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TWO-IMPULSE ABORT MANEUVERS FROM A LUNAR MISSION

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PROJECT APOLLO

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SUMMARY

This study investigates the possibilities of reducing the trip time from abort to landing on a lunar mission by employing a two-impulse abort maneuver rather than the normal one-impulse abort.

The phases of the lunar mission from which aborts are considered are the translunar coast phase, the lunar orbit insertion phase, and a portion of the transearth coast phase of a circumlunar mission. The only abort mode investigated in this study is the time-critical abort to an unspecified landing area.

The results show that the return time can be considerably reduced in many cases when the two-impulse abort maneuver is performed as compared to the return time of a one-impulse abort.

The desirability of this procedure depends on the operational aspects of such a retrograde maneuver prior to earth reentry. These aspects are not included in this preliminary study.

INTRODUCTION

The normal survival abort procedure using the SPS is to add the required ΔV to insure a posigrade reentry within a safe corridor. No retrograde impulse is applied before reentry. The time-critical abort mode utilizes the maximum ΔV available to reduce the trip time and at the same time not exceed the maximum V_R specified. In many cases, due to the V_R constraint, the ΔV which may be used is much less than that available.

The two-impulse procedure investigated in this study is similar to the above. However, more of the available ΔV is utilized since the V_R of the abort trajectory is allowed to exceed the maximum V_R allowed. This V_R is again reduced to a safe level by means of a second impulse prior to reentry.

NOTATION

CM	command module
H_R	height at earth reentry
$I_{R\,MAX}$	maximum return inclination
LM	lunar module
LOI	lunar orbit insertion
RCS	reaction control system
SM	service module
SPS	service propulsion system
T_{AL}	time from abort to landing
V_R	inertial reentry velocity
ΔV	velocity increment
γ_R	reentry flight-path angle measured from local horizontal

ANALYSIS

The "AS-504 Preliminary Reference Trajectory" (ref. 1) was used as the reference for this study. For time-critical, unspecified-area aborts, the characteristic receiving the most attention is the time from abort to landing. Reentry velocity, return inclination, height at reentry, and reentry flight-path angle are constrained to certain limits to insure a safe reentry. The values and limits of these characteristics are as follows:

$$V_R = 36\,333 \text{ ft/sec}$$

$$H_R = 400\,000 \text{ ft}$$

$$\gamma_R = -6^\circ$$

$$I_{R\,MAX} = 40^\circ$$

A patched conic program using conic sections resulting from impulsive ΔV's to represent abort paths was used in the analysis. In all cases, the lunar module was jettisoned prior to abort.

RESULTS

Translunar Coast Aborts

Aborts were performed during the translunar coast until approximately 61 hours from translunar injection. Figure 1 shows the variation of T_{AL} and V_R with abort ΔV for a typical abort initiated at 61 hours from translunar injection. The ΔV capability of the CSM used in this portion of the study is assumed to be 10 000 ft/sec. It can be seen from figure 1 that for a one-impulse abort the maximum ΔV which does not cause V_R to exceed the maximum V_R allowable is approximately 7750 ft/sec. The corresponding T_{AL} is 47 hours. However, for a two-impulse abort the ΔV can be increased to 9650 ft/sec, and the remainder of the available 10 000 ft/sec will be sufficient to reduce the V_R to 36 333 ft/sec. The corresponding T_{AL} is reduced to 38 hours. This two-impulse abort is shown in figure 2 and is typical of the aborts considered in this study.

Plots similar to figure 1 were made for abort times from 0 to 61 hours on the translunar coast. The results are summarized in figures 3 and 4. From figure 3, it is apparent that no reduction in return time can be realized for two-impulse aborts occurring less than 33 hours from translunar injection. In this region the V_R is less than the maximum V_R allowable for all aborts and the complete ΔV available is utilized. However, from figure 4 it is seen that the ΔV for one-impulse aborts decreases from 10 000 ft/sec due to the V_R constraint as the abort time exceeds 33 hours. It is in this region that the two-impulse aborts reduce trip time, as shown in figure 3.

Figure 4 shows that, for these aborts, the ΔV required to reduce the V_R to 36 333 is below 300 ft/sec for a high percentage of the abort region. It is possible that, if the SPS does not restart, the SMRCS would be sufficient to provide the second impulse.

