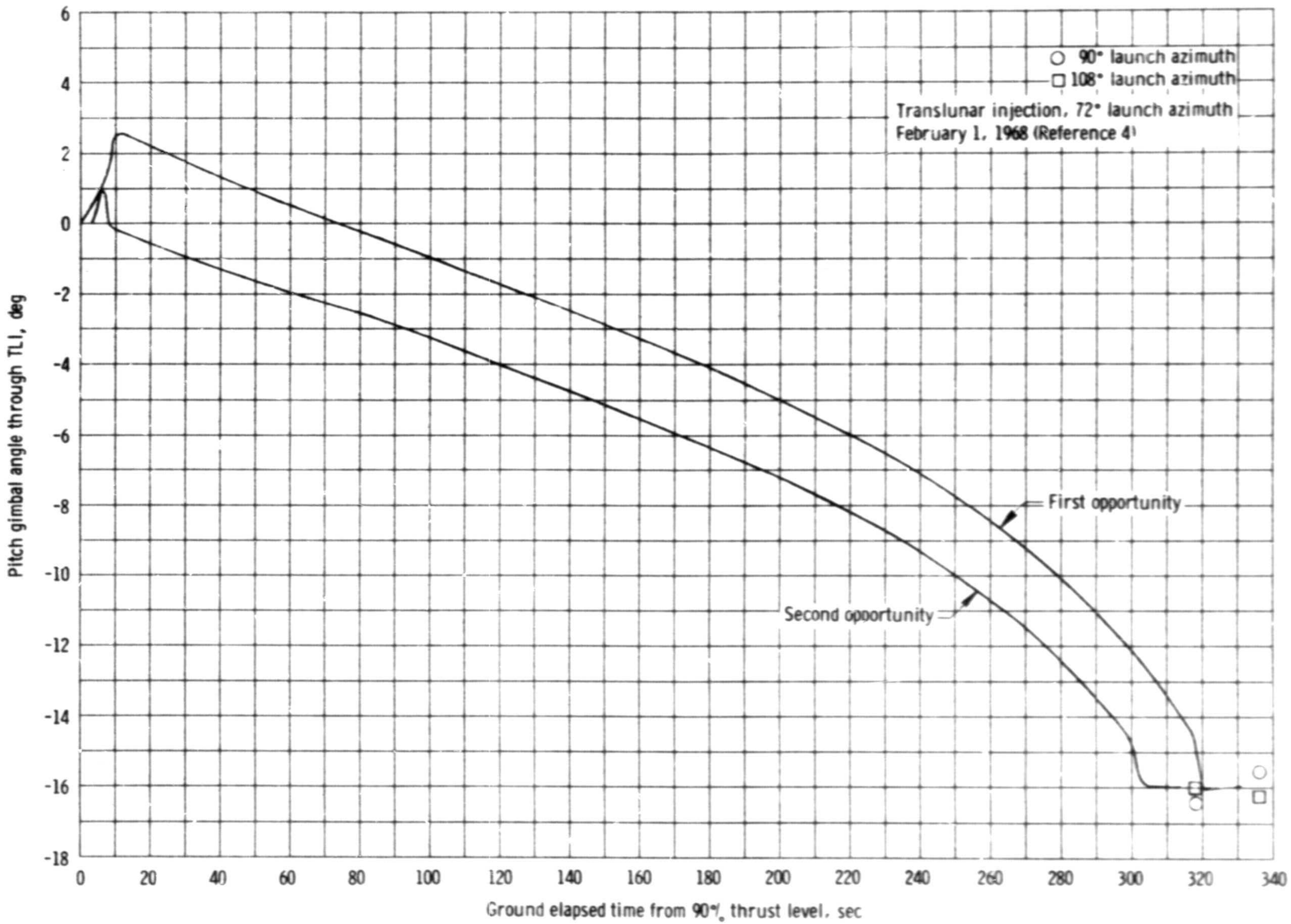


Figure 1. - Pitch gimbal angle variation with TLI injection opportunity.

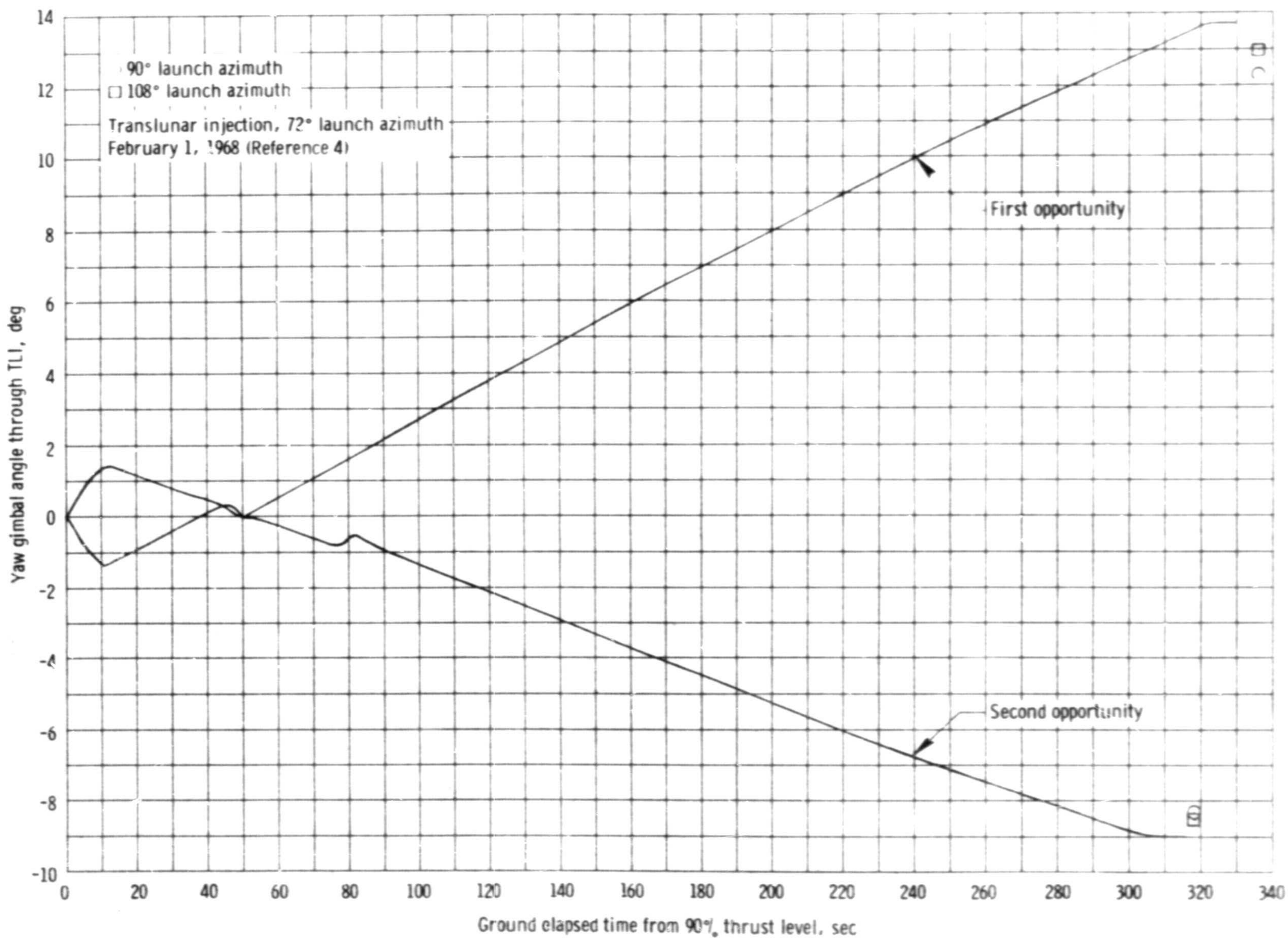
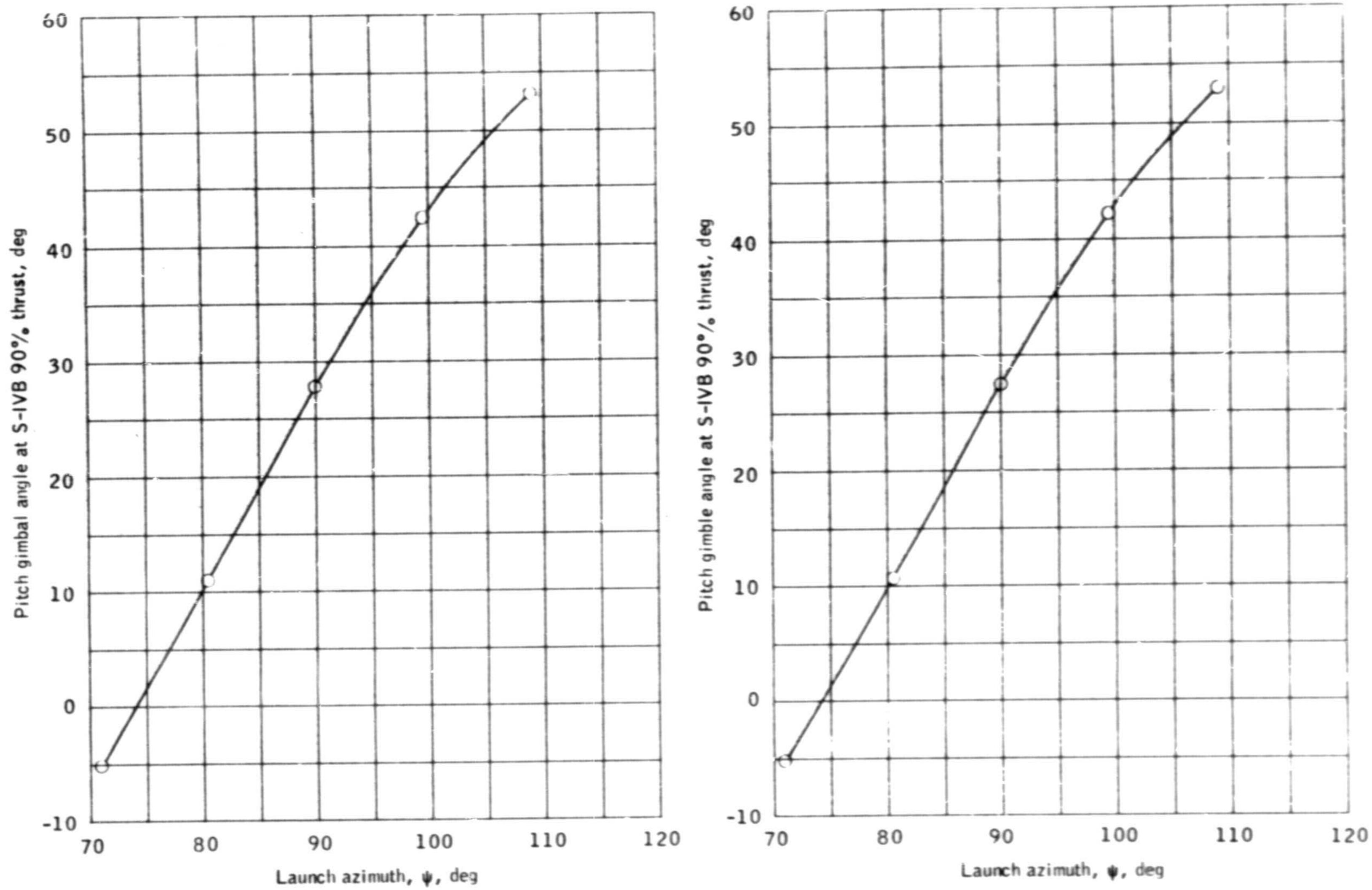


