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# PLANNED RENDEZVOUS TECHNIQUE FOLLOWING LM ABORT FROM POWERED DESCENT

Orbital Mission Analysis Branch

MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

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PROJECT APOLLO

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By Jerome A. Bell
Orbital Mission Analysis Branch

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MISSION PLANNING AND ANALYSIS DIVISION
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## CONTENTS

Section Page

SUMMARY. . . . . . . . . . . . . . . . . . . . . . . . . . . . 1

INTRODUCTION . . . . . . . . . . . . . . . . . . . . . . . . . 1

SYMBOLS. . . . . . . . . . . . . . . . . . . . . . . . . . . . 2

RENDEZVOUS PROFILE FOLLOWING LM ABORT FROM POWERED DESCENT . . . 2

  LM Rendezvous. . . . . . . . . . . . . . . . . . . . . . . . 2

  CSM Rescue . . . . . . . . . . . . . . . . . . . . . . . . . 4

CONCLUDING REMARKS . . . . . . . . . . . . . . . . . . . . . . 5

APPENDIX - SOFTWARE VARIABLE TARGETING EQUATION. . . . . . . . . 21

REFERENCES . . . . . . . . . . . . . . . . . . . . . . . . . . 26

# FIGURES

Figure | Page

1 Insertion characteristics following an abort from powered descent . . . . . . . . . . . . . . . . . . . . 6

2 LM horizontal insertion velocity required for a CSI maneuver at 50 minutes after insertion to result in a 15-nautical mile Δh . . . . . . . . . . . . . . 7

3 The ΔV required for LM CSI and CDH maneuvers to result in a 15-nautical mile Δh when CSI occurs 50 minutes after insertion . . . . . . . . . . . . . 8

4 Time required between maneuvers for a LM rendezvous in a 15-nautical mile Δh when CSI occurs 50 minutes after insertion . . . . . . . . . . . . . . . . . . . 9

5 LM horizontal insertion velocity required for a CSI maneuver at apocynthion to result in a 15-nautical mile Δh . . . . . . . . . . . . . . . . . . . . . . 10

6 The ΔV required for LM CSI and CDH maneuvers to result in a 15-nautical mile Δh when CSI occurs at apocynthion . . . . . . . . . . . . . . . . . . 11

7 Time required between maneuvers for a LM rendezvous to result in a 15-nautical mile Δh when CSI occurs at apocynthion . . . . . . . . . . . . . . . . 12

8 In-orbit ΔV penalty for initiating CSI at 50 minutes from insertion rather than at apocynthion . . . . . 13

9 Typical relative motion profile in CSM-centered curvilinear coordinate system for a LM-active rendezvous

(a) LM abort at PDI-plus-90-seconds . . . . . . . . . 14
(b) LM abort at PDI-plus-410-seconds . . . . . . . . . 15
(c) LM abort at PDI-plus-584-seconds . . . . . . . . . 16

10 The ΔV required for CSM, CSI, and CDH maneuvers of a rescue; the planned LM CSI maneuver occurs 50 minutes after insertion . . . . . . . . . . . . . 17

Figures Page

11 Coelliptic differential altitude at CDH for a CSM resuce following LM abort from powered descent; planned LM CSI maneuver to occur 50 minutes from insertion . . . . . . . . . . . . . . . . . . . . . . . . 18

12 Time between maneuvers for CSM rescue following LM abort from powered descent; planned LM CSI maneuver to occur 50 minutes from insertion . . . . . . . . . . 19

# PLANNED RENDEZVOUS TECHNIQUE FOLLOWING LM ABORT FROM POWERED DESCENT

By Jerome A. Bell

## SUMMARY

The latest rendezvous technique is presented for a LM that aborts from powered descent from PDI to PDI-plus-600-seconds. The technique incorporates recent changes to the LM software approved by the Software Control Board; namely, variable insertion targeting logic, and an option to control the position of the CDH maneuver by having it occur half a period from CSI and placing the desired radial velocity at insertion into erasable memory.

These changes have simplified the rendezvous technique for both the LM and CSM rendezvous.

## INTRODUCTION

Several LM software changes for Apollo Mission G have been approved by the Software Control Board since the publication of the reference. These changes simplify the abort and rescue plans for a LM abort from powered descent.

The major change to the LM AGS and the PGNCS software has been the addition of the variable insertion targeting logic for LM aborts during powered descent. The inclusion of this logic into the LM software provides the following advantages for most of the powered descent phase:

1. Allows the LM to rendezvous from below the CSM and always to achieve the nominal differential altitude of 15 n. mi.

2. Maintain approximately the nominal timeline between LM insertion and rendezvous.

3. Simplify CSM rescue by reducing the time and number of burns required, and by making the maneuver sequence identical to that for a LM rendezvous.

Other approved changes which improve not only the nominal rendezvous but also contingency rendezvous during this phase of the lunar mission are the option to control the position of the CDH maneuver by (1) having it occur half a period from CSI, and (2) placing the desired radial velocity at insertion into erasable memory, thus providing the capability to insert with other than a 0° flight-path angle.

The latest rendezvous technique planned if the LM aborts from powered descent is presented in this document. Although the data is preliminary, the basic technique will not change. The precise data which will be presented in the Mission G operational abort and rescue plan will depend upon both the final descent profile and the answers to some questions that are, as yet, unresolved. The equations for the variable targeting of both the PGNCS and AGS are given in the appendix.

## SYMBOLS

| | |
|---|---|
| AGS | abort guidance system |
| CDH | constant differential height maneuver |
| CSI | coelliptic sequence initiation maneuver |
| CSM | command and service modules |
| LM | lunar module |
| PDI | powered descent initiation |
| PGNCS | primary guidance, navigation, and control subsystem |
| TPF | terminal phase finalization maneuver |
| TPI | terminal phase initialization maneuver |

## RENDEZVOUS PROFILE FOLLOWING LM ABORT FROM POWERED DESCENT

### LM Rendezvous

The objective in establishing the LM rendezvous procedures following an abort from powered descent is to retain as much of the nominal rendezvous profile as possible (e.g., the timeline between insertion and rendezvous, a coelliptic differential altitude of 15 n. mi.).

An analysis has shown that this objective is feasible from PDI to approximately PDI-plus-600-seconds (about 90 seconds prior to nominal touchdown) by inserting the LM directly into a phasing orbit. This plan is feasible primarily because the relative position of the CSM with respect to the LM (phase angle) changes as a function of time into powered descent so that the required performance from the LM is reduced as the LM capability is reduced. (See figure 1.)

In order to rendezvous from below, the LM must be trailing the CSM at CDH. Therefore, for early aborts in which the LM inserts ahead of the CSM, the LM must be in a high enough orbit both after insertion and after CSI to be at the proper relative position at CDH. Similarly, for late aborts in which the LM is trailing the CSM at insertion, the LM must be in an orbit from which it will be able to catch up to the CSM.

One point should be made at this time. The LM will be constrained so as not to insert into an orbit with an apocynthion lower than 30 n. mi. If an abort later than PDI-plus-600-seconds with an apocynthion lower than 30 n. mi. is computed, the nominal $\Delta h$ and possibly even the nominal rendezvous time must be abandoned. However, for this document only aborts up to PDI-plus-600-seconds are considered.

The LM insertion orbit depends directly on the maneuver points for the remainder of the rendezvous (CSI, CDH, TPI, TPF). It has been definitely established that TPI should occur at the second CSM passage of the midpoint of darkness following LM insertion. It has also been established that CDH should occur half an orbital period from CSI. The problem that now remains is the location of the CSI maneuver.

It has been determined for the nominal mission that about 50 minutes is needed from insertion to CSI to allow for all the required crew activities and that this time is about the latest time that can be allowed if ample time is to be provided between CDH and TPI (about 35 minutes); it has also been recognized that CSI should occur at apocynthion in order to conserve RCS fuel. The result of these two requirements is that the insertion $\Delta V$ has a radial component in order to shift apocynthion back to insertion-plus-50-minutes.

For rendezvous following abort from powered descent, the question arises as to whether CSI should be performed at a fixed time from insertion or at the apocynthion of the insertion orbit. Since it is valid to assume that a constant value of radial insertion velocity will exist in the software even though the apocynthion altitude of the insertion orbit will vary from about 130 n. mi. to 30 n. mi., the consequences of having CSI at apocynthion would be that CSI could occur either much earlier or later than 50 minutes from insertion depending on the value of the radial component, and would crowd either the insertion to CSI or the CDH-to-TPI timeline. The value that was selected for the radial $\Delta V$ component was 19.5 fps, which is based on the LM passing through apocynthion 50 minutes after insertion when the LM is in a 30-n. mi. apocynthion altitude orbit.