Aborts Following Premature LOI Shutdown

In the event of a premature shutdown of the SPS during LOI it may be necessary to initiate an immediate return-to-earth abort. (See ref. 2, section 7.) In this analysis it is assumed that the SPS shutdown was not due to SPS failure, i.e., the SPS could be restarted when desired. The amount of ΔV remaining would be determined by the duration of the LOI burn. In this analysis it is also assumed the burn was 130 seconds. The resulting trajectory is a moon-centered ellipse.

Figure 5 shows the variation of T_{AL} and V_R with abort ΔV for an abort initiated 4 hours from LOI shutdown. The ΔV available following LM jettison is assumed to be 8000 ft/sec, which allows for a 5% reserve. For reasons identical to those in the discussion of translunar coast aborts, the trip time using a two-impulse abort can be reduced to 33.5 hours as compared to the normal time-critical, one-impulse abort trip time of 52 hours. The V_R will be reduced from 37 100 ft/sec to an acceptable 36 333 ft/sec by the second impulse.

Plots similar to figure 5 were made for abort delay times from 0 to 4 hours following the 130 seconds LOI burn. The results are summarized in figure 6. The total impulse for all two-impulse aborts presented is always less than the ΔV available. The considerable reduction in return times using the two-impulse aborts is evident.

Transearth Coast Aborts for a Circumlunar Mission

Following a lunar landing, the ΔV available during the transearth coast is such that the V_R constraint is not exceeded for a one-impulse, time-critical abort, and all ΔV available may be used. Therefore, two-impulse aborts are not desirable during the transearth phase following a lunar landing.

If a lunar landing is not attempted and the spacecraft passes pericynthion without initiating LOI, the ΔV available is much higher than the maximum ΔV which could be used for a one-impulse, time-critical abort without exceeding the V_R constraint. It is assumed that the ΔV available is 9500 ft/sec, which allows for a 5% reserve. Two impulse-aborts may be performed in this case.

The abort analysis of this region is restricted to aborts initiated 1 hour post-pericynthion. Figure 7 shows the variation of T_{AL} and V_R with abort ΔV. For these aborts, the return time can be reduced from 53.8 hours for a one-impulse, time-critical abort to 29.0 hours for a two-impulse abort. The velocity is decreased by 1350 ft/sec prior to reentry to satisfy the reentry conditions.

CONCLUSIONS

It is shown that the two-impulse abort maneuver can reduce the return time in many instances during the lunar mission. For translunar coast aborts, the SMRCS may be able to provide a backup capability for the second impulse. However, the basic philosophy of the two-impulse maneuver is such that a second impulse must be provided prior to entry to reduce the V_R to an allowable value. Therefore, the success of such a time-critical abort depends on the ability of the SPS to reignite to provide the final retrograde impulse.

If the two-impulse abort procedure appears operationally feasible, it would be the abort mode with the shortest return time. It is possible that contingencies might occur which would require a time reduction of such a magnitude as to make a two-impulse abort mandatory.

