

*Collins*

MSC-01220



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

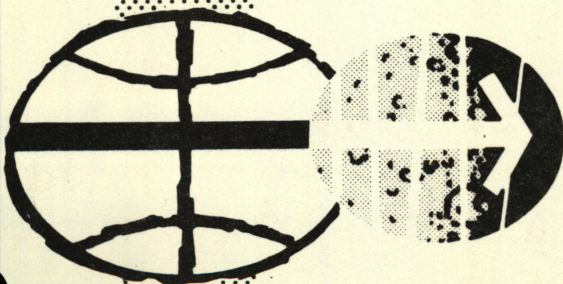
## MSC INTERNAL NOTE

NOVEMBER 7, 1969

*Worth saving because it shows  
all the 18 cases —*

## MISSION H-1 ABORT FROM LUNAR POWERED DESCENT AND SUBSEQUENT RENDEZVOUS

## TECHNIQUES DESCRIPTION



APOLLO SPACECRAFT PROGRAM OFFICE  
MANNED SPACECRAFT CENTER  
HOUSTON, TEXAS







MSC INTERNAL NOTE

---

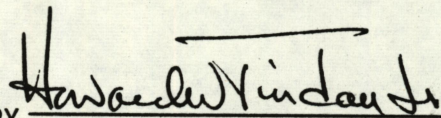
MISSION H-1  
ABORT FROM LUNAR POWERED DESCENT  
AND SUBSEQUENT RENDEZVOUS

---

November 7, 1969

APOLLO SPACECRAFT PROGRAM OFFICE  
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION  
MANNED SPACECRAFT CENTER  
HOUSTON, TEXAS

Approved by



Howard W. Tindall, Jr., Chief  
Apollo Data Priority Coordination



035-0-52M

0-02-18CH-87117

035-0-52M

MISSION #1  
REPORT FROM LUNAR TOWER STATION  
AND SURVEILLANCE STATION

035-0-52M

REPORT OF LUNAR TOWER STATION  
AND SURVEILLANCE STATION  
MISSION #1

*[Signature]*  
John W. Smith  
John W. Smith



## FOREWORD

This Abort from Lunar Powered Descent and Subsequent Rendezvous Techniques Document is one of several documents describing the H-1 (Apollo 12) mission. The others are as follows:

- Launch Aborts (same as G mission)
- Earth Parking Orbit and Translunar Injection (same as G mission)
- Translunar Midcourse Corrections and Lunar Orbit Insertion (same as G mission)
- Lunar Orbit Activities
- Lunar Descent
- Lunar Surface Activities
- Manual Ascent (same as G mission)
- Powered Ascent (change pages to G mission document)
- Transearth Injection, Midcourse Corrections, and Entry
- Tracking Data Selection Controllers Procedures
- Contingency Procedures

These documents contain the officially approved guidance and control sequence of events, the data flow, and real-time decision logic for the H-1 mission. The purpose of these documents is to ensure compatibility of all related MSC and supporting contractor activities.

For each mission phase, a Data Priority Working Group has been established under the direction of Chief, Apollo Data Priority Coordination, ASPO. These groups, which are comprised of representatives of MSC and support contractors



## FOREWORD (Continued)

hold frequent meetings to coordinate their various associated activities and develop agreed upon mission techniques. TRW assists in the development of the techniques and documents them for ASPO. After formal review by ASPO, E&DD, FCOD, FOD, GAEC, MDC, MIT, NR, and TRW, a document such as this one is issued.



# CONTENTS

	Page
1. INTRODUCTION. . . . .	1-1
2. GENERAL DESCENT ABORTS DESCRIPTION. . . . .	2-1
3. DISCUSSION . . . . .	3-1
3.1 Ground Rules. . . . .	3-1
3.2 Abort Modes . . . . .	3-2
3.2.1 PGNCS Control . . . . .	3-2
3.2.2 AGS Control . . . . .	3-4
3.3 Monitoring After Descent Abort . . . . .	3-4
3.3.1 Monitor Engine Performance . . . . .	3-4
3.3.2 Monitor Guidance and Control Performance . . . . .	3-5
3.3.3 Monitor Engine Shutdown. . . . .	3-6
3.4 Stage DPS. . . . .	3-9
3.5 Postinsertion Activity. . . . .	3-9
3.5.1 VGX Residual Trimming . . . . .	3-9
3.5.2 Tweak Burn . . . . .	3-10
3.5.3 IMU Alignment and Drift Check . . . . .	3-11
3.6 Rendezvous Techniques for PDI No Go and Descent and Lunar Surface Aborts . . . . .	3-11
3.6.1 PDI No Go Rendezvous Sequences . . . . .	3-11
3.6.1.1 LM-Active Sequence . . . . .	3-12
3.6.1.2 CSM-Active (Rescue) Sequences . . . . .	3-20
3.6.2 Descent and Lunar Surface Abort Rendezvous Sequences. . . . .	3-20
3.6.2.1 LM-Active Sequences . . . . .	3-20
3.6.2.2 CSM-Active Sequences. . . . .	3-24
3.6.3 Postabort Rendezvous Tracking Schedule . . . . .	3-24
3.6.4 Rendezvous Maneuver Solution Determination . . . . .	3-25
3.6.4.1 Phasing and Height Adjust Maneuvers . . . . .	3-25
3.6.4.2 CSI and CDH Maneuvers . . . . .	3-25
3.6.5 Onboard Rendezvous Checklists . . . . .	3-30
4. LUNAR DESCENT ABORT TECHNIQUES . . . . .	4-1
REFERENCES. . . . .	R-1







## TABLES

		Page
1.	PDI No Go and Postabort Rendezvous Maneuver Sequences . . . . .	3-13
2.	PDI No Go Rescue 2 Rendezvous Sequences . . . . .	3-21
3.	Nominal Onboard Tracking Schedule for H-1 Mission . . . . .	3-26
4.	Onboard Tracking Schedule for Additional CSI Maneuvers in Multiple CSI Rendezvous Sequences . . . . .	3-29
5.	Abort Situations Covered by Specific LM Onboard Checklists . . . . .	3-31
6.	Abort Situations Covered by Specific CSM Onboard Checklists . . . . .	3-32

## ILLUSTRATIONS

1.	Powered Descent Timelines . . . . .	1-3
2.	Luminary Control of APS Burns at Staging . . . . .	3-7
3.	Rendezvous Schematics for the Nominal LM-Active Sequences . . . . .	3-16
4.	NO-PDI Plus 12-Minute Abort Data Pad . . . . .	3-19
5.	LM Checklist for a NO-PDI <sub>1</sub> Plus 12-Minute Abort . . . . .	3-34







# (banned) NOMENCLATURE

AGS	abort guidance system
APS	ascent propulsion system
ATT	attitude
AUTO	automatic
CDR	commander
CMC	command module computer
CMP	command module pilot
CONT	control
CSM	command service module
CSI	coelliptic sequence initiation
CDH	concentric delta height
DAP	digital autopilot
DEDA	data entry and display assembly
DPS	descent propulsion system
DOI	descent orbit insertion
DSKY	display and keyboard
g.e.t.	ground elapsed time
GDA	gimbal drive actuator
G&N	guidance and navigation
GNCS	CSM primary guidance navigation and control system
H	altitude
$\dot{H}$	altitude rate
HAM	height adjust maneuver
$H_{PD}$	predicted perilune altitude (measured above the landing site)
HT	height adjust



## NOMENCLATURE (Continued)

IMU	inertial measurement unit
INS	insertion
LGC	lunar module guidance computer
LM	lunar module
LMP	lunar module pilot
LS	landing site
MCC-H	Mission Control Center-Houston
MCC-1, MCC-2	midcourse corrections 1 and 2
N	number of apsidal crossing
PDI	powered descent initiation
PFP	powered flight processor
PH	phasing
PGNCS (PGNS)	LM primary guidance navigation and control system
RCS	reaction control system
RDZ	rendezvous
RR	rendezvous radar
SPS	service propulsion system
TEI	transearth insertion
TIG	time of ignition
TPI	terminal phase initiation
TPF	terminal phase final
$T_1, T_2$	first and second lunar stay/no stay lift-off times
TM	telemetry
VHF	very high frequency (CSM radar)



## NOMENCLATURE (Continued)

VG	velocity to be gained
VGX	X component of VG
VI	velocity magnitude
$\Delta H$	difference in height of LM and CSM
$\Delta V$	delta velocity
$\Delta V X$	X component of maneuver $\Delta V$
$\Delta V G X$	X component of velocity to be trimmed
$\Delta V G Z$	Z component of velocity to be trimmed
$\Delta W_p$	predicted wedge angle
P12	Powered Ascent Guidance Program
P20	Rendezvous Navigation Program
P30	External $\Delta V$ Program
P32	CSI Targeting Program
P33	CDH Targeting Program
P34	TPI Program
P40	DPS or SPS Thrust Program
P41	RCS Thrust Program
P42	APS Thrust Program
P47	Thrust Monitor Program
P52	IMU Realign Program
P63	Braking Phase Program
P64	Approach Phase Program
P65	Landing Phase (Auto) Program
P66	Landing Phase (Rate of Descent) Program
P67	Landing Phase (Manual) Program



## NOMENCLATURE (Continued)

PDI no go aborts are rendezvous sequences as discussed in Section 3.1. The LDM no go rendezvous maneuver is not included in the flow charts because the LDM no go aborts are handled separately following descent and early lunar surface aborts. Any descent or early lunar surface abort (through  $T_2$ ) and subsequent rendezvous will follow the procedures presented in this document. Aborts from the lunar surface at  $T_2$  are presented. Rendezvous Out-of-Plane Display Routine. One procedure is basically identical to those for lunar surface aborts initiated prior to  $T_2$ . Aborts from the lunar surface after  $T_2$  are handled as preferred lift-off times and so employ nominal ascent procedures and rendezvous techniques (References 2 and 3).

Timelines of the powered descent functions and corresponding lunar module (LM) abort capability are presented in Figure 1.



## 1. INTRODUCTION

The guidance and navigation sequence of events, the flow of data, and the real-time decisions which must be made for aborts prior to or during the powered-descent and early lunar surface phases of the H-1 lunar landing mission (Apollo 12) are presented in this document. The recommended procedures are presented in flow charts (Section 4) which are preceded by a description of the techniques. These charts document the standard, approved procedures to be used in the event of a primary guidance, navigation, and control system (PGNCS) failure, a descent propulsion system (DPS) failure, or some other critical system failure.

Routine procedures are included in the flow charts, as required, to verify the continued operation of unfailed PGNCS or DPS during an abort so that the proper alternative action will be taken in the event of subsequent malfunction. The flow charts contain a block near each decision point which indicates the responsibility for determining the decision point data limit and the date of its availability.

The abort procedures described herein begin at DOI plus 10 minutes\* and are categorized as follows:

- Powered descent initiation (PDI) no go aborts which are initiated at either the nominal PDI TIG plus 12 minutes (LM-active) or one-half revolution after the nominal PDI TIG (CSM-active)
- Powered descent or early lunar surface aborts initiated at any time during powered descent through the first lunar stay/no stay lift-off time ( $T_1^{**}$ )
- Lunar surface abort at the second stay/no stay lift-off time ( $T_2^{***}$ )

---

\*DOI plus 10 minutes is the latest planned opportunity for a direct return abort.

\*\*  $T_1$  is the latest time on the lunar surface that the PGNCS abort program P71 can be used.

\*\*\*  $T_2$  is the first discrete lift-off time that utilizes the nominal PGNCS ascent program P12.



PDI no go aborts are planned abort maneuvers which simply initiate rendezvous sequences as discussed in Section 3.6. The PDI no-go rendezvous maneuver computation and execution are not included in the flow charts because they are basically the same as corresponding maneuvers following descent and early lunar surface aborts. Any descent or early lunar surface abort (through  $T_1$ ) and subsequent rendezvous will follow the procedures presented in this document. Procedures for lift-off from the lunar surface at  $T_2$  are presented in Reference 1. The subsequent rendezvous procedures are basically identical to those for lunar surface aborts initiated prior to  $T_1$ . Aborts from the lunar surface after  $T_2$  are executed at preferred lift-off times and so employ nominal ascent targeting and rendezvous techniques (References 2 and 3).

Timelines of the powered descent functions and corresponding lunar module (LM) abort capability are presented in Figure 1.



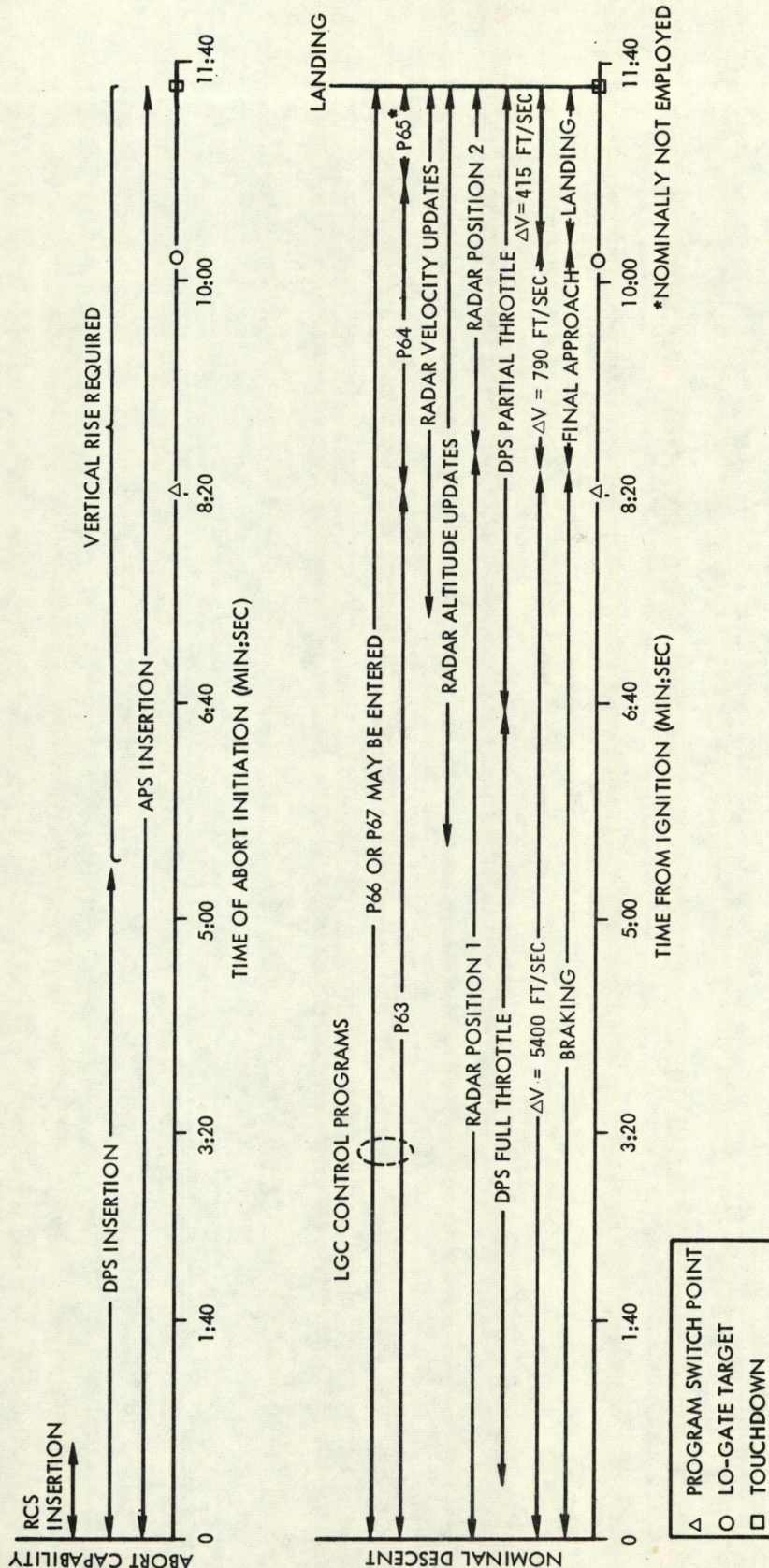


Figure 1. Powered Descent Timelines







## 2. GENERAL DESCENT ABORTS DESCRIPTION

Control of aborts from the powered descent phase of the lunar landing mission will be accomplished by either the PGNCS or the LM abort guidance system (AGS).