The insertion velocity and subsequent rendezvous parameters based on a CSI at 50 minutes after insertion are shown in figures 2 through 4. It can be seen from figure 3 that the CDH maneuver will have a radial component ($\Delta V_Z$) varying between 150 fps and 0 fps, depending on the time of abort. It is also seen that the minimum time between CDH and TPI is about 34 minutes.

Data related to performing CSI at apocynthion is shown in figures 5 through 7. It is seen that the CDH maneuver will be horizontal; however, two other problems may exist. They are (1) CSI time may vary about 9 minutes, and (2) a time interval of 30 minutes may exist between CDH and TPI.

An analysis of both CSI locations shows that the fixed time of 50 minutes is the best approach to use. Although it is obvious that a $\Delta V$ penalty will occur (fig. 8) with this CSI location, the penalty decreases with time and is zero at the point that fuel becomes critical.

This technique does have the advantages of stabilizing the time from insertion to CSI and providing the maximum time between CDH and TPI. It must be decided, however, if the pitched CDH maneuver is acceptable.

Having established the CSI time, CDH will occur half a period later. The altitude at CDH will be 15 n. mi. below the CSM orbit. Having performed CDH, the LM then initiates a TPI maneuver for a 130° transfer at the time the elevation angle reaches 26.6°, which nominally occurs at the midpoint of darkness.

Relative motion profiles for three abort times are shown in figure 9.

## CSM Rescue

Once the LM has achieved the proper insertion orbit, CSM rescue will be identical to rescue procedures planned for the nominal lift-off. That is, 1 minute after the planned LM CSI maneuver, the CSM will initiate its own coelliptic flight plan (CSI, CDH, TPI, TPF). Note the maneuver sequence is identical to that for a LM-active rendezvous. The rendezvous parameters associated with a CSM CSI maneuver 51 minutes after insertion are shown in figures 10 through 12.

Two points should now be noted: (1) The time between CDH and TPI will be reduced primarily because of the delay in the CSM initiation of the CSI maneuver, and (2) the $\Delta h$ at CDH will vary depending on the location of CDH over the LM insertion orbit.

## CONCLUDING REMARKS

The rendezvous procedure following a LM abort from powered descent has been greatly simplified due to the fact that variable insertion targeting was approved for implementation into both the PGNCS and the AGS.

Not only is the LM abort rendezvous made similar to the rendezvous following a nominal lift-off from the lunar surface but the rescue problem is also simplified. Instead of being forced to use the six-impulse rescue sequence for early LM aborts and having a rendezvous time of about 10 hours, the crew can accomplish a rescue in about 4 hours.

A detailed dispersion analysis of the onboard targeting equations must be performed not only to determine the best flight constants to use but also to determine the magnitude of inaccuracies associated with both the PGNCS and AGS.

An updated evaluation of the rendezvous for LM aborts later than PDI-plus-600-seconds will be published in a later document.

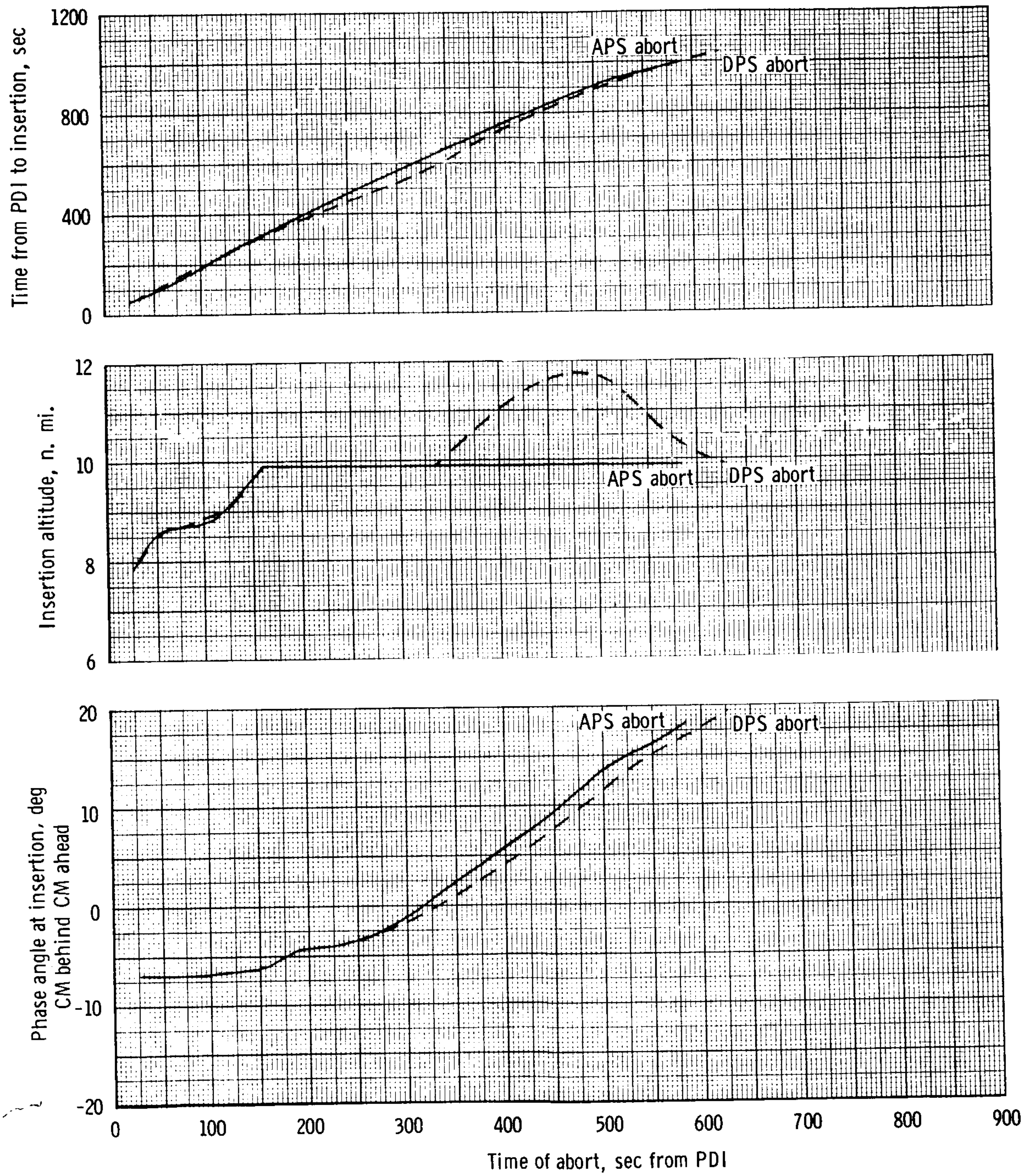


Figure 1. - Insertion characteristics following an abort from powered descent.

