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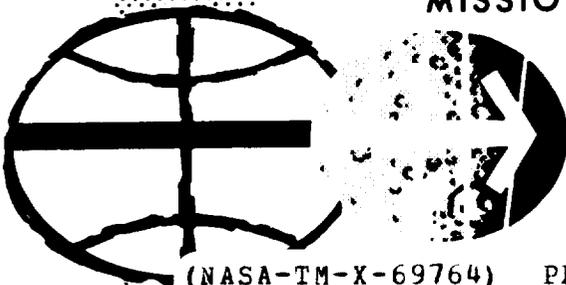
PRELIMINARY ANALYSIS
OF LM ABORT AND CSM RESCUE
FROM A 60 - N. MI. CIRCULAR ORBIT
FOLLOWING AN LM ABORT
FROM POWERED DESCENT



By Jerome A. Bell and Allan L. Dupont,
Orbital Mission Analysis Branch

(This revision supersedes MSC Internal Note No. 67-FM-65
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MISSION PLANNING AND ANALYSIS DIVISION



MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

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PROJECT APOLLO

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PRELIMINARY ANALYSIS OF LM ABORT AND CSM
RESCUE FROM A 60-N. MI. CIRCULAR ORBIT FOLLOWING
AN LM ABORT FROM POWERED DESCENT

By Jerome A. Bell and Allan L. DuPont

SUMMARY

A study was made of LM abort and CSM rescue techniques for the lunar orbit phase of the first lunar landing mission. Investigated were IM-active rendezvous, CSM rescue, and CSM assist following an IM abort from powered descent.

The study showed the LM is capable of rendezvousing with the CSM following an LM abort anytime during the powered descent phase provided it has the propulsion to do so. It also showed that only one rendezvous sequence, the coelliptic sequence, is required, and that a CSM rescue or assist can be accomplished during this phase, although the procedure is more complicated and may require assistance from the MSFN.

INTRODUCTION

Since the publication of reference 1, there has been a change in the lunar parking orbit of the CSM which has necessitated a re-examination of the LM abort and CSM rescue techniques for the lunar orbit phase of the first lunar landing mission. The CSM parking orbit was lowered 20 n. mi., from an 80-n. mi. circular to a 60-n. mi. circular orbit.

The preliminary data contained in this internal note will illustrate the rescue and abort techniques presently considered for an LM abort from the powered descent phase. In this note, the powered descent phase is considered to extend from powered descent initiation to about 13 minutes following touchdown. (Contingencies arising after touchdown are in the realm of an any-time lift-off. Techniques for these will be presented in a later report.)

In this report, an LM abort implies that the LM is capable of terminating the mission and returning to the CSM without assistance from the CSM. A CSM rescue implies that the LM is completely passive after aborting

during powered descent and inserting into orbit; thus the CSM is required to perform all the rendezvous maneuvers. A CSM assist implies that the LM is able to perform one or more, but not all the rendezvous maneuvers, and requires assistance from the CSM.

Except for a total loss of propulsion capability by the LM, there was no attempt to identify the failure source which caused the mission to be aborted; likewise, a dispersion analysis was not considered at this time.

SYMBOLS

CDH	constant differential height maneuver
CPM	coelliptic phasing maneuver
CSI	coelliptic sequence initiation
CSM	command and service modules
Δh	coelliptic differential altitude
DPS	descent propulsion subsystem
DOI	descent orbit initiation
LM	lunar module
MSFN	Manned Space Flight Network
PDI	powered descent initiation
PGNCS	primary guidance and navigation control system
TPI	terminal phase initiation

POWERED DESCENT PHASE

Presently, the LM is scheduled to initiate powered descent at pericyynthion of the LM orbit (nominally, 50 000-ft altitude) approximately 57 minutes after DOI. The PDI position is about 15° central angle prior to the arrival over the landing site.

Nominally, the powered flight time from PDI to touchdown is about

11.5 minutes. An additional 85 seconds of hover capability is included in the LM descent ΔV budget. At PDI, the LM is about 7° phase angle ahead of the CSM; however, as time into powered descent increases prior to an LM abort, the CSM will catch up and eventually be in front of the LM at LM insertion. For an abort at nominal LM touchdown (11.5 minutes from PDI), the LM will insert about 23° phase angle behind the CSM. For each minute delay in abort following touchdown, the CSM will be an additional 3.03° phase angle ahead of the LM at LM insertion. Figure 1 illustrates the phasing situation at LM insertion as a function of abort time from PDI. The LM insertion position is about 9.5° west of the landing site; the powered flight time is about 6.8 minutes.

At present, the PGNCS contains two insertion velocities to target for, 5551 and 5510 fps. For aborts up to high gate, about 8.2 minutes into powered descent, the LM will target for an insertion velocity of 5551 fps, which results in a 60-n. mi. by 60 000-ft altitude orbit. Beyond high gate, the LM targets for a velocity of 5510 fps, which is the same velocity used for a nominal lunar lift-off to a 30-n. mi. by 60 000-ft altitude orbit.

LM-ACTIVE RENDEZVOUS FOLLOWING AN ABORT FROM POWERED DESCENT

An LM-active rendezvous following an abort from powered descent can be classified under two categories--those which occur early in the descent and those which occur late in the descent. Early aborts are classified as all aborts prior to high gate where, as mentioned previously, the LM will be targeted for a 60-n. mi. by 60 000-ft altitude insertion orbit; late aborts consist of all aborts later than high gate where the LM inserts into a 30-n. mi. by 60 000-ft altitude orbit.

The rendezvous sequence for all LM aborts, either early or late, is the coelliptic sequence. Figure 2 is a sketch of an LM-active rendezvous for both early and late aborts from powered descent. For an early abort, the rendezvous will be from above, whereas for late aborts it will be from below.

Figure 3 illustrates the technique for an LM-active rendezvous for aborts occurring at PDI to about 13 minutes after touchdown^a. As stated earlier, the coelliptic sequence is used throughout the entire abort region shown. In order to control the differential altitude at CDH, i.e., to control the magnitude of the braking maneuver and to control

^aIn the figures Ωt is the transfer angle from TPI to rendezvous and the elevation angle is the line-of-sight angle from the LM to the CSM at TPI.

the effects of dispersions on TPI time, etc., the parameters governing the coelliptic sequence (TPI time, CSI time, and apsis for CDH) are varied. It is seen from figure 3 that, from PDI to touchdown, TPI will not occur later than two revolutions following LM insertion.

While figure 3 shows the "anytime abort" capability for circumstances where an immediate abort is required (DPS failure, for example), there are preferred times to abort in order to achieve a more favorable rendezvous situation. These times are considered only when a situation arises such that an immediate abort is not critical. For example, a circumstance could arise after PDI such that the decision not to land is made even though the DPS is operating satisfactorily. The astronaut, in this event, could, if he desired, select any abort time prior to touchdown. Figure 4 shows the preferred abort time as a function of time into descent. Abort times other than those shown could be selected from figure 3.

At present there are four preferred abort times shown, two prior to touchdown and two following touchdown. The first abort time, occurring about 4.5 minutes from PDI, was selected based on being able to use the consumables in the DPS after insertion. The LM cannot insert into orbit after about 5 minutes from PDI without staging the DPS; therefore, if the descent stage consumables are required, an abort must occur prior to that time. The 4.5 minutes was selected because it was late enough into the descent that the LM could keep the descent stage and also obtain a good Δh .

The second abort time, which occurs 9 minutes after PDI, allows the LM to fly the nominal timeline from insertion to rendezvous. That is, the rendezvous is identical to that which would result from a nominal ascent from the surface.

The remaining abort times shown on figure 4 occur after touchdown. They are based on achieving the nominal rendezvous profile (relative position and velocity) from CSI to rendezvous. For the third abort time (15.9 minutes from PDI), CSI occurs one revolution beyond the nominal CSI time. Hence, TPI is two revolutions from LM insertion.

The fourth preferred abort time occurs 23 minutes from PDI. The only difference is that CSI occurs two revolutions from LM insertion and TPI is three revolutions from LM insertion.

Additional abort times may be obtained by adding additional 7-minute increments to these times; however, after about 37 minutes from PDI, the LM lifetime may be exceeded because of the long catch-up time required between LM insertion and rendezvous.

CSM RESCUE FOLLOWING AN LM ABORT FROM POWERED DESCENT

In order to initiate a CSM rescue of an LM following an abort from powered descent, the LM must first achieve orbit. There are two rescue techniques required for an LM-active rendezvous based on whether the LM aborted early or late into powered descent. These two different techniques are required since the CSM cannot rendezvous from below. (Recall that figure 3 shows that the LM will be required to rendezvous from both above and below.) The technique illustrated in figures 5(a) and 5(b) will now be discussed.

CSM Rescue Following an Early LM Abort from Powered Descent

The six impulse technique is used for CSM rescue for LM aborts up to high gate and is illustrated in figure 6(a). This technique is identical to the CSM rescue procedure planned during the Hohmann descent phase (ref. 2). During this abort region, the LM inserts into an orbit which is very nearly that of the Hohmann descent orbit. The only difference is the additional 10 000-ft pericyynthion altitude of the insertion orbit.

It is assumed the initial rescue maneuver could be initiated one minute after the LM CSI maneuver time (31 minutes following LM insertion). This is based on no prior knowledge of LM trouble until it reaches the planned CSI time. Of course, if it is known prior to the planned CSI maneuver that a rescue is required, the CSM could initiate the rescue sequence earlier.

It is seen from figure 6(a) that the TPI time will be between 5.5 and 7.5 hours from LM insertion. (Thus, the time from LM insertion until the crew transfers to the CSM is between 7 and 9 hours.) The boundary for the proper TPI time was determined by the point where the CSI maneuver becomes retrograde.

CSM Rescue Following a Late LM Abort from Powered Descent

At present, it is not positively known what rescue procedure will be used for a late LM abort, although a form of the coelliptic sequence is a leading candidate. A sketch of this type of rescue is shown in figure 5(b). There exist, at present, two forms of the CSM rescue coelliptic flight plan. One form is to completely retarget the CSI and CDH maneuvers for a CSM-active rendezvous; i.e., compute the maneuvers as if the CSM were the maneuvering vehicle. However, since the CSM does not have the on-board capability to compute the maneuvers, the maneuvers would either need to be computed by the LM or the ground. It is assumed that the CSM would initiate the CSI maneuver about 1 minute after the time of the planned

LM CSI maneuver. Figure 6(b) illustrates the various rendezvous parameters resulting from such a technique.