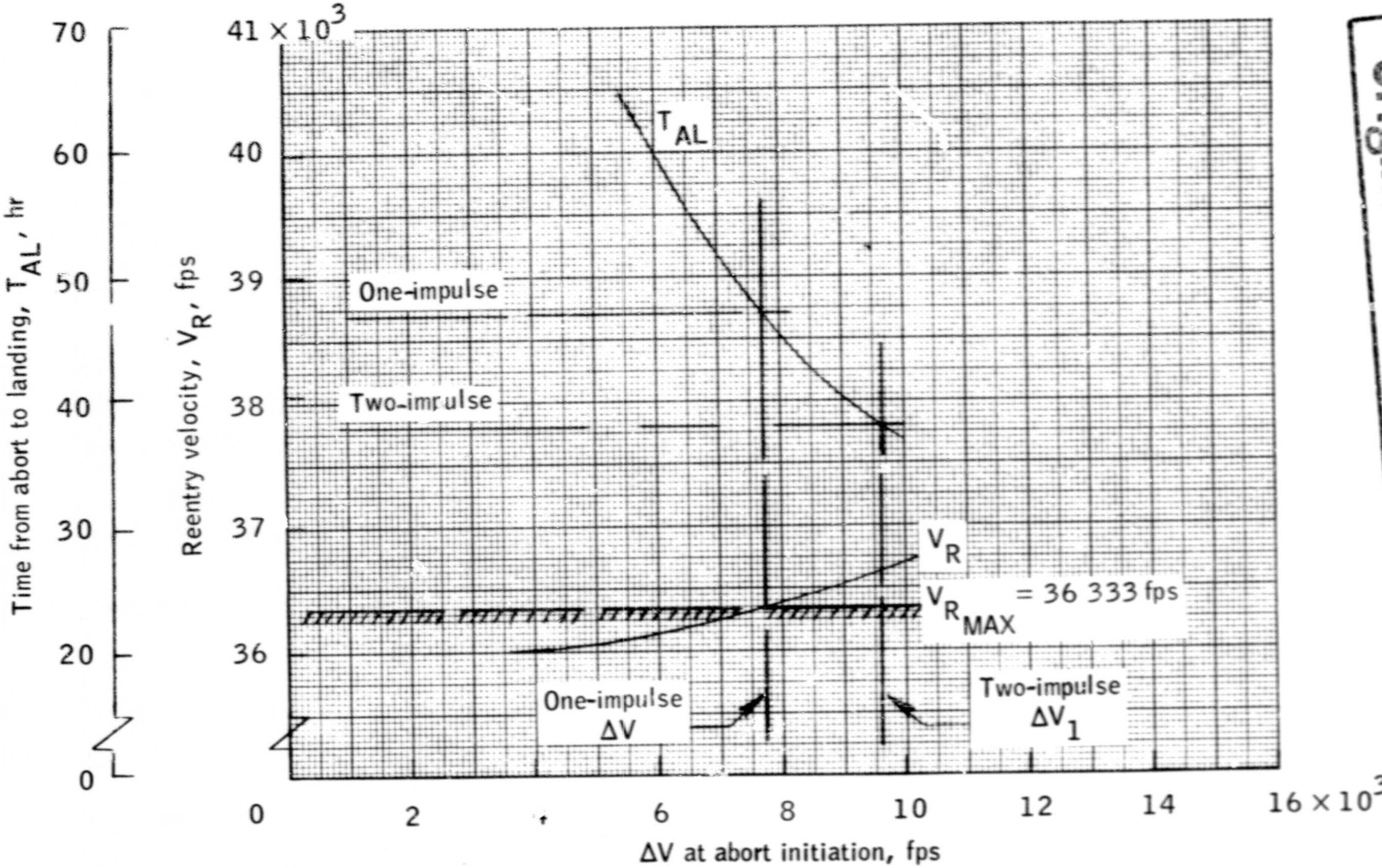

Figure 1.- Time-critical aborts during translunar coast (abort initiated 61 hours from translunar injection).

