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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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FEBRUARY 15, 1970

APOLLO MISSION TECHNIQUES MISSION H-2 AND SUBSEQUENT

LUNAR DESCENT

TECHNIQUES DESCRIPTION

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SPACECRAFICED SPACECRAFT PROGRAM OFFICE USTON, TEXAS MANNED SPACECRAFT CENTER HOUSTON, TEXAS

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APOLLO MISSION TECHNIQUES MISSION H-2 AND SUBSEQUENT LUNAR DESCENT TECHNIQUES DESCRIPTION

February 15, 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 Lunar Descent Mission Techniques Document is one of several documents describing the H-2 (Apollo 13) mission. The others are as follows:

- Launch Aborts
- Earth Parking Orbit and Translunar Injection
- Translunar Midcourse Corrections and Lunar Orbit Insertion
- Lunar Surface Phase
- Descent Abort and Subsequent Rendezvous
- Manual Ascent
- the second second
 - Powered Ascent
 - Lunar Orbit Activities
 - Transearth Injection, Midcourse Corrections, and Entry
 - Tracking Data Selection Controllers Procedures
 - Contingency Procedures

These documents contain the officially approved guiddance and control sequence of events, the data flow, and realtime decision logic for the H-2 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

FOREWORD (Continued)

comprised of representatives of MSC and support contractors 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.

This is the final issue of the Lunar Descent Mission 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. CONTENTS

Page

¥

•

1.	INTRODUCTION										
2.	FUNCTIONAL DESCRIPTION OF THE LUNAR DESCENT ACTIVITIES										
3.	GENERAL TECHNIQUES DECISIONS										
	3.1	Decision Responsibility									
	3.2	Go/No-Go Decision for PDI									
	3.3	Abort of	r Abort/Stage Decision								
	3.4	PGNCS	to AGS Switchover Decision								
4.	DET.	AILED TI	ECHNIQUES DESCRIPTION								
	4.1	Pre-PD	I Activities								
		4.1.1 4.1.2 4.1.3	P63 Data Check								
		4.1.4	MCC-H Preignition Activities								
	4.2	PDI to V	Visibility Phase Activities								
		4. 2. 1 4. 2. 2 4. 2. 3 4. 2. 4 4. 2. 5 4. 2. 6	DPS Ignition and Performance Monitoring LGC Targeting Update LM Attitude and Attitude Rate Monitoring LR Acquisition LR Data Acceptance Checks Gimbal Drive Actuator (GDA) Failure Monitoring								
		4.2.7	MCC-H Monitoring of PGNCS, AGS and								
		4.2.8	MCC-H Monitoring of DPS Commanded								
		4.2.9	Throttledown Monitoring								
	4.3	Visibilit	y Phase to Touchdown Activities								
		4.3.1 4.3.2 4.3.3 4.3.4 4.3.5 4.3.6 4.3.7 4.3.8	Visibility Phase Pitch Maneuver AGS Altitude Update LR Velocity Data MCC-H Propellant Adequacy and RCS Plume Impingement Monitoring Landing Site Redesignation MSFN Altitude Update Low Level Propellant Monitoring Final Descent Phase LM Activities								

CONTENTS (Continued)

ILLUSTRATIONS

۰.

.

2 - 1	LM Powered Descent Events
2-2	Descent Timeline
4 - 1	PDI and No PDI + 12-Minute Abort Pad
4-2	Maximum Allowable PGNCS Minus Landing Radar Altitude Difference versus Altitude
4-3	Maximum Allowable PGNCS Minus Landing Radar Altitude Difference versus Time to High Gate after Partial Update
4-4	Maximum Allowable GDA Offset at the Time of GDA Failure versus Time
4-5	Commanded Thrust versus Horizontal Velocity
4-6	Commanded Thrust versus Horizontal Velocity
4-7	Delta Time versus Initial FTP Thrust
4-8	DPS Propellant Margin (Typical)
4-9	RCS Plume Impingement Limits During Powered Descent
4-10	Lunar Terrain Effects on LPD Angle
A-1a	AGS/PGNCS Velocity Residuals (Downrange)
A-1b	AGS/PGNCS Velocity Residuals (Crossrange)
A-1c	AGS/PGNCS Velocity Residuals (Radial)
A-2a	PFP/PGNCS Velocity Residuals (Downrange)
A-2b	PFP/PGNCS Velocity Residuals (Crossrange)
A-2c	PFP/PGNCS Velocity Residuals (Radial)
A-3	Altitude versus Altitude Rate • • • • • • • • • • • • • • • • • • •

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Page

NOMENCLATURE

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ACA	attitude controller assembly
AEA	abort electronics assembly
AEG	analytic ephemeris generator
AGS	abort guidance system
AOS	acquisition of signal
AOT	alignment optical telescope
APS	ascent propulsion system
ASPO	Apollo Spacecraft Program Office
ATT	attitude
AUTO	automatic
CDR	commander
CDU	coupling data unit
CIRC	circularization burn
СМ	command module
CMD	command
CMP	command module pilot
CONT	control
CR	crossrange
CSM	command and service module
DAP	digital autopilot
DEDA	data entry and display assembly
DES QTY	low propellant level
DOI	descent orbit injection
DPS	descent propulsion system
DSKY	display and keyboard

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- E enter
- E&DD Engineering and Development Directorate
- ENG engine
- FCOD Flight Crew Operations Division
- FDAI flight director attitude indicator
- FOD Flight Operations Division
- FOV field of view
- FTP fixed throttle phase
 - g gravity
- G&N guidance and navigation
- GAC Grumman Aerospace Corporation
- GDA gimbal drive actuator
- g. e. t. ground elapsed time
 - H altitude
 - H altitude rate
 - IA input axis
 - IMU inertial measurement unit
- LAND landing-site location vector used for LGC targeting
 - LGC lunar module guidance computer
 - LM lunar module
 - LMP lunar module pilot
 - LOI lunar orbit insertion
 - LOS line of sight
 - LPD landing point designator
 - LR landing radar

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MAN	manual								
MCC-H	Mission Control Center - Houston								
MDC	McDonnell Douglas Corporation								
meru	milli earth rate unit								
MIT	Massachusetts Institute of Technology								
MOCR	Mission Operations Control Room								
mr	milliradian								
MSC	Manned Spacecraft Center								
MSFN	Manned Space Flight Network								
N	noun								
NR	North American Rockwell Corporation								
OA	output axis								
Р	pitch gimbal angle								
P 30	External ΔV Program								
P40	DPS Thrusting Program								
P63	Braking Phase Program								
P64	Approach Phase Program								
P65	Landing Phase (Full Auto) Program								
P 66	Landing Phase (ROD) Program								
P67	Landing Phase (Manual) Program								
P 68	Landing Confirmation Program								
P 70	DPS Abort Program								
P71	APS Abort Program								
PAD	data voiced to crew from ground								
PDI	powered descent initiation								

