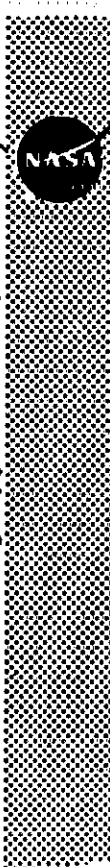


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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MSC INTERNAL NOTE

FEBRUARY 23, 1970

APOLLO MISSION TECHNIQUES
MISSION H-2 AND SUBSEQUENT.
MANUAL ASCENT.

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FEBRUARY 23, 1970

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

FOREWORD

This Manual Ascent Mission Techniques Document is one of several documents describing the H-2 Mission (Apollo 13). The others are as follows:

- Launch Aborts
- Earth Parking Orbit and Translunar Injection
- Translunar Midcourse Corrections and Lunar Orbit Insertion
- Lunar Descent
- Abort from Lunar Powered Descent and Subsequent Rendezvous
- Lunar Surface Activities
- Powered Ascent
- Lunar Orbit Activities
- 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-2 mission. The purpose of these documents is to insure 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, hold frequent meet-

FOREWORD (Continued)

irgs 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, GAG, MDC, MIT, NR, and TRW, a document such as this one is issued.

This is the final issue of the Manual Ascent Techniques Document. The mission dependent data limits and trajectory parameter values are applicable to the H-2 mission; the sequence of events, data flow and decision logic are applicable to the H-2 and subsequent Apollo missions.

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NOMENCLATURE

ACA	attitude controller assembly
ACC	accelerometer
AEA	abort electronics assembly
AGS	abort guidance system
AOT	alignment optical telescope
APS	ascent propulsion system
ASA	abort sensor assembly
AT	P57 alignment technique
ATCA	attitude and translation control assembly
AUTO	automatic
GES	control electronics section
CMD	lunar module commander
CDH	concentric delta height
CDU	coupling data unit
CSI	coelliptic sequence initiation
CSM	command service module
DAP	digital autopilot
DEDA	data entry and display assembly
DKI	docking initiation
DPS	descent propulsion system
DSKY	display and keyboard
EPS	electrical power system
FDAI	flight director attitude indicator
GASTA	gimbal angles sequence transformation assembly
GYR	gyro

NOMENCLATURE (Continued)

h	altitude
h_a	altitude of perilune
h_p	altitude of perilune
HAM	height adjust maneuver
ICDU	inertial subsystem coupling data unit
IMU	inertial measurement unit
LEMMASS	LGC's value of lunar module mass
LGC	lunar module guidance computer
LM	lunar module
LMP	lunar module pilot
MCC-H	Mission Control Center - Houston
MSC	Manned Spacecraft Center
N	number of apsidal crossing
n mi	nautical mile
P12	Ascent Program
P51	IMU Orientation Determination Program
P52	IMU Realignment Program
P57	LGC Lunar Surface Alignment Program
PDI	powered descent initiation
PONCS	LM primary guidance, navigation, and control system
PFP	powered flight processor
PSA	power and servo assembly
R03	DAP data load routine
RCS	reaction control system
ROA	rate gyro assembly

NOMENCLATURE (Continued)

RR	rendezvous radar
TD	touchdown
TPI	terminal phase initiation
TPF	terminal phase final
TIG	time of ignition
VG	velocity to be gained (VGX is X-axis component)
ΔV_S	velocity impulse required to achieve 35,000-foot perilune altitude (computed at MCC-H during lunar ascent)
VIT	variable insertion targeting
\dot{Y}	out-of-plane velocity
γ	flight-path angle

1. INTRODUCTION

The guidance and navigation sequence of events which must be performed for a powered ascent using either a manual technique or degraded guidance system are presented in this document. The recommended procedures are presented in chronological sequence and are preceded by a description of the rationale involved.

The nominal mission techniques for powered descent are presented in the lunar descent document (Reference 1), and the techniques for the period just preceding the lunar ascent are described in the lunar surface document (Reference 2). The nominal mission techniques for lunar ascent are presented in the powered ascent document (Reference 3), and the techniques for the period following insertion are described in the lunar orbit activities document (Reference 4).

2. DISCUSSION OF THE MANUAL ASCENT PROBLEM

Manual ascent from the lunar surface or from an aborted powered descent would be necessary in the event of a double failure that disabled automatic guidance steering in both PGNCs and AGS. While the probability of any specific pair of failures occurring is extremely small, there are many combinations of double failures (Table 2-1) which would disable both PGNCs and AGS automatic steering. This is especially true for ascent since the current H-2 mission rules do not require AGS to be functional after high gate.*

It is generally agreed that

- Given a rate command attitude control system, the crew should be able to guide the LM into orbit quite satisfactorily using the lowest priority attitude reference (horizon viewed through the overhead window). The resultant orbit would probably be far from nominal, which could present rendezvous problems, but simulations have shown that the LM should at least attain a safe orbit.
- Both the AGS/CES and the PGNCs have a substantial capability, even if the accelerometers are malfunctioning. However, special procedures are required to use this capability.
- The failure of an attitude gyro in either guidance system virtually eliminates the use of that guidance system for vehicle control. The failure of a CES rate gyro causes loss of AGS automatic capability in the disabled axis only.

For a safe manual insertion, it is necessary for the crew to have both an accurate attitude reference and a usable attitude control mode. An attitude control system is considered unusable if it provides insufficient control authority or requires greater than human manual dexterity. The attitude control and display modes available to the crew for automatic and manual ascent steering are listed in Table 2-2 in order of priority. The pulse and minimum impulse modes of attitude control are not considered

*The AGS system is required until high gate. However, based on the real-time situation (nominal conditions) and particular failure mode, descent may be aborted or continued (Reference 5).