Note the time between CDH and TPI shown on figure 6(b). As is seen, the time between the CDH maneuver and the TPI maneuver can become small. This could be a serious problem. It is brought about by the difference in the angles each vehicle travels between CSI and CDH. The LM will travel about 50° less than 180° since it is in an elliptic orbit and is applying the CSI maneuver about midway between pericyynthion and apocynthion. The CSM, on the other hand, being in a circular orbit, will travel 180° . In addition, since TPI is a multiple of 320° from insertion (20 minutes prior to darkness for a 10° sun elevation angle at touchdown), the CSM will travel a smaller angle between CDH and TPI (hence, there will be less time). The reduction in angle is equal to the difference between a CSM-active and LM-active travel angle between CSI and CDH plus the phase angle the CSM is ahead at CSI.

For multiple revolutions between CDH and TPI (a two-revolution TPI, first-apsis CDH, for example), the reduction in time presents no problem; however, the problem occurs when TPI is nominally near the CDH point. TPI could, if permitted, be delayed by the time required to permit an acceptable time between CDH and TPI without significantly changing the rendezvous.

A second form of the coelliptic sequence is the "mirror image" technique, which is currently being planned for Missions D and E. Essentially this plan is based on having the CSM perform the LM maneuvers in the opposite direction. The first maneuver would probably be performed a minute after the nominal LM CSI maneuver. Figure 6(c) illustrates this type of technique. The CDH maneuver was applied at the nominal LM CDH time.

Several points should be made about this type of technique. See figure 6(c). Since the CSM will not likely be over the LM apsis point at CDH and since the CDH maneuver for the LM is horizontal, the CSM will not end up in a coelliptic orbit by applying the LM CDH maneuver. Also, the CSI maneuver required for the CSM will not be exactly that for the LM, and the difference in angles traveled from CSI to CDH affect the rendezvous parameters.

As is evident from figure 6(c), the range in differential height can vary significantly, TPI will occur early, and the time between CDH and TPI can become small.

Although no data is presented here, there are some possibilities that can be utilized to improve the situation. These would include biasing the CSI maneuver, horizontally and/or radially, biasing the time of CDH, and biasing the CDH maneuver. A great deal more work needs to be performed before a decision can be made.

CSM ASSIST FOLLOWING AN LM ABORT FROM POWERED DESCENT

The philosophy underlying a CSM assist can be divided into two major areas: (1) that for the planned maneuvering of the CSM and (2) that for the unplanned maneuvering of the CSM. An example of the planned CSM maneuvering is to set up the proper conditions at TPI and then allow the LM to execute the terminal phase maneuvers. This procedure would have the benefit of saving both LM and CSM RCS propellant.

The unplanned CSM maneuvering would be required if an LM failure occurred at scheduled maneuvering points other than the initial maneuver point. (It was previously stated that if the LM cannot perform the initial maneuver, the CSM activity is classified as a rescue and not as an assist.)

Therefore, there are two places following an LM abort from powered descent that an unplanned CSM maneuver could occur (excluding a failure after TPI)--after either the CSI maneuver or the CDH maneuver. If a failure occurs after the LM performed CDH, the CSM could initiate the terminal phase maneuver at the same time the LM would have. However, if the failure occurs following the CSI maneuver, problems may arise. The remainder of this section is devoted to a discussion of this situation.

LM Aborts Early Into Powered Descent

As mentioned previously, for LM aborts early into powered descent an LM-active rendezvous will occur from above. The sketch in figure 7 illustrates the orbital geometry after the LM executes the CSI maneuver whereas figure 8 illustrates the trajectory parameters at the time of CDH (LM orbit and phase angle).

If the LM is unable to perform the CDH maneuver, the simplest CSM procedure, performing the coelliptic maneuver, is eliminated due to the pericyynthion altitude of the LM. It can be seen from figure 8 that the LM pericyynthion altitude will remain between 17 and 25 n. mi. Since the CSM would be in an orbit coelliptic and below with Δh being between 10 and 20 n. mi., the CSM could end up in an unsafe orbit. This problem also occurred in the Hohmann descent phase. It was recommended there (ref. 2) that this technique not be attempted after about 25 minutes from DOI. In fact, it was recommended that the LM not abort during the period between 25 and 40 minutes following DOI. However, since this situation always exists for aborts up to high gate and since aborts during the powered descent will likely be time critical situations, a solution to this problem had to be found.

Shown also on figure 8 is the phasing situation at the scheduled time for the LM to perform CDH. It is seen that the phasing will vary between 12° and 2.5° , and that the CSM will be behind the LM. Three rendezvous

sequences were selected for investigation. They were (1) a direct intercept, (2) a stable orbit, and (3) a modified six-impulse. The merits and disadvantages of these three techniques are discussed below.

Direct intercept.- It might readily appear that direct intercept is the proper technique to use. The CSM could be prepared to initiate a direct rendezvous within a minute after the time the LM should have performed the CDH maneuver. Three basic constraints govern the use of the direct intercept. They are (1) total ΔV , (2) magnitude of the braking maneuver, and (3) resultant pericyynthion after the initial maneuver. It should be added that the angle between the initial maneuver and rendezvous affects the above constraints. Figures 9(a), 9(b), and 9(c) illustrate the direct intercept capabilities as a function of insertion phase angle and transfer angle.

It is seen that this technique encounters difficulties with ΔV and pericyynthion when the LM aborts early into the powered descent if the plan calls for a two-revolution TPI, first-apsis CDH. (See figure 3.) This technique could possibly be utilized for later aborts; however, the braking maneuver (not shown) will be larger than desired.

Stable orbit.- The stable orbit technique is utilized in the same manner as the direct intercept for initiation of the rescue. However, instead of rendezvousing with the LM, the CSM was to achieve a 20-n. mi. displacement ahead of the LM. The same constraints imposed on the direct intercept were imposed on the stable orbit; however, the braking maneuver will not be large although the stable orbit maneuver (that maneuver which gets the CSM into the LM orbit) may be.

Figure 10(a), 10(b), and 10(c) illustrate the first two maneuvers of the stable orbit rendezvous sequence. It is seen that the same difficulties arise in the same area for stable orbit as they did in the direct intercept. Like the direct intercept, the stable orbit approach could possibly be utilized for later aborts.

Modified six-impulse.- As is evident, a CSM assist in the event the LM cannot perform the CDH maneuver is not fulfilled by either a stable orbit or direct intercept for the entire region of early LM aborts. Therefore, a new type of sequence had to be developed; this resulted in the modified six-impulse sequence discussed below.

It was assumed that, like the two previous techniques discussed, the initial rescue maneuver could occur shortly after the LM was scheduled to do the CDH. Since this maneuver would quite likely occur out of MSFN contact, it was desirable to have it be a "canned" maneuver.

The initial maneuver was chosen to be the same as the initial rescue maneuver from Hohmann descent; i.e., one that places the CSM in a 60-n. mi.

by 20-n. mi. altitude orbit. However, at pericyynthion the CSM would perform a CPM computed by the ground such that the CSI maneuver would create a differential altitude of 10 n. mi. above the LM at CDH. The CSI maneuver was scheduled to occur one revolution after the CPM. CDH was to occur 180° beyond CSI with TPI within 180° of CDH.

Figure 11 illustrates the capability of the modified six-impulse technique. It is seen from the figure that, although the CSM could get into an orbit as low as 20 n. mi. by 12 n. mi. altitudes, it is nevertheless maintains both a safe pericynthion and a reasonable ΔV requirement to rendezvous. The technique also has the advantage of maintaining both a low braking ΔV requirement and a desirable approach trajectory.

LM Aborts Late Into Powered Descent

It is seen from figure 3 that, for a late LM abort (beyond high gate), the rendezvous will occur from below. If the LM could not perform CDH, the CSM, being above the LM, could initiate the coelliptic maneuver without the problem of an unsafe orbit. This coelliptic maneuver could either be one that actually places the CSM orbit coelliptic with the LM orbit or it could be the opposite LM CDH maneuver. A more detailed analysis is required prior to defining the exact technique.

CONCLUDING REMARKS

It has been shown in this report that only one rendezvous sequence is required for an LM-active rendezvous following an LM abort from powered descent. The inputs to that sequence - the coelliptic sequence - is governed by the time the LM aborts during powered descent.

For a CSM rescue two rendezvous sequences are required. The first sequence - the six-impulse - is recommended for LM aborts up to high gate. Beyond high gate, a form of the coelliptic sequence is preferred although a more detailed analysis is required prior to the selection of the exact technique.

For CSM assists following the LM execution of the CSI maneuver, the modified six-impulse technique is suggested up to high gate, as it is applicable for the entire region of early LM aborts. Beyond high gate it is suggested that the CSM perform the coelliptic maneuver, either an updated CDH or the opposite LM CDH maneuver. Again, the exact technique is dependent on a more detailed analysis.