- PFP Powered Flight Processor
- PGNCS primary guidance, navigation, and control system
 - PIPA pulse integrating pendulous accelerometer
 - ppm parts per million
 - R roll gimbal angle
 - R04 landing radar self test routine
 - R05 S-band antenna routine
 - R11 abort discrete monitor routine
 - RCS reaction control system
- RG or RGO range to go
 - $\underline{\mathbf{R}}_{\mathbf{LS}}$ landing site vector
 - ROD rate of descent
 - RR rendezvous radar
 - rss root sum squared
 - RTCC Real-Time Computer Complex
 - SA spin axis
 - SM stable member
 - SPS service propulsion system
 - SSR system support room
 - TFI time from ignition
- TG or TGO time to go in given phase
 - THR thrust
 - TIG time of ignition
 - TM telemetry

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TR.	time	remaining

- TRW TRW Systems Group of TRW, Inc.
- TTCA thrust translation controller assembly
 - T/W thrust to weight ratio
 - V verb
 - V47 AGS initialization from PGNCS
 - V57 LR update enable
- VI or V inertial velocity magnitude or total velocity
 - X LM X-axis
 - Y LM Y-axis, or yaw gimbal angle
 - Z LM Z-axis
 - ΔH altitude difference
 - $\Delta \underline{R}_{LS}$ LGC targeted RLS correction vector
 - ΔV delta velocity
 - ΔVg velocity-to-be-gained residual
 - ΔVM · measured ΔV magnitude
 - ΔVX X-velocity component of external ΔV or target ΔV
 - ΔVY Y-velocity component of external ΔV or target ΔV
 - ΔVZ Z-velocity component of external ΔV or target ΔV
 - σ standard deviation
 - ρ range
 - p range rate

1. INTRODUCTION

The guidance and navigation (G&N) sequence of events, flow of data, and real-time decisions that must be made for the powered lunar descent phase of the H-2 (Apollo 13) lunar landing mission are presented in this document. A functional description of the activities is presented in Section 2, followed by a general discussion of techniques decisions in Section 3. Section 4 presents a detailed description of the techniques, and the flow charts are contained in Section 5. The procedures and comparison limits were extracted, in part, from References 1 through 18.

These charts document the standard, approved procedures for the verification and use of the available navigation and guidance data and the alternate procedures to be used in the event of a primary guidance and navigation system (PGNCS) failure. Routine procedures are included in the flow charts, as required, to clarify a particular technique.

The segment of the lunar landing mission discussed herein starts with acquisition of signal (AOS) at powered descent initiation (PDI) - 33 minutes and terminates about 5 minutes after the lunar module (LM) reaches the lunar surface. Mission techniques for the period from lunar orbit insertion (LOI) to PDI are presented in Reference 1. Mission techniques applicable after touchdown are presented in Reference 2.

2. FUNCTIONAL DESCRIPTION OF THE LUNAR DESCENT ACTIVITIES

This section presents a brief description of the nominal sequence of events during descent to the lunar surface.

The descent orbit insertion (DOI) burn is performed by the command and service module (CSM) 2 revolutions after lunar orbit insertion (LOI) while the LM and CSM are still in the docked configuration. * After undocking, and 1-1/2 revolutions before PDI, the CSM performs a circularization burn (CIRC) to achieve a 60-nautical mile circular orbit. The LM remains in the elliptical descent orbit while its systems are checked by the crew.

Powered descent begins near perilune of the 60-nautical mile by 50,000-foot Hohmann transfer orbit, with the actual ignition time being determined by an ignition algorithm. Termination of powered descent occurs with lunar contact and engine shutdown. A conceptual diagram of a powered descent trajectory is presented in Figure 2-1. This diagram illustrates nominal LM performance. The major phases of the descent trajectory are designated as the braking phase (terminating at approximately 7, 437 feet altitude^{**}), the approach or visibility phase (terminating at approximately 120 feet altitude), and the landing or vertical descent phase (terminating at touchdown). An 8-second ullage phase and a 26-second trim phase at 10 percent throttle, precede the braking phase. A timeline of powered descent activities is presented in Figure 2-2.

Three PGNCS programs (P63, P64, and P66) control the trajectory in such a way that various position, velocity, acceleration, and visibility requirements are met. These programs provide an automatic guidance and control capability for the LM vehicle from PDI to touchdown. P63 is the Braking Phase Program. It is initiated approximately 8 minutes before descent propulsion system (DPS) ignition and controls the LM to a program

^{*} In previous missions, the LM performed DOI 1/2 revolution before PDI. The CSM DOI profile was selected in order to conserve LM propellants and to provide additional tracking data for descent orbit determination.

^{**} Altitude is defined as the height above the lunar radius of the designated landing site.



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switch point occurring at approximately 8 minutes 30 seconds after ignition. The corresponding altitude is approximately 7, 437 feet^{*}. The Approach Phase Program (P64) is automatically entered at the termination of P63 (time to go (TG) = 62 seconds) and exercises trajectory control for achieving landing site visibility. During a nominal descent, the crew will select the Landing Phase (rate of descent) Program (P66), prior to the completion of Program P64, at an altitude of approximately 500 feet (horizontal velocity = 80 feet per second and vertical velocity = -16 feet per second). If P66 is not entered manually, it would be entered automatically when TG = 12 seconds in P64.

P66 is initiated when the crew switches the PGNCS mode control (CONT) from the automatic (AUTO) to attitude hold (ATT HOLD) position and then actuates the rate of descent (ROD) control. When the LM is guided by P66, the vehicle attitude changes are controlled manually by the crew; the DPS engine throttle level is under program control, and the commander (CDR) can command changes in the rate of descent by 1-foot-persecond increments using the ROD switch. If the MODE CONT switch is returned to the AUTO position, P66 will control the LM descent automatically by nulling the horizontal velocity relative to the surface and maintaining rate of descent at 3 feet per second. In previous missions, P65 would be entered automatically after P64 (if the crew did not select P66), and would null the LM's horizontal velocity and maintain the rate of descent at 3 feet per second. P65 has now been deleted as a program entity, and its capabilities have been made available to the crew as an option in P66.

To obtain manual control of the DPS throttle and digital autopilot (DAP), the thrust control (THR CONT) switch is placed in the manual (MAN) position. This manual mode of DPS control will not normally be

^{*} The guidance equations in P63 will compute and display the LM altitude once during the LGC computation cycle beginning at PDI + 8 minutes 30 seconds. During the latter half of this cycle, P64 will be selected for use, but will not be entered until the next LGC cycle, 2 seconds later. Hence, the last LGC cycle under P63 control begins at 8 minutes 30 seconds (displayed altitude of 7, 437 feet), and the first LGC cycle under P64 control begins at 8 minutes 32 seconds (displayed altitude of 7, 107 feet).

used for landing. In previous missions, the selection of manual throttle control caused an irreversible entry to P67 which did not permit a subsequent return to automatic throttle control. To eliminate this situation, P67 was deleted, and manual throttle control was provided as a crew option in any landing program.

Following LM contact with the lunar surface, the CDR will disarm the DPS engine, determine LM stability with respect to the lunar surface, and make a stay/no-stay decision. Once a stay decision has been reached, the CDR will key in the Landing Confirmation Program (P68) which will terminate the landing programs and initialize the LGC for lunar surface operations.

