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PRELIMINARY BACKUP ABORT PROCEDURES FOR ABORTS OCCURRING DURING TRANSLUNAR INJECTION

By

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Flight Analysis Branch

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By Bobbie D. Weber

SUMMARY

An analysis was conducted to determine the feasibility of performing a fixed-attitude abort maneuver for premature S-IVB shutdowns during the translunar injection (TLI) maneuver. The results show it is operationally feasible to perform a fixed-attitude, fixed delay time abort following a premature S-IVB shutdown. The backup abort procedures to be followed for this type abort are presented.

INTRODUCTION

During the past several months, personnel from MPAD and TRW have met to establish abort procedures for the lunar landing mission. References 1 and 2 represent the culmination of this effort for TLI abort procedures. Noticeably absent from these references are procedures to follow if a contingency should arise causing the S-IVB to be shutdown prematurely and an immediate abort to be initiated. The reason such procedures were not defined was that the contingencies requiring such action had not been defined. To date such contingencies still have not been defined. However, we cannot eliminate the possibility of such contingencies occurring. We assume that, if such contingencies should occur, the effect would be near catastrophic and the procedures to follow should be as safe and simple as possible. Therefore, this study was initiated to determine the feasibility of performing fixed-attitude abort maneuvers using the earth's horizon as an attitude reference and to prescribe the backup abort procedure to follow for a fixed-attitude abort.

A fixed-attitude midcourse maneuver was also considered at a fixed time following the abort as a means of obtaining the entry corridor.

Investigations are currently being conducted by the Flight Analysis Branch to establish a final abort procedure based on a more thorough analysis of operational considerations such as preabort and postabort tracking, propellant requirements for a fixed-attitude midcourse maneuver, horizon lighting, and postabort landing sites resulting from different TLI positions.

CONSIDERATIONS IN THE ABORT STUDY

When this study was initiated, in order to keep the procedures as simple as possible, we wanted to keep three parameters constant. The three parameters were the delay time (t_d) of the abort maneuver from S-IVB cutoff, the magnitude of velocity to be applied (ΔV) for the abort maneuver, and the attitude angle (Ψ) of the abort maneuver measured between the thrust vector and the pilot's line of sight to the horizon. Other considerations were that the abort maneuver should not require excessive amounts (greater than half) the ΔV available, the fixed attitude should allow the horizon to appear near the center of the window, and time from abort to entry should be equal to or less than the return times that could be realized by preparing for and executing an abort maneuver using the primary guidance navigation and control system (PGNCS).

Abort Attitude

After reviewing some work done by TRW on fixed-attitude aborts (ref. 3, 4, and 5), we decided to eliminate using the near horizon (horizon in the direction of motion - fig. 1) as an attitude reference for the abort maneuver. Also, we decided to eliminate attitudes in which the crew would be oriented heads-down while viewing the far horizon (horizon opposite the direction of motion - fig. 1). Listed below are some of the reasons why the aforementioned attitudes were eliminated.

1. If the crew were oriented heads-up viewing the near horizon, the abort ΔV requirements would be excessive, the entry velocities would exceed the maximum, and the entry flight times would be too short.

2. If the crew were oriented heads-down viewing the far horizon, the abort ΔV requirements would be low, the abort maneuver would be fairly insensitive to attitude errors, and the entry velocities would not exceed the maximum, but the entry flight times would be excessive, particulary for aborts occurring during the last third of the TLI burn.

The bottom of the command module window can be viewed by the pilot at an angle of about $6.5°$ from the X-body axis and the top of the window can be viewed at an angle of about $37°$ from the X-body axis when the pilot's couch is in the entry position. As discussed before, we would prefer that, with the fixed attitude, the earth's horizon appear in the center of the window. However, we found that, for the crew in a heads-up position viewing the far horizon so that the earth's horizon appears near the center or near the top of the window ($20° \leq \Psi \leq 40°$), the problems encountered would be similar to those mentioned in (1) above. Therefore, the range of angles considered were $6.5° \leq \Psi \leq 15°$ for the crew in a heads-up position using the far horizon as the attitude reference.

Abort Delay Time

At first, it was thought the delay time from S-IVB cutoff should be approximately 40 minutes. This delay time would have allowed more than enough time for ground updates and for establishing spacecraft attitude. The reason for selecting this time was that the ΔV requirements to achieve the middle of the entry corridor were minimal for the late S-IVB shutdowns, and the return times were fairly short. However, it was found that for the S-IVB shutdowns late in the burn the longer the abort maneuver was delayed the more sensitive to attitude errors it became. (i.e., very small attitude errors could cause the entry point to be outside the entry corridor.) We also analyzed very short delay times (0 minutes $\leq t_d \leq$ 5 minutes) and found that the abort maneuver was very insensitive to attitude and ΔV errors, but the ΔV requirements were very large and the return times were too fast (e.g., for very early S-IVB shutdowns the time to 400 000-ft altitude from abort initiation was less than the abort maneuver burn time). Therefore, the range of delay times considered was from 10 minutes to 20 minutes.

Abort Delta Velocity

After analyzing the entry positions for the range of Ψ angles and t_d's considered, it was found that if the t_d and Ψ were held constant, the ΔV could not be constant throughout the TLI burn and assure an entry near the center of the entry corridor. This parameter then became the only variable to be considered for the fixed-attitude abort procedures.

RESULTS

Abort Study

Parametric analysis of entry points for various t_d's, ΔV's, and Ψ angles.- Figures 2(a), 2(b), and 2(c) show the entry velocity vectors (inertial velocity, V_i; and inertial flight-path angle, γ_i) resulting from applying various ΔV's at various Ψ angles for delay times of 10, 15, and 20 minutes, respectively. The data is presented for three cutoff times during the TLI burn; at 120 seconds and 240 seconds from TLI ignition, and at TLI (327.9 seconds). On figure 2(a), the bold line on the data for "TLI burn time = 120 seconds," represents the locus of entry vectors that would result from performing abort maneuvers with a fixed Ψ (in this case $\Psi = 6.5°$) and various ΔV's. Also, on figure 2(a), the bold line on the data for "TLI burn time = 240 seconds," represents the locus of entry vectors that would result from performing abort maneuvers with a fixed ΔV at various Ψ angles. The entry corridor used (negative lift overshoot boundary and 10-g full-lift undershoot boundary) was taken from reference 6.

For the range of data presented ($15° \geq \Psi \geq 6.5°$ and 20 minutes $\geq t_d \geq$ 10 minutes), a point of optimization (i.e., a maximum, minimum, or inflection point) cannot be shown that would clearly define the best Ψ angle or t_d for the abort maneuver. As mentioned previously, the optimum Ψ angles occur when the crew would be in a heads-down attitude viewing the far horizon. However, in this position the entry flight times are excessive. Also, it has been mentioned that, for the range of Ψ angles analyzed, the optimum ΔV's (minimum ΔV's for late TLI shutdowns) would occur at a delay time of approximately 40 minutes. However, at this delay time very small attitude errors (less than 0.8°) could cause the entry position to lie outside the corridor. In the final analysis, trade-offs will be made between those operational considerations mentioned previously to determine the Ψ angle and t_d which would yield the most favorable results. From this analysis it can be seen that the entry vectors for increasing t_d's move in the entry corridor toward the narrow boundaries in the high velocity regions. Therefore, it seems that t_d will be very short (10 to 20 minutes). Also, a Ψ angle of about 10° would place the horizon view within the window and approach the optimum solutions which would exist for a heads-down attitude.