2-2

AGS (Guidance Control)		Equipment Failed Function Lost		ATCA				AEA		ACA		RGA ²⁻		ASA		DEDA ⁴⁻		FDA1		EPS			
		28V B00-	15V DC	Logic Select	ATT			CMD	LMP	P	R	Y	Gyr	Acc		CMD	LMP	CHD 28 VDC	LMP 28 VDC	115V 400-			
																				A	B		
Att Control Modes	Auto	X	X	X	X		X	X		X	X	X	X	X ¹⁻	X								
	Rate Command W/Att. Hold	X	X	X	X		X	X	X	X	X	X	X						X				
	CES Rate Command	X	X	X	X			X	X	X	X	X							X				
	Direct							X	X	X	X	X						X					
	Emergency Direct (hardover)							X	X	X	X	X						X					
	Pulse		X	X	X			X	X	X	X	X						X					
	Attitude Indicator (8-ball)																	X					
	Error Needles	X			X		X						X	X ¹⁻	X	X	X	CHD only	LMP only	X ⁵⁻	X ⁶⁻		
	Rate Needles	X									X	X	X					PGNCS only	AGS only				
	RCS Primary Coils																						
	RCS Secondary Coils																						
APS Auto Off		X			X	X							X ⁸	X				SYS A only	SYS B only				
RCS Cross Feed																							
APS Feed																							
RR																		#1 only	#2 only				
Tapemeter																		X		X			
Cross Pointer																		CHD only	LMP only		X		

PGNCS (Guidance Control)		Equipment Failed Function Lost		LGC		TMU		GASTA		FDA1		ACA ²⁻		DSKY ³		PSA		ICDU		EPS			
						Gyr	Acc			CMD	LMP	CMD	LMP							CHD 28VDC	LMP 28 VDC	115V 400-	
																						A	B
Att Control Modes	Auto	X	X	X																			
	Rate Command W/Att. Hold	X	X	X																			
	Emergency Direct (hardover)											X	X	X	X	X	X	X					
	Minimum Impulse	X										X	X	X	X					X			
	Attitude Indicator (8-ball)											X	X										
	Error Needles	X	X	X				PGNCS only	X	X										CHD only	LMP only	X ⁵⁻	X ⁶⁻
	Rate Needles																			PGNCS only	AGS only		
	RCS Primary Coils	X																					
	RCS Secondary Coils																						
	APS Auto Off	X																		SYS A only	SYS B only		
	RCS Cross Feed															X				X			
APS Feed																							
RR																		#1 only	#2 only				
Tapemeter																	X		X				
Cross Pointer																		X		CHD only	LMP only	X	

Notes for Table 2-1:

1. X-accelerometer failure disables AGS auto attitude control and error needles completely. Y- or Z-accelerometer failure disables auto control and error needle in the axis of disabled accelerometer only.
2. Failure of rate gyro disables auto, CES rate command, rate command with attitude hold, and error needle in axis of disabled gyro only.
3. DSKY failure can be circumvented by using ground uplink to PGNCs.
4. DEDA failure will cause function to be disabled only if function input has not been entered prior to DEDA failure.
5. Loss of CMD eight-ball only and GASTA
6. Loss of LMP eight-ball and AEA attitude reference signals
7. A failure of CMD or LMP ACA effects only the manual attitude control capability of the astronaut whose ACA is disabled.
8. APS Auto Off disabled by X-accelerometer failure only

Table 2-2. Attitude Control and Display Modes

Priority of Control Modes

PGNCS automatic
AGS automatic
PGNCS rate command/attitude hold
AGS rate command/attitude hold
CES rate command
Direct (two-jet with ACA breakout switches)
Hardover (four-jet direct with ACA hardstop switches)

Priority of Attitude Displays

PGNCS error needles (computed steering commands)
AGS error needles (computed steering commands)
PGNCS total attitude (FDAI eight-ball) - four-step or 30-second increment
FDAI pitch profile
AGS total attitude (FDAI eight-ball) - four-step or 30-second increment
FDAI pitch profile
Horizon viewed out the window - four-step horizon pitch profile.

since it is thought that they lack sufficient control momentum to overcome ascent engine disturbance torques.

If automatic steering control is not available, the highest priority display mode available (Table 2-2) will be used in conjunction with either the four-step angle-time method or the 30-second increment angle-time method of performing orbit insertion. A typical four-step pitch profile using horizon angles (as viewed through the overhead window) is presented in Table 2-3 for manual ascent from the lunar surface. The horizon angles and corresponding FDAI angles for the four-step pitch profile are documented in Reference 6. The horizon and FDAI angles for the 30-second increment angle technique are documented in Reference 7 and summarized in Table 2-4. The lowest priority combination of control modes and attitude reference (CES rate command/horizon angle) that will provide a high probability of attaining a safe orbit is discussed in Section 3.2.

The following combinations of system failure modes are considered in this document:

- Failed AGS and failed PGNCs accelerometer
- Failed AGS and failed LGC
- Failed PGNCs and failed AGS X-axis accelerometer
- Failed PGNCs and failed AGS Z-axis accelerometer
- Failed PGNCs and failed AGS Y-axis accelerometer
- Failed PGNCs and failed CES rate gyro.

The contingency procedures for these various failure modes are summarized in Table 2-5. If only the direct or hardover mode of attitude control is available, the four-step pitch profile will be used to reduce the number of attitude commands given to the responsive, light ascent stage. With any other attitude control mode and with a good IMU alignment and FDAI, the 30-second increment angles will probably be used for manual insertion.

2.1 GROUND MONITORING DURING MANUAL ASCENT

In the event of manual steering during ascent, the ground will monitor the LM's performance and advise the crew of necessary corrective attitude maneuvers. Out-of-plane velocity errors are displayed as \dot{Y} on

Table 2-3. Typical Manual Ascent Steering Techniques (Four-Step Pitch Profile Using Horizon Angles)*

Time (min:sec)	
0:00	Lift-off - vertical rise Yaw to proper azimuth heading
0:15	Initiate pitch to first horizon angle (37 degrees) viewed through overhead window Use vehicle shadow or preselected landmark for roll attitude Use horizon line for yaw attitude Use ACA to hold horizon line attitude
1:14	Initiate pitch to second horizon angle (32 degrees) viewed through overhead window Use landmark for roll attitude Use horizon line for yaw attitude Use ACA to hold horizon line attitude
3:26	Initiate pitch to third horizon angle (25 degrees) viewed through overhead window Use landmark for roll attitude Use horizon line for yaw attitude Use ACA to hold horizon line attitude
5:24	Initiate pitch to final horizon angle (11 degrees) viewed through overhead window Use landmark for roll attitude Use horizon line for yaw attitude Use ACA to hold horizon line attitude
6:30	Close RCS interconnect
7:22	Maintain horizon attitude until fuel depletion or until MCC-H indicates $\Delta V_S = 0$

* Angles do not include correction for APS engine cant.