Two PGNCS programs, Luminary Programs P70 and P71, are available for control of descent aborts. These programs are essentially executive logic routines which order the computations necessary to control the LM along an ascent trajectory targeted to orbit insertion. P70 is the DPS Abort Program designed to accomodate descent engine thrusting, and P71 is the Ascent Propulsion System (APS) Abort Program designed for ascent engine thrusting.

The AGS uses virtually the same computational procedures as PGNCS. However, there are no unique DPS or APS abort programs, and AGS does not exercise control over DPS throttle variations.

Proper phasing for the subsequent rendezvous following a descent abort is achieved by variable insertion targeting. For the first PDI opportunity ( $PDI_1$ ), target apolunes will vary from approximately 128 to 30 nautical miles between TIG and TIG + 10 minutes, and from approximately 60 to 30 nautical miles between TIG + 10 minutes and ( $T_1$ ).<sup>\*</sup> For the second PDI opportunity ( $PDI_2$ ), target apolune will vary from approximately 180 to 30 nautical miles<sup>\*\*</sup> between TIG and  $T_1$ .<sup>\*</sup> Variable insertion targeting, thus described, provides the LM to CSM phasing required for a nominal rendezvous maneuver sequence as discussed in Section 3.6.2.1. Descent abort targeting is identical for both PGNCS and AGS controlled aborts with the exception that the AGS does not provide variable insertion targeting for  $PDI_1$  aborts between  $PDI + 10$  minutes and  $T_1$ . In this period the AGS targets to a constant 30-nautical mile apolune which is increased to the variable insertion value by a postinsertion RCS tweak burn which is further discussed in Section 3.5.2.

---

\* The  $T_1$  times for  $PDI_1$  and  $PDI_2$  are  $PDI_1 + 16:20$  (minutes:seconds) and  $PDI_2 + 14:24$  (minutes:seconds).

\*\* The  $PDI_2$  targeting in the LGC is uplinked after the decision to delay PDI has been made.







### 3. DISCUSSION

The following paragraphs describe the techniques and rationale used in developing the sequence of events, the data flow, and the real-time decision logic for aborts from the lunar powered descent phase of the Apollo H-1 mission.

#### 3.1 GROUND RULES

The following ground rules were used in the development of all abort techniques and procedures presented in this report:

- a) The abort procedures should be as simple and straight forward as possible without compromising the success of the abort.
- b) It is acceptable to burn the DPS and the APS to propellant depletion.
- c) The DPS should be used in abort situations whenever possible, even if there is only a few seconds burn available, to aid in establishing a positive radial rate and to improve propellant margins.
- d) A "working" engine should not be shut down until a safe orbit is achieved.
- e) Short APS burns (less than 3 seconds) are to be avoided.

A highly desirable feature during an abort is uninterrupted communications with the ground so that MCC-H can continue to monitor and verify the state of the LM and its subsystems. Maintaining S-band communications requires that the high-gain antenna always view the earth.\* This implies that LM attitude changes and attitude rates must be compatible with antenna orientation capability and drive rates. Any LM yaw maneuvers required during an abort should be performed in the direction which keeps the +Y-axis pointing away from the moon to provide communication potential.

---

\*S-band communication can also be maintained with the omni antennas if the 210-foot earth antenna coverage is available; this coverage is planned for the H-1 mission.



In performing aborts from lunar powered descent, the following major functions must be accomplished:

- a) Establish abort mode
- b) Monitor engine performance during abort
- c) Monitor G&N performance during abort
- d) Monitor engine cutoff conditions
- e) Stage DPS when necessary
- f) Perform tweak burn or null velocity to be gained (VGX) residual
- g) Complete rendezvous

The significant elements in these functions are described below.

### 3.2 ABORT MODES

Aborts will proceed under the control of the PGNCS, if operating, otherwise under the control of the AGS. A manual guidance scheme is available as a back-up procedure in the event of a combined PGNCS and AGS failure. This scheme is presented in a separate Mission Techniques Document (Reference 4). Propulsion will be provided by the DPS, if operating, otherwise by the APS. When a decision to abort on DPS is made after the descent has been in progress for approximately 300 seconds, orbit insertion will require an APS burn after DPS propellant depletion.

#### 3.2.1 PGNCS Control

An abort situation in which the DPS and PGNCS are both operational implies that some other subsystem is at fault. For this case the recommended procedure is to push the ABORT button. This action provides a discrete signal to the lunar module guidance computer (LGC) and AGS. At DPS ignition the Abort Discretes Monitor Routine (R11) is activated. This routine detects the presence of the ABORT discrete and calls the DPS Abort Program (P70) for use by the LGC.



When the DPS is not operational, the procedure is to press the ABORT STAGE button. Pressing the ABORT STAGE button closes switch contacts that activate relays to:

- a) Dearm the descent engine
- b) Switch to ascent electrical power
- c) Signal the LGC and AGS that ABORT STAGE was selected
- d) Close the "auto start" circuit for the APS
- e) Pressurize the APS system
- f) Activate pyrotechnic devices to separate DPS from APS

The Abort Discretes Monitor routine (R11) detects the presence of the ABORT STAGE discrete and calls APS Abort Program P71 for use of the LGC.

The LM may be under control of any one of the PGNCS programs P63 through P67 at the time either the ABORT or ABORT STAGE button is pushed. Under the automatic landing programs, P63, P64, and P65\*, the LGC controls the LM attitude and DPS throttle. Under P66 the LGC controls the throttle and the crew controls LM attitude changes since the MODE CONT switch is in the ATT HOLD position. Under P67 the crew controls both changes in the throttle and the LM attitude, since the THR CONT switch is in the MAN position and the MODE CONT switch is in the ATT HOLD position.

In order for the LM to respond to PGNCS Abort Program P70 the attitude MODE CONT switch must be set to the AUTO position, and either the engine thrust control switch, THR CONT, must be in the AUTO position or the crew must manually advance the throttle to its maximum thrust position. A manual throttle advance is preferred over the thrust control switch action. These actions should follow the ABORT event as soon as possible.

---

\* Not nominally employed on Mission H-1.



Similarly, for proper LM response to PGNCS Abort Program P71 the attitude MODE CONT switch must be set to the AUTO position. Since the APS engine is not throttleable, the program will not respond to prior engine control constraints; therefore, switching to AUTO throttle is unnecessary. Again, the required action should follow the ABORT STAGE event as soon as possible.

### 3.2.2 AGS Control

In the event of a PGNCS failure, aborts will be performed under AGS control. The readiness state for AGS was achieved prior to PDI. The AGS MODE CONT switch will be in the AUTO position. The commander (CDR) will place the LM under AGS control by setting the GUID CONT switch to AGS position. When this is done, the subsequent action depends on the operational status of the DPS. Assuming the DPS is operating satisfactorily, the CDR will manually advance the throttle to its maximum position to ensure commanded maximum thrust since AGS does not provide thrust control. The CDR will next press the ABORT button to enable engine off at target conditions. In the event the DPS is not operating properly or propellant depletion is imminent before cutoff conditions are achieved, the CDR will ensure APS ullage; then the CDR will press the ABORT STAGE button. The AGS will control the LM under APS thrusting until guided cutoff.

## 3.3 MONITORING AFTER DESCENT ABORT

### 3.3.1 Monitor Engine Performance

Onboard indications and ground monitoring, if available, will be used to establish the operational status of the DPS engine. Continued monitoring of engine performance during aborts will help to ensure achievement of target conditions for subsequent LM-active rendezvous.

For aborts initiated on DPS, thrust level, throttle response, and uniformity of burn are items that should be watched. If the DPS is operating in the throttleable region and an abort on DPS is commanded, the crew will manually advance the throttle to maximum; the thrust level should rise to the full thrust point. If this action does not produce the desired result, the subsequent step is to abort stage and continue on the APS.



Onboard instrumentation available for monitoring DPS engine performance are the thrust level gage, thrust to weight (T/W) gage and the DPS engine trim gimbal light. If the T/W is less than 1.6 g's and the thrust level gage indicates that the thrust level is less than 80 percent with the X-axis velocity to be gained (VGX) still greater than 30 feet per second, control is switched from the CDR throttle to the LMP throttle. If the thrust does not recover within 100 seconds of the first indication of low thrust and VGX is still greater than 30 feet per second, the LM is abort staged. If VGX becomes less than 30 feet per second, the DPS is shut down manually and the crew stands by for an RCS tweak burn. If only one of the gages indicates low thrust, a second cue is required to verify low thrust. If no second cue is present and MCC-H does not confirm the low thrust, no action is taken. Other DPS monitoring cues are the DPS engine trim gimbal light on, attitude errors indicating an offset of greater than 3 degrees, or an unexpected increase in RCS activity. If any one of these cues is present, the gimbal drive actuators (GDA's) are switched to the OFF position and insertion is continued.

### 3.3.2 Monitor Guidance and Control Performance

Physiological cues, onboard instrumentation, and ground monitoring, if available, will furnish the crew data for assessing the status of LM guidance and control. The primary indications are attitude rates greater than 5 degrees per second for the DPS and 10 degrees per second for the APS. Use of the AGS and PGNCS error needles provide another indication of a PGNCS failure. If these error needles indicate greater than a 5-degree error for DPS or a 10-degree error for APS, a second cue such as the horizon angle would be grounds for a switch to AGS. If no second cue is present and the error needles do not agree, the AGS has failed and switchover will be inhibited. Ground monitoring of descent aborts is based on the abort predictor plotboard display of predicted perilune



altitude ( $H_{PD}$ ) versus predicted wedge angle ( $\Delta W_p$ )<sup>\*</sup>. If the PGNCS  $H_{PD}$  is less than 40,000 feet<sup>\*\*</sup> or  $\Delta W_p$  is greater than 1 degree, and if the AGS is performing better than PGNCS, MCC-H will advise a switch to AGS. Strip chart velocity and range rate residual displays, along with a comparison of the PGNCS predictor values with those for AGS and the PFP, are used to determine whether or not to switch from PGNCS to AGS.

### 3.3.3 Monitor Engine Shutdown

When a DPS abort is initiated after TIG plus 300 seconds, DPS propellant depletion will nominally occur prior to guided cutoff. At DPS engine shutdown it is necessary to know the velocity to be gained (VG) for achieving the target condition, since the crew decision regarding subsequent action to stage the DPS is a function of VG. Two problem areas enter into the decision: first, an overburn possibility and second, a minimum APS burn-time constraint.

An analysis of the Luminary Program presented in Reference 5 indicates that, when the VG exceeds approximately 33 feet per second, the crew can abort stage and expect a proper guided cutoff of the APS engine. As VG decreases toward zero large overburns can occur if abort stage action is taken. Figure 2 shows overburn velocity as a function of VG at staging. The 2-second guidance cycle creases these conditions.

For short APS burns, the propellant will freeze in the engine injector. A considerable delay is then required before another burn may be made. Although it is not anticipated that a postinsertion APS burn will ever be desired, it is considered worthwhile to leave this avenue open.

---

\*The predictor display propagates a given state vector through the remainder of powered ascent and computes predicted values of perilune altitude and wedge angle. This display can be driven by the powered flight processor (PFP) or PGNCS or AGS state vectors. The PFP is an RTCC processor that uses doppler observations from several tracking stations to obtain by triangulation the state vector change since the last set of observations. The processor uses Kalman filter equations to compute the state vector corrections at the time of a set of doppler observations. After the update, the state and weighting matrices are propagated to the next set of doppler observations and another state correction is computed.

\*\*The  $H_{PD}$  less than 40,000 feet constraint is used to ensure that the actual  $H_{PD}$  never becomes less than 30,000 feet.



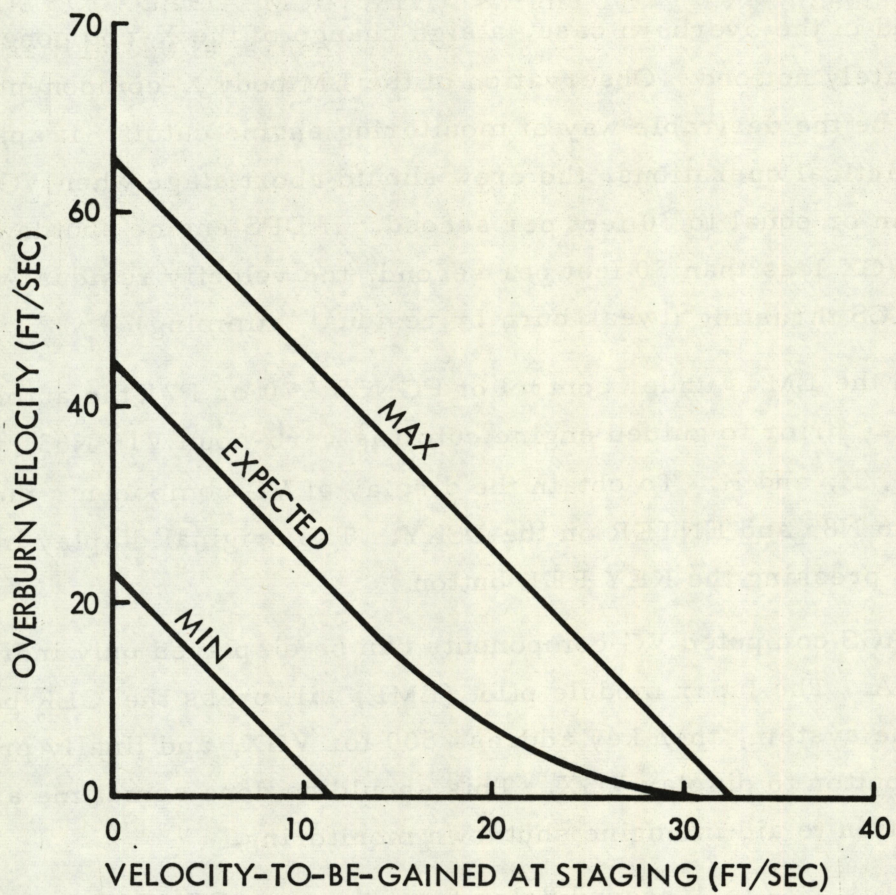


Figure 2. Luminary Control of APS Burns at Staging



The minimum allowable burn to avoid the freezing problem is approximately 3 seconds. The average acceleration near orbit insertion for a fully loaded ascent stage is approximately 11 feet per second per second. The velocity gained in a 3-second burn is about 33 feet per second, which correlates with the overburn bound.

Components of VG with respect to LM body axes are available for display on the DSKY. These values have signs associated with their magnitudes, and in the overburn case, a sign change of the X-component would be immediately noticed. Observation of the LM body X-component of VG appears to be the desirable way of monitoring engine cutoff. It appears that for practical operations, the crew should abort stage when VGX is greater than or equal to 30 feet per second. If DPS engine shutdown occurs at VGX less than 30 feet per second, the velocity residual will be nulled by RCS thrusting (tweak burn or residual trimming).

When the LM is under control of PGNCs P70 or P71, the automatic DSKY display prior to guided engine cutoff is verb-noun V16 N63, which displays VI,  $\dot{H}$ , and H. To obtain the display of VG components the crew will key V16 N85 and ENTER on the DSKY. The original display may be recalled by pressing the KEY REL button.

The AGS computed VG components can be displayed only individually on the DEDA. The lunar module pilot (LMP) will press the CLR button to initialize the system, then key address 500 for VGX, and finally press the READOUT button to display VGX. This should be done sometime after abort initiation to aid in engine shutdown monitoring.