Delta velocity requirements for $\Psi = 10^\circ$.- Figure 3 shows the ΔV required to hit the middle of the entry corridor (geometric center), if $\Psi = 10^\circ$ is used as the abort attitude, for delay times of 10, 15, and 20 minutes. This data is simply a cross plot of the data presented in figures 2(a) through 2(c).

Abort maneuver sensitivity with respect to ΔV, Ψ, and t_d.- In figures 4(a) through 4(c) we have assumed the nominal abort attitude to be 10° and the ΔV required for the abort maneuver to be that shown in figure 3. Then by again cross plotting the data in figures 2(a) through 2(c) we have shown the attitude error ($\Delta\Psi$) and/or delta velocity error [$\Delta(\Delta V)$] that can be tolerated and still lie within the entry corridor. This data is shown for S-IVB cutoff times of 120 seconds, 240 seconds, and 327.9 seconds (TLI), respectively. This data indicates very clearly how the attitude errors affect the entry velocity vectors and show that, as the delay time increases beyond 10 minutes, the abort maneuver becomes very sensitive with respect to the errors.

Procedures For Performing The Abort Maneuver

Even by performing the abort maneuver very early (10 minutes) the sensitivity with respect to abort attitude is very critical. The way the abort maneuver is to be performed (i.e., the attitude maintained) should be the simplest and as free from premission unknowns as possible. There are three possible ways the maneuver could be performed using the earth's horizon as an attitude reference:

1. The crew could perform the maneuver manually by keeping the thrust vector fixed inertially after aligning the spacecraft attitude with a line on the window.

2. The crew could perform the maneuver manually by keeping the line of sight of the horizon fixed on a line on the window throughout the maneuver.

3. The crew could align the initial spacecraft attitude by a line on the window, then perform the maneuver using the automatic stabilization and control subsystem (SCS) mode in which the thrust vector is held fixed inertially.

In the first two procedures a great deal of crew training would be involved. Procedure 1 would require the crew to know how the earth's horizon should move through the window during the abort maneuver. This might be feasible for one or two fixed times of abort during TLI (S-IVB cutoff on a predetermined time during the burn), but would not be practical for all points during the burn. Using the second method would more than likely yield the most precise results; the only unknown would be how well the crew could line up the spacecraft attitude using the horizon. The only problem with procedure 2 is that the abort burns are quite lengthy (5 or 6 minutes) and the pilot's hands might be needed to assist in the contingency that has arisen. The third procedure appears the most practical for these reasons:

1. After SPS ignition the pilot can assist in whatever contingency has arisen.

2. The only unknown in the abort maneuver computations would be how well the crew could make the real-time initial spacecraft attitude alignment. We should have good premission knowledge of how accurately the thrust vector of the service propulsion subsystem (SPS) is aligned through the spacecraft center of gravity (c.g.), the accuracy of aligning the spacecraft's attitude with respect to the earth's horizon from previous Apollo missions, and the accuracy of the SCS in performing the fixed-attitude maneuver.

Please note that one parameter mentioned of which we have knowledge is how well the SPS thrust vector is aligned through the c.g. This should imply that the SPS should not be used prior to the abort maneuver. For separation purposes the reaction control subsystem (RCS) would be burned. This is not at all unreasonable, for the type of contingencies we would be confronted with are those occurring in the spacecraft, not in the booster. If some contingency should develop in the booster, the SPS would be used for emergency separation and an alternate mission would be in order.

Fixed-time aborts.- The real-time procedures to be used immediately following the abort decision would be a function of the severity of the contingency which has arisen. If possible the crew should continue the TLI burn to some fixed time for which a set of digital data would be provided following orbital insertion for the abort maneuver. With this in mind the S-IVB burn times of 120 seconds, 240 seconds, and 327.9 seconds (TLI) were arbitrarily chosen as fixed times of abort for this study. The data that would be provided in real-time should include:

1. The fixed time referenced to S-IVB ignition (in seconds).

2. Inertial velocity to be gained (V_{go}) by the S-IVB at the fixed time.

3. The fixed time referenced to lift-off (ground elapsed time).

4. The ground elapsed time of the abort maneuver.

5. The SPS ΔV required for the abort maneuver.

6. The SPS burn time required for the abort maneuver.

7. The entry velocity vector following the abort maneuver, V_i, γ_i, at 400 000 ft.

8. A set of data describing the backup entry mode. This would include initial lift vector position for entry and times and/or g levels to indicate the onset of a different lift vector position. (See ref. 6 for backup entry mode definitions.)

9. Times of different entry events such as beginning and ending of blackout, chute deployment times, etc.

10. Latitude and longitude of landing position.

As mentioned in the Introduction, we are also analyzing the feasibility of using a fixed attitude for performing a midcourse at some fixed time following the abort maneuver. This midcourse maneuver would utilize the line put on the window for the launch aborts. This line is about 31.7° from the X-body axis and would be used with crew viewing the far horizon or the near horizon, depending upon the midcourse required. Although we have just begun studying this area, it appears the crew will be heads down viewing the far horizon for midcourses that require lowering (making more negative) the flight-path angle at entry and heads down viewing the near horizon for midcourses that require raising (making less negative) the flight-path angle at entry. This would require another parameter, the ground elapsed time of the midcourse, to be added to the set of data for the fixed-time aborts. At present, we are planning the midcourse for about one hour following the SPS abort maneuver.