3. GENERAL TECHNIQUES DECISIONS

This section discusses the division of decision responsibility and the three basic decisions to be made:

- Go/no-go for PDI
- Abort or abort/stage
- Primary to abort guidance switchover

3.1 DECISION RESPONSIBILITY

All decision logic presented in Section 5 is designed to ensure a safe landing on the lunar surface and the capability to abort from powered descent, if required. The Mission Control Center - Houston (MCC-H) is responsible for detecting insidious, slow drift malfunctions and advising the crew of their decision; thus, high bit rate communications with the ground are required to obtain PGNCS and abort guidance system (AGS) state vector data. ^{*} The crew is responsible for detecting errors that require immediate action. This division of responsibility is further emphasized by an MCC-H to LM abort decision/communication delay which may be as large as 20 seconds.

3.2 GO/NO-GO DECISION FOR PDI

The basic requirements for initiating PDI are that the LM must have the capability to land on the lunar surface, ascend, rendezvous, and dock without violating any mission rules. A go decision for PDI means that a descent will be initated, while a no-go denotes an abort or a delay for one LM revolution to allow time for the possible correction of the malfunction. In addition to acceptable equipment checks, a go for PDI requires

- Agreement between PGNCS and MCC-H computed
- (PAD) targets
- Acceptable alignment of PGNCS

^{*}Mission rules allow for the continuation of the mission without high bit rate data, provided that the operation of the G&N systems can be verified by manual readout and voice transmission to MCC-H.

- Acceptable alignment of AGS with respect to PGNCS*
- Adequate high bit rate and voice communication
- Proper LM ignition pitch attitude
- LGC functioning properly

If a no-go for PDI is given, either an abort maneuver is performed at PDI + 12 minutes or PDI is delayed for one revolution, which provides additional time to assess the malfunction. A delay is generally undesirable because of the increased descent targeting degradation which results from orbit perturbations during the extra revolution.

3.3 ABORT OR ABORT/STAGE DECISION

An abort or abort/stage decision is made when a malfunction has been detected that will affect the crew safety or the capability of the LM to abort from powered descent. The abort procedures are designed to ensure an orbit with a pericynthion altitude greater than 30,000 feet. *** The decision to abort is based on the occurrence of one of the following:

- a) Propulsion
 - Zero or low DPS thrust
 - Failure of the DPS to throttle
 - Impending DPS propellant depletion
 - Loss of redundant ascent propulsion system (APS) start capability
 - Uncontrollable DPS engine gimbal failure

^{*}The AGS is required until high gate (P63 to P64 program change). However, based on the real-time situation (nominal conditions) and particular failure mode (open item), descent may be continued or aborted.

High bit rate and voice communications are required during descent to assess guidance and control performance and to make a go/no go decision at PDI + 10 minutes. (See footnote on previous page.)

^{***} The pericynthion altitude value (30,000 feet) was selected to ensure adequate clearance between the LM and the highest lunar terrain point.

- b) Guidance and navigation
 - PGNCS malfunction
 - AGS malfunction prior to high gate
 - Lack of landing radar (LR) data
 - Incompatible difference between PGNCS and LR altitude data
- c) Trajectory constraints
 - Violation of specified abort limits on MCC-H displays
- d) Landing site
 - Unsatisfactory
 - Redesignation unreasonable
- e) General
 - Loss of S-band high bit rate or voice communication
 - CSM malfunctions that may affect rescue capability

When the choice is available, the DPS-to-orbit capability is used which is available for aborts before PDI + 5-1/2 minutes. Aborts after this time require an abort/stage following DPS fuel depletion. The decision to abort/stage implies one of the following:

- DPS fuel depletion following an abort decision
- DPS performance limits are violated
- Excessive reaction control system (RCS) plume impingement
- LM tipover after lunar contact

3.4 PGNCS TO AGS SWITCHOVER DECISION

When PGNCS performance has degraded so that it is not adequate to abort safely (30,000-foot pericynthion altitude), an abort decision ^{*} is made, and the guidance and control function is switched from PGNCS to AGS. The PGNCS performance required for a descent abort is more constraining than that required for a lunar landing; thus, a descent could be aborted that might otherwise be completed. This abort rule is imposed to eliminate the risk of hazardous insertion conditions should already offnominal conditions worsen. The ground is the prime (and only) method whereby the slow-drift malfunctions can be detected and isolated. To accomplish this function, the following displays are used:

- PFP^{**}/PGNCS velocity residuals
- AGS/PGNCS velocity residuals
- MSFN *** / PGNCS range rate residuals
- MSFN/AGS range rate residuals

The powered flight processor (PFP) data are differenced with the PGNCS data to serve as a third data source to assist in the isolation of a degraded guidance system. The MSFN-PGNCS and MSFN-AGS range rate residuals are used to confirm the results of the PGNCS/AGS/PFP isolation technique. A flow diagram of the technique is shown in Section 5. The detailed discussion is contained in the Appendix.

^{*}See Section 3.3

^{**} The PFP, or Lear filter, is an RTCC processor which 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.

^{***} Manned Space Flight Network

4. DETAILED TECHNIQUES DESCRIPTION

This section presents, in chronological order, the G&N activities as related to the data requirements, rationale for real-time decisions, and techniques during the lunar descent.

The discussion of these techniques is divided into four phases:

- Pre-PDI
- PDI to visibility
- Visibility to touchdown
- Posttouchdown

Many of the checks and verifications are performed periodically during descent; however, each will be discussed in the approximate order of its appearance in the logic flows (Section 5).

4.1 PRE-PDI ACTIVITIES

This phase includes the activities from AOS (TIG - 33 minutes) to PDI. Several events related to these activities which occur prior to this period include the following:

Event	Approximate Time (min:sec)
Accelerometer bias update (PGNCS)	TIG - 130:00
Inertial measurement unit (IMU) alignment	TIG - 70:00
Abort guidance system (AGS) update and alignment	TIG - 55:00

4.1.1 P63 Data Check

The CDR calls P63 for a short period of time at about 28 minutes before the nominal time of ignition (TIG). The display and keyboard assembly (DSKY) display of time from ignition (TFI) to aim condition or time to go (TG), TIG, TFI, and displacement of the landing site out of the LM orbital plane or crossrange (CR) are compared to the PAD reference values. This comparison verifies the LGC targeting. Figure 4-1 shows sample PAD forms of the PDI maneuver and PDI + 12 minutes abort information. TFI is counting down with real time, but TIG, TG, and CR are constant. These parameters should have only minor deviations from expected values because they are relatively insensitive to expected trajectory dispersions and IMU errors.

P63 will be reentered about 8 minutes prior to TIG to start the powered descent phase. At this time, the DSKY displays will reflect the result of the latest state vector and landing site update, discussed in Section 4.1.4, which was input to the LGC. The new TIG should agree with the old TIG (obtained from the previous P63 data check) within a few seconds.

4.1.2 S-Band Communications Verification

S-band communications are verified at AOS. If communications are lost, the antenna is maneuvered manually to acquire S-band tracking. The crew may also perform a small (10 to 30 degrees) yaw maneuver in order to avoid antenna line-of-sight blockage. The decision on the adequacy of S-band for the descent phase is made between TIG - 33 minutes and TIG - 6 minutes. If S-band communications are inadequate, PDI will be delayed one revolution.

4.1.3 AGS Alignment and LM Preignition Activities

By this time, approximately 45 minutes have elapsed since the last AGS alignment. To provide a more accurate AGS abort capability, a V47 initialization to PGNCS will be performed at TIG - 10 minutes, and an alignment to PGNCS will be performed at TIG - 3 minutes.