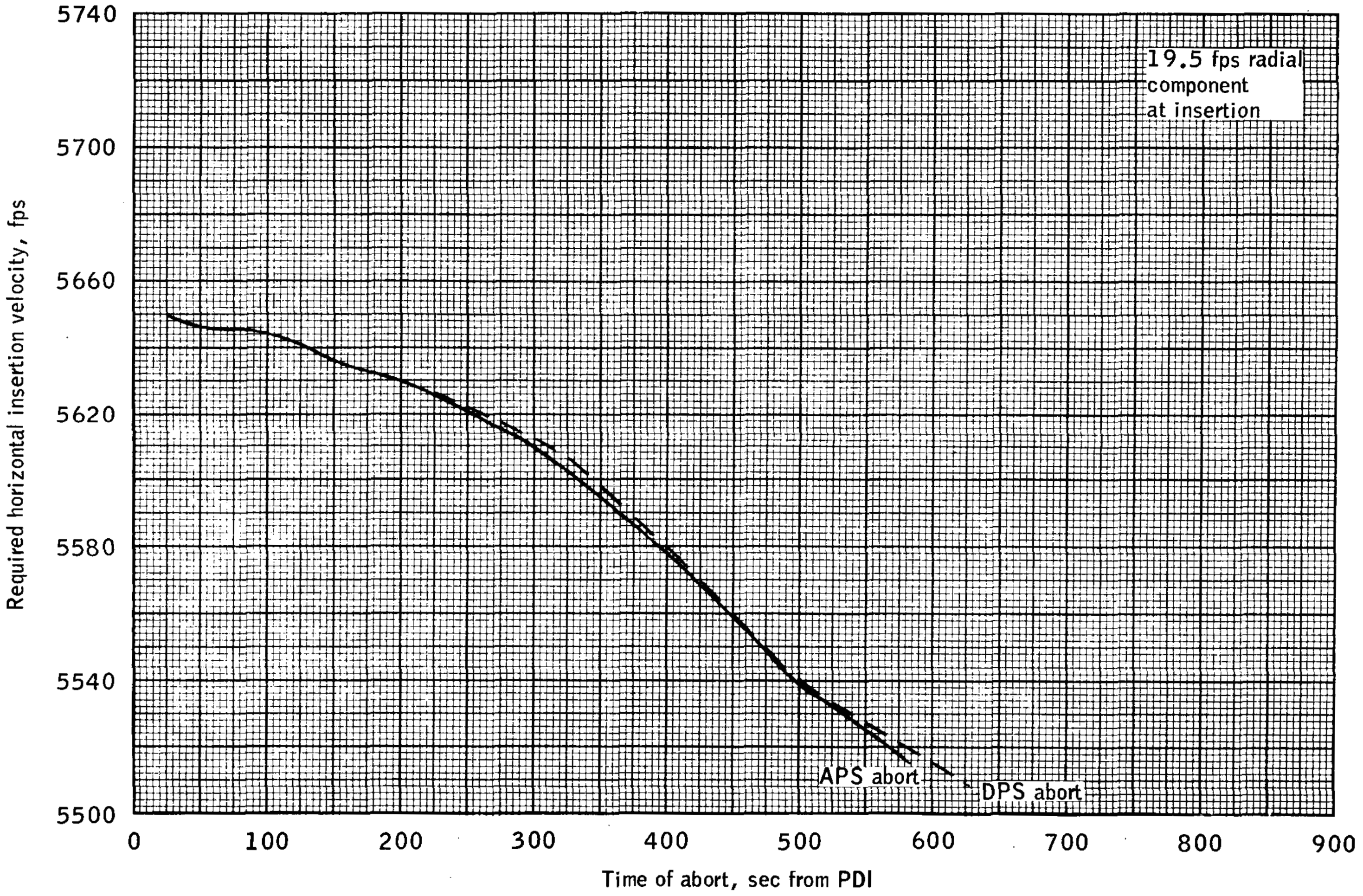


Figure 2.- LM horizontal insertion velocity required for a CSI maneuver at 50 minutes after insertion to result in a 15-nautical mile Δh.

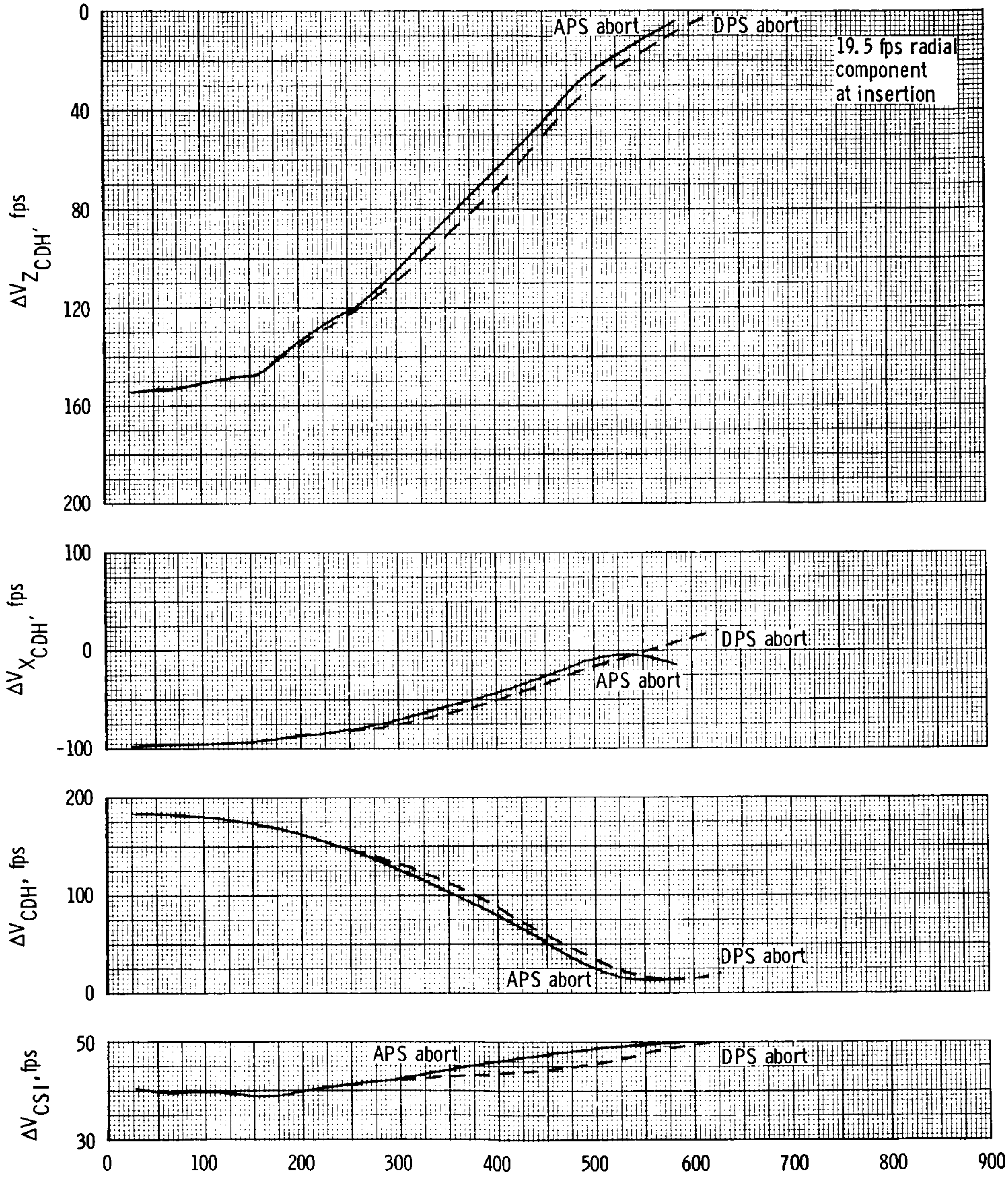


Figure 3.- The ΔV required for LM CSI and CDH maneuvers to result in a 15-nautical mile Δh when CSI occurs 50 minutes after insertion.

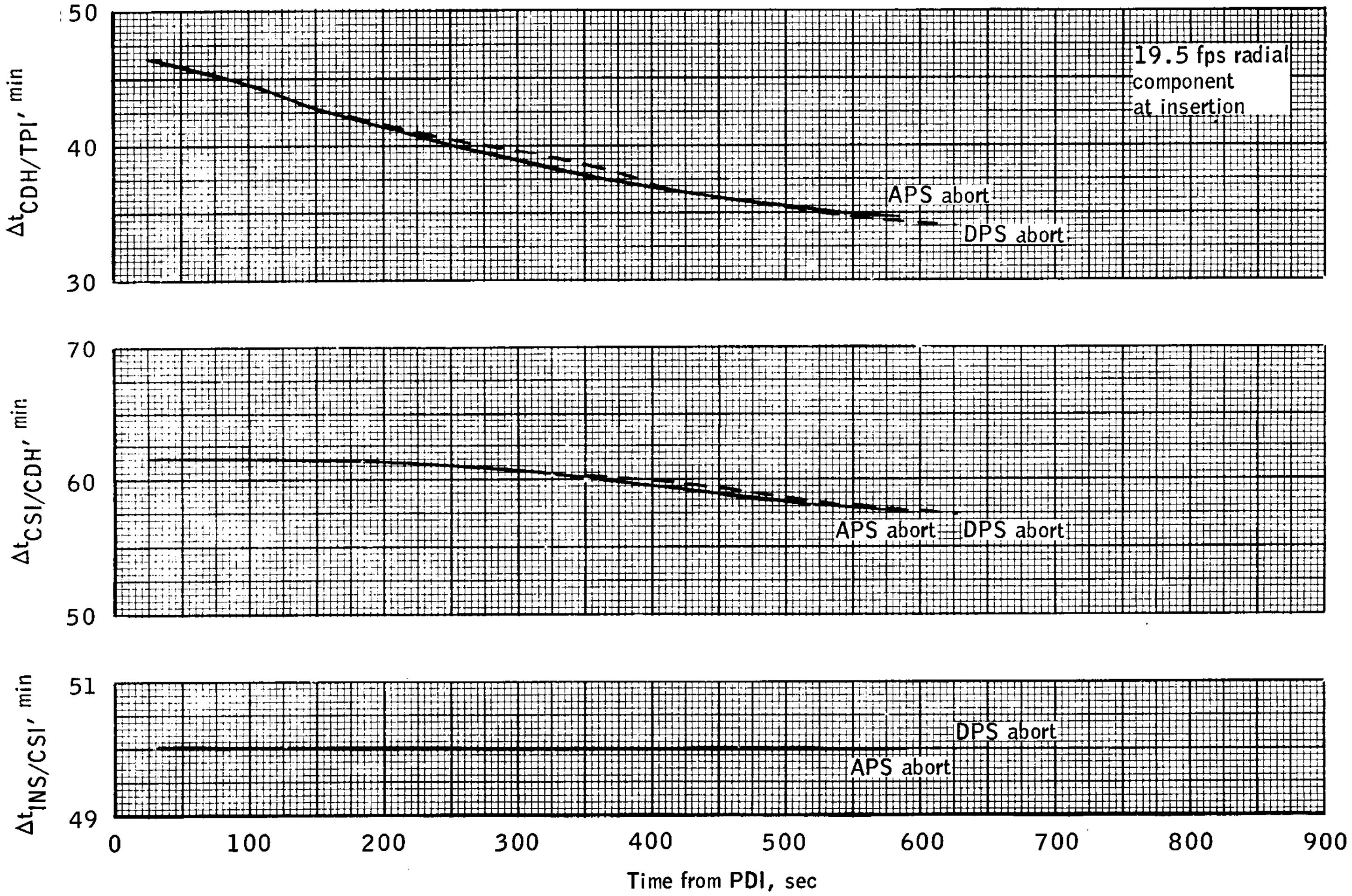


Figure 4.- Time required between maneuvers for a LM rendezvous to result in a 15-nautical mile $\Delta h$ when CSI occurs 50 minutes after insertion.