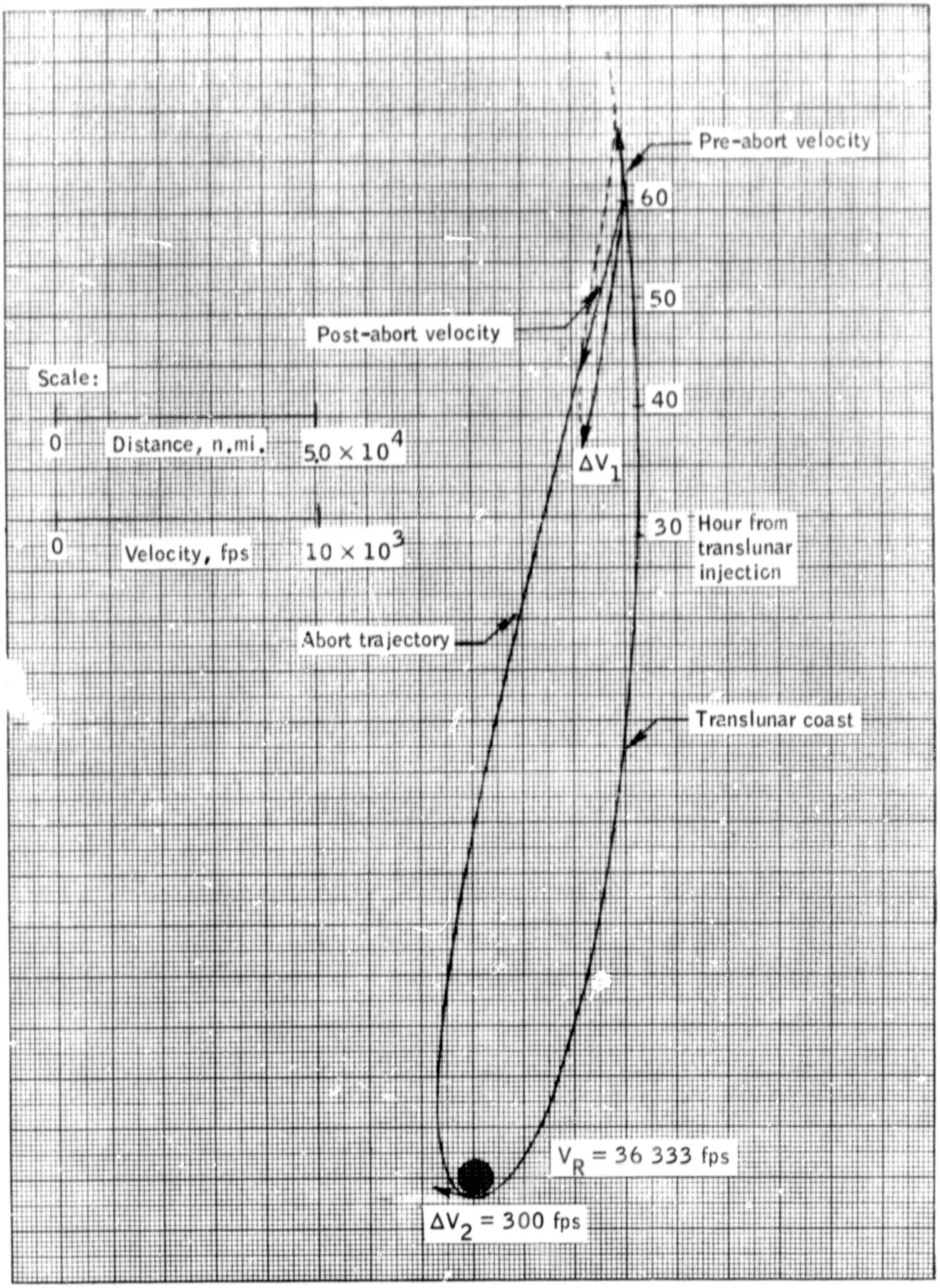

Figure 2.- Two-impulse abort during translunar coast.

