Log in FM, Route to RED

MAY 15 1969

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MSC INTERNAL NOTE NO. 69-FM-141

May 14, 1969

FEB 9 1970

SEPARATION PROCEDURES FOR APOLLO 10 NOMINAL, ALTERNATE, AND ABORT MISSIONS

FLIGHT ANALYSIS BRANCH
MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

(NASA-TM-X-69845) SEPARATION PROCEDURES FOR APOLLO 10 NOMINAL, ALTERNATE, AND ABORT MISSIONS (NASA) 75 p

N74-70867

Unclas
00/99 16257

Internal Note No. 69-FM-141

MSC INTERNAL NOTE NO. 69-FM-141

PROJECT APOLLO

SEPARATION PROCEDURES FOR APOLLO 10 NOMINAL, ALTERNATE, AND ABORT MISSIONS

By Marland L. Williamson
Flight Analysis Branch

May 14, 1969

MISSION PLANNING AND ANALYSIS DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

Approved: Charlie C. Allen
Charlie C. Allen, Chief
Flight Analysis Branch

Approved: John P. Mayer
John P. Mayer, Chief
Mission Planning and Analysis Division

CONTENTS

Section Page

Section | Page

Section | Page

Section Page

SEPARATION PROCEDURES FOR APOLLO 10 NOMINAL, ALTERNATE, AND ABORT MISSIONS

By Marland L. Williamson

1.0 SUMMARY AND INTRODUCTION

1.1 Summary

All separation procedures presented in this report are not free from recontact problems because contingencies exist that can cause recontact problems to develop. For those contingencies that have been identified that may cause recontact, alternate procedures are proposed and discussed. The proposed alternate procedures are based on elimination or avoidance of a potential recontact problem.

1.1.1 Nominal mission.- There are three areas in the nominal mission procedures in which recontact problems can develop. If the S-IVB LH_2 propulsive vent fails to close at TLI plus 15 minutes and cannot be closed prior to LM ejection, the CSM should orient to the evasive maneuver attitude immediately after ejection and should perform a 5-second +X RCS translation, as recommended in section 3.2. The SPS evasive maneuver is performed as planned at TLI plus 2 hours (appendix A).

During the nominal lunar rendezvous, the descent stage will be staged in a posigrade direction 10 minutes prior to the ascent stage insertion maneuver. If the ascent stage insertion is delayed or if staging occurs early, it is possible for the descent stage to translate ahead, above, and behind the ascent stage and be in the wrong relative position for the insertion burn. It is recommended in section 3.4 that staging not be performed at 63 ±10 minutes prior to insertion (appendix B, fig. 5).

After staging, the descent stage motion relative to the CSM is retrograde, but because of the longer period, the descent stage will approach the CSM from a posigrade direction approximately 15 orbits later. This phasing of the descent stage and CSM orbits results in the possibility of recontact, which can be greatly reduced by performance of a CSM out-of-plane maneuver. An effective time to perform such a maneuver would be during the time that the descent stage is at perilune after the ascent stage jettison and APS burn to depletion. The nominal

miss distances based on a standard lunar potential model are presented in appendix B. The minimum theoretical miss distance of 30 n. mi. increases to approximately 103 n. mi. when the nominal lunar rendezvous is simulated with the R+2 lunar gravitational model currently in use in the RTACF. A dispersion of only 1 fps, however, can decrease this distance by approximately 50 n. mi.

The procedure for the CSM evasive maneuver after LM jettison (section 3.5) is the same as the procedure for the Apollo 9 mission. However, the Apollo 10 crew has indicated that after LM jettison they will maneuver above the LM and perform a radially outward evasive maneuver (ΔV = 2 fps) to attain the correct relative position for the APS burn.

1.1.2 Alternate missions.- Alternate missions during which recontact problems might develop include the semisynchronous earth orbit mission, the APS-only earth rendezvous mission, and the APS-only lunar rendezvous mission.

Descent stage separation in a posigrade direction is presently planned for a semisynchronous alternate mission. The descent stage is staged with a ΔV of 1 fps which causes the CSM/LM to translate behind, below, and then ahead of the descent stage (section 4.4.3). For ascent stage jettison and APS burn to depletion, the CSM evasive maneuver is performed radially outward (section 4.4.4). It is necessary that this maneuver avoid any retrograde or posigrade components. A posigrade component greater than 1 fps would result in a closing separation rate between the CSM and descent stage, and a retrograde component would decrease the perigee altitude. Therefore, retrograde or posigrade ΔV components should be nulled to zero.

During an ascent-stage-only, earth rendezvous alternate mission, staging of the descent stage is planned at 15 minutes prior to the ascent stage phasing maneuver. If the ascent stage phasing maneuver is delayed or if staging occurs early, it is possible for the descent stage to translate behind, below, and ahead of the ascent stage and to be in the wrong relative position for the phasing burn. It is recommended in section 4.2.4 that staging not occur more than 15 minutes prior to phasing (appendix C).

During an ascent-stage-only, lunar rendezvous alternate mission, staging of the descent stage is planned at 15 minutes prior to the APS DOI maneuver. If the staging is delayed or if the DOI maneuver is performed early, it is possible for the descent stage still to be in the wrong relative position for the DOI burn. The descent stage is jettisoned retrograde and, after 15 minutes, will be behind and below the LM. If staging is delayed, it is possible for the descent stage to be only behind and not a sufficient distance below the LM for the retrograde DOI maneuver. Therefore, it is recommended that staging not be less than 15 minutes prior to the DOI maneuver. Note that the recommendations for ascent-stage-only earth and lunar rendezvous are not the same, and in fact are reversed from each other.

1.1.3 Aborts.- Mission phases during which abort procedures might result in recontact problems are tumbling launch phase aborts, earth orbit aborts, LM staging prior to CSI and TPF on a PDI abort, and a DPS failure during the phasing burn of lunar rendezvous.

The possibility of recontact during a mode III or mode IV tumbling abort arises after the SPS ignition for the abort burn. It is possible that the CSM could be in the wrong relative position with respect to the S-IVB and the jettisoned SLA panels for the desired abort burn. No single procedure can be defined which would place the CSM in the proper relative position for a mode III or mode IV SPS abort because the LV is tumbling at separation and panel jettison.

For earth orbit aborts, the CSM separates and the SLA panels are jettisoned at 20 minutes prior to the deorbit burn. Under present procedures, two of the SLA panels are jettisoned in the orbital plane and could cause interference with an early or late retrofire; therefore, deorbit should be performed at 20 ±5 minutes after separation. A more desirable procedure would be to roll the S-IVB 45° prior to separation, which would insure out-of-plane components on all four panels and would greatly reduce any recontact possibilities with an early or late retrofire.

For a PDI abort, when the descent stage is separated prior to the APS CDH maneuver, a long-term undesirable situation exists. The descent stage moves retrograde relative to the CSM. Because of its longer period, the descent stage will approach from a posigrade direction and will phase with the CSM orbit approximately 45 hours later. This phasing occurs after the nominal time for TEI, which means that at TEI the descent stage will be down range, ahead of the CSM.

Staging prior to the CSI maneuver is not desirable because possible recontact problems could develop between the descent stage and the spacecraft. An alternate procedure (section 7.7.2.2) has been recommended if staging prior to CSI is necessary. For a descent stage separation prior to CSI for which a retrograde ΔV of 4.5 fps or greater is imparted to the descent stage, recontact with the spacecraft could occur. Therefore, if staging is necessary prior to CSI, it is recommended that it be performed out of plane (appendix B).

Descent stage separation prior to the first braking gate of TPF should be avoided. Even though the procedure presented in section 7.7.2.5 incorporates an out-of-plane staging, recontact problems between the descent stage and the spacecraft may still exist. A 45° north out-of-plane ΔV of 3 fps imparted to the descent stage will result in a miss distant of only 350 feet. Should the CSM be 350 feet north of the LM at staging, the current procedure will not avoid possible recontact (appendix B). A 350-foot miss distance will be generated only if the LM is approaching the CSM inplane.

If the DPS fails during the phasing maneuver of a lunar rendezvous and if the cutoff ΔV is between 81.0 fps and 92.5 fps, the descent stage should not be separated. Staging for this range of ΔV's may result in recontact problems between the descent stage and CSM. It is recommended (section 7.7.4) that, prior to staging, the LM -X RCS translation be used to null the cutoff phasing ΔV to less than 81.0 fps. Then staging may be performed and the phasing maneuver completed with the APS without any potential recontact problems. If the cutoff phasing ΔV cannot be nulled, then staging should be performed out-of-plane.

1.2 Introduction

Separation techniques and procedures for the Apollo 10 (Mission F) nominal, alternate and aborted missions are presented in this report. The following separation procedures are included for the nominal mission.

a. CSM from the SLA/LM/S-IVB (T&D)

b. CSM/LM from the S-IVB (LM ejection)

c. LM undocking

d. LM staging

e. CSM jettison of the LM

f. CM jettison of the SM

Alternate missions are divided into the following three categories.

a. Earth orbit alternates (section 4.0)

b. 1. Earth orbit rendezvous (section 4.1)

2. Ascent-stage-only rendezvous (section 4.2)

3. Ascent-stage-only rendezvous, mini- and maxifootball (section 4.3)

4. Semisynchronous earth orbit (section 4.4)

b. Lunar mission alternates (section 5.0)

   1. Lunar flyby with the LM (section 5.1)

   2. Lunar orbit, CSM only (section 5.2)

   3. DPS TEI (section 5.3)

c. Lunar orbit alternates (section 6.0)

   1. Descent-stage-only rendezvous (section 6.1)

   2. Ascent-stage-only rendezvous (section 6.2)

   3. Ascent-stage-only rendezvous, mini- and maxifootball (section 6.3)

Separation procedures for aborts are presented for the following mission phases.

a. Launch phase aborts, stable

   1. Mode I

   2. Mode II

   3. Mode III

   4. Mode IV

   5. No SLA SEP

b. Launch phase aborts, tumbling

c. Earth orbital aborts

d. TLI aborts

e. TLC aborts

   1. 90-minute abort

   2. Direct abort from TLC

f. Circumlunar aborts

g. Abort and rescue, lunar rendezvous

   1. Direct return

   2. PDI aborts

   3. CSM rescue

   4. Partial phasing

h. Contingency TEI

i. Emergency separation procedures from the S-IVB

2.0 SYMBOLS

AOS	acquisition of signal
APS	ascent propulsion system (LM)
AUTO	automatic
CMC	command module computer
CMP	command module pilot
COI	contingency orbit insertion
CSM	command/service module
DPS	descent propulsion system (LM)
DRPA	docking ring and probe adapter
IMU	inertial measuring unit
LET	launch escape tower
LH	local horizontal
LM	lunar module
LOS	line-of-sight
LV	launch vehicle
RCS	reaction control system
SEP	separation
S-IVB	Saturn V third stage
SLA	spacecraft/LM adapter
T, D and E	transposition, docking and extraction
TEC	transearth coast
TEI	transearth injection
TLC	translunar coast

TLI	translunar injection
TPF	terminal phase finalization
TPI	terminal phase initiation
T_{ff}	time of free-fall to entry interface
V_i	inertial velocity vector
ΔV	change in velocity

3.0 NOMINAL MISSION SEPARATION PROCEDURES

3.1 CSM separation from the S-IVB, transposition and docking (ref. 1)

Time from TLI cutoff, hr:min:sec	Event
00:00:00	S-IVB holds cutoff attitude.
00:00:20	S-IVB orients to and holds local horizontal (LH).
00:15:00	S-IVB orients to and holds T, D, and E attitude of yaw 40°, pitch 120°, roll 180° with respect to the LH (May 18 launch).
00:25:00	CSM separates from the S-IVB, and SLA panels are jettisoned. Perform CSM +X RCS translation for a $\Delta V = 0.8$ fps. For separation, CSM is controlled by CMC/AUTO mode.
00:25:35	Perform CSM -X RCS to null 0.3-fps separation rate.
00:25:40	Initiate CSM pitch of 180° at 1.5 deg/sec rate.
00:27:40	Null CSM pitch rate. Initiate CSM roll left 60° at 0.5 deg/sec rate.
00:29:40	Null CSM roll rate. Perform CSM +X RCS to null 0.5-fps separation rate. Initiate 1.0 fps closing rate.
00:32:10	Perform CSM -X RCS to null 1.0-fps closing rate.
00:32:15	Begin docking. CSM control is CMC/FREE. Estimated worst case dock is completed by TLI cutoff plus 1.5 hr.

3.2 CSM/LM ejection from the S-IVB (appendix D)

Time from TLI cutoff, hr:min:sec	Event
01:30:00	CSM/LM is ejected from the S-IVB. CSM is controlled by CMC/FREE. S-IVB attitude at ejection with respect to LH is yaw 40°, pitch 174.8°, roll 180° (May 18 launch). Relative spring actuator nominal ΔV = 0.9 fps (maximum ΔV = 1.04 fps, minimum ΔV = 0.77 fps). CSM/LM ejection may be executed ±0.5 hr from time indicated; all following items would be executed at ±0.5 hr, respectively.
01:30:05	Initiate CSM -X RCS translation. No change in CSM attitude.
01:30:08	Terminate CSM -X RCS translation. ΔV = 0.4 fps.
01:30:19	The CSM will have translated approximately 25 feet based on nominal spring actuator ΔV. For a minimum ΔV (48% efficiency), 25 feet will be achieved at 21.5 sec; for a maximum ΔV (90% efficiency), 25 feet will be achieved at 17.5 sec (appendix E). The CSM begins orientation at 0.5 deg/sec rate to the evasive maneuver attitude, pitch, down (toward earth) 75° and yaw 0° with respect to LH. Roll is positive 55° from heads-up to view the S-IVB in the left side window (May 18 launch) from the left couch position. The spacecraft gimbal angles are as follows. Pitch (IGA) = 255.7° Yaw (MGA) = 358.4° Roll (OGA) = 55.7°
01:31:10	If the LH_2 propulsive vent on the S-IVB fails to close prior to ejection, the CSM/LM must perform a 5-sec +X RCS translation immediately after orientation to the SPS evasive maneuver attitude to prevent possible recontact with the S-IVB (appendix A).

Time from TLI cutoff, hr:min:sec	Event
02:00:00	Initiate SPS evasive maneuver.
02:00:03	Terminate SPS evasive maneuver. ΔV = 19.7 fps. SPS evasive maneuver may be executed anytime after the CSM has obtained the proper attitude but should not exceed a delay longer than 1 hr 30 min. The S-IVB inhibit release on TB8 must occur after the SPS evasive maneuver, and for a first opportunity injection, it should not occur later than 3.5 hr after TLI or 1 hr 30 min after the nominal time for the SPS evasive maneuver.

3.3 LM undocking and CSM separation (ref. 1 and 2)

3.3.1 LM undocking.-

Time from lift-off, hr:min:sec, g.e.t.	Event
98:10:00	For LM undocking, the CSM +X is alined to the inertial separation burn attitude. Spacecraft gimbal angles are as follows. Pitch (IGA) = 14.3° Yaw (MGA) = 0° Roll (OGA) = 180° Spacecraft LH angles are as follows. Pitch = 13.3° Yaw = 0° Roll = 180° The CSM undocks from the LM at $98^h10^m00^s$ during REV 12. The LM nulls the relative range rate at a distance of 40 to 50 ft. The CSM performs stationkeeping. The LM performs 120° negative roll (Pilot yaw right) and a 90° pitch maneuver to obtain a heads-down, eye-to-eye attitude with the CSM. While the CMP photographs the LM, the LM will perform a rotation maneuver of 2 deg/sec (pilot yaw) for 360°. After completion of photography, the LM performs stationkeeping while the CMP prepares for the RCS separation burn.

3.3.2 Separation burn.-

Time from lift-off, hr:min:sec, g.e.t.	Event
98:35:16	The CSM +X axis is alined with positive radius vector, pitch 90° from the LH. An attitude maneuver should not be required at this time because the CSM undocking attitude was the inertial separation burn attitude. The LM position will be slightly ahead of and above the CSM to allow visual monitoring of separation. The CSM performs -X RCS translation (radially downward) for a ΔV = 2.5 fps. The separation burn occurs at a central angle of approximately 180° prior to DOI at a g.e.t. of $98^h35^m16^s$.

3.4 LM staging (ref. 1, relative motion in appendix B, fig. 1-4).

Time from lift-off, hr:min:sec, g.e.t.	Event
102:33:18	LM staging occurs at a g.e.t. of $102^h33^m18^s$, 10 minutes prior to the insertion burn. LM +X axis is alined with the negative V_i, +Z-axis down. LM gimbal angles are as follows. Pitch (IGA) = 127.1° Yaw (MGA) = 0.0° Roll (OGA) = 180° LM LH angles are as follows. Pitch = 180° Yaw = 0° Roll = 180° Perform LM -X RCS translation for a ΔV = 2.0 fps (posigrade). Separate the descent stage and immediately perform LM +X RCS translation for a net ΔV = 2 fps (retrograde). Because of possible descent stage recontact with the LM, staging should not be performed earlier than 63 ± 10 min prior to insertion. (appendix B, fig. 5).

Time from lift-off, hr:min:sec, g.e.t.	Event
	Approximately 30 hr after staging, the descent stage will phase with that of the CSM. The descent stage relative motion is retrograde; but because of its longer period, it will approach the CSM from a posigrade direction 15 orbits after staging. Possible recontact problems are discussed in appendix B. Performance of out-of-plane CSM maneuver at descent stage perilune after the APS burn to depletion will greatly reduce the possibility of recontact.
102:43:18	The APS performs the 15-sec insertion maneuver, pitched at 155.6° from the LH for a ΔV = 213 fps.

3.5 Ascent stage jettison and APS burn to depletion
(ref. 2, relative motion presented in appendix B, fig. 6)

Time from lift-off, hr:min:sec, g.e.t.	
106:50:45	(NOTE: This procedure for ascent stage jettison and APS burn to depletion is the same as for the Apollo 9 mission. However, the Apollo 10 crew had indicated that after LM jettison they will maneuver above the LM and will perform a radially outward evasive maneuver (ΔV = 2 fps) to attain the correct relative position for the APS burn.) After the LM is configured for the unmanned APS burn to depletion, the CSM/LM is maneuvered to the APS burn to depletion inertial attitude and begins attitude hold. Spacecraft LH angles are as follows. Pitch = 150° Yaw = 0° Roll = -60° Spacecraft gimbal angles are as follows. Pitch (IGA) = 70.3° Yaw (MGA) =0° Roll (OGA) = -60°
108:09:00	The ascent stage is jettisoned near 90° E longitude, in the burn to depletion inertial attitude. CSM is controlled by CMC/AUTO.

Time from lift-off, hr:min:sec, g.e.t.	Event
108:09:00	The CSM performs -X RCS translation to achieve a net ΔV = 1.0 fps at jettison (radially downward). The CSM nulls the jettison ΔV, and maneuvers to a stationkeeping position down range of the LM, ahead with respect to V_i. The CSM performs stationkeeping down range of the LM and orients to the evasive maneuver attitude. CSM LH angles are as follows. Pitch = -60° from retrograde LH; Yaw = 45° south; Roll to headsup.
108:16:57	At 22 min prior to APS burn to depletion, perform CSM -X RCS translation for a ΔV = 3 fps. This maneuver will place the CSM 3300 ft above and 2300 ft behind the ascent stage and 2100 ft out-of-plane at APS burn ignition (appendix B, fig. 6).
108:38:57	APS burn to depletion is performed. LM ascent stage attitude with respect to the LH (this attitude is the same as the inertial LM jettison attitude) is as follows. Pitch = 0°; Yaw = 0°; Roll = 0°

3.6 CM/SM separation (appendix F).

Time from lift-off, hr:min:sec, g.e.t.	Event
191:01:16	At t_{ff} = 17 min, the CSM performs the IMU alinement attitude check. The IMU alinement check is performed with CSM heads down, +X-axis alined 31.7° above the LOS to the backward horizon in the orbital plane (0° yaw). The CSM then yaws 45° north and holds this attitude for SM separation.

Time from lift-off, hr:min:sec, g.e.t.	Event
191:03:16	At t_{ff} = 15 minutes, the CM jettisons the SM and then orients to the entry attitude.

4.0 ALTERNATE MISSIONS, EARTH ORBIT

4.1 Earth orbit rendezvous (appendix C, figs. 3 and 4)

4.1.1 CSM separation from the S-IVB, T&D during earth orbit

4.1.1.1 No TLI burn (ref. 3)

a. Prior to separation, the S-IVB orients to and holds the T, D, and E attitude for earth orbit.
b. The CSM separates from the S-IVB, and SLA panels are jettisoned at the beginning of a daylight pass.
c. CSM separation ΔV = 1.0 fps.
d. One minute after separation, at a range of 50 ft, the CSM nulls the 0.5-fps separation rate.
e. The CSM pitches 180°.
f. The CSM nulls the remaining separation velocity.
g. The CSM performs +X RCS translation to close in on the S-IVB.
h. After the docking interface is reached, the CSM rolls -60° and docks.

4.1.1.2 Partial TLI - same procedure as nominal (section 3.1)

4.1.2 CSM/LM ejection from the S-IVB in earth orbit

4.1.2.1 No TLI burn (ref. 4)

a. CSM/LM is ejected, coasts 5 seconds.
b. Initiate CSM -X RCS translation for 3 seconds.
c. Terminate CSM -X RCS translation.
d. CSM pitches down 50° (toward earth) from ejection attitude.
e. CSM performs -X RCS translation for 6 seconds at 3 minutes after ejection.

4.1.2.2 Partial TLI - same procedure as nominal (section 3.2)

4.1.3 LM undocking

a. Aline CSM +X-axis with negative V_i (retrograde).
b. Undock.
c. LM performs stationkeeping.
d. CSM alines +X-axis with negative radius vector.

4.1.4 Rendezvous

a. CSM performs minifootball, +X RCS ΔV = 2.5 fps radially downward.
b. LM performs phasing maneuver.

c. LM performs CDH maneuver.
d. LM staging (DPS retrograde) is performed 10 to 30 minutes prior to TPI.
   1. LM +X-axis is alined with V_i.
   2. Perform LM -X RCS for a ΔV = 3 fps (retrograde).
   3. Immediately initiate LM +X RCS for a net ΔV = 3 fps (posigrade).
   4. Stage the LM at the beginning of LM +X (thrust acceleration detection).
e. LM APS TPI maneuver is performed.
f. LM APS TPF and docking are performed.

4.1.5 Ascent stage jettison and APS burn to depletion (same as nominal procedure, ref. 5, appendix C, fig. 3)
a. After the LM is configured for the unmanned APS burn to depletion, the CSM/LM orients to the APS burn to depletion inertial attitude and begins attitude hold.
b. At 30 minutes prior to the APS burn, jettison the LM in attitude hold. The CSM performs -X RCS translation for a net ΔV = 1.0 fps.
c. The CSM nulls the jettison ΔV and maneuvers to a stationkeeping position down range of the LM, ahead with respect to V_i.
d. The CSM performs stationkeeping down range of the LM and orients to the evasive maneuver attitude. CSM LH angles are as follows.
   Pitch = -60° from retrograde LH
   Yaw = 45° south
   Roll to heads up
e. At 22 minutes prior to the APS burn, the CSM performs -X RCS translation for a ΔV = 3 fps.
f. This maneuver will place the CSM above and north of the APS at burn ignition. (If the APS burn is targeted out of plane towards north, then the CSM yaw in the preceding item should be north.)
g. The APS burn to depletion occurs approximately 21 minutes after the CSM evasive maneuver.

4.1.6 CM/SM separation, earth orbit (ref. 6)
a. The CSM orients to the retrofire attitude and performs the deorbit burn.
b. The CSM holds the deorbit burn attitude and yaws the +X-axis 45° north.
c. The CM jettisons the SM and then orients to the entry attitude.

4.2 Ascent-stage-only rendezvous, earth orbit (appendix C, figs. 4 and 5)

4.2.1 CSM/S-IVB separation - same procedure as section 4.1.1

4.2.2 CSM/LM ejection - same procedure as section 4.1.2

4.2.3 LM undocking - same procedure as section 4.1.3

4.2.4 Rendezvous; APS only; DPS inoperative

a. CSM alines +X-axis with negative radius vector.
b. CSM performs minifootball, +X RCS $\Delta V = 2.5$ fps.
c. LM staging (DPS retrograde) performed 15 minutes prior to phasing.

NOTE: Because of possible recontact problems between the descent stage and the ascent stage, staging should not occur more than 15 minutes prior to the LM APS phasing maneuver (appendix C).

1. LM +X-axis is alined with positive V_i.
2. Perform LM -X RCS for a $\Delta V = 3$ fps (retrograde).
3. Immediately initiate LM +X RCS for a net $\Delta V = 3$ fps (posigrade).
4. Stage the LM at the beginning of LM +X (thrust acceleration detection).

d. LM APS performs phasing.
e. LM APS completes rendezvous (CDH, TPI, TPF).
f. Docking is performed.

4.2.5 Ascent stage jettison and APS burn to depletion - same procedure as section 4.1.5

4.2.6 CM/SM separation - same procedure as section 4.1.6

4.3 Earth orbit rendezvous, ascent stage only, mini- and maxifootball (appendix C, figs. 6 and 7)

4.3.1 CSM separation from the S-IVB - same procedure as section 4.1.1

4.3.2 CSM/LM ejection from the S-IVB - same procedure as section 4.1.2

4.3.3 LM undocking - same procedure as section 4.1.3

4.3.4 Rendezvous

a. CSM alines +X-axis with negative radius vector.
b. CSM performs minifootball, +X RCS, $\Delta V = 2.5$ fps.
c. Perform LM staging (DPS retrograde) after CSM minifootball.

1. LM +X-axis alined with V_i.
2. Perform LM -X RCS for a $\Delta V = 3$ fps (retrograde).
3. Immediately initiate LM +X RCS for a net $\Delta V = 3$ fps (posigrade).
4. Stage the LM at the beginning of LM +X (thrust acceleration detection).

d. LM APS performs phasing.
e. LM APS completes rendezvous (TPI and TPF).
f. Perform docking.

4.3.5 Ascent stage jettison, no APS burn to depletion
a. Aline CSM +X-axis with positive V_i.
b. Jettison; perform CSM -X (retrograde) for a $\Delta V = 2$ fps.

4.3.6 CM/SM separation - same procedure as section 4.1.6

4.4 Semisynchronous earth orbit alternate, 12-hour period

4.4.1 CSM separation from S-IVB - same procedure as nominal, section 3.1

4.4.2 CSM/LM ejection - same procedure as nominal, section 3.2

4.4.3 LM staging is performed (CSM/LM APS translates retrograde) 3 hours prior to apogee, docked configuration
a. CSM +X-axis alined with positive V_i (posigrade).
b. Perform LM +X RCS for a $\Delta V = 1$ fps (retrograde).
c. Stage the LM at the beginning of LM +X (thrust acceleration detection).
d. Descent stage moves ahead, above, and then behind the spacecraft and causes no interference with an early retrofire.

4.4.4 Ascent stage is jettisoned 30 minutes prior to apogee
a. After the LM is configured for the unmanned APS burn to depletion, the CSM/LM orients to the APS burn to depletion inertial attitude and begins attitude hold.
b. At 30 minutes prior to the APS burn, jettison the LM in attitude hold and perform CSM -X RCS translation for a net $\Delta V = 1.0$ fps.
c. The CSM nulls the jettison ΔV, maneuvers above the LM and then performs a radially outward evasive maneuver for a $\Delta V = 2$ fps.
d. Avoid any retrograde ΔV components, because perigee altitude is very sensitive to maneuvers near apogee, particularly on a semisynchronous orbit. Posigrade or retrograde components in the radial translation maneuver should be nulled to zero.
e. This maneuver will place the CSM above the ascent stage at burn ignition.
f. The APS burn to depletion occurs at apogee.

4.4.5 CM/SM separation - same procedure as section 4.1.6

5.0 LUNAR MISSION ALTERNATES

5.1 Lunar flyby with the LM (alternate mission from TEC - unmanned APS)

5.1.1 CSM separation from the S-IVB - same procedure as nominal, section 3.1

5.1.2 CSM/LM ejection - same procedure as nominal, section 3.2

5.1.3 The LM is staged from a docked configuration

a. At 5 hours prior to nominal LOI, perform docked DPS burn.

b. After flyby and AOS, perform a docked staging of the LM.

1. Aline the CSM +X-axis with the local horizontal.
2. Perform CSM +X RCS translation for the required ΔV, jettison the descent stage, and then null the ΔV with LM +X RCS.
3. A posigrade or retrograde LH alinement and the required ΔV for staging will depend on the descent stage targeting.
4. The crew configures the LM for jettison and the unmanned APS burn to depletion.

NOTE: Should the SM RCS not be operable, stage the DPS by use of the LM RCS as outlined above. Ascent stage jettison is performed with the CSM +X-axis 45° south out of plane from negative V_i.

The tunnel is pressurized prior to jettison to attain the maximum separation ΔV. Do not perform APS burn to depletion.

5.1.4 APS jettison (30 min prior to the APS burn)

a. After the LM is configured for the unmanned APS burn, the crew alines the CSM/LM to the inertial APS burn to depletion attitude and begins attitude hold. CSM +X-axis is alined with negative V_i.

b. At 30 minutes prior to ignition, jettison the ascent stage and perform CSM -X RCS translation (posigrade) for a net $\Delta V = 1$ fps.

c. Yaw the CSM +X-axis 45° north out of plane from negative V_i and perform CSM +X RCS translation (retrograde) for a $\Delta V = 1.5$ fps.

d. This maneuver will place the CSM north and lateral to the ascent stage at ignition.

e. The APS burn to depletion occurs approximately 28 minutes after the CSM evasive maneuver.

5.1.5 CM/SM separation - same procedure as nominal, section 3.6

5.2 Lunar orbit, CSM only, LM staging and jettison during TLC (alternate mission from TLC - unmanned APS)

5.2.1 CSM/S-IVB separation - same procedure as nominal, section 3.1

5.2.2 CSM/LM ejection - same procedure as nominal, section 3.2

5.2.3 SPS correction burn performed to correct partial TLI

5.2.4 Docked LM staging, second day of TLC - same procedure as lunar flyby alternate, section 5.1.3

5.2.5 Ascent stage jettison and unmanned APS burn to depletion - same procedure as lunar flyby, section 5.1.4

5.2.6 CM/SM separation - same procedure as nominal, section 3.6

5.3 DPS TEI

5.3.1 Nominal CSM and LM; LM staging and jettison during TEC - same procedures as lunar flyby, sections 5.1.3 and 5.1.4

5.3.2 For a nonnominal CSM, retain LM (LM jettison during TEC)

5.3.2.1 LM jettison during TEC - same procedure as staging, section 5.1.3

5.3.2.2 LM jettison occurs during TEC, after 3-hour t_{ff}

a. Yaw CSM +X-axis 45° south out of plane from negative V_i.

b. Jettison the LM ascent and descent stages and perform CSM -X RCS translation (posigrade) for a net ΔV = 3 fps. The CSM translates posigrade and to the north of the LM.

5.3.3 CM/SM separation - same procedure as nominal, section 3.6

6.0 LUNAR ORBIT ALTERNATES

6.1 Descent-stage-only rendezvous (appendix B)

6.1.1 LM undocking and CSM separation - same procedure as nominal, section 3.3

6.1.2 DPS staged at TPF - same procedure as staging prior to TPI, PDI abort, section 7.7.2.5

6.1.3 DPS is not staged during rendezvous but after docking with the CSM

a. Docked DPS staging after descent-stage-only rendezvous - APS burn to depletion is planned; CSM/LM translates behind, below, and then ahead of DPS.

b. Aline CSM +X-axis with positive V_i.

c. Perform LM +X RCS translation for a $\Delta V = 3$ fps (retrograde).

d. Immediately stage the DPS at the beginning of LM +X translation.

e. The DPS will move ahead, above, and then behind the CSM/LM (appendix B, fig. 17).

6.1.4 Ascent stage jettison and APS burn to depletion - same procedure as nominal APS jettison, section 3.5

6.1.5 LM jettison after rendezvous, descent stage not jettisoned during rendezvous or after docking, no APS burn to depletion (contingency TEI, appendix B, fig. 17)

a. LM is jettisoned after docking (CSM translates behind, below, and then ahead of the LM).

b. For a contingency (early) TEI, jettison should occur 1 hour (but not later than 30 min) prior to the TEI burn.

c. Aline CSM +X-axis with positive V_i (posigrade).

d. Jettison the LM and immediately perform CSM -X RCS translation (retrograde) for a net $\Delta V = 1.0$ fps. [Relative motion for $\Delta V = 3$ fps is presented in appendix B (fig. 18).]

e. The LM will move ahead of, above, and then behind the CSM.

6.1.6 DPS retained during rendezvous for DPS TEI

a. Unmanned APS burn to depletion during TEC - same procedure as lunar flyby, sections 5.1.3 and 5.1.4.

b. No APS burn to depletion during TEC, jettison LM - same procedure as LM jettison during TEC, section 5.3.2.

6.1.7 APS inoperative

a. No APS burn, jettison LM prior to TEI - same procedure as LM jettison after rendezvous, section 6.1.5.

b. DPS TEI - jettison LM during TEC - same procedure as section 5.3.2.

6.2 Ascent-stage-only rendezvous, lunar orbit, DPS inoperative (appendix B, fig. 19)

a. LM undocking, CSM separation - same procedure as nominal, section 3.3.

b. LM staging (DPS retrograde) - same procedure as for earth orbit ascent-stage-only rendezvous, except DPS staging occurs 15 minutes prior to APS DOI, section 4.2.4.

NOTE: Because of possible recontact problems between the DPS and the LM, separation of the descent stage should not occur less than 15 minutes prior to the DOI maneuver.

c. APS jettison and burn to depletion - same as nominal procedure, section 3.5.

6.3 APS-only, mini-maxi lunar rendezvous (appendix B, figs. 20 and 21)

a. LM undocking, CSM separation - same procedure as nominal, section 3.3.

b. LM staging (DPS retrograde) - same procedure as for earth orbit mini-maxi rendezvous, except DPS staged 15 minutes prior to nominal APS DOI, section 4.3.4.

c. APS jettison - same as earth orbit mini-maxi jettison, section 4.3.5.

7.0 ABORTS

7.1 Launch phase, stable (nontumbling) abort (refs. 7 and 8)

7.1.1 Mode I aborts

a. Mode I aborts are LET jettisons of the CM from the LV.
b. The SM and the SLA panels remain attached to the LV.
c. The DRPA is jettisoned with and remains attached to the LET.

7.1.2 Mode II aborts

a. The abort is initiated; booster is cut off; and CSM +X RCS four-jet ullage is ON.
b. CSM/S-IVB physical separation occurs 3 seconds after abort initiation; CSM +X ullage becomes +X translation; SLA panels are jettisoned.
c. Terminate CSM +X translation 24 seconds after abort initiation.
d. Orient the CSM to entry attitude.
   1. If $t_{ff} > 2$ minutes, yaw CSM +X-axis 45° north out of plane.
   2. If $t_{ff} < 2$ minutes, remain in entry attitude.
e. Jettison the SM and the DRPA.
f. If necessary, reorient to the CM entry attitude and fly full lift (heads down) to landing.

7.1.3 Mode III aborts

a. Abort is initiated; booster is cut off; and CSM +X RCS four-jet ullage is ON.
b. CSM/S-IVB physical separation occurs 3 seconds after abort initiation; CSM +X ullage becomes +X translation; SLA panels are jettisoned.
c. Terminate CSM +X translation 24 seconds after abort initiation.
d. Orient to the mode III abort burn attitude: CSM heads up, CSM +X-axis 31.7° below the LOS to the rearward horizon; begin attitude hold and perform the required SPS abort burn.
e. Remain in the abort burn attitude.
   1. If $t_{ff} > 2$ minutes, yaw the CSM +X-axis south out of plane.
   2. If $t_{ff} < 2$ minutes, remain in the abort burn attitude.
f. Jettison the SM and the DRPA.
g. Orient to the CM entry attitude.

7.1.4 Mode IV aborts, contingency orbit insertion (COI)

a. Abort is initiated; booster is cut off; and CSM +X RCS four-jet ullage is ON.
b. CSM/S-IVB physical separation occurs 3 seconds after abort initiation; CSM +X ullage becomes +X translation; SLA panels are jettisoned.

c. Terminate CSM +X translation 24 seconds after abort initiation.
d. Orient to the mode IV COI attitude: CSM heads down, CSM +X-axis 31.7° above the LOS to the forward horizon; begin attitude hold and perform the required SPS COI burn.
e. CSM inserts into a contingency earth orbit.
f. CM/SM separation during entry for a contingency earth orbit.
   1. CSM remains in the deorbit burn attitude.
   2. Yaw the CSM +X-axis 45° north out of plane.
   3. Jettison the SM and the DRPA.
   4. Orient to the CM entry attitude.

7.1.5 Launch phase aborts, no SLA SEP (ref. 9)

a. Abort is initiated; booster is cut off; CSM +X RCS four-jet ullage is ON.
b. At 3 seconds, SLA panels fail to separate, terminate CSM +X.
c. Perform CM jettison of the SM/SLA/S-IVB.
d. The SM -X RCS jets are ON for burn to fuel depletion at CM/SM SEP.
e. The CM orients to entry attitude.

7.2 Launch phase, nonstable (tumbling) aborts (refs. 10 and 11)

7.2.1 Modes II, III, and IV

a. Abort is initiated; booster is cut off; and CSM +X RCS four-jet ullage is ON.
b. CSM/S-IVB physical separation occurs at 3 seconds after abort initiation; CSM +X ullage becomes RCS rate damping; SLA panels are jettisoned.
c. RCS rate damping continues until CSM rates are as follows.
   1. For mode II, the rates must be low enough to permit orientation to entry attitude and jettison of the SM and DRPA (less than 5 deg/sec). The CM RCS can complete rate damping, if necessary.
   2. For modes III and IV, the rates must be low enough to permit orientation to the proper abort burn attitude.
   3. If time permits, the crew should try to establish that the S-IVB and the jettisoned SLA panels are not in the same direction as the abort burn.

7.3 Earth orbital aborts

7.3.1 CSM aborts from the SLA/LM/S-IVB (refs. 8 and 12)

7.3.1.1 Primary abort procedure (retrograde attitude)

a. The crew manually orients the CSM/S-IVB configuration to the abort attitude: CSM heads up, CSM +X-axis 31.7° below the LOS to the rearward horizon.

b. Abort is initiated; CSM +X RCS four-jet ullage is ON.
c. CSM/S-IVB physical separation occurs 3 seconds after abort initiation; CSM +X ullage becomes +X translation; SLA panels are jettisoned.
d. Terminate CSM +X translation 24 seconds after abort initiation; begin coast for 20 minutes.
e. Orient the CSM to the abort burn attitude: CSM heads up, +X-axis 31.7° below the LOS to the rearward horizon.
f. SPS ignition occurs at 20 minutes after abort initiation.
g. CM/SM separation - same procedure as a contingency earth orbit entry, section 7.1.4.

7.3.1.2 Secondary abort procedure (posigrade attitude)

a. If the crew cannot take manual control of the S-IVB, the orbital abort will be performed with the CSM/S-IVB alined in the posigrade, LH attitude.
b. Abort is initiated; CSM +X RCS four-jet ullage is ON.
c. CSM/S-IVB physical separation 3 seconds after abort initiation; CSM +X ullage becomes +X translation; SLA panels are jettisoned.
d. Terminate CSM +X translation 24 seconds after abort initiation; begin coast for 30 seconds.
e. During the 30-second coast period, the CSM orients to a heads-up attitude and alines the +X-axis 31.7° below the LOS to the rearward horizon.
f. At 54 seconds after abort initiation, perform CSM +X RCS translation for 30 seconds.
g. Orient to the SPS abort burn attitude: CSM heads up, +X-axis 31.7° below the LOS to the rearward horizon.
h. SPS ignition at 20 minutes after abort initiation.
i. CM/SM separation - same procedure as a contingency earth orbit entry, section 7.1.4.

7.3.2 CSM docked, aborts from the LM/S-IVB, earth orbit (ref. 13)

a. The CSM/S-IVB docked configuration is alined with the LH, CSM +X-axis retrograde.
b. Abort is initiated; CSM jettisons the LM/S-IVB (the DRPA remains with the LM) and performs -X RCS translation for 21 seconds.
c. The CSM orients to a heads-up attitude with the +X-axis alined 31.7° below the LOS to the rearward horizon and initiates +X RCS translation for 30 seconds.
d. The CSM orients to the deorbit burn attitude: heads up, +X-axis 31.7° below LOS to rearward horizon.
e. SPS ignition occurs at 20 minutes after abort initiation.

f. CM/SM separation.
   1. CSM remains in the deorbit burn attitude.
   2. Yaw the CSM +X-axis 45° north out of plane.
   3. Jettison the SM.
   4. Orient to the CM entry attitude.

7.3.3 CSM aborts from the LM, earth orbit (ref. 12)

a. After the LM is configured for jettison, the crew orients the CSM to a posigrade, heads-down attitude and alines the CSM +X-axis 31.7° above the LOS to the forward horizon.

b. Abort is initiated; the CSM jettisons the LM (the DRPA remains with the LM) and performs -X RCS translation for 21 seconds.

c. The CSM then orients to the abort burn attitude: CSM heads up, +X-axis 31.7° below the LOS to the rearward horizon.

d. SPS ignition occurs at 20 minutes after abort initiation.

e. CM/SM separation is performed.
   1. CSM remains in the deorbit burn attitude.
   2. Yaw the CSM +X-axis 45° north out of plane.
   3. Jettison the SM.
   4. Orient to the CM entry attitude.

7.4 TLI abort (ref. 14)

7.4.1 Booster shutdown is required

a. Abort is initiated; booster is cut off; and CSM +X RCS four-jet ullage is ON.

b. CSM/S-IVB physical separation occurs 3 seconds after abort initiation; CSM +X ullage becomes +X translation; SLA panels are jettisoned.

c. Terminate +X RCS translation 13 seconds after abort initiation, and aline CSM +X-axis with the negative radius vector, towards the earth.

d. At 1 minute after abort initiation, perform CSM RCS -X translation for 8 seconds, $\Delta V = 1.5$ fps.

e. Orient to SPS abort burn horizon referenced attitude; thrust vector alined 4.7° below LOS to rearward horizon.

f. SPS ignition occurs at 10 minutes after abort initiation.

g. CM/SM separation - same procedure as nominal, section 3.6.