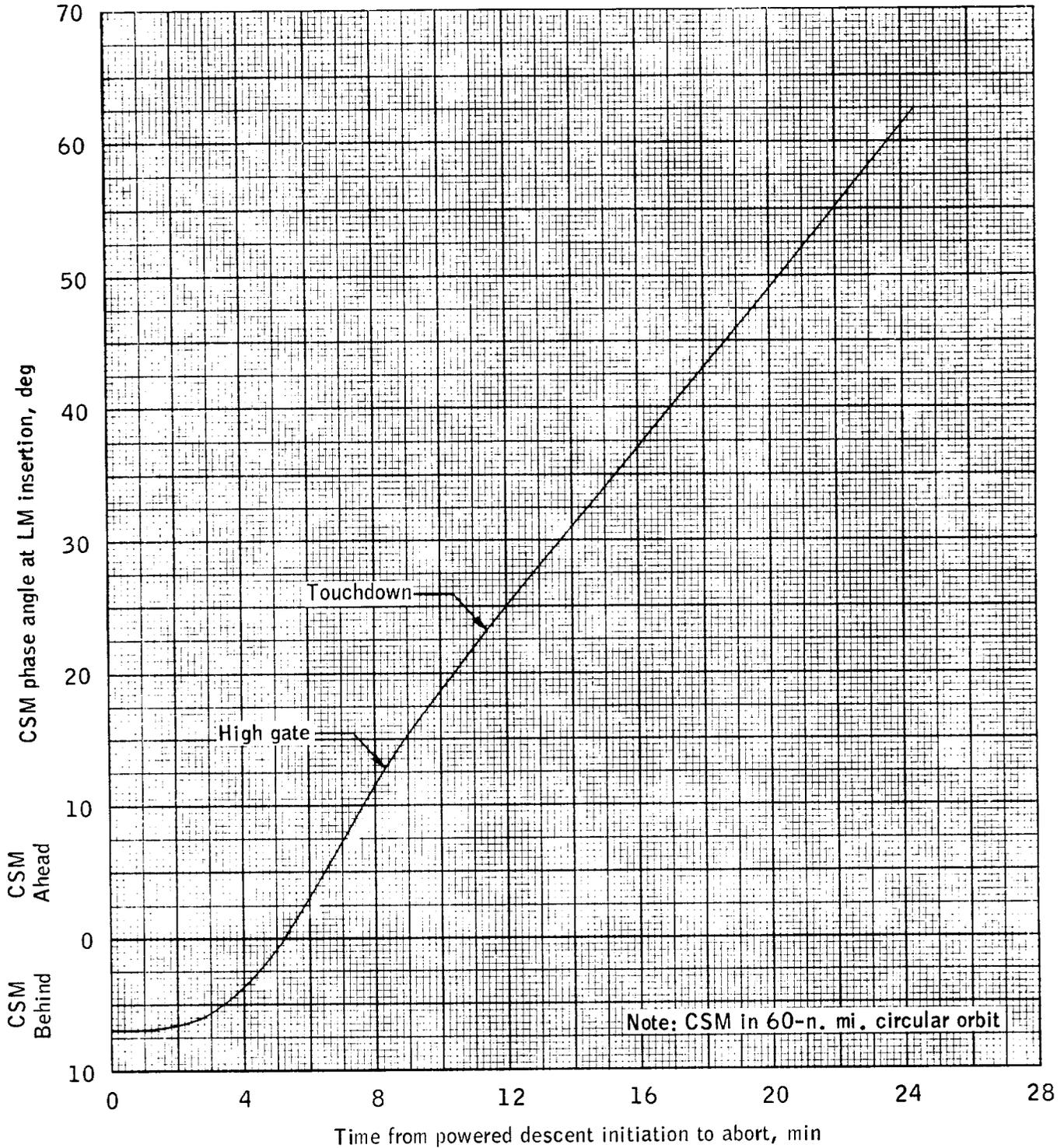
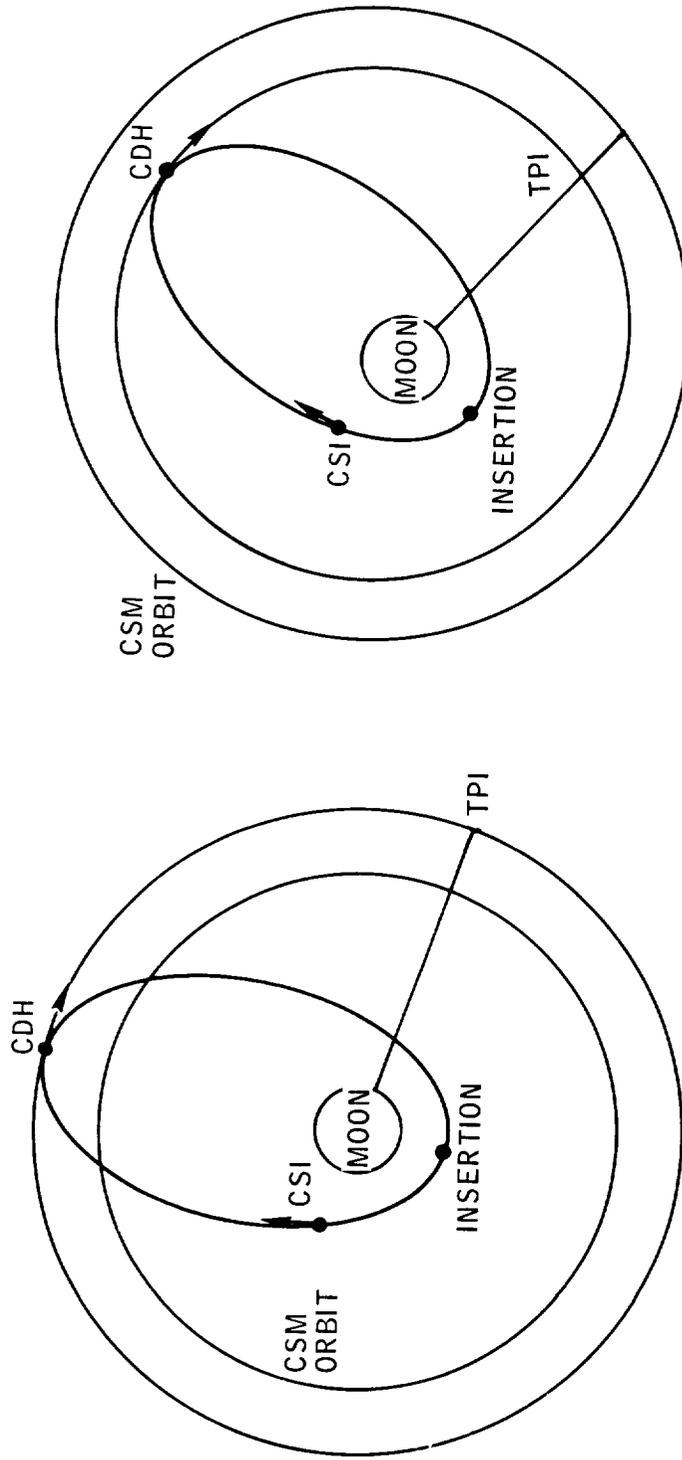


Figure 1.- Phase angle profile for LM aborts during powered descent.



(a) Early abort.

(b) Late abort.

Figure 2.- LM-active rendezvous following abort from powered descent.

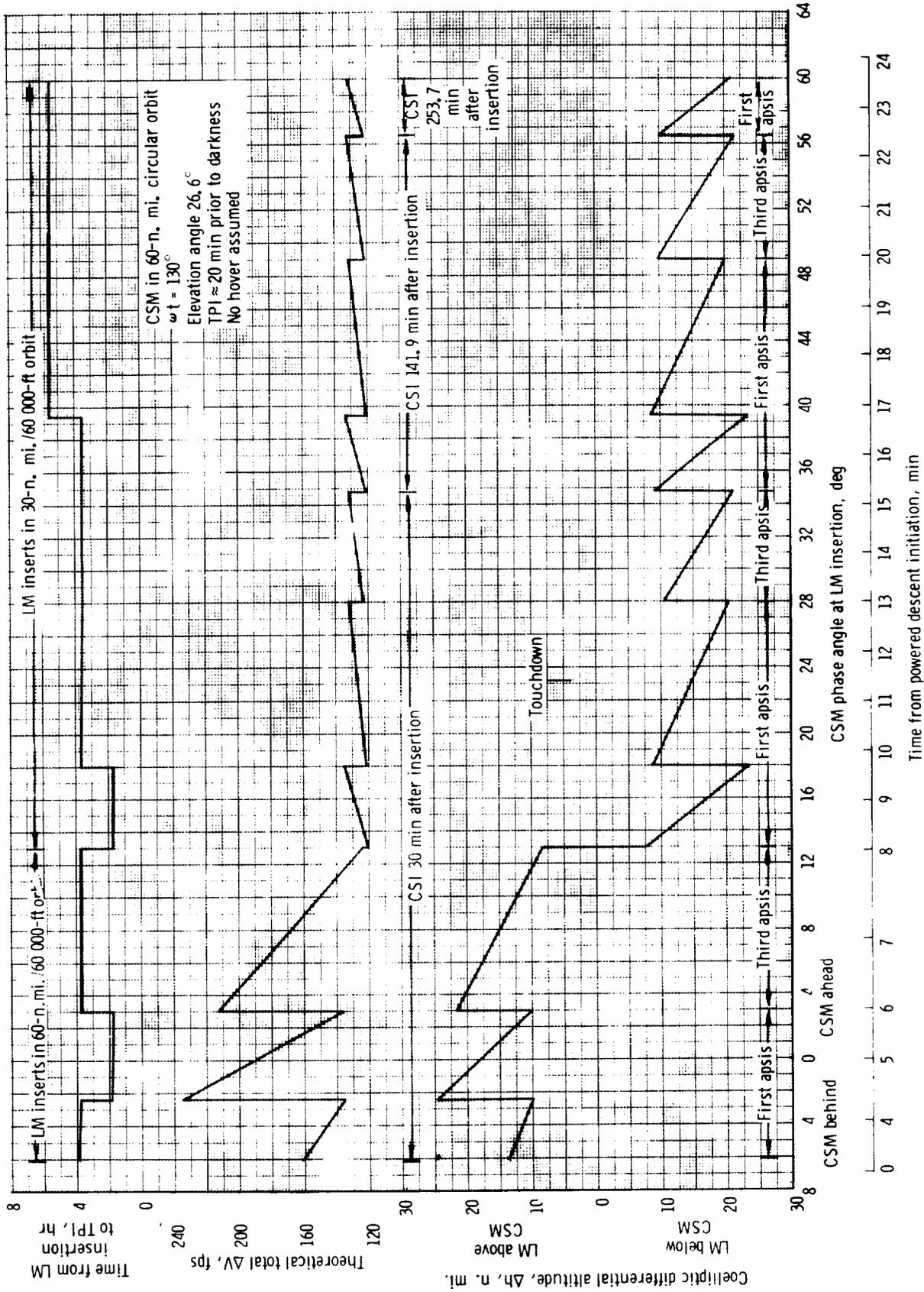


Figure 3. - LM-active rendezvous following an abort from powered descent.