Figure 2. - Yaw gimbal angle variation with TLI injection opportunity.



(a) First opportunity.

(b) Second opportunity.

Figure 3. - Pitch gimbal angle at 90% thrust as a function of launch azimuth.

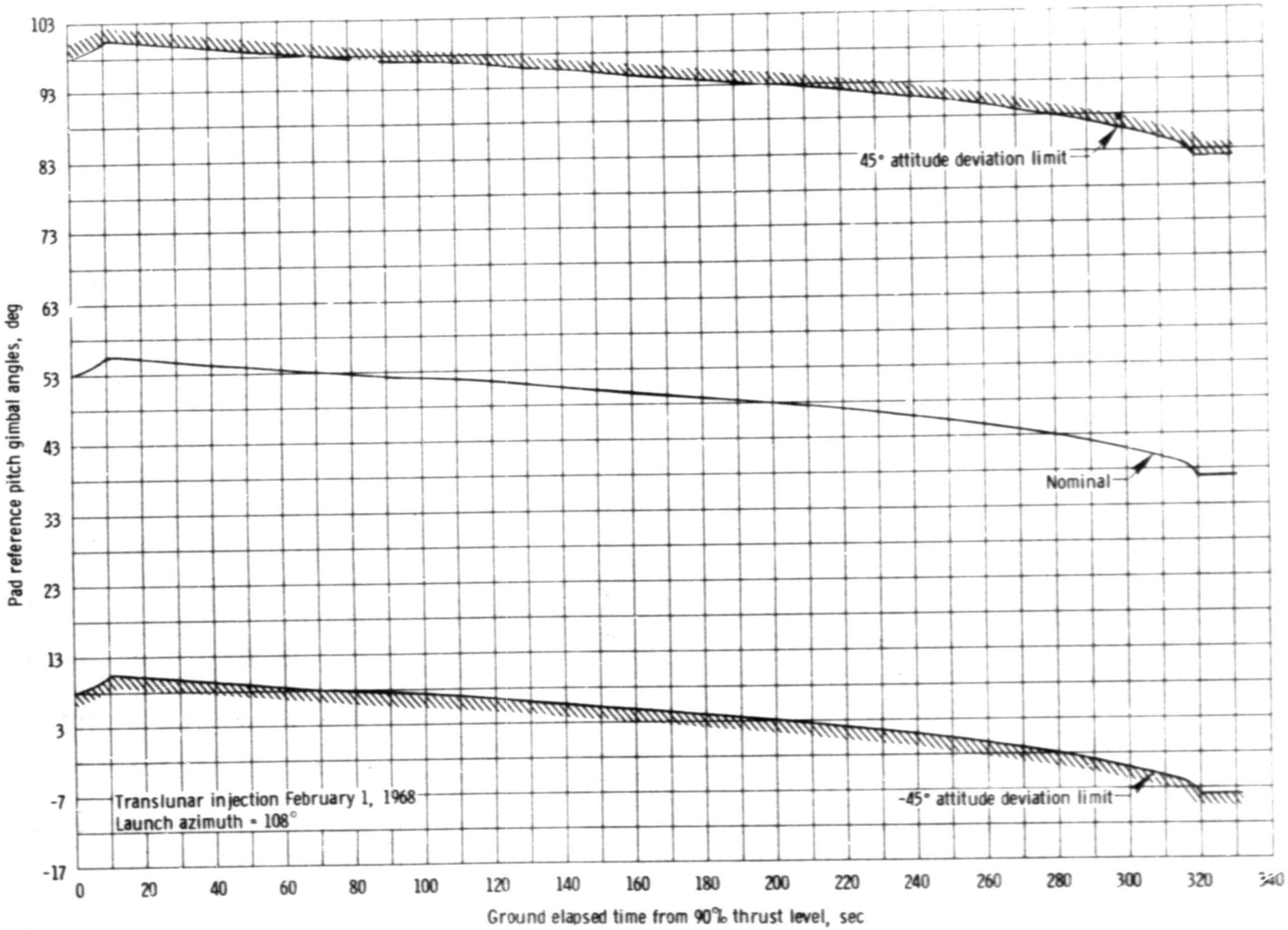


Figure 4. - Typical TLI pitch gimbal angle history and attitude deviation limits.