Table 2-4. Crew Checklist Horizon and FDAI Angles for Ascent Monitoring (30-Second Pitch Profile)

<u>FDAI Angles (deg)</u>	<u>Horizon Angle[*] (deg)</u>	<u>Time from Ignition (min:sec)</u>
		-0:05
		0:00
		0:10
308	39	0:30
305	38	1:00
302	35	1:30
299	33	2:00
296	31	2:30
292	29	3:00
289	26	3:30
285	24	4:00
281	21	4:30
277	19	5:00
273	16	5:30
269	13	6:00
264	10	6:30
259	7	7:00
258	6	7:10

* Viewed from overhead window with no yaw maneuver.

Table 2-5. Summary of Manual Ascent Procedures

<u>Failure</u>	<u>Attitude Control</u>	<u>Attitude Display</u>	<u>Alignment for Lift-off</u>	<u>APS Cutoff</u>	<u>Comments</u>
AGS failed PGNCS accelerometer failed	PGNCS rate command/ attitude hold	PGNCS FDAI, Fly 30-sec increment FDAI profile	Program 57 AT-2 (two stars) to standard lift-off REFSMAT	Fuel depletion or $\pm V_S = 0$	The LGC program during ascent is P12. The LGC mass parameter must be set equal to its lower limit prior to lift-off.
AGS failed LGC failed	AGS CES rate command	PGNCS FDAI or horizon reference. Fly four- step profile or 30-sec increment angles	Either keep the current alignment or cage the IMU to LM body axes and determine body attitude from two star sightings.	Fuel depletion or $\pm V_S = 0$	
PGNCS failed AGS X-axis accelera- ometer failed	AGS attitude hold/rate command	AGS FDAI, Fly four- step FDAI profile or 30-sec increment angles	AGS lunar align	Fuel depletion or $\pm V_S = 0$	
PGNCS failed AGS Z-axis accelera- ometer failed	AGS auto in all three axes	Horizon reference	AGS body axis align	Automatic APS cutoff	Zero scale factor and enter pseudo bias of broken accelerometer. Enter V_{g_0} and 623 + 10000 to orient Z-axis accelerometer out of the maneuver plane.
PGNCS failed AGS Y-axis accelera- ometer failed	AGS auto in all three axes	Horizon reference	AGS body axis align	Automatic APS cutoff	Zero scale factor and bias of the broken accelera- ometer. Enter 623 + 00000 to orient Y-axis accel- erometer out of the maneuver plane.
PGNCS failed One AGS rate gyro failed	AGS auto in the two unaffected axes. AGS direct in the axis of the disabled gyro.	AGS FDAI, Fly four- step FDAI pitch profile or 30-sec increment angles in disabled axis if required	AGS lunar align	Automatic APS cutoff	

the lunar Descent/Ascent Digital Display (MSK 0084), MCC-H will recommend attitude changes (roll) in increments of 2 degrees if \dot{Y} becomes larger than approximately 50 feet per second. In addition to out-of-plane error monitoring, MCC-H will be monitoring the analog displays of flight-path angle versus velocity, altitude versus range-to-go, and altitude versus altitude rate. About 3-1/2 to 4 minutes after lift-off, the crew will be advised of any pitch adjustments (in 2-degree increments) needed to insure a safe insertion.

Presently, a ground-controlled insertion (GCI) technique is being developed by FCD and MPAD for manual ascents from the lunar surface or for ascents from a powered descent abort. As documented in Reference 8, the GCI technique is basically a closed loop system which attempts to duplicate the PGNCS variable insertion targeting (VIT) and involves the LM, RTCC, Flight Controllers, and astronauts. The flight controllers monitor a display of LM altitude rate (\dot{h}) versus altitude and give the astronauts attitude commands to cause \dot{h} to approach the maximum value $(\dot{h}_{\max})^*$ and the cutoff value $(\dot{h}_{\text{cutoff}})^*$ at 1/2 TGO and TGO=0, respectively.

For manual ascents from the lunar surface, TGO would be equal to the nominal ascent burn times. For descent aborts, TGO would be estimated as the time elapsed between PDI and the abort. For aborts occurring prior to approximately PDI + 4 minutes, there would be no vertical rise period, and the astronauts would perform a pitch maneuver until the horizon was visible at the lower edge of the overhead window. After the astronauts confirmed acquisition of the horizon, a pitch maneuver of approximately $(30/T_{\text{abort}})^{**}$ degrees would be commanded by the ground. Thereafter, the flight controllers would issue attitude changes in 5- or 10-degree increments in order to achieve \dot{h}_{\max} by $T_{\text{abort}}/2$. Engine shutdown would be commanded when the desired \dot{h} and inertial velocity had been achieved.

* \dot{h}_{\max} , \dot{h}_{cutoff} , and the desired inertial velocity at insertion will be determined from ground charts.

** T_{abort} is the elapsed time between PDI and the abort in minutes.

For descent aborts occurring after approximately PDI + 4, a period of vertical rise would be commanded until the flight controller insured that \dot{h} was positive. The astronaut would then be informed to pitch until the horizon was acquired in the lower edge of the overhead window and to stand by for further commands. Subsequent changes in attitude would be voiced to the astronaut to achieve the desirable \dot{h} and V_I at insertion.

At the present time, the GCI technique is not compatible with the four-step or 30-second increment pitch profile. Thus, if ascent were initiated with the GCI technique and ground communications were lost, these other manual techniques could not be used. To alleviate this disadvantage, it is anticipated that onboard charts will be developed to enable the astronaut to continue manual ascent if ground communications were lost. Another difficulty with the GCI technique is that the yaw maneuver, which must be performed to insure communications, adversely affects the astronaut's ability to use the horizon as an attitude reference. A technique which consists of performing a roll maneuver with each ground-commanded pitch attitude change has been proposed to circumvent this difficulty.

Although not currently a mission techniques recommendation, the GCI technique eventually may achieve that status if it proves to be more reliable than the current four-step and 30-second increment angle-time methods.

2.2 APS CUTOFF FOR MANUAL ASCENT

In the case of manual ascent, the APS will be run until MCC-H calls $\Delta V_S = 0$ (ΔV_S is the velocity impulse required to achieve a 35,000 foot perilune altitude with the current altitude, h , and flight-path angle, γ) or until fuel depletion, if it occurs earlier. $\Delta V_S = 0$ cutoff will protect against an apolune greater than 300 nautical miles if the altitude at insertion is greater than 35,000 feet and the flight-path angle is approximately zero. The RCS interconnect will be open for the first 6-1/2 minutes or until VGX = 500 feet per second (nominal procedure) if a VGX display is available.