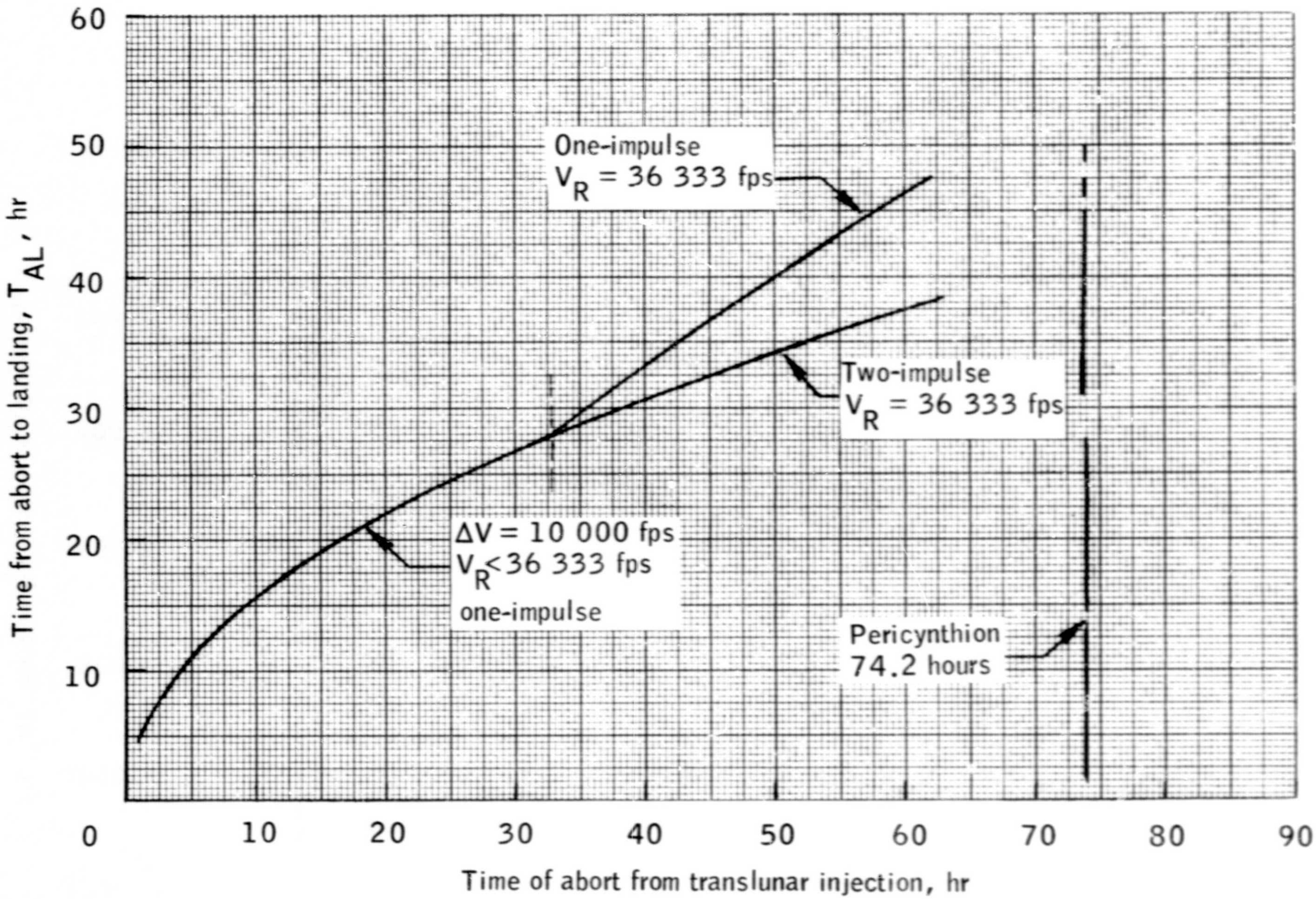

Figure 3.- Time-critical unspecified area aborts during translunar coast.