There is a 2- to 4-second delay from the time PGNCs VG components are computed until they can be displayed on the DSKY. This delay complicates the decision/action process, since the crew has difficulty in establishing present values for the VG components.

If a DPS engine shutdown occurs when the present display shows VGX greater than 100 feet per second, the crew can abort stage immediately knowing that the actual VGX will be in the region where abort stage action



should be taken. When DPS engine shutdown occurs with VGX less than 100 feet per second displayed, the crew can safely wait for the display to stabilize before making a decision as to the subsequent action necessary. A delay of 6 seconds should be adequate for display stabilization. If the DPS engine has shutdown when VGX is greater than 30 feet per second, abort stage action is required. When VGX is less than 30 feet per second the velocity residuals will be included in a MCC-H computed tweak burn.

If the DPS continues to thrust as VGX goes negative, the engine should be stopped immediately by manual action. The resulting overburn will be accounted for in a subsequent MCC-H computed tweak burn.

As in the case of DPS, if the APS continues thrusting as VGX goes negative, the engine should be stopped immediately by manual action. An overburn will occur and the residual will be accounted for during the tweak burn. In the event of a significant APS underburn, VGX greater than 200 feet per second which corresponds to an APS thrust failure 10 seconds before insertion, the crew will attempt to restart the engine before continuing on RCS thrusting. If the underburn is less than or equal to 200 feet per second, VGX will be driven to zero using the RCS. Any residuals will be trimmed out during the tweak burn.

### 3.4 STAGE DPS

As indicated in the preceding discussion, the DPS will be staged when a DPS malfunction is detected. Staging is also performed at DPS propellant depletion or engine cutoff when VGX is greater than 30 feet per second. If VGX is less than or equal to 30 feet per second, staging is optional. The DPS can be retained throughout rendezvous if it is desirable to do so.

### 3.5 POSTINSERTION ACTIVITY

#### 3.5.1 VGX Residual Trimming

The nominal postinsertion technique following a descent or lunar surface abort is to trim the VGX residual to zero on the MCC-H recommended G&N system (i. e., PGNCs or AGS). This is done to ensure a near



nominal rendezvous coelliptic delta height ( $\Delta H = 15$  nautical miles). (A 10-foot per second VGX overburn or underburn changes  $\Delta H$  by about 5 nautical miles.) Crossrange and radial residuals have little effect on  $\Delta H$  and can be more accurately removed during later rendezvous maneuvers which incorporate rendezvous navigation data.

In the event that communications are lost, VGX will be trimmed on PGNCS (assuming a PGNCS insertion). The PGNCS and AGS residuals are then compared and if they agree within 10 feet per second no further action is taken. In the event they disagree, both systems are compared with the RR. If the AGS/RR difference is less than the PGNCS/RR difference, then VGX will be trimmed on AGS.

### 3.5.2 Tweak Burn

The AGS does not provide variable insertion targeting for aborts between  $PDI_1 + 10$  minutes and  $PDI_1 + 16:20$  (minutes:seconds) on Apollo 12. For aborts on AGS in this period the ground computes an RCS tweak burn which is the  $\Delta VX$  difference between the AGS and PGNCS targeting. This maneuver consists of a  $\Delta VX$  and TIG which is voiced to the crew for execution within two minutes after insertion. As a backup in the event of a communication failure, the crew can determine the  $\Delta VX$  onboard from a crew chart which provides the necessary  $\Delta VX$  as a function of phase angle at insertion. The phase angle is obtained by calling up DEDA address 303 in the AGS Orbit Insertion Routine.

In the event of an abort insertion on a degraded PGNCS or AGS, or a premature DPS shutdown with  $VGX < 30$  feet per second, the ground will also compute an RCS tweak burn consisting of a  $\Delta VX$  and TIG. If required, the tweak burn will be voiced to the crew within 30 seconds after insertion; the specified TIG will always be within two minutes after insertion. In "no comm" situations involving excessive insertion residuals (i.e., residuals greater than about 10 feet per second) or significant discrepancy between PGNCS and AGS residuals, the LM crew will attempt to receive relayed advice from MCC-H via the CSM.



If a tweak burn is required and the LM becomes inactive and/or it is undesirable to stage the DPS, MCC-H will voice the tweak burn  $\Delta V_X$ , TIG, and pitch angle to the CSM for execution at insertion plus 12 minutes. The CSM will execute the burn on RCS provided  $\Delta V_X$  does not exceed 12 feet per second. In the event  $\Delta V_X$  does exceed 12 feet per second, the SPS will be used.

### 3.5.3 IMU Alignment and Drift Check

Following the residual trimming or tweak burn activity, MCC-H will uplink the LM telemetry state vector to the CMC. Both the LM and CSM perform an IMU realign to REFSMMAT (P52) after entering darkness to remove any alignment errors that may offset subsequent rendezvous navigation. Following the PGNCs alignment, the AGS state vectors are initialized from the PGNCs, and the AGS is aligned to the PGNCs. The detailed alignment and drift check rationale is discussed in Reference 3. The logic and limits are presented in the flow chart (page 4-8).

### 3.6 RENDEZVOUS TECHNIQUES FOR PDI NO GO AND DESCENT AND LUNAR SURFACE ABORTS\*

The PDI maneuver is nominally executed near perilune of the DOI Hohman transfer orbit one-half revolution after DOI. However, PDI can either be slipped one revolution or declared no go depending on the state of LM (and CSM) onboard systems. A PDI no go decision made at any time after DOI plus 10 minutes (the latest direct return abort opportunity\*\*) and the nominal PDI TIG results in a NO-PDI plus 12-minute abort initiated at  $PDI_1$  plus 12 minutes. A no go decision made at any time after slipping  $PDI_1$  results in a NO-PDI plus 12-minute abort initiated at  $PDI_2$  plus 12 minutes. Once PDI (either  $PDI_1$  or  $PDI_2$ ) is initiated, a subsequent no go for lunar landing results in a descent or early lunar surface abort as described in Sections 3.1 through 3.5.

---

\* The rendezvous sequence discussion presented herein is based on References 6 and 7; a thorough analysis of each sequence including relative motion and relative range plots is presented therein.

\*\* Direct return aborts after separation are defined in the Lunar Orbit Activities Mission Techniques document (Reference 3); a comprehensive analysis is presented in Reference 7.



The particular PDI no go and postabort rendezvous sequences for both LM-and CSM-active situations are summarized in Table 1. Rendezvous schematics for the nominal sequences (LM-active) are presented in Figure 3. These maneuver sequences generally attempt to provide the necessary height (raising and lowering apolune or perilune) and phasing (orbital speedup or slowdown with respect to target vehicle) maneuvers necessary to achieve a CSI/CDH coelliptic sequence with a  $\Delta H$  of 15 nautical miles. In some PDI no go rescue instances, the 15-nautical mile  $\Delta H$  is not possible without unduly extending the rendezvous sequence. These are targeted instead for a  $\Delta H$  of 10 nautical miles. Once the last CSI maneuver in a given sequence has been initiated, the nominal rendezvous procedures become directly applicable. These procedures are presented in Reference 3 and so are not duplicated herein.

The rendezvous situations indicated in Table 1 will always employ the LM-active sequence whenever possible. This eliminates the need in certain cases for the CSM to maneuver into a lower orbit which would require additional SPS propellant for TEI and in some instances tend to jeopardize crew safety. In the unlikely event a rescue sequence is required, it is expected that the CSM will execute all rescue maneuvers because the rescue sequence would be initiated only in the event of total LM inability to maneuver.

### 3. 6. 1 PDI No Go Rendezvous Sequences

#### 3. 6. 1. 1 LM-Active Sequence

The PDI no go rendezvous sequences shown in Table 1 result from either a NO-PDI plus 12-minute abort (LM-active) or a so-called rescue 2 maneuver (CSM-active). The NO-PDI plus 12-minute abort consists of a five-impulse rendezvous maneuver sequence (Figure 3a) initiated at PDI plus 12 minutes which after phasing is basically identical to the nominal coelliptic rendezvous sequence (CSI/CDH) presented in Reference 3.

The initial PDI<sub>1</sub> abort (phasing) maneuver is MCC-H targeted and sent up on the pre-DOI PDI plus 12 minute abort pad shown in Figure 4. This pad is updated for PDI<sub>2</sub> once the decision to slip PDI one additional revolution has been made.



Table 1. PDI No Go and Postabort Rendezvous Maneuver Sequences

<u>Abort Initiation</u>	<u>LM-Active</u>	CSM-Active (Assumes LM Inactive)
DOI + 10 min until PDI + 12 min (assuming no PDI)	NO-PDI + 12 min abort (phasing (PH)/five impulse):	NO-PDI rescue 2 (height (HT)/five impulse):
	<ul style="list-style-type: none"> <li>LM (or CSM after PH burn if LM becomes inactive) executes PH/CSI/CDH/TPI/TPF; burn sequence initiated 1/2 rev after DOI for PDI<sub>1</sub> or 1-1/2 rev after DOI for PDI<sub>2</sub></li> </ul>	<ul style="list-style-type: none"> <li>CSM executes HT/CSI<sub>1</sub>/CSI<sub>2</sub> (nom zero)/CSI<sub>3</sub> (nom zero)/CDH/TPI/TPF; burn sequence initiated 1 rev after DOI for PDI<sub>1</sub> or 2 revs after DOI for PDI<sub>2</sub></li> </ul>
	<ul style="list-style-type: none"> <li>MCC-H provides phasing <math>\Delta V</math> and TIG to backup onboard chart</li> </ul>	<ul style="list-style-type: none"> <li>MCC-H provides HT <math>\Delta V</math> and TIG, CSI<sub>1</sub> and TPI TIG's</li> </ul>
	<ul style="list-style-type: none"> <li>TPI occurs at approximately LM midpoint of darkness on the second rev after DOI for PDI<sub>1</sub> or on the third rev after DOI for PDI<sub>2</sub></li> </ul>	<ul style="list-style-type: none"> <li><math>\Delta H = 10</math> n mi</li> <li>TPI occurs at approximately LM midpoint of darkness on the fourth rev after DOI for PDI<sub>1</sub> or on the sixth rev after DOI for PDI<sub>2</sub></li> </ul>
PDI <sub>1</sub> until PDI <sub>1</sub> + 10 min (descent abort); PDI <sub>2</sub> until PDI <sub>2</sub> + 14:24 min:sec (descent abort through PDI + 11:16 min:sec and abort from lunar surface after PDI + 11:16 min:sec	LM rendezvous (nominal sequence):	CSM mirror image rescue:
	<ul style="list-style-type: none"> <li>LM executes INS/CSI/CDH/TPI/TPF burn sequence</li> </ul>	<ul style="list-style-type: none"> <li>After LM insertion, CSM executes CSI/CDH/TPI/TPF burn sequence (mirror image of LM rendezvous sequence)</li> </ul>



Table 1. PDI No Go and Postabort Rendezvous Maneuver Sequences (Continued)

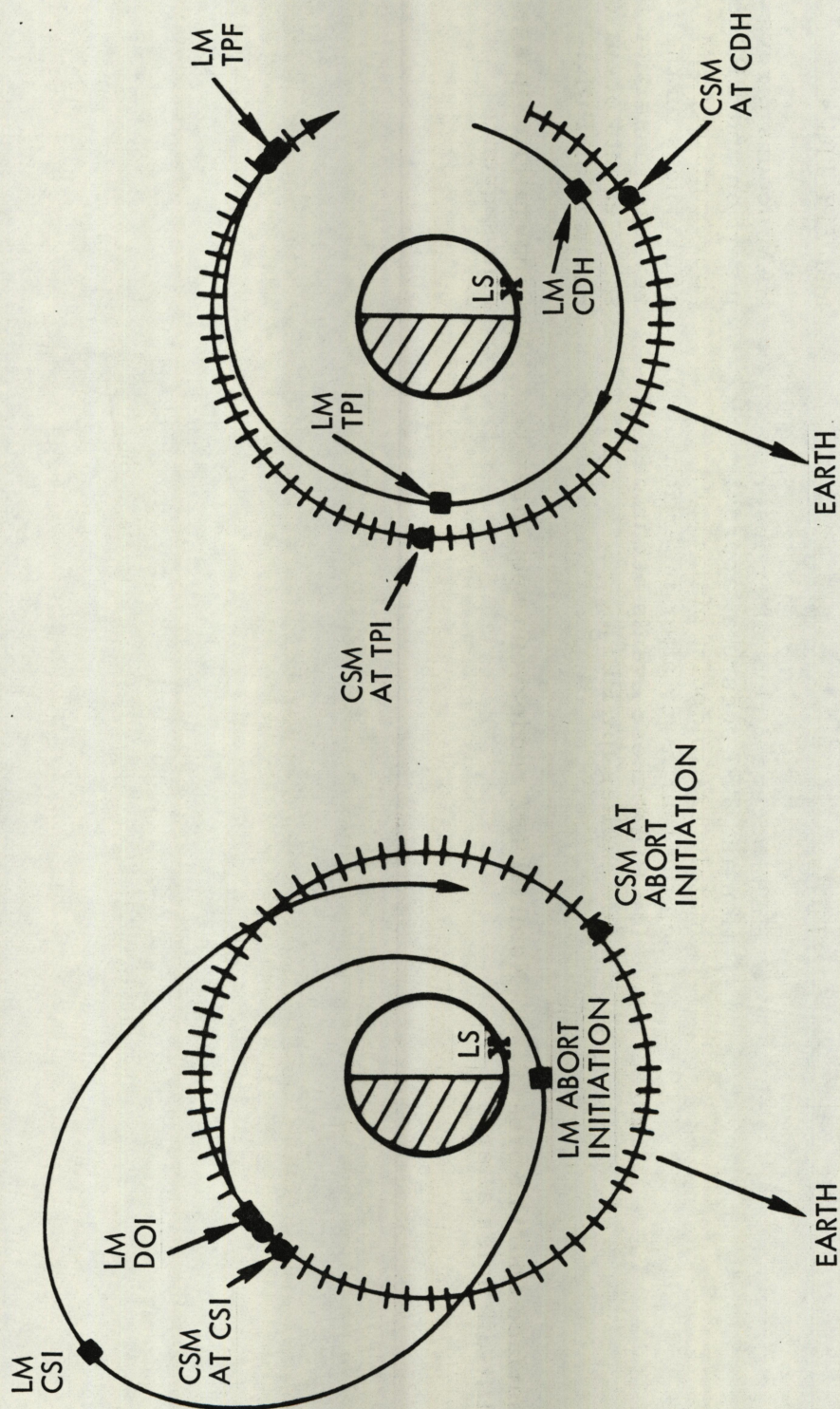
<u>Abort Initiation</u>	<u>LM-Active</u>	<u>CSM-Active</u> (Assumes LM Inactive)
PDI <sub>1</sub> + 10 min until PDI <sub>1</sub> + 16:20 min:sec (descent abort through PDI + 11:16 min:sec and abort from lunar surface after PDI + 11:16 min:sec)	<ul style="list-style-type: none"> <li>• TPI occurs at approximately LM midpoint of darkness on the second rev after insertion</li> </ul> <p>LM rendezvous (insertion (INS)/PH/ five impulse):</p> <ul style="list-style-type: none"> <li>• LM executes INS/PH (10 fps)/ height adjust maneuver (HAM) CSI/CDH (nom zero)/TPI/TPF burn sequence</li> <li>• MCC-H provides PH TIG, HAM ΔVX and TIG, and CSI, and TPI TIG's</li> </ul> <p>LM rendezvous (INS/PH/ five impulse):</p> <ul style="list-style-type: none"> <li>• LM executes INS/PH (10 fps)/ HAM/CSI/CDH (nom zero)/ TPI/TPF burn sequence</li> </ul>	<ul style="list-style-type: none"> <li>• MCC-H provides CSI and TPI TIG's</li> <li>• TPI occurs at approximately LM midpoint of darkness on the second rev after insertion</li> </ul> <p>CSM rescue (five impulse):</p> <ul style="list-style-type: none"> <li>• After LM insertion, CSM executes HAM/CSI/CDH/ TPI/TPF burn sequence</li> <li>• MCC-H provides HAM ΔVX and TIG, and CSI, and TPI TIG's</li> <li>• TPI occurs at approximately LM midpoint of darkness on the third rev after insertion</li> </ul> <p>CSM rescue (PH/ five impulse):</p> <ul style="list-style-type: none"> <li>• CSM executes PH (10 fps)/ HAM/CSI/CDH (nom zero)/ TPI/TPF burn sequence</li> </ul>
Lunar surface abort at T2 (PDI <sub>1</sub> + 21:22 min:sec or PDI <sub>2</sub> + 20:58 min:sec)		