2.3 MANUAL ABORTS FROM POWERED DESCENT

A manual descent abort would probably require the crew to control vehicle attitude by means of CES rate command or direct attitude control with the horizon viewed through the forward window as an attitude reference. Horizon and FDAI pitch profiles for aborts using the APS or DPS DPS/APS have been developed in Reference 9*. Figure 2-1 shows the pitch angle-time history for a manual abort from powered descent using the APS engine and the horizon as viewed through the docking window. The chart is subdivided into three abort zones:

- Zone I - full throttle position PDI + 26 seconds) to PDI + 2 minutes
- Zone II - PDI + 2 minutes to PDI + 10 minutes
- Zone III - PDI + 10 minutes to touchdown.

The first 26 seconds of powered descent are not considered for aborts as the LM perilune remains above 30,000 feet (safe orbit) during this period.

As illustrated on the right side of Figure 2-1, manual insertion is accomplished in abort Zone I by burning at a constant attitude angle, Angle 1 (θ_1), for duration Time 1. Time 1 includes the time necessary to execute the pitch maneuver from the abort initiation attitude to Angle 1. There is no vertical rise period in abort Zone I.

For Zone II, a vertical rise phase of 20 seconds is included as part of Time 1. The 20 seconds of vertical rise also includes the time required to maneuver from the abort initiation attitude to the local vertical. After the vertical rise phase, the vehicle is maneuvered to Angle 1 (θ_1) and remains there for the remainder of Time 1. Subsequently, a pitch attitude of Angle 2 (θ_2) is maintained for the period Time 2. Time 2 includes the time necessary to pitch from Angle 1 to Angle 2.

* Apollo 11 profiles

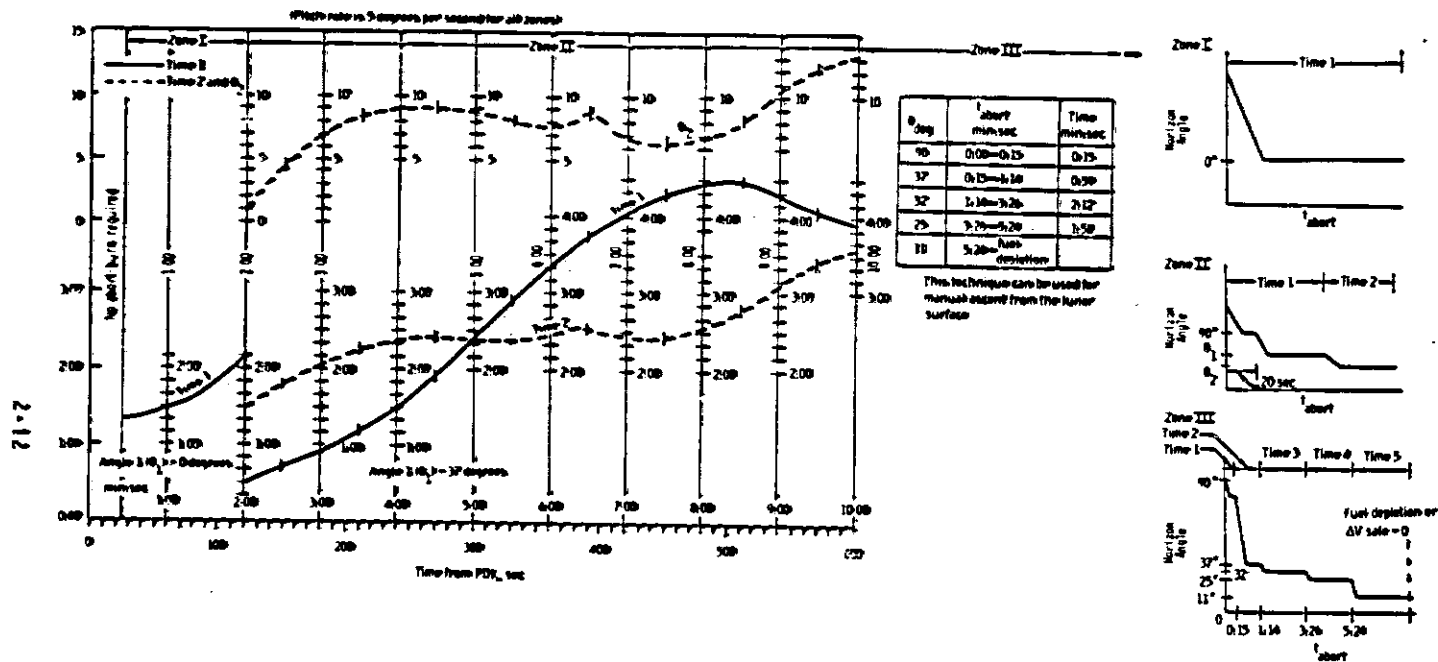


Figure 2-1. Preferred Horizon Angles for a Manual Descent Abort Using the APS Engine*

*Data based on Apollo 11 but technique applicable to Apollo 13.

() Since the altitude at abort initiation in Zone III will be less than 1000 feet, the pitch profile for insertion will be the same as the one for a manual ascent from the lunar surface (Table 2-3).

The charts documented in Reference 9 will be available at MCC-H for a manual descent abort. Depending upon crew preference, the data on these charts can be made available in the form of cue cards for onboard use. These cue cards would provide appropriate burn attitudes and burn durations based on the time of abort and the highest priority attitude reference system available.

2.4 MANUAL TAKEOVER DURING POWERED ASCENT

() It is unlikely that both PONCS and AOS would fail during ascent; therefore, a manual takeover during ascent would probably result from a single system failure during ascent subsequent to a failure in the other system prior to lift-off. Following discovery of the first system failure, the crew will configure the failed system so as to best utilize it for backup in the event of a second system failure during ascent. In all failure cases, the 30-second increment horizon angles from the checklist will be available for attitude reference (Table 2-4).

3. ASCENT WITH DEGRADED PGNCs AND FAILED AGS

The following procedure will be used if the AGS has failed and the PGNCs is degraded. Section 3.1 presents the recommended procedures to be used when a PGNCs accelerometer has failed. Section 3.2 presents the recommended procedures to be used when the LGC has failed. A PGNCs gyro failure will necessitate the use of the horizon as the attitude reference and emergency direct (hardover) as the control mode.