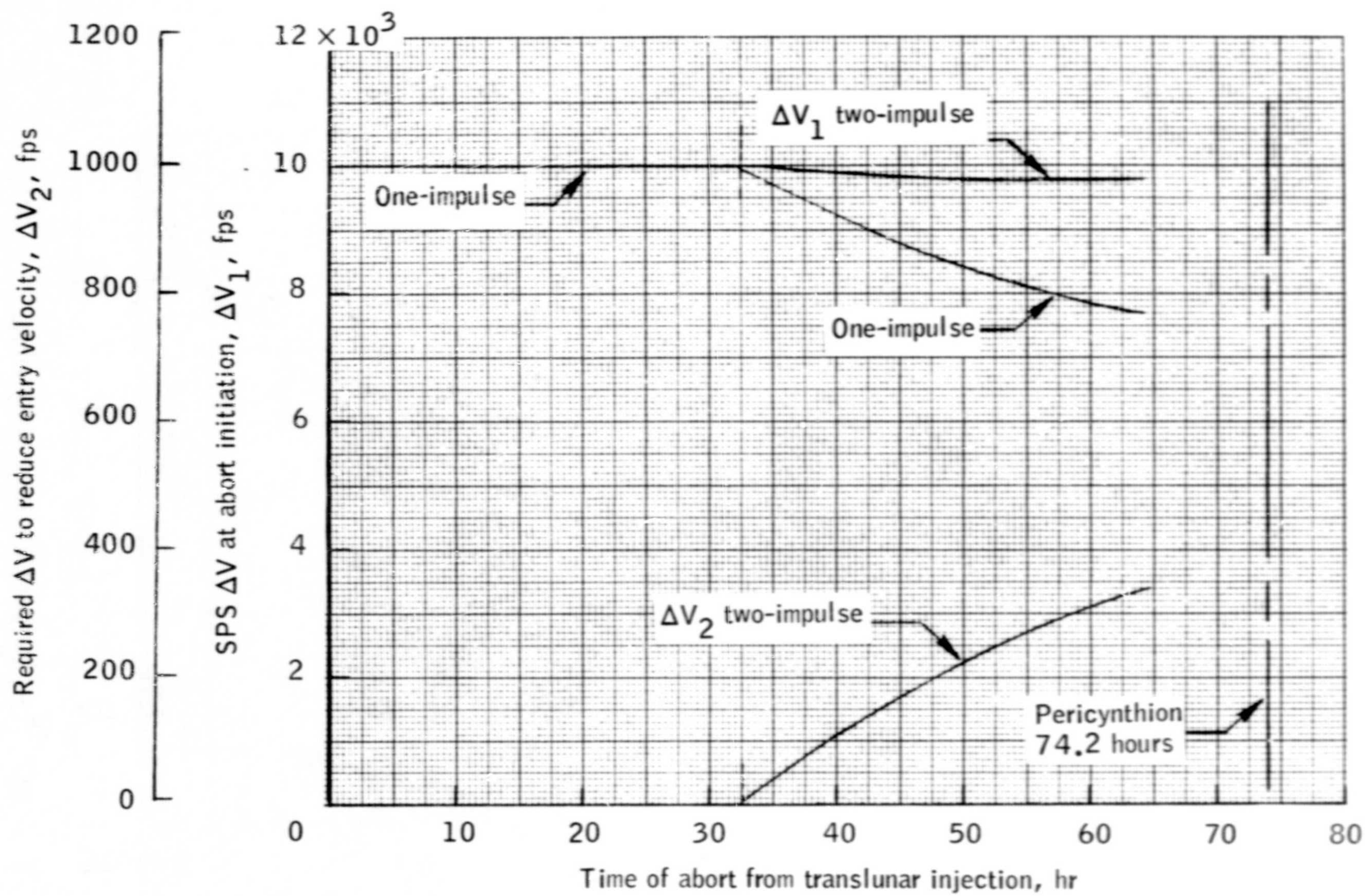

Figure 4.- Time-critical aborts during translunar coast (unspecified area).

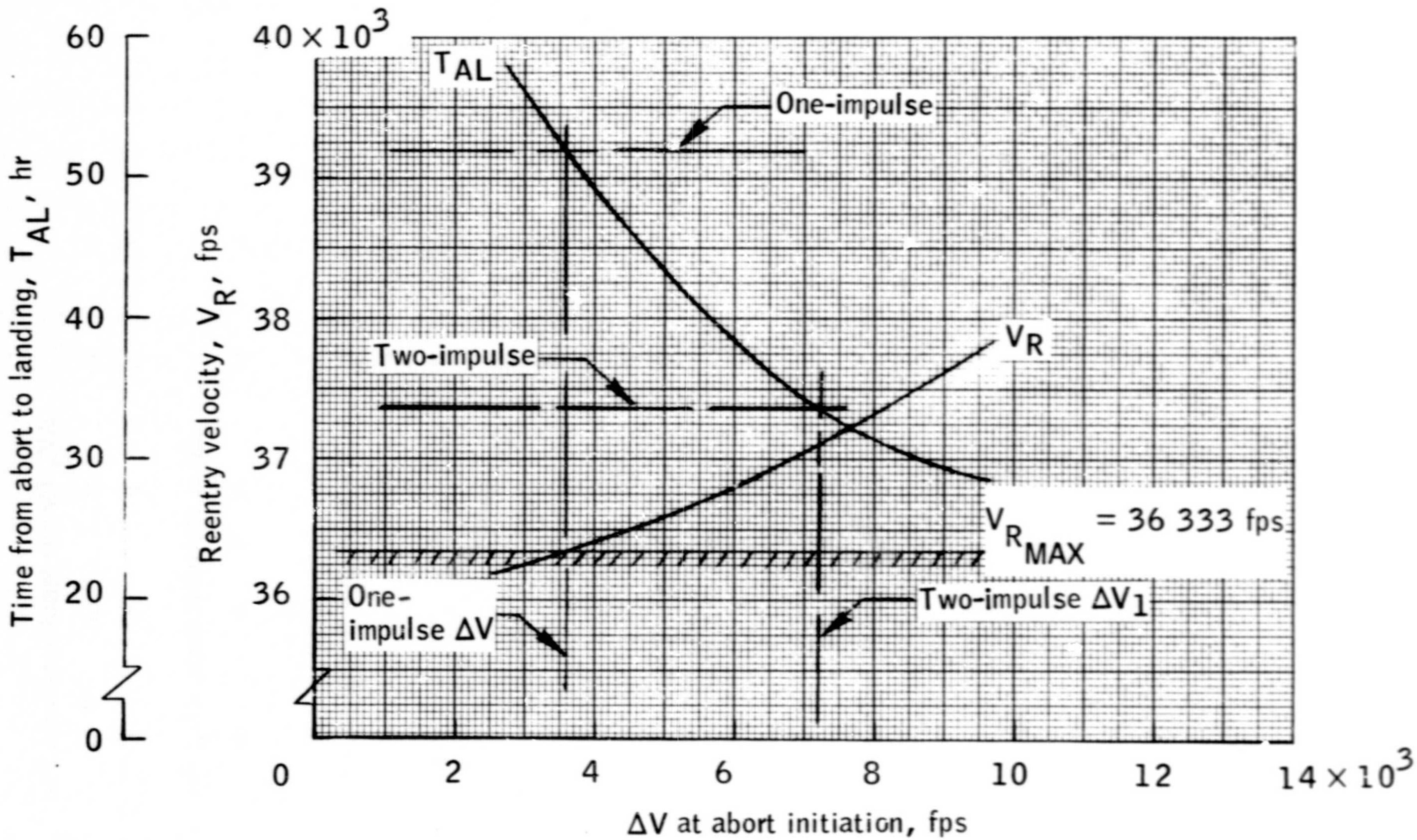

Figure 5.- Abcrts following premature SPS shutdown during lunar orbit insertion with a 130 second SPS burn (4 hour delay in resulting ellipse prior to abort; time-critical unspecified area).