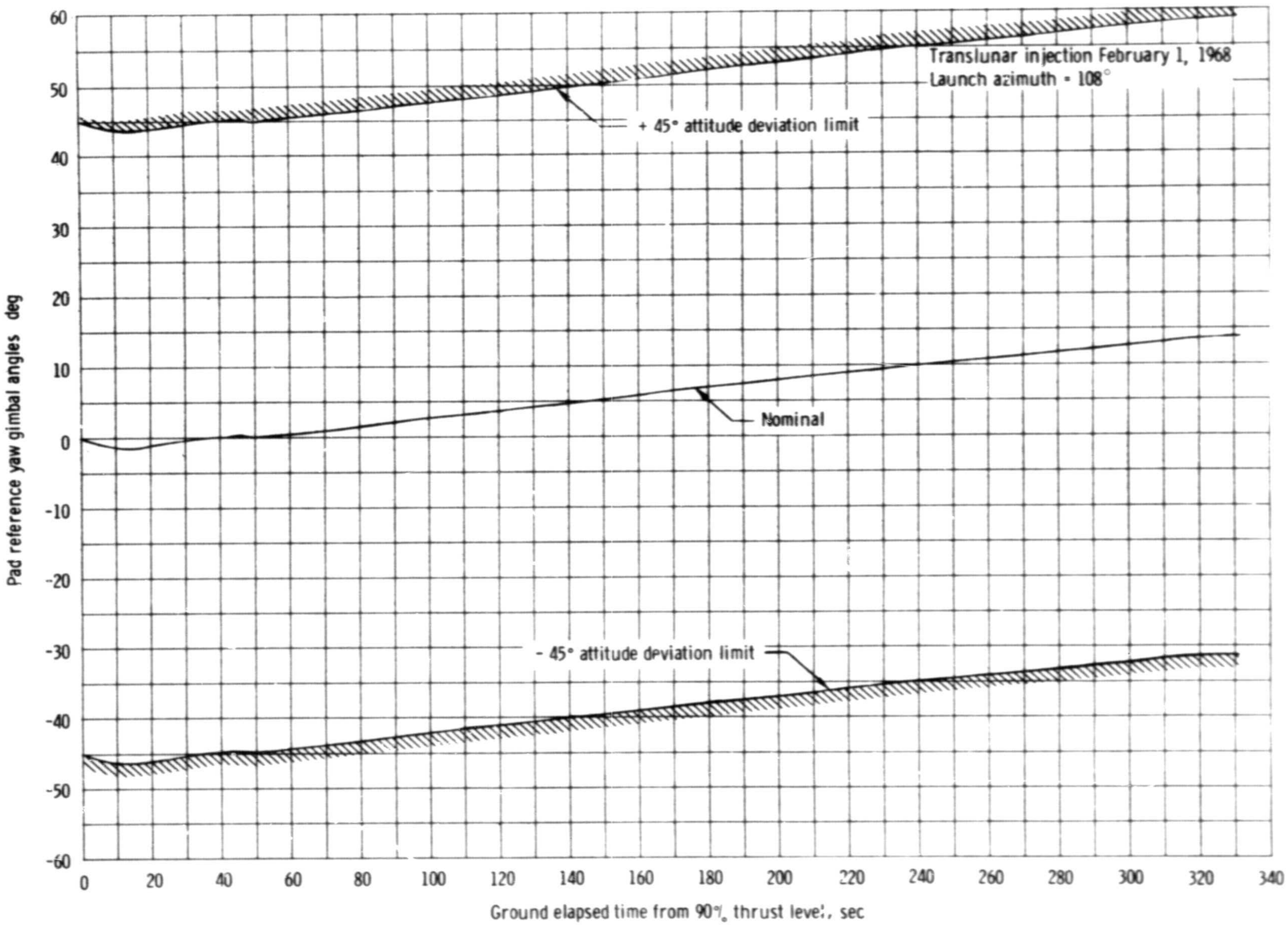


Figure 5. - Typical TLI yaw gimbal angle history and attitude deviation limits.

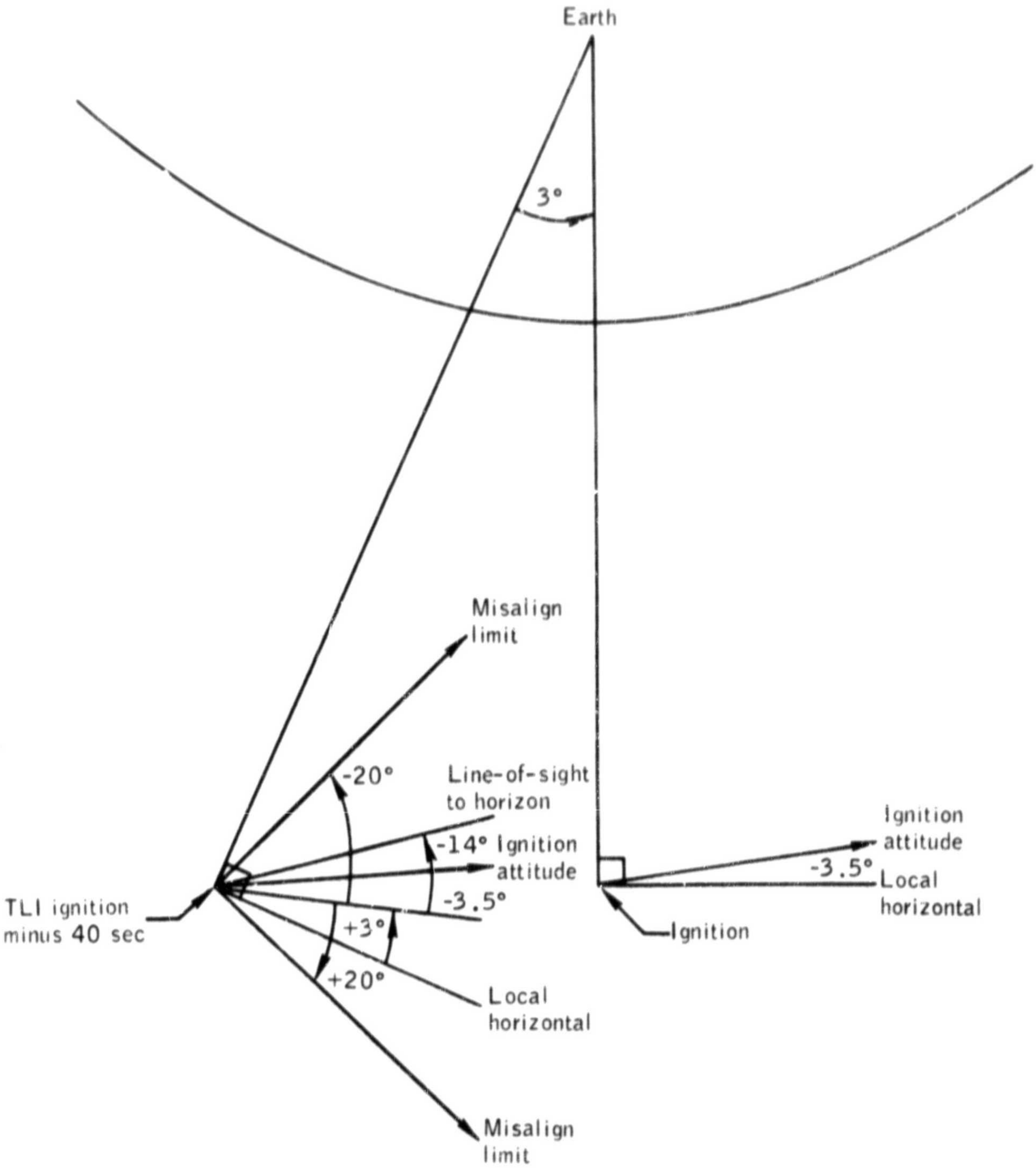


Figure 6. - Ignition geometry and misalignment limits.