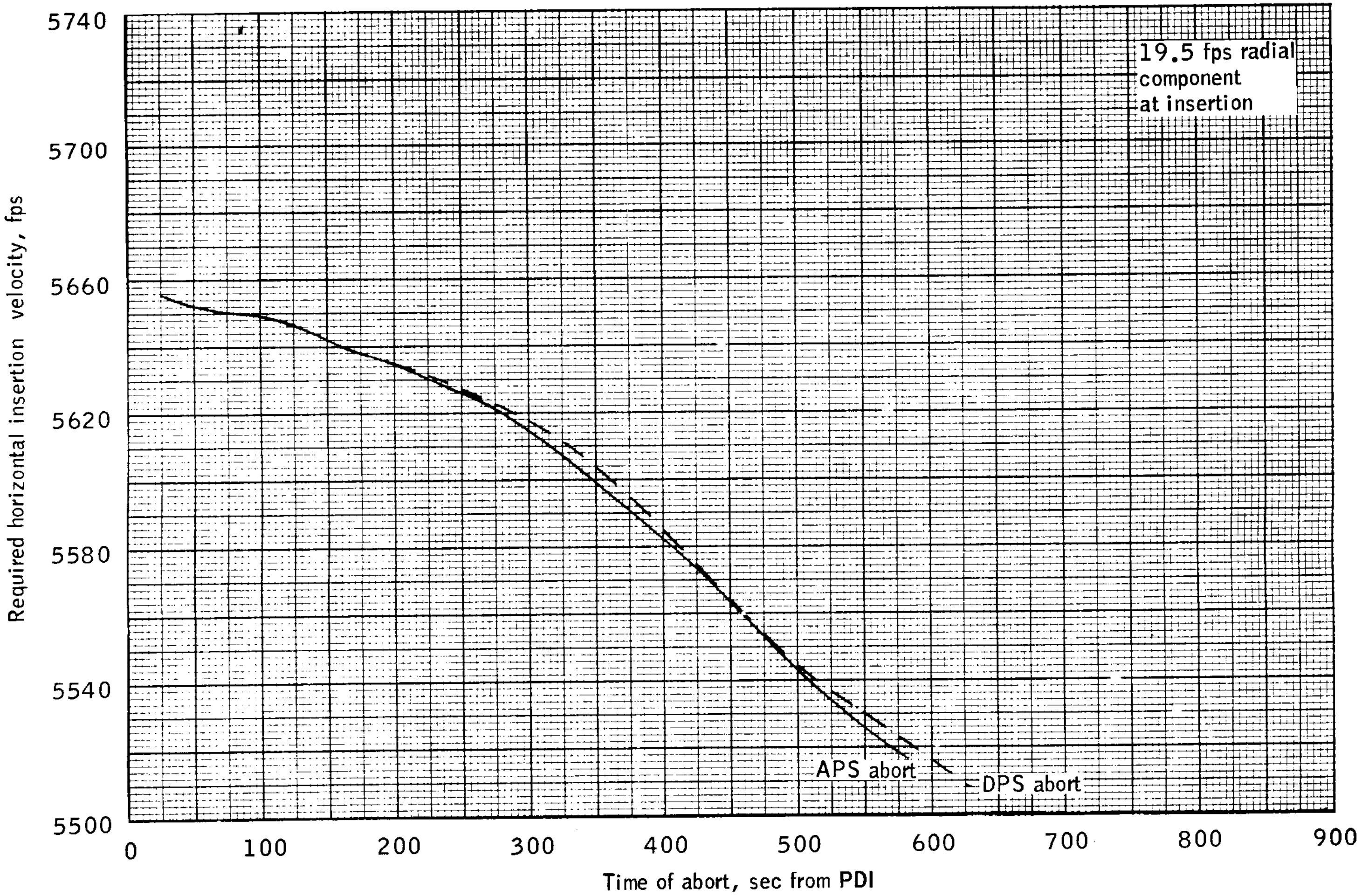


Figure 5.- LM horizontal insertion velocity required for a CSI maneuver at apocynthion to result in a 15-nautical mile Δh.

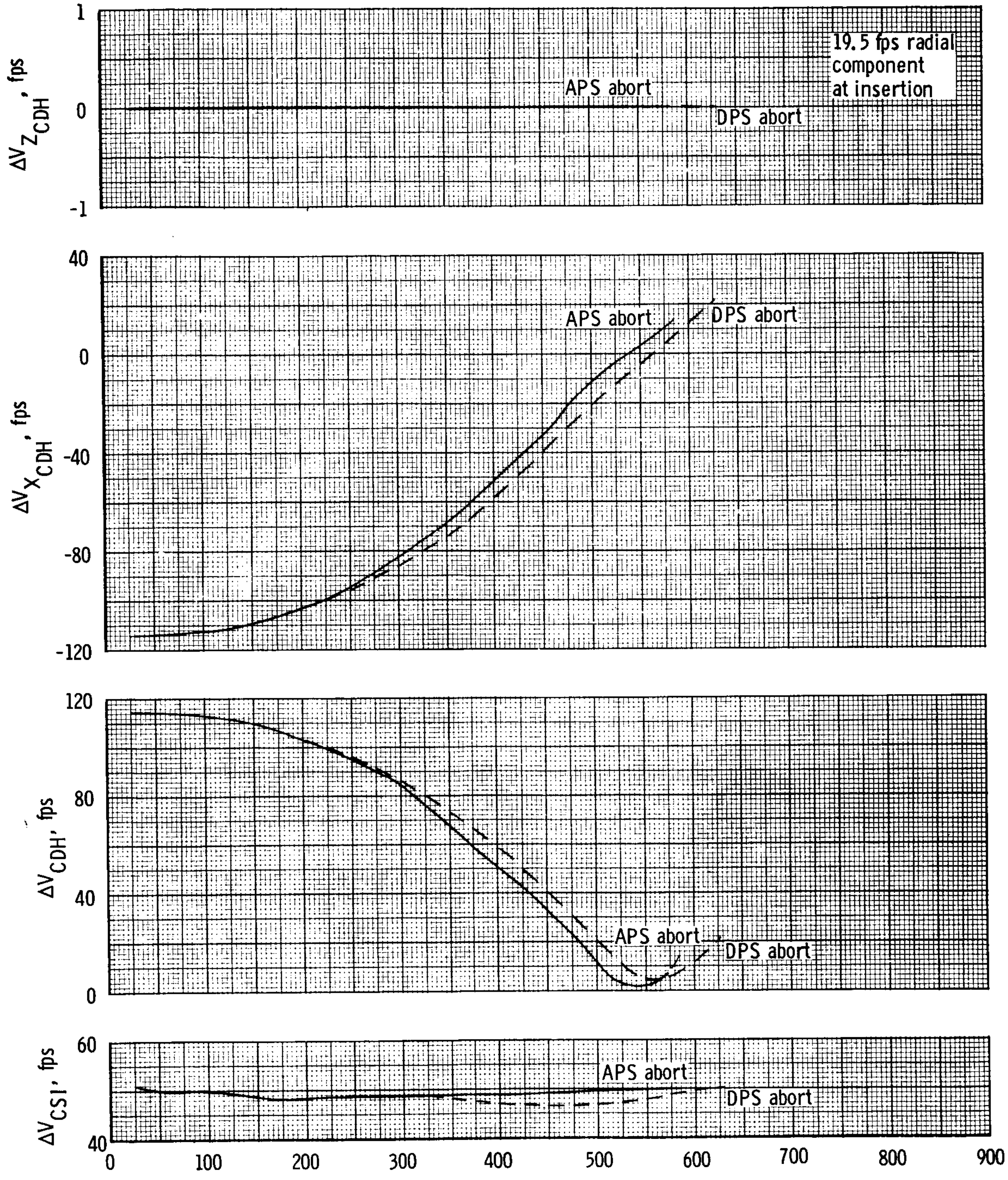


Figure 6.- The ΔV required for LM CSI and CDH maneuvers to result in a 15-nautical mile Δh when CSI occurs at apocynthion.