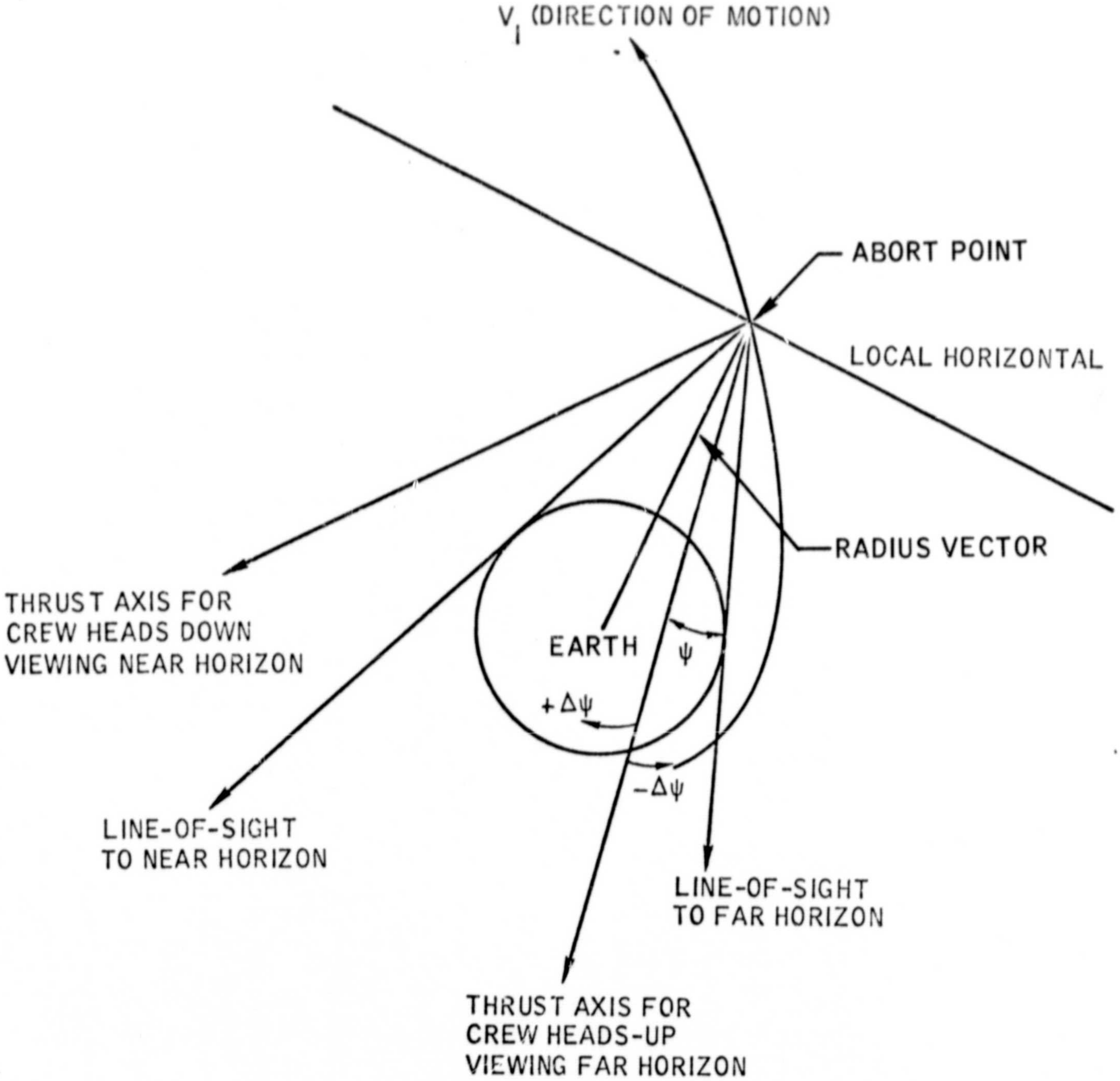
Crew charts.- One consideration in selecting the fixed times of abort would be to locate the landing sites near a planned landing area (PLA), a contingency landing area (CLA), or, if neither of these are possible, in the middle of the ocean. If the contingency was such that the crew could not continue the burn to a fixed time, they might attempt to continue the burn until the manual abort would result in a water landing. A chart such as figure 3, which presents abort ΔV as a function of inertial velocity to be gained (V_{go}), would be provided with those solutions resulting in water landings indicated. This chart would provide the non-digital solutions for aborts occurring between the fixed times of abort. The data transmitted after orbital insertion to update the fixed time aborts could be used to update this chart.

One other chart, similar to figure 5, would be required. This chart would indicate not only the time from the abort point to entry (t_{ar}) but whether the crew should prepare for a midcourse following the abort maneuver. The midcourse follows the abort maneuver by one hour. We should preserve 20 minutes following the midcourse time for the crew to prepare for entry. Therefore, if the time from abort to entry (400 000 ft) is less than 1 hour 20 minutes, the midcourse should not be performed and the ground should be able to provide backup entry data by 20 minutes following the abort maneuver. By this time, for the very early S-IVB shutdowns, the CM would be entering at about 400 000 ft. This should also imply that if a midcourse is performed (t_{ar} > 1 hour 20 minutes) the backup entry data should be transmitted to the crew by 20 minutes following the midcourse. This keeps the procedures straightforward if it is always kept in mind that the backup entry data should be transmitted before 20 minutes following the last SPS maneuver. Figure 7 presents a flow diagram indicating the abort procedures to follow and the source of the abort solution for the manual aborts both when there is voice communication with the ground and when there is not.

RECOMMENDATIONS AND CONCLUSIONS

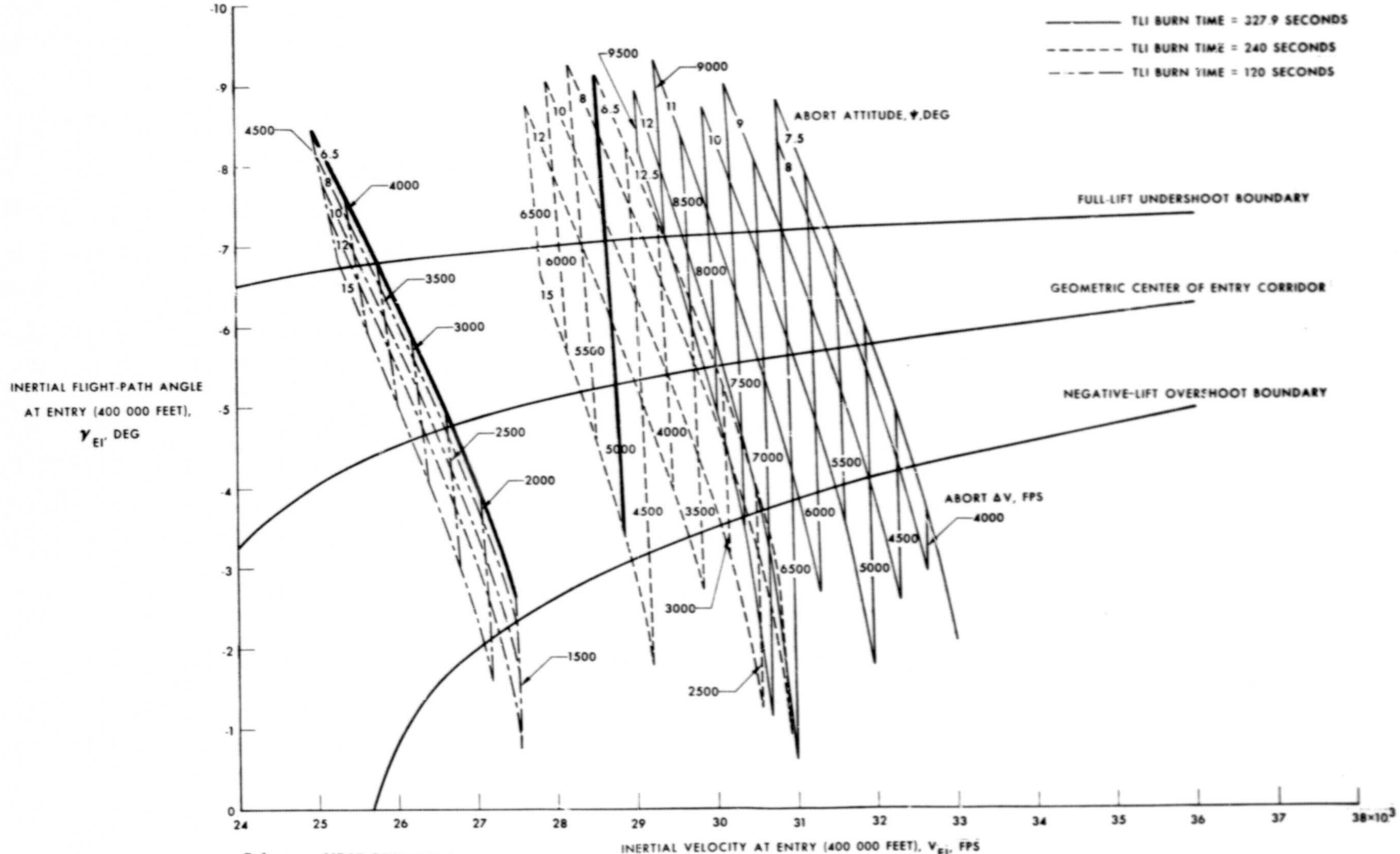
It is recommended that a fixed-attitude, fixed-delay-time abort procedure be utilized for contingencies resulting during TLI which require an immediate S-IVB shutdown and an immediate return of the crew.