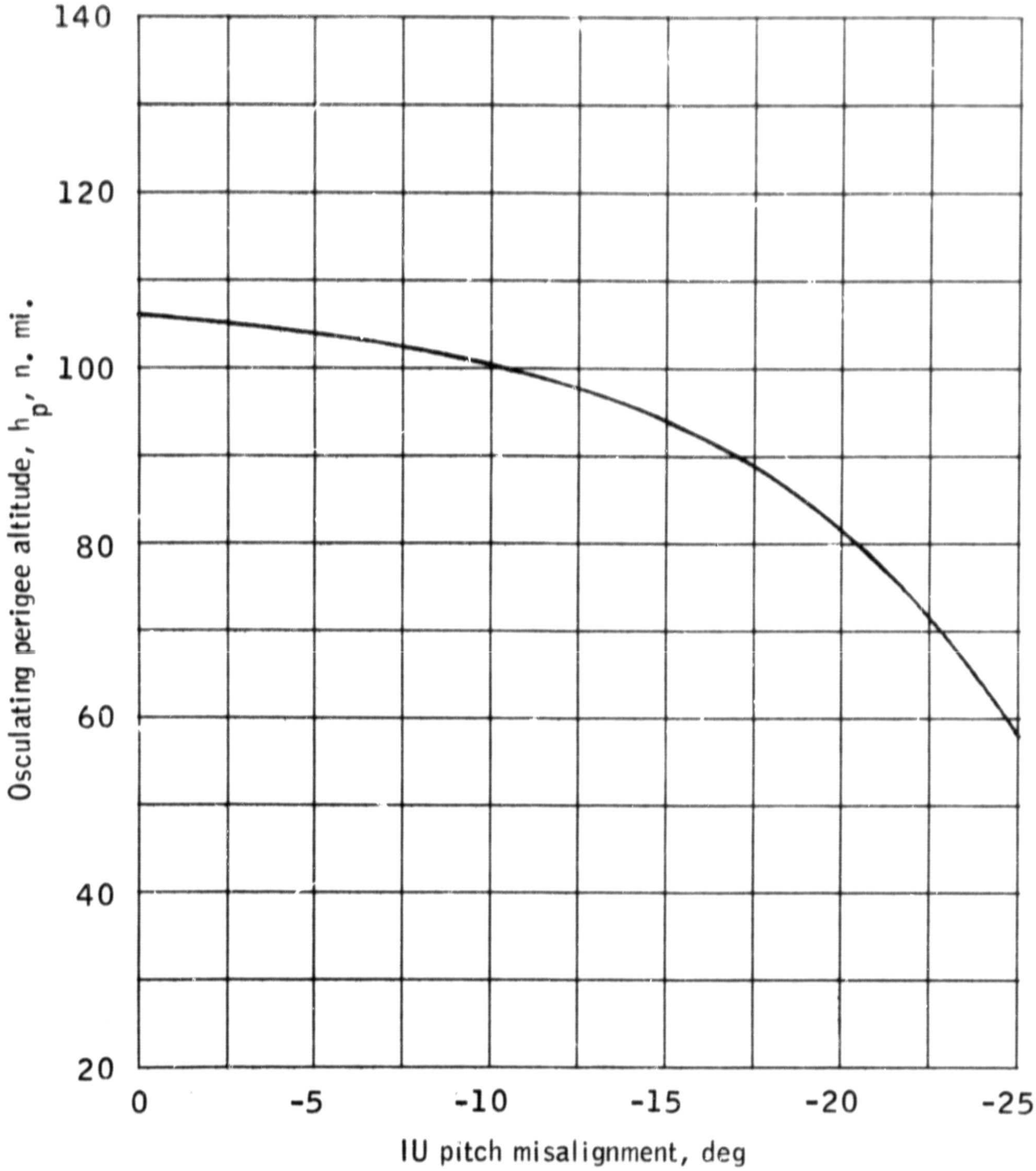
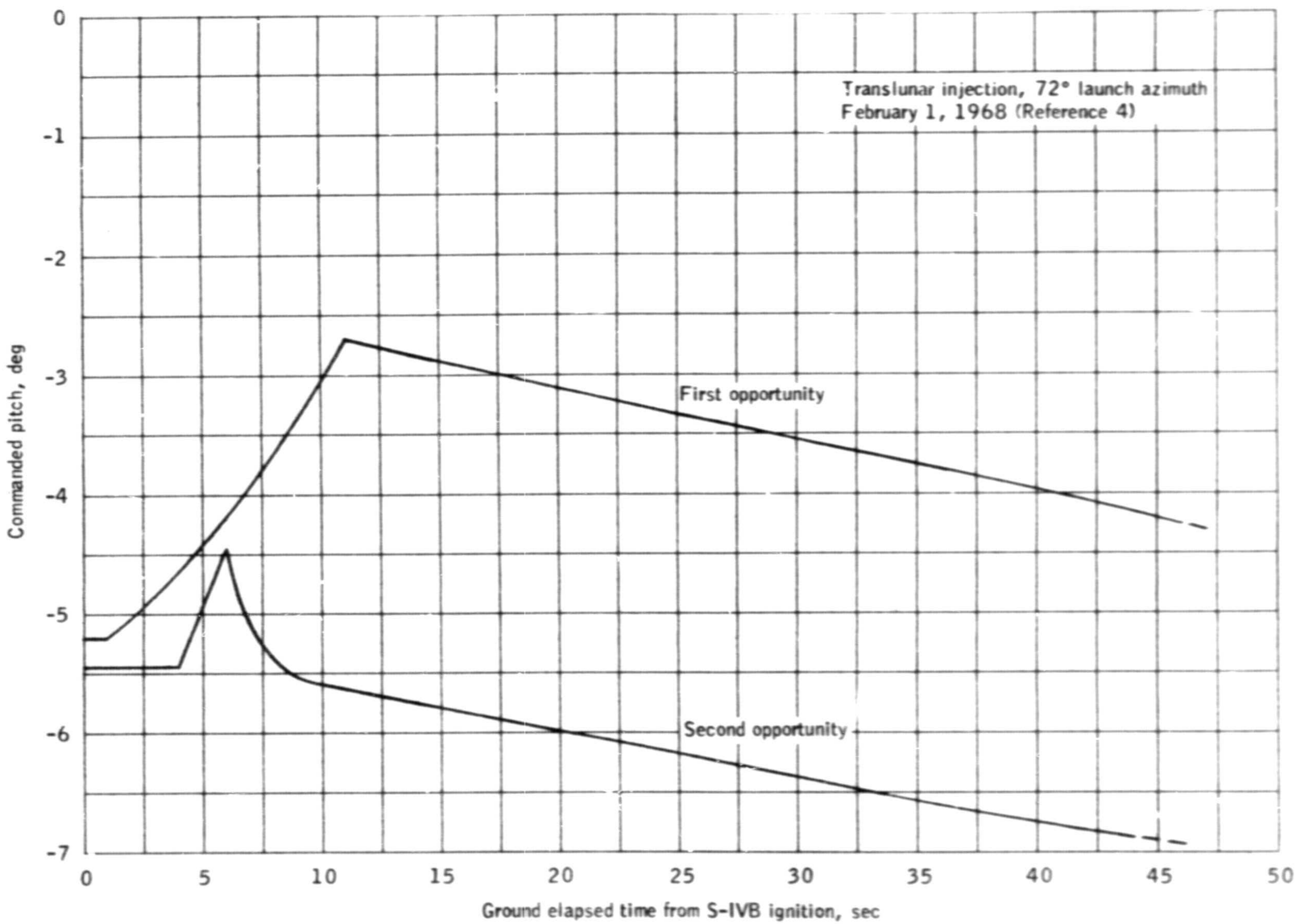
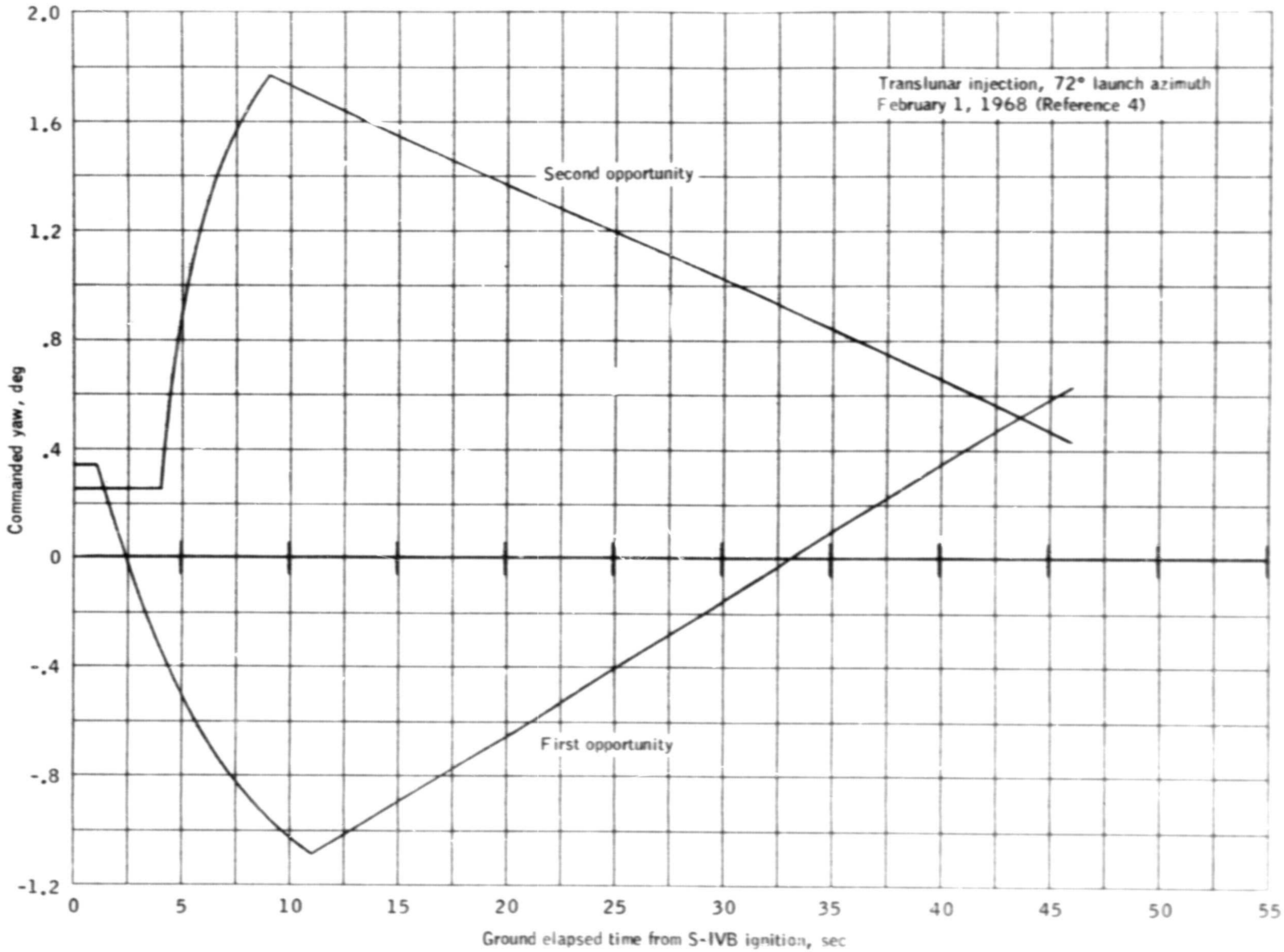


Figure 7.- Effects of negative pitch misalignment during TLI on perigee.



(a) Commanded pitch.

Figure 8.- Typical attitude excursions during first opportunity TLI due to the S-IVB propellant utilization system.