After the V47 update, the AGS will clear its state vector buffer storage locations, which will then be reloaded via the data entry and display

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	CROSSRANGE																
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Figure 4-1. PDI and No PDI + 12 Abort Pads

assembly (DEDA) with the approximate LM state vector at touchdown. Approximately 6 minutes after touchdown, this preloaded state vector will be moved to working storage with a DEDA entry of 414 + 20000. This procedure will ensure that the AGS state vector used for ascent targeting, with an AGS lunar alignment, will provide a safe insertion orbit.

At TIG - 30 seconds, the average-g equations are initiated. The DSKY display is changed to

- VI total velocity
- TFI time from ignition
- ΔV_M magnitude of accumulated pulse integrating pendulous accelerometer (PIPA) output from time of average-g on.

After ullage (TIG - 7.5 seconds) is verified, the DPS is ARMED, and engine on is enabled by keying PROCEED on the DSKY in response to flashing NOUN(N) 99.

Since ullage is initiated by the LGC, failure to obtain ullage suggests possible serious problems and a no-go for PDI decision is made.

4.1.4 MCC-H Preignition Activities

Approximately 33 minutes prior to PDI, the LM will be acquired by the MSFN which will track the LM, and MCC-H will initiate monitoring of telemetry (TM) data. MCC-H will use the tracking data from revolution 13 to compute an updated LM state vector and corresponding landing site vector (\underline{R}_{LS}). These vectors will be uplinked to the LGC at about PDI - 23 minutes.

Shortly after AOS, the line of sight from the ground tracking stations to the LM will lie along the downrange direction. At this time, MSFN range data will be compared with the LM state vector to determine downrange position error. The result of this comparison will provide MCC-H with the opportunity to assess the magnitude of the downrange orbit perturbations which occurred while the LM was behind the moon. The descent planning table, an RTCC program, is then called by the ground with the LM telemetry vector as input to compute the expected descent trajectory. The LM state vector is also used to initialize the PFP.

The RTCC enters the high-speed computational mode at 8 minutes before PDI and computes the PGNCS, AGS, and MSFN differences. The PFP (Lear Processor) is initiated at PDI - 4 minutes. These data are differenced with PGNCS velocity data and displayed on strip chart recorders. The adequacy of the preignition telemetry data is assessed by the ground, and the resulting decision on descent is relayed to the LM.

MCC-H will establish that PGNCS-AGS differences are acceptable and advise the crew regarding the PGNCS and AGS status for AGS updating. MCC-H will monitor the AGS alignment for coupling data unit (CDU) transients. If the system is functioning properly, none should occur. The crew will be advised to repeat the alignment should a transient occur. Depending on the real-time situation and the particular failure mode^{*}, a degraded AGS constitutes a no-go for PDI.

4.2 PDI TO VISIBILITY PHASE ACTIVITIES

This phase includes the activities from the ignition of the DPS at TIG to the entry of the PGNCS lunar surface visibility program P64 at about TIG + 8 minutes 32 seconds. The powered descent maneuver starts with a 26-second trim phase with the throttle set at 10 percent. A fixed throttle phase (FTP) with the throttle at 92.5 percent follows the trim phase. Following ignition, the LM trajectory is such that after about 4 seconds of FTP, the LM is in a circular orbit with an altitude of 50,000 feet; after about 7 seconds of FTP, the LM is in an orbit with a perilune altitude of 0 feet.

^{*} AGS malfunctions will be evaluated by the flight director in real time.

- At TIG, the automatic DSKY display is changed to
 - V_I magnitude of inertial velocity with respect to reference coordinate system
 - H altitude rate
 - H altitude above the lunar radius at the designated landing site

4.2.1 DPS Ignition and Performance Monitoring

The ignition algorithm in the LUMINARY Program computes TIG, and the LGC sends the engine start signal at the designated time. (An LGC alarm will be displayed if the engine does not ignite within 8 seconds after the programmed ignition time.) At 5 seconds after ignition, the descent engine command override switch is turned on to prevent an inadvertent shutdown of the DPS. If the engine does not ignite by TIG + 5 seconds, the CDR will attempt a manual start by pressing the DPS engine command override switch. If the DPS is started manually, the 5-second delay enables the ground to determine if the APS has lost the redundant start capability. If this capability is lost, the crew will be advised to abort.

If the engine does not respond to a manual start attempt, the CDR will exit P63. If upon initial investigation the crew or ground determines that the system fault is correctable, PDI will be attempted on the next revolution. In this case, the ullage ΔV is not removed but retained and taken into account in retargeting. If, however, the crew or ground verifies that the malfunction cannot be corrected, the abort maneuver at PDI + 12 minutes will be performed.

If the FTP is not attained after the trim phase, the crew will stop thrusting and discontinue the descent. To accomplish a lunar landing, the PGNCS must have the capability to throttle the DPS; therefore, manual throttle positioning is not attempted.

The performance of the DPS is monitored by the crew periodically observing the thrust meter, the thrust-to-weight ratio (T/W) indicator,

and the velocity change on the DSKY. These measurements can isolate a degraded DPS or possibly a degraded PGNCS Z-accelerometer. In the case of an apparent accelerometer failure, the ground will provide the crew with subsequent action. If the thrust degrades to less than 80 percent as monitored from pulse integrating pendulous accelerometer (PIPA) counts (the commanded thrust is 100 percent), the thrust translation controller assembly (TTCA) control switch is moved from the CDR to the LM pilot (LMP) position in an attempt to correct the problem. Should this procedure fail, an abort/stage decision must be made within 100 seconds. The 100-second limit represents the total time the DPS engine can be operated in the non-throttleable region (63 to 92-1/2 percent). Continued DPS engine operation in this region may result in a catastrophic failure.

4.2.2 LGC Targeting Update

Orbital mechanics yields a relation between downrange position error and PFP-PGNCS radial velocity residuals prior to PDI (in the ratio of 1,000 feet to 1 foot per second) which could be used to further update the LM state vector. It is not possible, however, to perform a state vector uplink during powered descent. Therefore, in order to utilize the PFP information to improve the LGC targeting, the crew will receive a PAD of downrange errors^{*}, stated in terms of a correction to the LGC \underline{R}_{LS} ($\Delta \underline{R}_{LS}$)**, which will be entered in the LGC with V21N69 at TIG + 2 minutes. (Noun 69 can also be used to input a crossrange and/or altitude correction if techniques for determining these errors are available in real time.)

Mission rules state that if the downrange error is less than 2,000 feet or greater than 35,000 feet, it will not be sent to the crew. The 2,000-foot limit is based on the expected PFP accuracy, and the 35,000-foot limit is based on the PFP/PGNCS radial velocity abort limit discussed in the Appendix.

The LGC targeting equations use the vector LAND as the location of the landing site. LAND is computed as the sum of the preloaded landing site vector, $\frac{R}{LS}$, and the N69-loaded correction to the landing site vector, $\frac{\Delta R}{\Delta LS}$.

4.2.3 LM Attitude and Attitude Rate Monitoring

The LMP verifies that the control system and the flight director attitude indicator (FDAI) displays are operating properly by comparing the steady-state readings of the error needles on the two FDAI's while under PGNCS control. An unexpected or prolonged error of 5 degrees on the PGNCS error needles or attitude rates of 5 degrees per second indicates a control system failure; in which case, an abort on AGS will be performed. The crew will also periodically compare navigated trajectory parameters against the expected values as a gross check on the progress of the powered descent phase.