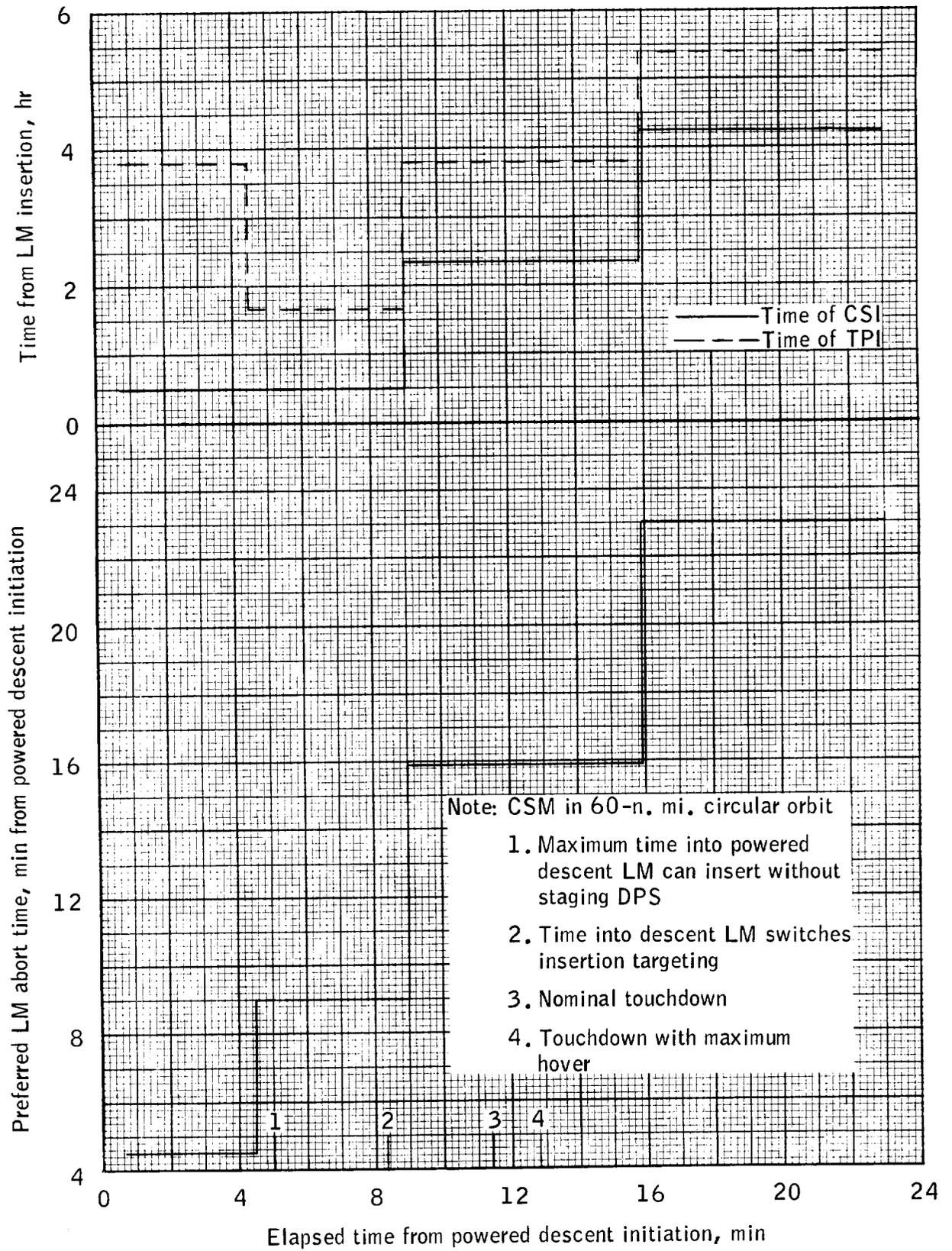
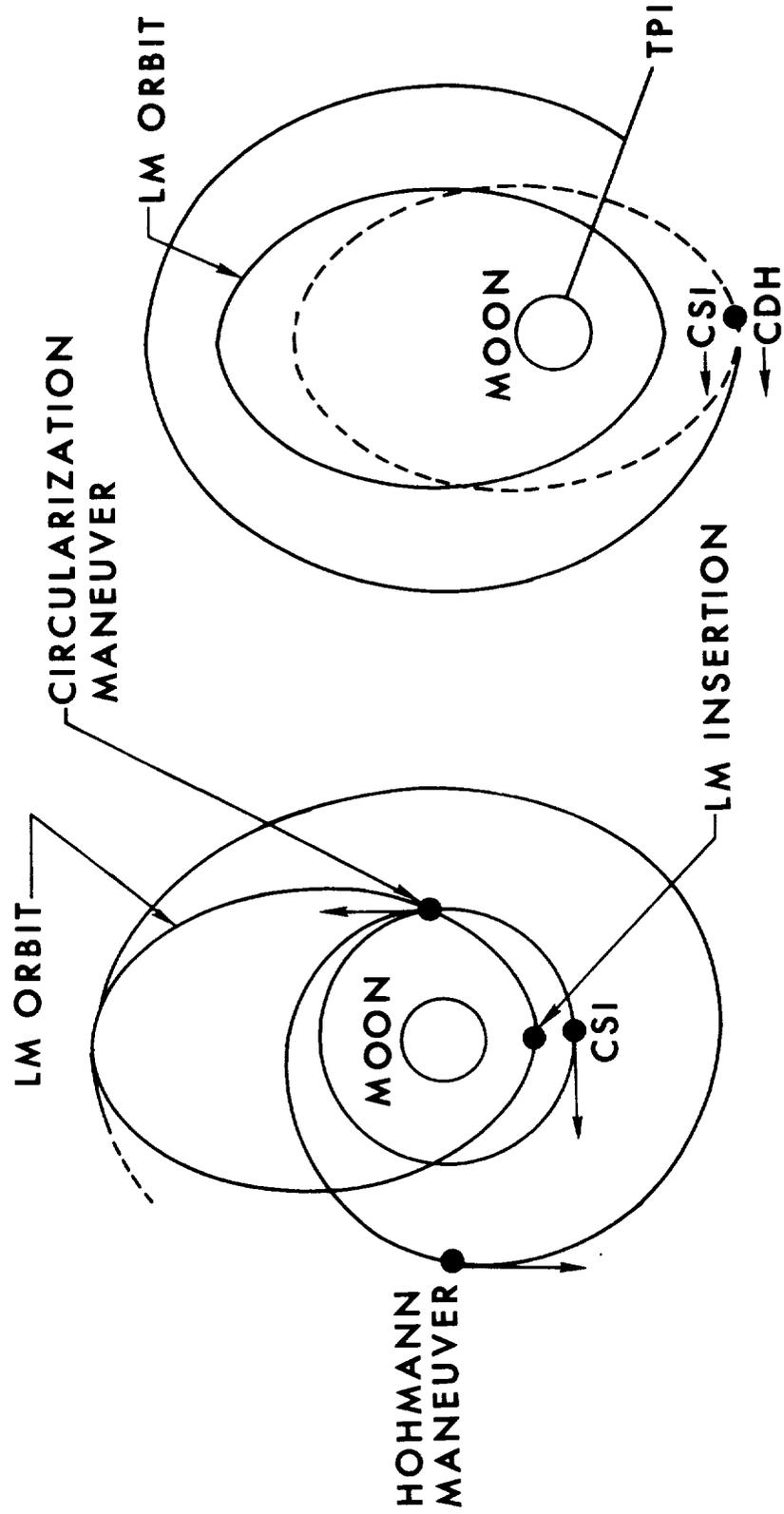
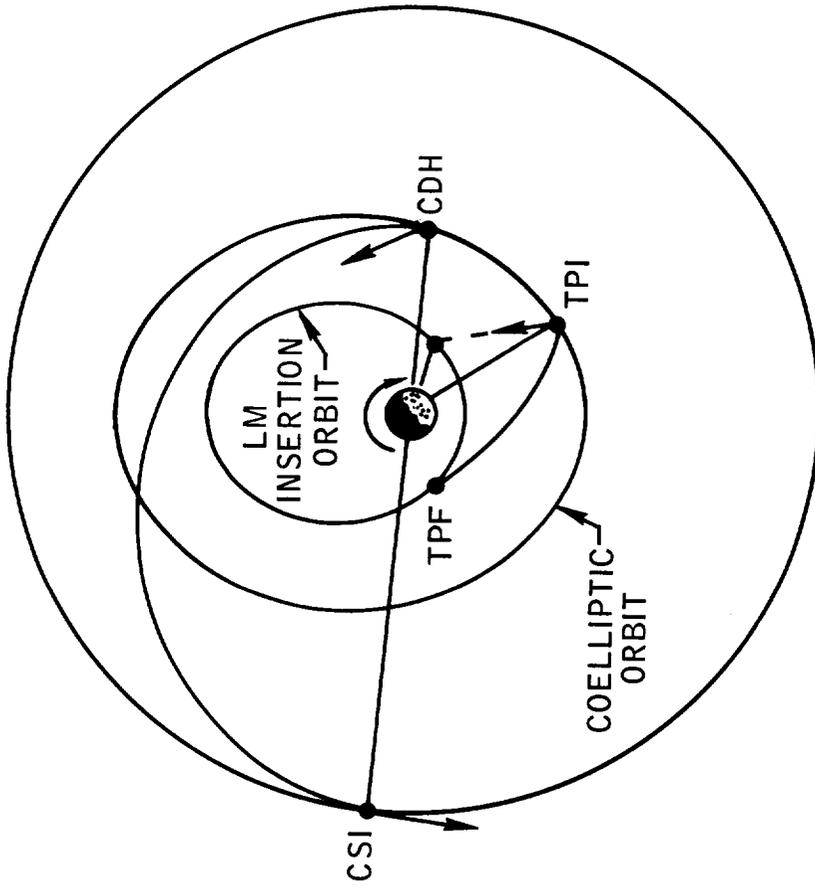


Figure 4.- Preferred abort time following powered descent initiation.