3.1 PGNCs ACCELEROMETERS FAILED

3.1.1 Attitude Display and Control Modes

The general effect of an accelerometer failure is to preclude measurement of LM velocity change in that axis. Since the zeroing of the scale factor of a PGNCs accelerometer is not possible, the degraded accelerometer cannot be isolated from the system; consequently, automatic guidance steering using accelerometer outputs will not be performed. The highest priority control mode available (Table 2-2) is PGNCs rate command/attitude hold. The attitude display mode of highest priority (Table 2-2) is IMU total attitude as indicated on an FDI.

3.1.2 IMU Alignment

Since the IMU gyros and LGC are functioning properly, the inertial platform can be aligned to a preferred attitude. This can be accomplished by using alignment technique 2 (two star) to the standard lift-off REFSMAT (option 4, landing site). Gravity alignments (technique 1 or 3) must not be used. The alignment can be accomplished onboard without MCC-H assistance, and the 30-second increment angles from the crew checklist can be used for a manual steering reference during ascent.

3.1.3 LGC Procedures

Although automatic guidance steering is not available, the ascent program (P12) will be entered prior to lift-off. P12 automatically selects the 1-degree attitude control deadband and the four-jet translation. In addition, selection of P12 is part of the nominal ascent procedures. The

output of the failed accelerometer may cause the LGC's value of the LM's mass (LEMMASS) to be decremented erroneously. Therefore, in order to insure attitude control stability, the minimum value of LEMMASS (2200 kg) will be entered in the LGC prior to lift-off.

3.1.4 Ascent Procedures

TIG - 45 min	Perform a technique 2 (two star) alignment to the standard lift-off REFSMMAT (landing site). MCC-H uplinks state vectors as usual.
TIG - 30 min	Load initial value of LEMMASS in the LGC via R03 to be equal to its lower limit.
TIG - 15 min	Flight program is P12 Guidance control switch - PQNCS Mode control switch - HOLD Attitude control switches - MODE Nominal RCS interconnect procedures
TIG	Arm APS. Push ABORT STAGE Push START Fly manual ascent using the 30-second increment FDAI pitch profile from the crew checklist.
TIG + 6-1/2 min	Close RCS interconnect. Fly to fuel depletion or until MCC-H indicates $\Delta V_S = 0$.

3.2 LGC FAILURE (CES RATE COMMAND/HORIZON REFERENCE)

3.2.1 Attitude Display and Control Modes

An LGC failure will disable the DAP and cause loss of IMU alignment capability using routines P51, P52, and P57. The IMU, however, is still functional, and, if it is or can be aligned to the preferred lift-off orientation, it will be available as the highest priority attitude reference. If the above is not the case, the attitude reference will be the horizon viewed out the window.

The PQNCS control modes available are direct and hardover; however, CES rate command will be used if it is available. The ascent procedures (Section 3.2.3) assume that the manual control mode is CES rate command.

In the case where the nature of failures is undetermined or in the case of specific double failures (PQNCS failed and AEA failed, etc.), the procedures described in this section for undesirable IMU orientation are applicable. In other words, CES rate command (or direct) with the horizon viewed out the window as the attitude reference will be used.

3.2.2 IMU Alignment

If the IMU was aligned to lift-off orientation prior to LGC failure and shortly before lift-off, data from two AOT star sightings and FDAI angles voiced to MCC-H may be used to check the alignment accuracy for lift-off (case 1). If, however, the IMU was not aligned to lift-off orientation prior to LGC failure, the star sighting data and FDAI angles may be used to determine if a body axis align will provide IMU alignment sufficiently close to lift-off orientation (case 2). In either case 1 or case 2, MCC-H will recommend that the crew use the four-step FDAI pitch profile or the 30-second angle increments on the crew checklist if the desired lift-off IMU orientation can be achieved. If the IMU cannot be placed in a desirable orientation, the crew will use the horizon viewed out the window as an attitude reference.

3.2.3 Ascent Procedures

TIO - 60 min

Crew performs two star sightings and voices the data to MCC-H.

Crew reads the present FDAI angles to the ground.

MCC-H computes the LM body axis orientation and present IMU orientation.

TIO - 30 min

Crew cages the IMU to body axes if recommended by MCC-H.

TIG - 20 min

AEA power off
Guidance control switch - AGS
Mode control switch - HOLD
Attitude control switch - MODE

Select four-jet translation.
Nominal RCS interconnect procedures

TIG

Arm APS
Push ABORT STAGE
Push START

Fly manual ascent using the four-step or
30-second increment FDAI pitch profile
(desirable IMU orientation) or horizon
reference (undesirable IMU orientation).

TIG + 6-1/2 min

Close RCS interconnect.

Fly to fuel depletion or until MCC-H
indicates $\Delta V_S = 0$.

4. ASCENT WITH A DEGRADED AGS AND FAILED PGNCs

The general effect of an AGS accelerometer failure is to disable measurement of velocity changes in that vehicle axis only. The AEA can be made to ignore any spurious output from the failed accelerometer by setting that accelerometer's scale factor constant in the AEA to zero. It should be noted that this could not be accomplished in the case of a malfunctioning PGNCs accelerometer.

4.1 AGS X-AXIS ACCELEROMETER FAILED

4.1.1 Attitude Display and Control Modes

When an X-axis accelerometer fails, the automatic ascent guidance program is disabled since the major component of engine thrust is not measured. The AGS capability to measure vehicle attitude is not affected; consequently, the AGS FDAI attitude display and the AGS rate command/attitude hold control modes are available and have the highest priority.

4.1.2 AGS Alignment

The AGS X-axis accelerometer is not used by AGS lunar align; therefore, nominal AGS alignment procedures will be used to prepare for lift-off. The AGS lunar align uses a gravity vector measured by the Y- and Z-axis accelerometers for vertical erection. One AOT star sighting is performed, and the data are voiced to the ground. MCC-H processes these sighting data and voices to the crew the new azimuth data which are manually loaded via the DEDA. If an AGS gyro calibration is performed, it must be preceded by an AGS lunar align.

4.1.3 AGS Entries to Prepare for Lift-off

In addition to performing the standard DEDA entries which load AGS azimuth and call AGS lunar align, the crew will manually load the LM and GSN state vector data voiced up from MCC-H. Lunar align will be exited by the nonstandard DEDA entry of 400 + 00000 which calls the attitude hold control mode.