Please note that the sensitivity of the abort manuever with respect to both attitude and ΔV is a function of the entry corridor used. At the present time the Reentry Studies Section of MPAD is awaiting action by other MSC organizations to determine whether the entry corridor can be enlarged by increasing the entry loading on the undershoot boundary. Also, the negative-lift overshoot boundary used in this study is slightly unconservative. (The actual boundary will be slightly more constraining.) Until the definition of the entry corridor is more final, the final set of backup abort procedures cannot be defined. The target line that was used in this study is the geometric center of the entry corridor and not an SPS target line. The geometric center is used to allow for greater attitude and ΔV inaccuracies at the abort point.



Reference: MPAD 2327 S(IU)

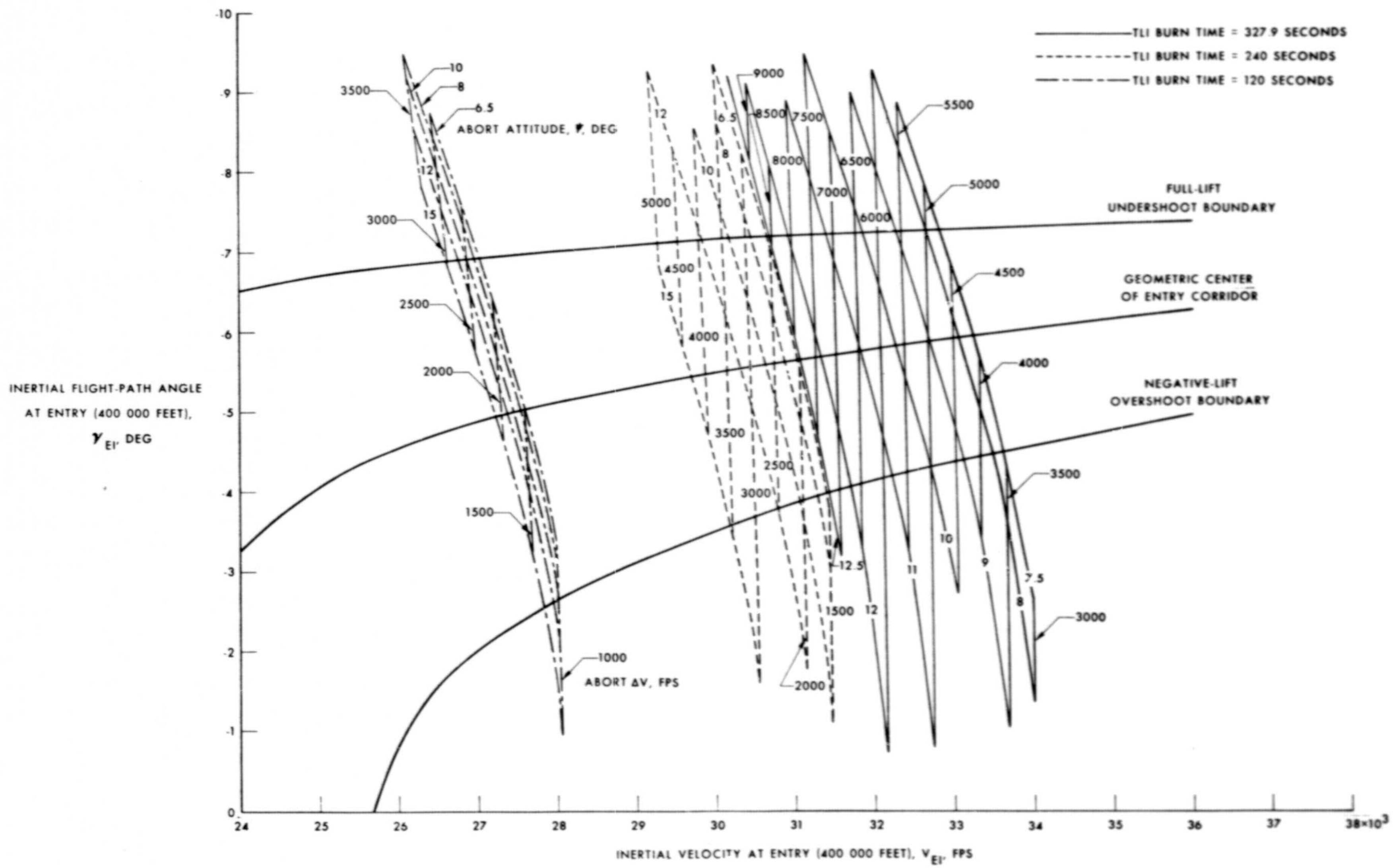
Figure 1.- Definition of near/far horizons, ψ, and $\Delta\psi$.



Reference: MPAD 2331 S(IU)

(a) Time delay = 10 minutes.

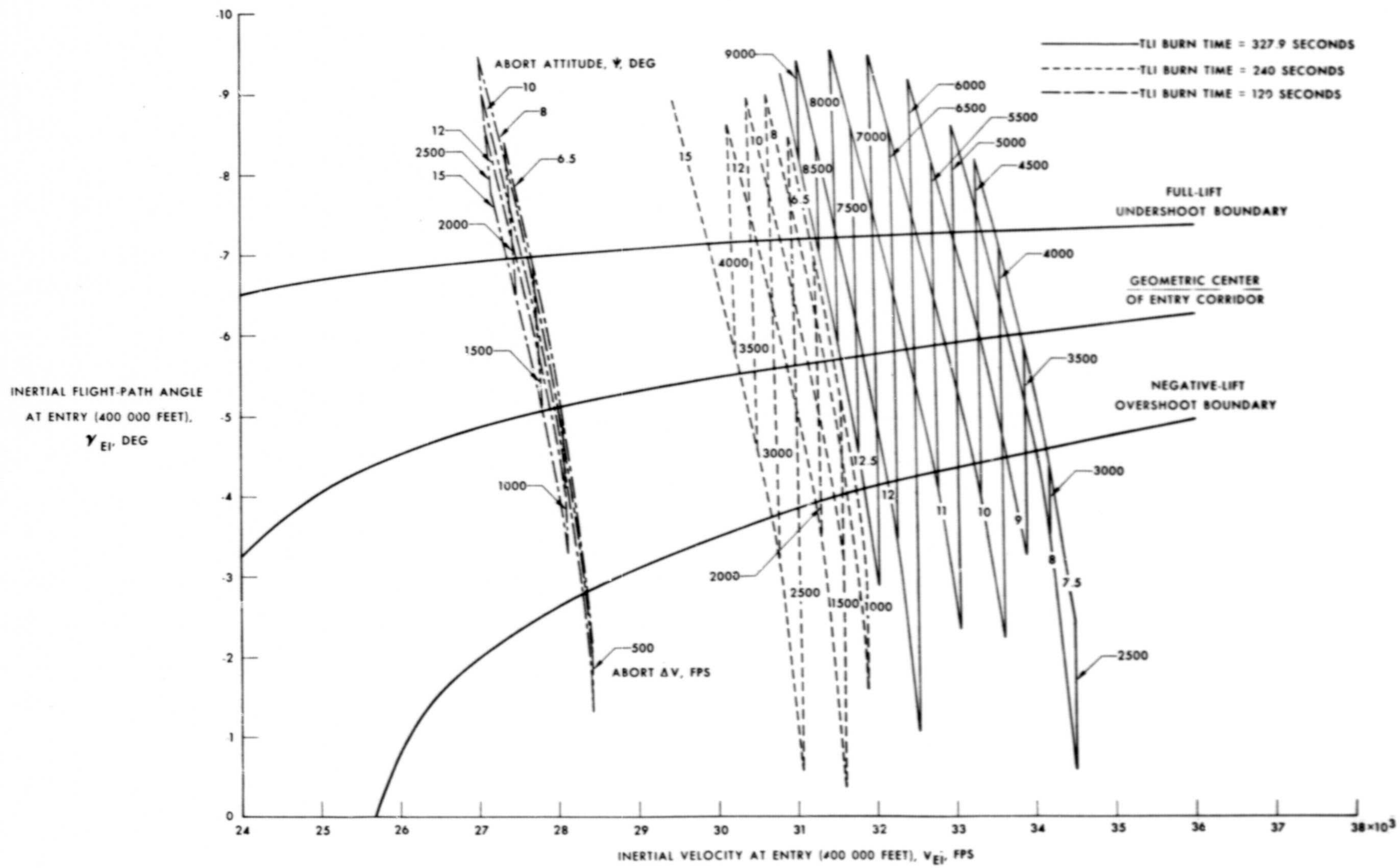
Figure 2.- Post abort entry vectors for various abort ΔV's and attitude angles following S-IVB TLI cutoffs at 120 seconds, 240 seconds, and 327.9 seconds (TLI).