Table 1. PDI No Go and Postabort Rendezvous Maneuver Sequences (Continued)

<u>Abort Initiation</u>	<u>LM-Active</u>	<u>CSM-Active</u> (Assumes LM Inactive)
Lunar surface abort at preferred lift-off times after T <sub>2</sub>	<ul style="list-style-type: none"> <li>MCC-H provides PH TIG, HAM ΔVX and TIG, and CSI and TPI TIG's</li> </ul>	<ul style="list-style-type: none"> <li>MCC-H provides PH TIG, HAM ΔVX and TIG, and CSI and TPI TIG's</li> </ul>
	<ul style="list-style-type: none"> <li>HAM occurs 2 revs after insertion and TPI occurs at approximately LM midpoint on the fourth rev after insertion for PDI<sub>1</sub>; these events occur one rev earlier for PDI<sub>2</sub>.</li> </ul>	<ul style="list-style-type: none"> <li>HAM occurs 2 revs after insertion and TPI occurs at approximately LM midpoint of darkness on the fourth rev after insertion for PDI<sub>1</sub>; these events occur one rev earlier for PDI<sub>2</sub>.</li> </ul>
	Nominal LM rendezvous sequence	Nominal mirror image CSM rescue sequence

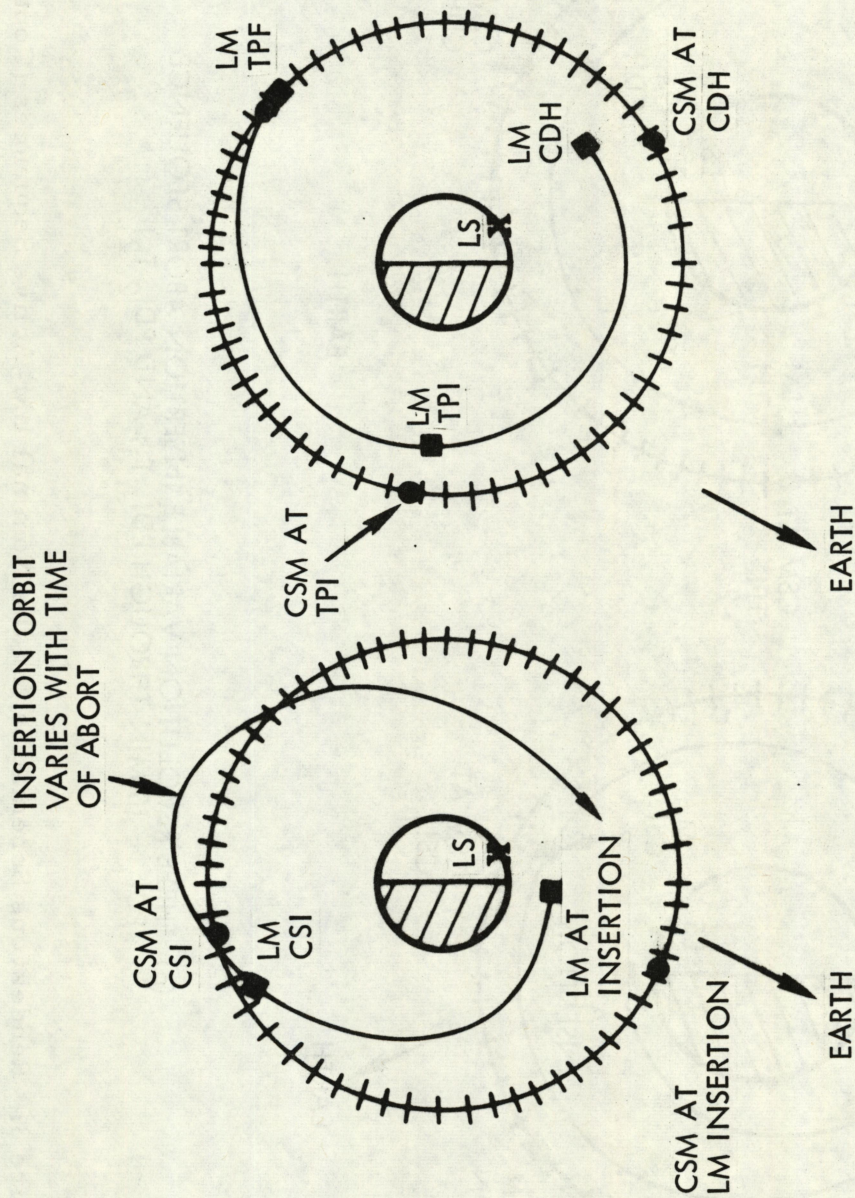




(a) NO - PDI + 12 MIN ABORT SEQUENCE

Figure 3. Rendezvous Schematics for the Nominal LM-Active Sequences

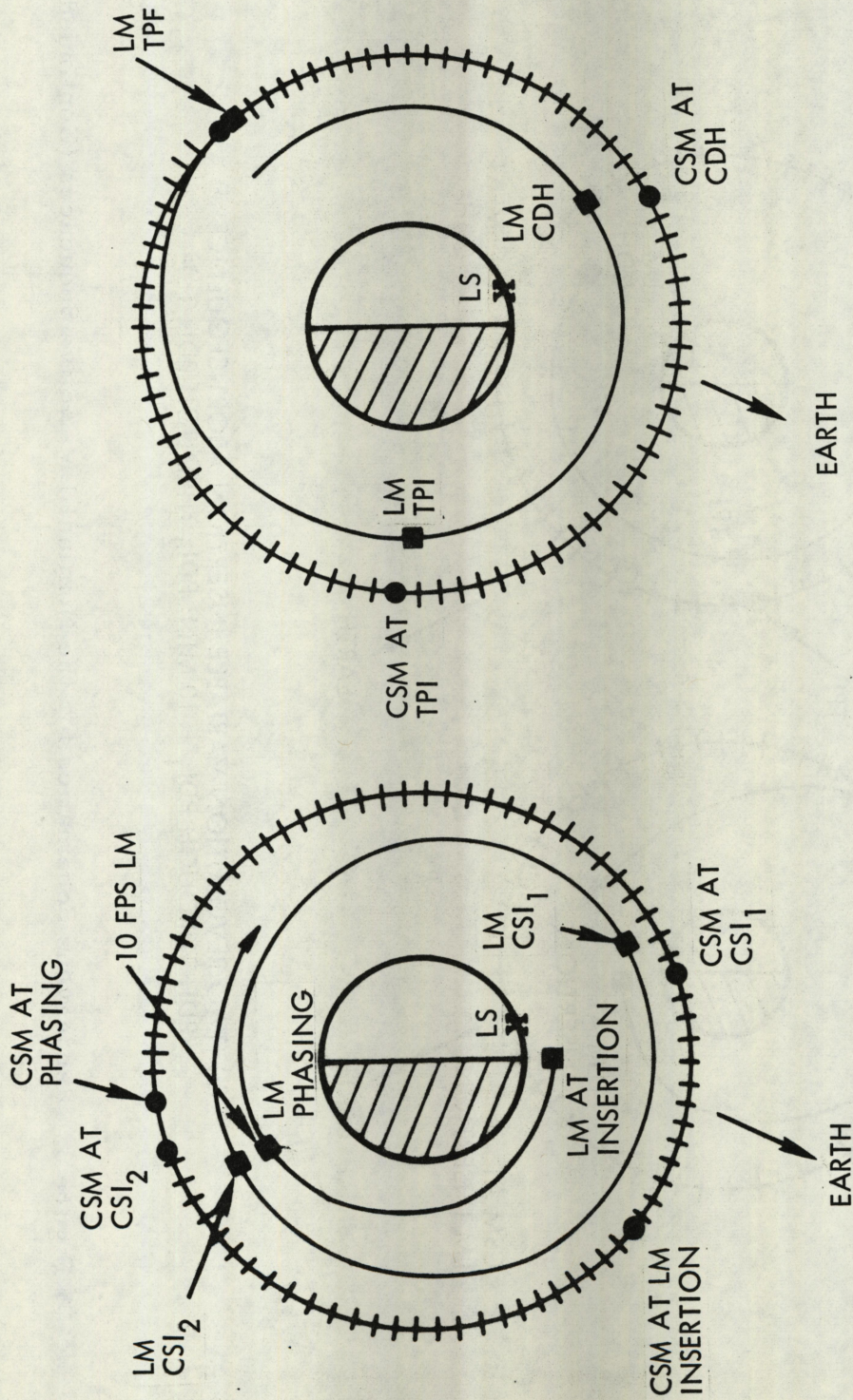




(b) TWO REVOLUTION VARIABLE INSERTION ABORT SEQUENCE  
(PDI<sub>1</sub> THROUGH PDI<sub>1</sub> + 10 MIN; PDI<sub>2</sub> THROUGH PDI<sub>2</sub> T<sub>1</sub>)

Figure 3. Rendezvous Schematics for the Nominal LM-Active Sequences (Continued)





(c) THREE REVOLUTION VARIABLE INSERTION ABORT SEQUENCE  
(PDI<sub>1</sub> + 10 MIN THROUGH PDI<sub>1</sub> T<sub>1</sub>; AND PDI<sub>2</sub> T<sub>2</sub>)

Figure 3. Rendezvous Schematics for the Nominal LM-Active Sequences (Continued)



NO-PDI + 12 ABORT DATA PAD (REV A, MAY 9, 1969)

TIG N33

HR	XXX	
MIN	XX	IGNITION TIME FOR THE MANEUVER
SEC	XX.XX	

LOCAL VERT N81

ΔVX	±XXXX.X (fps)	LOCAL VERTICAL ΔV COMPONENTS OF THE MANEUVER
-----	---------------	---

ΔVY	±XXXX.X (fps)	
-----	---------------	--

ΔVZ	±XXXX.X (fps)	
-----	---------------	--

ΔVR	+XXXX.X (fps)	TOTAL ΔV REQUIRED FOR THE MANEUVER
BT	X:XX (MIN:SEC)	DURATION OF THE MANEUVER

N86

VX AGS	±XXXX.X (fps)	LOCAL VERTICAL ΔV COMPONENTS OF THE MANEUVER USED TO TARGET THE AGS:
VY AGS	±XXXX.X (fps)	ROTATED THROUGH THE HALF-ANGLE OF THE BURN
VZ AGS	±XXXX.X (fps)	

FDAI INER

R	XXX (DEG)	INERTIAL PITCH AND ROLL FDAI
P	XXX (DEG)	ANGLES AT THE BURN ATTITUDE

Figure 4. NO-PDI Plus 12-Minute Abort Data Pad



### 3. 6. 1. 2 CSM-Active (Rescue) Sequences

In the event of a PDI no go decision, the CSM rescue sequence depends on what extent the LM was able to execute the NO-PDI plus 12-minute abort maneuver. If this phasing maneuver is executed accurately by the LM and then the CSM must rescue, the CSM simply applies a CSI/CDH sequence using the LM CSI and TPI times with  $N^*$  equal to 1 for CDH one-half period after CSI. Although these maneuvers differ slightly from those for the LM, the CSM sequence is essentially a mirror image of the LM sequence.

If the LM were unable (or partially able) to execute the NO-PDI plus 12-minute abort maneuver, the CSM applies the rescue 2 sequences shown in Table 2. The initial height adjust maneuvers shown in Table 2 are ground targeted (MCC-H provides  $\Delta V$  and TIG). The subsequent CSI maneuvers preceding the final CSI/CDH sequence are computed and executed like the nominal CSI maneuver using the indicated values for N. The  $CSI_1$  and TPI times are provided by MCC-H.

### 3. 6. 2 Descent and Lunar Surface Abort Rendezvous Sequences

#### 3. 6. 2. 1 LM-Active Sequences

The rendezvous maneuver sequence (Figure 3b) for aborts occurring between  $PDI_1$  and  $PDI_1$  plus 10 minutes (or between  $PDI_2$  and  $PDI_2$   $T_1^{**}$  is essentially identical to the rendezvous sequence which follows a nominal ascent. This is accomplished by variable insertion targeting in the PGNC S P70 and P71 abort programs and in the AGS. The primary difference is that variable insertion targeting inserts the LM into an orbit ranging

---

\* N is the apsidal crossing at which the CDH maneuver should occur after CSI.

\*\* The  $T_1$  and  $T_2$  times for  $PDI_1$  and  $PDI_2$  are:

	$T_1$	$T_2$
$PDI_1$	$PDI + 16:20 \text{ min:sec}$	$PDI + 21:22 \text{ min:sec}$
$PDI_2$	$PDI + 14:24 \text{ min:sec}$	$PDI + 20:58 \text{ min:sec}$

Lunar touchdown nominally occurs between approximately  $PDI$  plus 11:16 minutes:seconds and  $PDI$  plus 13 minutes depending on the required hover time.



Table 2. PDI No Go Rescue 2 Rendezvous Sequences

LM NO-PDI + 12-Minute Abort Phasing $\Delta V$	CSM Rescue 2 Sequence
For $PDI_1$ : $\Delta V > 60$ ft/sec	<ul style="list-style-type: none"> <li>Height adjust (rescue 2) maneuver one CSM revolution after DOI for <math>PDI_1</math> or two CSM revolutions after DOI for <math>PDI_2</math></li> </ul>
For $PDI_2$ : $\Delta V > 90$ ft/sec	<ul style="list-style-type: none"> <li><math>CSI_1</math> (phasing) maneuver one-half CSM revolution after the height maneuver with <math>N = 2</math></li> <li><math>CSI_2</math> (nominally zero) maneuver one-half CSM revolution after the <math>CSI_1</math> maneuver with <math>N = 1</math></li> <li>CDH/TPI/TPF initiated one-half CSM revolution after the <math>CSI_2</math> maneuver</li> </ul>
For $PDI_1$ : $\Delta V < 60$ ft/sec*	<ul style="list-style-type: none"> <li>Height adjust (rescue 2) maneuver one CSM revolution after DOI for <math>PDI_1</math> or two CSM revolutions after DOI for <math>PDI_2</math></li> </ul>
For $PDI_2$ : $40$ ft/sec $< \Delta V < 90$ ft/sec	<ul style="list-style-type: none"> <li><math>CSI_1</math> (phasing) maneuver one-half CSM revolution after the height maneuver with <math>N = 4</math></li> <li><math>CSI_2</math> (nominally zero) maneuver one CSM revolution after <math>CSI_1</math> maneuver with <math>N = 2</math></li> <li><math>CSI_3</math> (nominally zero) maneuver one-half CSM revolution after the <math>CSI_2</math> maneuver with <math>N = 1</math></li> <li>CDH/TPI/TPF initiated one-half CSM revolution after the <math>CSI_3</math> maneuver</li> </ul>
For $PDI_2$ : $\Delta V < 40$ ft/sec*	<ul style="list-style-type: none"> <li>Height adjust (rescue 2) maneuver two CSM revolutions after DOI</li> <li><math>CSI_1</math>(phasing) maneuver one-half CSM revolution after the height maneuver with <math>N = 6</math></li> </ul>

\*  $\Delta H = 10$  n mi (nominally  $\Delta H = 15$  n mi)



Table 2. PDI No Go Rescue 2 Rendezvous Sequences (Continued)

LM NO-PDI + 12-Minute  
Abort Phasing  $\Delta V$

CSM Rescue 2 Sequence

- CSI<sub>2</sub> (nominally zero) maneuver two CSM revolutions after the CSI<sub>1</sub> maneuver with N = 2\*
- CSI<sub>3</sub> (nominally zero) maneuver one CSM revolution after the CSI<sub>2</sub> maneuver with N = 1
- CDH/TPI/TPF initiated one-half CSM revolution after the CSI<sub>3</sub> maneuver

\* CSI<sub>2</sub> could be executed one CSM revolution after CSI<sub>1</sub> with N = 4 in which case as many as four CSI maneuvers could be employed.



between 10-by 180-nautical miles and 10-by 30-nautical miles\*. The nominal ascent insertion orbit is 9-by 45-nautical miles.