7.4.2 Booster shutdown not required, TLI burn completed - same procedure as TLC 90-minute abort, section 7.5

7.5 TLC aborts (ref. 14)

7.5.1 90-minute abort (no T&D)

a. Nominal TLI is completed; S-IVB holds cutoff attitude for 20 seconds.

b. S-IVB orients to and holds local horizontal until TLI cutoff plus 15 minutes.

c. S-IVB orients to and holds nominal T, D, and E attitude.
d. At TLI cutoff plus 25 minutes, initiate abort; CSM +X RCS four-jet ullage is ON.
e. CSM/S-IVB physical separation occurs 3 seconds after abort initiation; CSM +X ullage becomes +X translation; SLA panels are jettisoned.
f. Terminate +X RCS translation 13 seconds after abort initiation, and aline the CSM +X-axis with the negative radius vector, towards earth.
g. At 1 minute after abort initiation, perform CSM RCS -X translation for 8 seconds, $\Delta V = 1.5$ fps.
h. Orient to SPS abort burn horizon referenced attitude. The thrust vector is approximately 6° below the LOS to the rearward horizon. Perform the SPS abort burn.
i. CM/SM separation - same procedure as nominal, section 3.6.

7.5.2 Direct abort from TLC (T&D was performed)
a. Aline CSM +X-axis 180° from the SPS abort burn attitude (near the negative radius vector) 30 minutes prior to SPS ignition.
b. Jettison the LM.
c. Perform CSM -X RCS translation (retrograde) for a net $\Delta V = 1$ fps.
d. Perform SPS abort burn.

7.6 Circumlunar aborts

7.6.1 LM jettison prior to abort - same procedure as staging during TLC, section 5.1.3

7.6.2 LM jettison after abort - same procedure as LM jettison during TEC, section 5.3.2

7.7 Abort and rescue, lunar rendezvous

7.7.1 DOI overburn, direct return, LM staging required (appendix B, fig. 7)
a. Aline LM +X-axis with LOS to the CSM.
b. Perform LM +X RCS translation and stage the DPS at the beginning of +X.
c. Descent stage left in descent orbit; ascent stage returns to the CSM.
d. For a direct abort caused by a DPS overburn, the descent stage will impact the moon.

7.7.2 PDI aborts

7.7.2.1 Staging prior to APS PDI, DPS retrograde (appendix B, figs. 8 and 9)

a. The LM orients to the PDI attitude.
b. Perform LM -X RCS translation (retrograde) for a ΔV = 2 fps.
c. Perform LM +X translation and stage the descent stage.
d. Perform APS PDI.
e. The descent stage orbit will not phase with the CSM until approximately 51 hours later, after the nominal time for TEI. If TEI is delayed and if the descent stage passes ahead of the CSM, recontact problems during the TEI maneuver could exist.

7.7.2.2 Staging prior to CSI (DPS retrograde and north)

NOTE: If possible, avoid staging the descent stage prior to CSI because recontact problems between the descent stage and the CSM would exist (appendix B, figs. 8 and 10 through 12).

a. Aline the LM +X-axis 45° south out of plane with the positive V_i.
b. Perform LM -X RCS translation for a ΔV = 3 fps.
c. Stage the descent stage and perform LM +X RCS translation for a net ΔV = 3 fps.

7.7.2.3 Staging prior to CDH, LM APS translates retrograde (appendix B, fig. 13)

a. LM orients to CDH attitude.
b. Perform LM +X RCS translation and stage the DPS.
c. LM APS performs CDH.
d. The descent stage orbit will not phase with the CSM until approximately 45 hours later, after the nominal time for TEI. The descent stage will be down range, ahead of the LM at TEI (appendix B).

7.7.2.4 Staging prior to TPI

a. LM orients to TPI attitude.
b. Perform LM +X RCS translation and stage the DPS.
c. LM APS performs TPI.
d. No recontact problems exist.

7.7.2.5 Staging prior to TPF (first braking gate)

NOTE: Staging prior to the first braking gate of TPF should be performed only if necessary. TPF should be performed with the DPS and staging performed after docking. Although the following procedure stages the descent stage out of plane, recontact problems may still exist (appendix B).

a. Aline the LM +X-axis with the LOS to the CSM (after TPI).
b. Yaw the LM +X-axis 45° south out of plane.
c. Perform LM -X RCS translation (retrograde) for a ΔV = 3 fps.

d. Stage the descent stage and perform LM +X RCS translation (posigrade) for a net ΔV = 3 fps.
e. Ascent stage completes docking.

7.7.3 CSM rescue
a. The descent stage is not separated during rendezvous.
b. The CSM performs rescue maneuvers.
c. The procedures for staging and jettison in a docked configuration are covered in the descent-stage-only rendezvous, section 6.0.

7.7.4 Partial phasing, descent stage separation required (appendix B, figs. 14 and 15)

NOTE: If a partial phasing burn results in a ΔV = 81.0 to 92.5 fps and if staging is performed, recontact problems between the descent stage and CSM will exist. The following procedure will avoid this situation.
a. Partial phasing occurs; DPS staging is required.
b. ΔV from phasing is between 81.0 and 92.5 fps.
c. Do not stage; remain in the phasing attitude.
d. Perform LM -X RCS translation to achieve a net ΔV from phasing of less than 81.0 fps.
e. Stage the DPS immediately at the beginning of the LM +X translation.
f. Complete phasing with the LM APS.

7.7.5 LM jettison after lunar rendezvous abort - same procedures as nominal, section 3.5

7.8 Contingency (early) TEI - section 6.1.5 (appendix B, fig. 16)

8.0 EMERGENCY SEPARATION PROCEDURES FOR AN IMPENDING, DETECTABLE S-IVB EXPLOSION

8.1 CSM (alone) separation from the S-IVB (appendix G)

a. Warning is received; abort is initiated; S-IVB is shut down (if thrusting); initiate CSM +X RCS.

b. CSM/S-IVB physical separation at 3 seconds; continue RCS +X translation.

c. At 3 seconds after separation (6 sec after abort initiation), terminate RCS +X and perform a 4-second SPS burn.

d. The CSM will achieve a range of 7080 ft within 182 seconds. For a warning time of 200 seconds, a separation delay of up to 18 seconds could be tolerated.

8.2 CSM/LM separation from the S-IVB (appendix H)

a. Warning is received; CSM/LM ejects from the S-IVB.

b. After ejection, orient to the nominal SPS evasive maneuver attitude and perform an 8-second SPS burn. Burn time will vary depending on warning time remaining at SPS ignition (appendix H).

APPENDIX A

CONTINGENCY EVASIVE MANEUVER SEQUENCE

FOR APOLLO MISSIONS F AND G

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

NASA - Manned Spacecraft Center
Mission Planning & Analysis Division

TO : See List Below

DATE: APR 3 0 1969

69-FM37-187

FROM : FM3/Flight Analysis Branch

SUBJECT: Contingency evasive maneuver sequence for Apollo Missions F and G

Reference: MSC Memorandum 69-FM37-135 by Mr. Marland L. Williamson and Mr. Charles W. Fraley, "Evasive maneuver relative motion for the Apollo Missions F and G," dated March 26, 1969.

Recommendations

In the event a contingency condition develops where the S-IVB LH_2 propulsive vent has failed open following TLI, and cannot be closed prior to LM ejection, the contingency evasive maneuver sequence of Table I is recommended. Nominally, the LH_2 propulsive vent will open at TLI cutoff and close at TLI + 15 minutes, and the nominal evasive maneuver sequence published in the reference will be satisfactory.

The contingency sequence differs from the nominal in that at 1 to 5 minutes after ejection, the CSM performs a 5 second +X RCS maneuver in the SPS evasive maneuver attitude (pitch down 75° from the local horizontal). Otherwise, the nominal procedure is followed.

Summary

The second RCS maneuver is performed in the same attitude as the SPS evasive maneuver (pitch down 75° from the local horizontal) at approximately 70 seconds after LM ejection. As soon as the LM has cleared the S-IVB following ejection, the CSM+LM will orient to the SPS evasive maneuver attitude and immediately perform CSM +X translation for 5 seconds. This maneuver will result in the CSM passing below and behind the S-IVB for a no-vent case (figure 1) and below and ahead for an S-IVB 8 lb vent (figure 2). The expected thrust level at LM ejection is less than 5 lbs for a LH_2 vent failed open, therefore, these two cases will bound the relative motion.

As indicated by figures 1 and 2, the addition of a 5 second +X CSM RCS burn at 70 seconds after ejection in the SPS evasive maneuver attitude will prevent any recontact with the launch vehicle for a vent thrust of 0-8 lbs.

Marland L. Williamson

Charles W. Fraley

APPROVED BY:

John P. Mayer
Chief, Mission Planning
and Analysis Division

REM
CCA

Enclosures

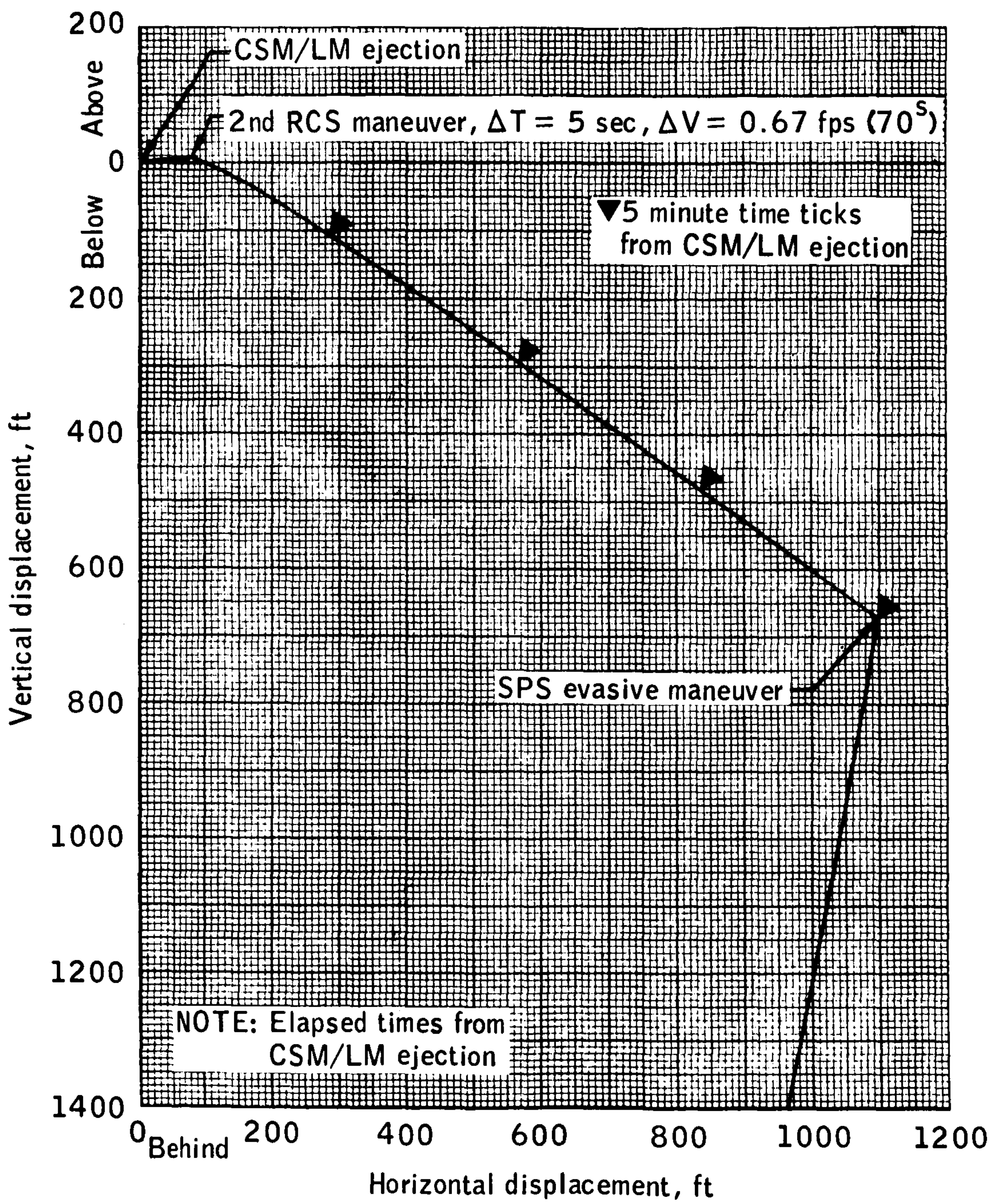
Addressees:
(See attached page)

Table I

Contingency Evasive Maneuver Sequence of Events[1]

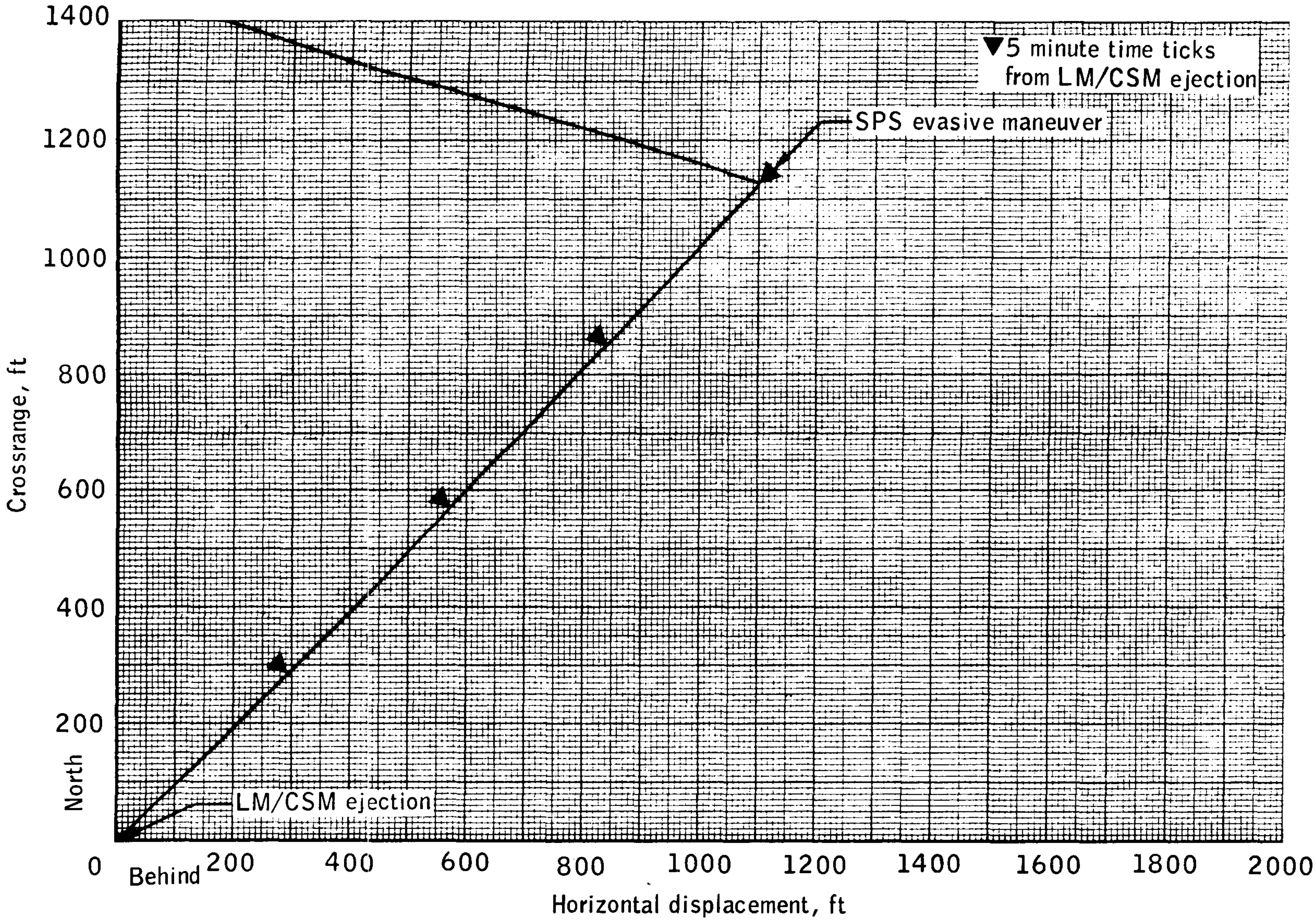
Time	Event
$0^h\ 0^m\ 0^s$	CSM/LM ejection.
$0^h\ 0^m\ 5^s$	Initiate CSM RCS -X translation.
$0^h\ 0^m\ 8^s$	Terminate CSM RCS -X translation.
$0^h\ 0^m\ 21.5^s$	a. The spacecraft will have translated approximately 25 feet (14 feet from the SLA ring station) based on a minimum spring ejection efficiency of 48 per cent. b. Initiate orientation to the SPS evasive maneuver attitude (pitch = -75°, yaw = 0, roll = 55° from heads-up attitude on May 18). Roll (OGA) = 55.7°, pitch (IGA) = 255.7°, yaw (MGA) = 358.4°.
$0^h\ 1^m\ 10^s$	Initiate CSM RCS +X translation, based on a CSM/LM pitch rate of 2°/seconds. Note: The clearance between the S-IVB and the CSM/LM at 70 seconds is 37 feet. For an 8 lb propulsive vent on the S-IVB, this clearance increases to a maximum of 73 feet at 3 minutes after ejection, then decreases to zero at 6 minutes. The clearance at 5 minutes is 39 feet. A lower pitch rate may be utilized for orienting to the proper attitude, therefore, and still allow RCS +X translation prior to 5 minutes.
$0^h\ 1^m\ 15^s$	Terminate CSM RCS +X translation.
$0^h\ 30^m\ 15^s$	Initiate SPS evasive maneuver.

[1]To be used in the event the S-IVB LH_2 propulsive vent fails open after TLI and cannot be closed prior to LM ejection.



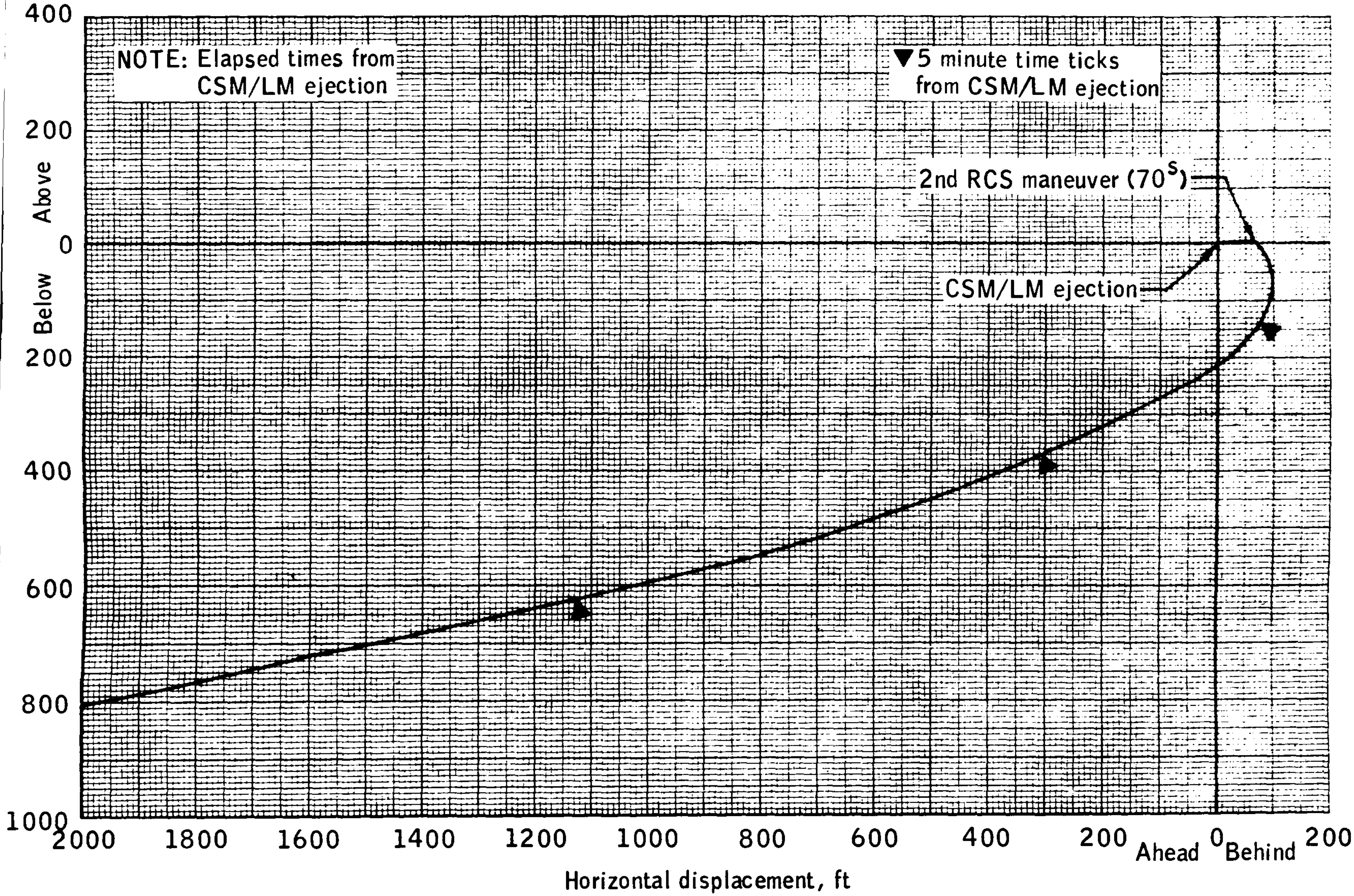
(a) Horizontal versus vertical displacement.

Figure 1.- Motion of the S/C relative to the S-IVB (no vent) with two RCS and one SPS evasive maneuvers.



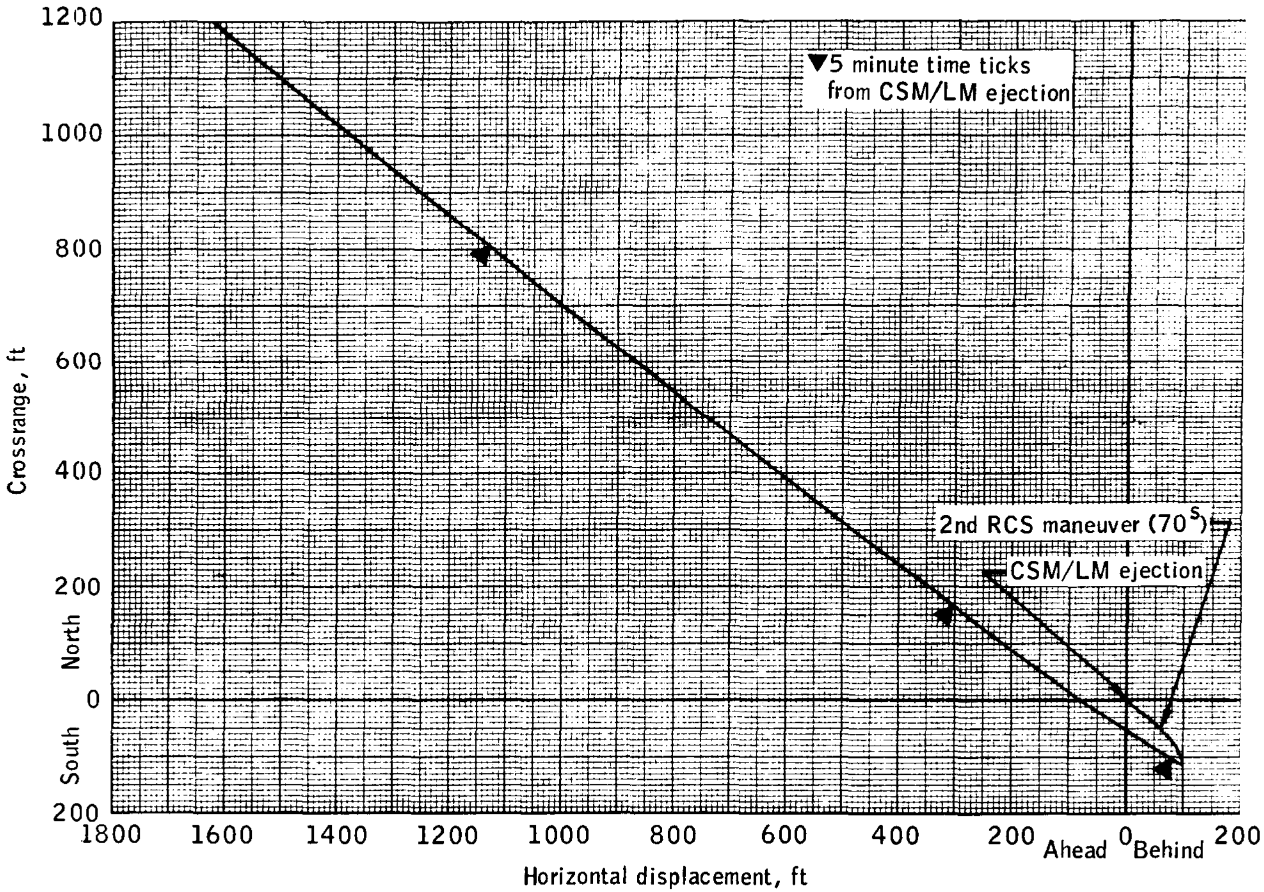
(b) Horizontal versus crossrange.

Figure 1.- Concluded.



(a) Horizontal versus vertical displacement.

Figure 2.- Motion of the S/C relative to the S-IVB (8lb vent) with two RCS and one SPS evasive maneuvers.



(b) Horizontal versus crossrange.

Figure 2.- Concluded.

APPENDIX B

SEPARATION AND RECONTACT STUDY

MISSION F LUNAR ORBIT ACTIVITIES

TRW

5524.8-60
2 May 1969

National Aeronautics and Space Administration
Manned Spacecraft Center
Houston, Texas 77058

Attention: M. L. Williamson, Task Monitor
MSC/TRW Task A-122.1
Mission Planning and Analysis Division

Subject: Separation and Recontact Study Mission F Lunar Orbit Activities

Gentlemen:

The attachments to this letter are the results of a study performed under Task A-122.1 for support of Mission F. The study covers all of the critical separation and recontact situations in lunar orbit, including the nominal lunar orbit maneuvers, contingency and abort procedures in lunar orbit, and the lunar orbit alternate missions. The alternate missions analyzed are the DPS-only rendezvous, the inoperative APS procedures, the APS-only rendezvous, and the mini-maxi football rendezvous.

Potentially serious recontact problems were found for the nominal rendezvous and two of the abort procedures. These problems are discussed in detail, and possible solutions are presented. In addition, potential recontact hazards are described for off-nominal execution of nominal maneuvers.

Yours truly,

Dell Davidson

D. A. Davidson, Task Manager
MSC/TRW Task A-122.1
Analytic Mechanics Section

W F Heugel

W. F. Heugel
Assistant Project Manager
Flight Dynamics
Mission Trajectory Control Program

DAD:DMG:PGW:eac

Attachments

DISTRIBUTION

MSC

C. C. Allen	FM3
R. V. Battey	PD
M. S. Burton	FM15
M. E. Donahoo	FM3
C. J. Gott	FM3
C. R. Huss	FM
R. E. McAdams	FM3
D. Owen	FM
R. P. Parten	FM13

TRW

J. M. Dreyfus
H. O. Eley
J. A. Gay
J. M. Wagner
MSD Section Heads
A-122 Personnel

ATTACHMENT

TRW Letter No. 5524.8-60

Separation and Recontact Study Mission F
Lunar Orbit Activities

MSC/TRW Task A-122.1

Prepared by:

D. A. Davidson

Analytic Mechanics Section
TRW Systems Group

TABLE OF CONTENTS

LIST OF FIGURES

16. Motion of the LM Relative to the CSM for LM Jettison Prior to TEI

17. Motion of the LM Descent Stage Relative to the CSM for the Docked Staging and CSM Evasive Maneuvers After a DPS-Only Rendezvous

18. Motion of the LM Relative to the CSM for LM Jettison After a DPS-Only Rendezvous (No APS Burn)

19. Motion of the CSM, LM Descent Stage, and LM Ascent Stage Relative to the Original CSM/LM Orbit for the APS-Only Rendezvous

20. Motion of the LM Ascent Stage Relative to the CSM for the Mini-Maxi Football Rendezvous

21. Motion of the CSM, LM Descent Stage, and LM Ascent Stage Relative to the Original CSM/LM Orbit for the Mini - Maxi Football Rendezvous

5524.8-60
2 May 1969

1.0 INTRODUCTION AND SUMMARY

The following sections present the results of a study of separation and recontact problems for the lunar orbit activities of Mission F. The results are organized into three parts: an analysis of the nominal mission maneuvers, an analysis of aborts that could be performed in lunar orbit, and an analysis of lunar orbit alternate missions. The results are presented in the form of relative motion plots, recontact hodographs, and discussions of the recontact problems that occur.

Three serious recontact problems are noted. The first is caused by the current staging maneuver during the nominal rendezvous. The LM descent stage is given a rearward secular drift of about 400 nautical miles per orbit, which is sufficient to lap the CSM in about 30 hours, before the TEI maneuver is executed.

The second recontact problem relates to the PDI abort profile when the LM staging is performed between the PDI maneuver and the following maneuver, CSI. LM staging during this period leaves the LM descent stage nearly on a collision trajectory with the CSM. If plume impingement dispersions during staging and state vector uncertainties are considered, a recontact is possible.

The third recontact problem occurs for a partial phasing maneuver where the LM stages and completes the maneuver with the APS engine. If the partial phasing occurs in the range of 81 to 92.5 feet per second, and the LM is staged to allow completion with the APS, the LM descent stage is left on a collision course with the CSM.

Detailed discussions of these problems and other recontact problems are given in the following text. In each case, possible solutions are presented.

2.0 RECONTACT PROBLEMS DURING THE NOMINAL LUNAR ORBIT MANEUVERS

The nominal lunar orbit activities begin at LOI-2 and continue through TEI. These activities include the nominal rendezvous and the APS burn-to-depletion. The nominal relative motion for these activities are presented below, along with a discussion of possible recontact problems.

2.1 Recontact Problems During the Nominal Rendezvous

The nominal LM staging for Mission F is scheduled to occur about 10 minutes prior to the insertion burn during the LM-active rendezvous in lunar orbit. Under certain conditions, there is a possibility that the LM descent stage will contact either the CSM or the LM ascent stage. These two problems were analyzed and are discussed separately below.

2.1.1 Recontact Problems Between the LM Descent Stage and CSM after Nominal Staging

Figure 1 shows the motion of the LM descent stage relative to the CSM for several orbits after staging. The first upward pass of the LM descent stage is about 100 nautical miles to the rear of the CSM. Subsequent passes are even further to the rear, because the LM descent stage has a rearward secular drift of about 400 nautical miles per orbit. This drift is due to the difference in periods, which is nominally 457 seconds. There are no recontact problems on the first pass, because the minimum miss distance of 100 nautical miles is only slightly affected by maneuver dispersions.

Figure 2 shows the nominal motion of the LM descent stage relative to the CSM at about 30 hours after the nominal staging. At this time, the CSM has lapped the LM descent stage and once more comes into its immediate vicinity. The closest approach of the LM descent stage indicated in Figure 2 is about 30 nautical miles to the rear of the CSM, occurring at about 15 LM descent stage orbits (16 CSM orbits) after staging. It should be emphasized that the relative motion of Figure 2 is only the theoretical motion of the LM descent stage, based on perfect execution of all the rendezvous maneuvers prior to staging, and assuming no velocity is imparted to the CSM during docking and during the LM jettison separation maneuver. If these dispersions and velocity increments are considered, a recontact is possible. For example, a velocity uncertainty at staging of one foot per second will produce an uncertainty of three feet per second in the rearward secular drift rate of the LM descent stage. This rate, propagated over 30 hours, means an uncertainty of 53.3 nautical miles in the closest miss distance. This is more than the theoretical miss distance of 30 nautical miles.

The relative motion plots of Figures 1 and 2 show that the LM descent stage crosses the CSM altitude about once every 200 nautical miles. Thus, if the uncertainty in the closest miss distance is 100 nautical miles or more (corresponding to a total velocity uncertainty of 2 feet per second or more), the phasing between the CSM and LM descent stage becomes completely random, and the CSM could be hit regardless of its initial phasing with the LM descent stage. Since the LM descent stage crosses the CSM altitude about every 200 nautical miles, the odds are about a thousand to one against passing within 600 feet of the CSM for the case of random phasing. However, a minimum miss distance of 100 nautical miles or less is certain.

Figure 3 shows the 60-nautical mile circular CSM orbit and the orbit of the LM descent stage, which has an apocynthion of 194.4 nautical miles and a pericynthion of 9.8 nautical miles. The orbits cross in two places. Regardless of the phasing of the LM descent stage, recontact will occur at one of these two points if it actually occurs. Consequently, these are the critical places where the astronauts should be looking for the LM descent stage. The times at which the CSM passes through these points can be accurately calculated, because they do not depend on the phasing of the LM descent stage in its orbit. For the three closest passes (labeled "Pass I", "Pass II" and "Pass III" in Figure 2), the g.e.t. are 134:06:20 (Pass I), 134:37:35 (Pass II), and 136:36:30

(Pass III). The uncertainty in these times is the "window", or period when a collision is possible. This window represents the uncertainty in the time at which the CSM crosses the LM descent stage orbit. For every uncertainty in the CSM velocity of one foot per second, the window is about one minute on either side of the nominal time.

During the window computed for Pass I, the astronauts should be looking for the LM descent stage along a line pitched 78 degrees up from the posigrade horizontal, because if the LM descent stage is on a collision path, it will be approaching from that direction. This angle can be accurately computed, and is not sensitive to minor velocity dispersions. In fact, the astronauts could use it to determine which way to maneuver, if necessary. This determination might otherwise be difficult, because the LM descent stage cuts through the CSM orbit with a relative velocity of about 460 feet per second. On the next two passes, Pass II and Pass III, the LM descent stage would be approaching from below. During the windows for these two passes, the astronauts should be looking along a line pitched down 78 degrees from the posigrade horizontal.

There is a possibility of establishing a minimum miss distance between the LM descent stage and CSM by staging the LM descent stage out-of-plane. Since the staging maneuver occurs near pericynthion, an out-of-plane maneuver tilts the plane of the LM descent stage so that its maximum out-of-plane separation occurs when it is near the CSM altitude. This possibility was evaluated by analyzing a staging maneuver where the LM descent stage is given a velocity increment of two feet per second at a yaw angle of 45 degrees from the horizontal posigrade direction (this angle is zero for the current maneuver). The resultant relative motion, illustrated in Figure 4, is a spiral around the track of the CSM. The minimum miss distance on an upward pass is about 1500 feet, and about 1000 feet on a downward pass. If the orbit were not seriously disturbed, these same minimum miss distances could be guaranteed thirty hours later, when the CSM laps the descent stage. However, the LM descent stage orbit is susceptible to disturbance by mass concentrations, particularly at pericynthion, which is only 9.8 nautical miles. A lateral disturbance at pericynthion could conceivably cancel the original maneuver.

2.1.2 Recontact Problems Between the LM Descent Stage and LM Ascent Stage after Nominal Staging

Figure 5 illustrates the motion of the LM descent stage and the LM ascent stage after the staging and insertion maneuvers, respectively. Both plots are given with respect to the orbit of the LM just prior to staging.

Under the current procedures, the LM staging is executed by orienting the +X axis of the LM along the retrograde horizontal, firing the -X RCS jets to acquire a velocity of two feet per second posigrade, staging the descent stage, and firing the +X RCS jets to null the original maneuver. This leaves the LM ascent stage in the original orbit, and imparts a velocity increment of two feet per second posigrade to the LM descent stage. In the relative motion plot of Figure 5, the LM descent stage begins its relative trajectory, and the LM ascent stage remains at the origin. Ten minutes later, when the LM descent stage is above and ahead of the LM ascent stage, the ascent stage executes the insertion maneuver with the APS engine. This maneuver is pitched 27.4 degrees up from the retrograde horizontal, with a velocity increment of 213.3 feet per second. At this time, the ascent stage leaves the origin and follows the trajectory shown for the LM ascent stage in Figure 5.

Since the LM descent stage is above and ahead of the ascent stage at the time of insertion, there is no possibility of recontact with the current procedures. However, Figure 5 does illustrate a limitation on the time at which staging may occur. The LM descent stage requires 65 minutes to reach the point where the trajectories cross, and the LM ascent stage requires 2 minutes to reach the same point. Consequently, if staging is done 63 minutes prior to insertion (as opposed to the currently planned 10 minutes), the ascent stage will recontact the descent stage 2 minutes after insertion. For this reason, early staging should be avoided.

2.2 Relative Motion for the Nominal APS Burn to Depletion

The nominal procedure for the LM jettison and the APS burn to depletion begins thirty minutes prior to the APS burn, when the CSM maneuvers to put the LM ascent stage into the inertial attitude for the APS burn, performs final LM jettison and uses the -X SM RCS jets to acquire a net separation velocity of one foot per second. As soon as the separation is complete, the CSM nulls the separation velocity and comes to a station-keeping position downrange of the LM. At 22 minutes prior to the APS burn, the CSM orients the +X axis along a line 60 degrees below the retrograde horizontal, yaws 45 degrees south, and executes a -X SM RCS burn for a velocity increment of 3 feet per second. The relative motion for this evasive maneuver is shown in Figure 6. At the time of the APS burn, which is targeted along the horizontal posigrade, the CSM is 3300 feet above the LM ascent stage, 2300 feet behind it, and 2100 feet out-of-plane.

3.0 RECONTACT PROBLEMS FOR LUNAR ORBIT ABORTS

The lunar orbit abort procedures which were studied included aborts from the lunar rendezvous and situations requiring an early TEI. The lunar rendezvous aborts were (1) a direct return from an overburn of the DOI maneuver, (2) a PDI abort, which is a five-impulse abort similar to the nominal rendezvous, and (3) an abort due to a partial phasing maneuver. Each of these problems is discussed separately below.

3.1 Aborts Due to a DOI Overburn

If an overburn occurs for the DOI maneuver, the current procedure calls for an RCS trim maneuver using the LM -X jets if the overburn is 12 feet per second or less. If the overburn is greater than 12 feet per second, the LM would pitch approximately 180 degrees to orient the LM +X axis along the line-of-sight to the CSM. In this attitude, the LM stages off the descent stage and executes a +X LM RCS interconnect burn to cancel the DOI velocity increment and establish a closing rate toward the CSM of eight times the range (closing rate in feet per second, range in nautical miles). This establishes a fixed return time of 12.5 minutes.

The only conceivable recontact problem associated with this type of abort is the possibility that the LM descent stage would lap the CSM because of the difference in periods, and once more come into its immediate vicinity. However, this problem does not exist, because the minimum overburn for which the abort is executed (12 feet per second) is sufficient to insure that the LM descent stage will crash into the lunar surface. Figure 7 illustrates the motion of the LM descent stage from DOI to lunar contact for this case.

3.2 PDI Aborts

If the DOI maneuver is underburned by 3 feet per second or less, the current procedure is to trim the residuals with the +X LM RCS thrusters. If the underburn is more than 3 feet per second, a PDI abort is initiated.

This abort is a five-impulse maneuver, similar to the nominal rendezvous, but requiring one less revolution to complete. The nominal profile for the PDI abort is shown in Figure 8.

The recontact problems for a PDI abort depend upon where the LM staging occurs. There are five discrete cases, corresponding to LM staging during each of the five coasting phases of the abort profile. Each case is discussed separately below.

3.2.1 PDI Abort; LM Staging Between DOI and PDI

This abort could be precipitated by a failure of the descent stage engine during DOI that would necessitate the use of the ascent stage engine for the remaining maneuvers of the abort. In any case, the procedure for this case is to keep the LM descent stage until just prior to the PDI maneuver, and then, in the PDI attitude (+X LM axis posigrade), fire the -X RCS jets to acquire 2 feet per second retrograde, stage, fire the +X jets to null the maneuver, then execute the PDI maneuver with the main ascent engine.

This procedure essentially leaves the LM descent stage in the orbit established by the DOI maneuver. The LM descent stage moves below and ahead of the CSM, and, as shown in Figure 9, there is no recontact problem for the first few orbits after staging. However, the period of the LM descent stage in less than that of the CSM by 275 seconds, and after 51 hours, the LM descent stage completely laps the CSM and once again returns to its immediate vicinity. If the CSM has not executed the TEI maneuver by this time, a recontact problem could exist. The problem is not recontact between the LM descent stage and an orbiting CSM, because the staging maneuver reduces the apocynthion of the LM descent stage to 58.5 nautical miles. Consequently, the CSM is always at least 9000 feet above the LM descent stage. However, if TEI is executed just after the LM descent stage laps the CSM, the LM descent stage could be below and ahead of the CSM. The TEI maneuver could be targeted in this direction.

3.2.2 PDI Abort: LM Staging Between PDI and CSI

If the descent engine is used to execute the PDI maneuver, the next option is to stage between PDI and CSI. The procedure for this option is to orient to the CSI attitude (+X LM axis oriented along the posigrade horizontal) and execute an RCS staging immediately prior to the CSI maneuver.

The motion of the LM descent stage for the first few orbits after staging at CSI is shown in Figure 10 for the case of a zero staging velocity increment. Actually, the LM descent stage will receive a slight retrograde velocity increment at staging due to RCS plume impingement, but the motion of Figure 10 serves to illustrate the problem. The LM descent stage loops around the CSM, drifting slightly to the rear. Obviously, there is a possible recontact problem, but it is not obvious just how recontact could occur.

Figure 11 is a recontact hodograph showing all of the possible maneuvers that could be executed at CSI that would result in recontact with the CSM. The ordinate and abscissa of the hodograph are vertical velocity increment and downrange velocity increment, so that each point represents some maneuver that could be imparted to the LM descent stage during the staging at CSI. The curves plotted on the hodograph are the locus of maneuvers that produce recontact with the CSM. Several branches of the curve are plotted in Figure 11. Branch I is the locus of all maneuvers which produce recontact within one orbit after staging. Similarly, Branch II is the locus of maneuvers for recontact during the second orbit after staging, etc.

The hodograph of Figure 11 is important primarily because it gives a complete solution, showing all of the possible maneuvers that can produce recontact. From this plot, the smallest maneuver that will produce recontact is easily identified. This maneuver lies on Branch III, and consists of imparting a retrograde velocity increment to the LM descent stage of 4.6 feet per second.