4.2.4 LR Acquisiton

If the LR altitude data-good signal has not been received by a PGNCS indicated altitude of 10,000 feet, the crew will abort. This limit assumes that the PGNCS is operating satisfactorily. If the strip chart quantities displayed in real time indicate that the PGNCS has exceeded its 3σ limits, the minimum altitude for no LR data will be raised to 18,000 feet. If an abort is required, these altitude limits provide a time margin sufficient for the LM to safely attain a positive radial velocity (Section A-3. 4).

4.2.5 LR Data Acceptance Checks

After calling ΔH (the difference between PGNCS and LR altitude) on the DSKY, the LR updating of the PGNCS altitude is enabled if the ΔH has been within limits for 10 seconds. The limits are defined in Figure 4-2 (Reference 3). If these limits have been violated for 60 seconds, an abort will be made. The 10 - and 60-second values are reasonability numbers. The limit lines of ΔH in Figure 4-2 are the maximum ΔH values which can be accepted by PGNCS without the LM impacting with the lunar surface. (The PGNCS targeting does not respect the lunar surface in aiming for the landing site.) The LM crew and MCC-H will verify that LR-PGNCS ΔH is converging.

Specific convergence limits have not been specified. ΔH convergence will be evaluated in real time by the flight director.



Figure 4-2. Maximum Allowable PGNCS Minus Landing Radar Altitude Difference versus Altitude

If the LR fails after having partially corrected the PGNCS altitude, descent can be continued to high gate where the crew will make a continueor-abort decision. Figure 4-3 exhibits the maximum allowable Δ H after a partial LR update of PGNCS altitude, as a function of time remaining to high gate. This Δ H is derived by taking the root sum square (RSS) of the altitude error due to a terrain slope with the 3 σ altitude rate error propagated to a resulting altitude error at high gate and subtracting this quantity from the altitude of the APS abort boundary at high gate (Reference 4). If LR data are reacquired after high gate, and Δ H is less than 1,000 feet, descent will be continued. If LR data are not reacquired after high gate, or if Δ H is greater than 1,000 feet, an abort is required.

4.2.6 Gimbal Drive Actuator (GDA) Failure Monitoring

If any one of the following three cues are present, the GDA's will be switched off:

- DPS engine trim gimbal light is "ON"
- Attitude errors show an offset greater than ±3 degrees
- Excessive RCS activity is evident

A successful mission may be flown without active GDA's for a relatively wide range of offset errors introduced by their failure. Figure 4-4 shows the maximum offset error angle that can be compensated by increased RCS activity, without violating the RCS plume impingement constraints (discussed in Section 4.3.4) as a function of time into powered descent. Impingement is, in general, the most limiting constraint; however, total torque capability may also be exceeded. Therefore, if the GDA's are turned off, MCC-H will monitor attitude rates, as well as impingement, and advise the crew of impending constraint violations.

4.2.7 MCC-H Monitoring of PGNCS, AGS and Trajectory Performance

Following DPS engine ignition, the ground monitors tracking and telemetry information to ensure that the PGNCS and AGS outputs and the trajectory parameters indicate that the descent may be continued safely. There are several primary RTCC displays used by MCC-H to determine



MAXIMUM ALLOWABLE TIME REMAINING TO HI-GATE (SEC)

Figure 4-3. Maximum Allowable PGNCS Minus Landing Radar Altitude Difference versus Time to High Gate After Partial Update

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ALLOWABLE \bigtriangleup H FOR PARTIAL UPDATING TO

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Figure 4-4. Maximum Allowable GDA Offset at the Time of GDA Failure versus Time

the PGNCS or AGS abort criteria. Since the logic requires a great deal of explanation and the use of several figures plus supporting graphs, the techniques are discussed in the Appendix. (See also Reference 5.) This will avoid loss of continuity in the sequence of events.

4.2.8 MCC-H Monitoring of DPS Commanded Thrust

Following the 26 seconds of 10 percent DPS throttle, the initial commanded thrust, as determined by the guidance equations, should be 160 \pm 10 percent. The ground has displayed commanded thrust versus horizontal velocity. A typical history is presented in Figure 4-5. A proper initial value is an indication that the LGC has the correct descent targets and is functioning properly.

Between ignition and throttledown (57 percent), the expected variation in the command thrust versus horizontal velocity function is generally parabolic with the slope becoming steeper as the braking progresses (Figure 4-5). Figure 4-6 is a similar plot; however, the commanded thrust is scaled in pounds to display commanded thrust sensitivity to actual engine thrust level. This figure shows that for low thrust cases, the PGNCS commanded thrust will increase and possibly become cyclic, resulting in large LM attitude excursions. This incompatibility between PGNCS guidance and a low thrust DPS should be detectable on this display when the actual curve begins to diverge markedly and reverse its normal trend. A trend reversal prior to TG equals 1 minute 20 seconds in P63 will be cause for an abort recommendation to the crew. If a reversal occurs after this time, the flight will be allowed to proceed into program P64.

4.2.9 Throttledown Monitoring

The TFI of throttledown is predicted from Figure 4-7. The results of Reference 6 show that the length of time from the loss of radial guidance (defined as a DPS thrust level of less than 93 percent) until DPS engine throttledown is a function of the fixed throttle point (FTP) thrust level. By monitoring the FTP thrust, the ground can predict and notify the crew of the TFI of throttledown. If throttledown does not occur (the



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Figure 4-5. Commanded Thrust versus Horizontal Velocity


Figure 4-6. Commanded Thrust versus Horizontal Velocity

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Figure 4-7. Delta Time versus FTP Thrust

commanded thrust is less than 57 percent) and the MCC-H confirms that the DPS will not throttle, an abort is made. If the throttle logic has failed, a second onboard abort cue will be the large attitude changes which occur when the commanded thrust becomes nearly zero (approximately 40 seconds after throttle down command).

An abort is also made if throttledown has not occurred by the nominal P63 to P64 program change time plus 15 seconds. If the DPS has not throttled by this time, the LM will develop a positive radial rate negating the possiblity of landing.

4.3 VISIBILITY PHASE TO TOUCHDOWN ACTIVITIES

This section discusses the descent techniques for the period beginning with the entry of P64 (an approximate altitude of 7, 107 feet at TIG + 8:32) and ending at touchdown (TIG + 11:26). When the TG in P63 is 62 seconds, the LGC should automatically select program P64, and the automatic DSKY displays change to

- TR time remaining for redesignation (TG 10 seconds); landing point designation (LPD) angle of the landing site
- H altitude rate
- H altitude

The crew's checklist specifies the maximum allowable H as a function of H. If the maximum H is exceeded, and the condition persists, an abort is required if the CDR cannot achieve safe manual control of the LM.

4.3.1 Visibility Phase Pitch Maneuver

P64 is entered with the PGNCS mode control in AUTO. A pitchover maneuver to achieve visibility is verified by observing FDAI angles, physiological cues, and the lunar surface in the forward window. In addition, the initial P64 TG should be about 2 minutes 50 seconds. As an alternative, P64 may be entered with the mode control in HOLD to allow the CDR to perform the pitchover maneuver manually. This can reduce the expected high AUTO pitch rate associated with the P63 to P64 program change, and provide the CDR an opportunity to assess the LM handling characteristics.