An established ground rule for variable insertion targeting is that the insertion orbit apolune should never be less than 30 nautical miles. Because of this, the rendezvous maneuver sequence for descent aborts after PDI plus 10 minutes through PDI<sub>1</sub> T<sub>1</sub> requires an additional revolution for LM catchup (Figure 3c). In order to ensure a safe perilune passage prior to initiating the nominal coelliptic rendezvous sequence (one revolution after insertion), a 10-foot per second phasing burn is performed at insertion plus 50 minutes; this raises the nominal 10-nautical mile insertion perilune to about 17 nautical miles. In addition, a HAM (nominally zero) is scheduled 60 minutes after the phasing maneuver to account for off-nominal rendezvous conditions.

In the PDI<sub>1</sub> + 10 minute through PDI<sub>1</sub> T<sub>1</sub> abort period, the PGNCS variable insertion targeting inserts the LM into an orbit ranging between 10- by 60-nautical miles and 10- by 30-nautical miles. As discussed in Section 3.5.2, the AGS does not provide variable insertion targeting in this abort period and so it is necessary for the LM to perform postinsertion tweak burn to achieve the corresponding PGNCS targeted orbit.

A lunar surface abort at the PDI<sub>2</sub> T<sub>2</sub>\*\* opportunity employs the same rendezvous maneuver sequence as a lunar surface abort at the PDI<sub>1</sub> T<sub>1</sub>\*\* opportunity (the insertion orbit in each instance is 10- by 30-nautical miles with identical LM/CSM phasing). A lunar surface abort at the PDI<sub>1</sub> T<sub>2</sub>\*\* opportunity also employs the same maneuver sequence except that an extra revolution between insertion and the nominal coelliptic sequence initiation is required.

---

\* Variable insertion conditions are a function of the LM guidance (PGNCS) versus AGS), LM propulsion (DPS versus APS), and the PDI opportunity (PDI<sub>2</sub> targeting generally requires a higher apolune altitude than PDI<sub>1</sub>; PDI<sub>1</sub> is limited to an apolune altitude of 128 nautical miles).

\*\* The T<sub>1</sub> and T<sub>2</sub> times for PDI<sub>1</sub> and PDI<sub>2</sub> are:

	T <sub>1</sub>	T <sub>2</sub>
PDI <sub>1</sub>	PDI + 16:20 min:sec	PDI + 21:22 min:sec
PDI <sub>2</sub>	PDI + 14:24 min:sec	PDI + 20:58 min:sec



### 3.6.2.2 CSM-Active Sequences

For the abort initiation periods between  $PDI_1$  and  $PDI_1$  plus 10 minutes and between  $PDI_2$  and  $PDI_2 T_1$  the CSM rescue maneuver sequence following LM insertion is the mirror image of the LM rendezvous sequences using the LM CSI and TPI maneuver times. CSM rescue sequences for descent and lunar surface aborts initiated in the period  $PDI_1$  plus 10 minutes through  $PDI_1 T_1$  utilize the LM maneuver sequence without the 10-foot per second phasing burn. The HAM is mirror image targeted at the LM TIG. In the event the LM becomes nonpropulsive after an abort on AGS in the  $PDI_1 + 10$  minute through  $PDI_1 T_1$  abort period, the CSM will perform an MCC-H targeted tweak burn at insertion plus 12 minutes to account for the AGS 10- by 30-nautical mile targeted insertion orbit.

The CSM rescue maneuver sequence for a LM abort initiated at the  $PDI_2 T_2$  opportunity is identical to that for a LM abort at the  $PDI_1 T_1$  opportunity. A rescue for a LM abort at the  $PDI_1 T_2$  opportunity employs the same maneuver sequence except that an extra revolution between insertion and the nominal coelliptic sequence initiation is required.

The above rescue cases assume that the LM has achieved an accurate insertion maneuver. However, either the mirror image or rescue 2 sequence can be effectively employed for off-nominal insertion cases other than minimum orbit insertions for early abort times in the variable insertion regions. These situations involve a high CSM dwell orbit for the LM to catchup in the opposite phasing direction; the normal rescue 2 sequence cannot be used because the CSM could not get into an orbit low enough below the LM orbit to catchup with the LM in the allowable time. A detailed discussion of the high dwell orbit technique is presented in Reference 6.

### 3.6.3 Postabort Rendezvous Tracking Schedule

Postabort rendezvous tracking is complicated by the fact that many of the rendezvous maneuver sequences involve one or more height adjust and/or phasing maneuvers prior to initiation of the coelliptic sequence (i.e., CSI/CDH). In some instances the tracking distances involved exceed



the RR and VHF ranging capability. The following tracking schedules are currently recommended (Reference 8):

- The nominal tracking schedule (Table 3) is generalized to postabort sequences by equating the maneuver which precedes the CSI/CDH sequence to "insertion" in the nominal tracking.
- The tracking schedule presented in Table 4 should be used for maneuvers which occur prior to the CSI/CDH sequence. This schedule provides about 25 minutes of tracking which is completed 12 minutes prior to the maneuver.

The only known postabort rendezvous cases that definitely involve tracking distances which exceed the RR and VHF ranging capability are:

- Certain  $PDI_2$  no go abort and rescue sequences
- Early  $PDI_2$  descent abort rendezvous sequences

For these cases the first tracking opportunity will employ W-matrix values of 10,000 feet, 10 feet per second, 15 mrad for the LM and 10,000 feet and 10 feet per second for the CSM. Thereafter the schedules presented in Tables 3 and 4 will apply.

#### 3.6.4 Rendezvous Maneuver Solution Determination

##### 3.6.4.1 Phasing and Height Adjust Maneuvers

The NO-PDI plus 12-minute abort phasing and rescue 2 height adjust maneuvers for the PDI no go aborts are determined by MCC-H. A backup technique using onboard charts exists for the NO-PDI plus 12-minute abort and is available in the event of a LM communication loss. MCC-H is also prime for computation of the phasing and height adjust maneuvers for descent and lunar surface aborts between  $PDI_1$  plus 10 minutes and  $PDI_1 T_1$ ) and lunar surface aborts at  $T_2$ . However, a backup procedure using P32 and an onboard chart will also be available.

##### 3.6.4.2 CSI and CDH Maneuvers

The CSI (other than the above mentioned phasing and height adjust maneuvers) and CDH maneuver solutions are computed using onboard P32 (CSI targeting) and P33 (CDH targeting) programs (LM and CSM). AGS (DEDA addresses 410 + 10000 for CSI and 410 + 20000 for CDH) and



Table 3. Nominal Onboard Tracking Schedule for Mission H-1

<u>LM Event</u>	<u>Time from Insertion (min)</u>	<u>CSM Event</u>	<u>Time from Insertion (min)</u>
Insertion	0	Insertion	0
V93 before first mark W = 10,000 ft, 10 ft/sec, 15 mrad		V93 before first mark W = 10,000 ft, 10 ft/sec	
Initiate tracking	18		19
		Initiate tracking (SXT + VHF)	
Cease tracking	40	Cease tracking	38
CSI	50	CSI	50
V93 before first mark W = 2,000 ft, 2 ft/sec, 5 mrad		V93 before first mark W = 2,000 ft, 10 ft/sec	
Initiate tracking	55		56
		Initiate tracking (SXT + VHF)	
Cease tracking	71	Cease tracking	78
		Plane change	79



Table 3. Nominal Onboard Tracking Schedule for Mission H-1 (Continued)

<u>LM Event</u>	<u>Time from Insertion (min)</u>	<u>CSM Event</u>	<u>Time from Insertion (min)</u>
V93 before first mark W = 2,000 ft, 2 ft/sec, 5 mrad		V93 before first mark W = 2,000 ft, 2 ft/sec	
Initiate tracking	81	Initiate tracking (SXT + VHF)	81
		Cease tracking	96
Cease tracking	98		
CDH	108	CDH	108
V93 before first mark W = 2,000 ft, 2 ft/sec 5 mrad		V93 before first mark W = 2,000 ft, 2 ft/sec	
Initiate tracking	110		
		Initiate tracking	115
Cease tracking	137	Cease tracking	134
TPI	147	TPI	147



Table 3. Nominal Onboard Tracking Schedule for Mission H-1 (Continued)

<u>LM Event</u>	<u>Time from Insertion (min)</u>	<u>CSM Event</u>	<u>Time from Insertion (min)</u>
V93 before first mark W = 2,000 ft, 2 ft/sec, 5 mrad		V93 before first mark W = 2,000 ft, 2 ft/sec*	
Initiate tracking	149		
		Initiate tracking (SXT + VHF)	152
		Cease tracking	159
Cease tracking	160		
MCC-1	162	MCC-1	162
V93 before first mark W = 2,000 ft, 2 ft/sec, 5 mrad		V93 before first mark W = 2,000 ft, 2 ft/sec**	
Initiate tracking	164		
		Initiate tracking	165
		Cease tracking	174
Cease tracking	175		
MCC-2	177	MCC-2	177

\* If SXT or VHF only, no V93 between TPI and MCC-1

\*\* If SXT or VHF only, V93 after 3 marks following MCC-1



Table 4. Onboard Tracking Schedule for Additional CSI Maneuvers  
in Multiple CSI Rendezvous Sequences

<u>Time from CSI (min)</u>	<u>Event</u>
<u>LM Rendezvous Radar:</u>	
-37	V93, W = 10,000 ft, 10 ft/sec, 15 mrad initiate track
-10	Cease track
0	CSI
<u>CSM Sextant and VHF:</u>	
-37	V93, W = 10,000 ft, 10 ft/sec initiate sextant and VHF track
-12	Cease track
0	CSI



onboard chart (using RR) solutions are also available. For comparison, the LM and CSM solutions must be biased in order to account for differences caused by relative orbital geometry. For PDI no go situations the solution biases for both CSI and CDH solutions will be provided by MCC-H. The CSI solution biases for both  $PDI_1$  and  $PDI_2$  descent aborts will be determined from onboard charts. The corresponding CDH solution biases will be determined by MCC-H.

Prior to their respective TIG's, the CSI and CDH maneuver solutions (PGNCS, GNCS, and AGS) are compared. If the LGC agrees with either the CMC or chart (VGX less than 3 feet per second for CSI maneuvers; VGX less than 2 feet per second and VGZ less than 6 feet per second for CDH maneuvers), the LGC solution will be used. If the LGC does not agree with either the CMC or AGS, the CMC solution will be used in the LGC if it agrees with the AGS (VGX less than 3 feet per second for CSI maneuvers; VGX less than 2 feet per second and VGZ less than 6 feet per second for CDH maneuvers). If all solutions disagree, the CMC solution will be used unless MCC-H specifies otherwise. The procedure is the same for both LM-active and CSM-active cases. Whenever the active vehicle uses the inactive vehicle solution, the biased value will be burned. In rendezvous situations where the tracking distance exceeds the onboard tracking capability, the LGC solutions for those CSI maneuvers will be prime because the PGNCS state vector is expected to be the best available. In the event of an AGS failure, the onboard chart solutions replace the AGS in the above comparison.

### 3.6.5 Onboard Rendezvous Checklists

The various abort rendezvous sequences and associated procedures presented herein will be exposed to limited crew training and simulations. As a result, "cookbooks" of procedures for the LMP and CMP have been developed. These consist of a variety of representative two-page checklists, each designed for a specific abort situation. Tables 5 and 6 list the abort situations and type of rendezvous maneuver sequence covered by checklists for the LM and CSM, respectively. A typical LM checklist example is presented in Figure 5.



Table 5. Abort Situations Covered by Specific LM Onboard Checklists

<u>Abort Situations (LM-Active)</u>	<u>Type of Rendezvous Maneuver Sequence</u>
1. NO-PDI <sub>1</sub> + 12 min abort	LM executes phasing/five impulse sequence
2. PDI <sub>1</sub> + 5 min descent abort	LM executes nominal rendezvous sequence
3. PDI <sub>1</sub> + 10 min descent abort	Same as (2) above
4. PDI <sub>1</sub> + 12 min descent abort	Same as (1) above
5. PDI <sub>1</sub> + 21:22 min:sec lunar surface abort	Same as (1) above
6. NO-PDI <sub>2</sub> + 12 min abort	Same as (1) above
7. PDI <sub>2</sub> + 14:24 min:sec lunar surface abort	Same as (2) above
8. PDI <sub>2</sub> + 20:58 min:sec lunar surface abort	Same as (1) above



Table 6. Abort Situations Covered by Specific  
CSM Onboard Checklists

<u>Abort Situations</u>	<u>Type of Rendezvous Maneuver Sequence</u>
1. Partial DOI (<25 ft/sec burned)- CSM rescue	CSM executes height/five impulse sequence (rescue 2)
2. Partial DOI (>25 ft/sec burned)- CSM rescue	Same as (1) above
3. NO-PDI <sub>1</sub> + 12 min abort - LM- active	LM executes phasing/five impulse sequence
4. LM burns <60 ft/sec phasing for NO-PDI <sub>1</sub> + 12 min abort - CSM-active	CSM executes height/five impulse sequence (rescue 2)
5. LM burns ≥ 60 ft/sec phasing for a NO-PDI <sub>1</sub> + 12 min abort - CSM-active	Same as (4) above
6. PDI <sub>1</sub> + 10 min descent abort - LM-active	LM executes nominal sequence
7. PDI <sub>1</sub> + 12 min descent abort - LM-active	LM executes phasing/five impulse sequence
8. PDI <sub>1</sub> + 12 min AGS descent abort - CSM-active	CSM executes tweak/five impulse sequence
9. PDI <sub>1</sub> + 21:22 min:sec lunar surface abort - CSM-active	CSM execute phasing/five impulse sequence
10. NO-PDI <sub>2</sub> + 12 min abort - LM-active	Same as (3) above
11. LM burns < 40 ft/sec phasing for a NO-PDI <sub>2</sub> + 12 min abort - CSM-active	Same as (4) above
12. LM burns 40 to 90 ft/sec for a NO-PDI <sub>2</sub> + 12 min abort - CSM-active	Same as (4) above
13. LM burns ≥ 90 ft/sec for a NO- PDI <sub>2</sub> + 12 min abort - CSM- active	Same as (4) above
14. LM insertion after descent or lunar surface abort initiated prior to PDI <sub>2</sub> + 14:24 min:sec (variable insertion targeting) - LM-active	Same as (6) above
15. LM insertion after lunar surface abort initiated at T <sub>2</sub> (PDI <sub>2</sub> + 20:58 min:sec) - CSM-active	CSM executes five impulse sequence



Table 6. Abort Situations Covered by Specific  
CSM Onboard Checklists (Continued)

<u>Abort Situations</u>	<u>Type of Rendezvous Maneuver Sequence</u>
16. LM insertion into a low contingency orbit - CSM-active	CSM executes phasing/height/coelliptic sequence: phasing and height maneuvers separated by three rev high dwell orbit
17. LM insertion into an overburn (manual insertion) contingency orbit - CSM-active	CSM executes phasing/five impulse sequence; phasing and height (CSI <sub>1</sub> ) maneuvers 1/2 rev apart (as usual)
18. Anytime lift-off for CSM 15 deg prior to landing site at lift-off - CSM-active	Same as (16) above