(b) Commanded yaw.

Figure 8.- Concluded.

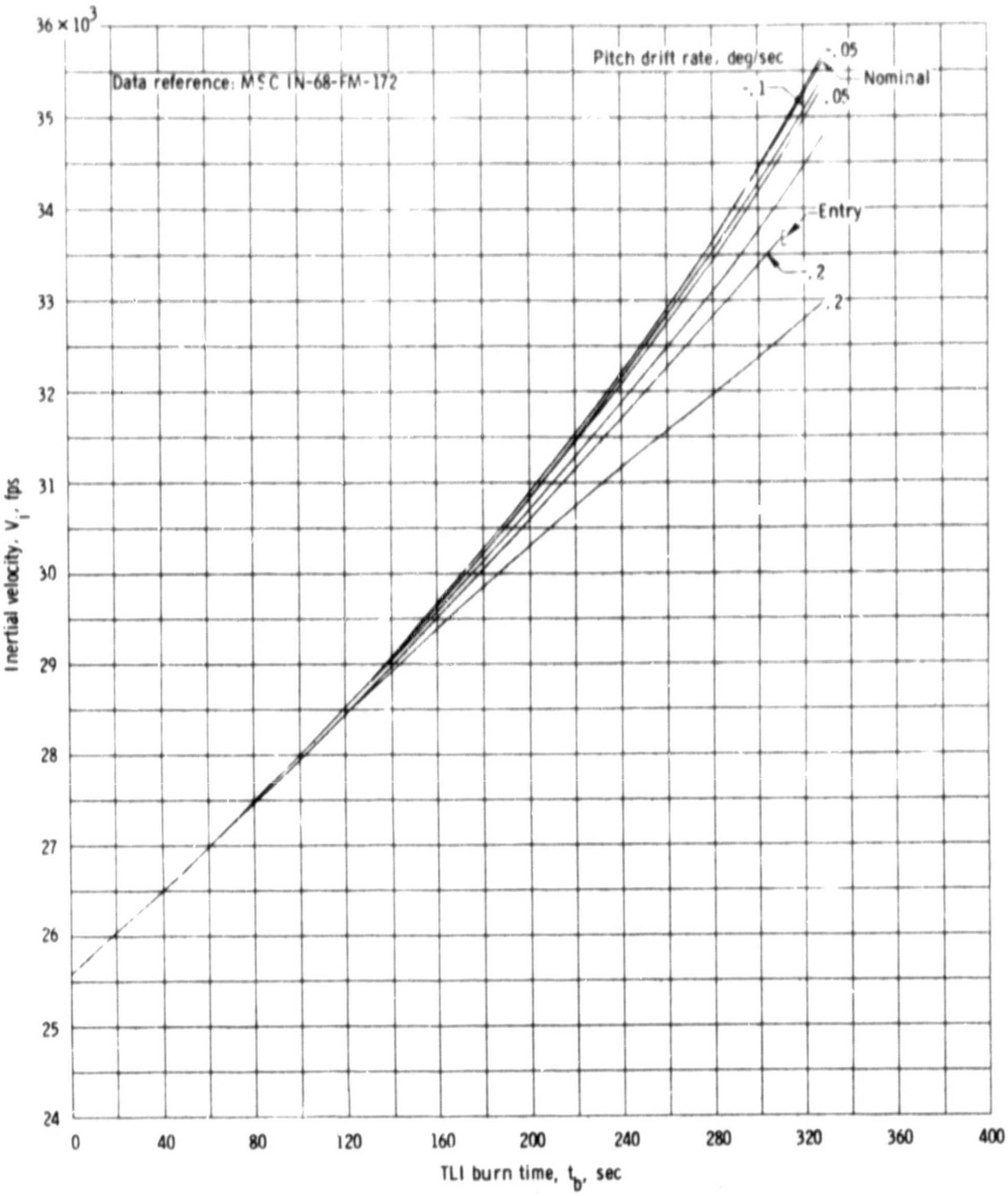


Figure 9. - Inertial velocity time histories for various drift rates during TLI.

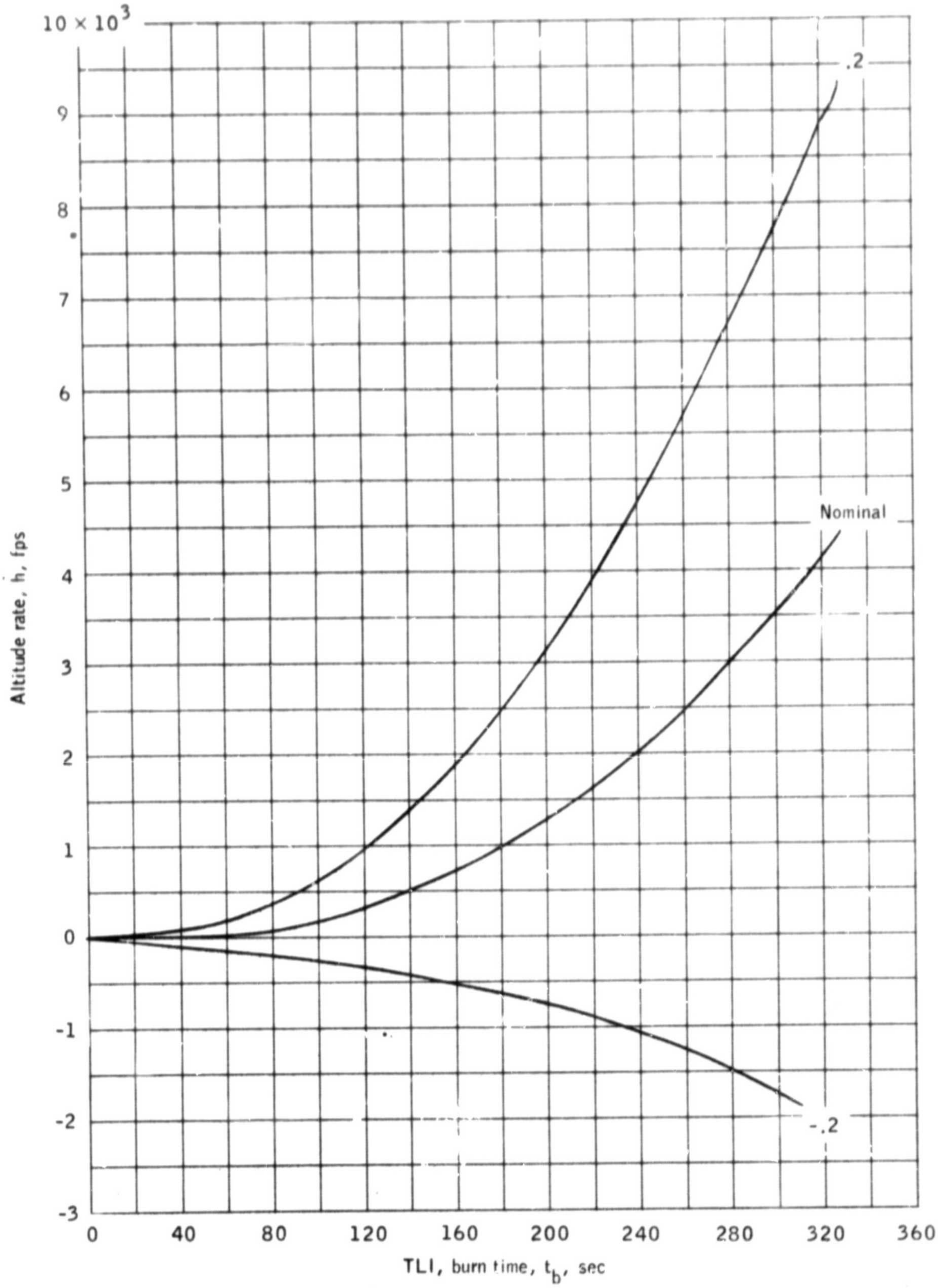


Figure 10.- Altitude rate time histories for various drift rates during TLI.