The corresponding recontact trajectory is shown in Figure 12. Since the maneuver was on Branch III of the hodograph, recontact occurs during the third orbit after staging. This type of recontact is definitely possible, because even the nominal procedure will impart a retrograde velocity increment to the LM descent stage at staging. This increment, caused by RCS plume inpingement, might be as much as 2 feet per second. The remaining velocity increment is within the cumulative uncertainty of the state vector at CSI.

The simplest way to avoid this problem is to execute the CSI maneuver with the descent engine, delaying the LM staging. If this is not possible, then the LM should be staged out-of-plane. This tilts the orbital plane of the LM descent stage so that it returns to the original plane only at apocynthion and pericynthion. Whenever the LM is at the CSM altitude, it would have a definite out-of-plane displacement.

3.2.3 PDI Abort; LM Staging Between CSI and CDH

If the descent engine is used to execute the CSI maneuver, the next opportunity for staging would be just prior to the CDH maneuver. This staging would require orienting the LM to the CDH attitude (+X LM axis oriented along the retrograde horizontal), and executing an RCS staging just before the CDH maneuver. The relative motion of the descent stage for this type of staging is shown in Figure 13 for about one orbit after staging. There is no recontact problem on the first few orbits, but a rearward secular drift rate of 285 nautical miles per orbit is evident. Consequently, the CSM will lap the LM descent stage after about 45 hours. This problem is similar to the one discussed for the nominal rendezvous, except that the time required for lapping is greater. Therefore, the LM descent stage might not fully lap the CSM. However, it could be in front of the CSM at the time of TEI.

3.2.4 PDI Abort; LM Staging Between CDH and TPI

If the LM is to be staged between CDH and TPI, the current procedure is to execute an RCS staging at the start of the TPI maneuver. This maneuver leaves the LM descent stage in a 45-nautical-mile circular orbit below the CSM. There are no recontact problems associated with this type of staging, because the LM descent stage remains below the CSM. In this orbit, the descent stage will lap the CSM after about 90 hours. However, TEI would be executed prior to this time.

3.2.5 PDI Abort; LM Staging Between TPI and TPF

If the LM descent stage is retained through the TPI maneuver, the next opportunity for staging is just before the first braking gate, when the CSM is 6000 feet from the CSM. The current procedure for this maneuver is to orient the +X axis of the LM along the line-of-sight to the CSM, yaw 45 degrees south out of plane, fire the -X LM RCS thrusters to acquire 3 feet per second, stage, and fire the +X LM RCS thrusters to acquire 3 feet per second, nulling the original maneuver.

As long as the LM is approaching the CSM in plane, this procedure will guarantee an out-of-plane miss distance of about 350 feet between the LM descent stage and the CSM. However, if the motion of the LM is not directly towards the CSM at TPF, a recontact may occur. Specifically, if the CSM is about 350 feet north of the relative velocity vector of the LM at TPF, the current procedure would result in recontact between the LM descent stage and CSM. For this reason, staging near TPF is not recommended. If the LM is unstaged at TPF, it should execute braking, dock with the CSM, and perform a docked staging.

3.3 Aborts Due to a Partial Phasing Maneuver

If the phasing maneuver during the nominal rendezvous is underburned by 3 feet per second or less, or overburned by 12 feet per second or less, the residuals will be trimmed by using the LM RCS thrusters. For an overburn of more than 12 feet per second, no trim would be attempted. Instead, the insertion maneuver would be retargeted. If there is an underburn of more than 3 feet per second, but less than 25 feet per second, the LM would stage and complete the phasing maneuver with the +X LM RCS thrusters. If the underburn is greater than 25 feet per second, the LM would stage and complete the maneuver with the APS engine. If the APS also fails, the LM would maneuver only if the partial phasing ΔV is less than 40 feet per second (out of a total phasing burn of 193.5 feet per second). In this case, the LM +X RCS thrusters would be used to boost the total phasing ΔV to 40 feet per second. Thereafter, the LM would await a CSM rescue.

The only recontact problem associated with these procedures lies in the fact that the LM descent stage can be left behind with a partial phasing ΔV. Prior to phasing, the LM is moving ahead of the CSM. The phasing maneuver puts it above and behind the CSM. Therefore, there is some partial phasing maneuver that would put the LM descent stage directly back towards the CSM. If the descent engine failed at this particular time during the phasing burn, and the LM staged and completed the phasing maneuver with the APS, the LM would be left on a collision course with the CSM.

This problem was investigated by plotting the recontact hodograph shown in Figure 14. The axes of this graph are the downrange velocity increment at phasing and the vertical velocity increment at phasing, so that each point on the graph represents some possible maneuver at phasing. The recontact lines that are plotted on the hodograph represent the locus of maneuvers that result in recontact with the CSM. There are several branches to the recontact curve. Branch I represents recontact within one orbit after phasing, Branch II is the locus of maneuvers for recontact during the second orbit after phasing, and so on. The maneuver line that is plotted on the hodograph represents the locus of all possible partial phasing maneuvers. All of the recontact curves intersect the maneuver line in a narrow region from 81 to 92.5 feet per second. Consequently, if there is a partial phasing in this range, there will be a possible recontact problem between the LM descent stage and CSM. The relative motion of the LM ascent and LM descent stage for a partial phasing of 92.5 feet per second is shown in Figure 15. As indicated, the LM descent stage recontacts the CSM in less than one orbit. Similar plots could be drawn for other partial phasing burns between 81 and 92.5 feet per second, showing recontact during the second orbit, third orbit, etc.

The critical range of partial phasing velocities can be avoided by using the -X LM RCS thrusters prior to staging. If a partial phasing of between 81 and 92.5 feet per second occurred, the -X thrusters could be used to reduce the phasing velocity to less than 81 feet per second. The LM could then be safely staged, and the maneuver completed with the APS engine.

3.4 LM Jettison Prior to a Contingency TEI

If a contingency TEI situation occurs before the nominal LM jettison, the jettison would be executed at least one hour prior to TEI. The procedure is to orient the CSM +X axis along the posigrade horizontal, jettison the LM, and fire the -X SM RCS thrusters to acquire a total velocity increment of one foot per second (including the velocity due to the jettison impulse). The relative motion for this case is shown in Figure 16. Since the jettison occurs at least one hour prior to TEI, the LM will be above and behind the CSM at TEI. For the nominal TEI, the same procedure is followed, except that it is executed about 1 3/4 orbits prior to TEI. The same relative motion applies, except that the LM is further behind the CSM at TEI.

4.0 RECONTACT PROBLEMS FOR LUNAR ORBIT ALTERNATE MISSIONS

There are four alternate missions that could be flown while in lunar orbit. First, there is a DPS-only rendezvous, in which the LM descent stage is retained throughout the nominal rendezvous, and the LM returns unstaged to the CSM. Second, there is the alternate mission precipitated by an inoperative APS engine. Third is the nominal rendezvous executed entirely with the APS engine, and fourth is the mini-maxi football, using the LM RCS jets.

4.1 DPS-Only Rendezvous

If the DPS engine is used for all the nominal rendezvous maneuvers (except TPF), so that the LM descent stage is retained through the entire rendezvous sequence, there are three possible cases to consider. First, if the LM descent stage had been retained during the rendezvous because of a problem with the consumables on the LM ascent stage, the DPS-only rendezvous would be followed by a docked staging and the nominal APS burn-to-depletion. The procedure for these maneuvers is to maneuver the CSM/LM to orient the +X axis of the LM along the retrograde horizontal, perform a docked staging, and fire the +X LM RCS thrusters for a total velocity increment of 3 feet per second. This separation is performed three hours prior to the APS burn-to-depletion. At thirty minutes prior to the APS burn, the CSM would orient to the inertial attitude for the long APS burn, perform final LM jettison, and come to a station-keeping position downrange of the LM. Twenty-two minutes before the APS burn, the CSM would pitch nose down 60 degrees from the horizontal retrograde, yaw the nose 45 degrees south, and perform an evasive maneuver of 3 feet per second with the -X SM RCS thrusters. The APS burn-to-depletion would be directed along the horizontal posigrade.

The relative motion for these maneuvers is shown in Figures 17 and 6. Figure 17 shows the motion of the LM descent stage relative to the CSM, including the effect of the CSM evasive maneuver. Note that the evasive maneuver has the effect of slowing the rearward drift of the LM descent stage. However, the drift is not reversed, so there is no recontact problem. Figure 6 shows the motion of the CSM with respect to the LM ascent stage for the CSM evasive maneuver. Twenty-two minutes after this maneuver, at the time of the APS burn, the CSM is 3300 feet above the LM ascent stage, 2300 feet behind it, and 2100 feet out-of-plane.

If the DPS-only rendezvous had been caused by a failure to stage or some other reason that prevents further APS engine burns, the LM would simply be jettisoned after the rendezvous. The procedure is to orient the CSM +X axis along the posigrade horizontal, perform LM jettison, and fire the -X SM RCS jets to acquire a velocity increment of 3 feet per second. The relative motion of the LM after this maneuver is shown in Figure 18.

A third reason for a DPS-only rendezvous is to retain the LM descent stage for a DPS TEI. In this case, LM staging and jettison are executed during TEC rather than in lunar orbit, using the same procedures as for the lunar flyby.

4.2 Inoperative APS Engine

If the APS engine becomes inoperative at any time after the LM-active rendezvous, the LM ascent stage would simply be jettisoned. The procedure is to orient the +X CSM axis along the posigrade horizontal, jettison the LM and fire the -X SM RCS jets to acquire 3 feet per second. The relative motion for this case is the same as that shown in Figure 18.

4.3 APS-Only Lunar Rendezvous

If all of the nominal rendezvous maneuvers are performed with the APS engine, the maneuver sequence and relative motion is the same as for the nominal rendezvous, except that LM staging would be performed during the CSM mini-football, 15 minutes prior to the DOI maneuver. The procedure for staging is to orient the +X axis of the LM along the posigrade horizontal, acquire a retrograde velocity increment of 3 feet per second with the -X LM RCS jets, stage, and fire the +X LM RCS jets to null the original maneuver. This procedure has the effect of imparting a retrograde velocity of 3 feet per second to the LM descent stage, and leaves the LM ascent stage in its original orbit.

Figure 19 shows the relative motion of the CSM, LM descent stage, and LM ascent stage with respect to the CSM/LM orbit just before the rendezvous. The first maneuver after undocking is a maneuver of 2.5 feet per second down, performed by the CSM. This puts the CSM into a mini-football ahead of the LM, as indicated in Figure 19. The staging maneuver is next, imparting a retrograde velocity of 3 feet per second to the LM descent stage, and leaving the LM ascent stage in the original orbit. At this juncture, the LM descent stage leaves the origin of Figure 19, and pursues the indicated trajectory. Fifteen minutes later, the LM ascent stage performs the DOI maneuver, which is a retrograde maneuver of 72 feet per second. At this time, the LM descent stage is 2000 feet below the LM ascent stage and 1600 feet behind it, so that the ascent stage passes 2000 feet above it after the DOI burn. It is important to stage no later than 15 minutes before DOI. Staging at any time after this will reduce this minimum miss distance.

4.4 Mini-Maxi Football Rendezvous

The mini-maxi football is an alternate lunar rendezvous executed with the LM RCS jets only. The sequence of events for this rendezvous is as follows:

- CSM/LM undocking
- CSM mini-football initiation, consisting of a +X SM RCS burn vertically down of 2.5 feet per second
- Coast one-half orbit, during which the LM is staged. The staging maneuver imparts a retrograde velocity to the LM descent stage of 3 feet per second, and imparts no net velocity to the LM ascent stage.

- LM ascent stage maxi-football initiation, consisting of a +X LM RCS burn of 80 feet per second, vertically up.
- Coast for three-fourths orbit.
- TPI maneuver, executed by the LM ascent stage, consisting of a +X LM RCS burn of 17 feet per second directed along a line pitched 15 degrees above the retrograde horizontal.
- Coast for 130 degrees of CSM travel.
- TPF maneuver, using the -X LM RCS as required.

Figure 20 shows the nominal relative motion for the rendezvous in CSM-centered coordinates, including the mini-football, the maxi-football, and the terminal phase. Figure 21 shows the relative motion of the CSM, LM descent stage and LM ascent stage in a coordinate system moving in the original CSM/LM orbit. In this system, the mini-football appears as a separate CSM maneuver. At the time of the mini-football initiation, the CSM leaves the origin of the coordinate system and enters the indicated CSM trajectory. At some time during the next half orbit, the LM descent stage is staged, and enters the relative trajectory indicated for LM descent stage in Figure 21. Since the LM descent stage trajectory does not intercept the CSM mini-football, the LM may be staged at any time during the mini-football without recontact between the LM descent stage and CSM.

At the end of the half-orbit mini-football coast, the LM initiates the maxi-football with a vertical maneuver of 80 feet per second, entering the LM ascent stage relative trajectory shown in Figure 21. After about one full orbit, the LM ascent stage returns to the CSM, intersecting the trajectory of the LM descent stage. However, by that time the LM descent stage has passed the intersection point, and is about 10 nautical miles downrange. Consequently, there are no recontact problems associated with the mini-maxi lunar football.

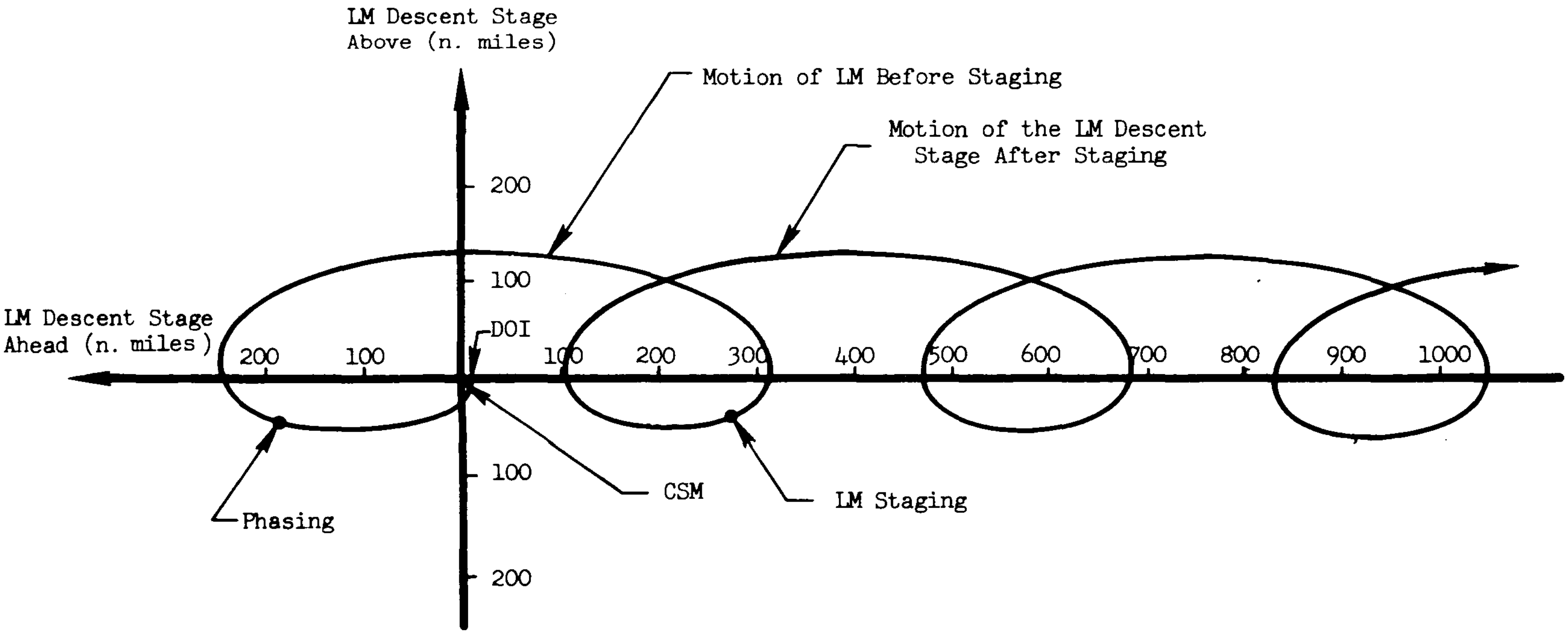


Figure 1. Motion of the LM Descent Stage Relative to the CSM for Two Orbits After Nominal Staging During the Lunar Rendezvous

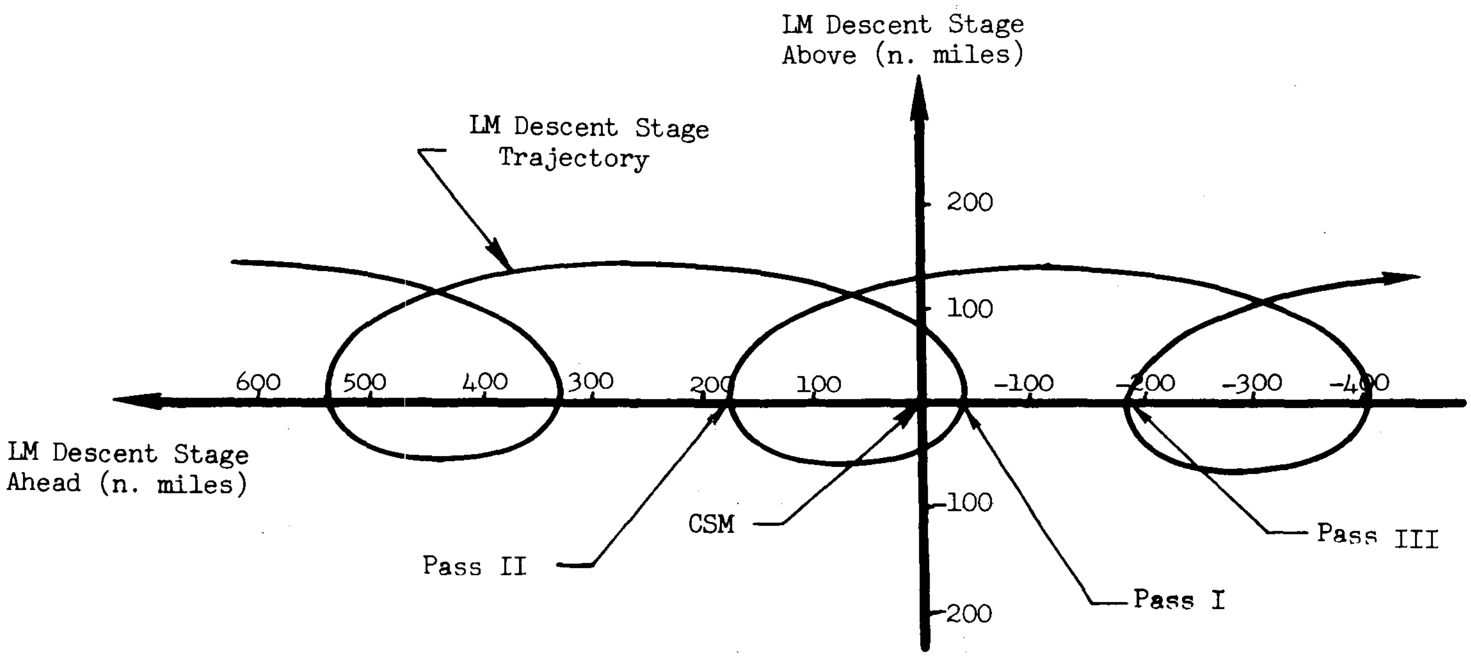


Figure 2. Motion of the LM Descent Stage Relative to the CSM Thirty Hours After Nominal Staging in Lunar Rendezvous

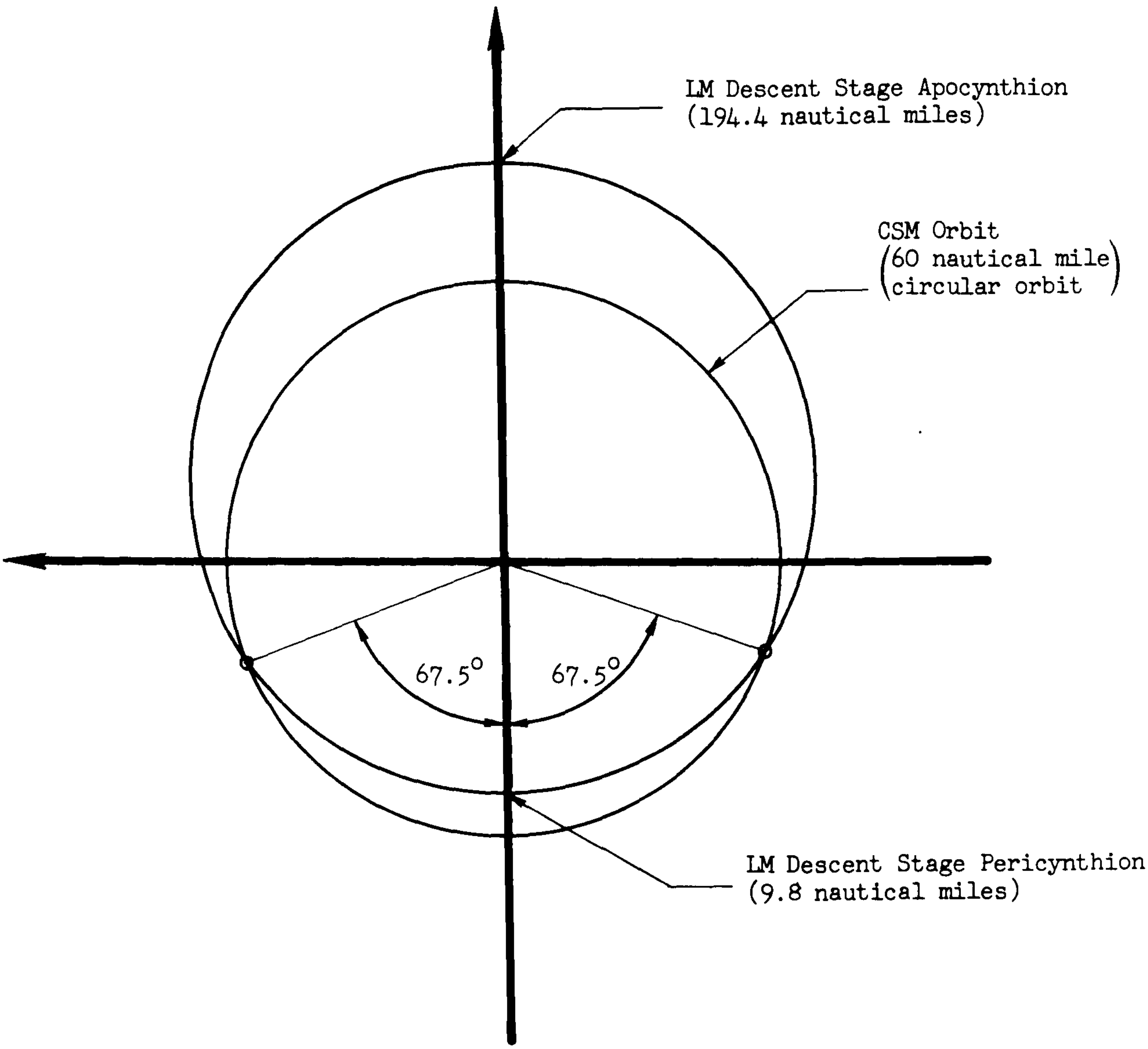


Figure 3. Orbits of the CSM and LM Descent Stage After a Nominal Lunar Rendezvous

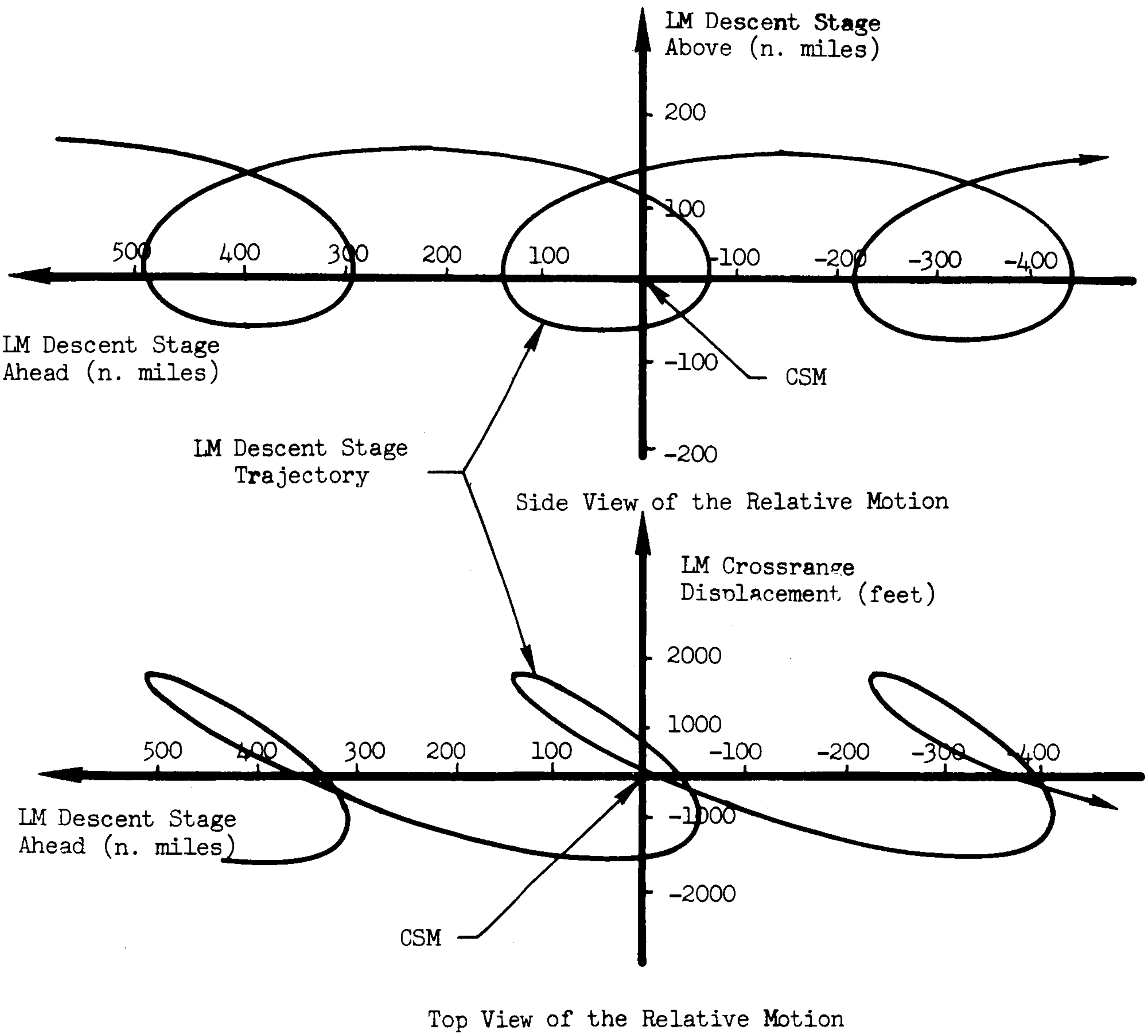


Figure 4. Motion of the LM Descent Stage Relative to the CSM for an Out-of-Plane Staging Maneuver Thirty Hours After Nominal Staging

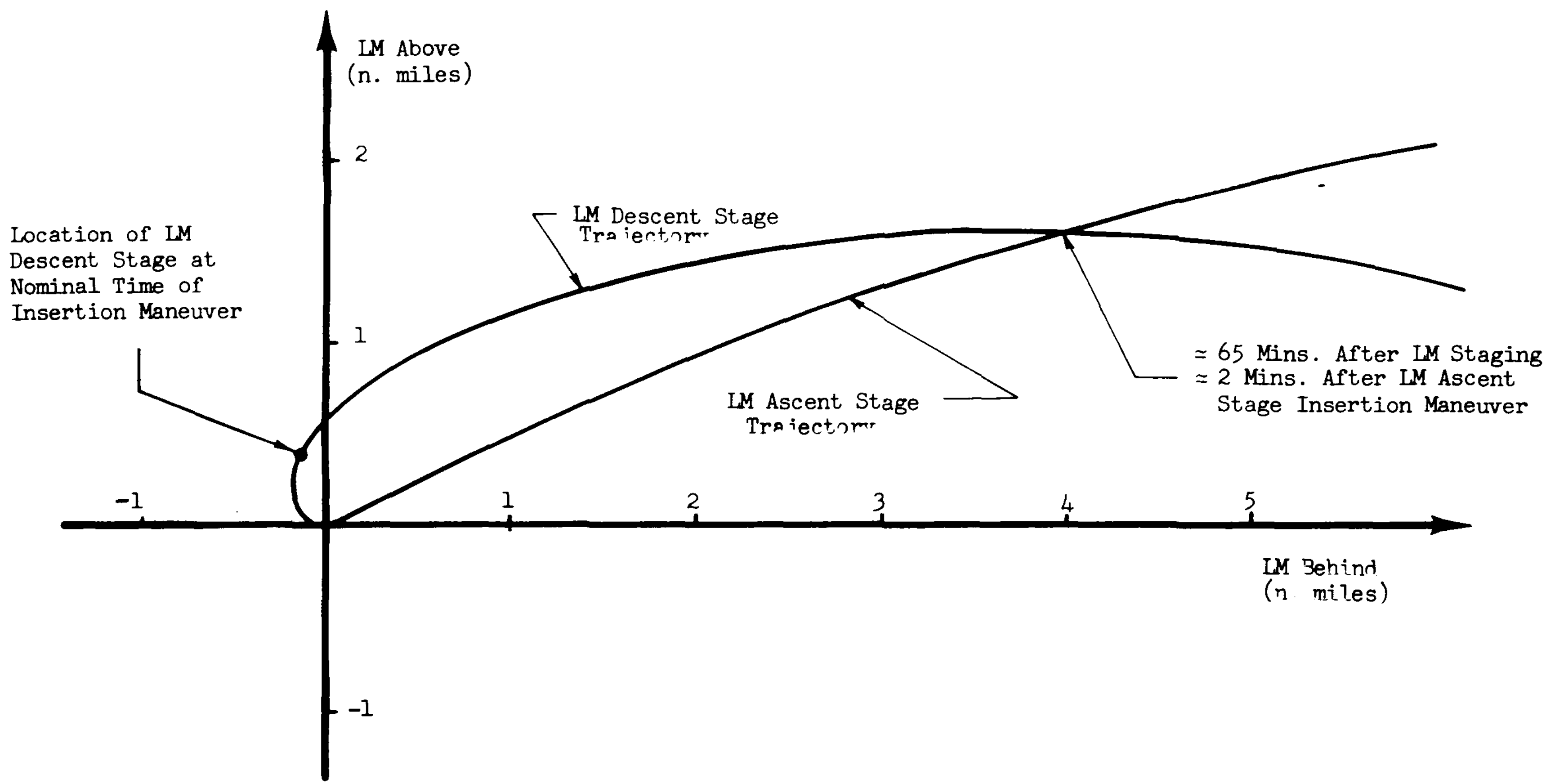


Figure 5. Motion of the LM Descent Stage and LM Ascent Stage Relative to the Original LM Orbit for the Nominal Staging Maneuver and Nominal Insertion Maneuver

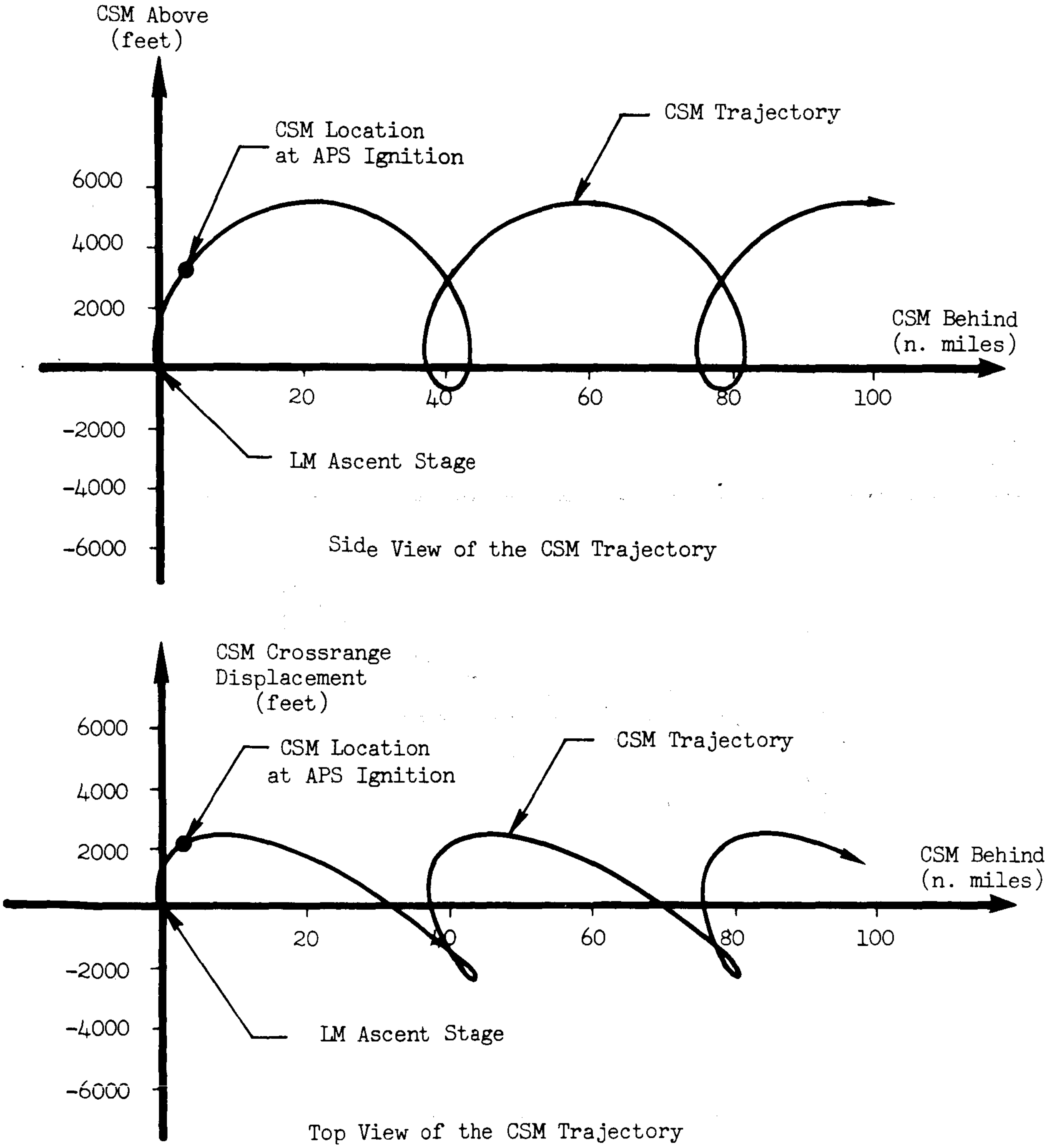


Figure 6. Motion of the CSM Relative to the LM Ascent Stage for the CSM Evasive Maneuver Performed Prior to the Unmanned APS Burn to Depletion

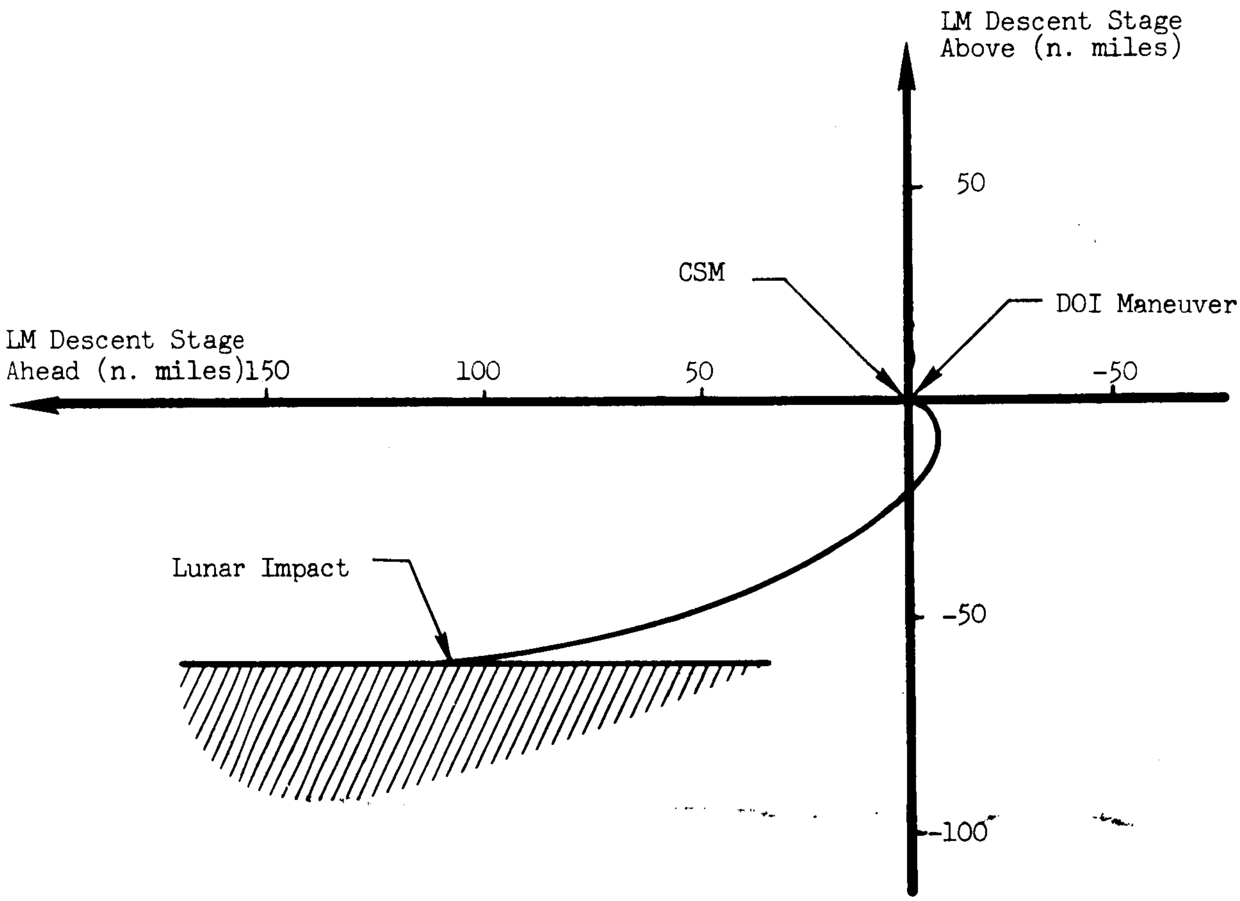


Figure 7. Motion of the LM Descent Stage Relative to the CSM for an Abort due to a DOI Overburn of 12 Feet Per Second

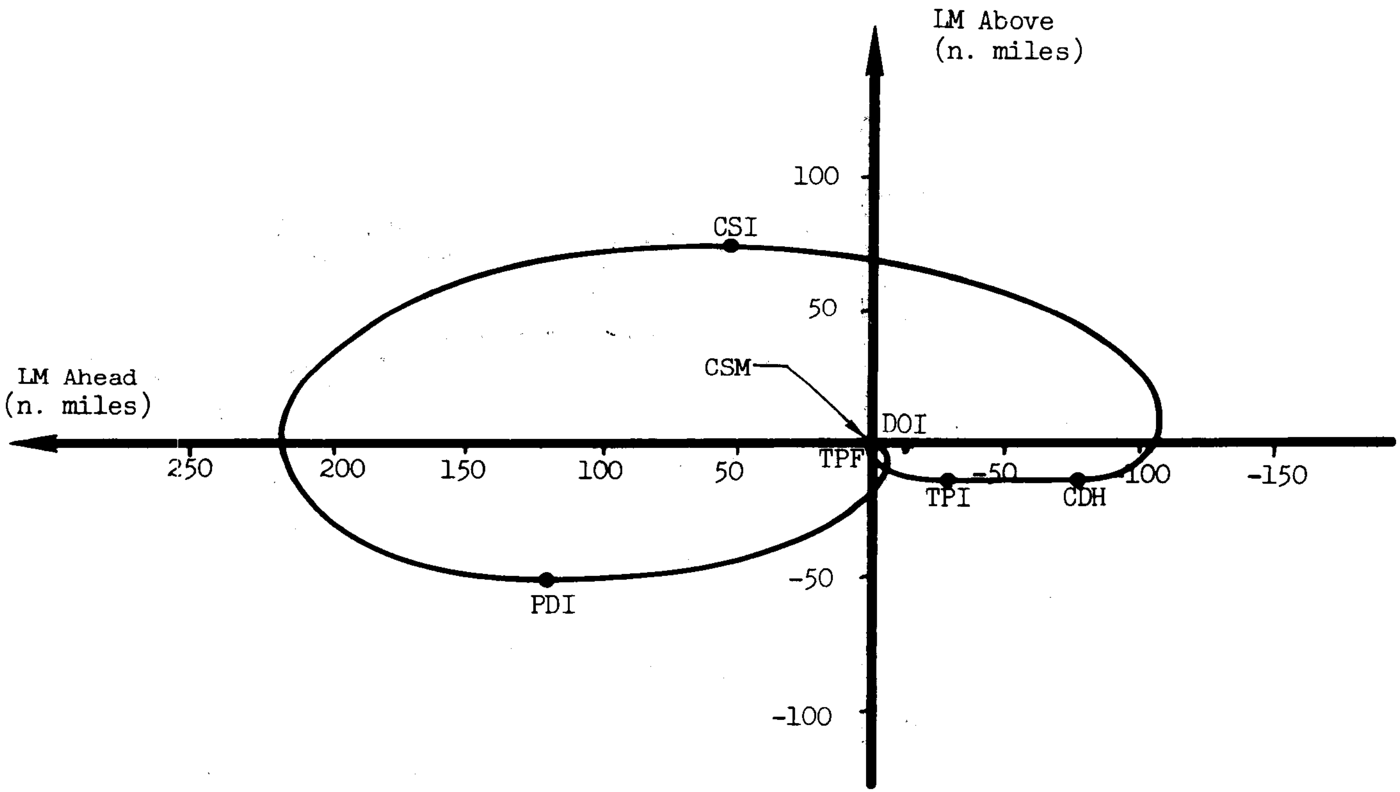


Figure 8. Motion of the LM Relative to the CSM; PDI Abort Profile

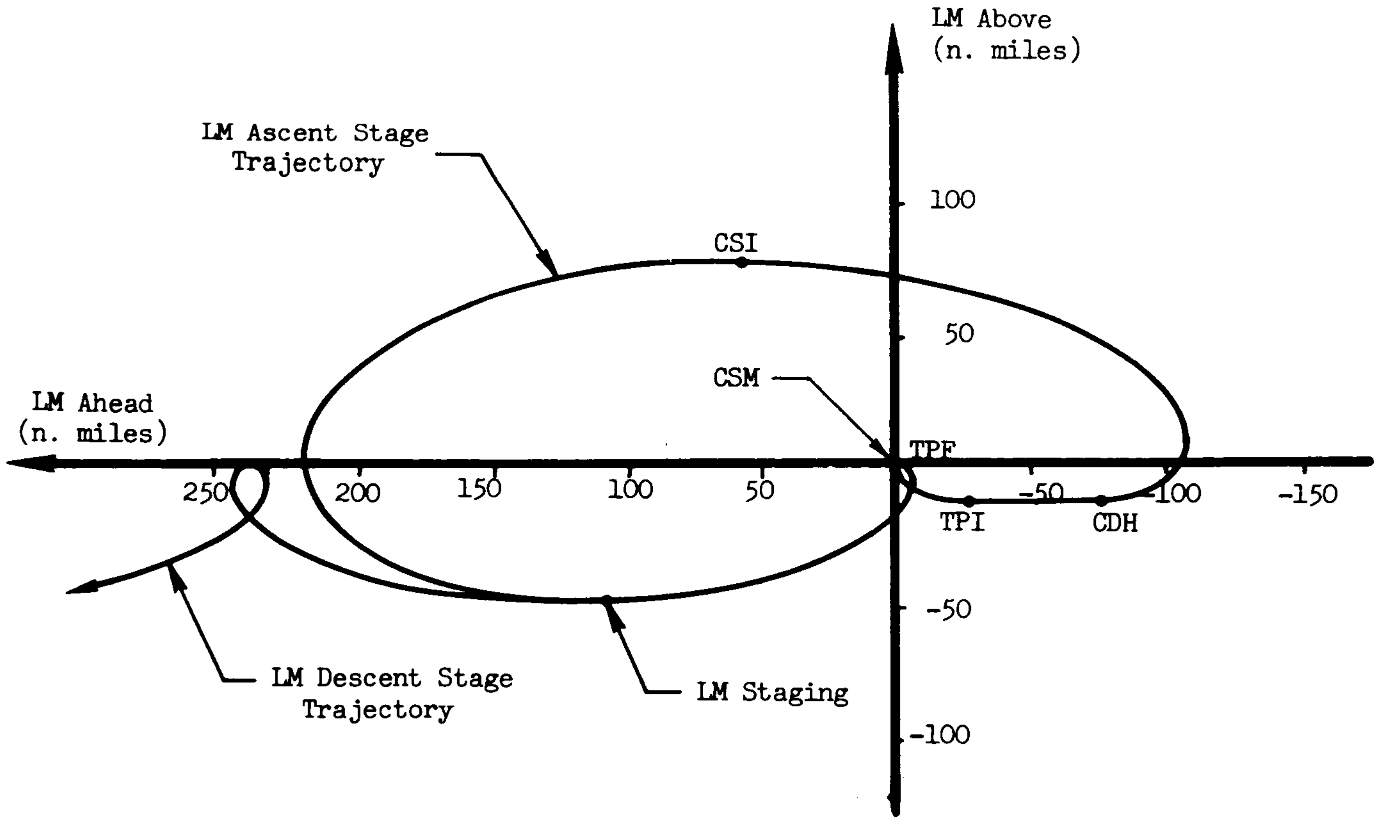


Figure 9. Motion of the LM Descent Stage and LM Ascent Stage Relative to the CSM for a PDI Abort with LM Staging Before PDI