Reference: MPAD 2333 S(IU)

(b) Time delay = 15 minutes.

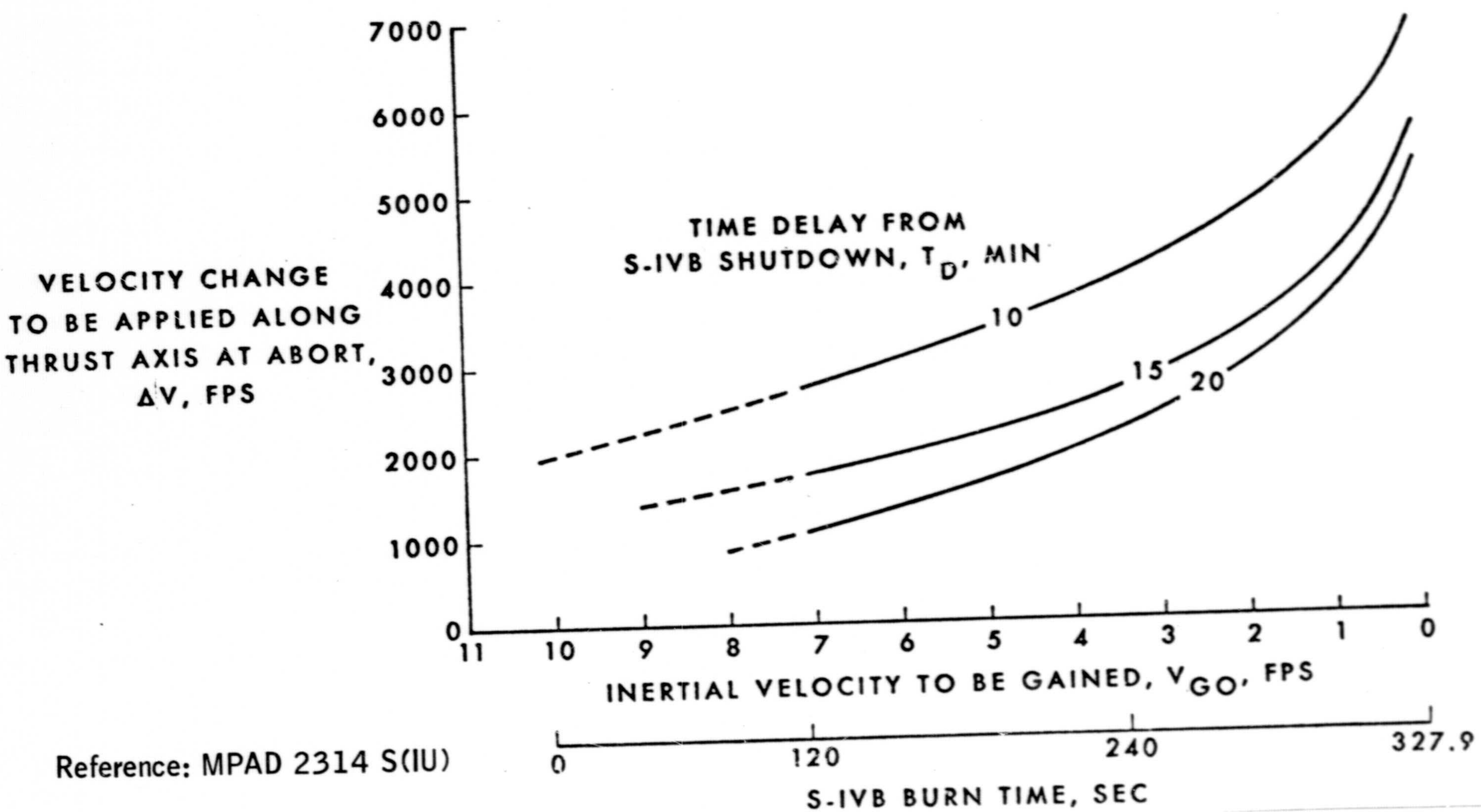
Figure 2.- Continued.



Reference: MPAD 2332 S(IU)

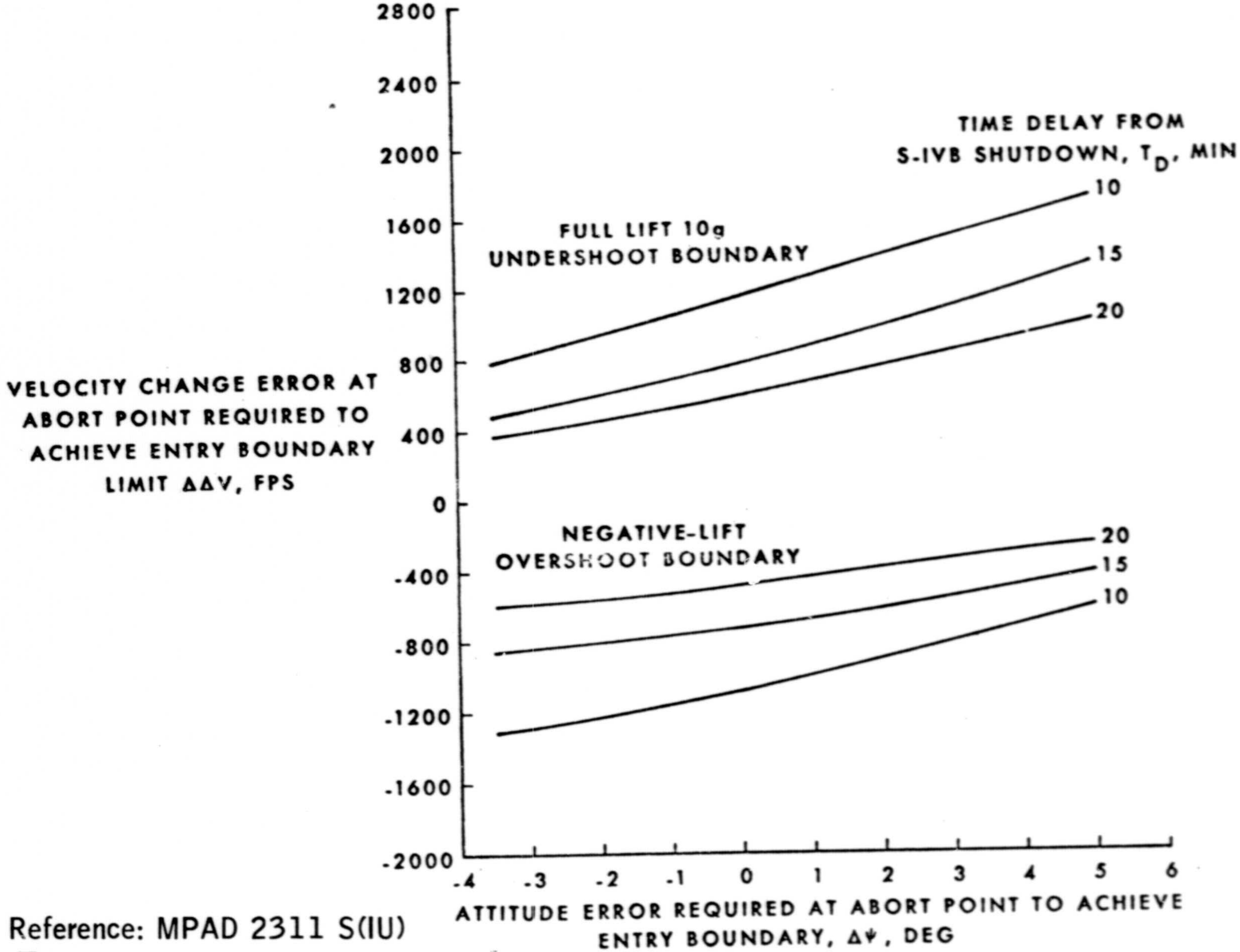
(c) Time delay = 20 minutes.