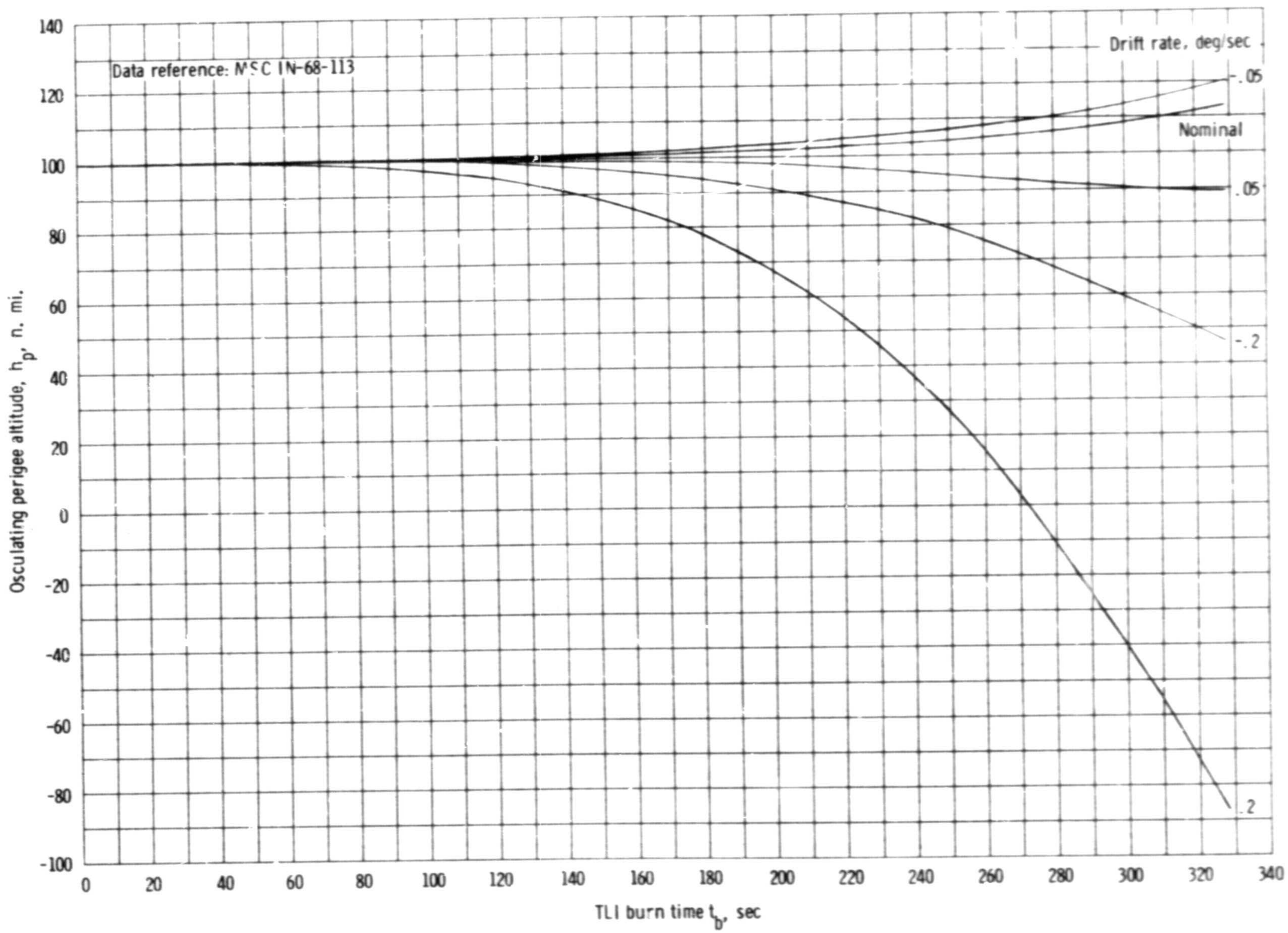
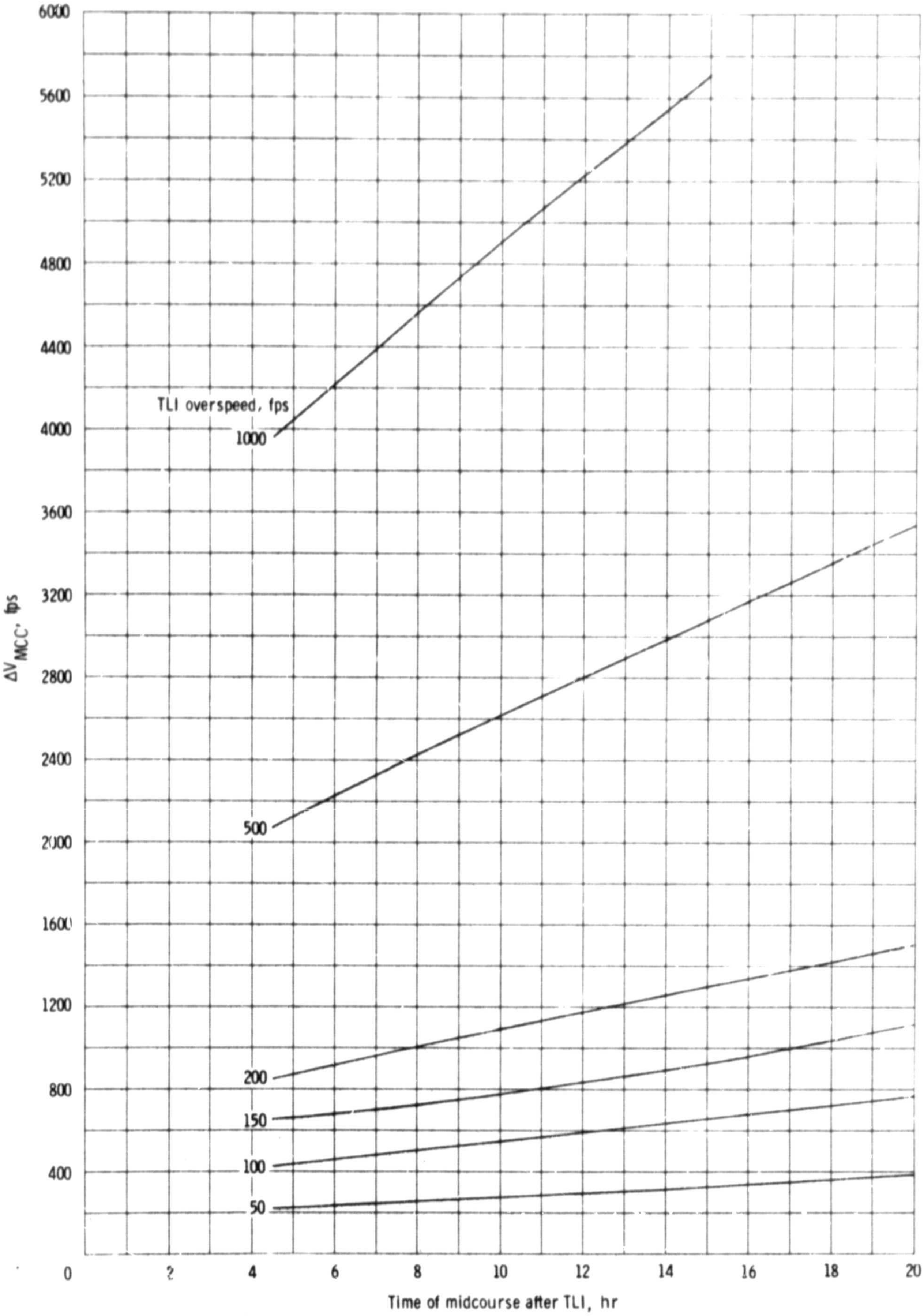


Figure 11. - Perigee histories for various drift rates during TLI.



(a) TLI overspeed.

Figure 12. - Effects of TLI overspeeds on midcourse ΔV.