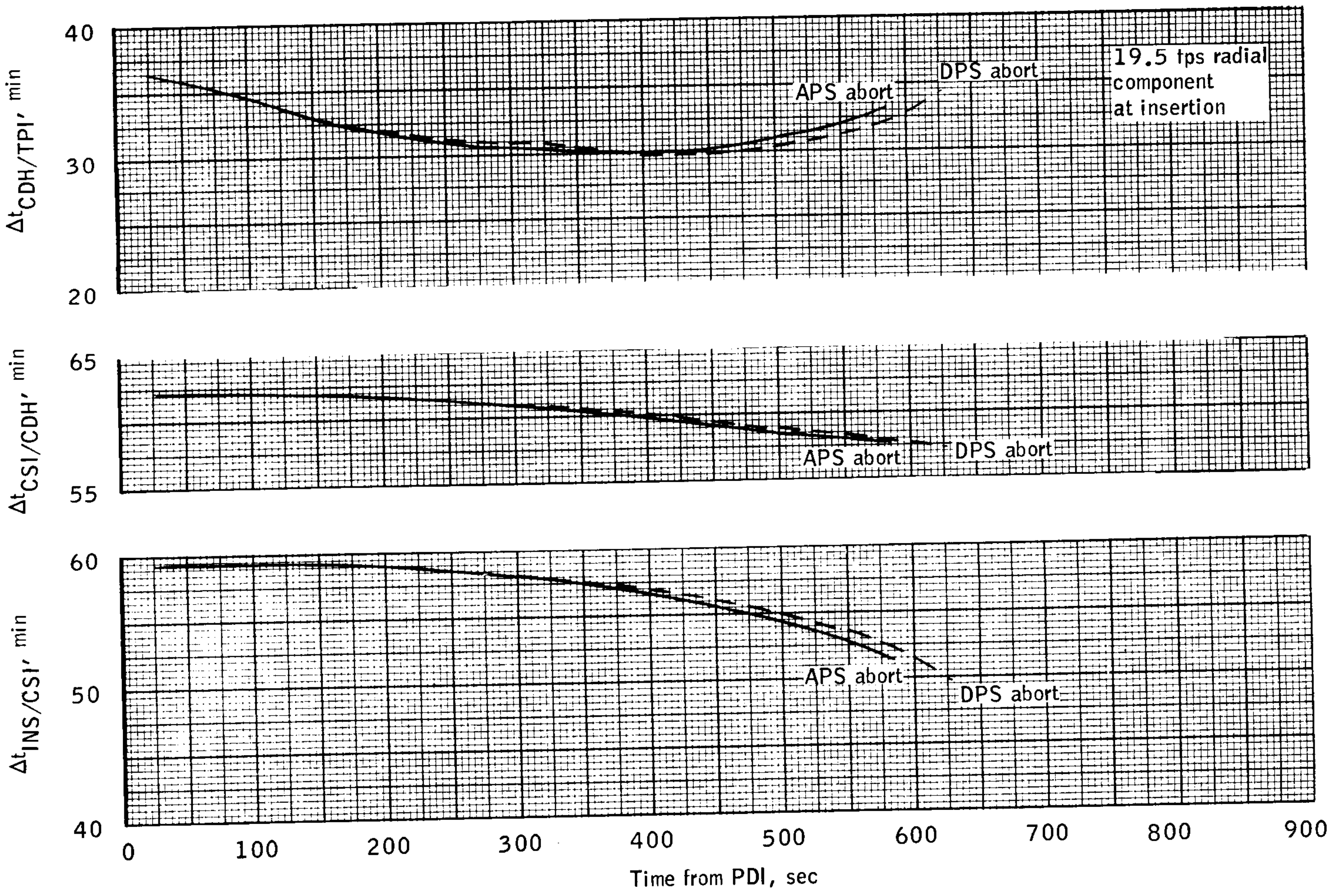


Figure 7.- Time required between maneuvers for a LM rendezvous to result in a 15-nautical mile $\Delta h$ when CSI occurs at apocynthion.