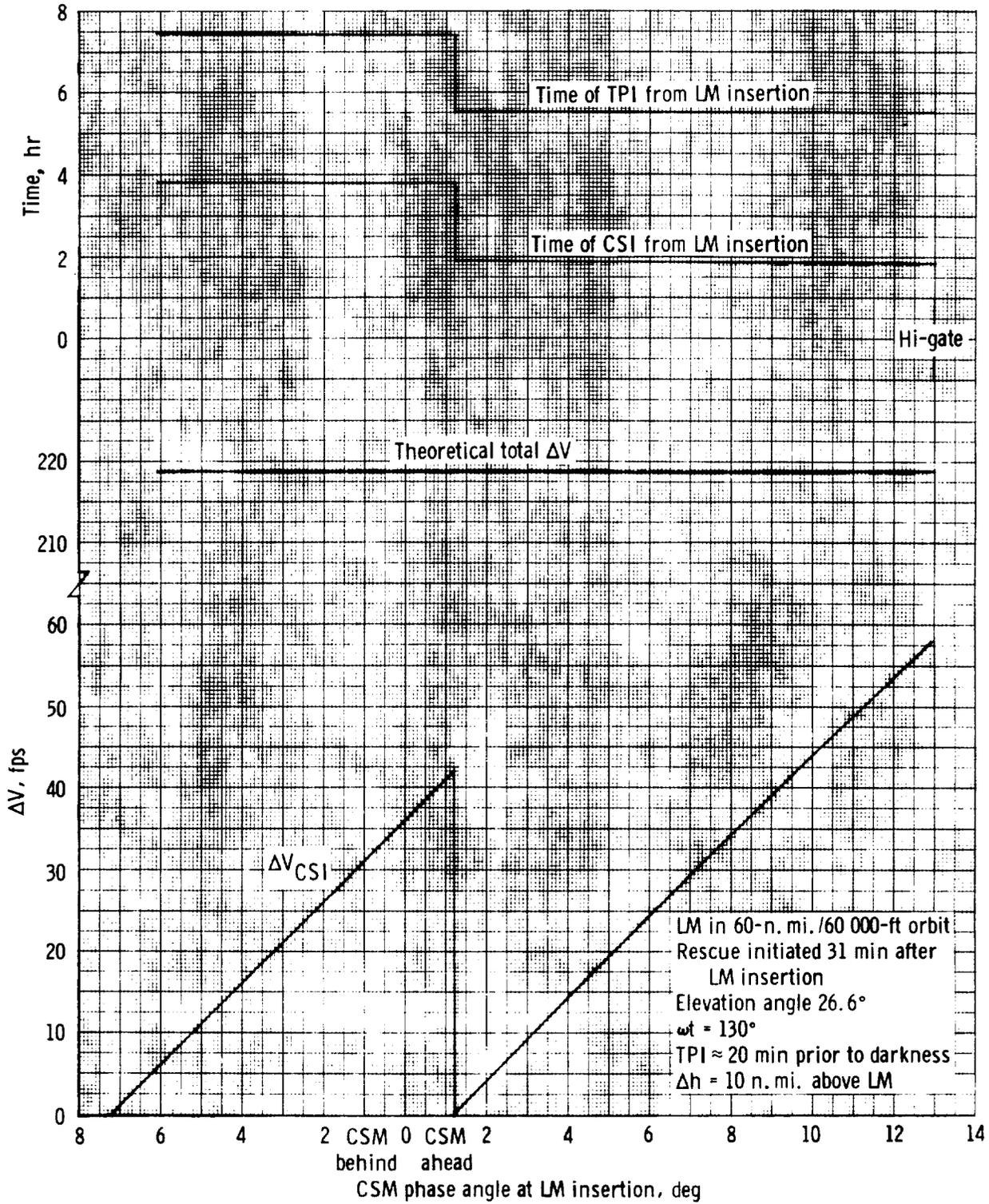
(a) Early abort.

Figure 5.- CSM rescue following LM abort during powered descent.



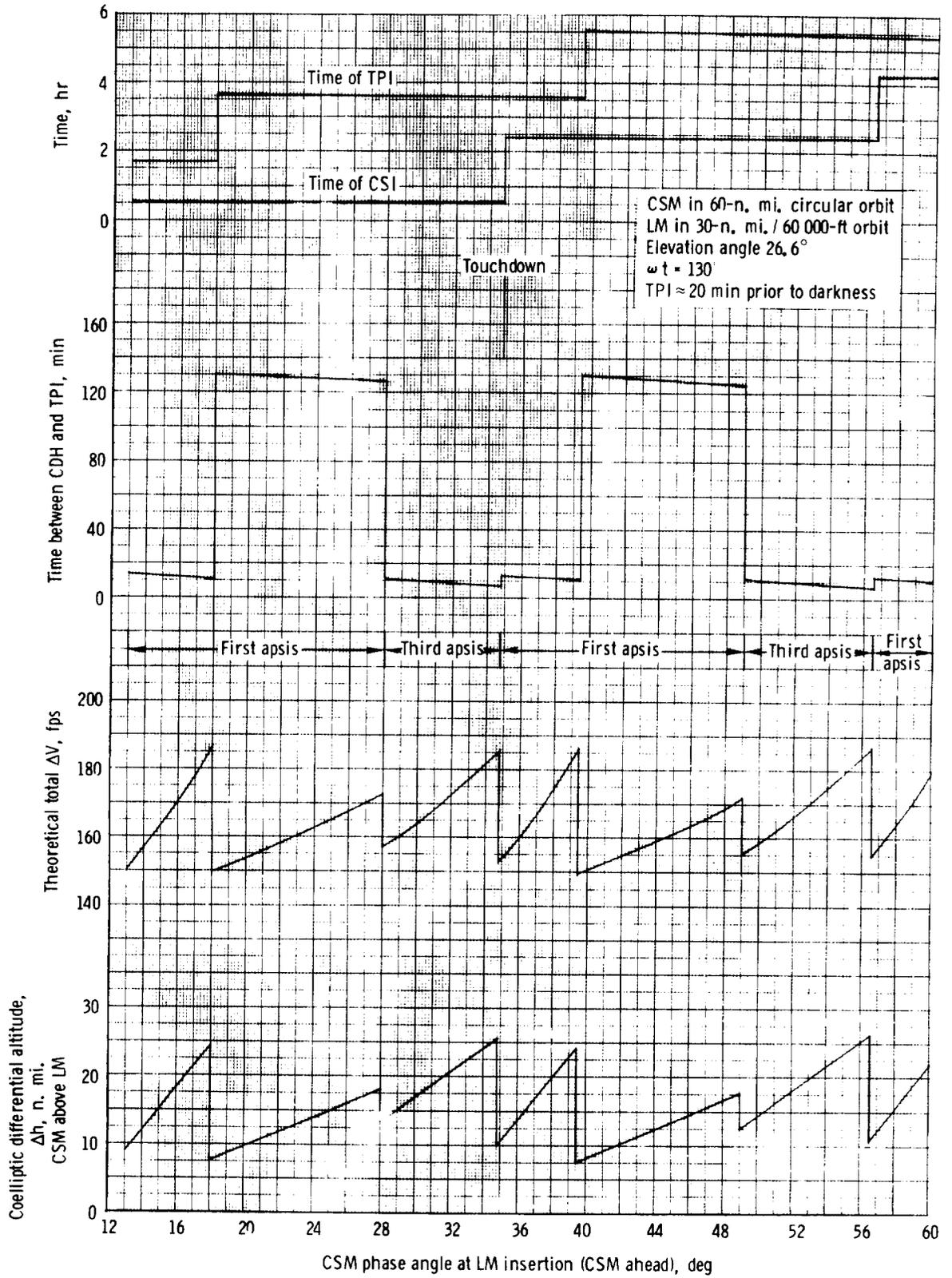
(b) Late abort.

Figure 5.- Concluded.



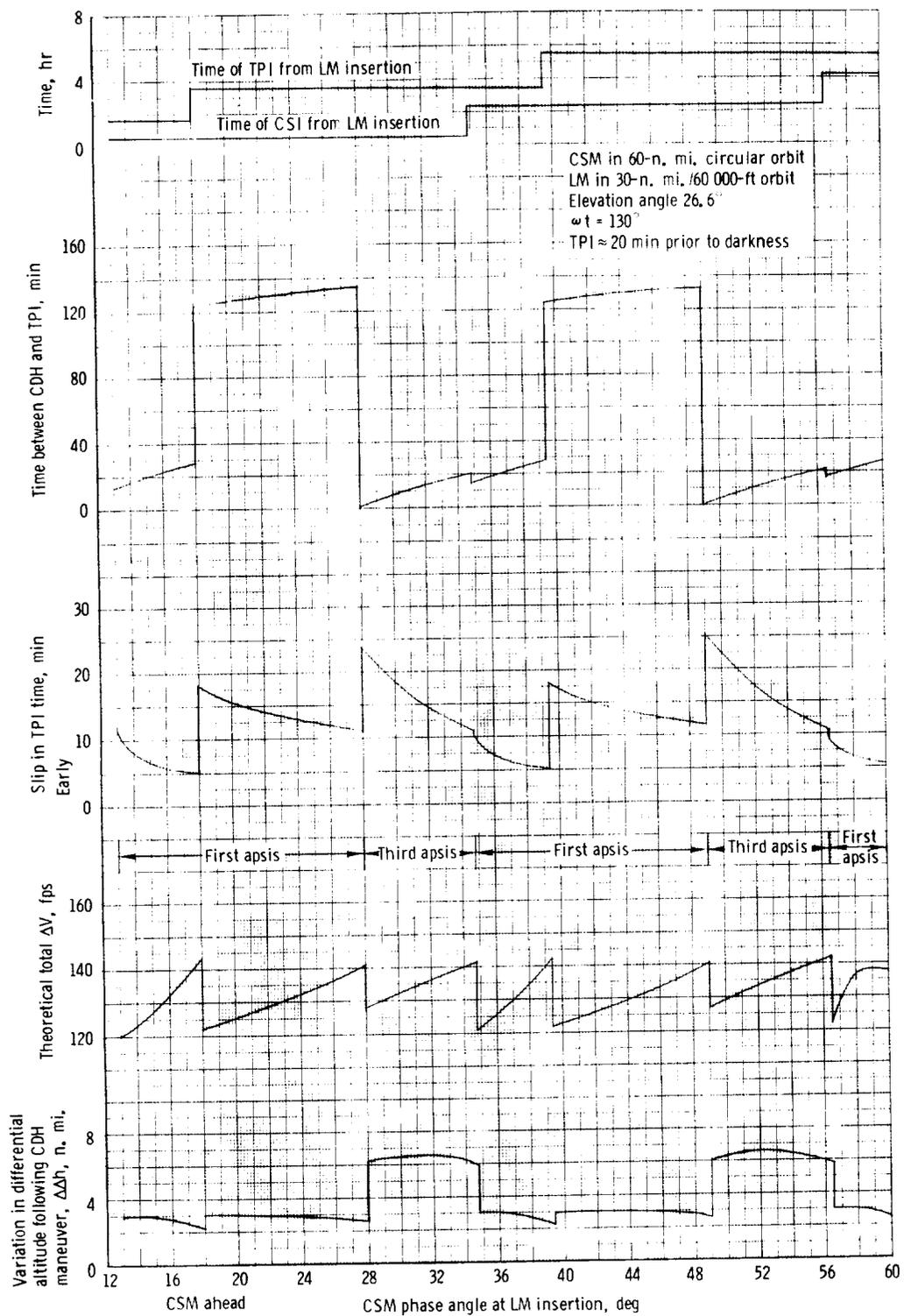
(a) Six-impulse sequence up to high gate.

Figure 6. - CSM rescue following LM abort from powered descent.



(b) Retargeted coelliptic sequence beyond high gate.

Figure 6. - Continued.



(c) Mirror image rescue beyond high gate.

Figure 6. - Concluded.