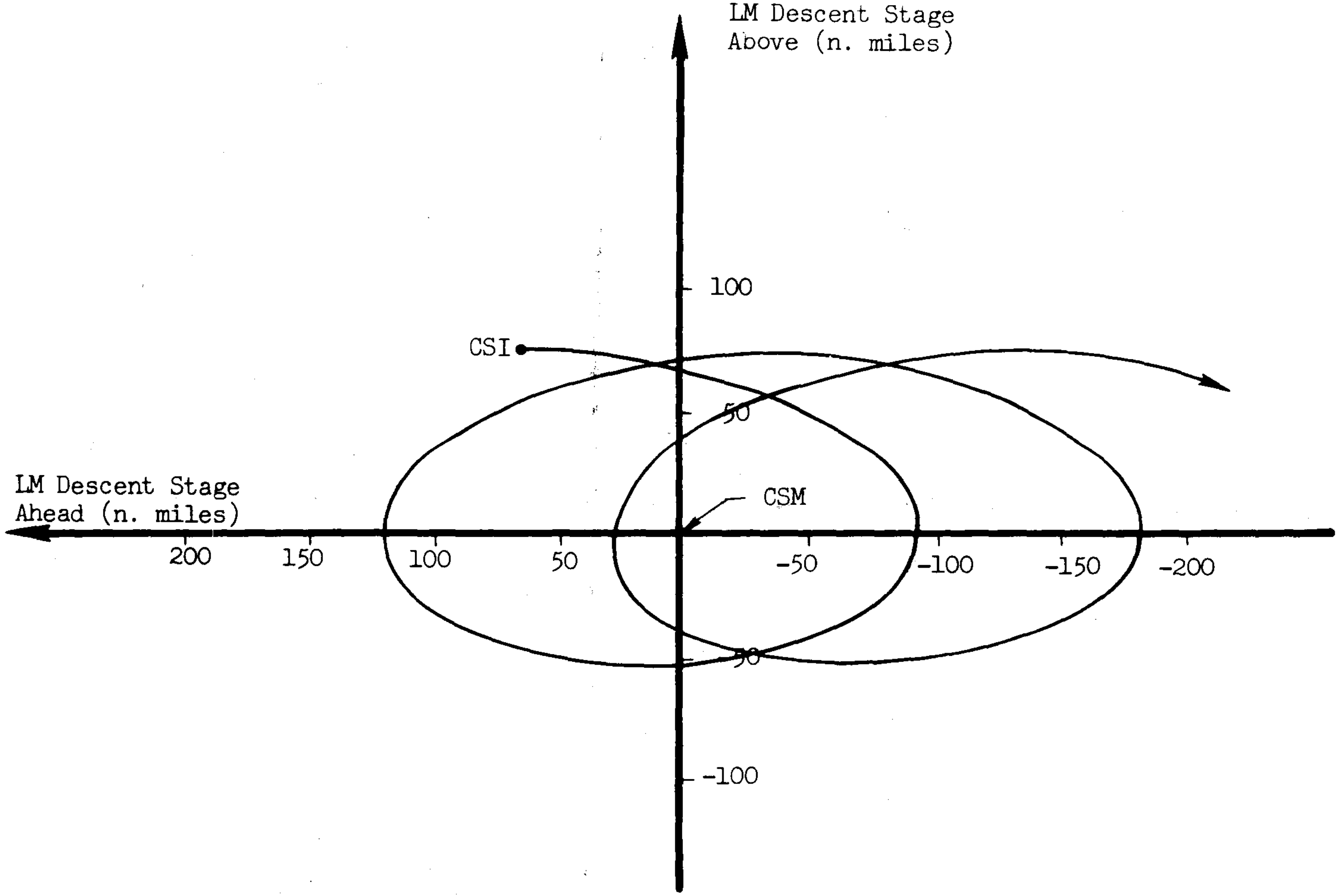


Figure 10. Motion of the LM Descent Stage Relative to the CSM After Staging at CSI During a PDI Abort; Zero Staging ΔV

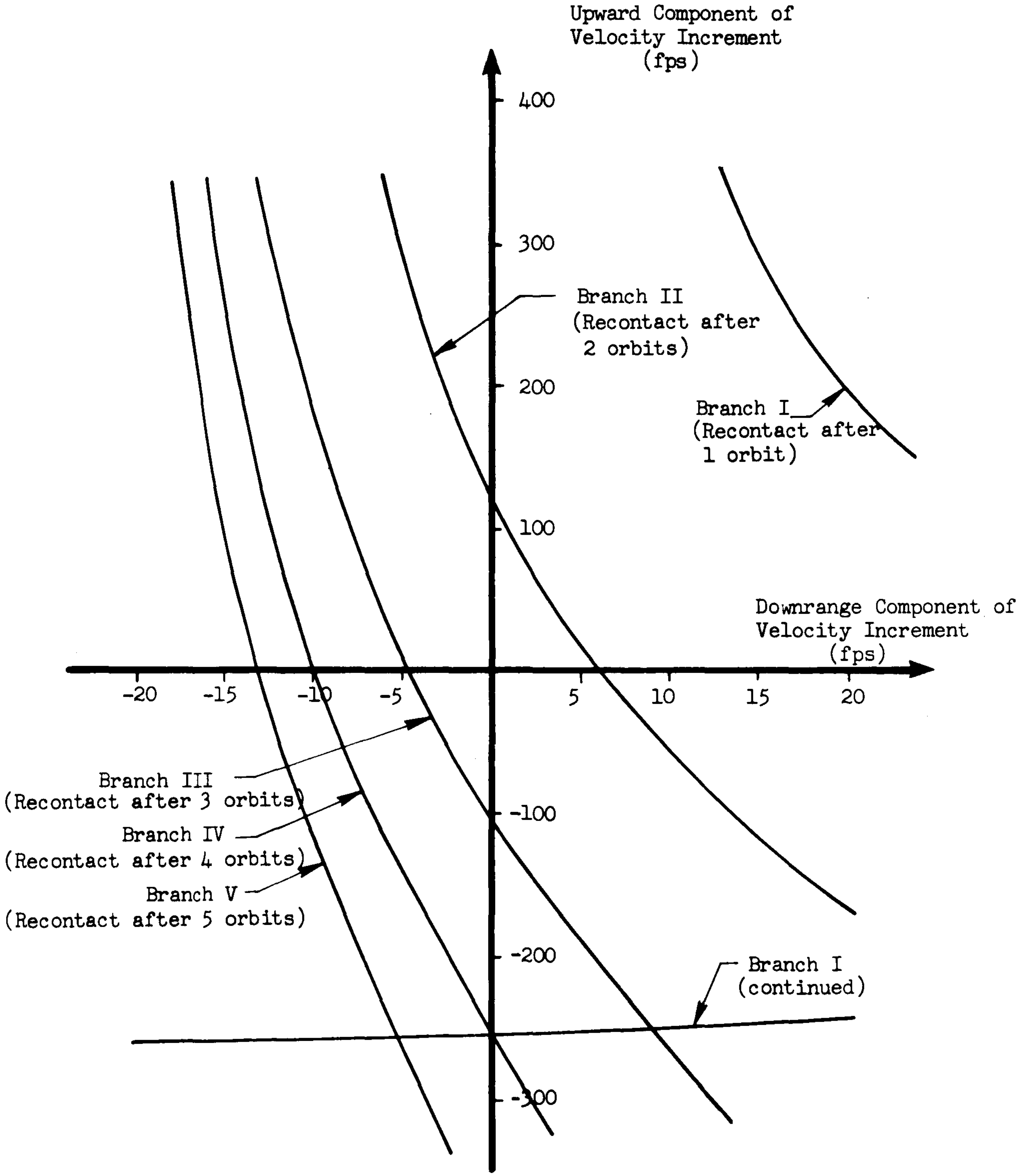


Figure 11. Recontact Hodograph for Staging at CSI During the PDI Abort

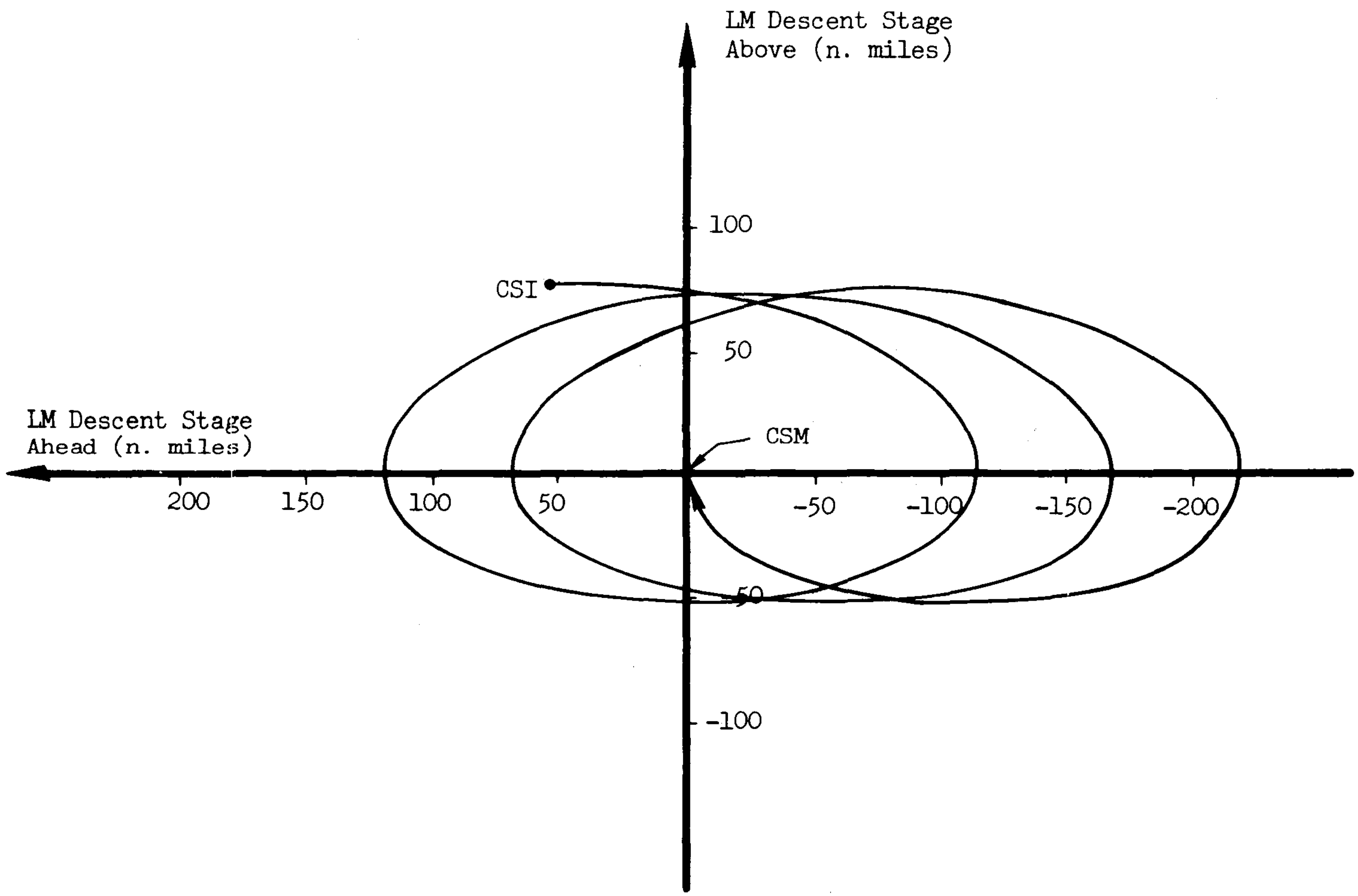


Figure 12. LM Descent Stage Recontact Trajectory for Staging at CSI During the PDI Abort, 4.6 fps Retrograde Staging ΔV

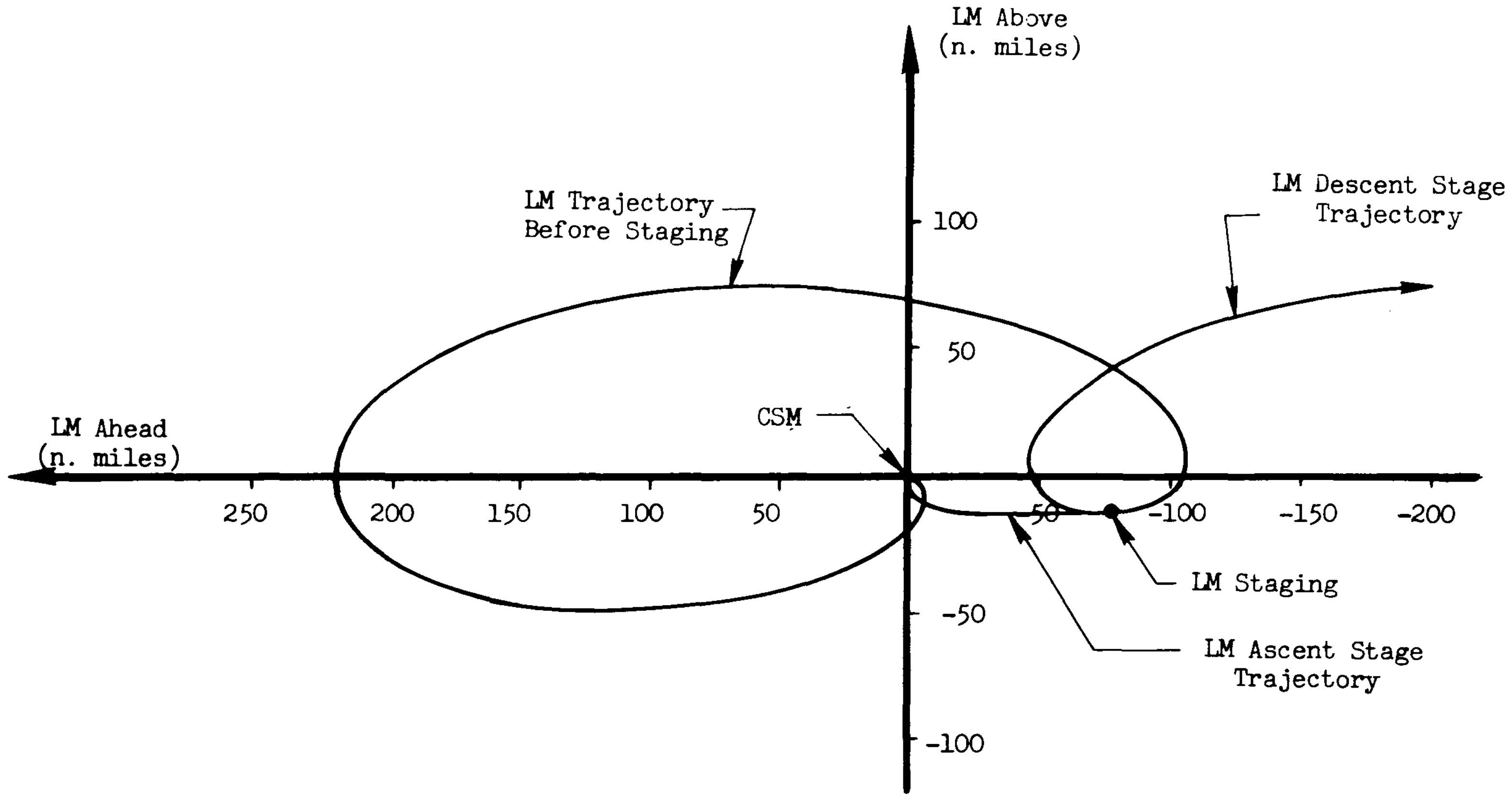


Figure 13. Motion of the LM Descent Stage and LM Ascent Stage Relative to the CSM for Staging at CDH During a PDI Abort

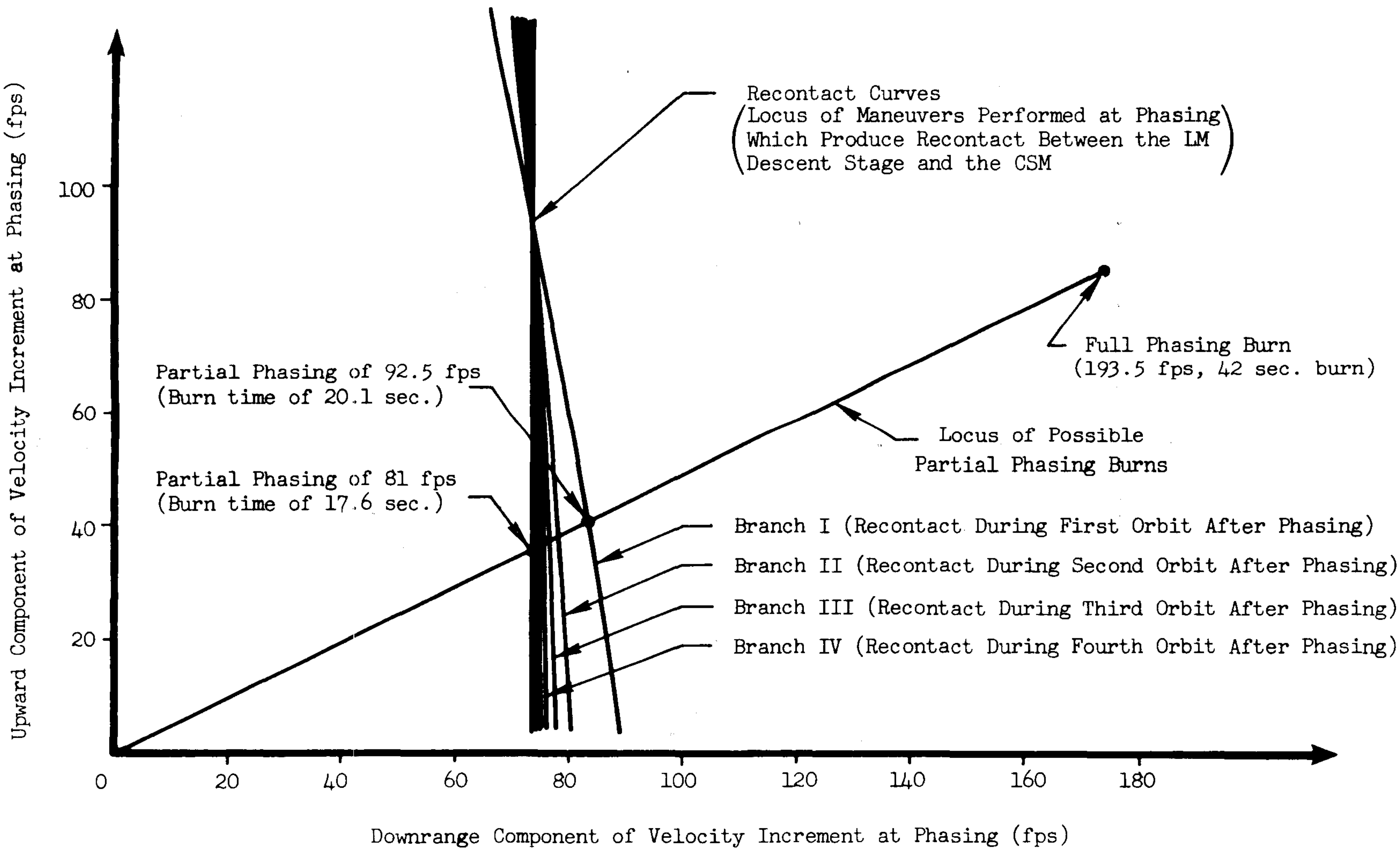


Figure 14. Recontact Hodograph for Maneuvers Performed at Nominal Phasing Showing Recontact for Certain Partial Phasing Maneuvers

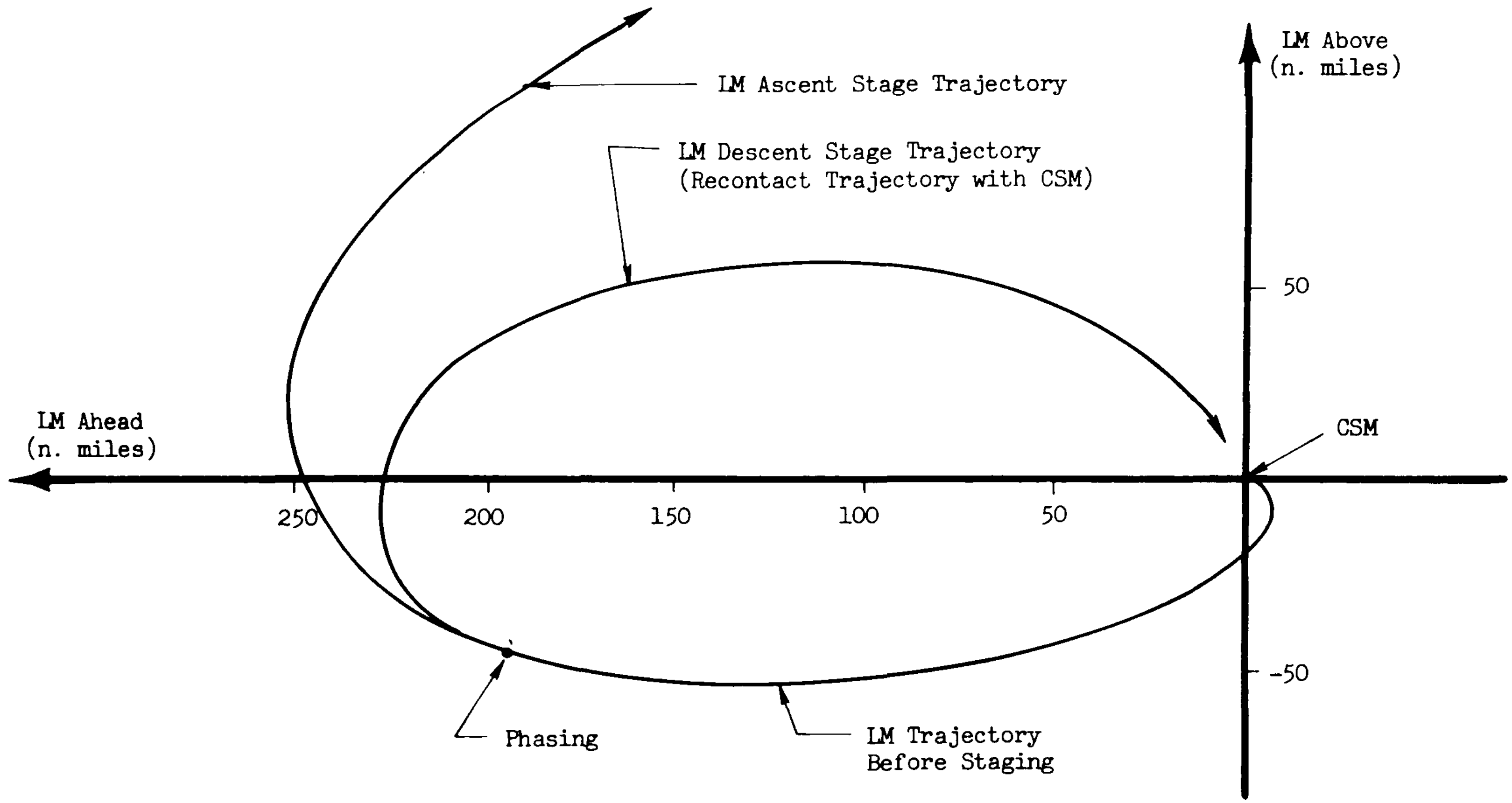


Figure 15. Motion of the LM Descent Stage and LM Ascent Stage for a Partial Phasing Burn of 92.5 fps, Followed by LM Staging and Completion of Phasing with APS

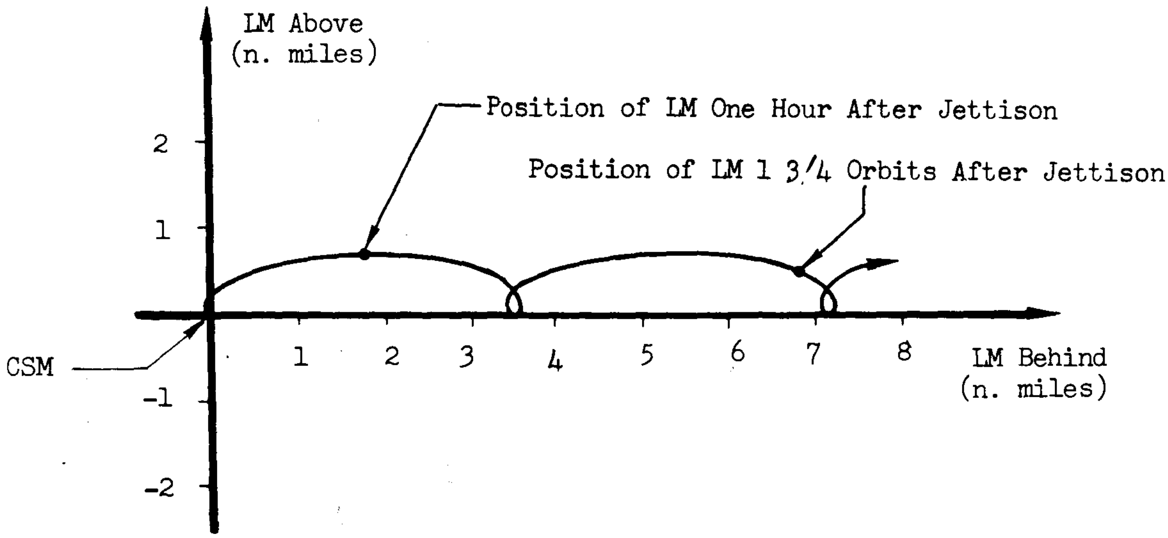


Figure 16. Motion of the LM Relative to the CSM for LM Jettison Prior to TEI

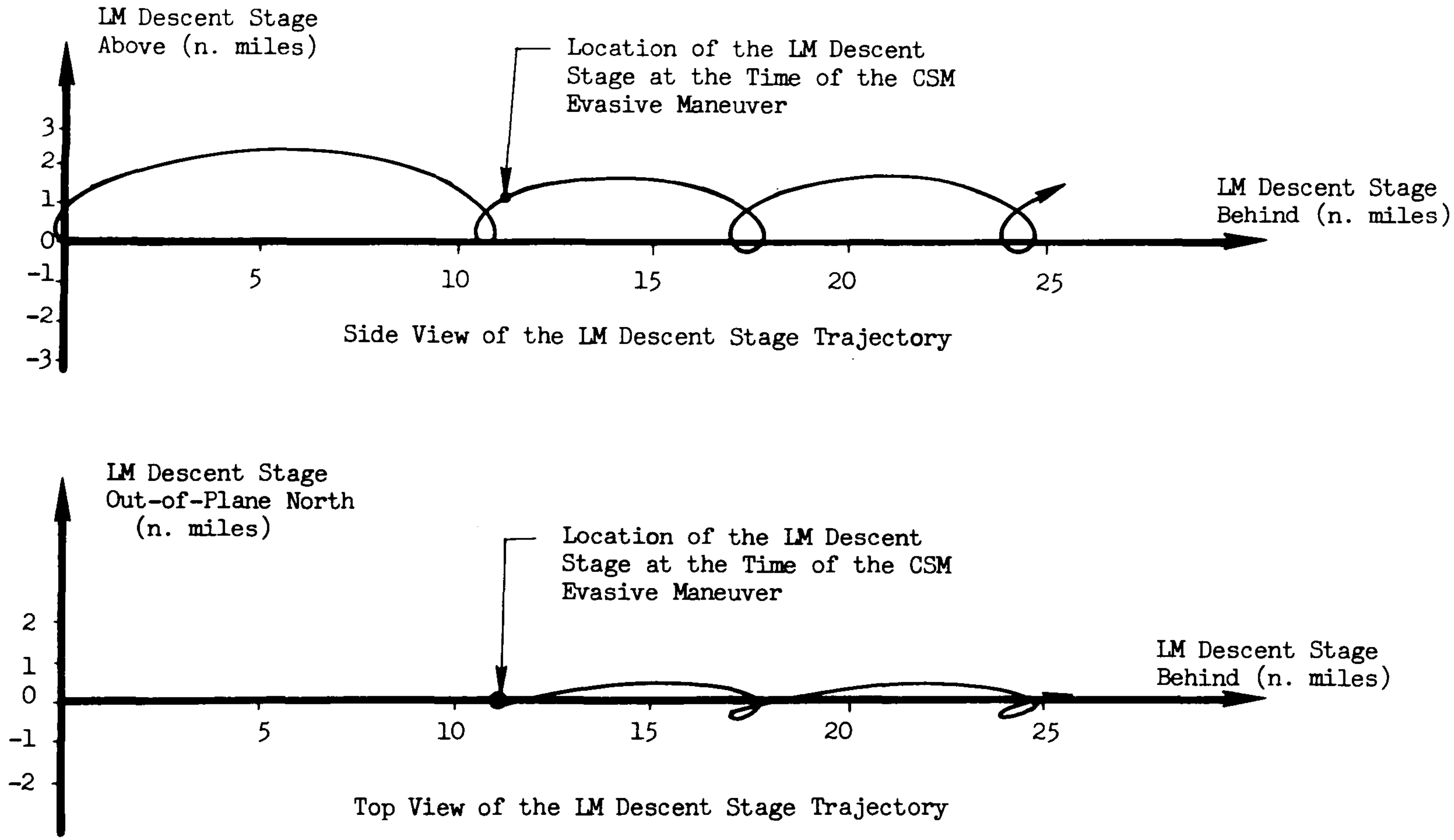


Figure 17. Motion of the LM Descent Stage Relative to the CSM for the Docked Staging and CSM Evasive Maneuver After the DPS-Only Rendezvous

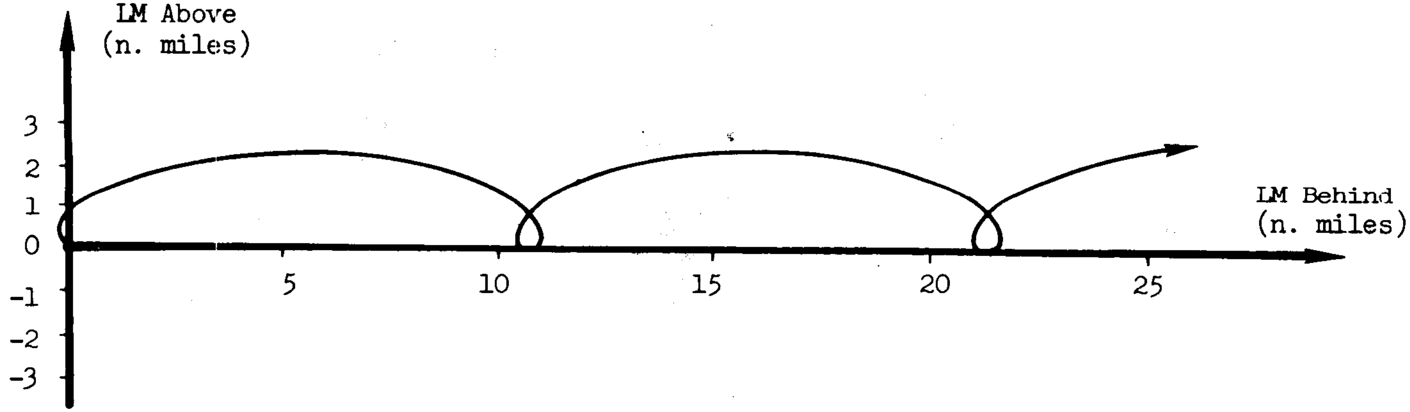


Figure 18. Motion of the LM Relative to the CSM for LM Jettison After a DPS-Only Rendezvous (No APS Burn)

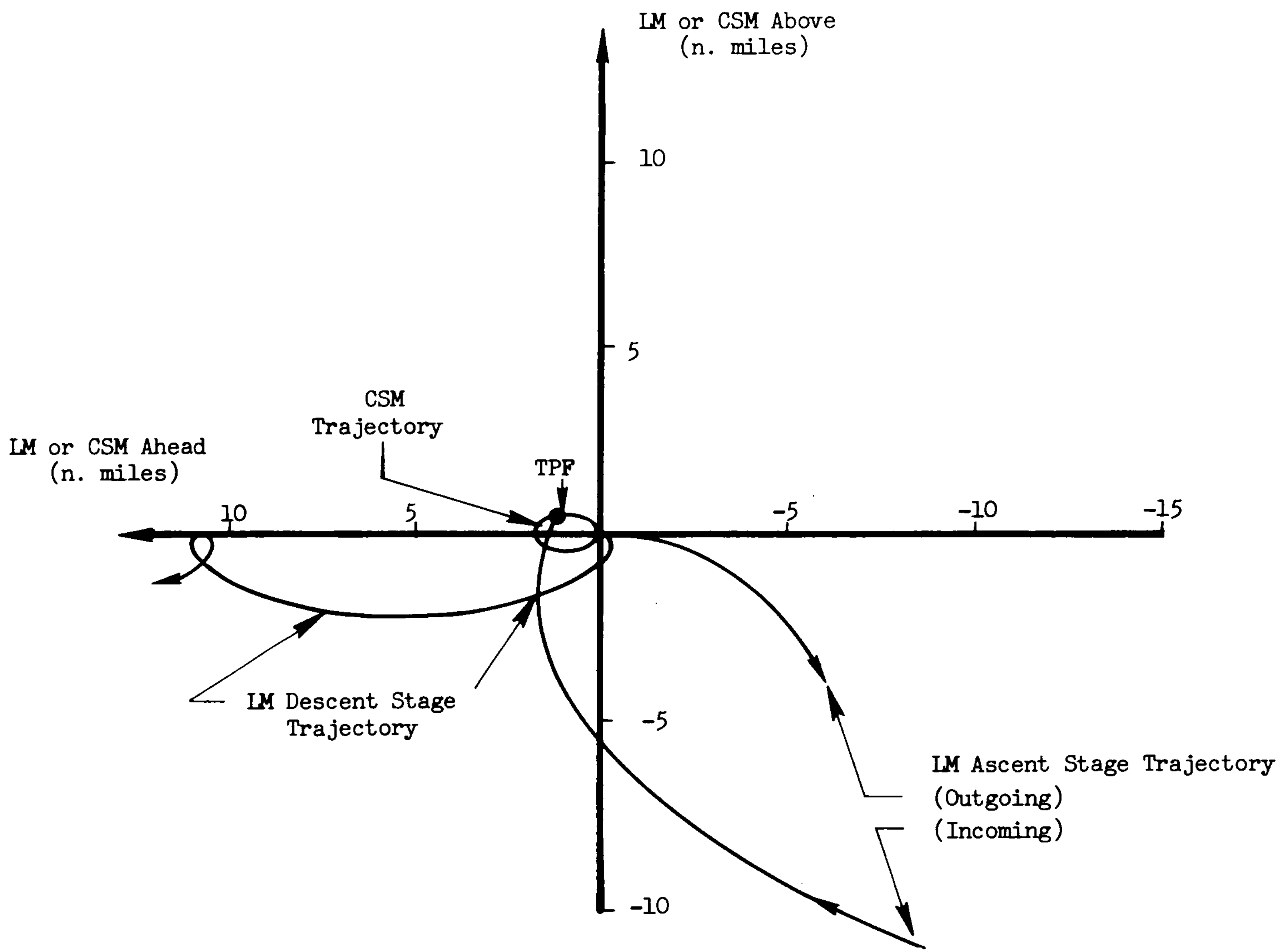


Figure 19. Motion of the CSM, LM Descent Stage, and LM Ascent Stage Relative to the Original CSM/LM Orbit for the APS-Only Rendezvous

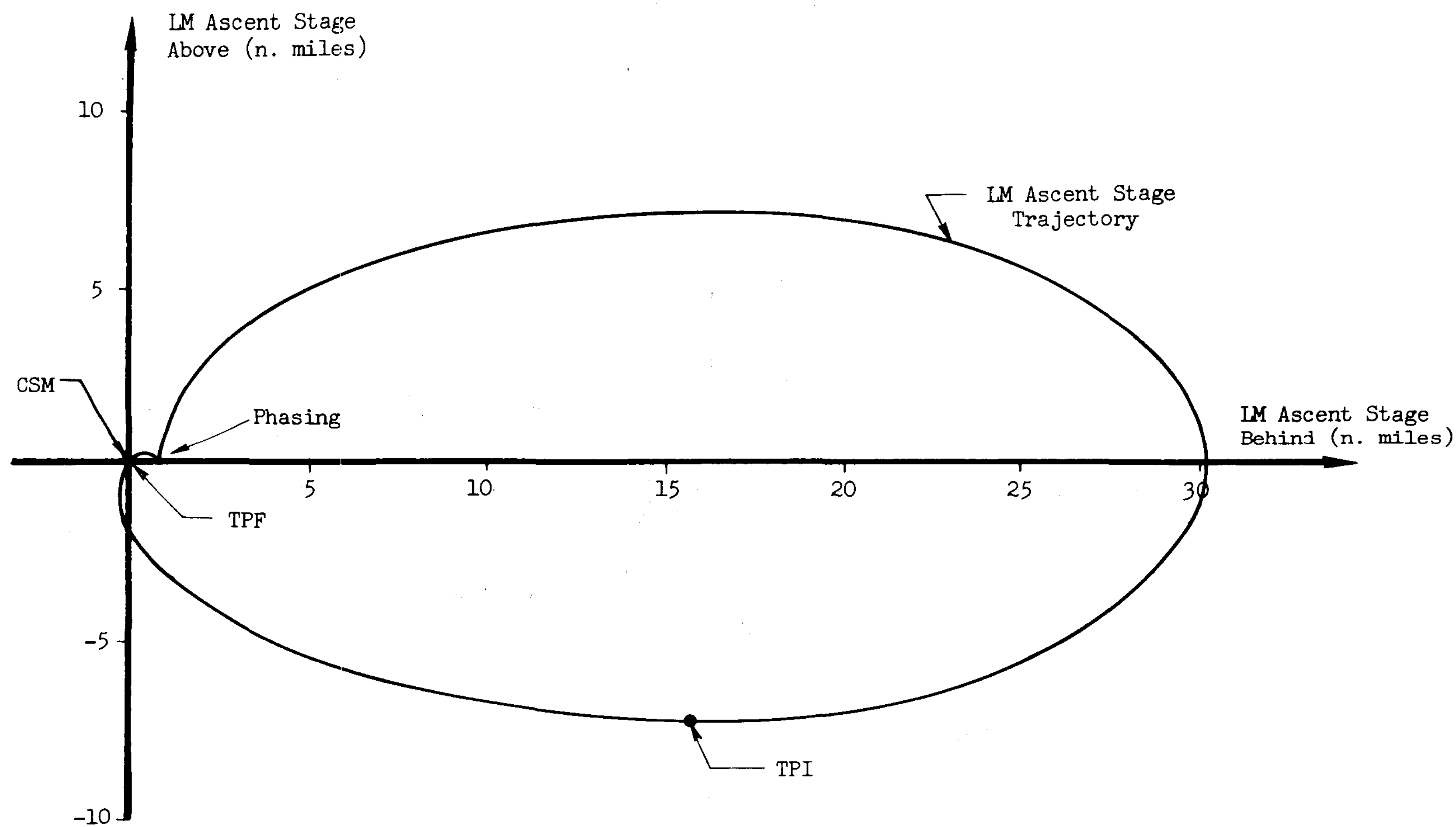


Figure 20. Motion of the LM Ascent Stage Relative to the CSM for the Mini - Maxi Lunar Football Rendezvous

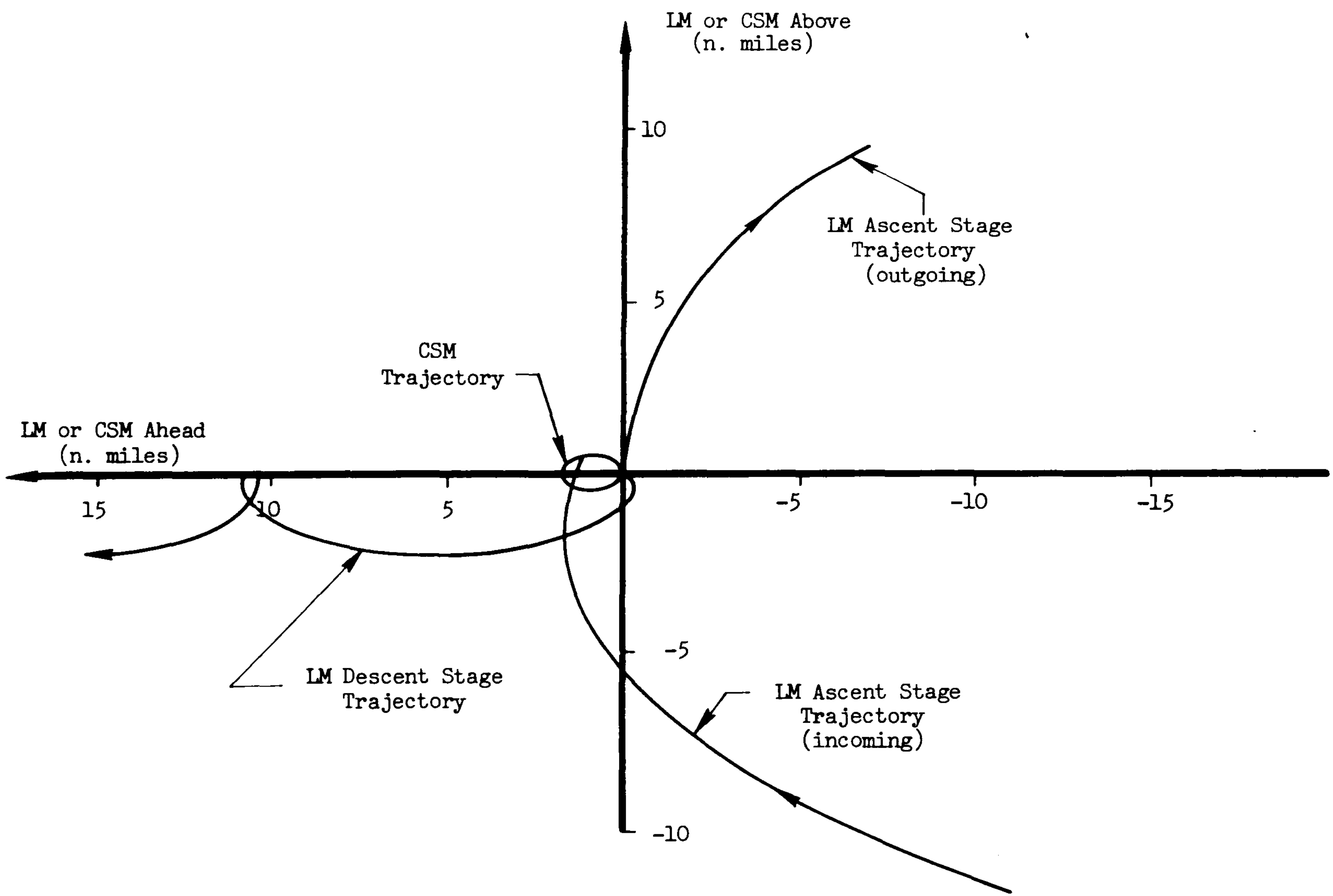


Figure 21. Motion of the CSM, LM Descent Stage, and LM Ascent Stage Relative to the Original CSM/LM Orbit for the Mini - Maxi Lunar Football Rendezvous

APPENDIX C

SEPARATION AND RECONTACT STUDY, MISSION F,

EARTH ORBIT ALTERNATE MISSIONS

5524.8-58
30 April 1969

National Aeronautics and Space Administration
Manned Spacecraft Center
Houston, Texas 77058

Attention: M. L. Williamson, Task Monitor
MSC/TRW Task A-122.1
Mission Planning and Analysis Division

Subject: Separation and Recontact Study, Mission F, Earth Orbit Alternate Missions

Gentlemen:

Under cover to this letter is the response to Task A-122.1, "Separation and Recontact Analysis for Mission F."