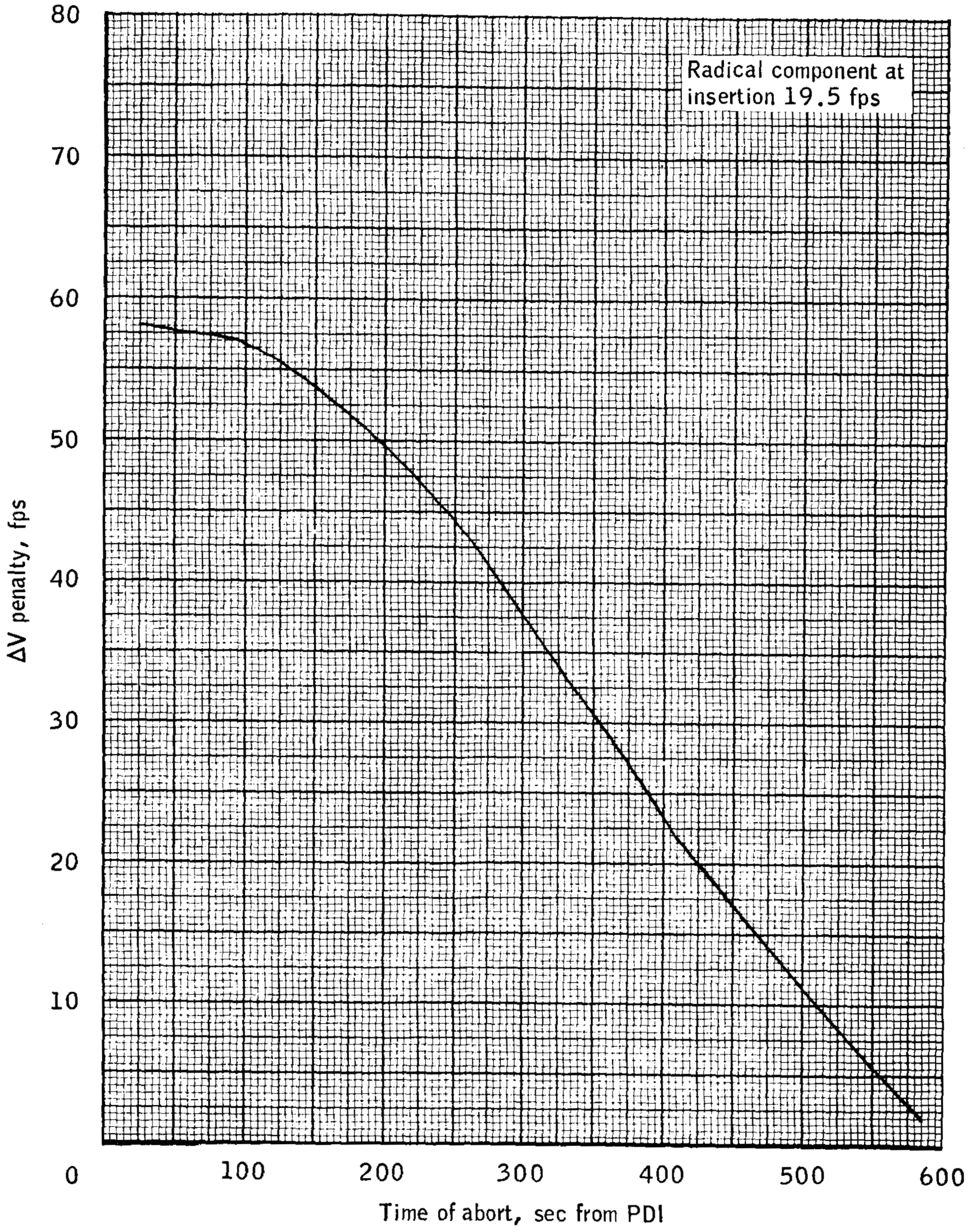
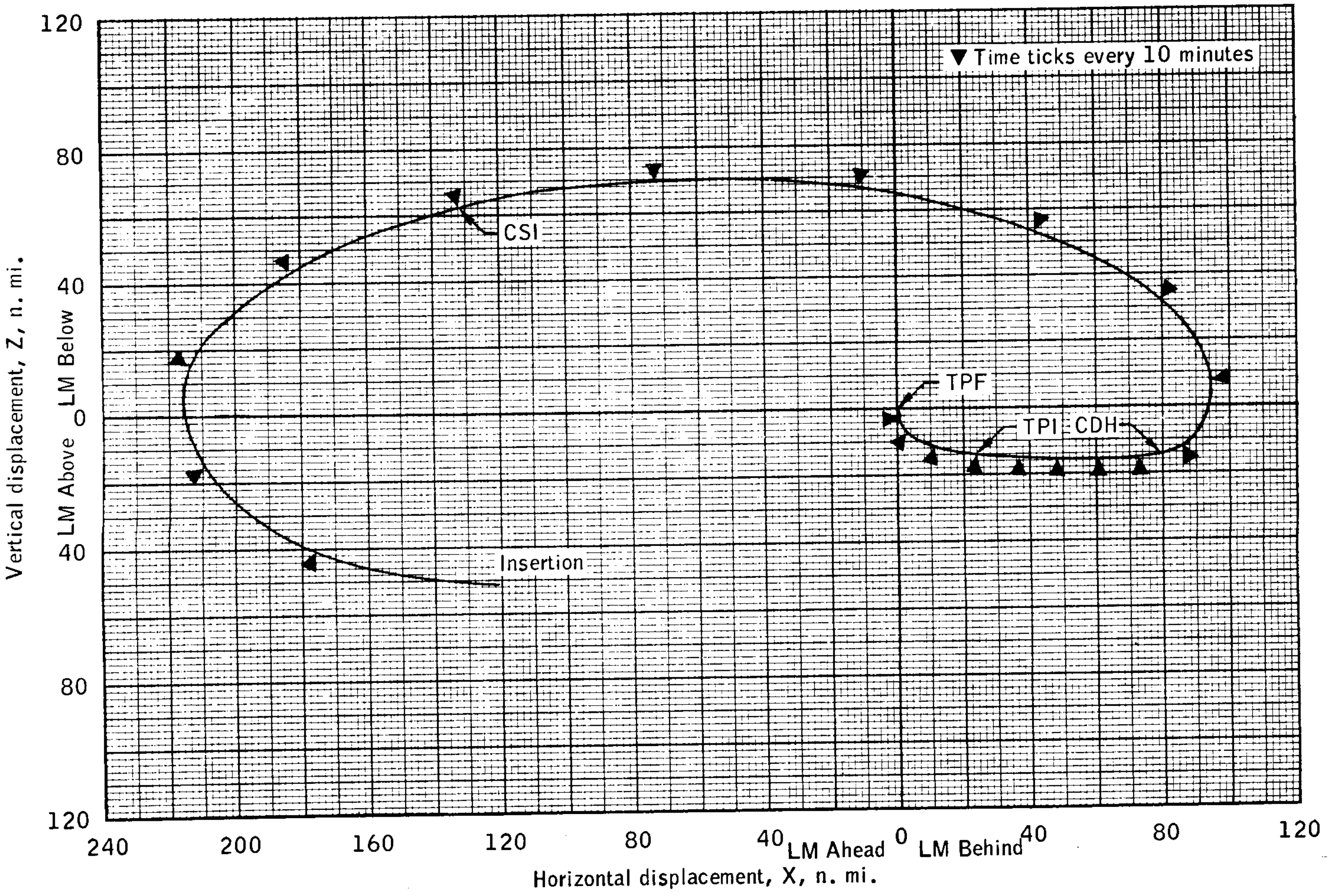
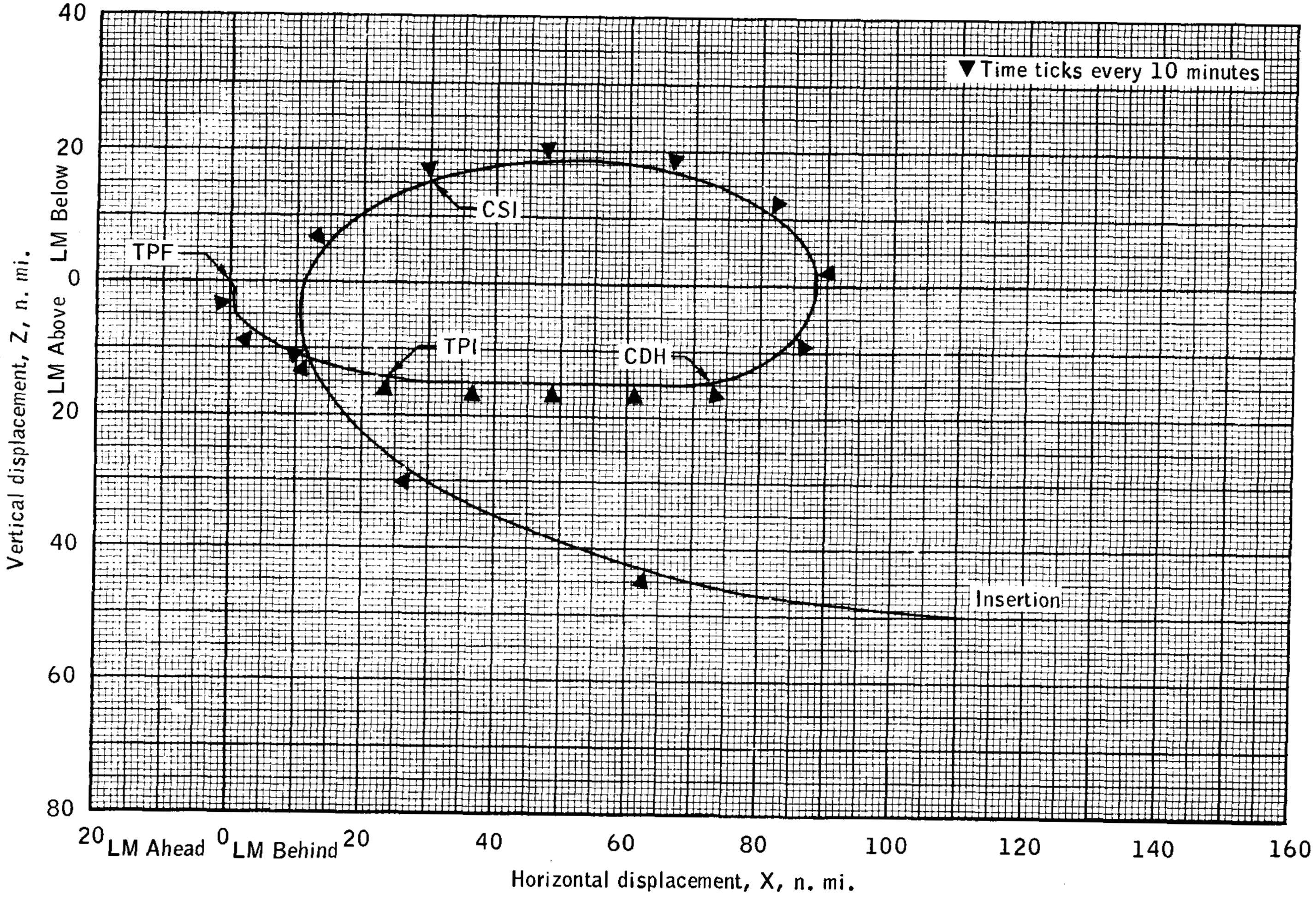


Figure 8.- In-orbit ΔV penalty for initiating CSI at 50 minutes from Insertion rather than at apocynthion.