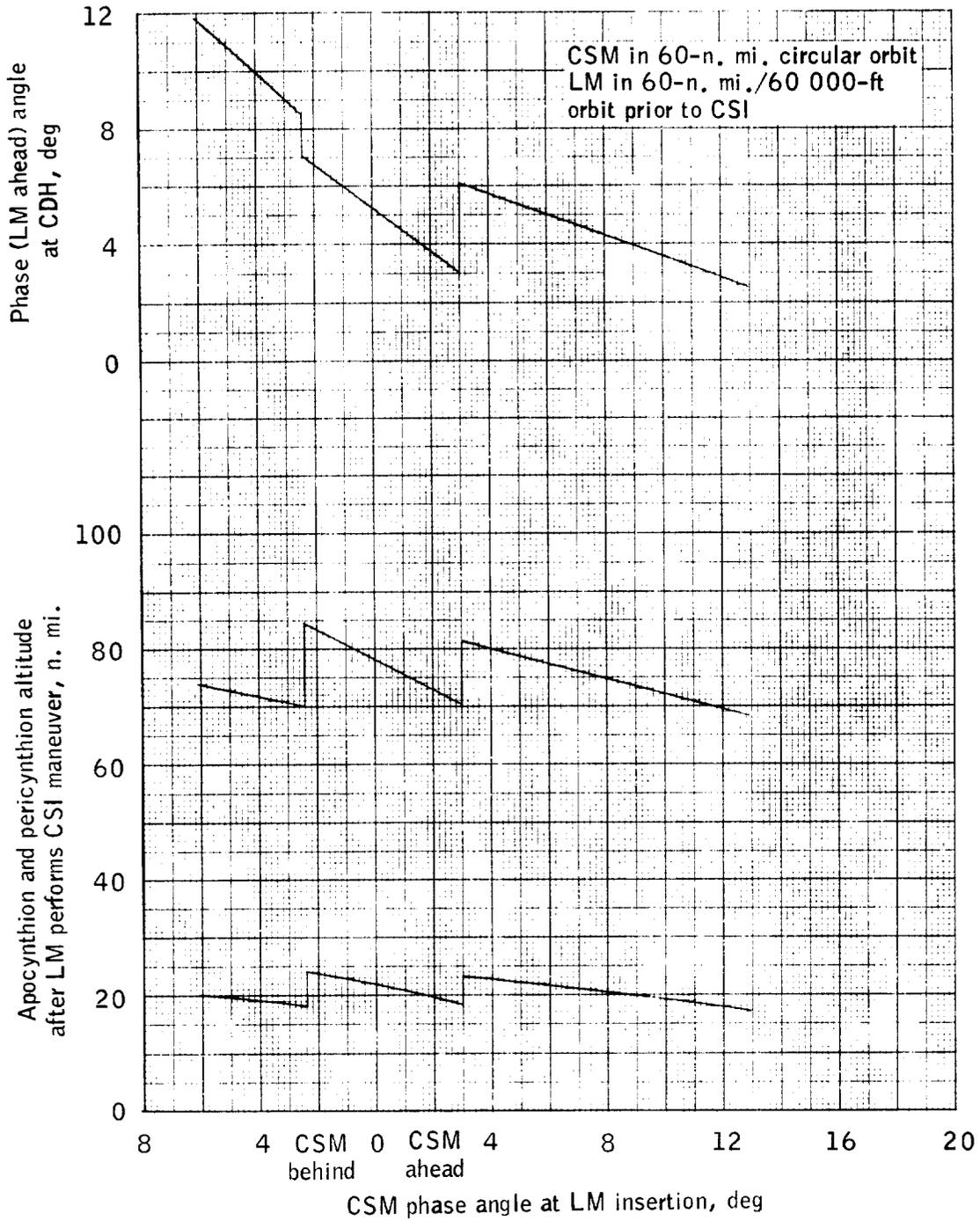
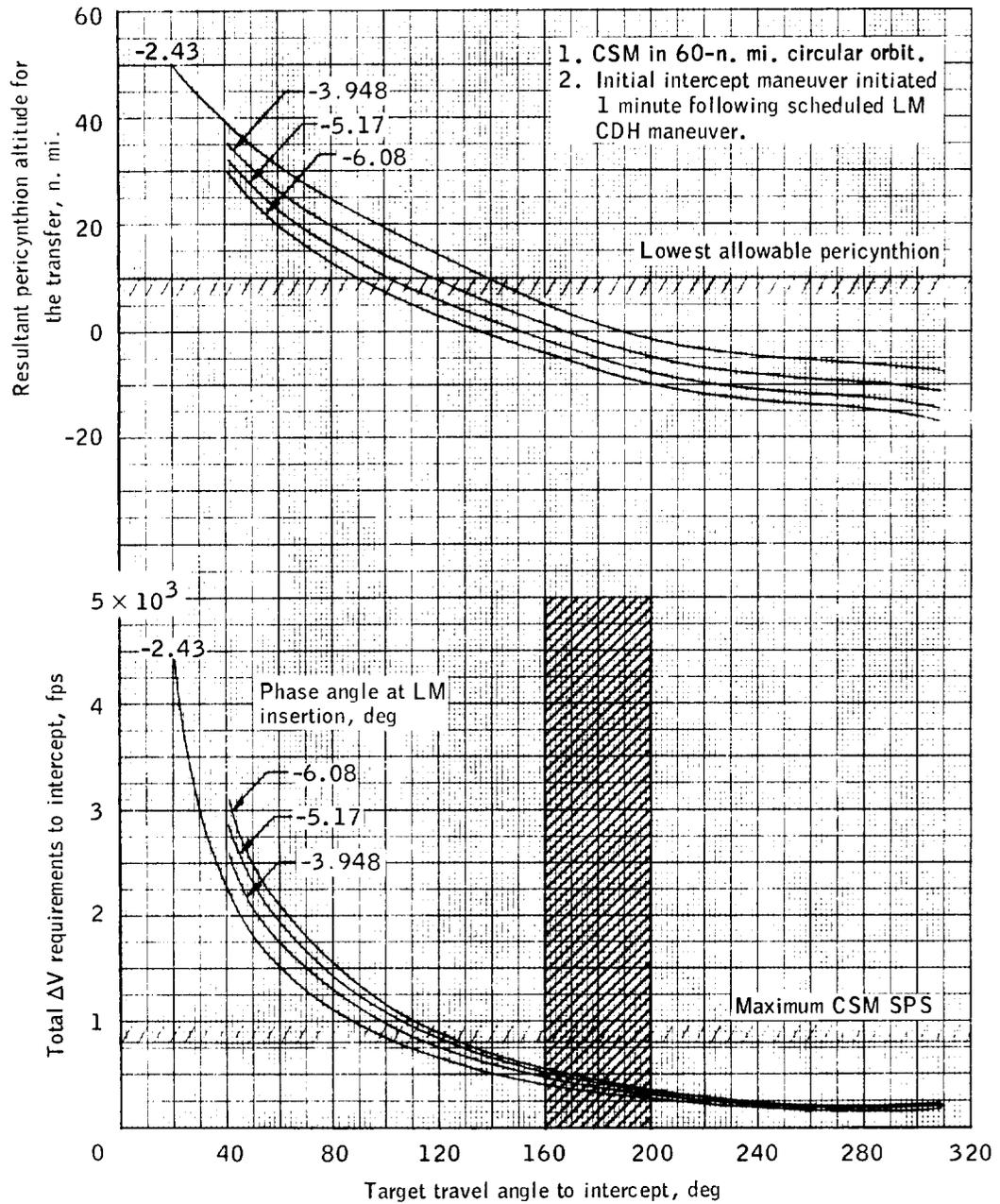
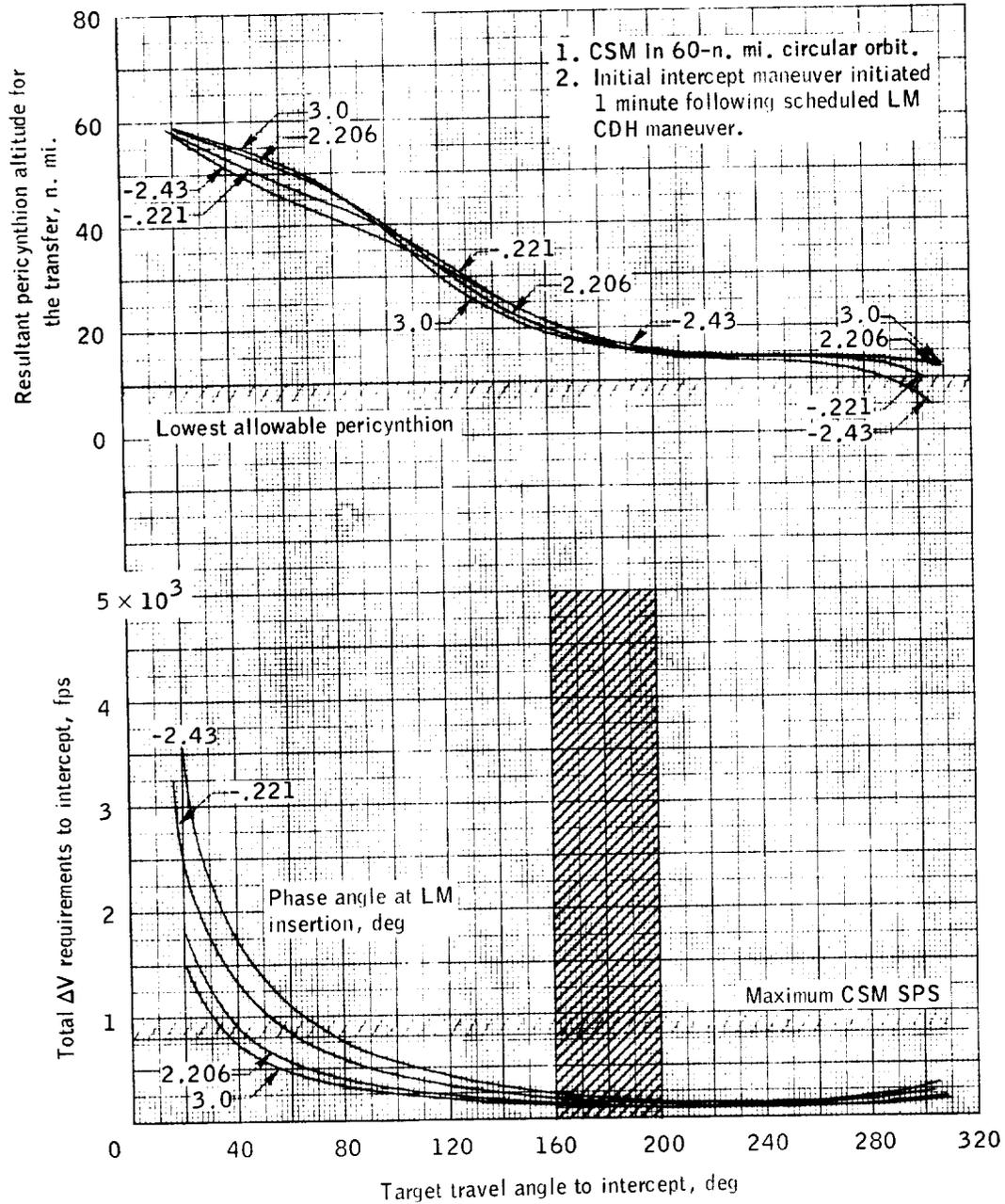


Figure 8.- Trajectory parameters resulting from LM CSI maneuver for LM aborts during powered descent (up to high gate).