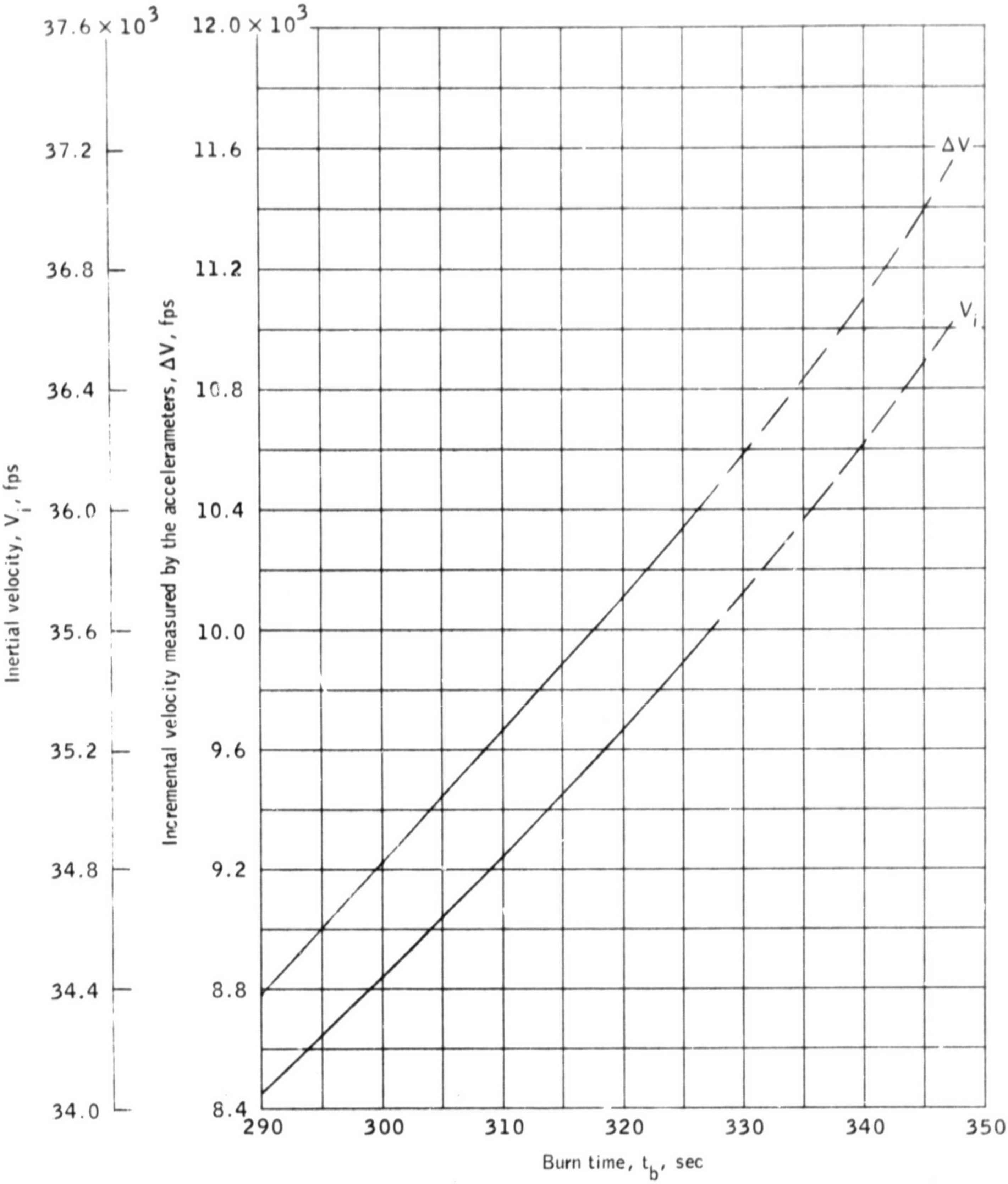


Figure 13.- Inertial velocity and EMS velocity near TLI injection.

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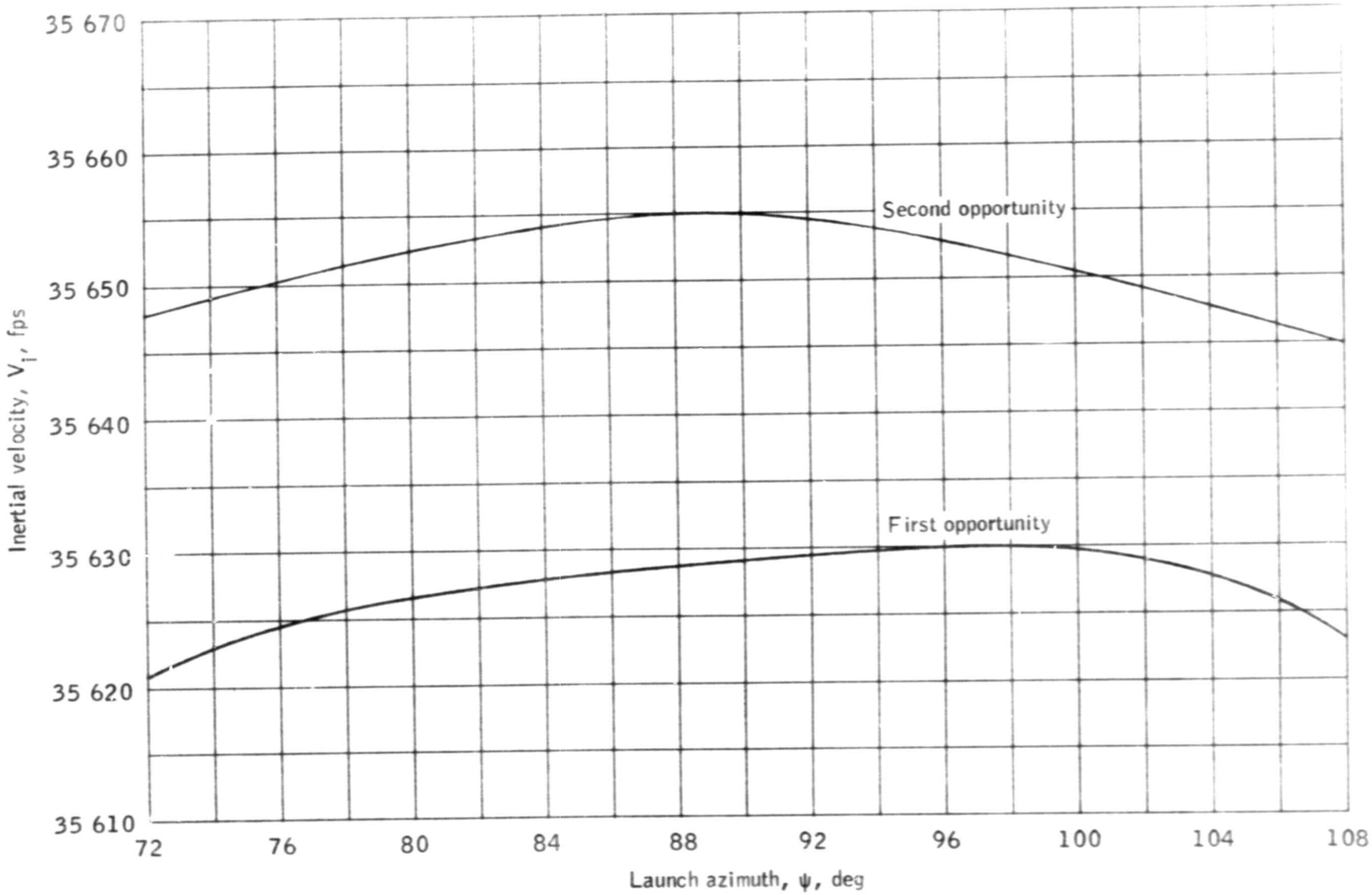
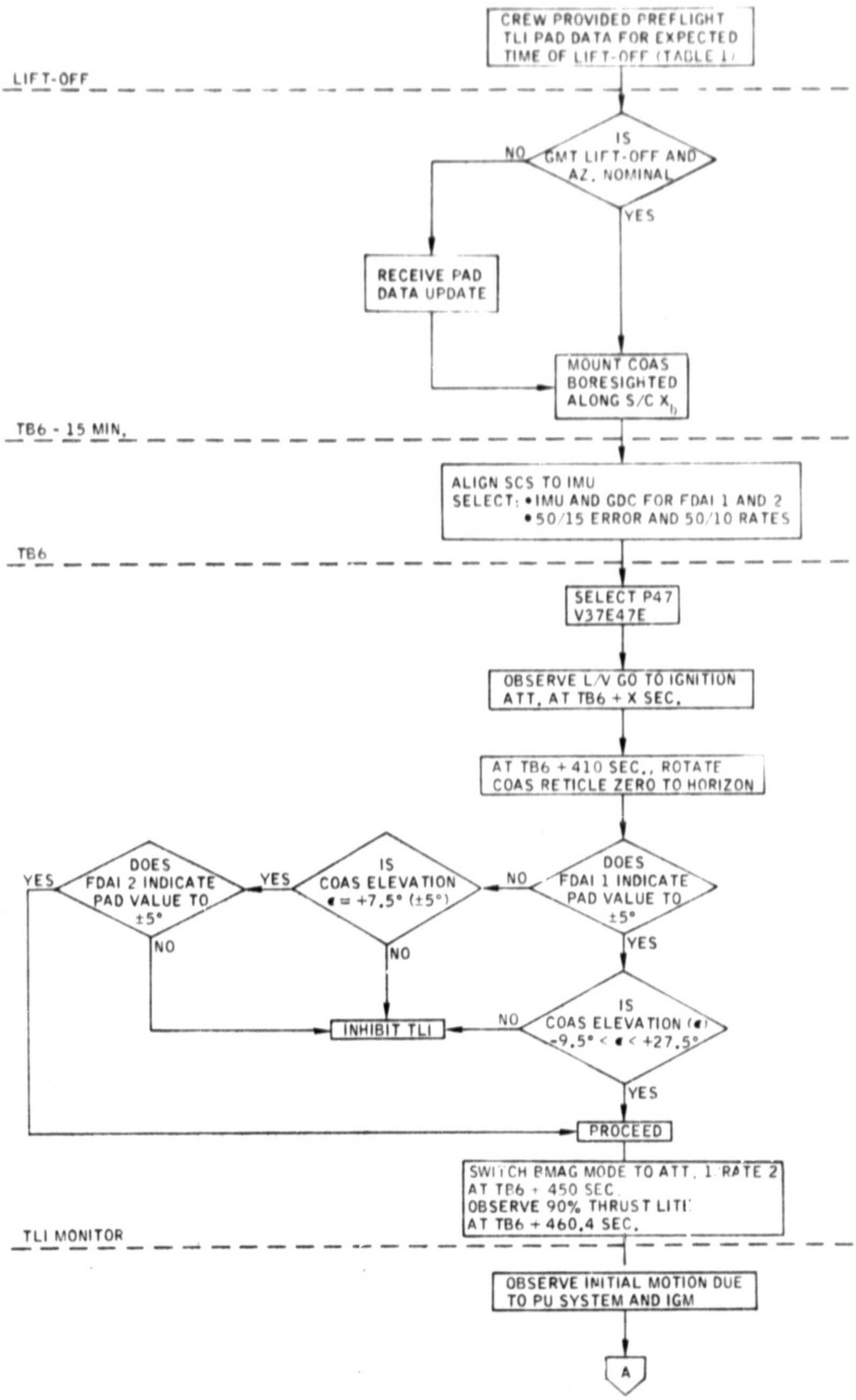
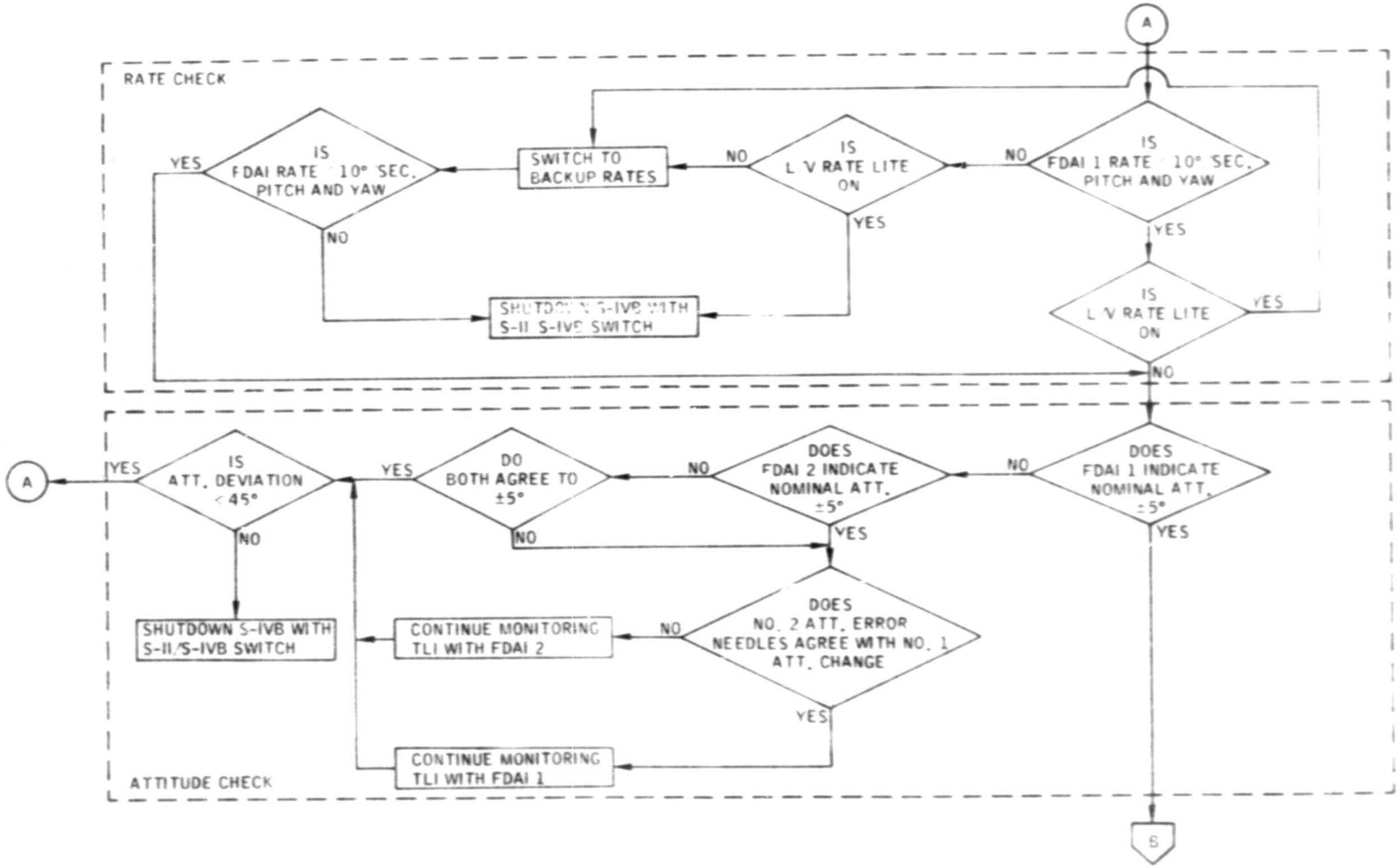