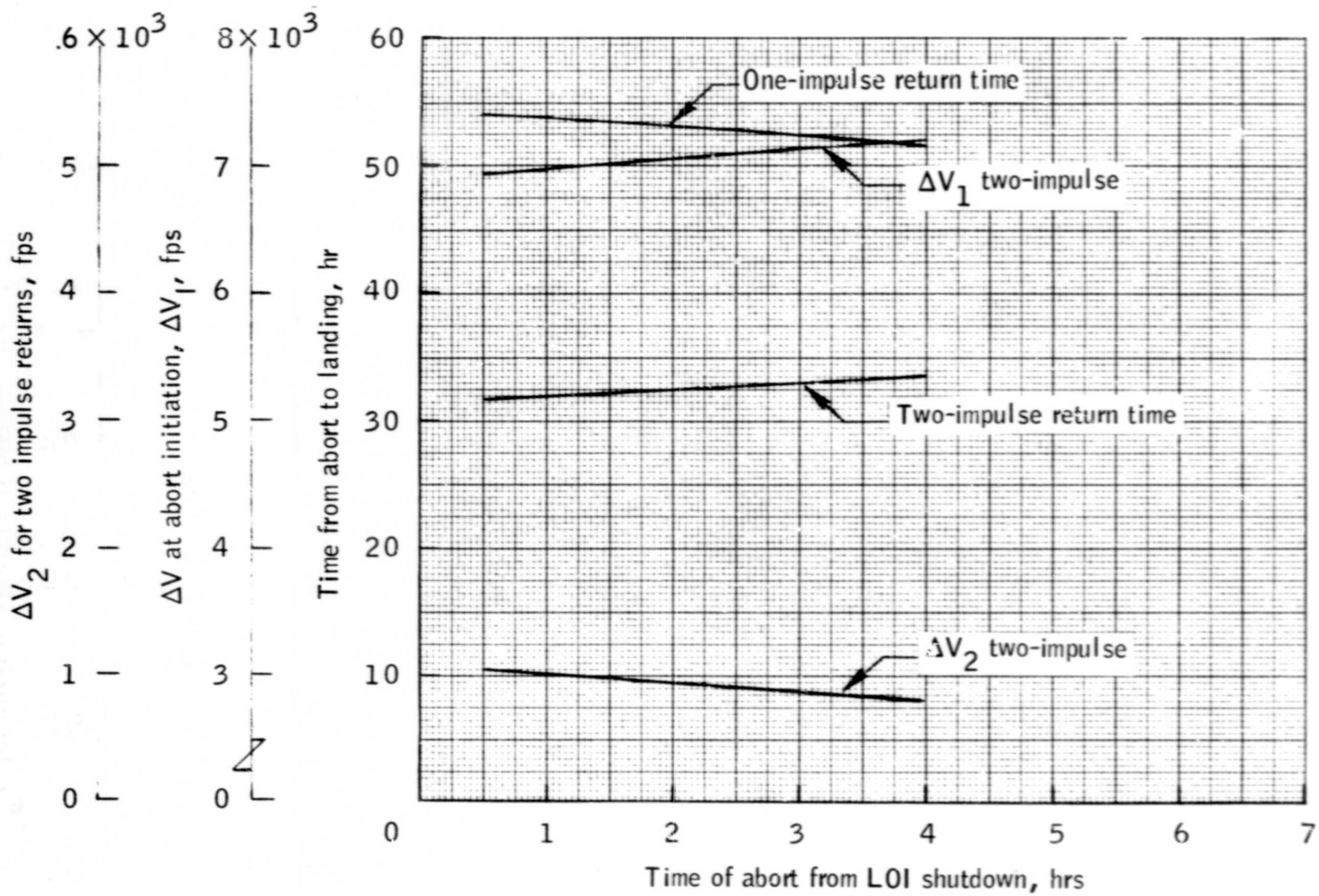

Figure 6.-Aborts following premature SPS shutdown during lunar orbit insertion with a 130 second SPS burn (Time-critical unspecified area).