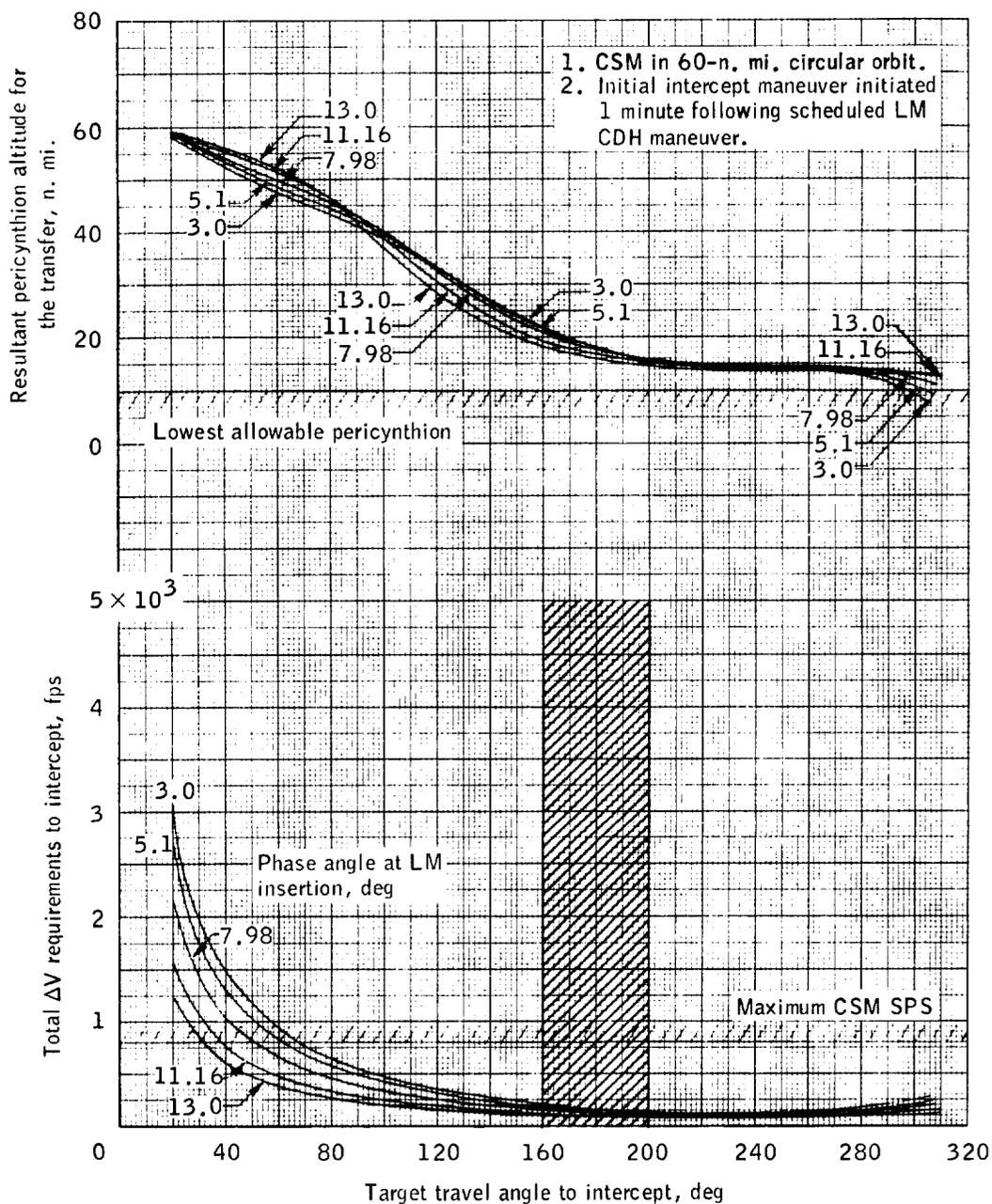
(a) LM targets for second-revolution TPI, first-apsis CDH.

Figure 9.- Direct intercept rescue capability following LM execution of CSI maneuver for LM aborts during powered descent (up to high gate).



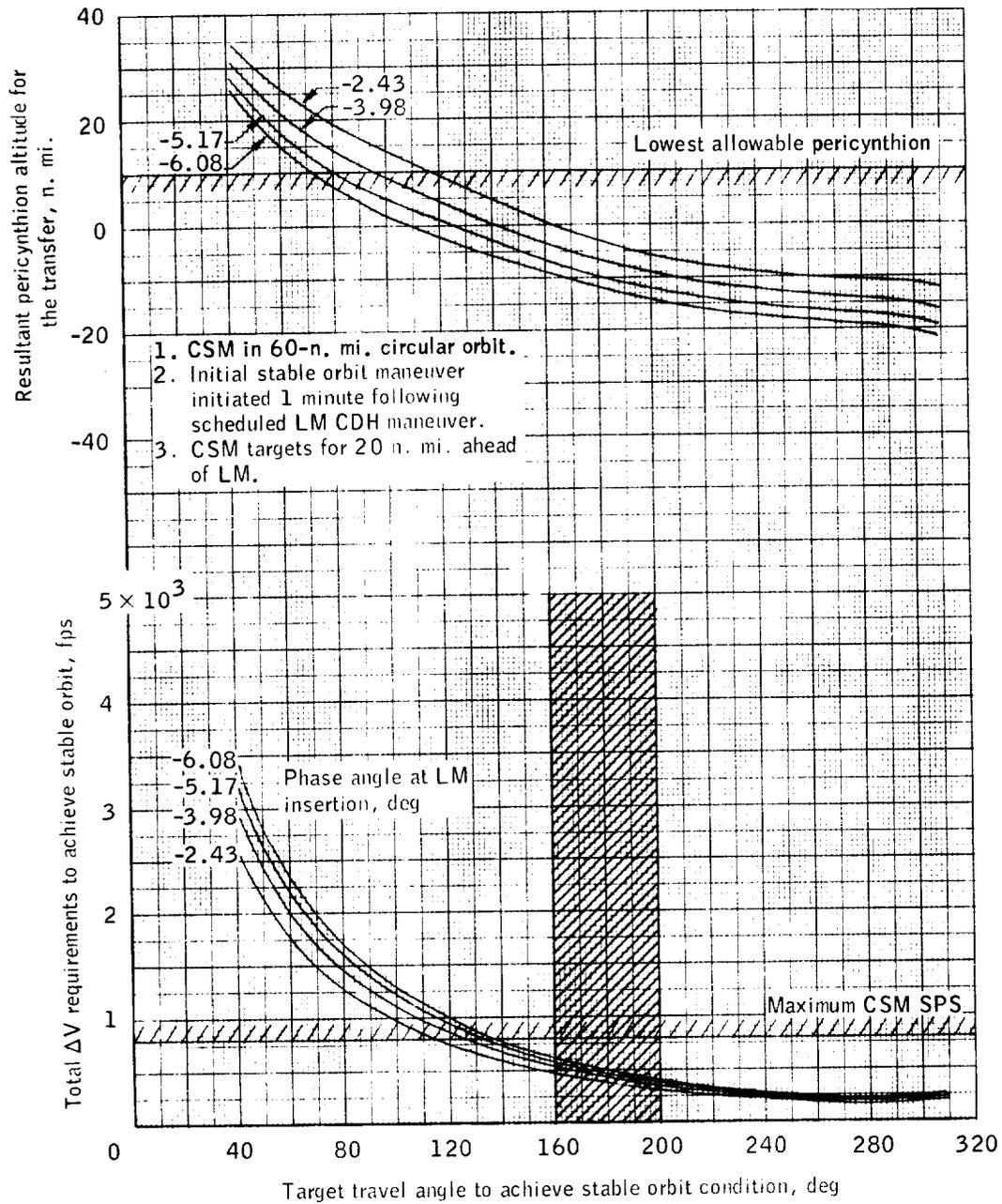
(b) LM targets for first-revolution TPI, first-apsis CDH.

Figure 9.- Continued.