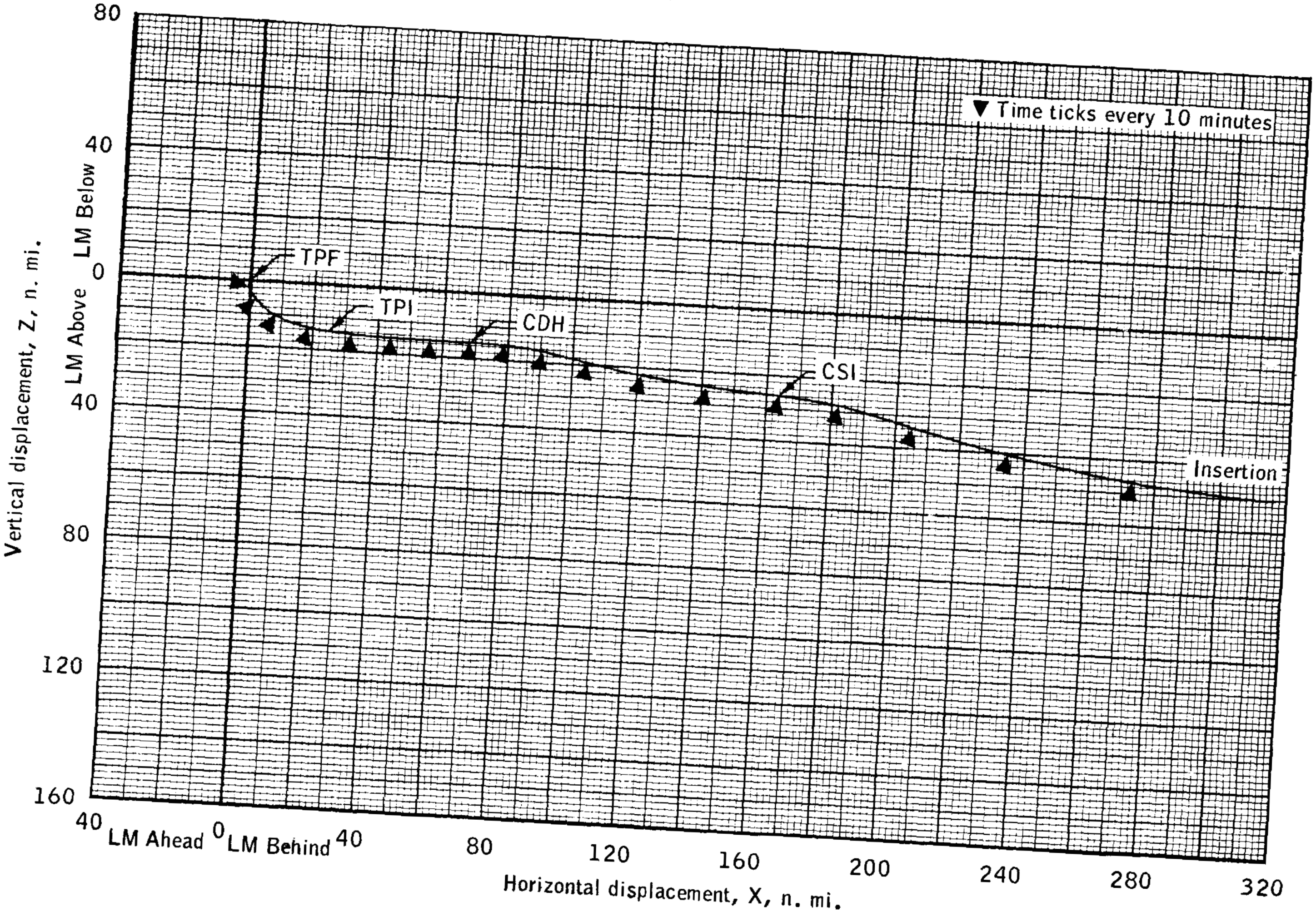
(a) LM abort at PDI-plus-90-seconds.

Figure 9.- Typical relative motion profile in CSM-centered curvilinear coordinate system for a LM-active rendezvous.



(b) LM abort at PDI-plus-410-seconds.

Figure 9.- Continued.



(c) LM abort at PDI-plus-584-seconds.

Figure 9.- Concluded.

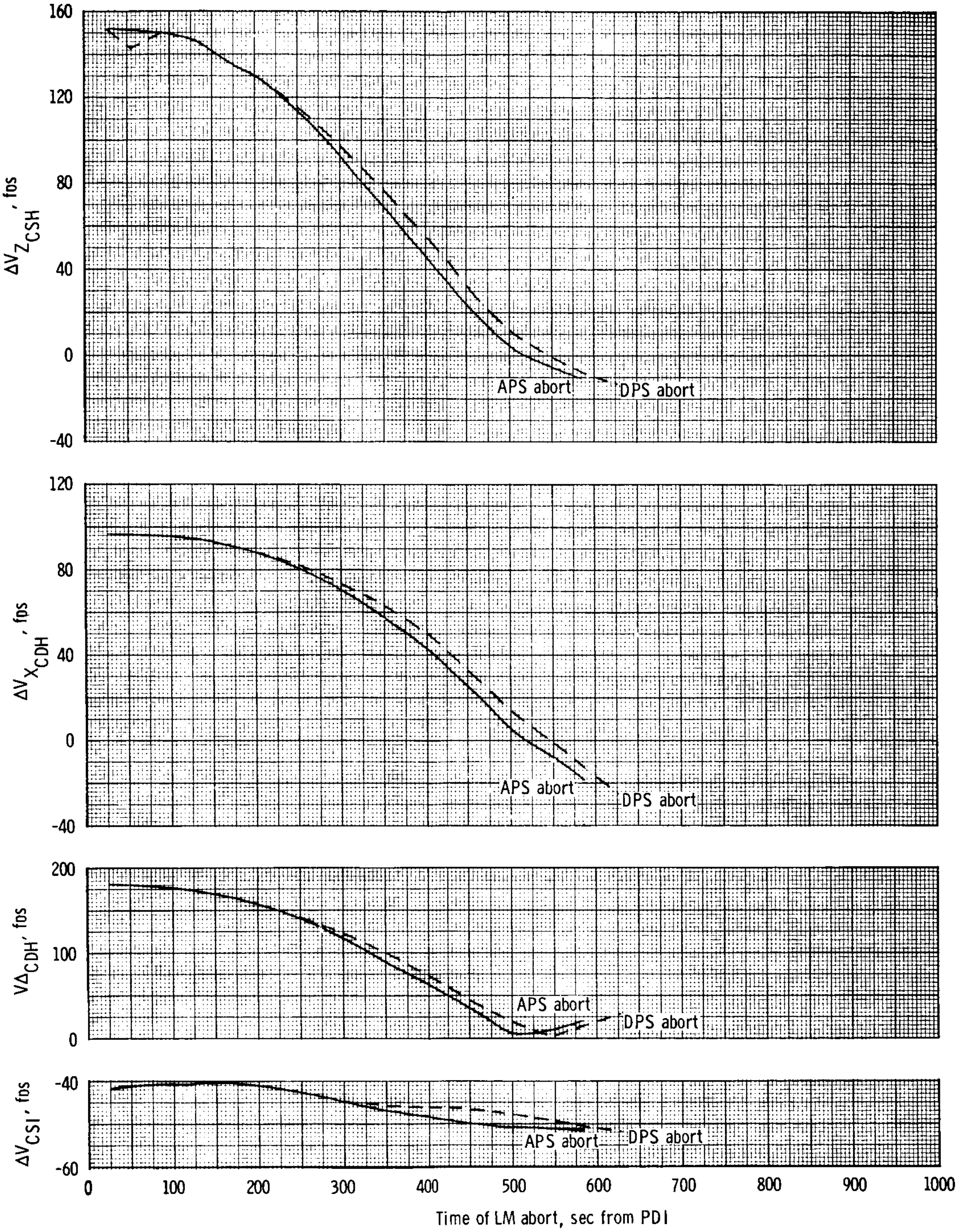


Figure 10.- The ΔV required for CSM, CSI, and CDH maneuvers of a CSM rescue; the planned LM CSI maneuver occurs 50 minutes after insertion.