The analysis has considered the nominal, APS-only, and mini-maxifootball earth orbit alternate rendezvous schemes. All separation, staging and maneuver events have been investigated to insure that no potential recontact situations exist. The results contained herein clearly show that no recontact hazards are inherent to the maneuver sequences studied.

Yours truly,

R. J. Reinhardt
Analytic Mechanics Section

D. A. Davidson, Task Manager
MSC/TRW Task A-122.1
Analytic Mechanics Section

W. F. Heugel
Assistant Project Manager
Flight Dynamics
Mission Trajectory Control Program

RJR:DMG:PGW:eac

DISTRIBUTION

MSC:

C. C. Allen	FM3
R. V. Battey	PD
M. S. Burton	FM15
M. E. Donahoo	FM3
C. J. Gott	FM3
C. R. Huss	FM
R. E. McAdams	FM3
D. Owen	FM
R. P. Parten	FM13

TRW:

J. M. Dreyfus
H. O. Eley
J. A. Gay
J. M. Wagner
MSD Section Heads
A-122 Personnel

5524.8-58
30 April 1969

ATTACHMENT

TRW Letter No. 5524.8-58

Separation and Recontact Analysis Mission F

MSC/TRW Task A-122.1

Prepared by:

R. J. Reinhardt

Analytic Mechanics Section
TRW Systems Group

EARTH ORBIT ALTERNATE MISSIONS

Nominal Rendezvous

The Mission F nominal rendezvous scheme calls for the LM descent propulsion system (DPS) to perform all rendezvous maneuvers except those of the terminal phase. Following rendezvous and docking, the LM ascent stage is oriented, separated, and burned to depletion; while the CSM observes from a safe position.

The maneuver sequence is as follows:

1. CSM/LM undocking
2. CSM initiates a mini-football by burning 2.5 fps +X RCS at a pitch attitude of 270 degrees (radially down)
3. Coast period, 1/2 CSM orbit (2702 seconds)
4. LM DPS performs a phasing maneuver of 190 fps at a pitch attitude of 292 degrees (ahead and down)
5. LM coast for just over 1 CSM orbit (6180 seconds)
6. LM DPS performs CDH maneuver of 112 fps at a pitch attitude of 180 degrees (retrograde)
7. LM coasts until 10 to 30 minutes prior to TPI before staging
8. LM staging via -X RCS retrograde burn of 3 fps, staging, +X posigrade of 3 fps

9. LM ascent stage performs TPI maneuver of 24 fps at a pitch attitude of 26.2 degrees (ahead and up)
10. LM ascent stage performs TPF maneuver as required

The above rendezvous scheme is depicted in Figure 1. Note that the coordinate system has its origin at and moving with the CSM. It can be seen that the relative motion is quite straight forward until the time of LM staging. At staging, the LM descent stage is slowed by 3 fps but continues essentially [1] on the same orbit relative to the CSM. The exact time of staging is left to the crew's discretion within the limits of 10 to 30 minutes prior to TPI.

The relative motion between the LM ascent and descent stages subsequent to staging is shown in Figure 2. Note that the origin is now centered on the LM ascent stage.

Two boundaries are shown corresponding to LM staging at 10 and 30 minutes prior to TPI. The LM descent stage trajectory would fall within the region defined by these boundaries for LM staging within this time interval. It can be seen that no matter what the time of LM staging within the defined span, no recontact hazard exists.

Upon completion of the rendezvous exercise, the LM APS is burned to depletion. The maneuver sequence, starting with the docked CSM/LM ascent stage configuration is as follows:

1. Orient LM APS to the burn-to-depletion attitude (+X axis along velocity vector) and begin inertial hold
2. Jettison LM ascent stage 30 minutes prior to APS burn
3. CSM performs evasive maneuver 22 minutes prior to APS burn of 3 fps -X RCS at a pitch attitude of 240 degrees (nose down and behind) and a yaw attitude of 45 degrees south

---

(1) Actually the 3 fps retrograde maneuver causes the LM descent stage to drift below as well as ahead; but this motion is imperceptible on the scale chosen for Figure 1.

4. LM APS burn-to-depletion, posigrade along velocity vector

The resulting relative motion is displayed in Figure 3. Note that the origin is centered on the initial CSM/LM ascent stage orbit. It can be seen that the CSM evasive maneuver places the CSM well above and behind LM ascent stage at APS ignition. In this position the CSM observes as the LM ascent stage accelerates away and ahead.

APS-only Rendezvous

In the event that the LM DPS is not available to perform the nominal rendezvous maneuvers, the APS will be used. The corresponding rendezvous sequence is quite similar to the nominal rendezvous scheme presented above. The only change is the need to jettison the LM descent stage much earlier such that the APS can perform the phasing burn. Accordingly, the LM descent stage is discarded 15 minutes prior to completion of the first 1/2 cycle of the CSM mini-football (2267 seconds). This can be seen in Figure 4.

Whereas, the nominal rendezvous scheme presented earlier and the mini-maxi football scheme to follow allow a wide latitude of crew discretion in selecting the exact time of LM staging, this is not the case here. As shown on the face of Figure 5, the LM ascent and descent stage trajectories intersect at 1420 seconds after LM staging and 32 seconds after the phasing maneuver. Therefore, if the LM were staged 1388 seconds (23.13 minutes) prior to the phasing maneuver, recontact would occur at this intersection. It must further be assumed that because of uncertainties and approximations in the analysis and errors in executing the staging and phasing maneuvers, sufficient separation from this critical time must be allowed. The selection of LM staging no earlier than 15 minutes prior to the phasing maneuver provides such an adequate separation. Thus, recontact is avoided.

Mini-Maxi Football

The so-called mini-maxi football rendezvous maneuver sequence provides a low ΔV rendezvous scheme. Such a scheme might be employed if both the LM ascent and descent propulsion systems were inoperable or otherwise unavailable. The maneuver sequence consists of the following events:

1. CSM/LM undocking
2. CSM performs a mini-football, 2.5 fps +X RCS at a pitch attitude of 270 degrees (radially down)
3. CSM coasts 1/2 orbit (approximately 2702 seconds) during which the LM is staged. The exact time of staging is left to the crew's discretion.
4. LM ascent stage performs maxi-football, 80 fps +X RCS at a pitch attitude of 90 degrees (radially upward)
5. LM ascent stage coasts for 3/4 of a CSM orbit
6. TPI performed by LM ascent stage, 17 fps -X RCS at a pitch attitude of 165 degrees
7. TPF performed by LM ascent stage RCS as required

The relative motion plots corresponding to the above maneuver sequence are shown in Figures 6 and 7. Referring to Figure 6, the mini-maxi football can be seen. Noting that this figure has its origin fixed to and moving with the CSM, the non-existence of any recontact problems between the LM ascent stage and the CSM is clearly shown. It remains only to show that no recontact hazards exist between the LM ascent and descent stages. Figure 7 shows that this is true. Note that for the equal times shown, the LM descent stage is considerably up range of the LM ascent stage at the point of intersection of their respective trajectories. The position of the LM ascent stage at this time (staging plus 5700 seconds)corresponds to LM staging immediately prior to the maxi-football maneuver. If the crew were to elect to jettison the LM descent stage earlier (recall they have a full 1/2 orbit coast period to do so) then additional clearance would be provided. The case shown therefore is a conservative one and it clearly shows no recontact is possible.

SUMMARY AND CONCLUSIONS

The nominal and alternate earth orbit rendezvous schemes have been studied as regards potential recontact hazards. It has been shown that the maneuver sequences planned provide adequate separation distances and no recontact hazards exists.

In all cases studied, the prime potential for recontact exists between the jettisoned LM descent stage and the active LM ascent stage. Of the three rendezvous schemes studied; the Nominal, APS-only, and the Mini-Maxi Football; only the APS-only has a critical time constraint on LM staging. Although it has been shown that adequate clearance is provided when the LM staging time constraint is observed (stage 15 minutes prior to completion of CSM mini-football) it must be emphasized that this constraint must be treated with respect.

If LM staging were to occur, in violation of the above constraint, at 23.13 minutes prior to completion of the mini-football, the LM descent stage would be placed on a collision course with respect to the LM ascent stage.

Figure 1.

EARTH ORBIT ALTERNATE MISSIONS

Nominal Rendezvous

Motion of LM Ascent and Descent Stages Relative to CSM

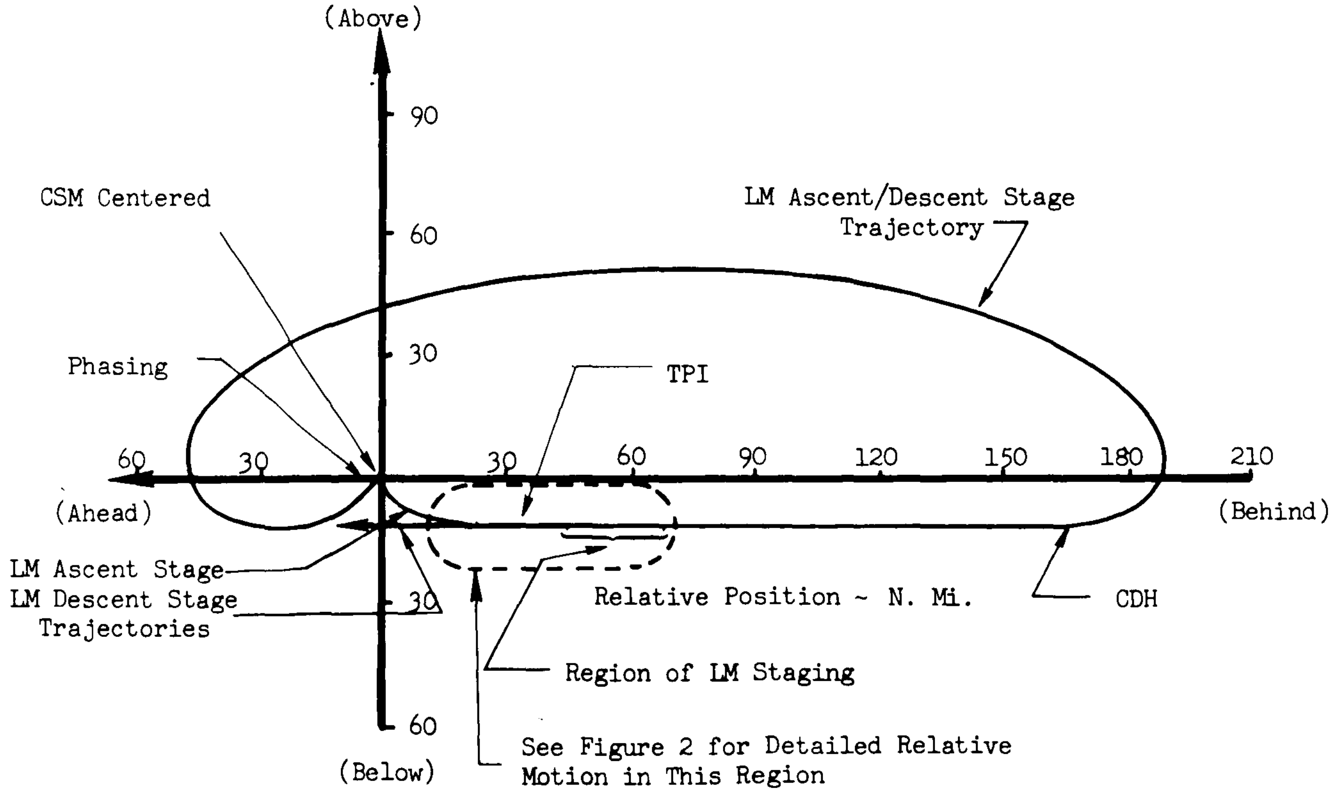


Figure 2.

EARTH ORBIT ALTERNATE MISSIONS

Nominal Rendezvous

Motion of LM Descent Stage Relative to LM Ascent Stage

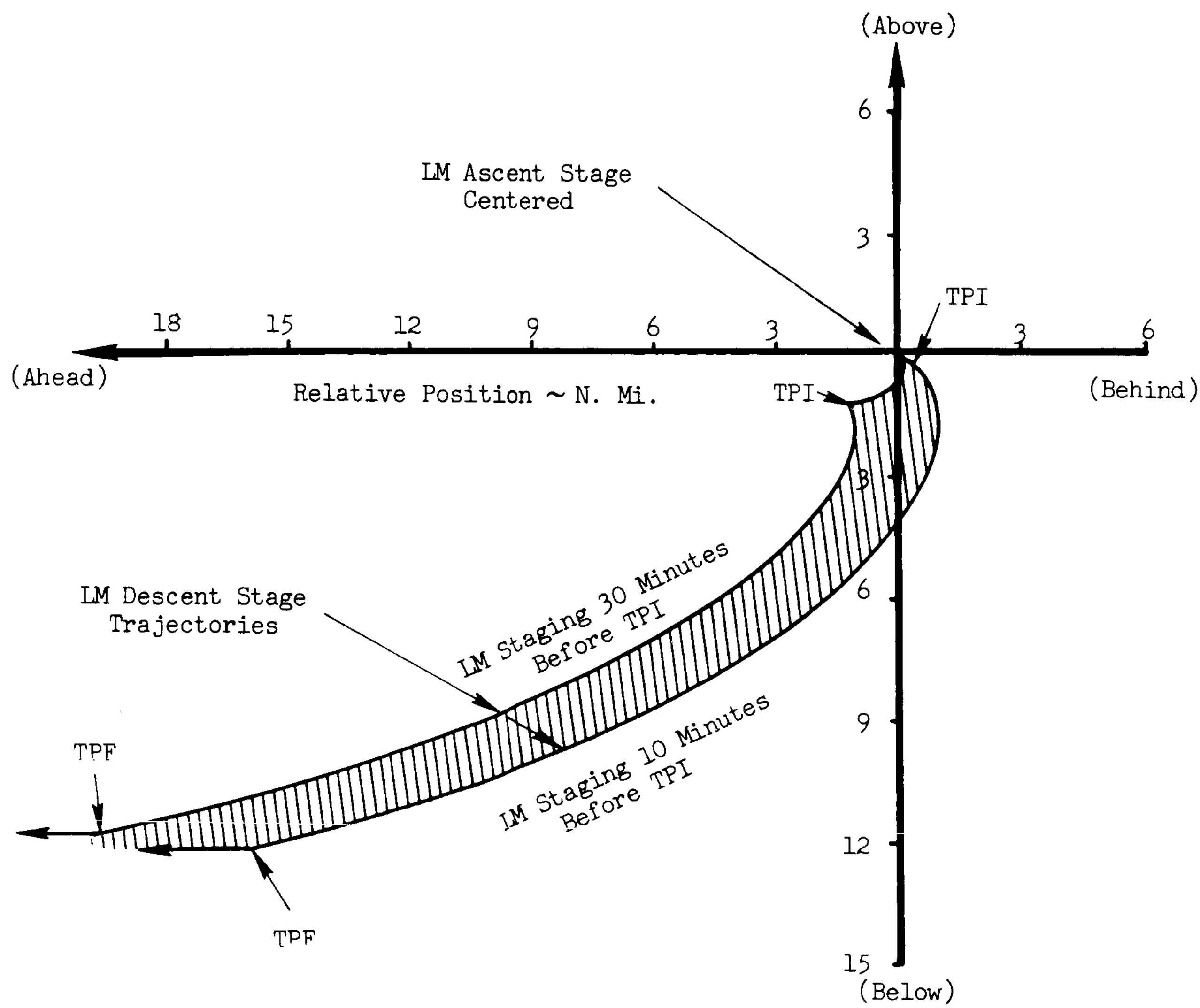


Figure 3.

EARTH ORBIT ALTERNATE MISSIONS

Nominal Rendezvous

Motion of CSM Relative to LM Ascent Stage due to CSM Evasive Maneuver and APS Burn-to-Depletion

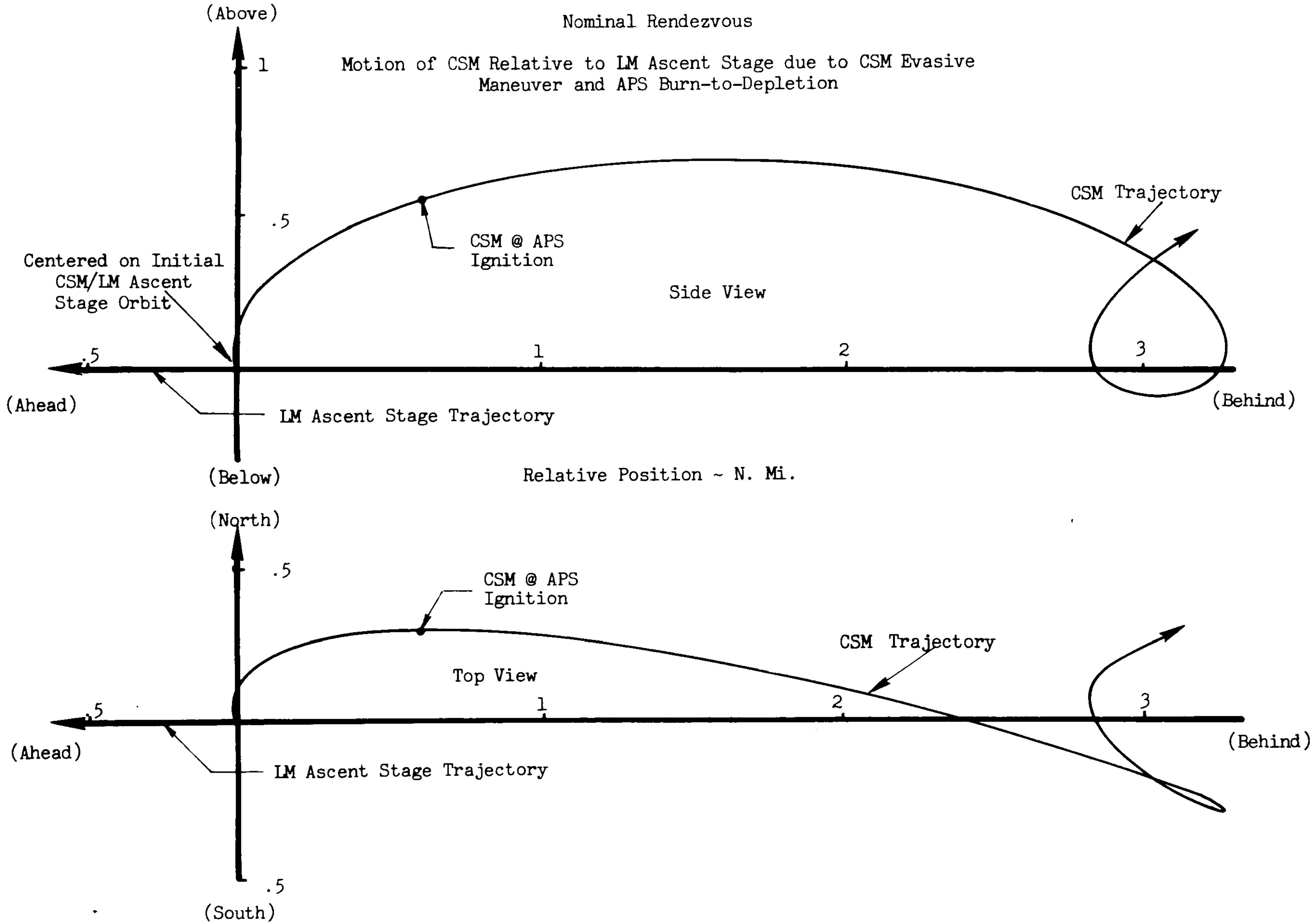


Figure 4.

EARTH ORBIT ALTERNATE MISSIONS

APS-only Rendezvous

Motion of LM Ascent and Descent Stages Relative to CSM

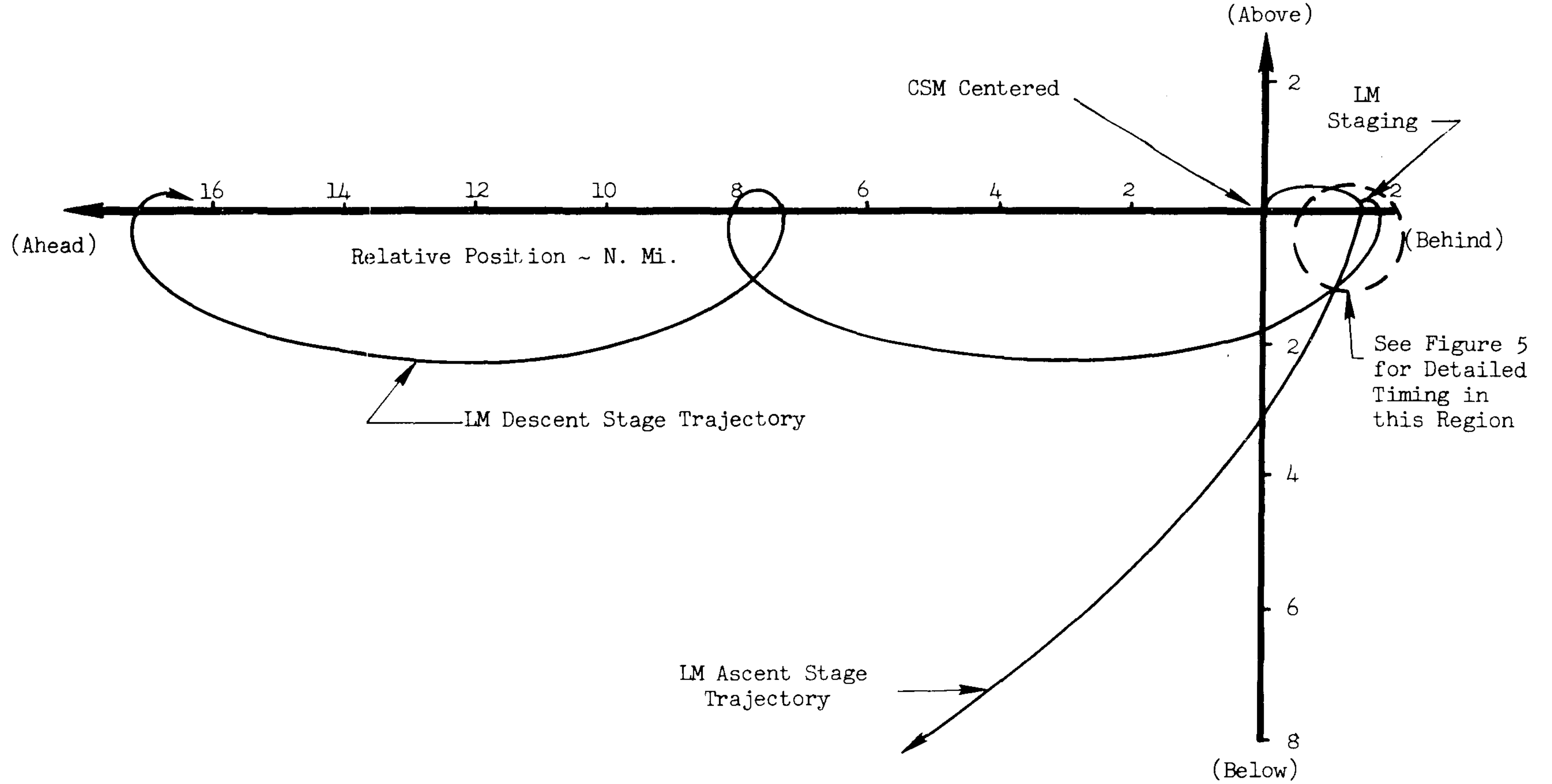


Figure 5.

EARTH ORBIT ALTERNATE MISSIONS

APS-only Rendezvous

Motion of CSM and LM Ascent and Descent Stages Relative to Initial CSM/LM Orbit

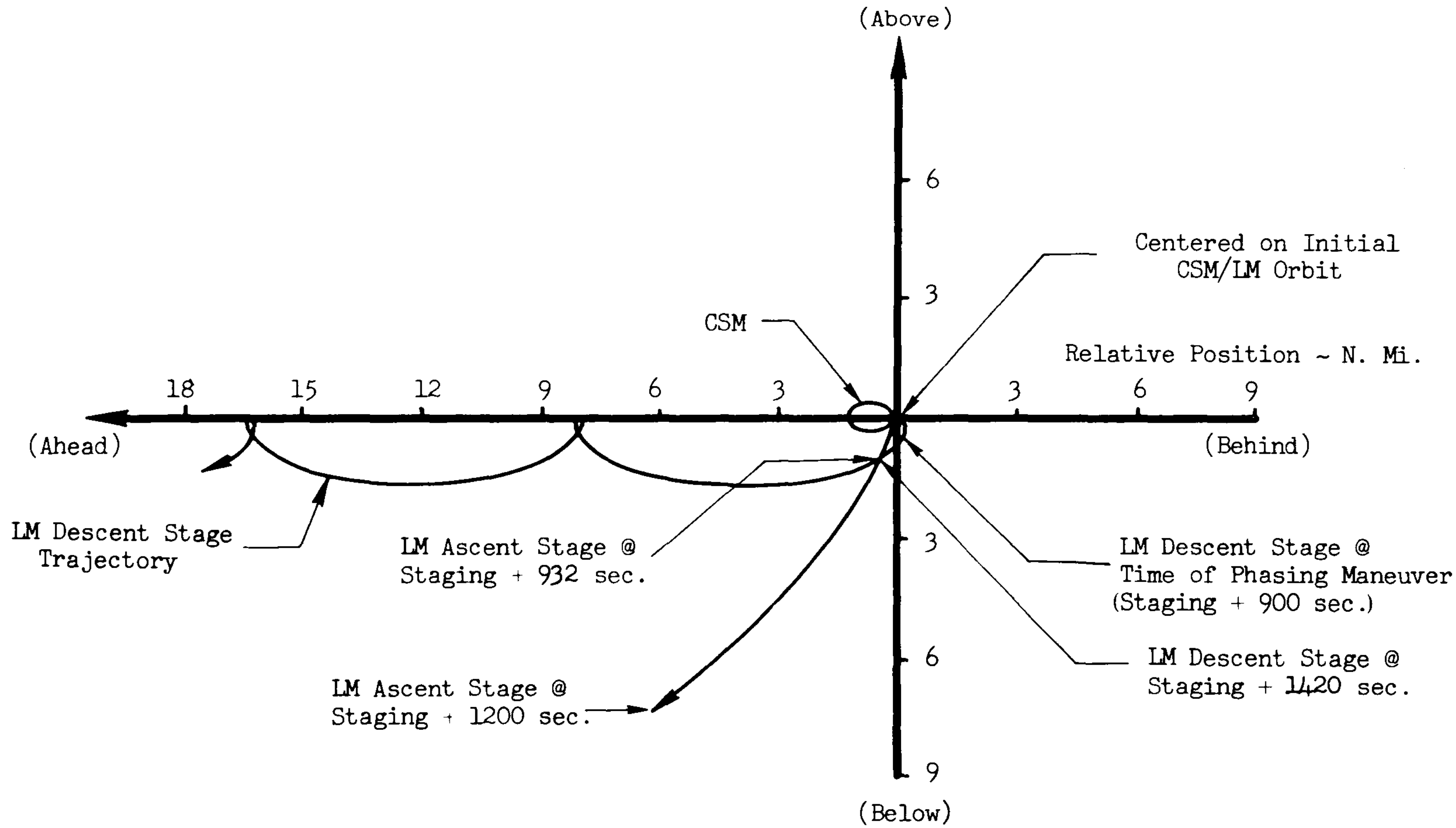


Figure 6.

EARTH ORBIT ALTERNATE MISSIONS

Mini-Maxi Football

Motion of LM Ascent Stage Relative to CSM

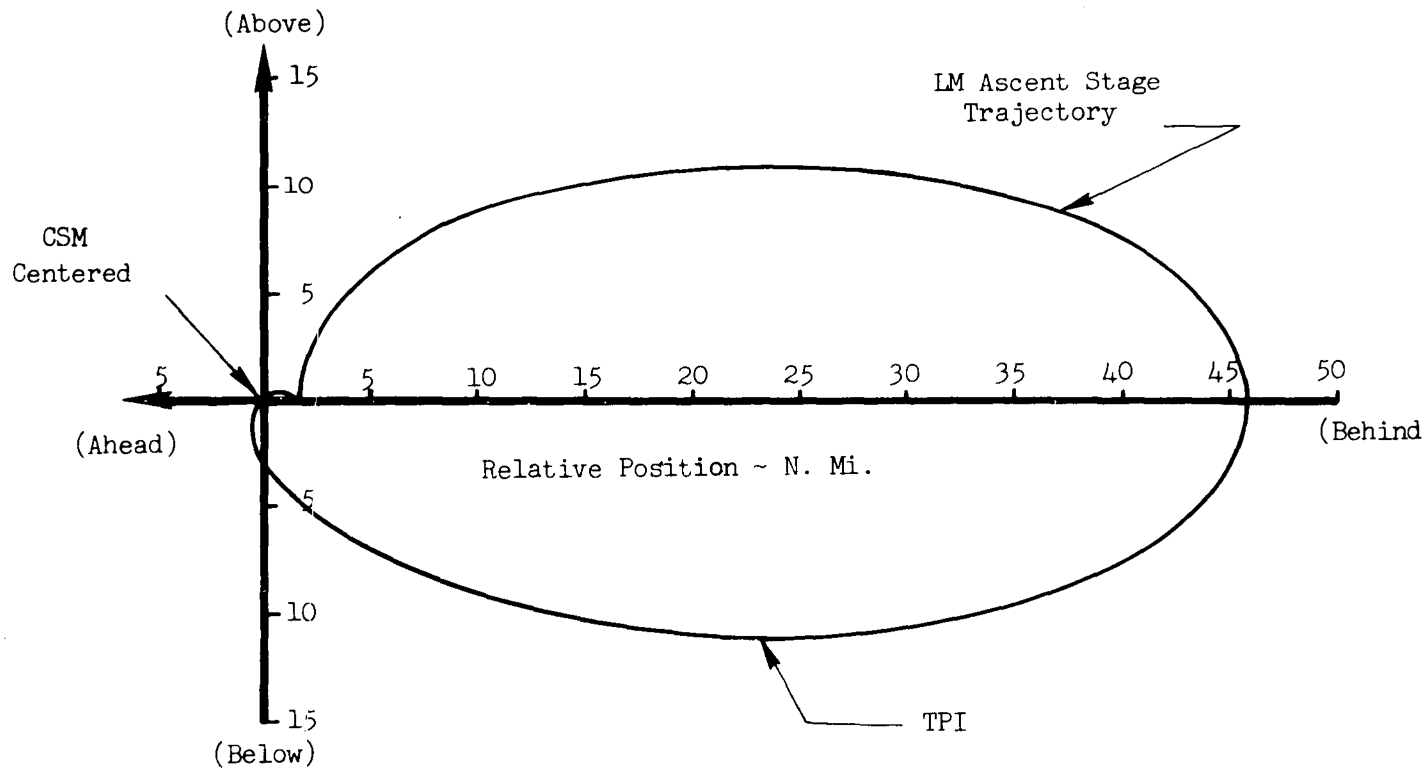
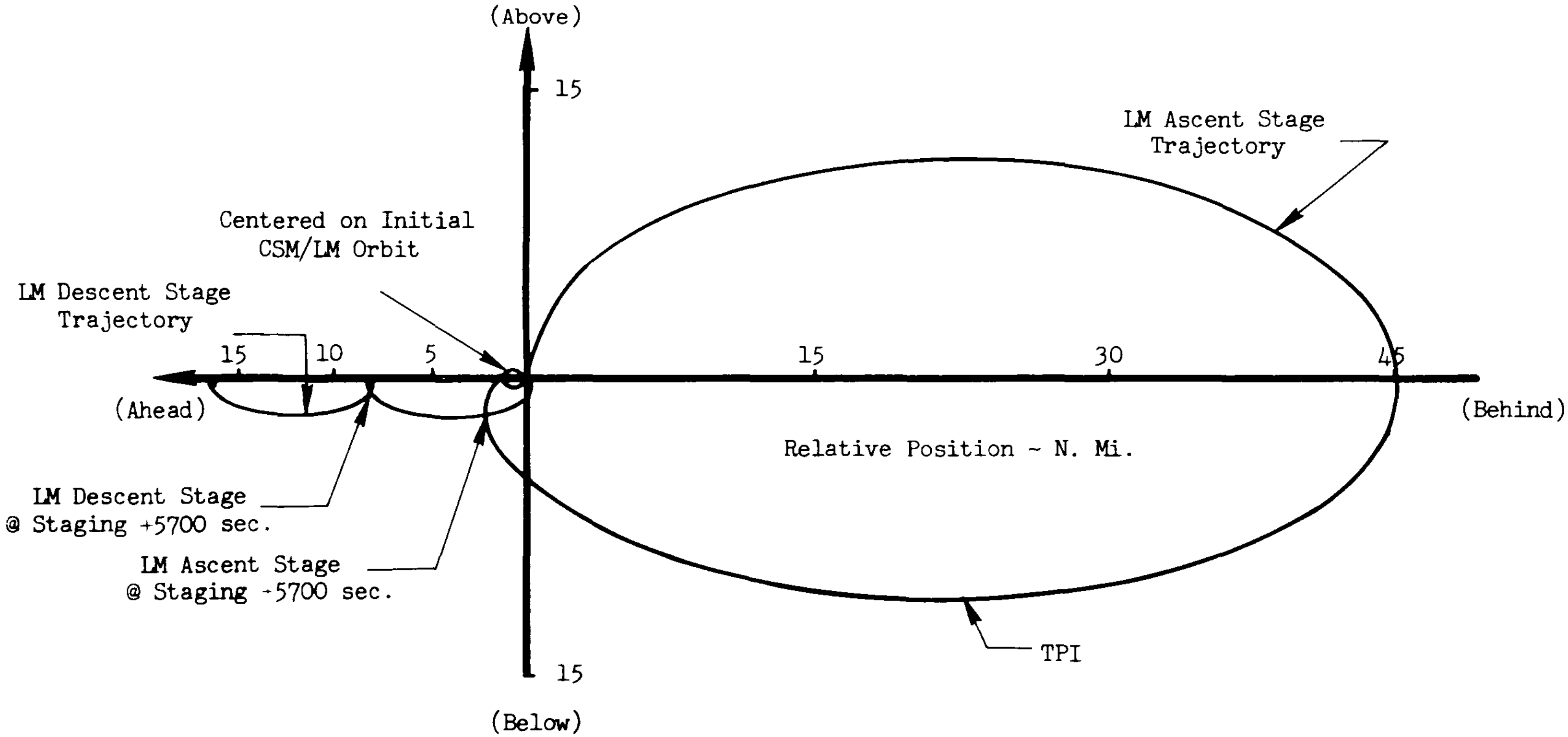


Figure 7.

EARTH ORBIT ALTERNATE MISSIONS

Mini-Maxi Football

Motion of CSM and LM Ascent and Descent Stages Relative to Initial CSM/LM Orbit



APPENDIX D

EVASIVE MANEUVER RELATIVE MOTION

FOR THE APOLLO MISSIONS F AND G

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

NASA - Manned Spacecraft Center
Mission Planning & Analysis Division

TO : See List Below

DATE: MAR 26 1969

69-FM37-135

FROM : FM3/Flight Analysis Branch

SUBJECT: Evasive maneuver relative motion for the Apollo Missions F and G

References

1. MSC memorandum 69-FM54-39 by J. D. Yencharis, "Spacecraft evasive maneuver on Apollo Mission F," dated February 19, 1969.

2. MSC memorandum 69-FM13-111 by J. A. McAnulty, "S-IVB slingshot timeline for Apollo 10 (AS-505, F mission)," dated February 26, 1969.

3. MSFC memorandum 68-M-115 by J. L. Vaniman, "Conditions to be expected during the LOX dump of the S-IVB for the C-Prime Mission," dated October 30, 1968.

Introduction

During the Apollo F and G missions, the spacecraft will perform an SPS maneuver following ejection of the LM from the S-IVB. Previous planning specified that the SPS evasive maneuver would be executed 20 minutes after ejection and the S-IVB dump sequence would begin 10 minutes later at TLI cutoff +2 hours (reference 1). In a meeting with personnel from the Astronaut Office and MPAD on March 10, a proposal was made by the crew to delay the SPS evasive maneuver until 30 minutes after ejection to allow adequate preparation time for the SPS burn. Crew simulations are planned to determine if the 30 minutes between CSM/LM ejection and the SPS evasive maneuver will be adequate.

Summary

Relative motion of the spacecraft (CSM+LM) with respect to the S-IVB from ejection through the S-IVB APS ullage is presented herein for the following conditions.

1. SPS evasive maneuver 30 minutes after ejection and the S-IVB dump sequence beginning 10 minutes later at TLI cutoff +2 hours and 10 minutes (figure 1).

2. SPS evasive maneuver 20 minutes after ejection and the S-IVB dump sequence beginning 10 minutes later at TLI cutoff +2 hours (figure 2).

3. SPS evasive maneuver deleted entirely and the S-IVB dump sequence beginning at TLI cutoff +2 hours (figure 3).

The relative motion generated for the condition 1 above (based on the sequence of events presented in Table I) indicates no recontact problems. The spacecraft position at the time of the SPS evasive maneuver performed 30 minutes after ejection will be approximately 2,000 feet behind and 1,700 feet out-of-plane or at a range of 2,600 feet (figure 1). The SPS evasive burn will result in the spacecraft passing 9,400 feet below with a crossrange of 2,000 feet approximately 9 minutes after SPS ignition (range ~10,000 feet). Assuming the dump sequence is initiated 10 minutes after the SPS evasive maneuver, the spacecraft range at the time of the LOX dump will be over 34,000 feet; approximately 25,000 feet below, 4,000 feet ahead, and 3,100 feet of crossrange from the S-IVB. Following the LOX dump, the range rapidly increases to over 210,000 feet at the termination of the S-IVB APS ullage.