Figure 2.- Concluded.



Reference: MPAD 2314 S(IU)

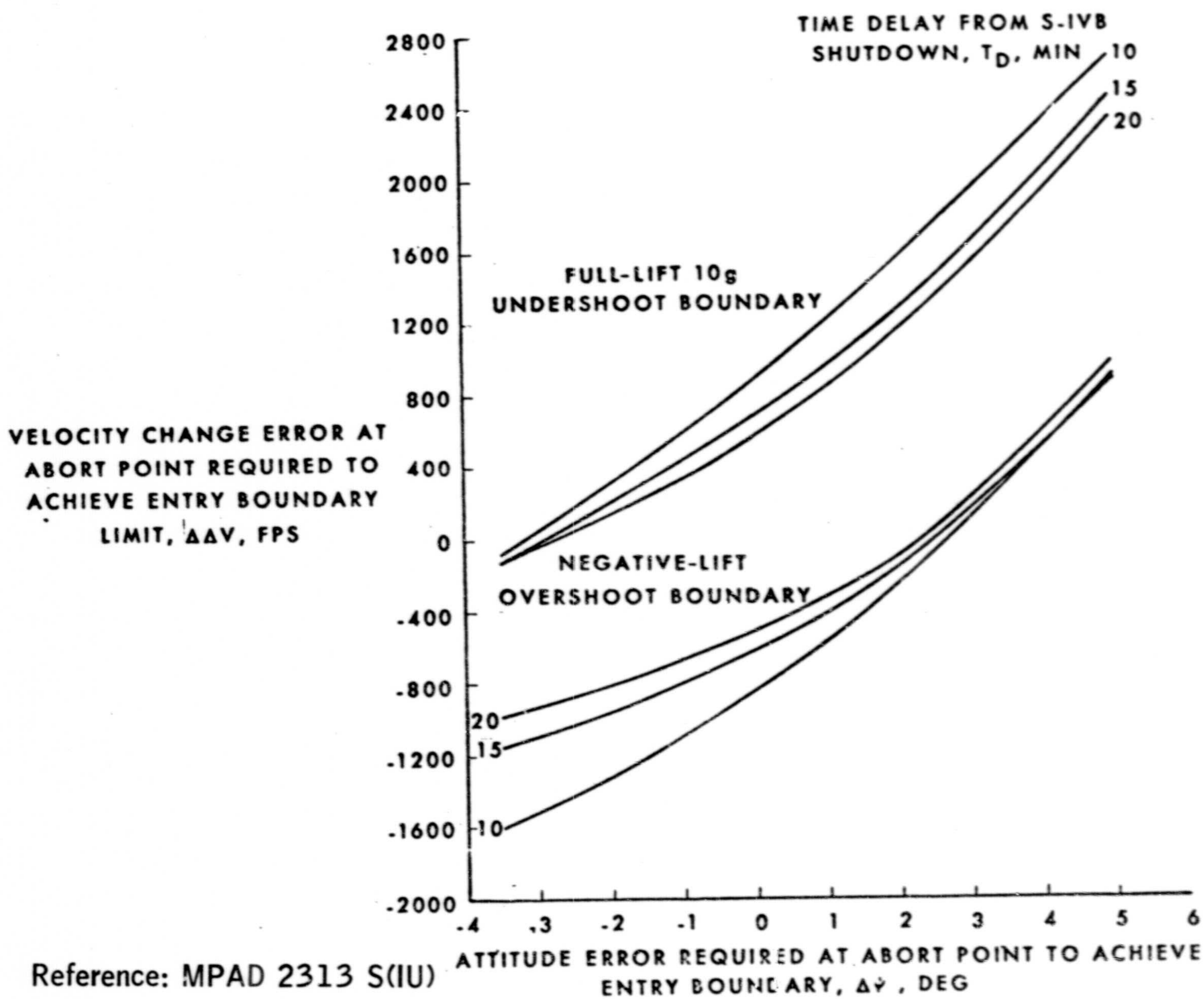
Figure 3.- Abort ΔV as a function of inertial velocity to be gained ($\psi = 10°$).



Reference: MPAD 2311 S(IU)

(a) S-IVB cutoff at 120 seconds.