4.1.4 Ascent Procedures

TIG - 60 min

*Crew performs one AOT sighting and voices data to MCC-H

*Crew selects AGS lunar align (400 + 40000) followed by AGS gyro calibration (400 + 60000). These routines require 3 and 5 minutes, respectively.

**MCC-H computes and voices to the crew the following azimuth data for DEDA input:

$\sin \delta_L$ (address 047)

$\cos \delta_L$ (address 051)

TIG - 30 min

**Crew selects AGS lunar align (400 + 40000)

*MCC-H voices LM and CSM state vectors to the crew for DEDA input. (16 entries)

**Nominal RCS Interconnect procedures

Guidance control switch - AGS
Mode control switch - HOLD
Attitude control switches (three) -
MODE

TIG - 2 min

Exit lunar align and enable attitude hold (400 + 00000)

TIG

Arm APS
Push ABORT STAGE
Push START

Fly manual ascent using the four-step or 30-second increment FDI pitch profile from the crew checklist.

TIG + 6-1/2 min

Close RCS interconnect.

Fly to fuel depletion or until MCC-H indicates $\Delta V_g = 0$.

*Standard procedure for bad PONCS, good AGS

**Standard procedure for nominal countdown

4.2 AGS Z-AXIS ACCELEROMETER FAILED

4.2.1 Attitude Display and Control Modes

The failure of an AGS Z-axis accelerometer does not disable the AGS automatic mode since the malfunctioning accelerometer can be pointed out of the maneuver plane and the AEA instructed to ignore its output. Even though it is not possible to perform an AGS lunar align, the AGS LM state vectors can be adjusted by MCC-H to be compatible with the alignment obtained. The AGS automatic mode of guidance control may, therefore, be used in all three axes. The LM will be ascending in an unusual attitude (on its side); therefore, system monitoring must be performed by the ground. Horizon angles can be used for attitude reference by yawing in-plane in the event of a manual takeover.

4.2.2 AGS Alignment

Since the lunar align mode cannot be used with a failed Y- or Z-axis accelerometer, the AGS must be aligned by performing a body axis align (400 + 50000). This DEDA entry sets the AGS direction cosines to the identity matrix and is exited (that is, the AGS goes inertial) with the next entry into location 400. The DEDA entry 400 + 10000 must be performed by the crew at the time requested by MCC-H, or the LM and CSM state vectors which have previously been entered will be inaccurate.

4.2.3 AGS Entries to Prepare for Lift-off

Since the Z-axis accelerometer output is unreliable, its output will be zeroed by a DEDA entry of 536 + 00000. The APS engine is canted 1-1/2 degrees toward the body Z-axis. Since the Z-axis accelerometer output has been zeroed, this thrust component will not be measured. Therefore, in order to compensate for this component of thrust acceleration, a pseudo-bias (equal to the average body Z-axis thrust acceleration during ascent) will be introduced by a DEDA entry of 542 + 00366 (0.366 ft/sec²). This technique is described in Reference 10.

The automatic reorientation of the body Z-axis out of the maneuver plane can be accomplished by first inserting the desired vector components W_{bx} , W_{by} , and W_{bz} and then entering S-band steering (623 + 10000). If this procedure is followed, the body X-axis would be oriented along the

VG vector and the body Z-axis would be oriented by nulling the dot product between body Z-axis and the \underline{W}_b vector.

At the present time, MCC-H has no capability for computing the \underline{W}_b vector. The easiest method for obtaining this vector is, therefore, to read out the unit vector normal to the CSM orbit plane (\underline{W}_c) and convert it to the desired quantity by rotating it 90 degrees about the inertial X-axis and then 180 degrees about inertial Y-axis. This must be done after the AGS is initialized with the CSM state vector. The operations which must be performed are summarized in Table 4-1 (Reference 10).

The CSM and LM state vectors will be voiced to the crew from MCC-H and manually loaded via DEDA. The LM state vectors on the crew checklist must not be used since they are not referenced to a body axis alignment.

AGS guidance steering will be enabled with the normal entry of 400 + 10000. The crew will enter the targeting parameters (altitude rate, altitude, upper limit of semimajor axis, lower limit of semimajor axis) into DEDA addresses 465, 232, 226, 225, respectively.

Table 4-1. Procedure for Generating \underline{W}_b Vector

<u>Step No.</u>	<u>Operation</u>
1	Read out via DEDA location 054, W_{cx} , in octal.
2	Compute the octal complement, change the sign, and enter into location 514, W_{bx} .
3	Read out via DEDA location 055, W_{cy} , in octal.
4	Compute the octal complement, change the sign, and enter into location 516, W_{by} .
5	Read out via DEDA location 056, W_{cz} , in octal.
6	Enter this value into location 515, W_{bz} .
7	Enter via DEDA 623 + 10000.

4.2.4 Ascent Procedures

TIG - 60 min

Crew performs two AOT sightings and voices the sighting data to MCC-H.

Crew loads Z-axis accelerometer pseudo bias (542 + 00366) and zeroes scale factor (536 + 00000).

Crew loads targeting parameters from checklist into DEDA addresses 465, 232, 225, and 226.

MCC-H computes LM body attitude in inertial space.

TIG - 30 min

MCC-H computes and voices to the crew the CSM and LM state vectors compatible with a body axis alignment. The crew loads these values using the standard checklist format (16 entries).

Crew performs body axis alignment (400 + 50000)

Guidance control switch - AGS

Mode control switch - AUTO

Attitude control switches (three) - MODE

Use nominal RCS interconnect procedure

Crew reads \underline{W} vector (054, 055, 056) and voices it to MCC-H

Crew loads \underline{W}_{bx} , \underline{W}_{by} , \underline{W}_{bz} voiced from MCC-H in DEDA addresses 514, 515, and 516, respectively.

Crew enters 623 + 10000 to arm \underline{W}_b targeting of yaw maneuver.

Crew selects ascent program (410 + 00000)

TIG - 2 min

Crew enables guidance steering (400 + 10000)

TIG

Arm - APS

Push - ABORT STAGE

Push - START

Fly the AUTO mode to orbit with auto APS shutdown. Use the nominal RCS interconnect procedures.

4.3 AGS Y-AXIS ACCELEROMETER FAILED

4.3.1 Attitude Display and Control Modes

The effects of a broken Y-axis accelerometer on AGS control and attitude displays is the same as a Z-axis accelerometer. The top priority control mode is AGS AUTO in all three axes. The crew checklist horizon angles can be used for manual ascent backup.