4.3.2 AGS Altitude Update

The AGS altitude is updated by the crew at an indicated PGNCS altitude of 6,000 feet. The updating of AGS reduces the AGS abort insertion uncertainty, since the PGNCS indicated altitude includes the LR altitude data, and is, therefore, essentially equal to the actual altitude of the LM.

4.3.3 LR Velocity Data

After the program switch, rather abrupt attitude changes may also occur as a result of LR velocity updates. A program alarm code (523) indicates that the LR antenna did not automatically move to Position 2 following the pitch maneuver. If manually repositioning the antenna fails, the CDR will key V58E PRO on the DSKY to terminate LR updating and clear the alarm condition. If the velocity reasonability test is failed (flashing light preceded by a steady light), a LR self check should be performed. If the test failure was a result of a cross lobe lock, this action will break lock on the radar and may result in good data. If good data cannot be obtained, the crew may continue without the velocity update as long as the visual assessment is adequate and the LR-PGNCS altitude difference Δ H has converged (Reference 7).

4.3.4 MCC-H Propellant Adequacy and RCS Plume Impingement Monitoring

After the LGC program has been changed from P64 to P66 by the crew or P66 has been entered automatically, MCC-H monitoring will concentrate on propellant adequacy and acceptability of the RCS plume impingement.

A number of PGNCS guidance parameters are obtained by telemetry, and a prediction based on nominal DPS performance is made for the amount of fuel and oxidizer required to fly the remainder of the descent trajectory. This requirement is subtracted from the measured fuel and oxidizer still remaining (obtained from TM data) to obtain the predicted margin at touchdown. The margins at touchdown are plotted versus time on an analog display (Figure 4-8). Prior to high gate, while the propellant margin is predicted as a function of horizontal velocity, the display will be used as a general indicator of overall system performance. After high gate, propellant margin is predicted as a function of LGC targeting and





associated DPS thrusting characteristics. This method is more accurate, and a zero margin, supported by some positive indication of an inability to land, such as the premature appearance of the DES QTY light, will be grounds for an abort.

The RCS plume can cause excessive temperature on the LM skin, resulting in failure of the insulation and supporting structure. The addition of plume deflectors, however, has increased the allowable jet-on time and has essentially eliminated impingement as an operational constraint.

The use of the deflectors has lengthened the continuous duty firing time from 15 to 30 seconds and the 50 percent duty cycle firing time from 15 to 80 seconds. In addition, the maximum duty cycle for unlimited operation has been increased from 2 to 15 percent (Figure 4-9). Therefore, RCS plume impingement monitoring by MCC-H will be of vital importance to a possible abort/stage decision only in such an extreme case as a GDA failure.

4.3.5 Landing Site Redesignation

The DSKY displays of TR/LPD, H, and H are monitored to ensure that the indicated trajectory is safe and that there is adequate time for redesignation. The primary use of the redesignation capability is to select an acceptable landing site if the targeted site is unsafe. Redesignation may also be used to achieve the objective of landing as near as possible to a specified point on the lunar surface. * If the indicated landing site is not acceptable and if the time and propellant remaining are insufficient for redesignation, an abort is required.

Since the LGC assumes that the LM is flying over a perfectly spherical moon, the LPD line of sight will not indicate the true landing site if the LM is flying over terrain which has a mean altitude that differs from that of the landing site. In order to determine the true line of sight to the landing site while flying over the H-2 approach terrain, the crew will mentally add 3 degrees to the DSKY indicated LPD angle until the LM altitude is

A primary objective of the H-2 mission is to land within a 1-kilometer radius of the targeted landing site (i.e., a pinpoint landing objective).



Figure 4-9. RCS Plume Impingement Limits During Powered Descent

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below 2,000 feet (Reference 8). * A schematic diagram which demonstrates the effect of terrain deviations on LPD accuracy is shown in Figure 4-10.

4.3.6 MSFN Altitude Update

MCC-H continues monitoring the trajectory and if required "* updates the MSFN altitude with PGNCS altitude data (after PGNCS has been updated with the LR data).

4.3.7 Low Level Propellant Monitoring

The ground has the capability of monitoring the quantity of propellant remaining in each of the tanks. After P64 is entered, MCC-H will determine which set of propellant tanks indicates the lesser amount of propellants remaining. Upon MCC-H advisement, the crew will switch the LM propellant quantity gauge to these propellant tanks for subsequent monitoring. However, the ground will assume the prime responsibility for warning the crew of impending DPS fuel depletion. Using the time at which the ground observes the DPS-propellant-level low (DES QTY) "light on" signal *** as a zero reference point, MCC-H will give voice cues to the crew indicating 30 and 60 seconds elapsed time, and fuel depletion. The timing of these cues will be biased (to account for transmission delay, fuel usage prediction errors, and sensor errors) so that the crew will hear "fuel depletion" when there will actually be 20 seconds of hover thrust (6 seconds of full thrust) remaining for an immediate landing or DPS abort. The crew may also use their event timer to count the elapsed time in parallel with MCC-H. If the DES QTY light fails, an abort will be made when the most critical propellant quantity gauge reads two percent.

^{*}The 3-degree bias and the 2000-foot switch-over point are based on a nominal descent trajectory and the present estimate of the H-2 mission approach terrain.

^{**} An operational value of (PGNCS-MSFN) altitude difference of about 300 feet is being used.

^{***} When the low level sensor light comes on there is approximately 114 seconds of 25 percent DPS thrust remaining.

4.3.8 Final Descent Phase LM Activities

The nominal final phase of descent will be performed with the LM under control of P66 and the visual monitoring continued. The automatic DSKY display is

- V (HORIZ), horizontal velocity with respect to the landing site
- H altitude rate
- H altitude

4.4 POSTTOUCHDOWN PHASE

This section includes the activities from touchdown to the entry of P68 (touchdown plus about 5 minutes) (Reference 2).

Immediately at touchdown, the Engine Stop button is depressed. The LM attitude and attitude rates are monitored closely in pitch, roll, and yaw for cues which would indicate that tipover is imminent; in which case, the crew would abort/stage. Once the LM is stabilized on the lunar surface, the RCS thruster firing is inhibited by keying PRO on the DSKY to zero attitude errors. In addition, the Descent Engine Command Override and the Engine Arm switches are set to OFF, and the PGNCS mode control switch is set to ATT HOLD. The crew will then make a DEDA entry of 413 + 10000 which performs the following:

- a) Stores the AGS azimuth for possible future lunar align
- b) Sets the abort electronics assembly (AEA) lunar surface signal
- c) Sets AGS attitude errors to zero
- d) Inhibits AGS accelerometer calibration
- e) Stops AGS acceleration measurement

At this time the LGC is still at a point in P66 waiting for another DSKY entry. The crew can abort/stage at any time prior to P66 program exit (which occurs at approximately PDI + 15 minutes) using the APS abort program P71. If a no-stay decision is reached after program exit, the next lift-off opportunity will occur at PDI + 20 minutes, 45 seconds.