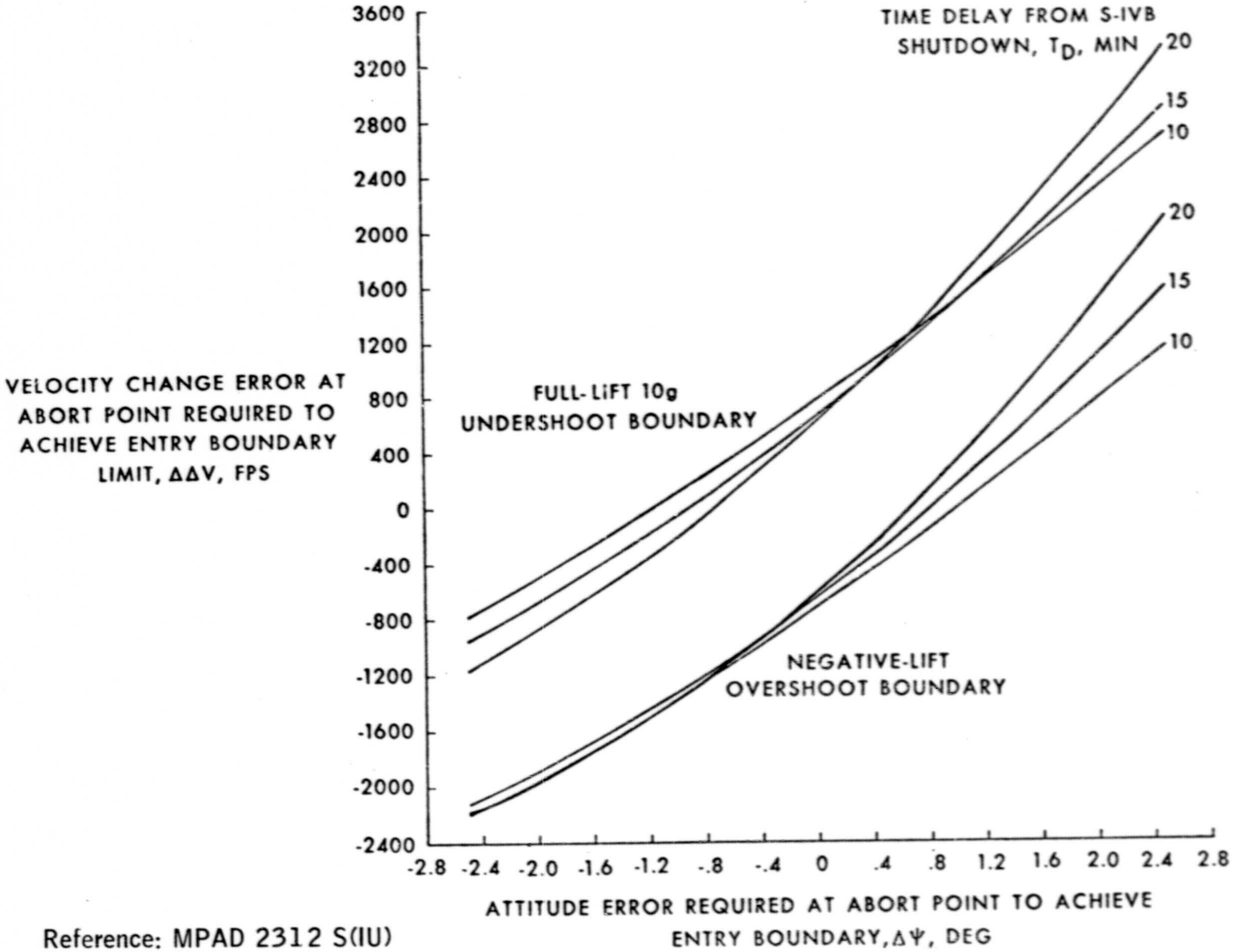
Figure 4.- Abort maneuver sensitivity to attitude and ΔV error.



Reference: MPAD 2313 S(IU)

(b) S-IVB cutoff at 240 seconds.

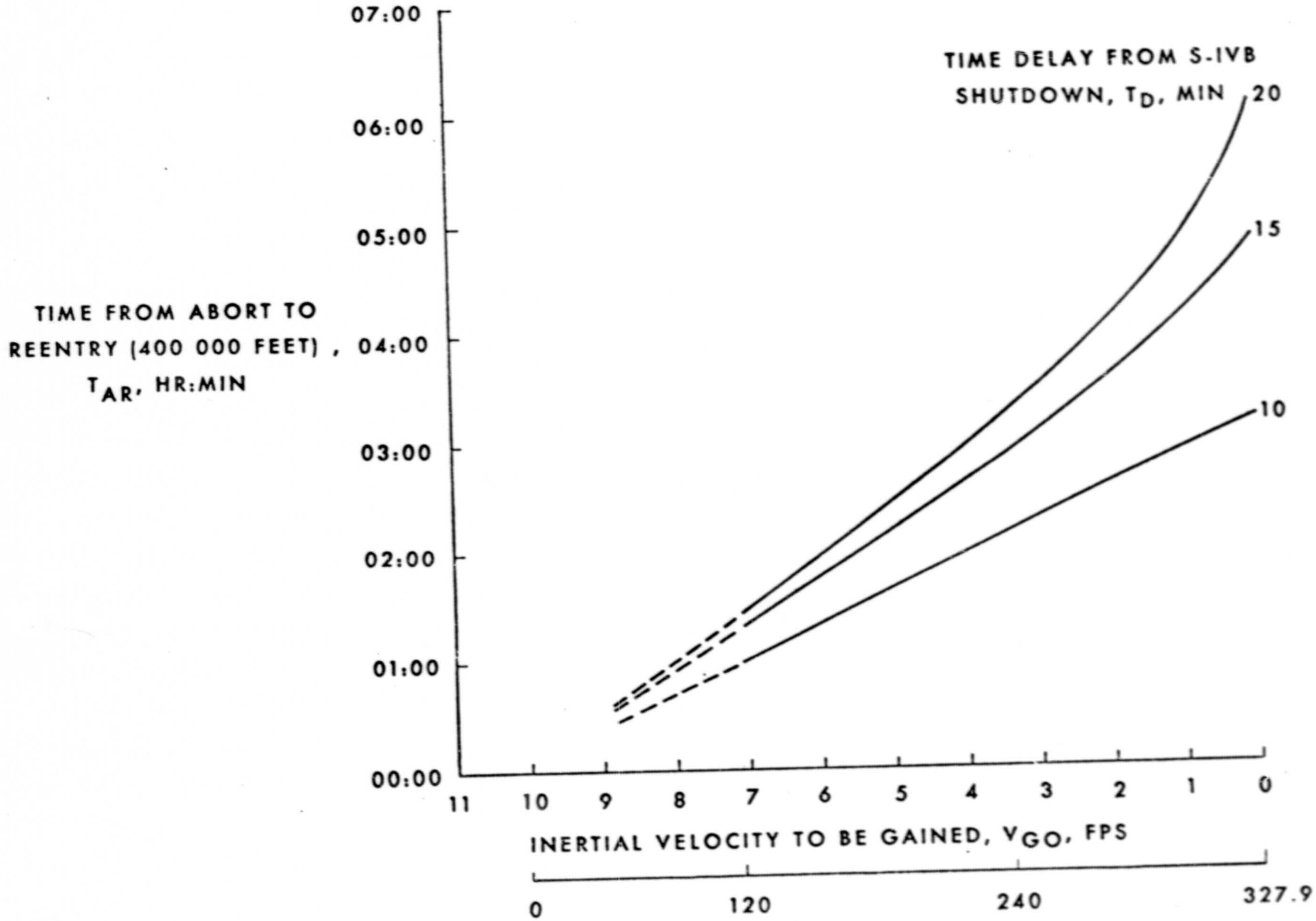
Figure 4.- Continued.



Reference: MPAD 2312 S(IU)