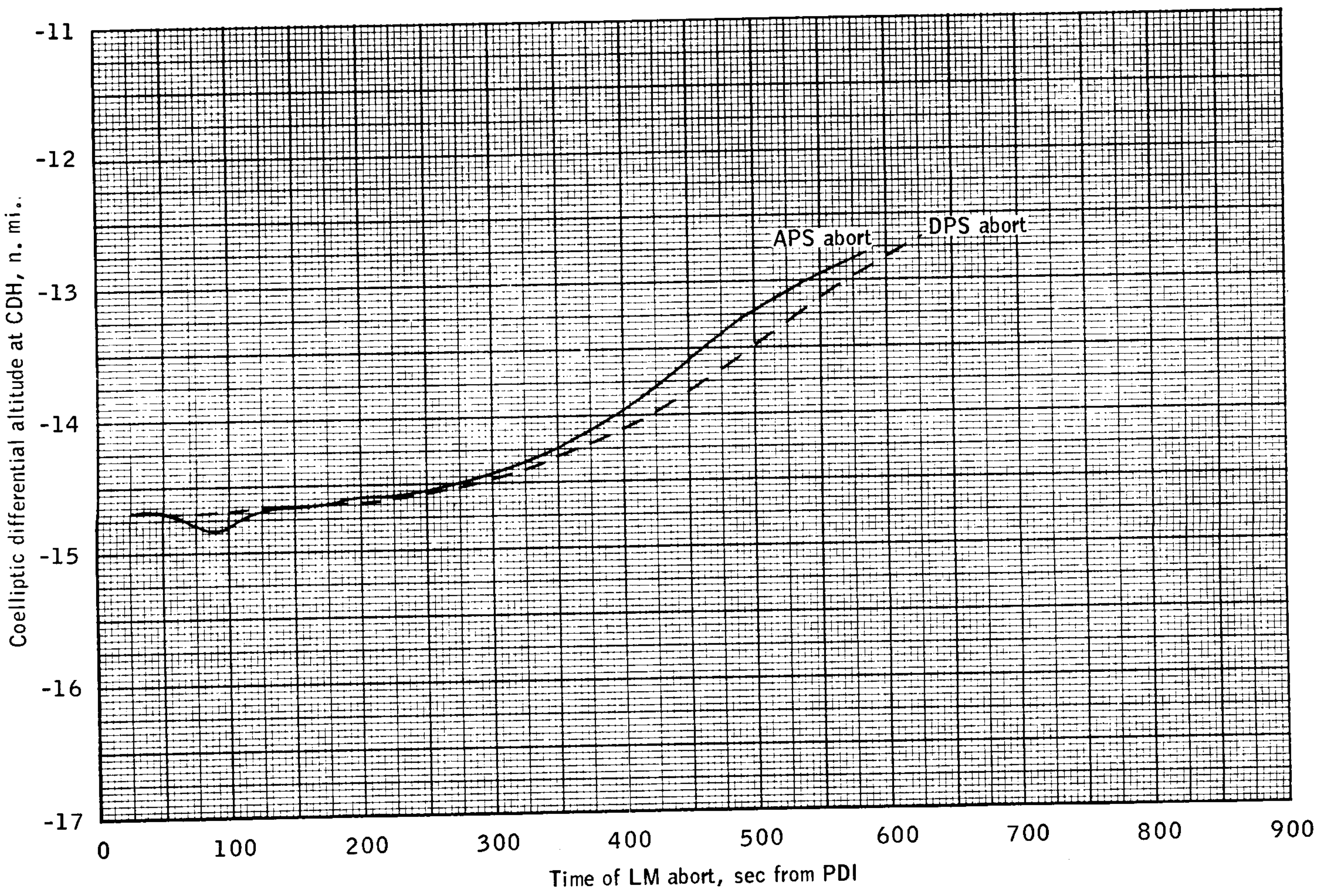


Figure 11.- Coelliptic differential altitude at CDH for a CSM rescue following LM abort from powered descent; planned LM CSI maneuver to occur 50 minutes from insertion.

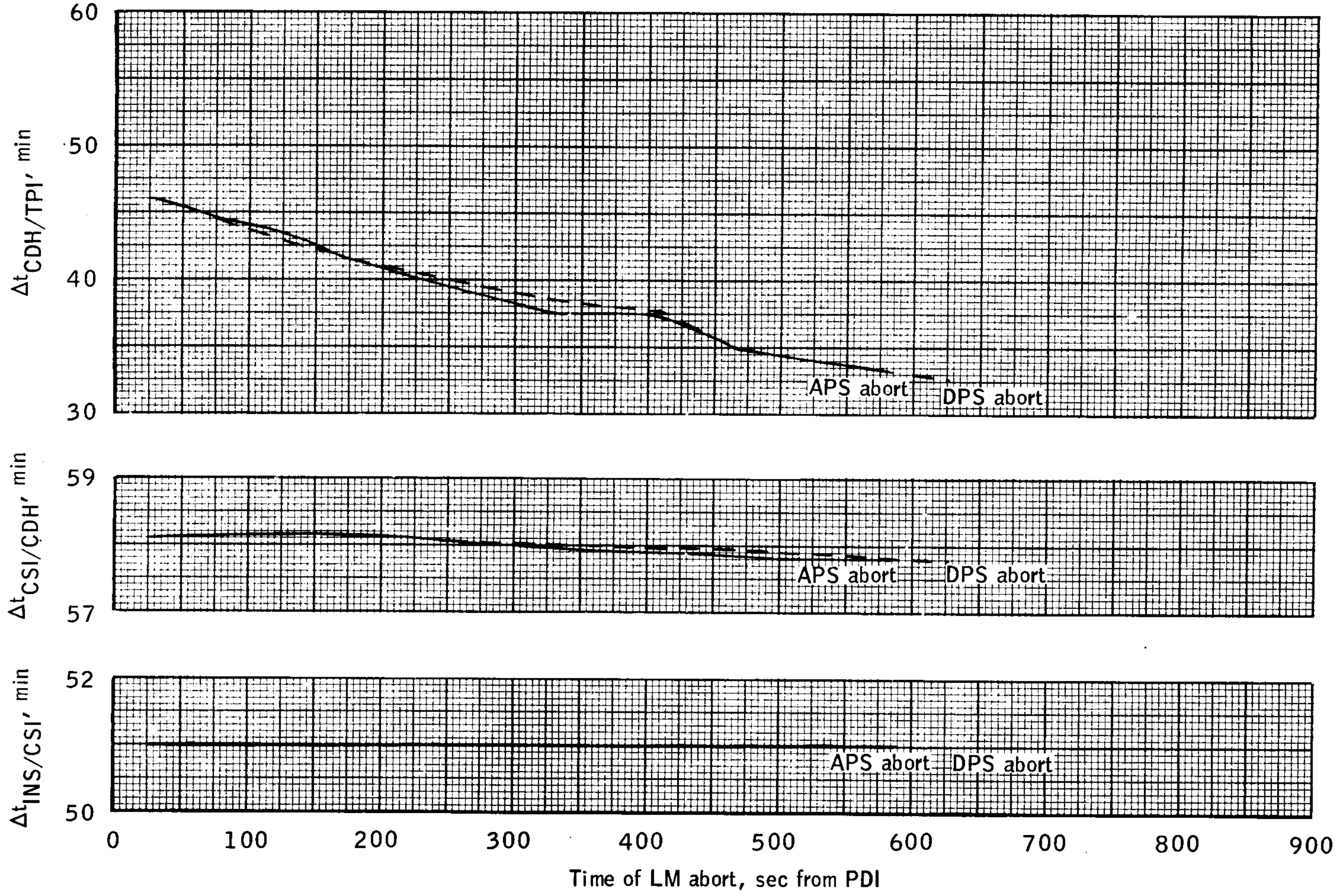


Figure 12.- Time between maneuvers for CSM rescue following LM abort from powered descent; planned LM CSI maneuver to occur 50 minutes from insertion.

# APPENDIX

# SOFTWARE VARIABLE TARGETING EQUATION

# SOFTWARE VARIABLE TARGETING EQUATION

## AGS

The AGS equations for determining the insertion velocity is as follows:

$$h_a = (K_1 + K_2\phi - h)6076.115486$$

$$r_a = r_{REF} + h_a$$

$$r_p = r_{REF} + h(6076.115486)$$

$$a = 0.5(r_a + r_p)$$

$$V_H = \left[\mu\left(\frac{2}{r_p} - \frac{1}{a}\right)\right]^{1/2}$$

$$V_r = 19.5 \text{ fps}$$

If $V_H < 5509$ fps, $V_H = 5509$ fps where

$h_a$ = desired apocynthion altitude, ft

$\phi$ = phase angle between CSM and LM (positive when CSM is ahead), deg

$r_{REF}$ = reference radius, ft

$V_H$ = desired horizontal velocity component

$V_r$ = desired radial component

$h$ = LM predicted cutoff altitude, n. mi.

The AGS computes the desired $V_H$ every computation cycle (2 seconds) using the phase angle existing at the time of computation.

The constant $K_1$ depends greatly on the desired rendezvous profile, whereas $K_2$ should not vary significantly. Both constants, however, should be insensitive to descent trajectory dispersions although a detailed analysis should be performed to verify this fact.

The one dispersion that could effect both constants would be a dispersion in CSM orbit.

For preliminary planning, values of $K_1 = 111.03$ and $K_2 = -3.708$ can be used although they are likely to change as later descent data becomes available. These values are based on CSI occurring 50 minutes after insertion. The actual values will need to be determined and loaded prior to earth lift-off.

## PGNCS

The PGNCS will contain a polynomial curve fit (programs P70 and P71) based on time of abort. There will be two equations - one for an abort situation (DPS and APS) and one for an abort stage (APS only) due to the difference in performance characteristics. The equations which are computed only one time - at the abort - will have the following form.

$$V_{H_{ABORT}} = K_1 + K_2t + K_3t^2 + K_4t^3$$

$$V_{H_{ABORT\ STAGE}} = K_1' + K_2't + K_3't^2 + K_4't^3$$

where t is abort time, sec

$V_H$ is desired horizontal velocity, fps

$V_R$ is desired radial velocity, fps

$V_H < 5509$ fps  $V_H = 5509$ fps

$V_R = 19.5$ fps

These constants are a function of the desired rendezvous trajectory and nominal descent trajectory. Also, dispersions in either the CSM orbit or descent trajectory will effect the accuracy of these equations. As for the AGS, a dispersion analysis will have to be performed.

For preliminary planning the following values can be used:

$K_1 = 5644.2$
$K_2 = .09613$
$K_3 = -.0009345$
$K_4 = .0000006857$

$K_1' = 5646.6$
$K_2' = .05157$
$K_3' = -.0007615$
$K_4' = .00000048214$

They are based on the trajectory resulting from the two-phase descent and on CSI occurring 50 minutes after insertion for the rendezvous. These values should be changed based on the single phase descent. The actual values will need to be determined and loaded prior to earth lift-off.

# REFERENCE

Bell, Jerome A.; Alexander, Mary T.; and DuPont, Allan L.: Preliminary LM Abort and CSM Rescue Plan for Apollo Mission G, Volume I - LM Abort, CSM Rescue and CSM Assist During Ascent and Descent. MSC Internal Note No. 68-FM-268, October 28, 1968.