Relative motion for an SPS evasive maneuver initiated at 20 minutes (condition 2 above) is presented in figure 2. The primary difference resulting from performing the SPS maneuver at 20 minutes is the horizontal range of the spacecraft from the S-IVB at SPS ignition, 1,350 feet as compared to 2,000, and the vertical displacement as the spacecraft passes below the S-IVB, 6,600 as compared to 9,400 feet.

In the event no SPS evasive maneuver is initiated and the dump sequence begins at TLI cutoff +2 hours, (condition 3 above) relative motion (figure 3) indicates the spacecraft would pass above the S-IVB by 700 feet, with a crossrange of 2,500 feet and a minimum total range of 2,600 feet. This would occur during the S-IVB LOX dump, approximately 44 minutes and 25 seconds after ejection. The spacecraft position at dump initiation is 2,300 feet in front of S-IVB, with a crossrange of 2,000 feet. Prior to maneuvering to the dump attitude, the S-IVB would be pointed almost directly at the spacecraft for 30 minutes after CSM/LM ejection. At dump sequence initiation, the S-IVB yaws 40° and performs the LOX dump and APS ullage in plane, thus insuring sufficient out-of-plane displacement to prevent recontact.

The dashed lines on figures 1, 2, and 3 represent the area the S-IVB LOX dump "cloud" would cover if it encompassed a 70° cone centered about the longitudinal axis of the S-IVB in the dump attitude. Reference 3 indicates that the majority of the solid particles emerging from the J-2 engine should be confined within a 15° cone. These particles are expected to be on the order of 3 to 15 mm. in size. Reference 3 assumes the entire LOX dump "cloud" will cover a cone from 120 to 150°, but recommends that the distance between the S-IVB stage and the spacecraft should be based on the effects of an explosion rather than those of the LOX dump.

As indicated by a comparison of figures 1, 2, and 3, the spacecraft would definitely enter a cone of 70° in less time performing an RCS evasive maneuver than it would performing an SPS maneuver and would also pass closer to the 15° concentrated area. In the RCS evasive maneuver in figure 3, the spacecraft enters a 70° cone approximately 3 minutes after dump initiation at a range of 2,800 feet. For the SPS evasive maneuver in figure 1, this cone is penetrated 11 minutes after dump initiation at a range of approximately 62,100 feet.

Conclusion

Performing an SPS evasive maneuver 20 or 30 minutes after ejection will not result in any recontact problems. Should the SPS evasive maneuver be deleted entirely and the S-IVB dump sequence still begin at TLI cutoff +2 hours, no recontact would occur although separation clearances would be substantially reduced. The primary factor preventing recontact for this situation is the 40° yaw angle in the spacecraft ejection attitude from the S-IVB. The inertial attitude of the S-IVB at ejection, the spacecraft attitude at SPS ignition (reference 1), and the S-IVB dump sequence, attitude, and ΔV (reference 2) are presented in Table I.

The inhibit release on the S-IVB dump sequence should be sent after a satisfactory evasive maneuver has been performed. For a 30 minute evasive maneuver, the spacecraft requires approximately 10 minutes to achieve a position normal to the S-IVB dump attitude. Therefore, the minimum time for inhibit release should be at TLI cutoff +2 hours and 10 minutes, 10 minutes after the SPS evasive maneuver.

The SPS evasive maneuver at 30 minutes results in achieving the best separation clearances and range with respect to the S-IVB LOX dump "cloud." Assuming the LOX dump covers a 70° cone area, the spacecraft would penetrate the resulting "cloud" 11 minutes after dump initiation at a range of approximately 62,100 feet. For an RCS evasive maneuver, penetration would occur 3 minutes after dump initiation at a range of 2,800 feet.

REM

CCA

Marland L. Williamson

Charles W. Fraley

APPROVED BY:

John P. Mayer
Chief, Mission Planning
and Analysis Division

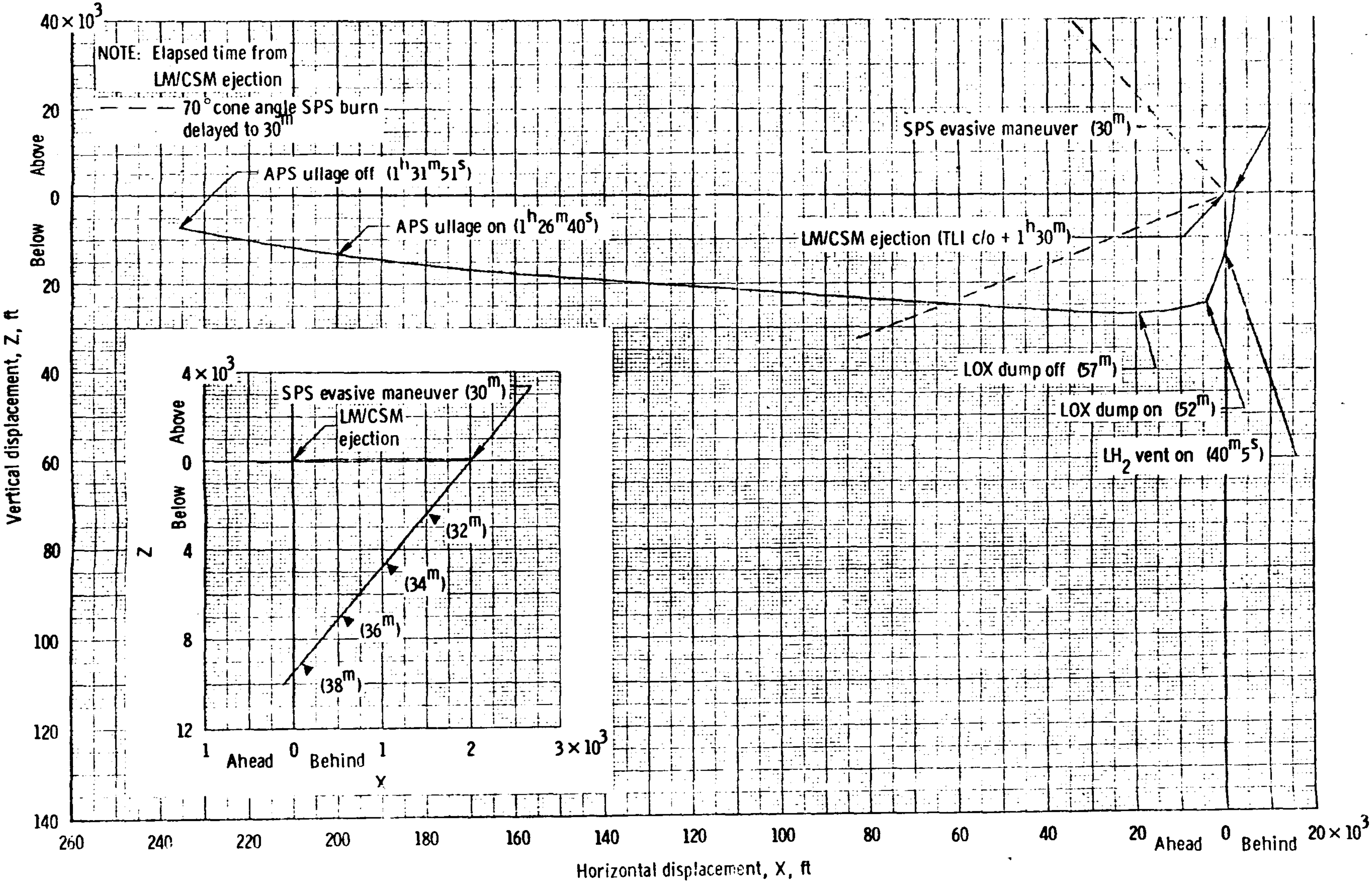
Enclosures

cc:
(See attached page)

Table I - 30 Minute SPS Evasive Maneuver Sequence of Events

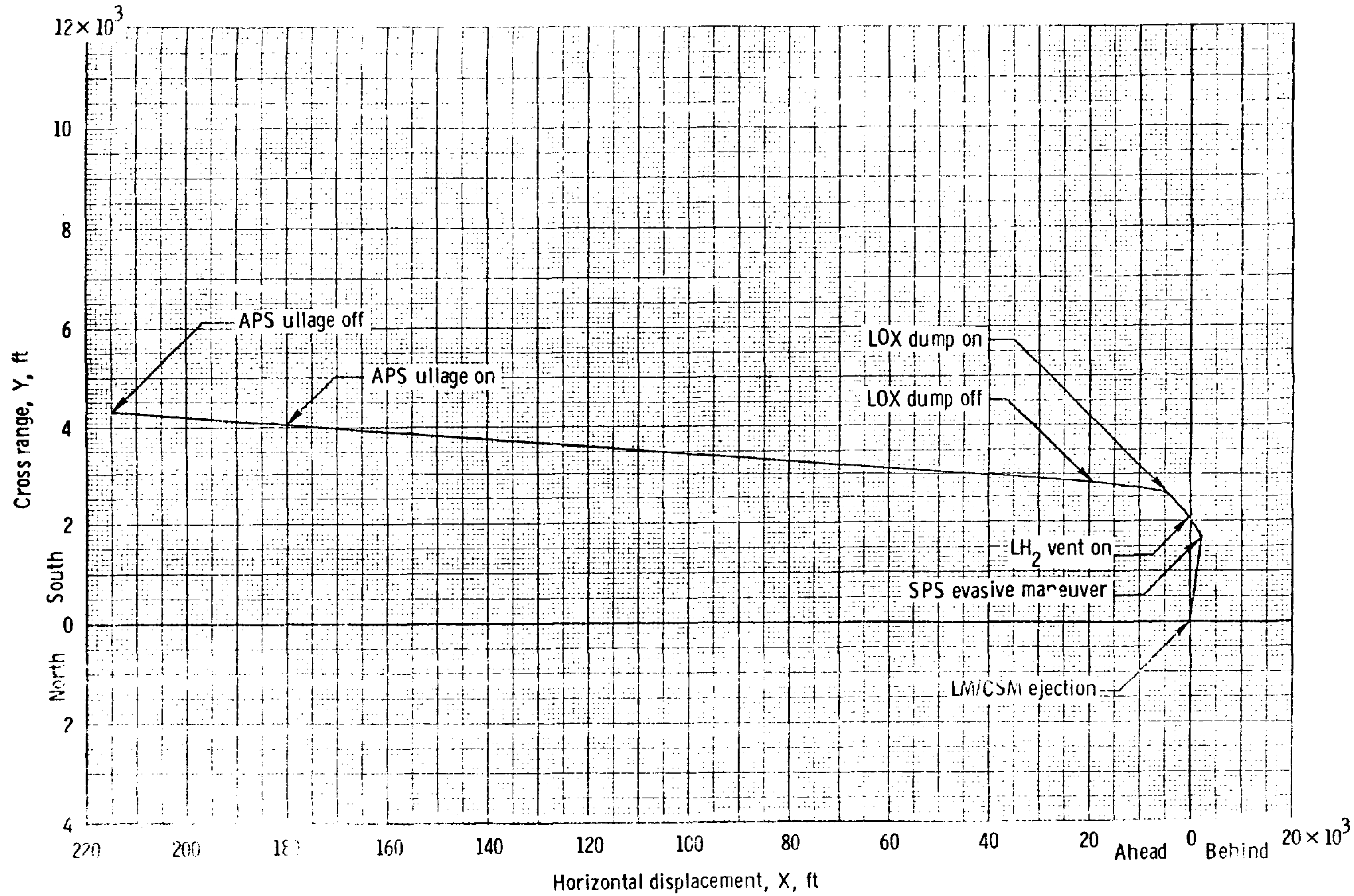
Time (hr:min:sec)	Event
$0^h\ 0^m\ 0^s$	a. CSM/LM ejection from the S-IVB (TLI cutoff +1.5 hours..
	b. S-IVB attitude at ejection with respect to the local horizontal (LH) pitch 174.8°, yaw 40°, roll 180°. These attitudes at ejection are based on an initial T, D, and E attitude of pitch 120°, yaw 40°, roll 180° held inertial from TB7+15 minutes.
	c. Relative spring actuator ΔV = 0.8 fps.
$0^h\ 0^m\ 5^s$	a. Initiate CSM RCS-X translation.
	b. No change in spacecraft attitude.
$0^h\ 0^m\ 10^s$	a. Terminate CSM RCS-X translation.
	b. ΔV = 0.67 fps.
	c. Total ejection ΔV = 1.47 fps. Additional relative motion analyses of total ejection ΔV from 0.5 to 2.0 fps has been performed and the results indicate no significant effect on the motion of the spacecraft relative to the S-IVB.
$0^h\ 0^m\ 17^s$	a. The spacecraft will have translated approximately 25 feet based on the above ΔV.
	b. After $0^h\ 0^m\ 17^s$ but prior to $0^h\ 30^m\ 0^s$ begin orientation to the SPS evasive maneuver attitude (reference 1). Pitch = -75°, yaw 0° with respect to the LH. Roll positive 60° from heads-up is required to view the S-IVB in the left side window on launch days with a+40° yaw in the T, D, and E attitude (May 17 and 18) and a negative 60° roll from heads-up is required to view the S-IVB in the right side window on launch days with a -40° yaw in the T, D, and E attitude (May 20, 23, 24, and 25). Gimbal angles will be provided by the RTCC for these attitudes (reference 1).

Time (continued)	Event
$0^h\ 30^m\ 0^s$	a. Initiate the SPS evasive maneuver.
	b. ΔV = 19.685 fps.
$0^h\ 40^m\ 0^s$	At TLI cutoff $+2^h\ 10^m$ initiate the S-IVB dump sequence (reference 2).
$0^h\ 40^m\ 5^s$	a. Continuous LH_2 propulsive vent ON.
	b. S-IVB begins orientation to the dump attitude: pitch 194°, yaw 0°, roll 180° with respect to the local horizontal (reference 2).
$0^h\ 52^m\ 0^s$	Initiate LOX dump (TLI+$2^h\ 22^m$).
$0^h\ 57^m\ 0^s$	a. Terminate LOX dump (TLI+$2^h\ 27^m$).
	b. ΔV = 84.3 fps.
$1^h\ 26^m\ 40^s$	Initiate S-IVB APS ullage (TLI+$2^h\ 56^m\ 40^s$).
$1^h\ 31^m\ 51^s$	a. Terminate S-IVB APS ullage (TLI+$3^h\ 01^m\ 51^s$).
	b. APS ullage ΔV = 43.6 fps.
	c. LH_2 PV ΔV = 6.6 fps.
	d. Total dump sequence ΔV = 134.5 fps (41 m/sec) reference 2.



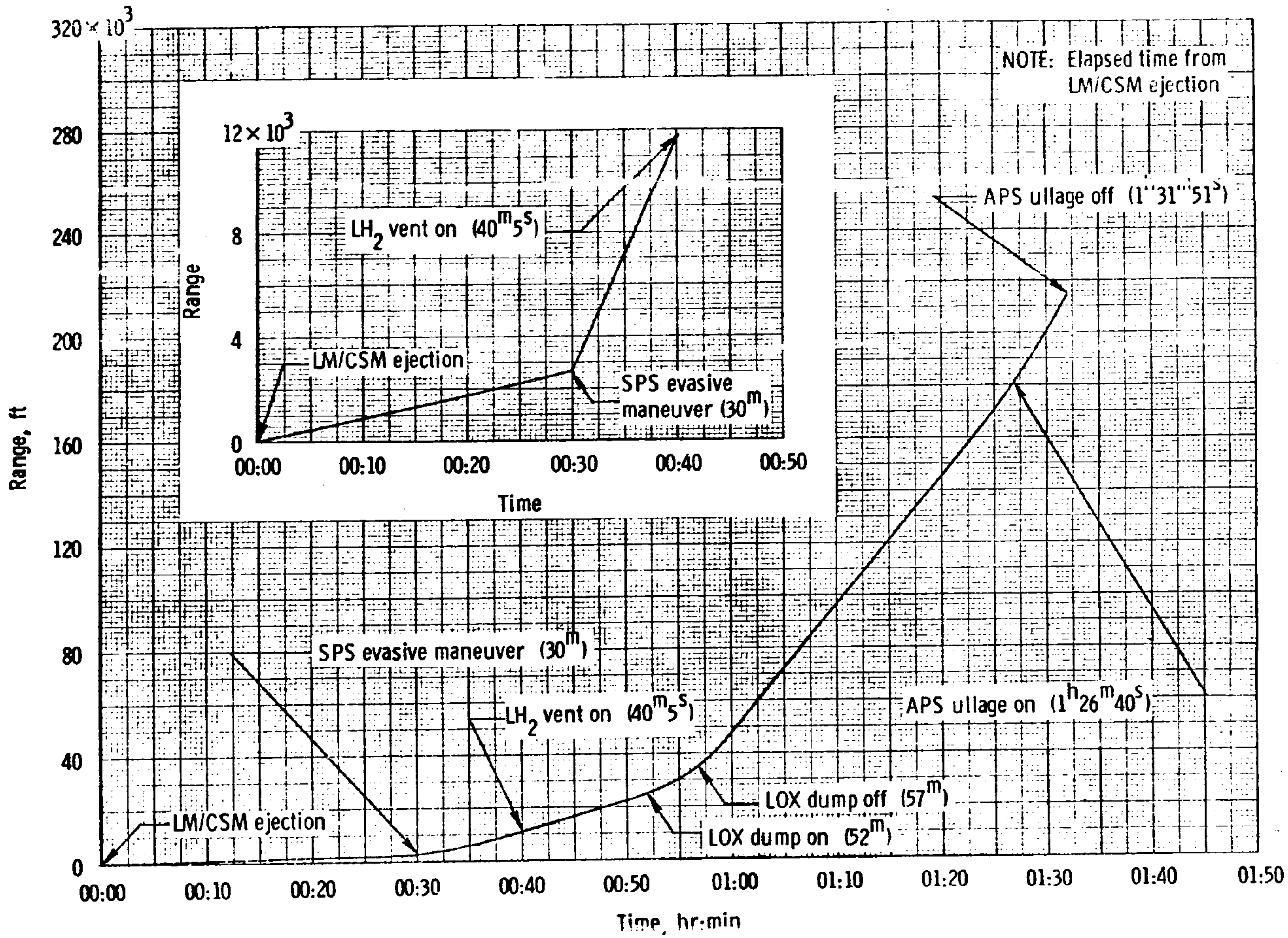
(a) Vertical displacement versus horizontal displacement.

Figure 1. - SPS evasive maneuver, dump sequence begins at $2^h 10^m$.



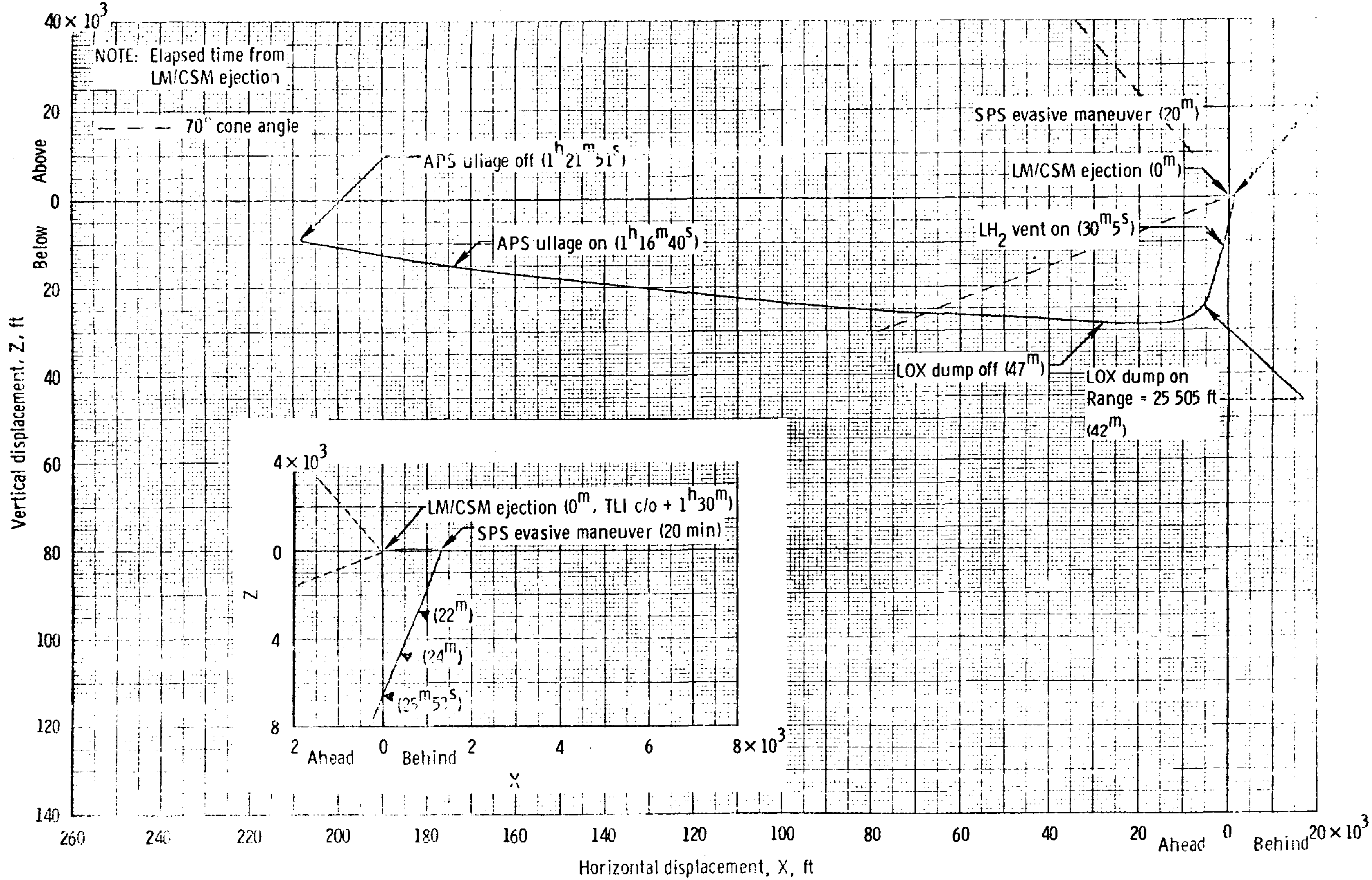
(b) Cross range versus horizontal displacement.

Figure 1. - Continued.



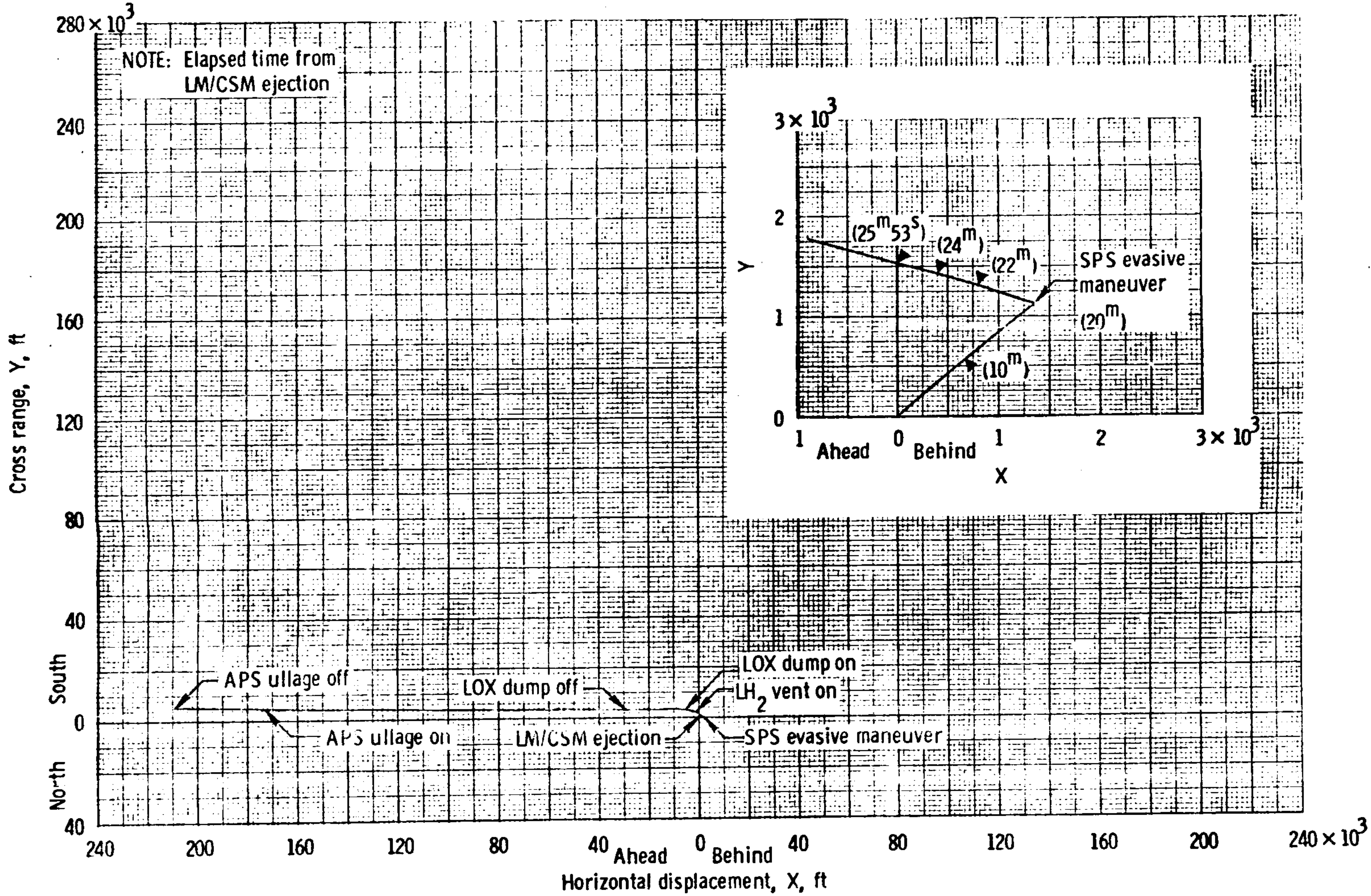
(c) Range versus time.

Figure 1. - Concluded.



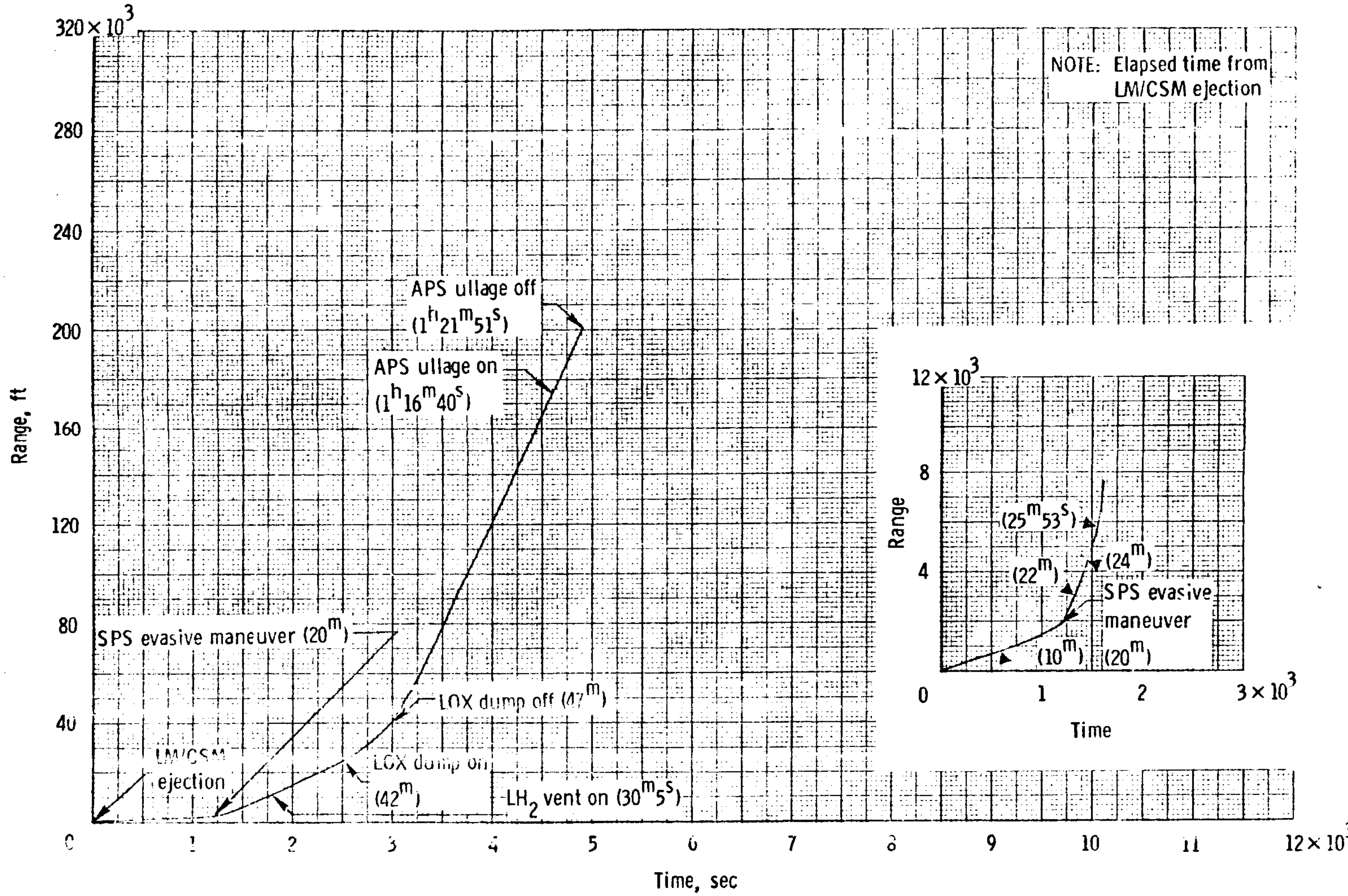
(a) Vertical displacement versus horizontal displacement.

Figure 2. - SPS evasive maneuver; dump sequence begins at 2^h00^m.



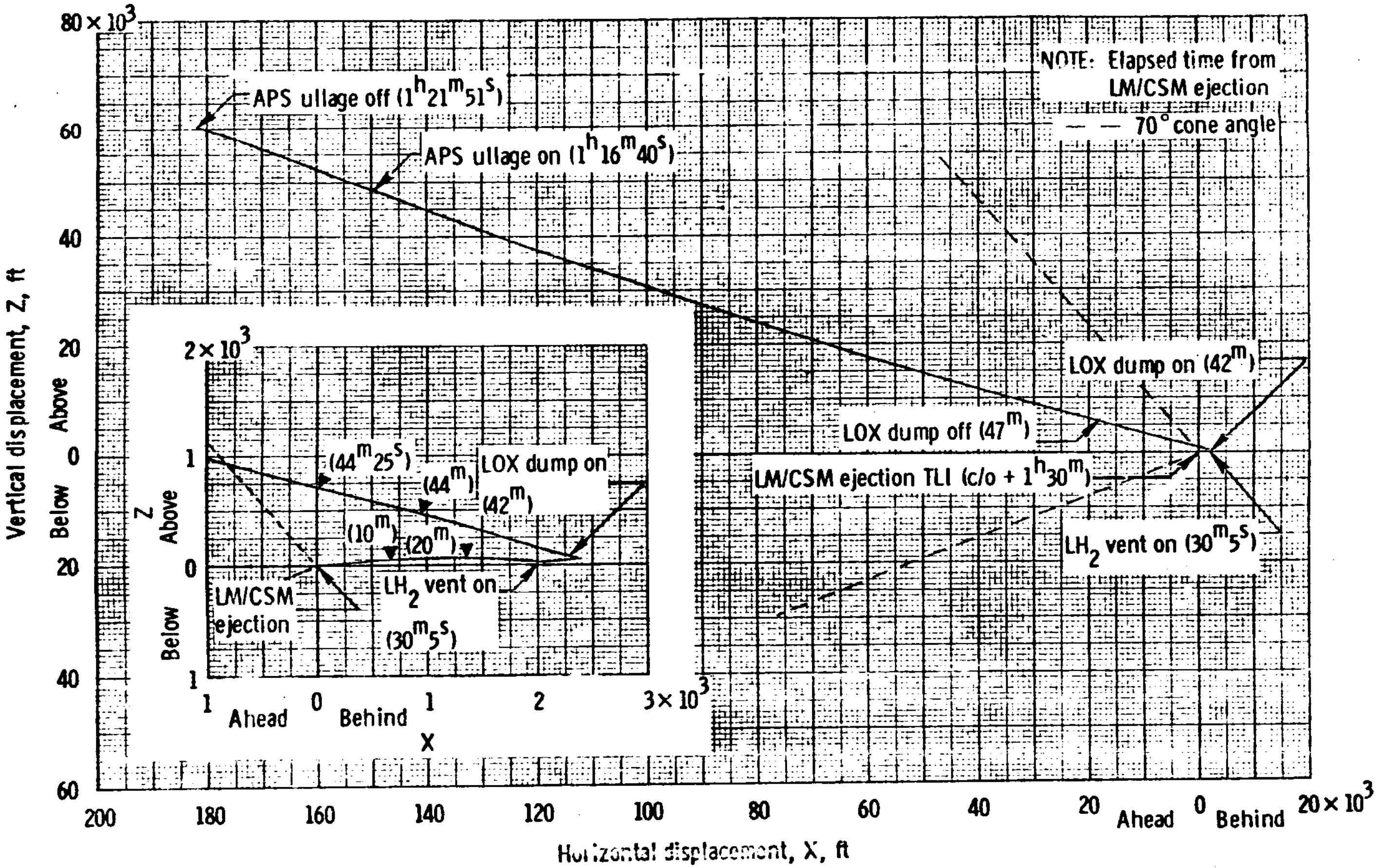
(b) Cross range versus horizontal displacement.

Figure 2.- Continued.



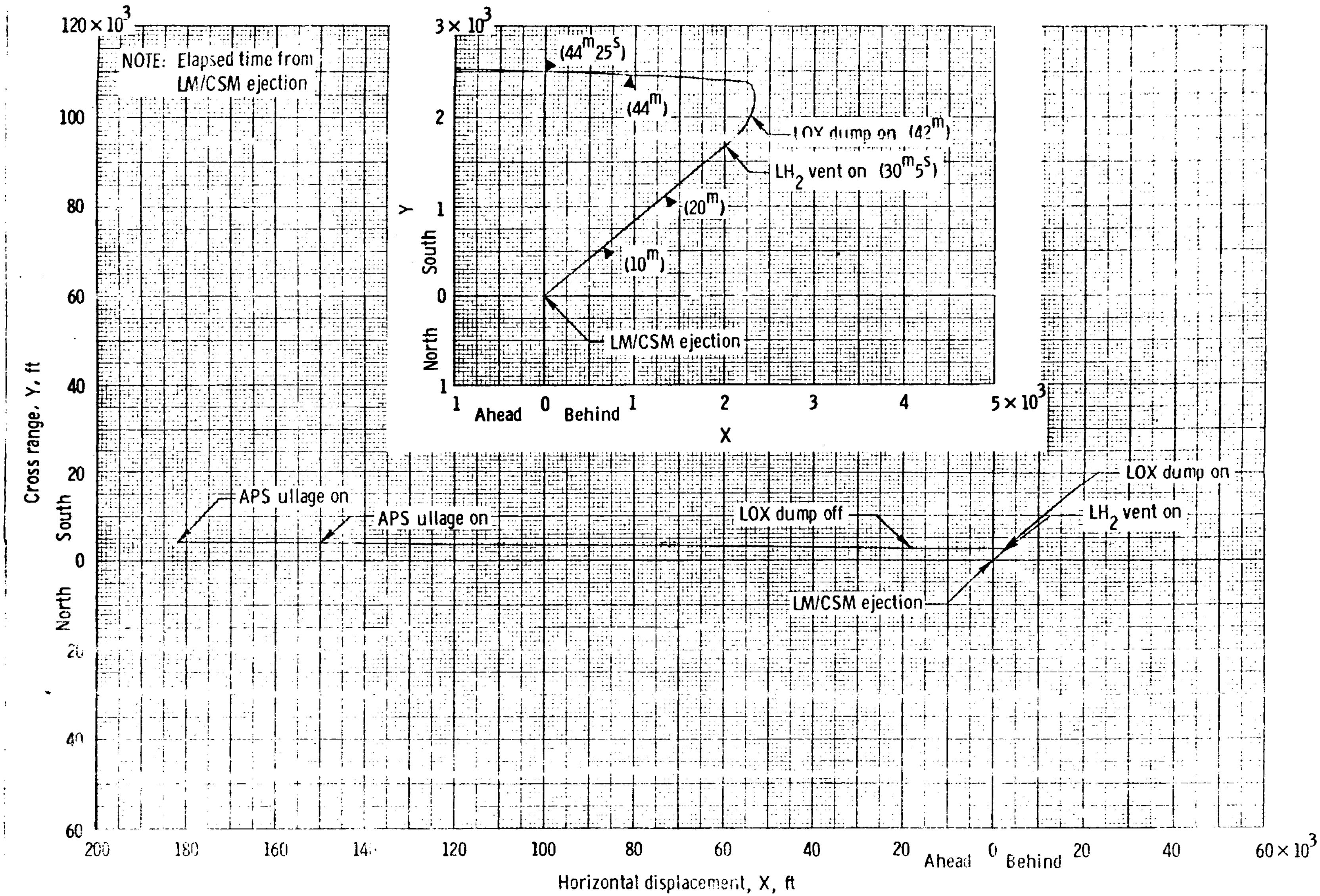
(c) Range versus time.

Figure 2.- Concluded.



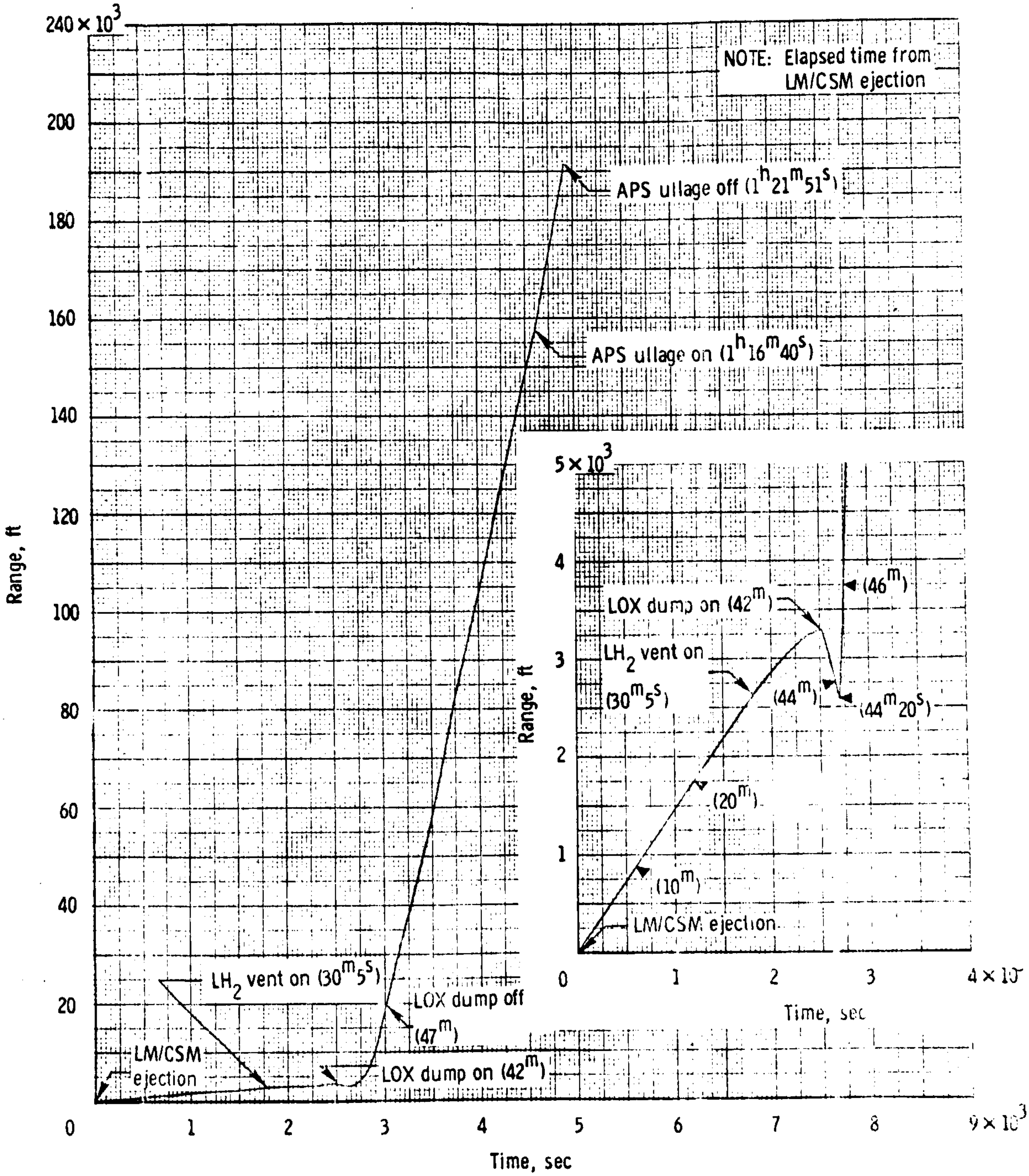
(a) Vertical displacement versus horizontal displacement.

Figure 3.- RCS evasive maneuver, dump sequence begins at 2^h00^m.



(b) Cross range versus horizontal displacement.

Figure 3. - Continued.



(c) Range versus time.

Figure 3. - Concluded.

APPENDIX E

CSM/LM CLOSE-IN SEPARATION RANGE FROM THE S-IVB VS TIME FOR APOLLO MISSIONS F AND G, WITH AND WITHOUT RCS TRANSLATION AT EJECTION

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

NASA - Manned Spacecraft Center
Mission Planning & Analysis Division

TO : See List Below

DATE: MAY 1 1969

69-FM37-182

FROM : FM3/Flight Analysis Branch

SUBJECT: CSM/LM close-in separation range from the S-IVB vs time for Apollo Missions F and G, with and without RCS translation at ejection

Introduction

At 1.5 hours after TLI cutoff, four spring actuators will eject the CSM+LM from the S-IVB. This ejection will impart a separation ΔV to the spacecraft and the launch vehicle. As the S-IVB fuel impacts the tank walls, the S-IVB ΔV will decrease, as is shown in Table 1. In addition, the spacecraft RCS thrusting added to the spring ejection ΔV will also alter the separation. The S-IVB LH_2 vent will not be opened during the ejection phase.