4.3.2 AGS Alignment

Since AGS lunar align cannot be performed with either a disabled Y- or Z-axis accelerometer and PGNCs is assumed to have previously failed, an AGS body axis align will be performed. The AGS inertial orientation will be computed with the procedures described in Section 4.2.2.

4.3.3 AGS Entries to Prepare for Lift-off

To prepare AGS for ascent with a broken Y-axis accelerometer, it will be necessary to make DEDA entries of 535 + 00000 and 541 + 00000 to zero the scale factor and bias of that accelerometer. The logic bit S623 will be set by a DEDA entry of 623 + 00000 which causes ascent targeting to point the body Y-axis out of the ascent plane.

The CSM and LM state vectors will be voiced to the crew from MCC-H and manually loaded via DEDA (16 entries). AGS guidance steering will be enabled with the normal entry of 400 + 10000. Targeting parameters must be entered via the DEDA in addresses 465, 232, 225, and 226.

4.3.4 Ascent Procedures

TIO - 60 min

Crew performs two AOT sightings and voices the sighting data to MCC-H.

Crew zeros Y-axis accelerometer bias (541 + 00000) and scale factor (535 + 00000).

Crew loads targeting parameters from checklist into DEDA addresses 465, 232, 225, and 226.

MCC-H computes LM body attitude in inertial space.

TIG - 30 min

MCC-H computes and voices to the crew the CSM and LM state vectors compatible with a body axis alignment. The crew loads these values using the standard checklist format (16 entries).

Crew performs body axis alignment (400 + 50000).

Guidance control switch - AGS
Mode control switch - AUTO
Attitude control switches (three) - MODE

Crew enters 623 + 00000 to instruct AGS to point the Y-axis out of the maneuver plane.

TIG - 2 min

Crew enables guidance steering (400 + 10000)

TIG

Arm APS
Push ABORT STAGE
Push START

Fly the AUTO mode to orbit with auto APS shutdown. Use the nominal RCS interconnect procedures.

4.4 ONE AGS RATE GYRO FAILED

4.4.1 Attitude Display and Control Modes

The loss of a rate gyro disables AGS automatic control in that vehicle axis. This has been verified by simulation; therefore, the top priority attitude control system is auto in the unaffected axes and direct in the disabled axis with the FDAI as an attitude reference for manual steering in the disabled axis. The crew checklist horizon angles can be used for manual backup.

4.4.2 AGS Alignment

Since rate gyros are not required by AGS lunar align, the nominal AGS alignment procedures will be used to prepare AGS for lift-off. It will be necessary for the crew to perform one AOT star sighting and voice the data to the ground. MCC-H processes these sighting data and voices to the crew new azimuth data which are manually loaded via the DEDA.

4.4.3 AGS Entries to Prepare for Ascent

In addition to performing the standard DEDA entries which load the AGS azimuth and call AGS lunar align, the crew will manually load the CSM and LM state vector data voiced from MCC-H and the targeting parameters.

4.4.4 Ascent Procedures

TIG - 60 min

* Crew performs one AOT sighting and voices data to MCC-H.

* Crew selects AGS lunar align (400 + 40000) followed by AGS gyro calibration (400 + 60000). These routines require 3 and 5 minutes, respectively.

Crew loads targeting parameters from checklist into DEDA addresses 465, 232, 225, and 226.

** MCC-H computes and voices to the crew the following azimuth data for DEDA input:

$\sin \delta_L$ (address 047)

$\cos \delta_L$ (address 053)

TIG - 30 min

** Crew selects AGS lunar align (400 + 40000)

* MCC-H voices LM and CSM state vectors to the crew for DEDA input. (16 entries)

Use nominal RCS interconnect procedures

Guidance control switch - AGS
Mode control switch - AUTO
Attitude control switches (two) - MODE
Attitude control switch - DIRECT

TIG - 2 min

** Exit lunar align and enable guidance steering (400 + 10000).

* Standard procedure for bad PGNCs, good AGS

** Standard procedure for nominal countdown

TIG

Arm APS
Push ABORT STAGE
Push START

Fly manual ascent in the disabled axis only (using the four-step FDAI pitch profile or 30-second increment from the crew checklist if required)

Use the nominal RCS interconnect procedure.

Use automatic APS shutdown.

5. RENDEZVOUS MANEUVER

In most manual insertion instances, a CSM active rendezvous will be required. With both the PGNCs and AGS inoperative, the required attitude reference and delta velocity displays on the LM probably would not be available. In addition, complications are encountered because the LM insertion orbit may have an apolune as great as 300 nautical miles and a perilune that requires the LM to perform an RCS burn at apolune. The ground (MCC-H) monitoring procedures, discussed in Section 2.1, should provide a perilune greater than 35,000 feet and an apolune greater than 100 but less than 300 nautical miles. Although the LM could perform some, or all, of the rendezvous maneuvers if a good attitude reference and burn monitoring source were available, a CSM active rendezvous is planned.

5.1 RENDEZVOUS SUBSEQUENT TO MANUAL ASCENT FROM THE LUNAR SURFACE

In most instances, the docking initiation (DKI) rendezvous sequence documented in Reference 11 will be used for CSM rescue of the LM after a manual ascent from the lunar surface. This rendezvous sequence, which is discussed in detail below, requires that the CSM perform a phasing maneuver followed by CSI, CDH, and TPI maneuvers. In order to make the DKI rendezvous sequence compatible with any LM insertion orbit, the lift-off time will be delayed 9 minutes from the nominal lift-off time. The 9-minute slip allows the CSM to delay rescue for approximately one revolution for all LM insertion orbits. If lift-off were performed at the nominal time and the LM achieved a minimum orbit, a different technique (i.e., high CSM dwell) would be required because the DKI technique would result in the violation of perilune constraints. The ΔV penalty for lifting-off 9 minutes later than nominal is approximately 50 feet per second. Even though the DKI technique can be used with any LM insertion orbit, it is highly desirable for the LM to achieve a minimum apolune of 30 nautical miles and a perilune of approximately 10 nautical miles.

In the unlikely event that the insertion flight-path angle is negative and the MCC-H estimated hp is less than about 10 nautical miles*, MCC-H will voice up a maneuver to be executed at insertion plus 3 minutes to raise perilune as much as possible.** This maneuver is to insure an actual hp greater than 35,000 feet. If the flight-path angle is positive (as expected) and the MCC-H estimated hp is less than about 10 nautical miles, an MCC-H computed apolune kick maneuver will be performed to raise hp up to about 16 nautical miles. In the event that the MCC-H estimated h_a is less than 30 nautical miles, an RCS maneuver at insertion will be executed to raise h_a up to 30 nautical miles. These techniques provide a minimum LM orbit of 16 by 30 nautical miles prior to the CSM rendezvous maneuver sequence.