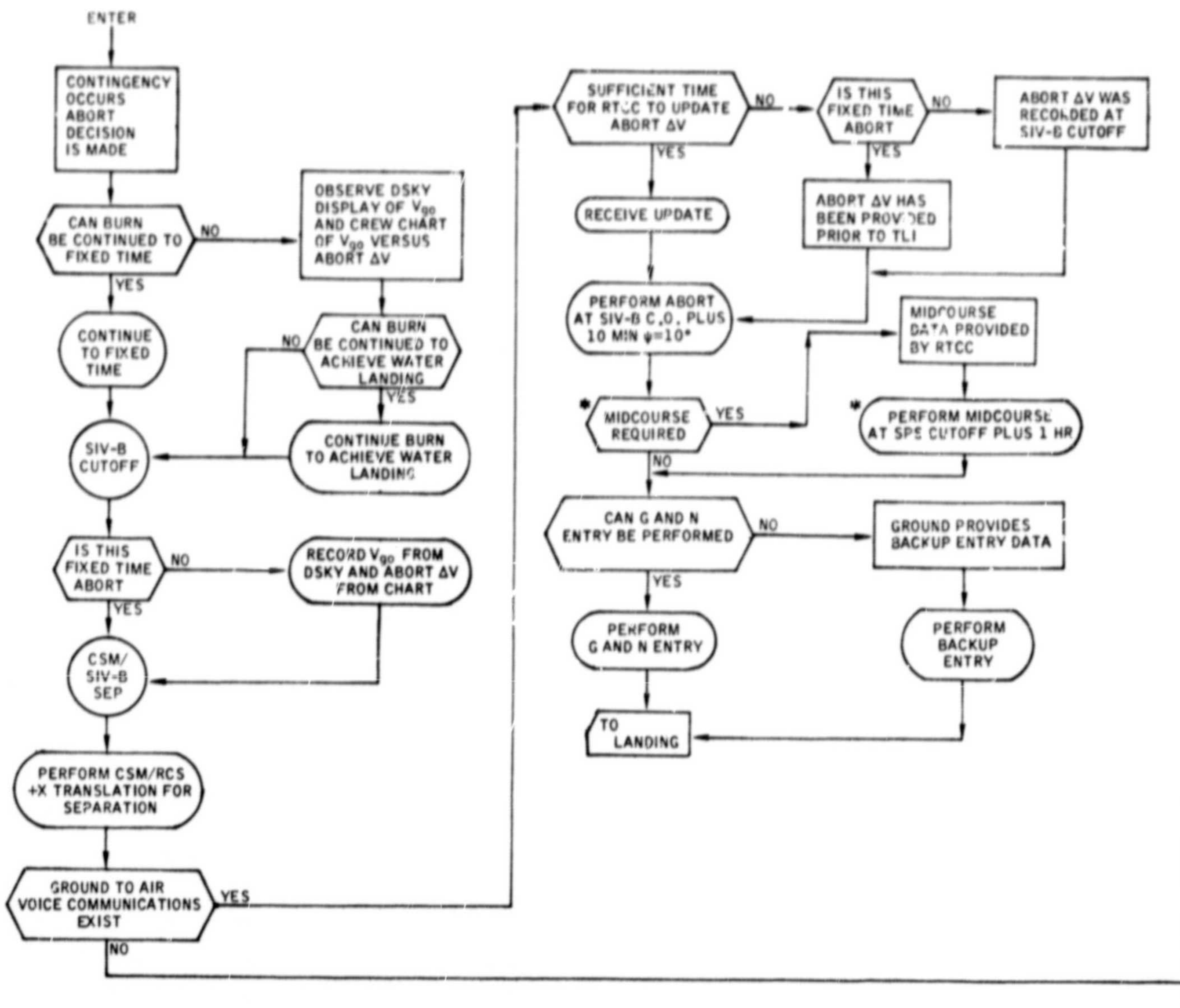
(c) S-IVB cutoff at 327.9 seconds (TLI).

Figure 4.- Concluded.



Reference: MPAD 2315 S(IU)

Figure 5.- Time from abort to reentry as a function of inertial velocity to be gained ($\psi = 10°$).

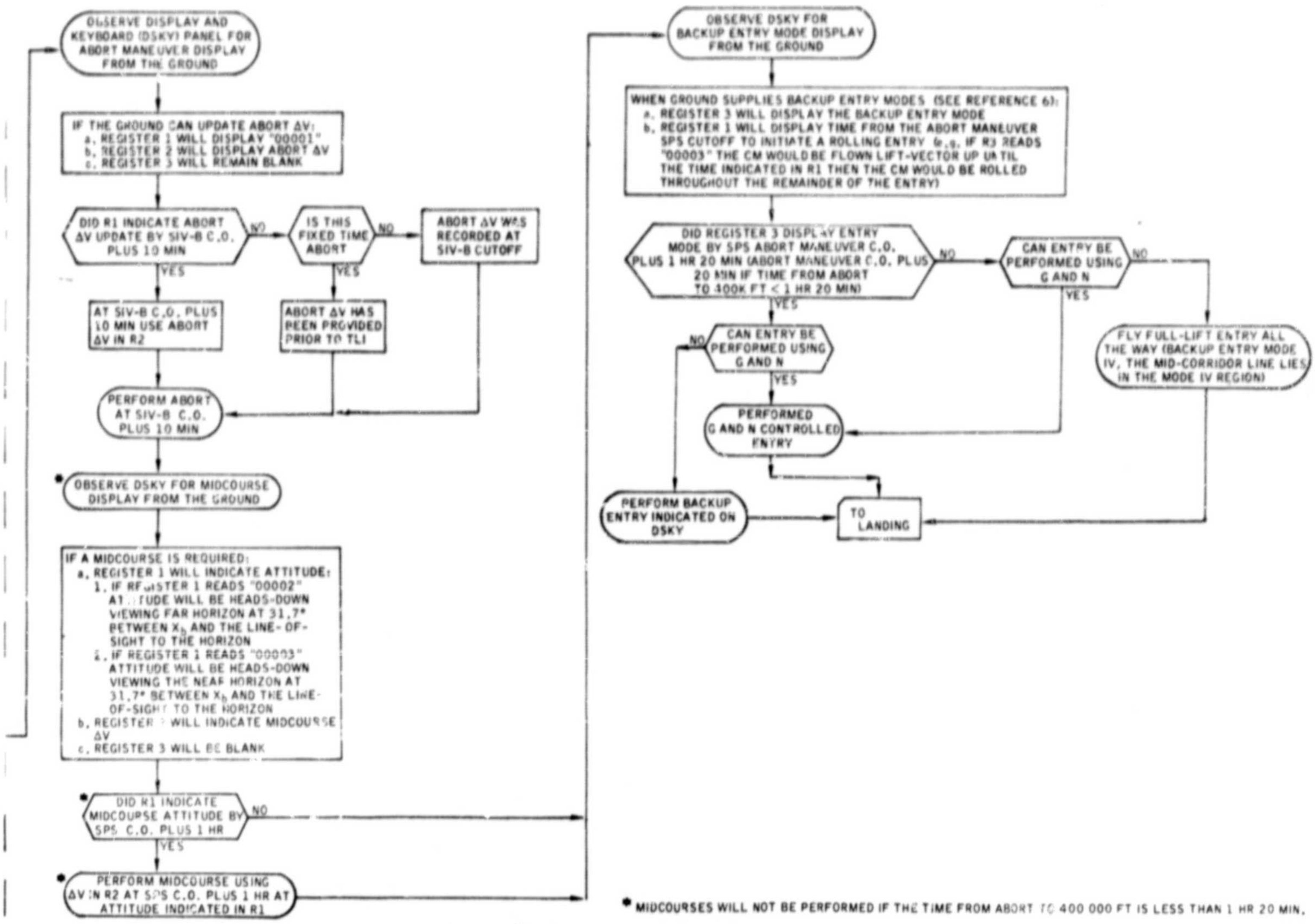


*MIDCOURSES WILL NOT BE PERFORMED IF THE TIME FROM ABORT TO 400 000 FT IS LESS THAN 1 HR 20 MIN.

Reference: MPAD 7328 S(IU)

(a) Voice

Figure 6. - Preliminary manual abort procedures for aborts occurring during the translunar injection (TLI) maneuver.



Reference: MPAD 2329 S(1U)

(b) No voice

Figure 6. - Concluded.

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3. TRW Memorandum 3422.5-90 to H. A. Lieske from R. D. Gilbertson, "Near and Far Horizon Abort Trajectory Solution Plots for Earth Horizon Angles of ± 30 degrees Subject to Various Velocity Increment Constraints," May 20, 1966.

4. TRW Memorandum 3430.3-2 to Distribution from H. A. Lieske, "Additional Data For Earth Horizon Reference Aborts." January 24, 1967.

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