Summary

To determine range vs time parameters for CSM/LM ejection, the following factors were considered: Spring efficiencies of 90 per cent (maximum), 70 per cent (nominal), and 48 per cent (minimum) and the respective ΔV's based on the NR fuel-slosh model (Table 1). Each case was simulated with and without a 3 second spacecraft RCS -X translation at 5 seconds after ejection (figures 1-3). The results indicate that 25 seconds after ejection the effect of using a 3 second RCS translation will increase the separation range by approximately 7 feet for a 90, 70, or 48 per cent efficient spring (Table 2). The time required for the CSM/LM (spacecraft) to obtain a displacement of 25 feet and a footpad clearance of approximately 14 feet from the SLA ring station is reduced from 24 to 19 seconds by using a 3 second RCS translation for nominal (70 per cent) spring efficiency (Table 2). For 90 and 48 per cent spring efficiencies, the time required to achieve a 25 foot separation displacement is reduced by 4 and 7.5 seconds, respectively.

Conclusion

When comparing the ejection procedure for varying spring actuator efficiencies (48, 70, and 90 per cent), and with and without the spacecraft 3 second RCS -X thrusting to determine when a 25 foot separation distance is achieved, the following results:

Procedure	Time (seconds)
1. With RCS -X thrusting 5 seconds after ejection	$19.0^{+2.5}_{-1.5}$
2. Ejection with no RCS thrusting	$24.0^{+5.0}_{-2.5}$

Note: This considers a spring efficiency of 70 per cent nominal with an unknown of +20 per cent and -22 per cent, respectively. Further, it considers the RCS thrusting to be with 4 jets and nominal.

Since there is a relatively small change in time required to reach the 25 foot separation criteria, the Flight Analysis Branch recommends the ejection be made without the use of RCS thrusting at 5 seconds. Additionally, adding the RCS system into use at this time adds more unknown because of the deviation which can be attributed to that system. Concisely, adding the RCS system and the spring actuator unknowns together will make it more difficult to determine exactly when the 25 foot separation criteria has been reached.

REM

CCA

Marland L. Williamson

Marland L. Williamson

APPROVED BY:

John P. Mayer
Chief, Mission Planning
and Analysis Division

Addressees:
(See attached page)

Table 1*

CSM/LM Ejection Separation Rates
(No Propulsive Venting, TLI Weights)

Spring Actuator Efficiency	Time From Separation (sec)	Separation Velocity (ft/sec)	S-IVB Separation Distance (ft)
90 per cent Maximum	0.0(1)	1.23	0.6
	14.3(2)	1.08	13.6
	39.4(3)	1.04	32.6
	396.0(4)	1.05	415.0
70 per cent Nominal	0.0	1.10	0.6
	16.1	0.96	13.6
	44.7	0.93	32.6
	446.0	0.93	415.0
48 per cent Minimum	0.0	0.91	0.6
	19.5	0.79	13.6
	53.9	0.77	32.6
	540.0	0.77	415.0

(1) Actuator stroke out
(2) LOX impact with top of tank
(3) LH_2 impact with top of tank
(4) LOX impact with bottom of tank

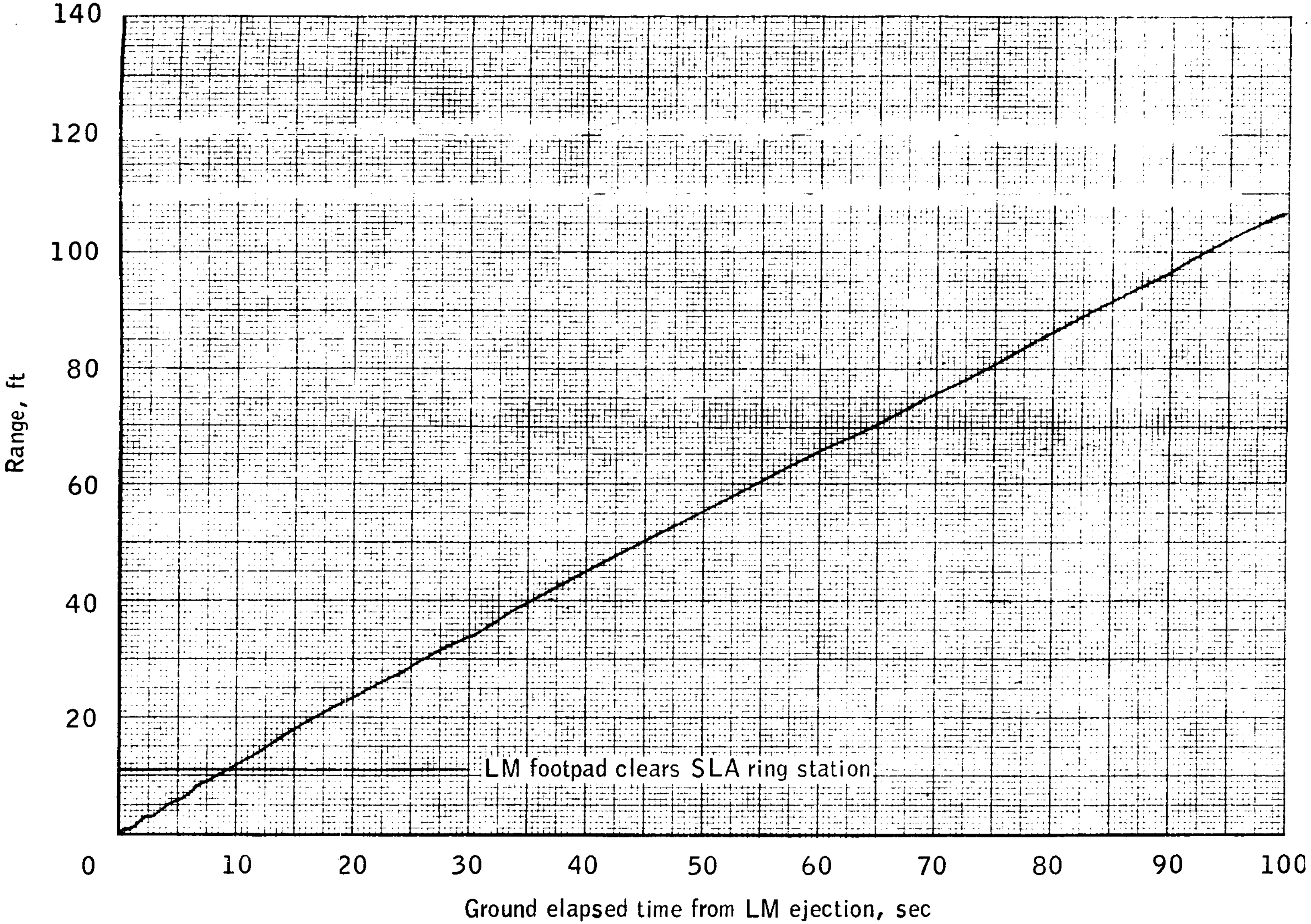
*This data was received through Mr. R. L. Kubicki from NR and is based on the NR fuel slosh model.

Table 2

Comparison of CSM/LM Ejection With and Without 3 Seconds of RCS

Spring Efficiency	With RCS	Without RCS	Time (sec)	Distance* (ft)
90 per cent	X		25	36
90 per cent		X	25	29
70 per cent	X		25	33
70 per cent		X	25	26
48 per cent	X		25	29
48 per cent		X	25	22
90 per cent	X		17.5	25
90 per cent		X	21.5	25
70 per cent	X		19.0	25
70 per cent		X	24.0	25
48 per cent	X		21.5	25
48 per cent		X	29.0	25

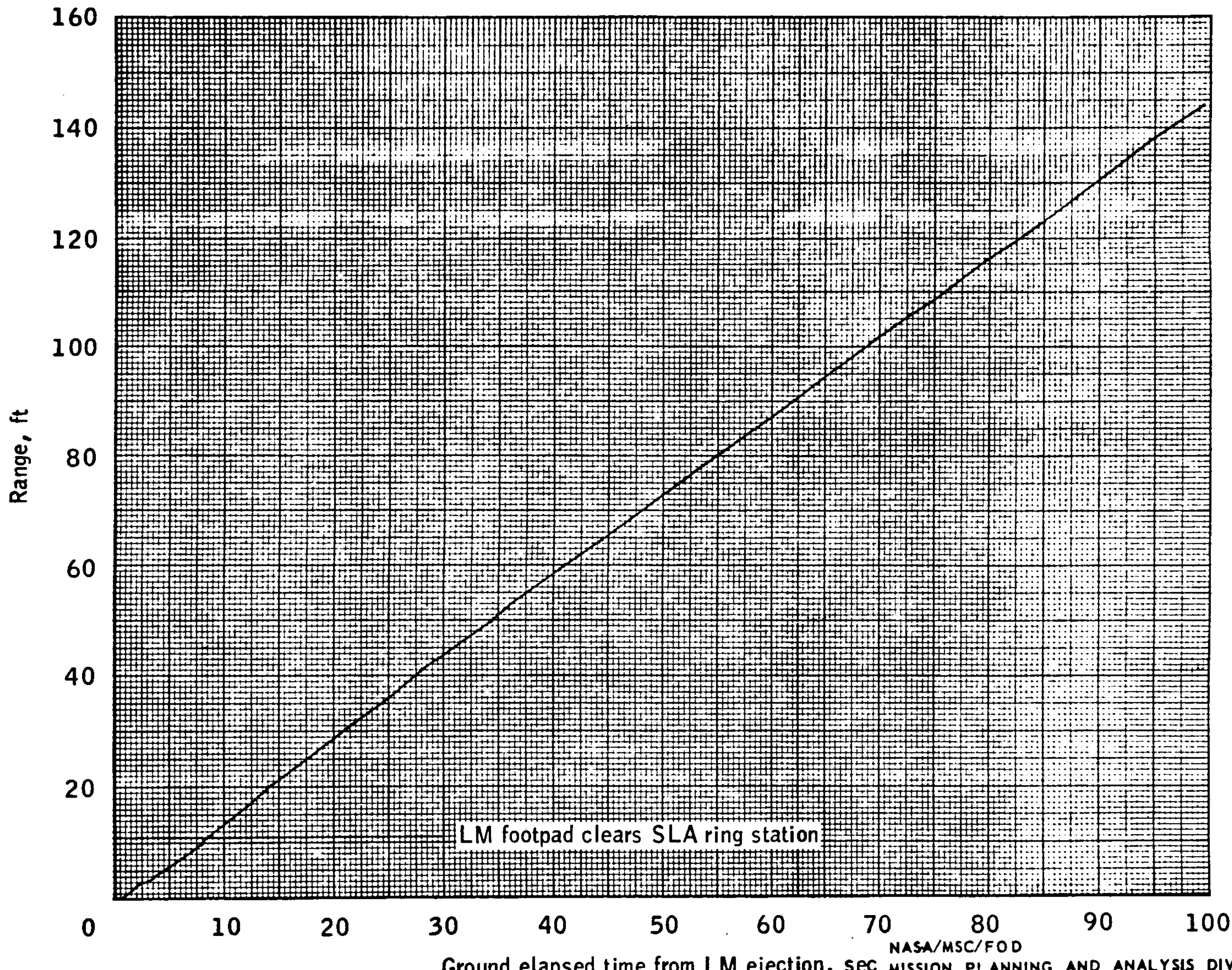
*The distance indicates the change in the relative positions of the CSM and S-IVB c.g.'s. The LM footpad clearance from the SLA ring station can be determined by subtracting 11 feet from the distances presented.



(a) No RCS translation at ejection.

NASA/MSC/FOD
MISSION PLANNING AND ANALYSIS DIVISI
BRANCH FAB DATE 5/1/69
BY Williamson PLOT NO. 18412

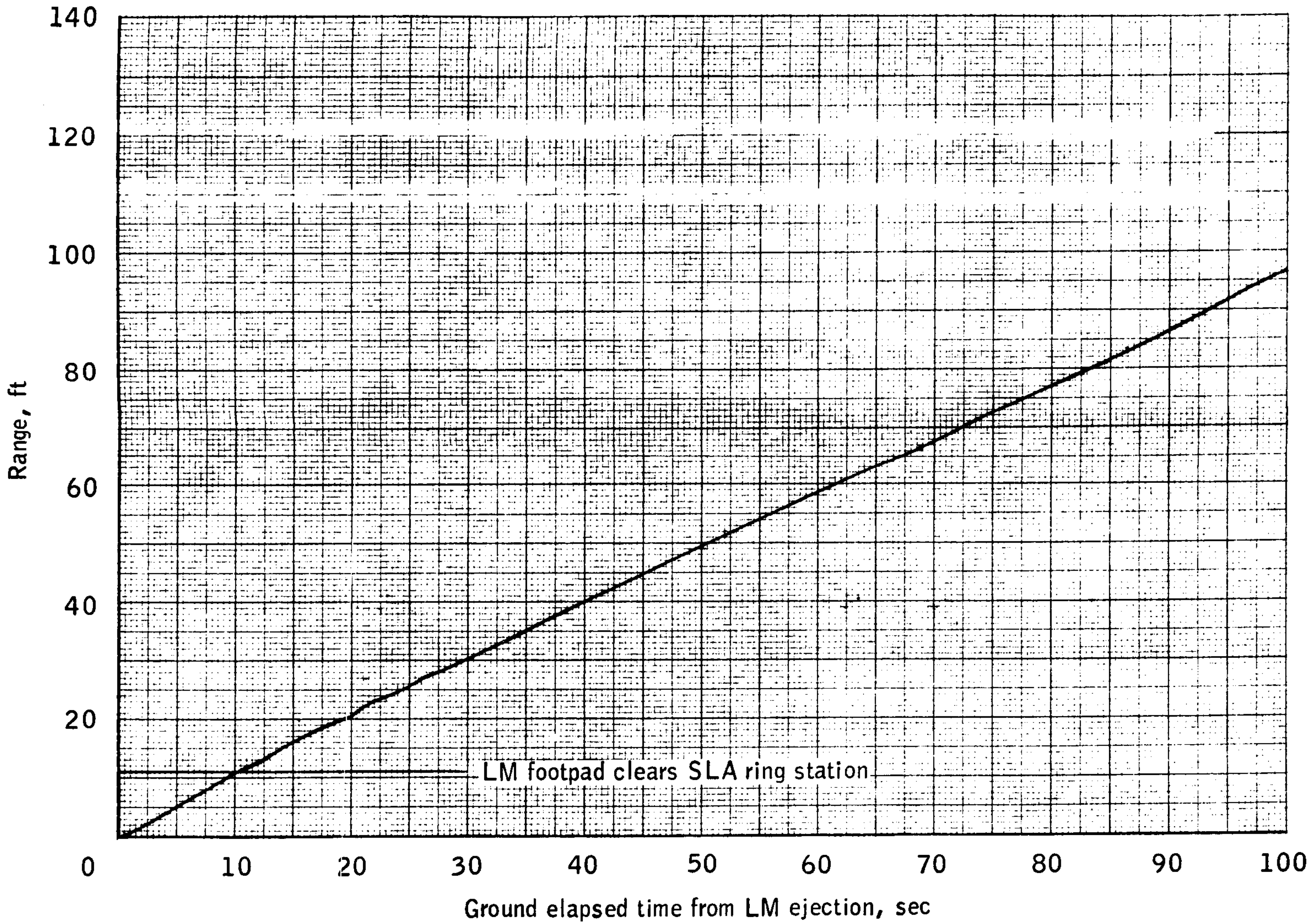
Figure 1.- Range versus time for CSM/LM ejection from the S-IVB, 90 percent efficient springs.



NASA/MSC/FOD
MISSION PLANNING AND ANALYSIS DIVISION
BRANCH FAB DATE 5/1/69
BY Williamson PLOT NO. 18413

(b) 3 second RCS translation at 5 seconds after ejection.

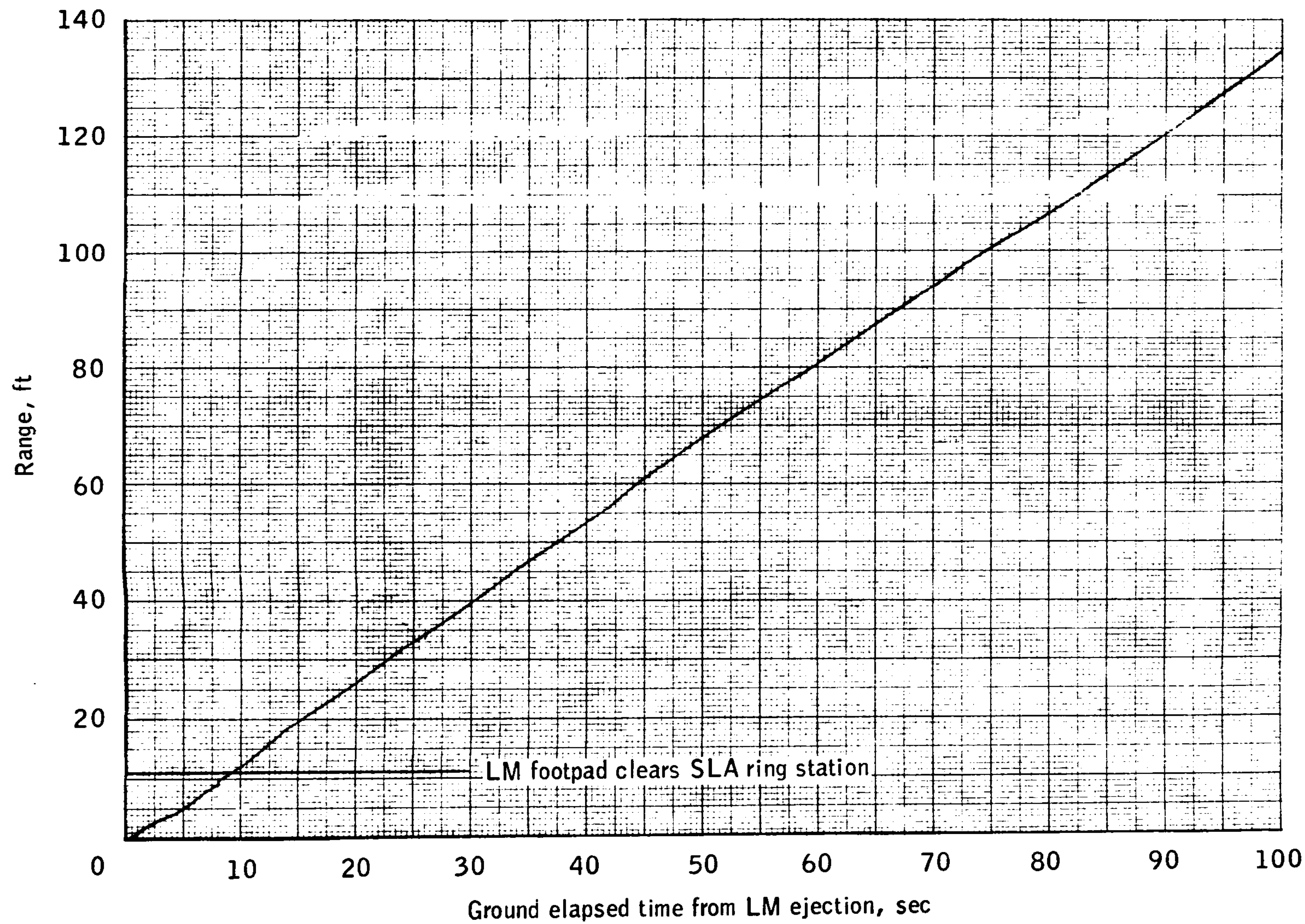
Figure 1.- Concluded.



NASA/MSC/FOD
MISSION PLANNING AND ANALYSIS DIVISI
BRANCH FAB DATE 5/1/69
BY Williamson PLOT NO. 18414

(a) No RCS translation at ejection.

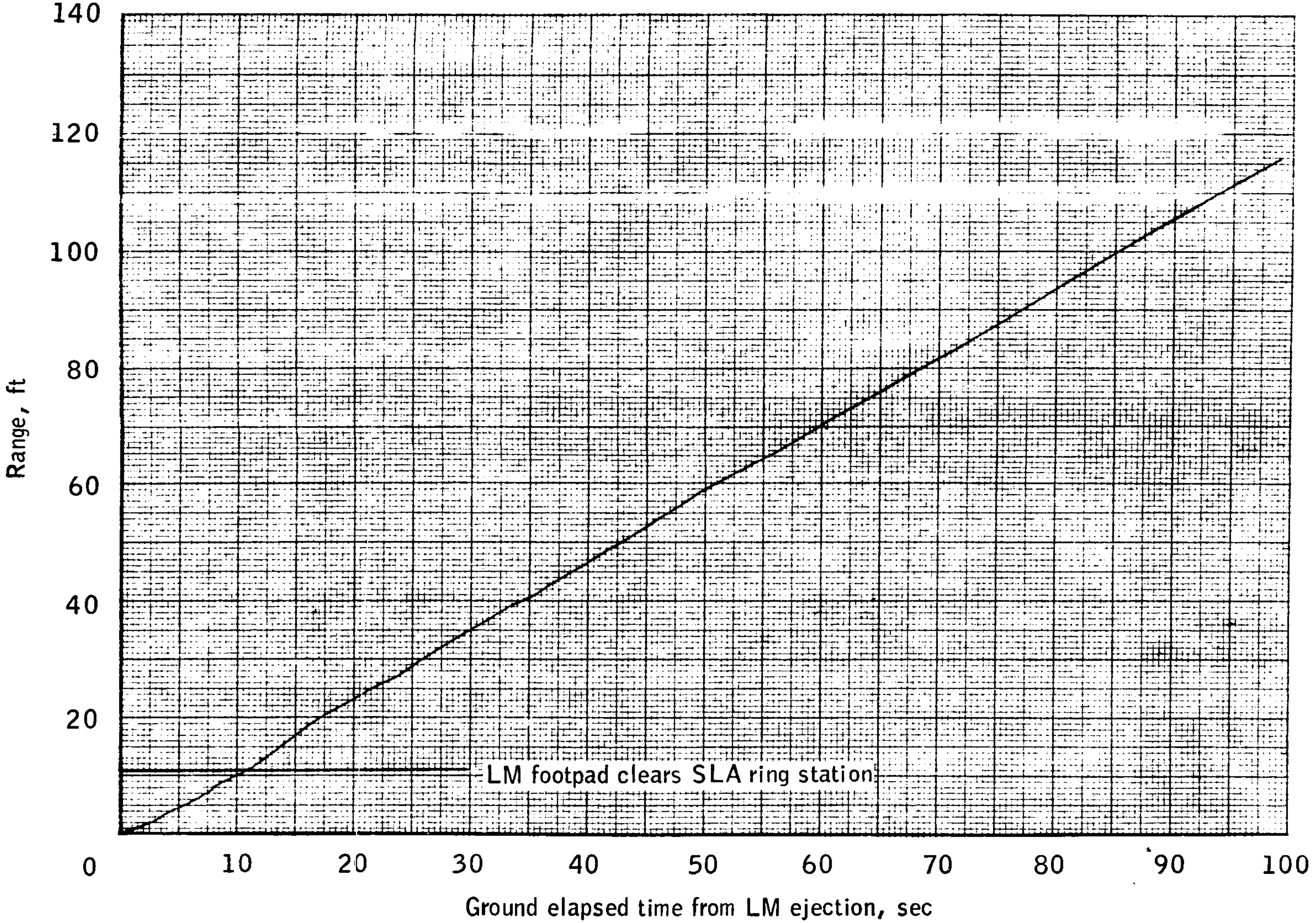
Figure 2.- Range versus time for CSM/LM ejection from the S-IVB, 70 percent efficient springs.



(b) 3 second RCS translation at 5 seconds after ejection.

Figure 2.- Concluded.

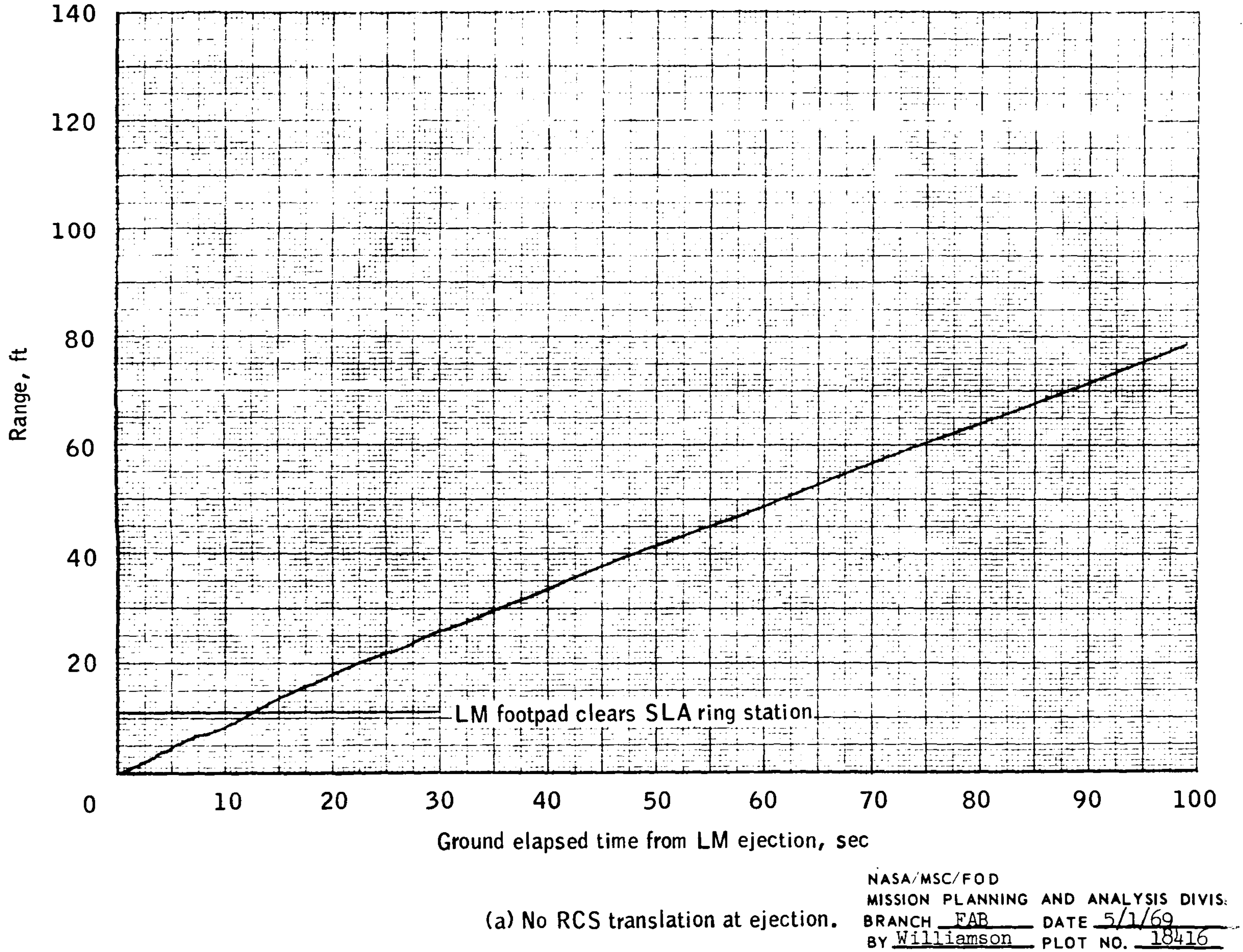
NASA/MSC/FOD
MISSION PLANNING AND ANALYSIS DIVISIC
BRANCH FAB DATE 5/1/69
BY Williamson PLOT NO. 18415



(b) 3 second RCS translation at 5 seconds after ejection.

Figure 3.- Concluded.

NASA/MSC/FOD
MISSION PLANNING AND ANALYSIS DIVI
BRANCH FAB DATE 5/1/69
BY Williamson PLOT NO. 13-17



(a) No RCS translation at ejection.

Figure 3.- Range versus time for CSM/LM ejection from the S-IVB, 48 percent efficient springs.

APPENDIX F

OUT-OF-PLANE CM/SM SEPARATION AND RECONTACT ANALYSIS FOR TLI ABORTS, TLC ABORTS AND NOMINAL ENTRY FOR MISSION F

TRW

5524.8-46
8 April 1969

National Aeronautics and Space Administration
Manned Spacecraft Center
Houston, Texas 77058

Attention: Mr. M. L. Williamson, Monitor, MSC/TRW Task A-122.1
Mission Planning and Analysis Division

Subject: Out-of-plane CM/SM Separation and Recontact Analysis for TLI Aborts, TLC Aborts and Nominal Entry for Mission F

Gentlemen:

The attachment to this letter presents the results of out-of-plane CM/SM separation and recontact analysis for Mission F. The analysis determines the recontact possibilities between the CM and SM during high speed entries which result from TLI aborts, TLC aborts and nominal entry. The study is restricted to the CM/SM entry profile for which the CM banks to the same direction as the SM is jettisoned at separation. There is no recontact problem for the nominal entry. For TLI or TLC, recontact problems develop when the SM separation weight and ΔV are less than 16,000 pounds and 18 feet per second, respectively.

Yours truly,

L. Jefferson
Analytic Mechanics Section

G. A. Skandalis, Task Manager
MSC/TRW Task A-122.1
Analytic Mechanics Section

W. F. Heugel
Assistant Project Manager
Mission Trajectory Control Program

LJ:DMG:PGW:eac

Attachments

5524.8-46
8 April 1969
Page 2

DISTRIBUTION

MSC

C. C. Allen FM3
R. V. Battey PD
M. S. Burton FM15
M. E. Donahoo FM3
C. J. Gott FM3
C. R. Huss FM
R. E. McAdams FM3
D. Owen FM
R. P. Parten FM13

TRW

J. M. Dreyfus
H. O. Eley
J. A. Gay
J. M. Wagner
MSD Section Heads
A-122 Personnel

TRW

5524.8-46
8 April 1969

Out-of-plane CM/SM Separation and Recontact Analysis for TLI Aborts, TLC Aborts and Nominal Entry for Mission F

MSC/TRW Task A-122.1

Prepared by:

L. Jefferson

Analytic Mechanics Section
TRW Systems Group

INTRODUCTION

This letter presents the results of CM/SM separation and recontact analysis for TLI aborts, TLC aborts and nominal entry for Mission F. The analysis is in partial fulfillment of requirements outlined in Reference 1. The analysis examines recontact possibilities between the CM and SM after separation during a lunar return nominal entry and CM/SM entries which result from aborts during TLI or TLC.

The simulation is restricted to the entry profile for which the CM banks at 1.5 g in the same direction the SM is jettisoned at separation. The intent is to simulate guidance commands which may send the CM south of the orbit plane. If the CM banks opposite to the direction that the SM is jettisoned then there is obviously no recontact problem.

For the lunar return nominal entry, the analysis considers the effect of delayed CM/SM separation (reduces nominal t_{ff}) on relative separation distance. The t_{ff} values considered are 15 minutes (nominal), 10 minutes and 5 minutes. For aborts during TLI or TLC, SM weights at CM/SM separation range from approximately 12,000 to 40,000 pounds. However, only those from 12,000 to 16,000 pounds can result in recontact problems.

DISCUSSION

The TLI abort region is approximately 5 minutes 7 seconds long followed by TLC which extends to initiation of the LOI maneuver. A time critical abort during TLI initiates the following sequence for the fastest possible return to earth.

Time from S-IVB Cutoff (min:sec)	Event
00:00	S-IVB C/O Four +X RCS jets on
00:03	CSM/S-IVB separation
00:13	+X RCS jets off Pitch to local vertical (CSM + X-axis with radius vector towards earth)
01:00	Four -X RCS jets on
01:08	-X RCS jets off Maneuver CSM to retro burn attitude
10:00	SPS ignition - (SCS auto retro burn)
Varible (Depending on the g.e.t. at which the abort occurs. Other abort procedures are given in Reference 2.)	CM/SM Separation

The sequence simulated here begins with an out-of-plane CM/SM separation. On reaching a sensible atmosphere, the CM flies a full-lift trajectory to 1.5 g and then banks (south) in the same direction the SM is jettisoned at separation. The analysis is restricted to this entry profile, since to bank opposite to the direction the SM is jettisoned makes recontact impossible. In addition, the sequence investigated simulates the effects of guidance commands which may send the CM south of the orbit plane.

The high speed operational entry corridor is presented in Table 1 and Figure 1. Further discussion of the entry corridor is contained in Reference 3. Aborts during TLI or TLC are always targeted to the steep target line, on which also lies the nominal entry point. The nominal entry point, due to the large entry velocity, is the worst case with respect to CM/SM relative separation distance. Therefore, initial conditions at separation for all cases in this analysis are based on this worst case entry point. It should be noted that for high speed entries CM roll commands are restricted to plus or minus 15 degrees until 1.5 g (0.2 g for low-speed entries). Subsequent to this g-point however, any maneuver may be performed.

Table 2 shows Mission F CM and SM vehicle characteristics and Table 3 presents initial conditions at CM/SM separation for a lunar return nominal entry at different values of t_{ff}. The nominal t_{ff} is 15 minutes. Other t_{ff} values of 10 minutes and 5 minutes are presented to show the effect of delayed CM/SM separation on relative motion during entry. The horizon monitor CM/SM separation attitude is heads down for Mission F (see Figure 2). Figure 3 illustrates the in-plane relative motion during a lunar return nominal entry for bank angles of 55 degrees and 90 degrees south. These bank angles are held constant in the same direction the SM is jettisoned from 1.5 g to splashdown. The separation ΔV is the redline value of 5 feet per second. The relative motion for different t_{ff} is shown in Figure 4.

Vehicle characteristics following aborts during TLI or TLC are presented in Table 4. Depending on the duration of the SPS deorbit burn, SM weights at CM/SM separation range from approximately 12,000 pounds to 40,000 pounds. However, only SM weights between 12,000 and 16,000 pounds can result in recontact problems. Figure 5 shows that for a separation ΔV of 5 feet per second, the path of the SM for this weight range goes behind the CM, with recontact problems indicated for SM weights between 15,000 and 16,000 pounds. For larger separation ΔV's, the SM path shifts forward and thus creates recontact problems for all SM weights less than 16,000 pounds. Figure 6, however, shows that a separation ΔV of 18 feet per second will alleviate all these problems.

Note that these recontact problems result only when the CM banks in the same direction the SM is jettisoned at separation. Figure 7 shows the separation ΔV required to alleviate the recontact problem for a given SM weight at separation. The corresponding RCS burn time and propellant requirement are presented in Figure 8.

SUMMARY AND CONCLUSIONS

This analysis was performed to examine the recontact possibilities between the CM and SM for entry profiles which require the CM to bank in the same direction the SM is jettisoned. The results show that there is no recontact problem for the lunar return nominal entry regardless of direction the CM banks. The in-plane separation distance is sufficient to avoid any recontact problem.

CM/SM entries which result from aborts during TLI or TLC develop recontact problems for SM separation weights between 12,000 and 16,000 pounds. Depending on the duration of the SPS deorbit burn, aborts during early TLI can produce SM weights during entry as large as 40,000 pounds. But only the smaller weights in conjunction with separation ΔV's less than 18 feet per second create recontact problems. Consequently, the following conclusions are reached concerning high-speed CM/SM entry.

1) There is no CM/SM recontact problem for the F Mission lunar return nominal entry regardless of the direction the CM banks at 1.5 g.

2) For aborts during TLI and TLC, there is no recontact problem if SM weight during entry is greater than 16,000 pounds or separation ΔV is greater than 18 feet per second.

3) If both SM weight and separation ΔV are less than 16,000 pounds and 18 feet per second, respectively, then always bank CM at 1.5 g opposite in direction SM jettisoned to assure no recontact problem.

NOMENCLATURE

BA	Bank Angle
CM	Command Module
CSM	Command Service Module
ε	SM pitch attitude at CM/SM separation
g.e.t.	ground elapsed time
h	spacecraft altitude at CM/SM separation
LOI	Lunar Orbit Insertion
γ_I	inertial flight-path angle
γ_{sep}	Spacecraft inertial flight-path angle at CM/SM separation
SCS	Stabilization and Control System
sec	second
SPS	Service Propulsion System
t_{ff}	estimated time of CM free fall from CM/SM separation to an altitude of 400,000 feet
TLC	Translunar Coast
TLI	Translunar Injection
V_I	inertial velocity
V_{sep}	Spacecraft inertial velocity at CM/SM separation

REFERENCES

1. G. A. Skandalis, "Separation and Recontact Analysis for Mission F, (MSC/TRW Task A-122)," TRW IOC No. 5524.8-42, March 31, 1969.

2. "Apollo Mission Techniques, Missions F and G Contingency Procedures," MSC Internal Note No. S-PA-9T-043, March 3, 1969.

3. B. D. Medearis, "RTCC Return-to-Earth Abort Processor, Entry Range Functions (Missions E and F)," TRW Note No. 68-FMT-685, November 30, 1968.

TABLE 1. Mission F

High Speed Operational Entry Corridor

Entry Velocity V_I (feet/second)	Entry Flight-Path Angle, γ_I (degrees) Steep Target Line	Shallow Target Line
27,000	-4.31	-2.91
28,000	-4.78	-3.62
29,000	-5.13	-4.17
30,000	-5.41	-4.59
31,000	-5.66	-4.96
32,000	-5.86	-5.27
33,000	-6.05	-5.54
34,000	-6.21	-5.80
35,000	-6.36	-6.03
36,210.49	-6.49	(Nominal entry point) Worst case with respect to CM/SM relative separation distance.

TABLE 2. Mission F

CM and SM Vehicle Characteristics

Parameter	CM	SM
Weight at Separation	12,135 pounds	16,254 pounds
Drag Coefficient, C_D	1.3022	1.8
Lift-to-drag ratio, L/D	0.2912	---

TABLE 3. Initial Conditions at CM/SM Separation for a Lunar Return Nominal Entry at Different Values of t_{ff}

Nominal Entry Point *						
Velocity (ft/sec)	γ (deg)	t_{ff} (min)	V_{sep} (ft/sec)	γ_{sep} (deg)	h (ft)	ε (deg)
36,210.49	-6.49	(nominal) 15	29,007.6	-36.9	12,179,080	19.09
↓	↓	10	31,515.7	-29.9	7,164,943	10.15
↓	↓	5	34,193.3	-20.1	2,969,906	-2.83

* Worst case with respect to CM/SM relative separation distance.