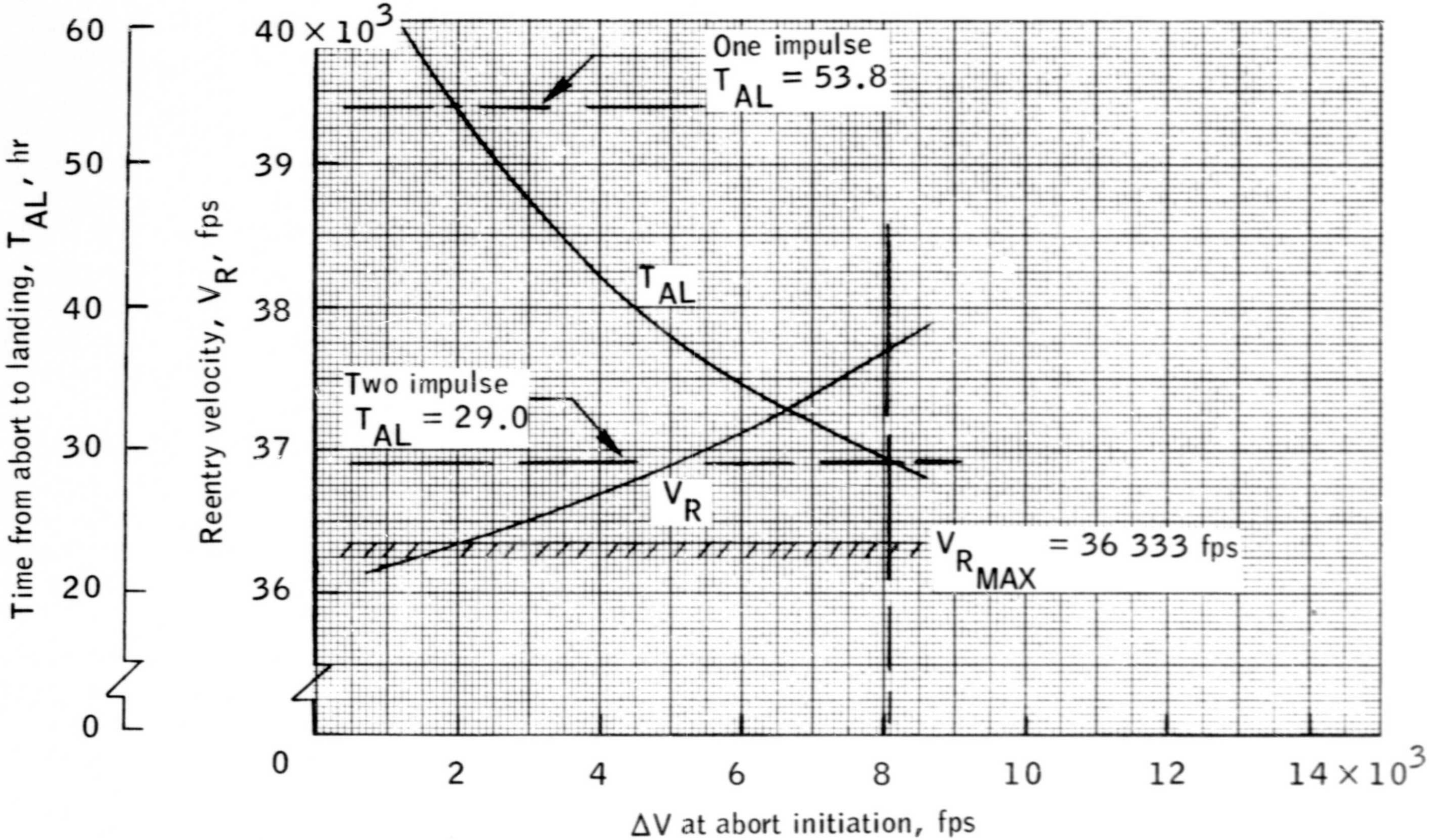

Figure 7.- Post-pericynthion aborts on circumlunar mission (abort time 1.0 hour post-pericynthion; time-critical unspecified area).

REFERENCES

1. Mission Analysis Branch: AS-504A Preliminary Spacecraft Reference Trajectory, (U) MSC IN 66-FM-70, July 1, 1966. (C)

2. Apollo Mission Planning Task Force: Abort Trajectory Performance Studies, Report No. LED-540-10, October 15, 1964.