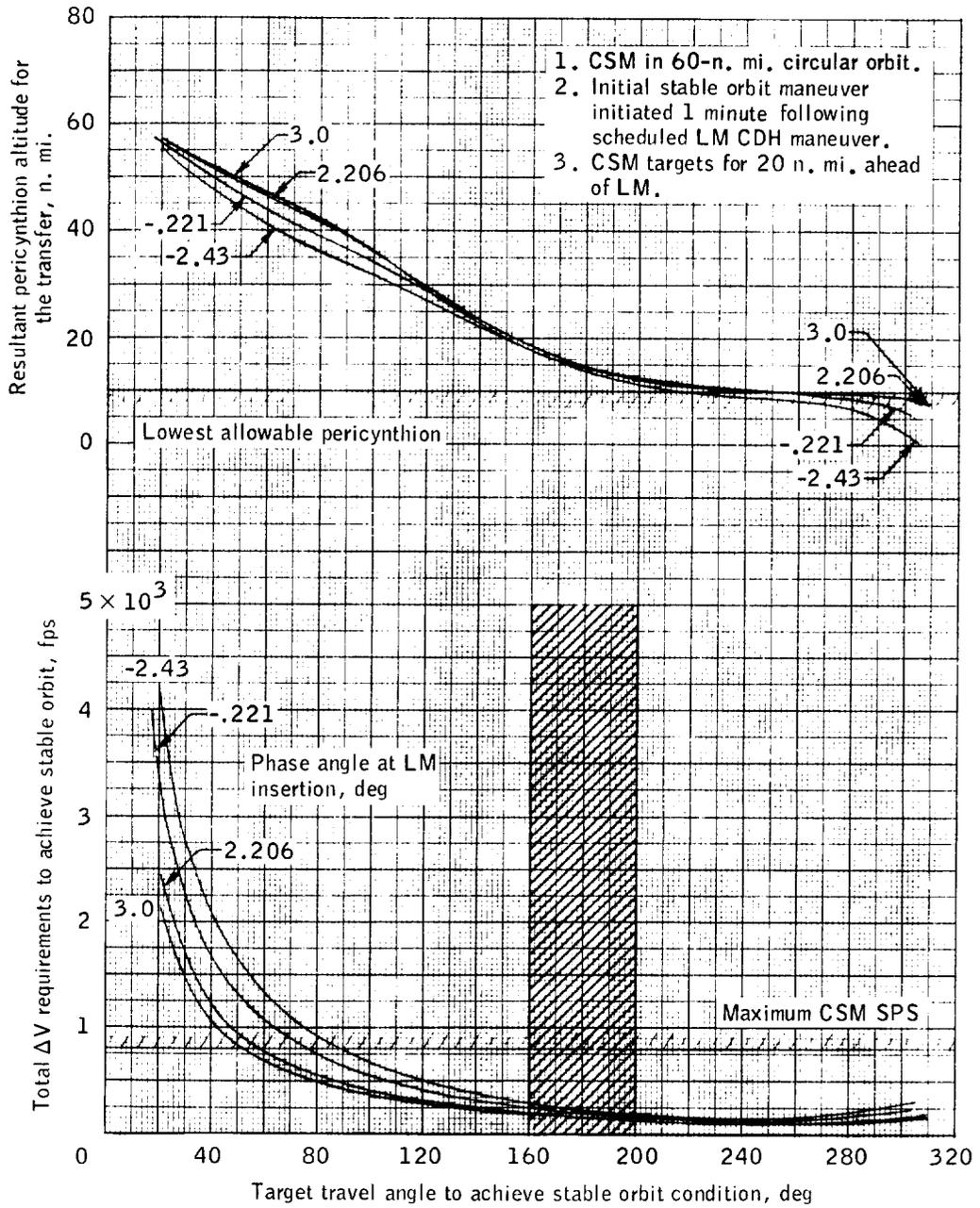
(c) LM targets for second-revolution TPI, third-apsis CDH.

Figure 9.- Concluded.



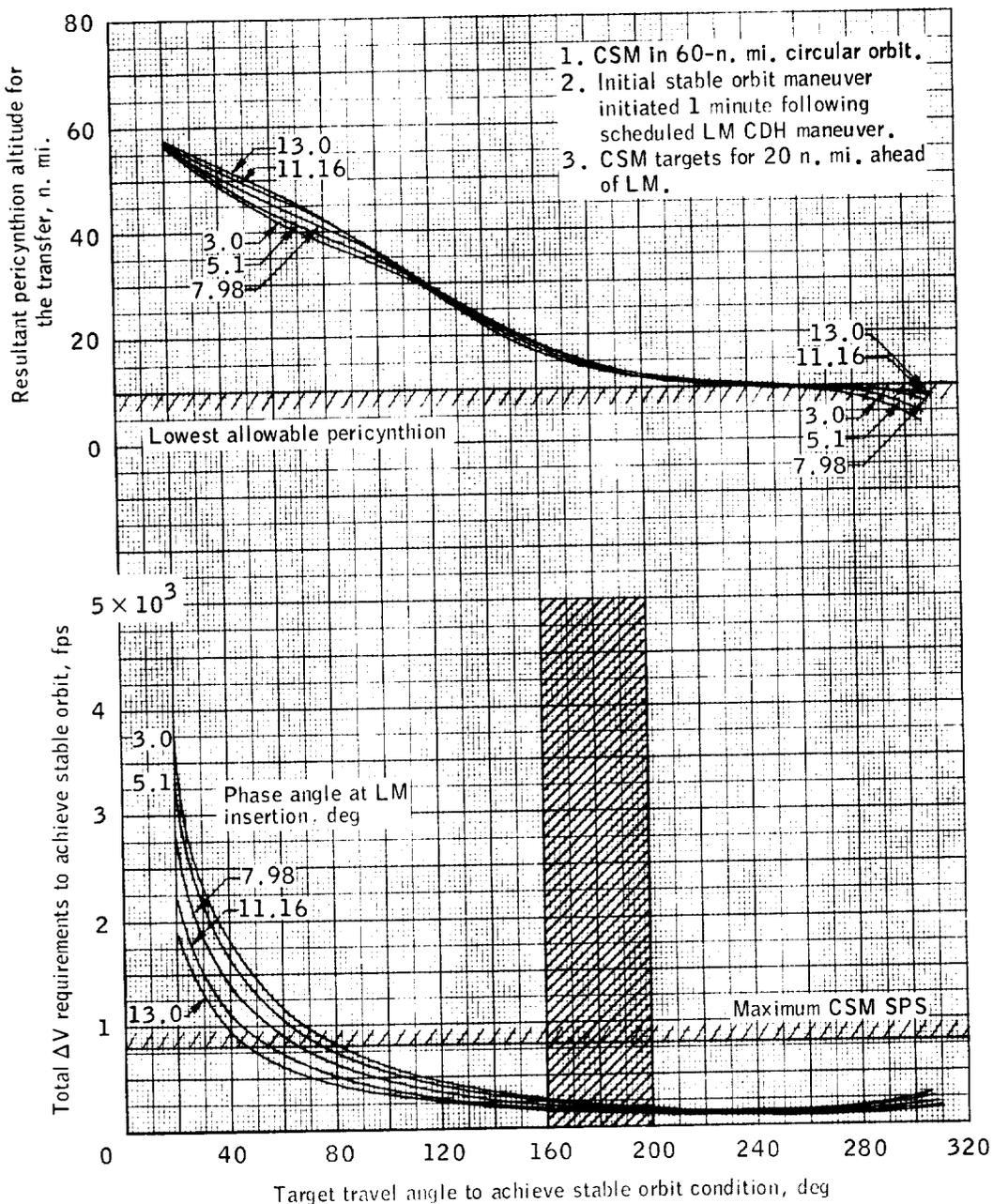
(a) LM targets for second-revolution TPI, first-apsis CDH.

Figure 10.- Stable orbit rescue capability following LM execution of CSI maneuver for LM aborts during powered descent (up to high gate).



(b) LM targets for first-revolution TPI, first-apsis CDH.

Figure 10.- Continued.



(c) LM targets for second-revolution TPI, third-apsis CDH.

Figure 10.- Concluded.

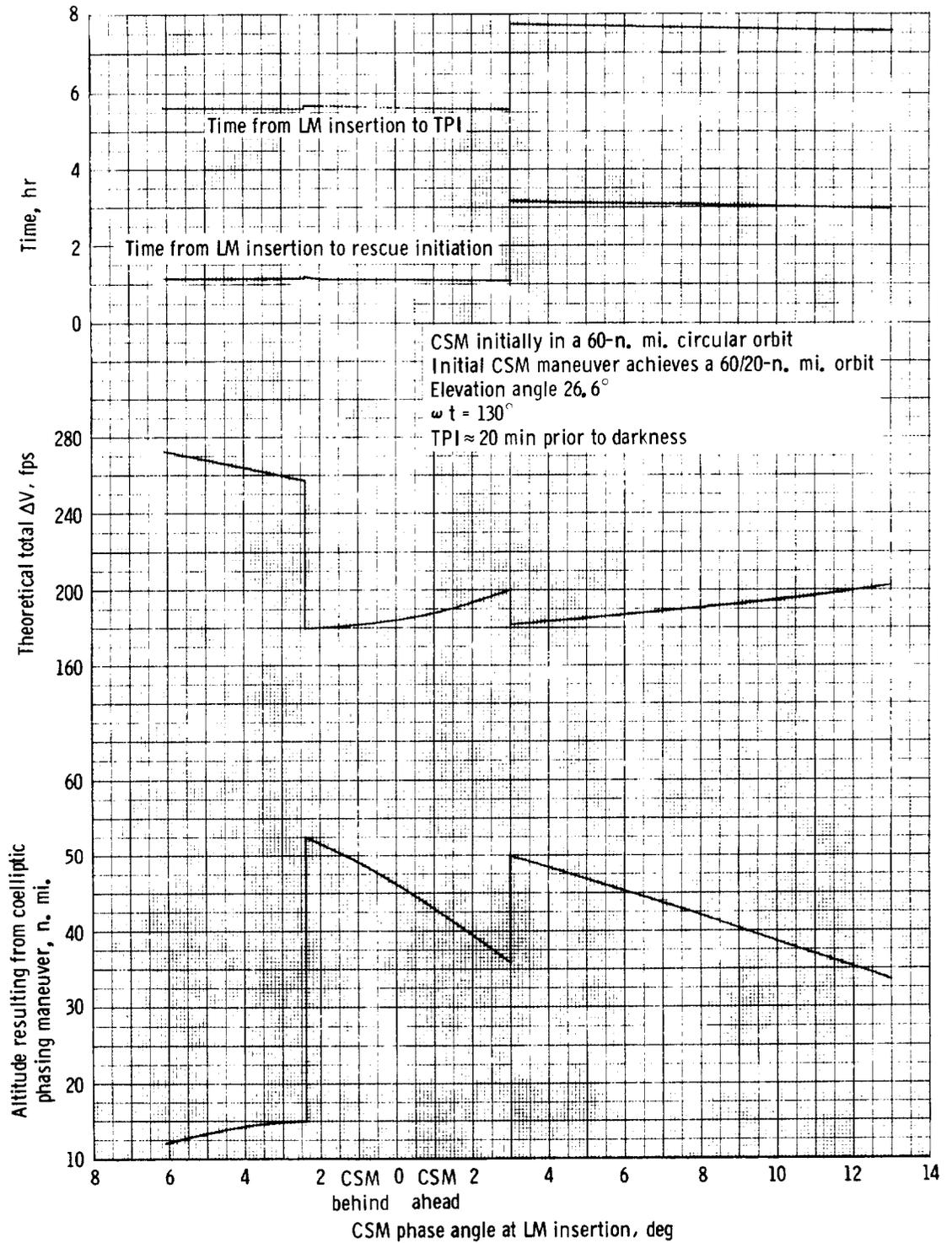


Figure 11. - CSM assist using a canned maneuver, coelliptic phasing maneuver, CSI, CDH, terminal phase assuming a LM failure after CSI for LM aborts during powered descent (up to high gate).

REFERENCES

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