Figure 4-10. Lunar Terrain Effects on LPD Angle

If a decision is given by MCC-H for the crew to stay, the crew will perform the following postlanding operations:

- a) Turn off the LR.
- b) Make a DEDA entry of 414 + 20000. This loads targeted landing site data, which was entered via the DEDA at about PDI - 5 minutes, into the AGS LM state vector locations.
- c) Enter AGS lunar align via DEDA entry 400 + 40000. Note that lunar align may be exited in 30 seconds with a 95 percent reduction in the initial alignment errors.
- d) Call the Landing Confirmation Program (P68).

P68 terminates the landing programs and initializes the LGC for lunar surface operation. P68 performs the following functions:

- a) Zeros attitude errors
- b) Terminates average-g integration
- c) Resets abort enable flag for use by the abort discretes monitor routine (R11) and the APS Abort Program (P71)
- d) Sets the lunar surface and APS flags
- e) Stores present position vector (\underline{R}_{LS}) in lunar fixed coordinates
- f) Displays the LGC calculated RLS coordinates (latitude, longitude, altitude)

MCC-H will monitor the LM activity during this period and advise the LM of their stay/no-stay status.

5. LUNAR DESCENT ACTIVITIES FLOW CHARTS

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 the descent phase of the lunar landing mission.

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- (1) CONTINUOUS PROCEDURE BEGINNING AT AOS
- (2) IF GN&C SYSTEM OPERATION CAN BE VERIFIED WITHOUT HBR DATA, PDI NEED WOT BE DELAYED.



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CDR LMP MCC-H COMPARE PGNC AND AGS ATTITUDES AND ESTIMATE AGS DRIFT RATE (1) IS DRIFT RATE NO < 2 DEG/HR ? ADVISE CREW: AGS DEGRADED-YES NO GO FOR PDI CONTINUE (2) NOTE MONITOR AGS ALIGNMENT FOR CDU TRANSIENTS. ALIGN AGS TO PGNCS (TIG -3 MIN) ADVISE CREW SET INSTRUMENT SWITCHES: TAPE METER MODE SELECT TO AGS
RANGE-ALTITUDE MONITOR SWITCHES TO H, H
LOS RATE, ERROR MONITOR SWITCH TO LR/COMPUTER FOR CROSSPOINTERS ON AGS, SET MULTIPLIER SWITCH TO HIGH NOTE CDR FDAL TO PGNCS
LMP FDAL TO AGS
SET ATTITUDE ERROR SWITCH TO PGNCS . CURRENT VALUE BASED ON GYRO REDLINE VALUES • RESPONSIBILITY G&CD • DATE AVAILABLE JUNE 27, 1969 • REFERENCE 9 (1) AGS DRIFT RATE AT WHICH AGS IS NOT USEFUL FOR DESCENT ABORTS PITCH = 2.0 DEG/HR ROLL = 2.0 DEG/HR YAW = 2.0 DEG/HR (2) DECISION DEPENDS ON FLIGHT DIRECTOR'S EVALUATION OF TOTAL SYSTEM OPERATION

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APPENDIX

MCC-H MONITORING OF PGNCS, AGS, AND TRAJECTORY PERFORMANCE

The present philosophy of ground descent monitoring is to abort when the monitored parameters indicate that the PGNCS has degraded to a point where if an abort was required the LM could not achieve an orbit with a pericynthion altitude greater than 30,000 feet.

The displays used to monitor descent are discussed first. The monitoring procedures shown in the flows (Page 5-10) are then discussed. These flows show how the ground can monitor descent and draw conclusions as to the status of the onboard systems.

A-1 DISPLAYS USED TO MONITOR DESCENT

The primary sources of data to detect and isolate a degraded system are:

- Velocity component differences using data from the PFP, PGNCS, and AGS versus elapsed time.
- MSFN range rate minus the PGNCS and AGS range rate versus elapsed time.

Some additional ground displays that may be used to verify the degraded system are:

- Altitude versus altitude rate
- Commanded thrust versus horizontal velocity
- Fuel margin display*

Discussed in Section 4
A-2 DESCRIPTION OF DISPLAYS

Velocity differences

The velocity component differences displayed are PGNCS/AGS and PFP/PGNCS. The PFP data are generated using the Kalman filter techniques. These data are displayed on strip charts and/or digitally. Figures A-1 and A-2 exhibit the nominal, $\pm 3\sigma$, and action lines.

• MSFN, PGNCS, and AGS range rate residuals versus elapsed time

This display is to demonstrate the integrity of the PGNCS and AGS by comparing the MSFN range rate with the range rate computed using telemetry data. These data are used to confirm decisions using PFP data. These data are on digital displays and analog displays (main plot board).

• Altitude versus altitude rate

This display evaluates the descendibility under PGNCS guidance and can be driven with various data sources (PGNCS, AGS, PFP). This display is theoretically useful to determine crew safety. Figure A-3 shows the nominal and $\pm 3\sigma$ curves for the PGNCS altitude (H) and altitude rate (H). Reference 3 concludes that $\pm 6\sigma$ PGNCS values are allowable if radar velocity update occurs; thus, the limits can expand to cover a major portion of the figure.

A-3 DISCUSSION OF GROUND MONITORING PROCEDURES^{*}

The flow diagram on Page 5-10 presents the basic velocity residual monitoring procedures and the recommended flight limits for the powered descent mission phase. The powered descent monitoring basically compares the PGNCS, AGS, and MSFN velocity vectors to determine the status for continuing the powered descent. In addition to the velocity residual monitoring, the flows also include a definition of the minimum altitude, as defined by the PGNCS, that should be permitted without landing radar altitude updating. ^{**}The discussion of powered descent monitoring includes the

The major part of this discussion is excerpted from Reference 18

Discussed in Section 4. 2. 4



Figure A-1a. AGS/PGNCS Velocity Residuals (Downrange)

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Figure A-1c. AGS/PGNCS Velocity Residuals (Radial)



Figure A-2a. PFP/PGNCS Velocity Residuals (Downrange)

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Figure A-2b. PFP/PGNCS Velocity Residuals (Crossrange)



Figure A-2c. PFP/PGNCS Velocity Residuals (Radial)

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H VS Ĥ 65 15.0 ORD II, ABI ORD I, ABI .NOMI'NAL= 60 13.5 PGNCS 55 12.0 ·3σ = PDI 50 10.5 '3σ = END BRAKING-9.0 45 40 7.5 APS'4 35 6.0 DPS X 20_ 30 4.5 25 3.0 272 TOUCHDOWN 127 20 1.5 ≂NOMINAL DPS | _____ -THROTTLE -177 UU 15 0 10 -1.5 Π I 2 0 -2 -4 -6 -8 -10 -12 -14 -16 -18 -20 -22 II 22 20 18 14 12 10 16 8 2 -2 6 4 0 PGNCS ALTITUDE RATE (fps X 10)

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Figure A-3. Altitude Versus Altitude Rate

PGNCS ALTITUDE (kft)

following topics:

- Downrange position evaluation
- Inplane monitoring
- Crossrange monitoring
- Pitch misalignment monitoring
- Crossrange misalignment monitoring

A-3.1 Downrange Position Evaluation

After high speed data becomes available, just prior to PDI, the PFP/PGNCS radial velocity residual and the MSFN/PGNCS and MSFN/AGS range position error exists. The error so determined from the PFP/PGNCS residual will be incorporated in the LGC targeting update ($\Delta \underline{R}_{LS}$) discussed in Section 4.2.2.