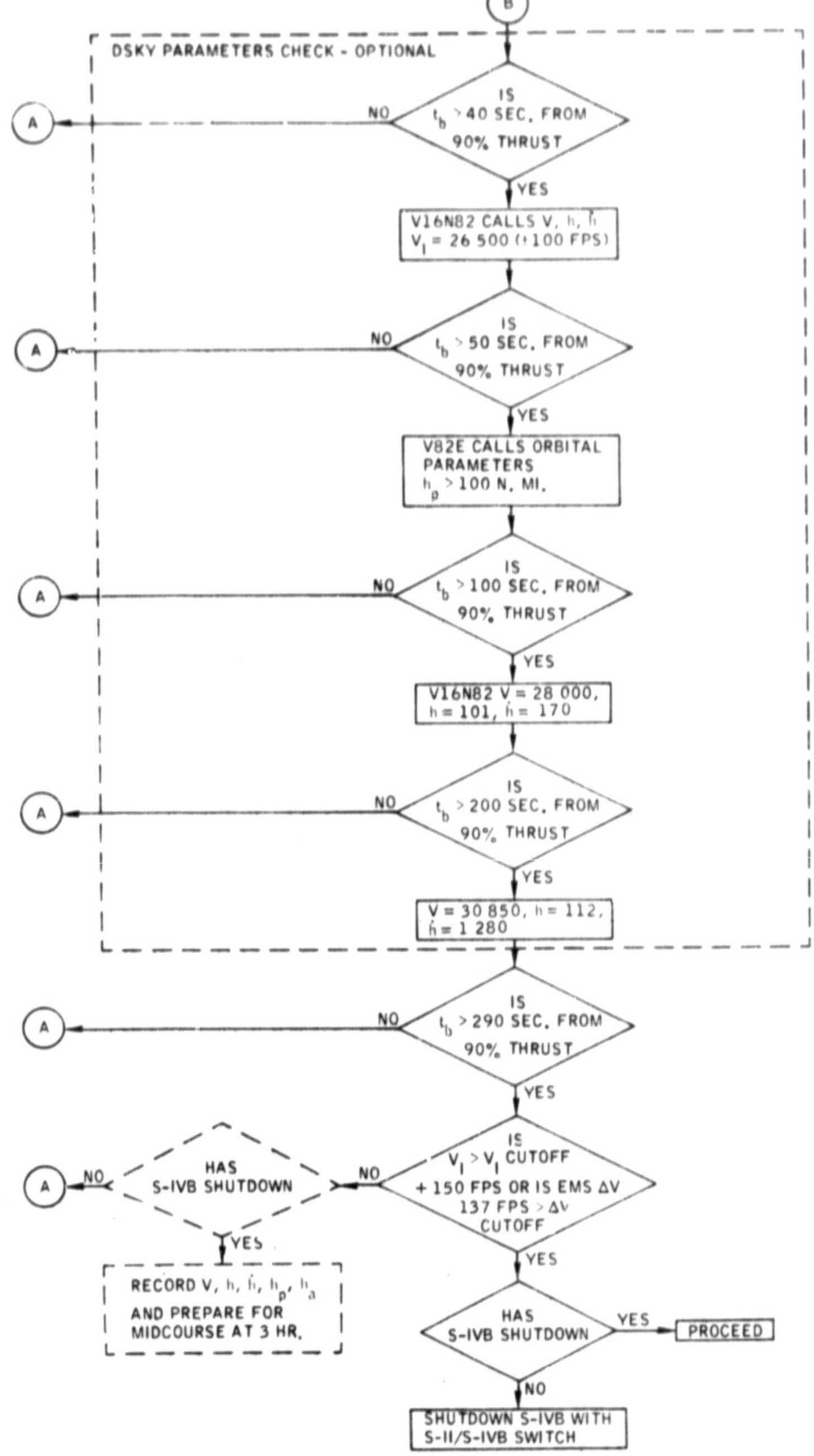
Figure 14.- Injection velocity variation with launch azimuth.



Flow chart I.- Detailed procedures for inflight evaluation of the translunar injection maneuver.



Flow chart I - Detailed procedures for inflight evaluation of the translunar injection maneuver - Continued



Flow chart I.- Detailed procedures for inflight evaluation of the translunar injection maneuver - Concluded.

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