TABLE 4. Vehicle Characteristics Following Aborts During TLI and TLC

	Abort, g.e.t. hr:min:sec	Approximate time from TLI cutoff, hr	CSM ΔV feet/second	SPS burn time, seconds	Weight loss,* due to deorbit burn, pounds	SM weight at separation pounds
Trans-Lunar Injection, TLI	2:51:22.7	-0.050 (3 min)	1,517.8	150.0	9,750	41,760.0
	2:53:42.7	-0.033 (2 min)	2,276.7	225.0	14,625.0	36,885.0
	2:55:22.7	0	4,047.5	400.0	26,000.0	25,510.0
Trans-Lunar Coast, TLC	4:25:42.7	1.5	5,125.0	506.5	32,922.5	18,587.5
	7:00:00	4.0	5,543.4	547.8	35,607.0	15,903.0
	14:00:00	11.0	4,759.2	470.3	30,569.5	20,940.5
	28:00:00	25.0	5,319.2	527.7	34,170.5	17,339.5
	38:00:00	35.0	4,703.7	464.8	30,212.0	21,298.0
	47:00:00	44.0	6,108.9	603.7	39,240.5	12,269.5

* Assumed CSM weight at SPS deorbit burn initiation = 63,645 pounds

Mass flow, $\dot{m}$ = 65 pounds/second

SPS thrust = 20,000 pounds

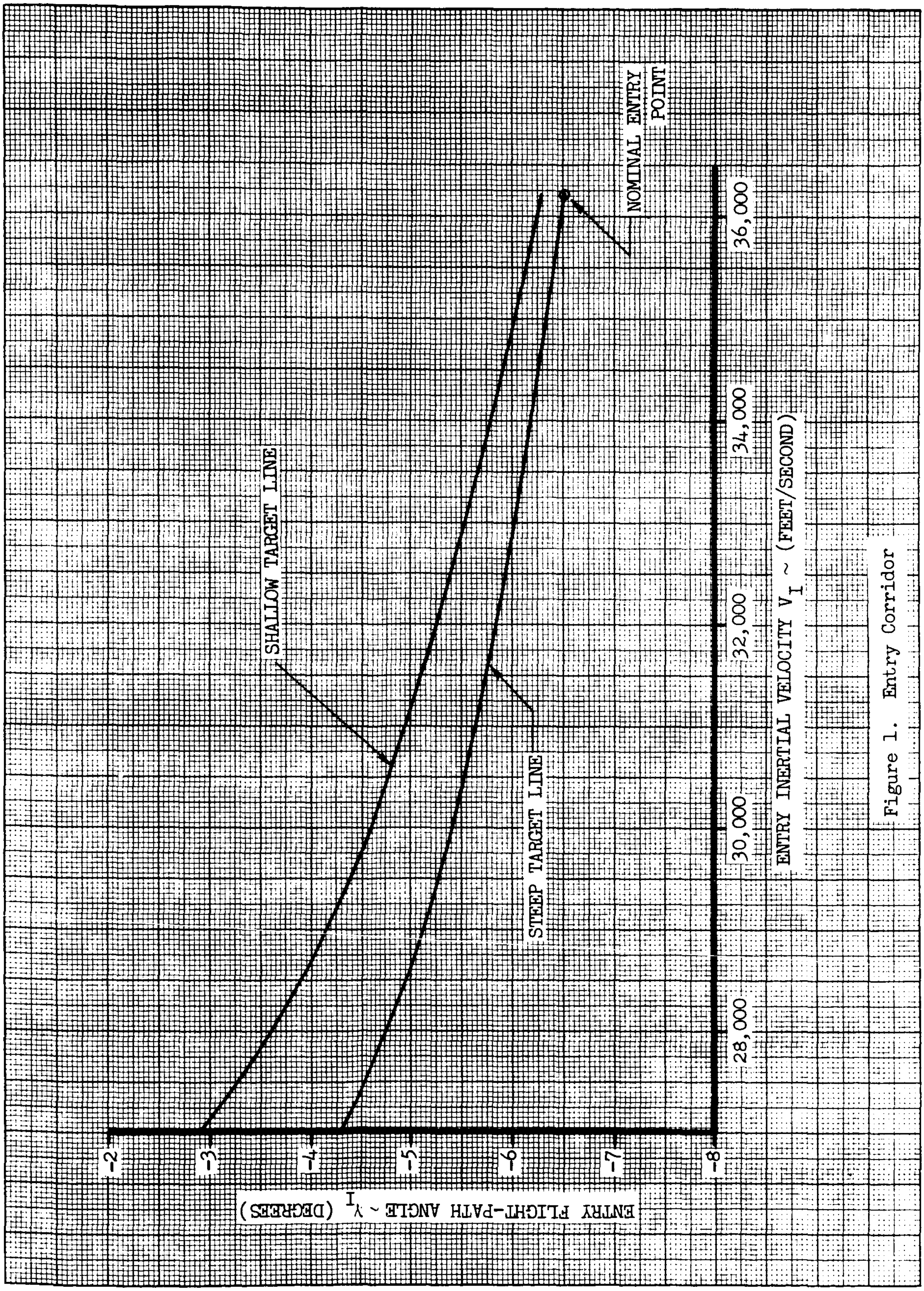


Figure 1. Entry Corridor

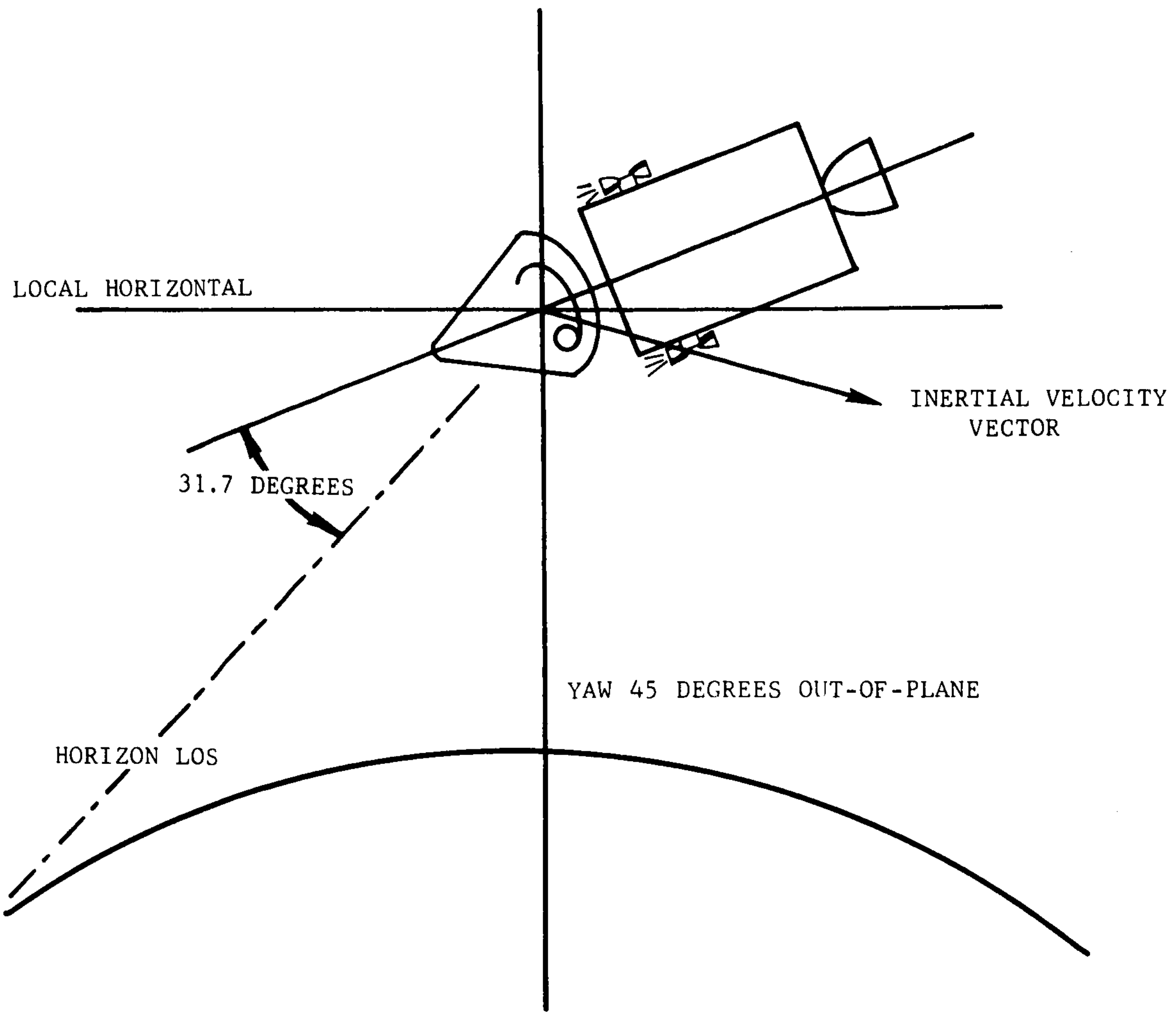


Figure 2. CM/SM Separation Attitude

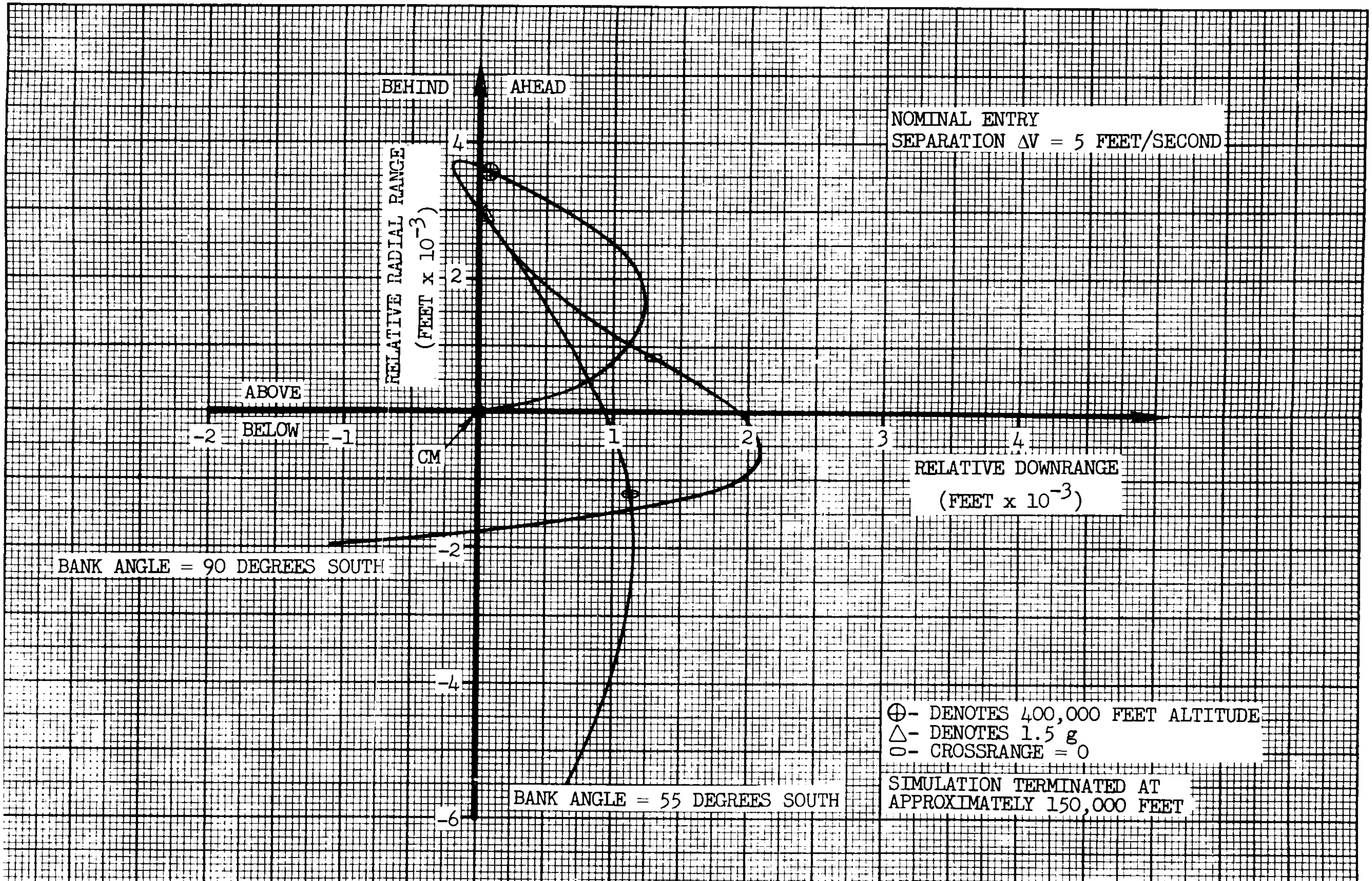


Figure 3. In-plane CM/SM Relative Motion

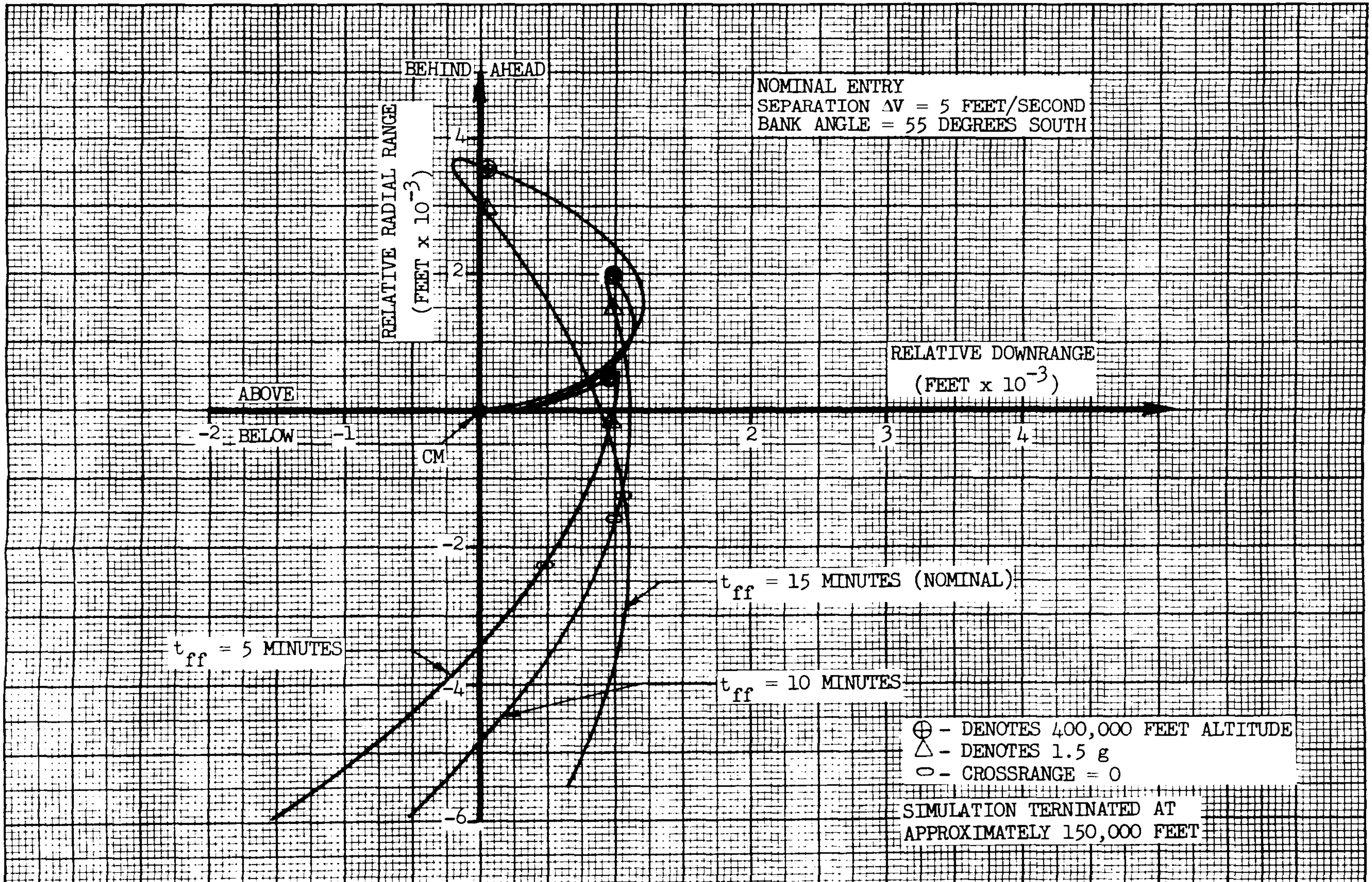


Figure 4. In-plane CM/SM Relative Motion for Different t_{ff}

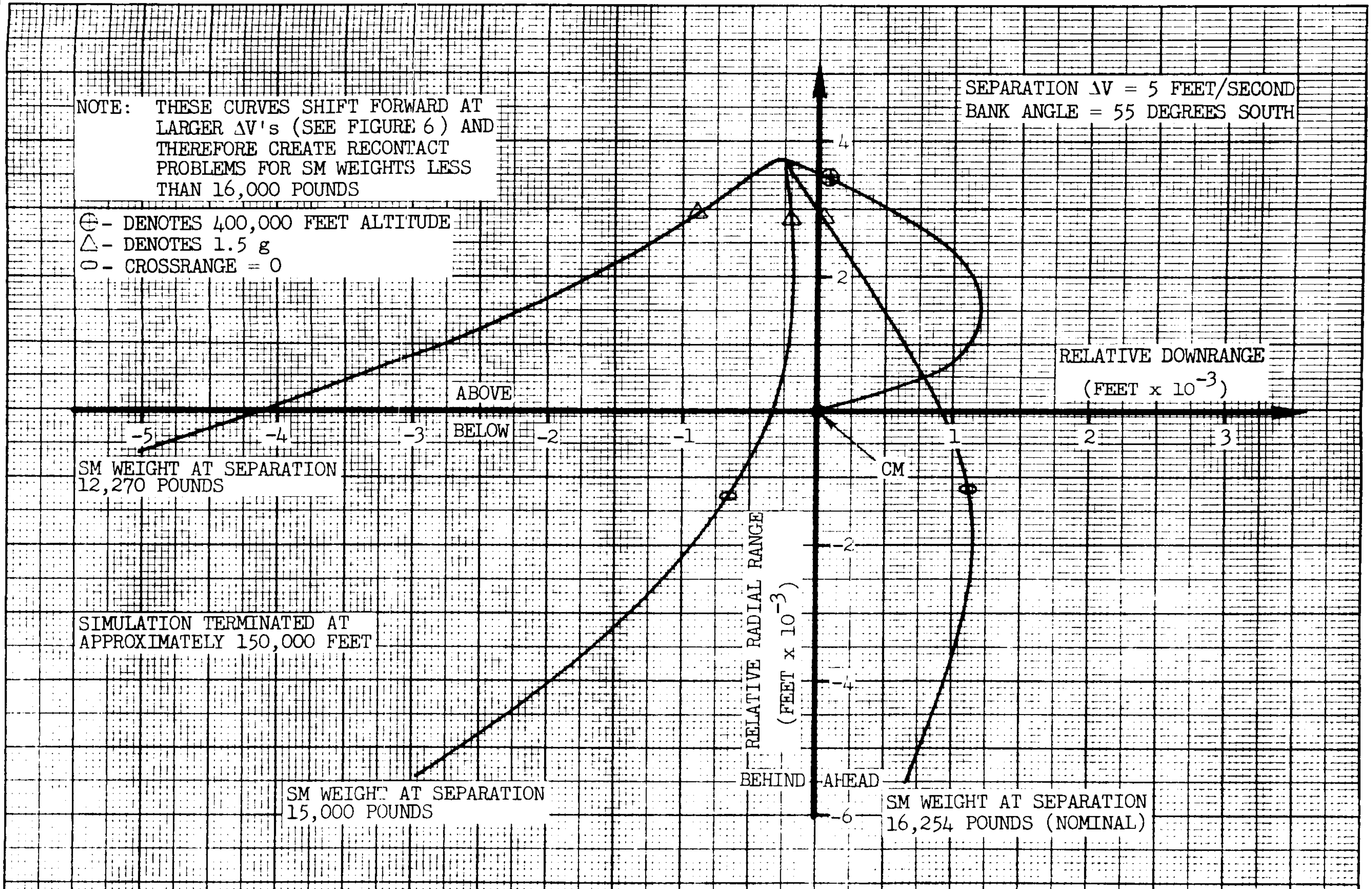


Figure 5. In-plane CM/SM Relative Motion

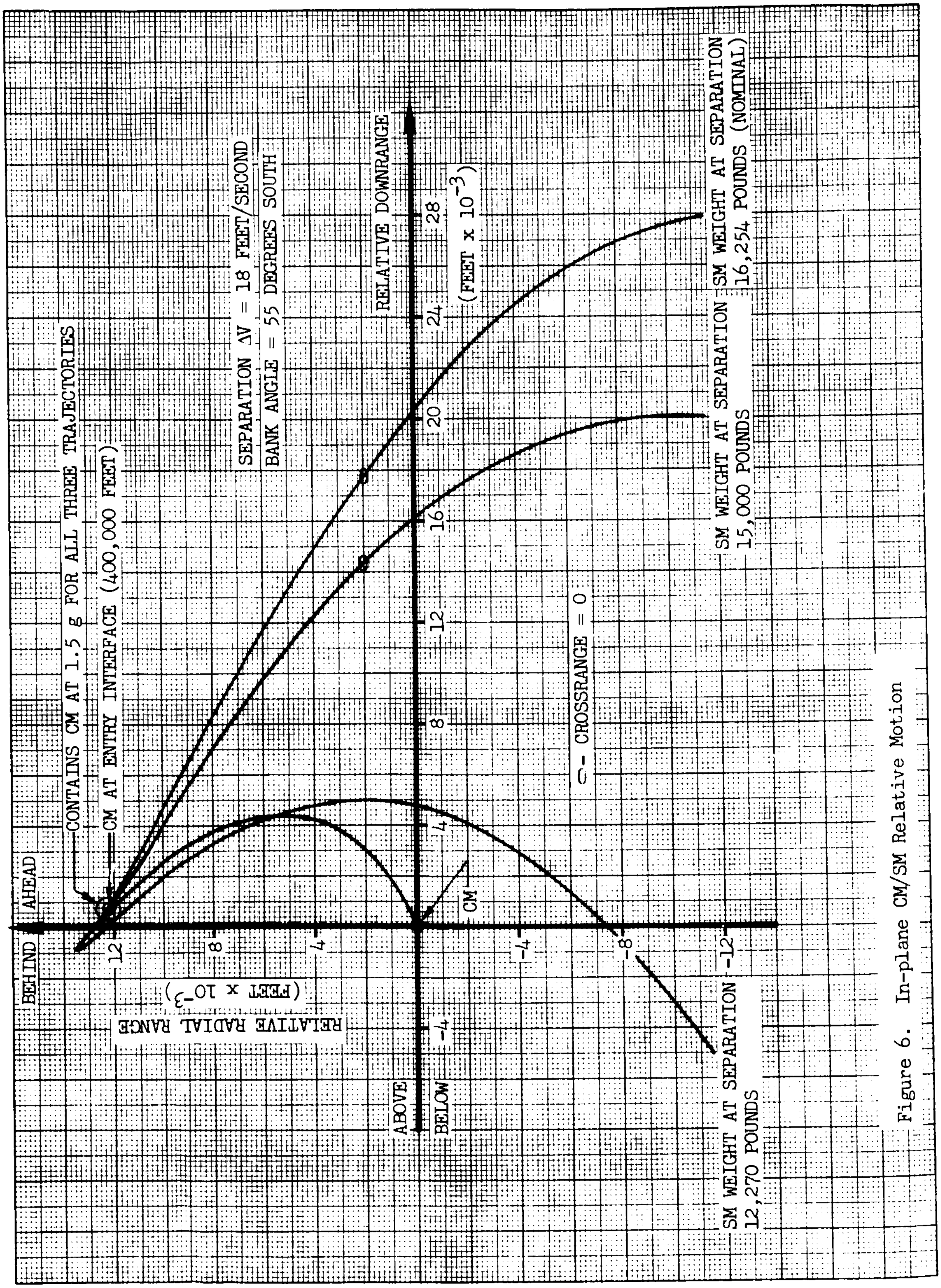


Figure 6. In-plane CM/SM Relative Motion

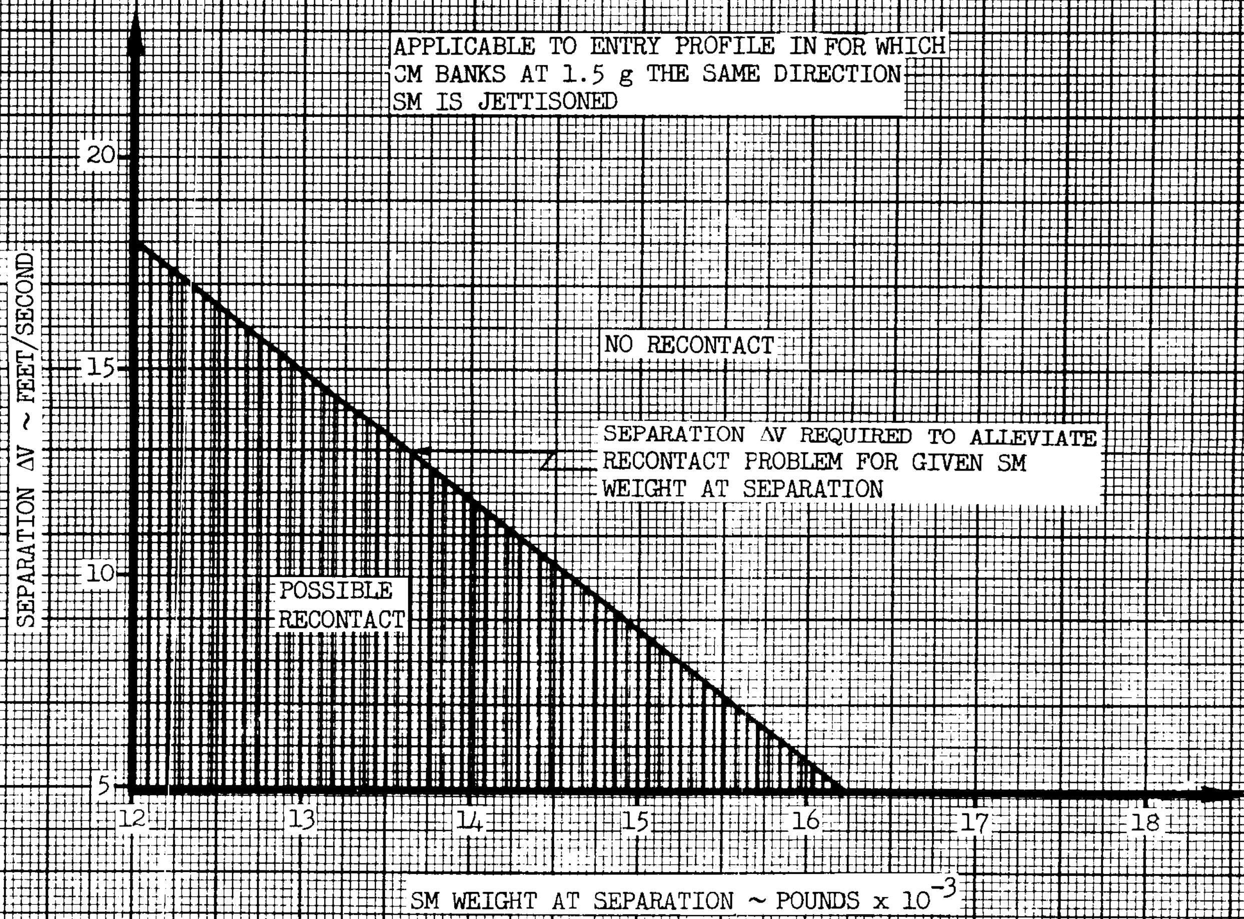


Figure 7. Separation ΔV Required to Alleviate Recontact

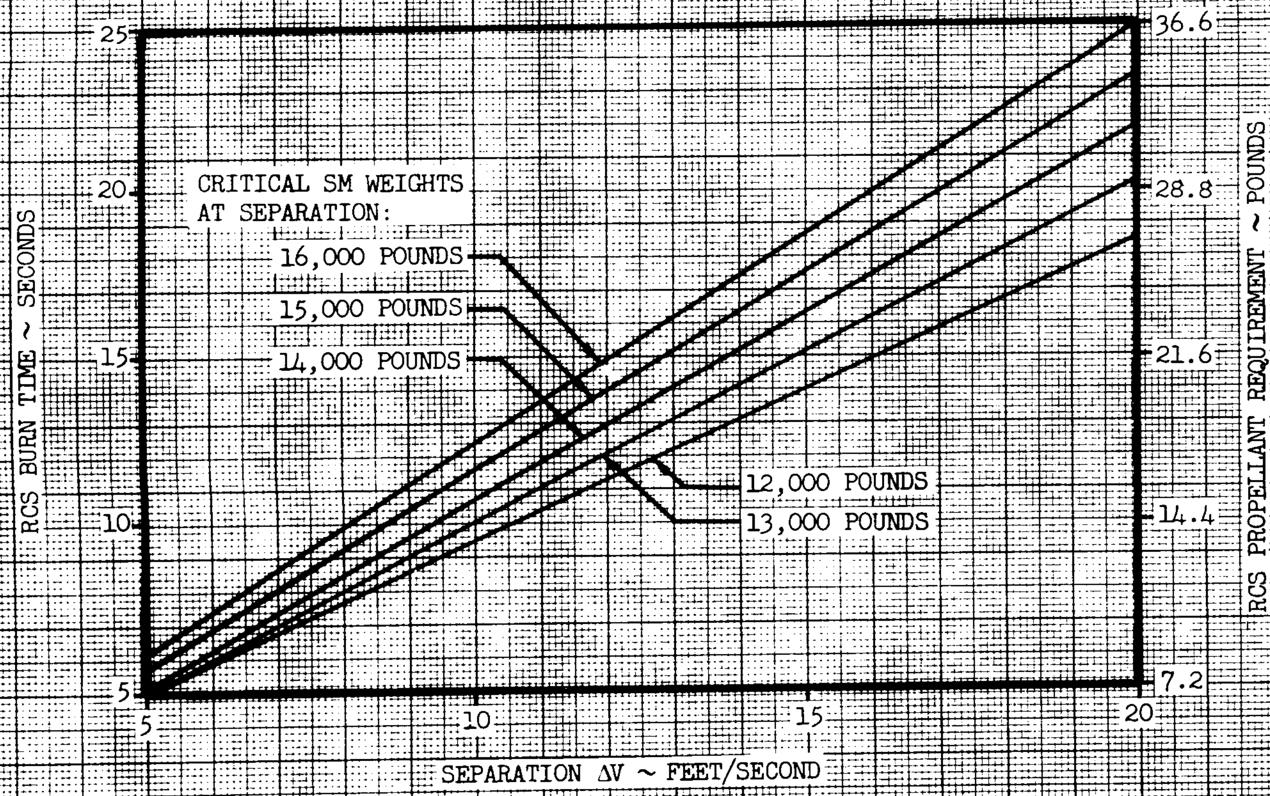


Figure 8. RCS Burn Time and RCS Propellant Requirement at Separation for Critical SM Weights

APPENDIX G

CSM SEPARATION FROM THE S-IVB FOR AN IMPENDING DETECTABLE S-IVB EXPLOSION FOR MISSION F (APOLLO 10)

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

NASA-Manned Spacecraft Center
Mission Planning & Analysis Division

TO : Informal Distribution

DATE: MAR 25 1969

69-FM37-139

FROM : FM3/Flight Analysis Branch

SUBJECT: CSM separation from the S-IVB for an impending detectable S-IVB explosion for Mission F (Apollo 10)

Reference: MSC memorandum 68-FM37-452 by Michael F. Donahoo, "CSM/S-IVB separation for an impending detectable S-IVB explosion for Mission C' (Apollo 8)," dated October 25, 1968.

An investigation of the analysis presented in the above reference indicates that the results are applicable to the F mission. The above statement is based on a CSM weight of 63,517 pounds and thrust from the RCS and SPS of 400 and 20,000 pounds, respectively. The following separation timeline will result in a safe separation distance (>7080 feet) within 179 seconds after physical separation.

Time (seconds)	Event
$T_o + 0$	Warning; abort initiated; RCS on
$T_o + 3$	CSM/S-IVB physical separation
$T_o + 6$	RCS off; SPS on
$T_o + 10$	SPS off; coast
$T_o + 182$	Separation distance equals 7080 feet
$T_o + 200$	S-IVB explosion

This information indicates that the crew could delay the abort initiate approximately 18 seconds from warning and still achieve a safe separation distance at warning plus 200 seconds. The information in the reference could also be employed to determine the required burn time for various crew delays after warning as shown in the enclosed figure.

Questions concerning these data should be directed to Michael E. Donahoo, extension 5381.

REM

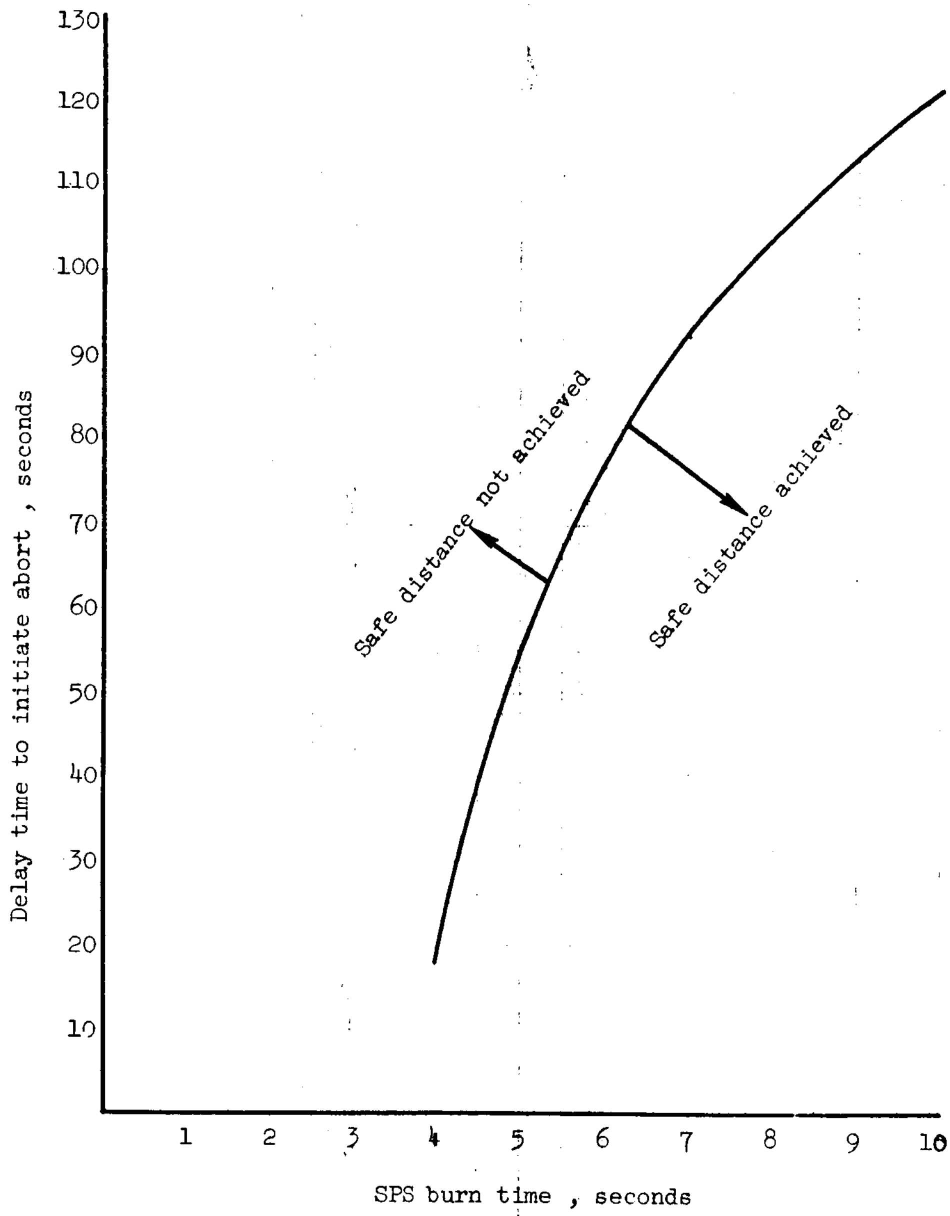
Michael E. Donahoo

APPROVED BY:

Charlie C. Allen
Acting Chief, Flight Analysis Branch

Enclosure

Distribution:
(See attached page)



SPS burn time versus delay time to initiate an abort subsequent to the warning

NASA/MSC/FOD
MISSION PLANNING AND ANALYSIS DIVISION
BRANCH FAB DATE 3/19/69
BY Donahoo PLOT NO. 18390

APPENDIX H

SEPARATION OF THE CSM+LM FROM THE S-IVB FOR AN IMPENDING S-IVB EXPLOSION (MISSION F)

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

NASA - Manned Spacecraft Center
Mission Planning & Analysis Division

TO : See List Below

DATE: APR 2 9 1969

69-FM37-191

FROM : FM3/Flight Analysis Branch

SUBJECT: Separation of the CSM+LM from the S-IVB for an impending S-IVB explosion (Mission F)

Summary

In the event of an impending, detectable explosion on the S-IVB subsequent to T and D and prior to ejection in which there is insufficient time to jettison the LM, the data from the enclosed figure should be used to select an SPS burn ΔV to assure a safe separation distance at the time of the explosion. An 8 second SPS burn could be initiated at warning plus 62 seconds and achieve >7080 feet separation distance between the CSM+LM and S-IVB at the time of the explosion (warning plus 200 seconds). This allows ~62 seconds to perform ejection, orientation, and SPS burn initiate.

Introduction

As presently defined, there exists a minimum of 200 seconds warning time for the crew to separate from the booster and achieve a safe separation distance (defined as 7000 feet) before an explosion. Although the crew cannot directly monitor the S-IVB fuel tank pressures subsequent to CSM/S-IVB separation, it is assumed that the ground will monitor the systems and inform the crew of an impending explosion at least 200 seconds prior to the critical tank pressures. With a 70 per cent efficient spring ejection system and no propulsive vents on the S-IVB, the CSM+LM could begin orientation at ejection plus 25 seconds and initiate the SPS burn at ejection plus 62 seconds (with an 8 second SPS burn).

Analysis

Based on a CSM+LM weight of 96224 pounds at separation from the S-IVB, a range of SPS burn times were considered and the resulting burn ΔV and separation distance versus time are presented in the enclosed figure. The attitude of the SPS burn has an insignificant effect on the separation distance obtained; however, other areas must be considered such as recontact and impact on the remaining mission. An attitude at which the SPS burn could be performed that would alleviate both of the previous considerations is the attitude of the nominally planned SPS evasive burn scheduled to be performed approximately 30 minutes subsequent to ejection. This would allow the CSM+LM to continue along the nominal mission profile without excessive deviations.

Conclusions

This analysis indicates for an impending S-IVB explosion with a minimum of 200 seconds crew warning time that LM ejection could be performed. Orientation to the SPS burn attitude could begin 25 seconds later. At ejection plus 62 seconds the SPS could be ignited for 8 seconds with the resulting separation distance from the S-IVB being >7080 feet at ejection plus 200 seconds. The Flight Analysis Branch recommends for this emergency procedure that the SPS burn be performed using the defined attitude for nominal ejection plus 30 minutes.

REM

CCA

Michael E. Donahoo

APPROVED BY:

John P. Mayer
Chief, Mission Planning
and Analysis Division

Addressees:
(See attached page)

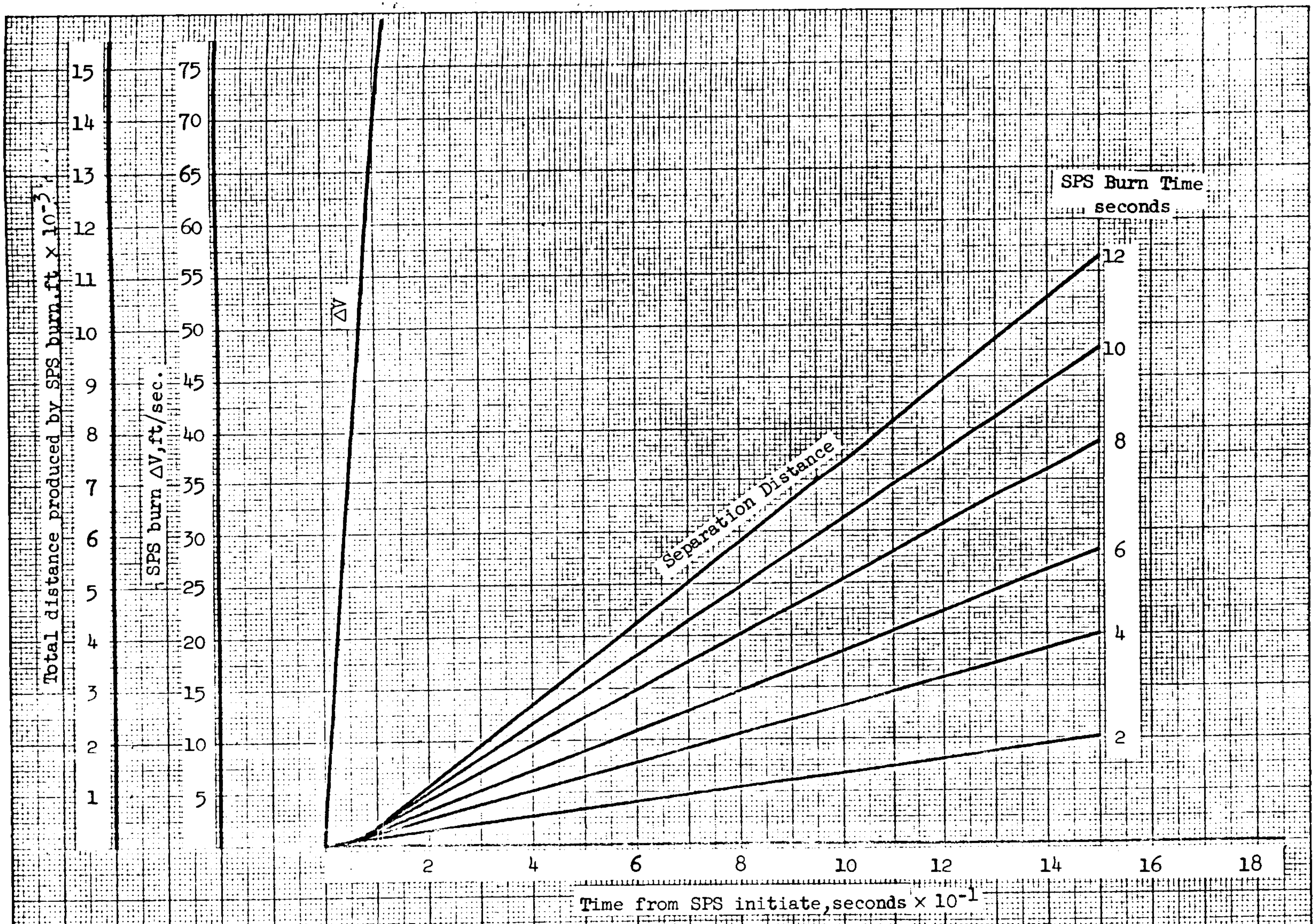


Figure SPS ΔV and separation distance versus time from SPS initiate for varying SPS burn times (CSM+LM configuration)

REFERENCES

1. OMAB; LMAB; and LAB: Spacecraft Operational Trajectory for Apollo Mission F, Volume I - Operational Mission Profile Launched May 17, 1969. MSC IN 69-FM-65, March 26, 1969.

2. Howell, E. C.; Hunt, C. R.; and Simmons, V. W.: Operational Spacecraft Attitude Sequence for Mission F. MSC IN 69-FM-113, April 23, 1969.

3. OMAB: Revision 1 to the Apollo 9 Spacecraft Operational Trajectory, Volume I - Mission Profile. MSC IN 69-FM-17, January 31, 1969.

4. Donahoo, M. E.: Apollo 9 CSM + LM Ejection from the S-IVB with 70% Efficient Springs. MSC memo 69-FM37-98, February 26, 1969.

5. Donahoo, M. E.: Recontact Analysis Between the CSM and LM Ascent Stage prior to the Apollo 9 APS Burn to Depletion. MSC memo 69-FM37-66, February 27, 1969.

6. Kincade, R. E.: CM/SM Separation and Recontact for the Nominal Apollo 9 Reentry. MSC memo 69-FM37-48, February 7, 1969.

7. Donahoo, M. E.: S-IVB and CSM Recontact Analysis for Apollo 9 Launch Aborts. MSC memo 69-FM37-34, February 4, 1969.

8. Williamson, M. L.; and Fraley, C. W.: Apollo 9 SLA Panel Jettison Separation and Recontact Analysis. MSC IN 69-FM-43, February 24, 1969.

9. Williamson, M. L.; and Fraley, C. W.: Motion of the CM Relative to the SM ± S-IVB for Apollo 9 Launch Phase Aborts where a SLA Separation Failure has Occurred. MSC memo 69-FM37-106, February 26, 1969.

10. Williamson, M. L.: CSM/S-IVB Tumbling Launch Abort Analysis for the Apollo 9 Mission. MSC memo 69-FM37-68, February 27, 1969.

11. Williamson, M. L.: Apollo 9 Launch Phase Recontact Analysis after SPS Ignition for Mode III and IV Aborts. MSC memo 69-FM37-47, February 7, 1969.

12. Donahoo, M. E.: Recontact Analysis of the CSM with Respect to the S-IVB or LM during Nontumbling, Orbital Aborts for Apollo 9. MSC memo 69-FM37-50, February 1, 1969.

13. Donahoo, M. E.: Orbital Aborts Initiated while Docked to the LM + S-IVB for Apollo 9. MSC memo 69-FM37-60, February 13, 1969.

14. Rippey, J. O.: Apollo Entry Summary Document, Mission F (AS-505/106/LM-4 Preliminary Copy. MSC IN MSC-CF-P-69-1, January 20, 1969.