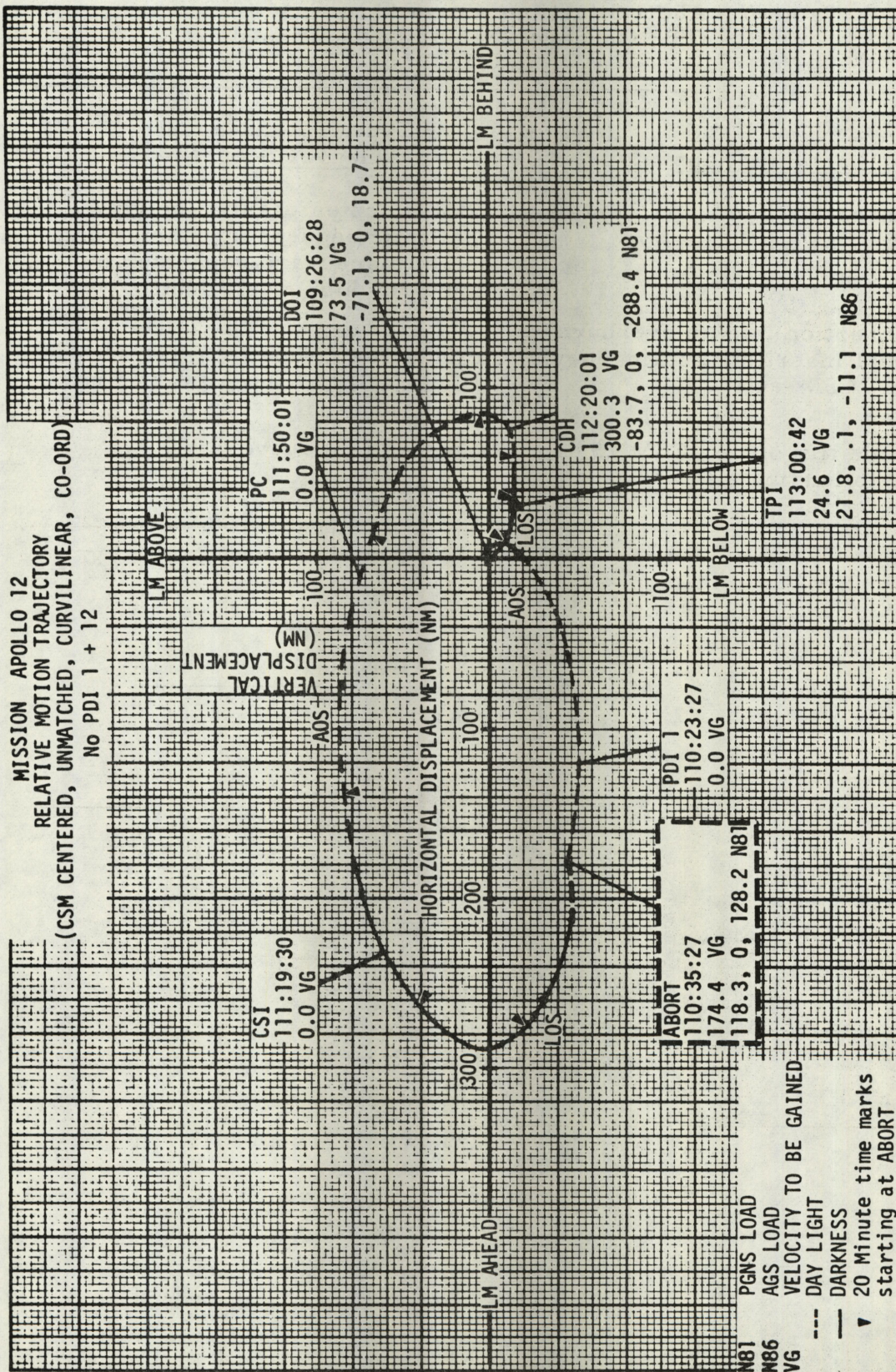


Figure 5. LM Checklist for a NO-PDI<sub>1</sub> Plus 12-Minute Abort



# No-PDI 1 + 12 Timeline

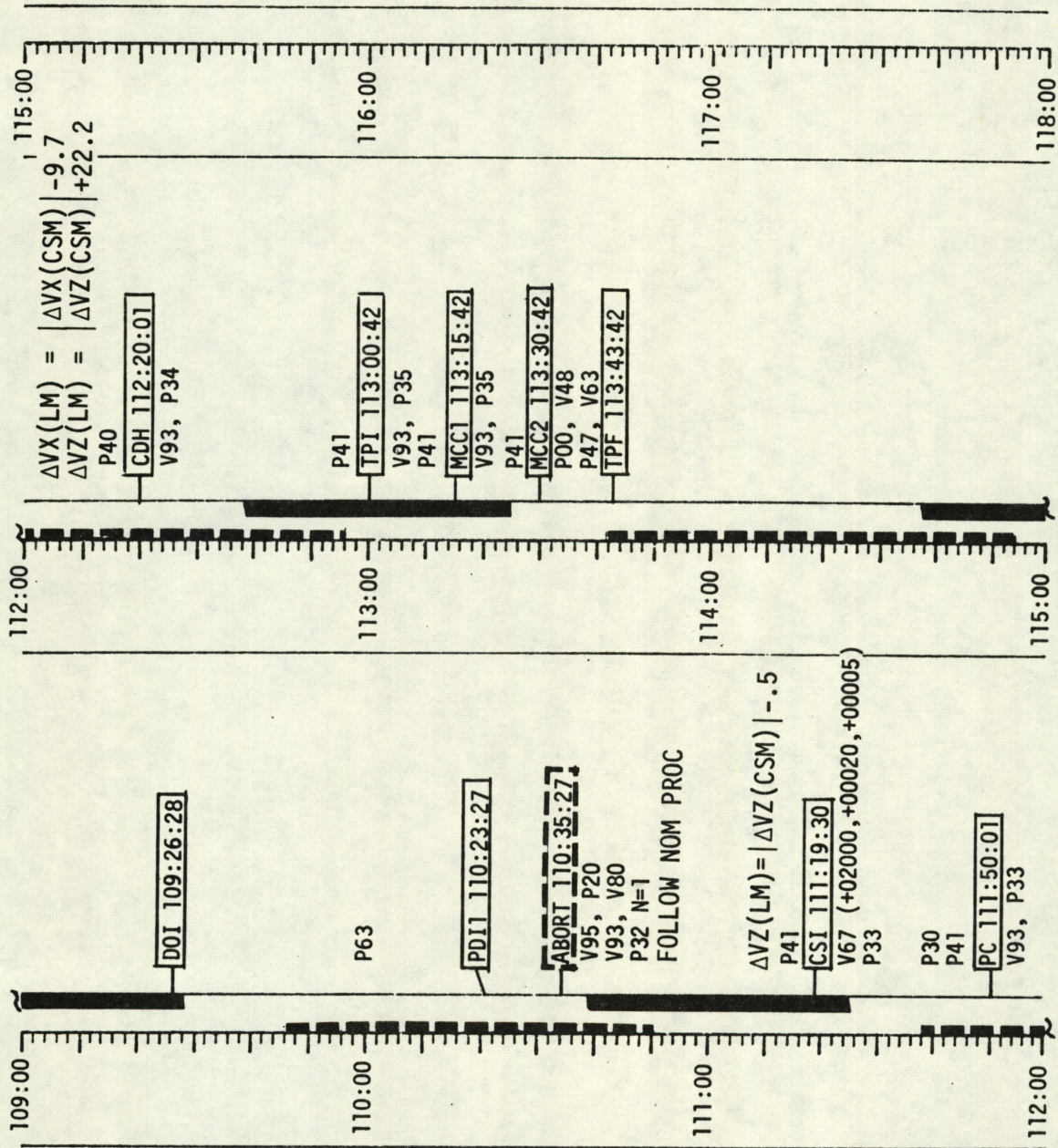


Figure 5. LM Checklist for a NO-PDI<sub>1</sub> Plus 12-Minute Abort (Continued)



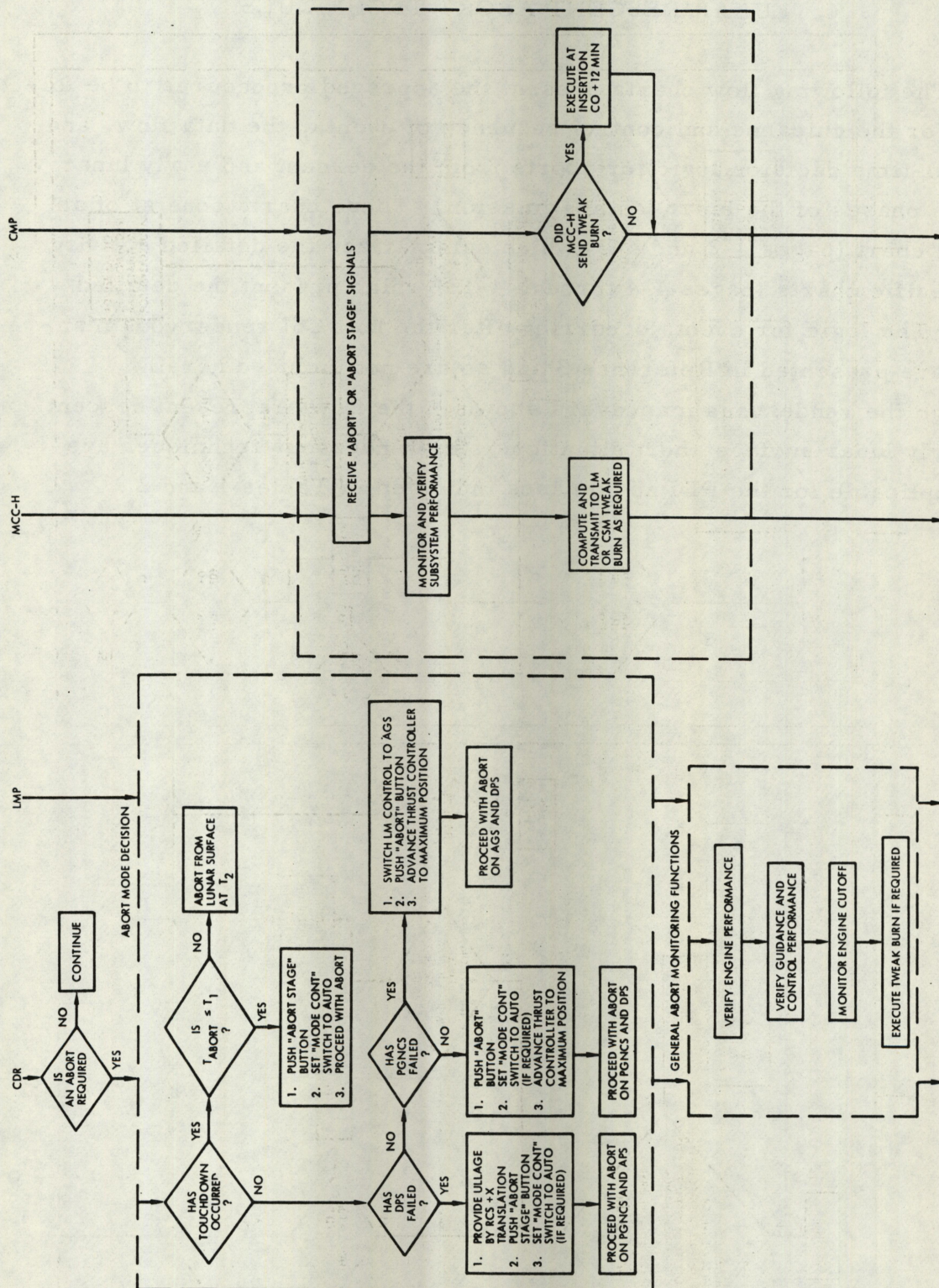




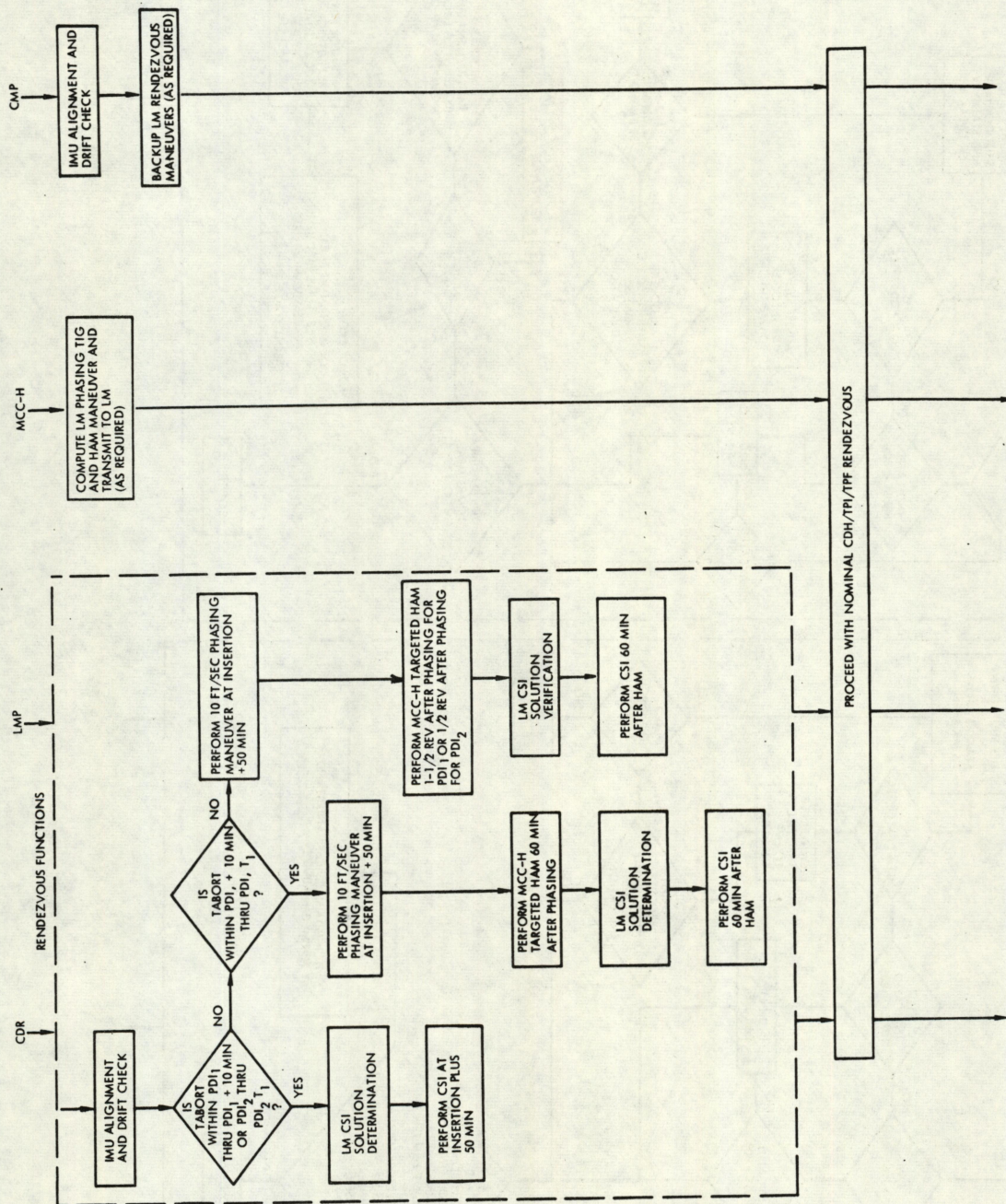
#### 4. LUNAR DESCENT ABORT TECHNIQUES

The following flow charts present the approved procedures to be followed for the guidance and control sequence of events, the data flow, and the real-time decision logic for aborts from the descent and early lunar surface phases of the lunar landing mission. These charts consist of an overall chart (pages 4-2 and 4-3) which summarizes the detailed activity and specific charts (pages 4-4 through 4-13) which present the detailed logic. The logic for events occurring after the last CSI rendezvous maneuver are presented in Reference 3 and so are not included herein. Although the rendezvous maneuvers shown in the flows represent descent and early lunar surface abort situations, the rendezvous techniques are also applicable for the PDI no go cases indicated in Tables 1 and 2.