A-3.2 Inplane Monitoring

The inplane velocity residual monitoring utilizes AGS/PGNCS differences to indicate when a potential problem exists. The PFP/PGNCS inplane residuals (downrange and radial) are used to isolate the errant system (i. e., the AGS or PGNCS). The limits for the AGS/PGNCS comparison and PFP/PGNCS comparison for errant system isolation is 10 feet per second either in the radial or the downrange direction. This limit for the AGS/PGNCS comparison is based upon 3σ systems performance at the point that LR velocity updating normally starts. If the AGS is the errant system, the powered descent is continued.

If the PGNCS is the errant system, additional checks are made. First, the PFP/PGNCS velocity residuals are compared to flight limits of 35 feet per second and 30 feet per second in the radial and downrange directions, respectively. If these limits are exceeded, the trend and magnitude of the AGS/PGNCS velocity residuals and the MSFN/PGNCS $\Delta \dot{\rho}$ are evaluated to develop confidence in the PFP/PGNCS indication of an abort situation. The flow logic defines the AGS/PGNCS velocity residual limits to be the same as for the PFP/PGNCS limits. These AGS/PGNCS limits

are not defined as hard limits for aborting but as approximate AGS/PGNCS velocity residuals required to substantiate PFP/PGNCS residuals. If the AGS/PGNCS trends and the MSFN/PGNCS $\Delta \phi$ trends substantiate the PFP indication of a PGNCS problem, and if the PFP/PGNCS flight limits are exceeded, an abort is required.

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In the event that the PFP is determined to be unsatisfactory for monitoring, the abort should be called based on the AGS/PGNCS flight limits of 35 feet per second and 30 feet per second in the radial and downrange directions, respectively, provided the MSFN/PGNCS $\Delta \dot{\rho}$ verifies that the PGNCS is the errant system. The value of MSFN/PGNCS $\Delta \dot{\rho}$ that indicates a PGNCS problem is based on the growth of this residual from PDI. A growth of about 10 feet per second indicates a PGNCS problem. Use of the growth rather than an absolute value is necessary since the error in MSFN range rate resulting from a 30 downrange position error is large compared to the value of this residual that results from PGNCS anomalies.

Once an abort is determined to be necessary, all other data available will be used to confirm confidence in the AGS. If the AGS performance is good, the abort will be performed on AGS, otherwise, on PGNCS.

For low trajectories, the 35-foot-per-second flight limit is adequate until about 420 seconds into the powered descent or until the PGNCS altitude is 18,000 feet. Beyond this point in powered descent, the 35-foot-persecond limit is not adequate to protect the abort capability without LR altitude updating. This is not a problem of crashing into the surface while attempting to initiate an abort, but rather a problem of achieving an orbit with a safe pericynthion. Thus, it is a critical problem that must be protected. To do so, it is necessary to use a combination of a velocity limit and a time into powered descent (or PGNCS altitude) without LR altitude updating. Since this abort is called by the ground, it is necessary to account for a 20-second-time delay in executing the abort. Thus, the abort without LR altitude updating must be called by 400 seconds into powered descent or at a PGNCS altitude of 22,000 feet if the actual trajectory is low. If the trajectory is high, it is safe to continue to a 10,000-foot-PGNCS altitude provided there are no problems.

A-3.3 Crossrange Monitoring

Crossrange monitoring is quite similar to the inplane monitoring. There are two differences however. One is that the MSFN/PGNCS $\Delta \dot{\rho}$ data cannot, be used to isolate the errant system. The other is that the crossrange flight limit is based upon an impending PGNCS accelerometer failure rather than minimum pericynthion altitude or minimum altitude during an abort.

Since the crossrange monitoring is not as critical as the inplane monitoring, a 60 AGS/PGNCS crossrange velocity residual is used to indicate a potential problem. The AGS/PGNCS and PFP/PGNCS crossrange velocity residuals that indicate a PGNCS problem are each 20 feet per second. The PFP/PGNCS and AGS/PGNCS flight limits are 90 feet per second. Here again, the AGS/PGNCS flight limit is not a hard limit but is used as an approximate magnitude that will, along with the trends, verify the PFP/PGNCS performance. The abort is called based upon the PFP/PGNCS crossrange velocity residual.

A-3.4 Pitch Misalignment Monitoring

Since the AGS attitude reference system is aligned to the PGNCS attitude reference system prior to PDI, a misalignment will affect both systems similarly and will not show up as an AGS/PGNCS velocity residual. Therefore, the PFP/PGNCS radial velocity residual, or, if the PFP is not performing properly, the MSFN/PGNCS $\Delta \dot{\rho}$ is used to determine a possible pitch misalignment problem. A residual of 20 feet per second in either parameter is an indication of a possible misalignment, or since downrange position errors show up as radial velocity errors, this residual could indicate a possible downrange position error at PDI. If the problem is a misalignment, the residuals will tend to grow with time. If the problem is a downrange position error, the residuals will remain almost constant, with a small growth with time. A final possibility is that the PFP/PGNCS radial velocity residual results from a PFP problem.

Problems with the PFP are determined by monitoring the trends of the MSFN/PGNCS and MSFN/AGS $\Delta \dot{\rho}$ and by monitoring the trends of the PFP/PGNCS radial velocity residual and MSFN/PGNCS $\Delta \dot{\rho}$. For example,

if the MSFN/PGNCS and MSFN/AGS $\Delta \dot{\rho}$ are consistent (i.e., the same trend), and if the PFP/PGNCS radial velocity residual and MSFN/PGNCS $\Delta \dot{\rho}$ trends are opposite, then the problem is probably not in the PFP. In this case the problem may be either a pitch misalignment or a downrange position error.

If it is confirmed that there is either a pitch misalignment or a downrange position error large enough to result in a PGNCS/PFP radial velocity residual of 35 feet per second, and if this is confirmed with a MSFN/PGNCS $\Delta \dot{\rho}$ of about 30 feet per second, a PGNCS abort is called. If the PFP is inoperative, the abort is called based on a MSFN/PGNCS $\Delta \dot{\rho}$ of 30 feet per second.

If there is a PFP/PGNCS velocity residual but the residual is between 20 feet per second and the 35 foot-per-second flight limit, the minimum PGNCS altitude is limited to 18,000 feet without LR altitude data if the actual trajectory is low compared to the PGNCS trajectory. Since this situation is not as critical as that caused by a radial accelerometer problem, it is sufficient to call this abort from the ground without biasing for the 20second-time delay. If the trajectory is actually high relative to the PGNCS trajectory, it is satisfactory to proceed to a PGNCS indicated altitude of 10,000 feet without LR altitude updating.

A-3.5 Crossrange Misalignment

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Neither the MSFN range rate data nor the AGS data can be used to detect and isolate crossrange misalignment problems. In this case, an abort is based upon the PFP/PGNCS crossrange velocity residual provided the inplane performance of the PFP is considered satisfactory (i.e., the AGS/PGNCS inplane residuals are consistent). The flight limit for this case is based upon gyro drift rate at the impending failure limit propagated from the time of IMU alignment. This limit is 200 feet per second.

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