The CSM rescue will be initiated by a ground computed DKI plan. The CSM will perform the following maneuvers: phasing (NC1), CSI (NH), CDH, and TPI. The phasing maneuver (NC1) will be performed approximately one revolution after insertion to establish the proper phasing for the NH maneuver point. Any initial out-of-plane velocity corrections will probably be included in the NC1 maneuver. The second maneuver (NH) establishes the proper phasing and differential altitude conditions for the CDH maneuver point and, depending upon the LM apolune altitude, will be executed either 1/2, 1-1/2, or 2-1/2 revolutions after NC1. The 1-1/2 revolution timeline will be applicable in most cases as it will be used for the most likely LM apolune altitudes of 100 to 300 nautical miles. The 1/2 revolution timeline will be applicable for minimum insertion orbits (LM apolune less than approximately 30 nautical miles) because the 1-1/2 revolution timeline would require an unsafe CSM orbit. For extremely high LM apolune altitudes, the 2-1/2 revolution timeline might be used as it results in lower ΔV requirements. The CDH maneuver, performed 1/2 period after CSI, is designed to place the CSM into an orbit which is

* MCC-H will nominally use the powered flight processor (Lear Filter) estimate of orbital parameters.

** The nominal insertion altitude is 60,000 feet, and an overburn insertion will not occur much higher; thus, the hp raising maneuver will be limited by that altitude.

coelliptic with the LM orbit with a constant delta height between the two orbits. The TPI maneuver, which is performed near the midpoint of darkness (approximately 35 to 40 minutes after CDH), is designed to place the CSM on a trajectory that will intercept the LM orbit after 130 degrees. The line-of-sight braking may be performed by either the LM or CSM. Table 5-1 presents the required LM and CSM maneuvers to insure that the planned CSM docking initiation (DKI) rendezvous sequence can be performed.

5.2 RENDEZVOUS FOR MANUAL TAKEOVER DURING POWERED ASCENT

With a nominal lift-off time, a manual takeover during ascent could make it impossible to use the DKI rendezvous sequence discussed in Section 5.1. If the resultant LM apolune altitude were less than approximately 75 nautical miles, the DKI sequence could not be used without violating perilune constraints. For this case, a special CSM high-dwell rendezvous sequence would be used for rescue. This technique is documented in Reference 11 and requires that the CSM dwell high enough for the LM to catch up almost a complete 360 degrees in the opposite phasing direction. The maneuvers required for this type of rendezvous are presented in Table 5-2.

For LM apolune altitudes greater than approximately 75 nautical miles, CSM rescue will be accomplished with the DKI rendezvous sequence.

5.3 RENDEZVOUS FOR MANUAL DESCENT ABORTS

Depending upon the orbit achieved subsequent to a manual descent abort, four different rendezvous techniques will be considered for the CSM rescue. These techniques are documented in References 11 and 12 and are summarized in Table 5-2. Depending upon the LM orbit parameters, a real-time decision will be made to select the technique that results in an effective, safe, rendezvous sequence. If it is determined that waiting one revolution after the manual LM insertion will not degrade the situation and will permit better LM orbit determination, the DKI rendezvous sequence discussed previously will be used.

Table 5-1. LM and CSM DKI Rendezvous Maneuvers

LM	CSM
If $h_p < 10$ n mi and $\gamma < 0$,	
perform RCS burn at cutoff+3 minutes	
If $h_p < 10$ n mi and $\gamma > 0$,	
perform RCS burn at apolune to raise perilune to 16 n mi	
If $h_a < 30$ n mi,	
perform RCS burn to raise apolune to 30 n mi	
	Phasing (NC1): performed approximately one revolution after insertion
	CSI (NH): Performed 1/2, 1-1/2, or 2-1/2 revolutions after NC1
	CDH: performed 1/2 revolution after CSI
	TPI: performed near midpoint of darkness

Table 5-2. Summary of CSM Active (Rescue) Rendezvous Sequences for Manual Ascent

Sequence	Applicability	Required Burns (Targeting)	Burn Execution Times
Rescue 2	Underspeeds following manual descent aborts (LM high enough for CSM to come down)	<ul style="list-style-type: none"> • Rescue-2 maneuver • CSI_1 (P32: $N = \text{even integer dependent on LM abort } \Delta V$. See Table 3) • $CSI_1 = \text{nominal } 0 \text{ fps}$ (P32: $N_1 = N_{1-1} - 2$, $N_1 \geq 2$) • $CSI = \text{nominal } 0 \text{ fps}$ (P32 nominal case: $N = 1$) • CDH (P33) • TPI (P34) 	<ul style="list-style-type: none"> • At longitude of CSM CIRC • At orbit perilune • Each rev after CSI_1 • 1/2 time between CSI ($N = 2$) and CDH • Result of P32 computations = 16 min before sunrise
Mirror Image	Manual aborts from descent: successful insertion	<ul style="list-style-type: none"> • Rescue from 2-rev sequence HAM/CSI/CDH/TPI • Rescue from 1-rev sequence CSI/CDH/TPI 	<ul style="list-style-type: none"> • Maneuvers at LM-active times • Maneuvers at LM-active times
Contingency Dwell	Underspeeds following descent aborts (CSM cannot come down)	<ul style="list-style-type: none"> • Phasing (MCC-H, P30) • Phasing₁ = nominal 0 fps (MCC-H, P30) • CSI (P32) • CDH (P33) • TPI (P34) 	<ul style="list-style-type: none"> • PDI + 67 min • One rev after previous phasing • At same longitude as phasing burns • Result of P32 computations = 16 min prior to sunrise
Manual Ascent	Following LM manual ascent from the lunar surface or for certain manual descent aborts	<ul style="list-style-type: none"> • Phasing (MCC-H, P30) • Phasing₁ = nominal 0 fps (MCC-H, P30) • CSI (P32) • CDH (P33) • TPI (P34) 	<ul style="list-style-type: none"> • One rev after insertion • One rev after previous phasing • 1/2, 1-1/2, or 2-1/2 revs after phasing depending on LM orbit • Result of P32 computations • Based on orbit after CSI

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