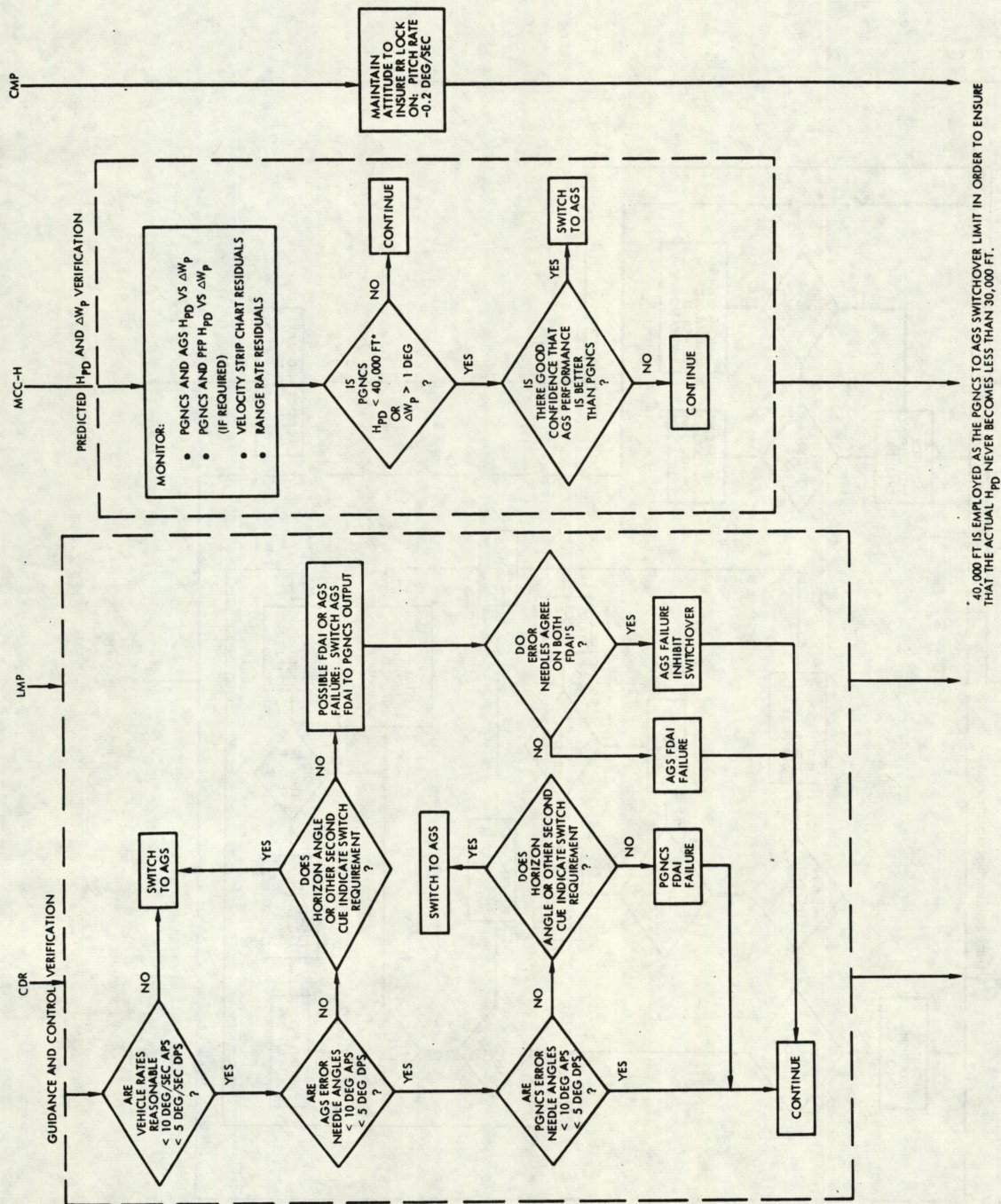




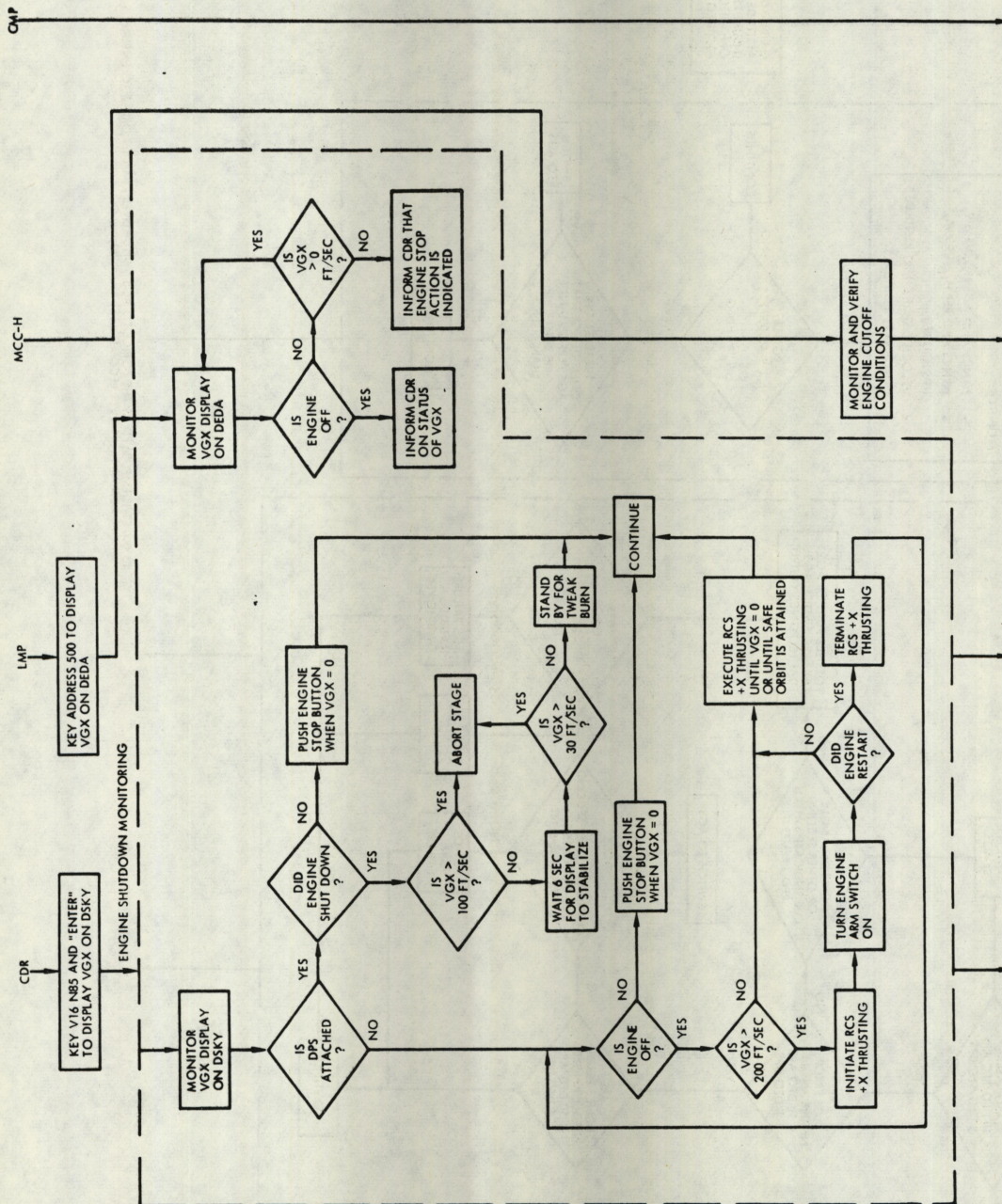




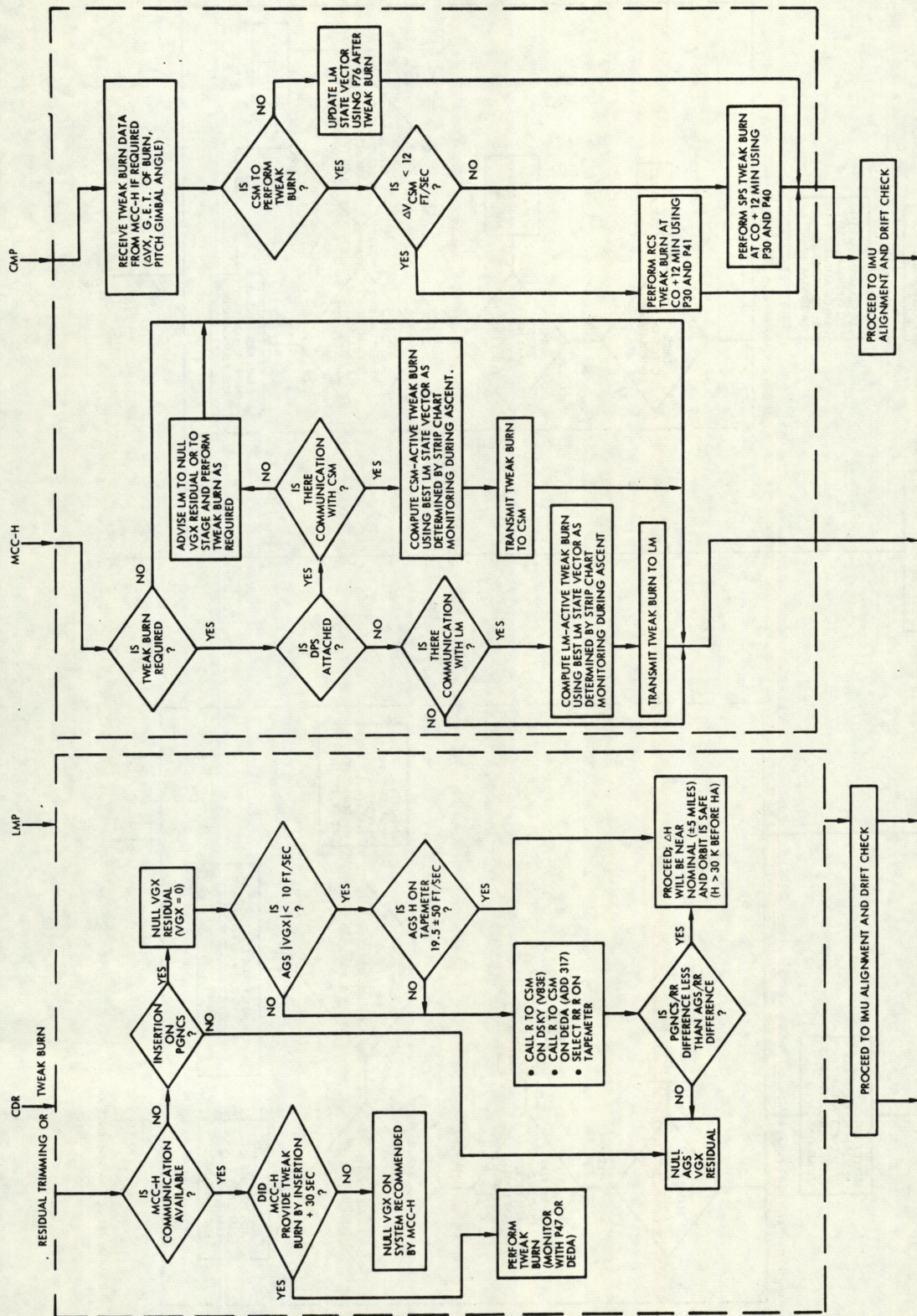




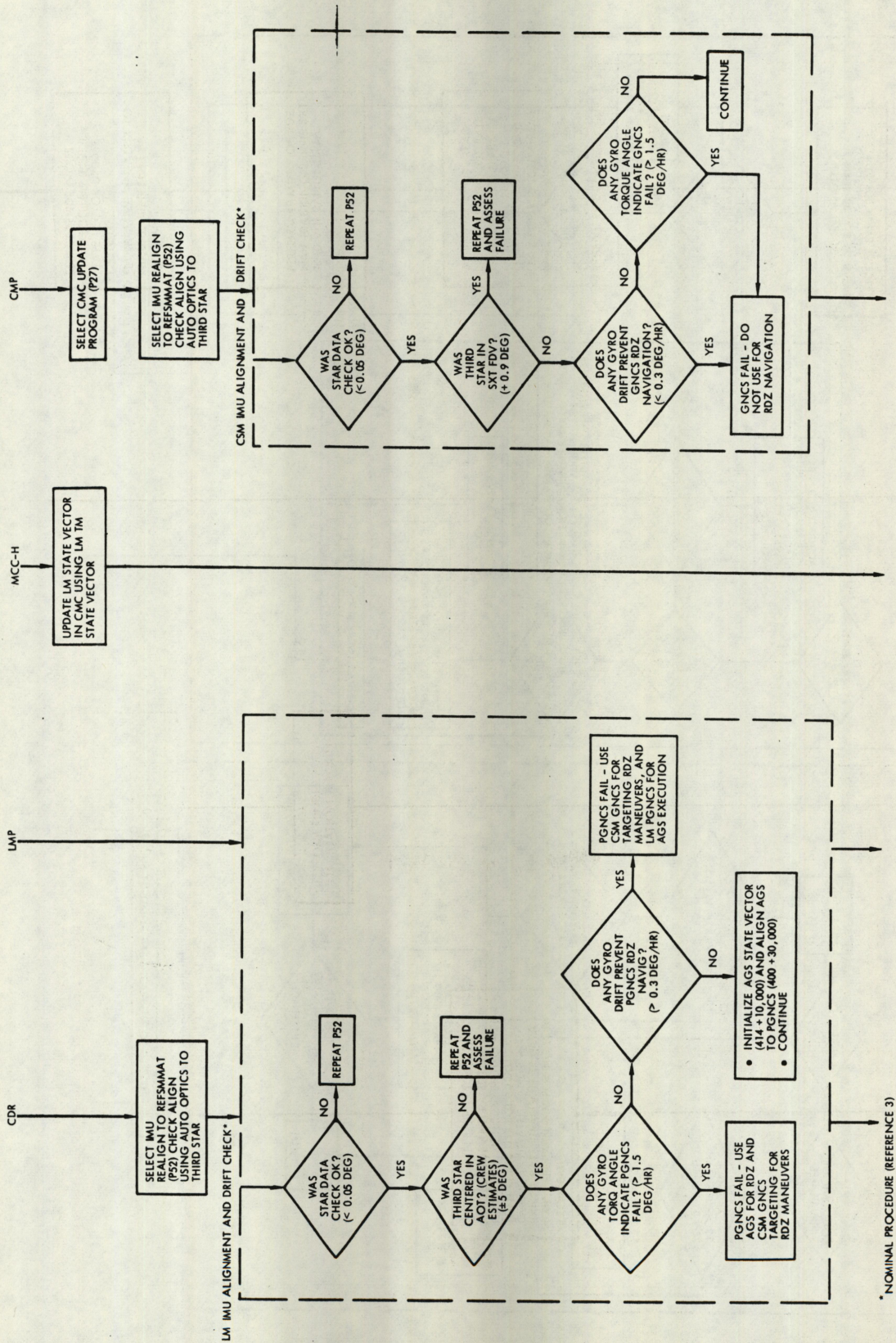




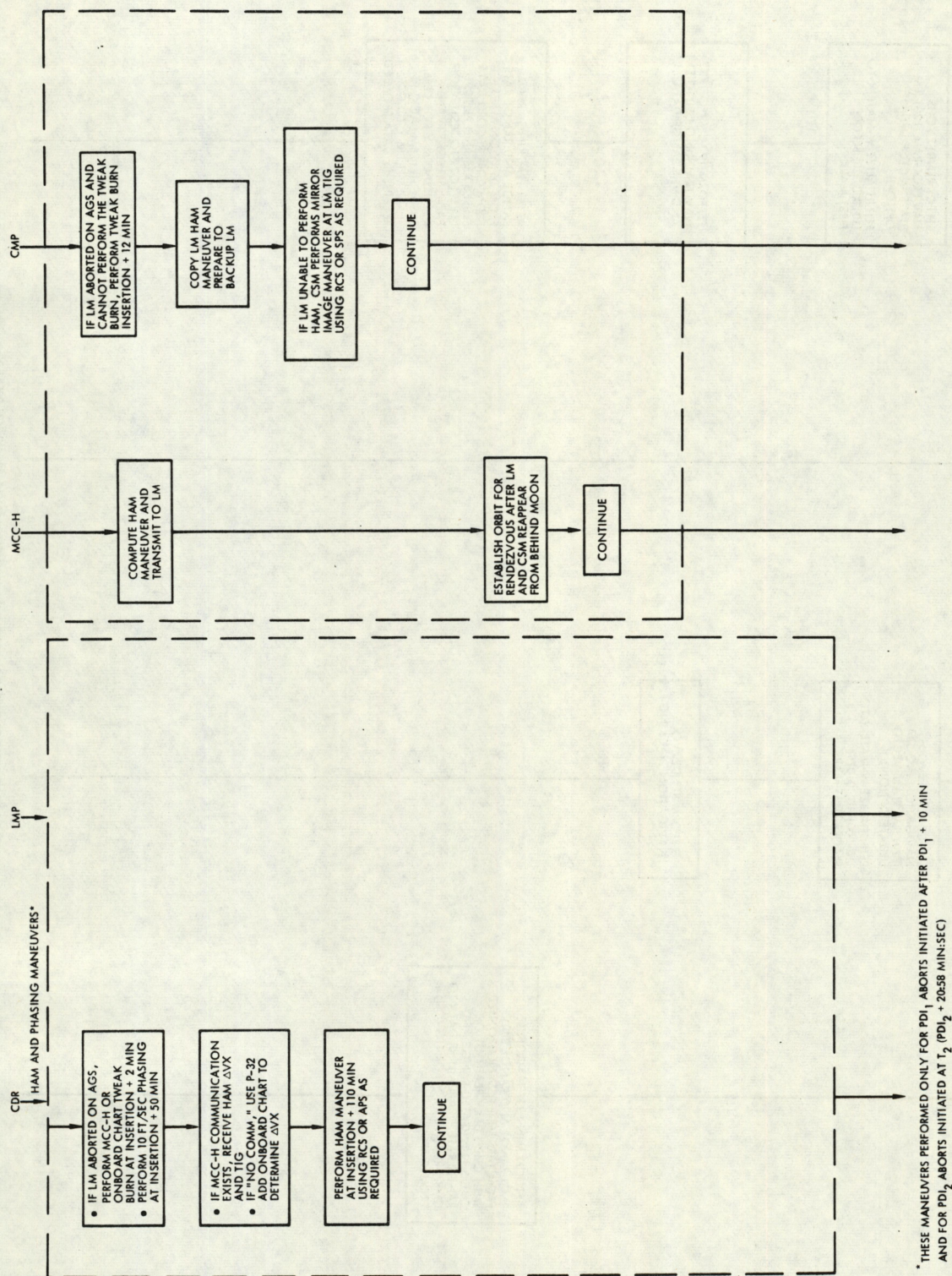






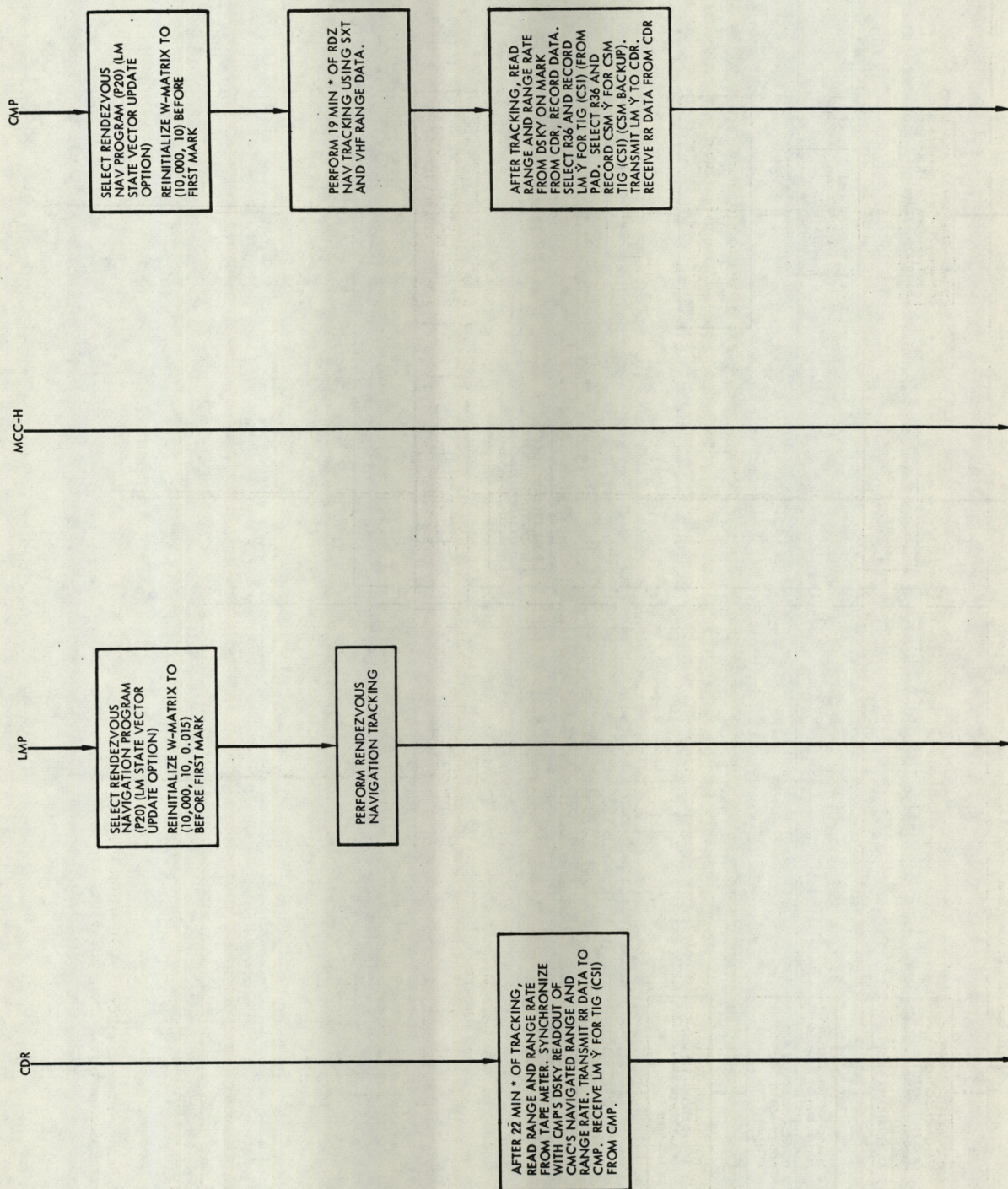






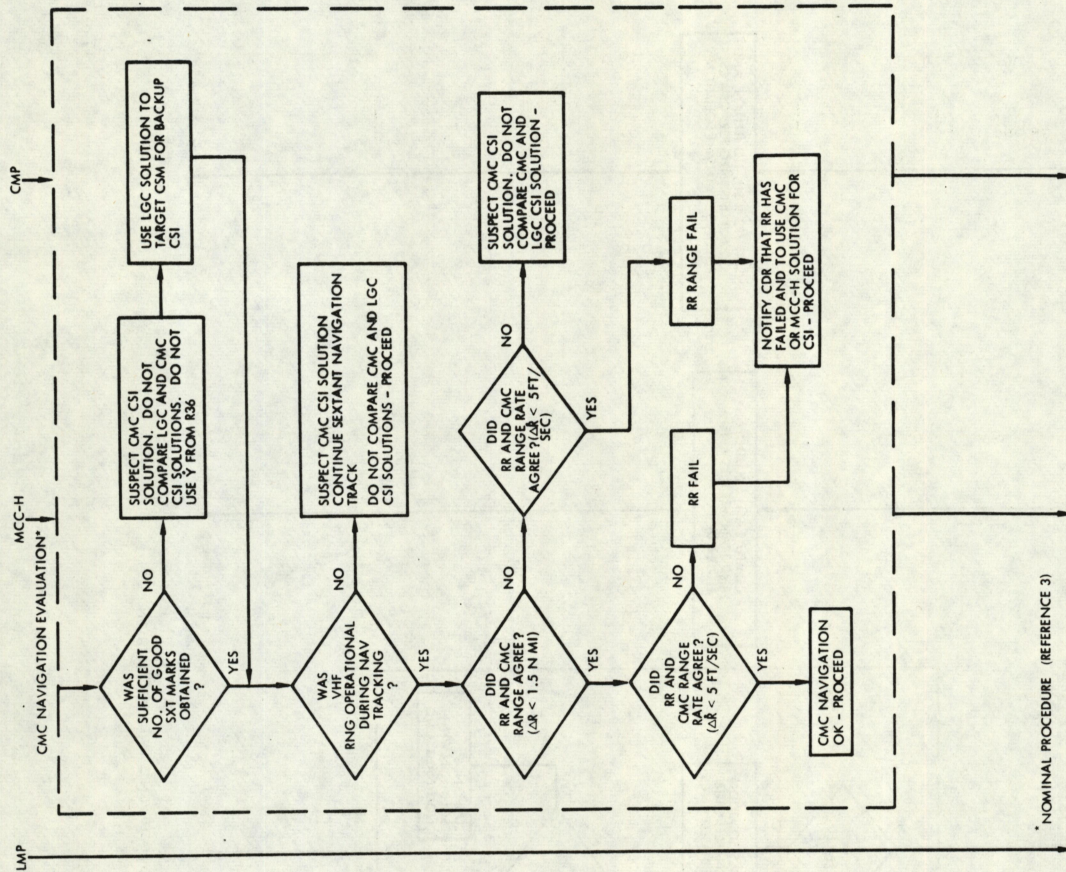
\* THESE MANEUVERS PERFORMED ONLY FOR PD<sub>1</sub> ABORTS INITIATED AFTER PD<sub>1</sub> + 10 MIN AND FOR PD<sub>1</sub> ABORTS INITIATED AT T<sub>2</sub> (PD<sub>1</sub> + 20:58 MIN:SEC)



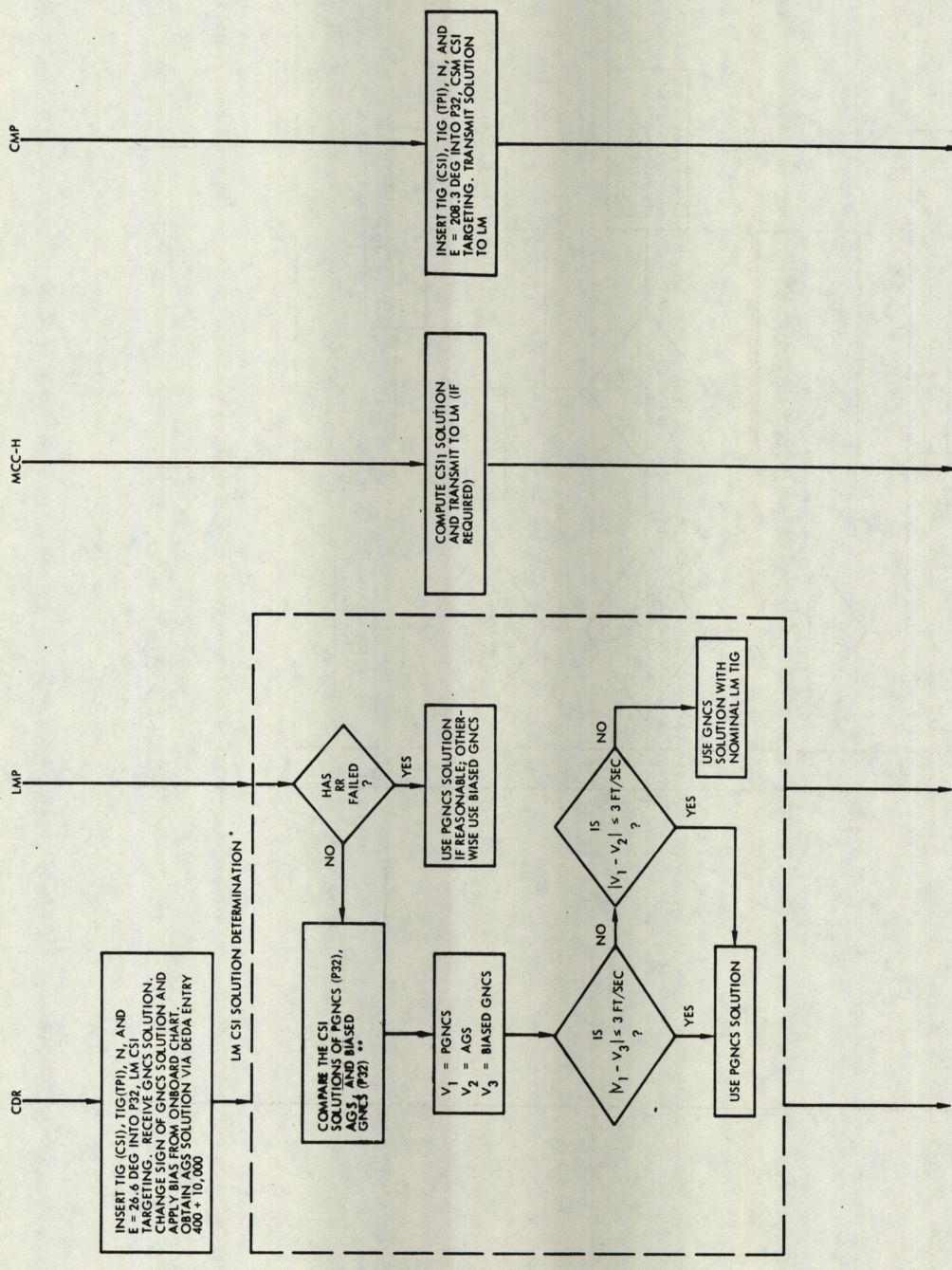


\*NOMINAL TRACKING PERIODS (TABLE 3): FOR HAM AND CSI MANEUVERS WHICH PRECEDE THE FINAL CSI/CDH SEQUENCE, THE TRACKING SCHEDULE IN TABLE 4 BECOMES APPLICABLE.

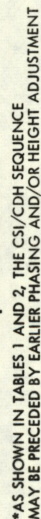


















## REFERENCES

1. "Apollo Mission Techniques Mission H-1 Lunar Surface Phase, Techniques Description," MSC Internal Note MSC-00178, 15 October 1969.
2. "Apollo Mission Techniques Mission G Powered Ascent, Techniques Description," MSC Internal Note S-PA-9T-128, 25 June 1969.
3. "Apollo Mission Techniques Mission H-1 Lunar Orbit Activities, Volume 1, Techniques Description," MSC Internal Note MSC-01212, 30 October 1969.
4. "Apollo Mission Techniques Mission G Manual Ascent, Techniques Description," MSC Internal Note S-PA-9T-055, 17 July 1969.
5. L. Berman, "Expected Overburn for Staging Near Orbit Insertion with Program Luminary," MIT Mission Simulation Memo 19-68, 19 June 1968.
6. "Operational LM Abort and Rescue Plan for Apollo 11 (Lunar Landing Mission)," MSC Internal Note 69-FM-175, 27 June 1969.
7. "Changes to LM Abort and Rescue Plan from Mission G to Mission H-1," MSC Internal Note 69-FM-303, to be published.
8. "Onboard Tracking Schedule for the Apollo 12 Rendezvous," MSC Memo 69-FM46-321, 8 October 1969.











