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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MSC INTERNAL NOTE

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APOLLO MISSION TECHNIQUES MISSION H-2 AND SUBSEQUENT LUNAR SURFACE PHASE

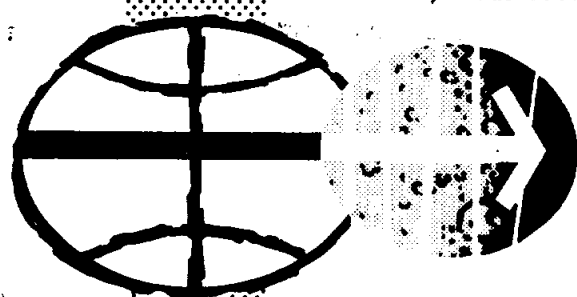
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APOLLO SPACECRAFT PROGRAM OFFICE
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

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FOREWORD

This Lunar Surface 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
- Descent Abort and Subsequent Rendezvous
- Manual Ascent
- 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 meetings to coordinate their various associated

FOREWORD (Continued)

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 Surface 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

AEA	abort electronics assembly
AGS	abort guidance system
ALT	altitude
AOS	acquisition of signal
AOT	alignment optical telescope
APS	ascent propulsion system
ASA	abort sensor assembly
AT	P57 alignment technique
ATT	attitude
BMAG	body mounted attitude gyro
BRCS	basic reference coordinate system
BSS	boresight star (PAD data)
BT	burn time (PAD data)
CDH	constant delta height
CDR	commander
CDU	coupling data unit
CMC	command module computer
CMD	command
CMP	command module pilot
COAS	crew optical alignment sight
CONT	control
CSI	coelliptic sequence initiation
CSM	command service module
DAP	digital autopilot
DEDA	data entry and display assembly

NOMENCLATURE (Continued)

DES	descent
DPS	descent propulsion system
DSKY	display and keyboard
EMS	entry monitoring system
ENG	engine
FDAI	flight director attitude indicator
FDO	Flight Dynamics Officer
g	gravity
GDC	gyro display coupler
G&N	guidance and navigation
g. e. t.	ground elapsed time
GETI	ignition time (PAD data)
GNCS	CSM guidance, navigation and control system
H	AGS insertion altitude
H_A, H_P	altitude of apogee and perigee, respectively, above lunar landing site radius (PAD data)
Hdot	AGS insertion radial rate
IMU	inertial measurement unit
K	AGS time bias
LAD	LM attitude determination program of RTCC
LAT	latitude
LGC	lunar module guidance computer
LM	lunar module

NOMENCLATURE (Continued)

LMK	landmark
LMP	lunar module pilot
LO	lift-off
LONG	longitude
LOS	loss of signal
LR	landing radar
LSD	landing site determination program of RTCC
MCC-H	Mission Control Center - Houston
MSFN	Manned Space Flight Network
N	noun
NAAF	CSM orbital period plus the nominal time interval from the time the CSM passes over the LM until the desired lift-off time (PAD data)
ORB RATE	orbital rate attitude control mode
OVRD	override
P	CSM orbit period (PAD data)
P12	Ascent Program
P22	Landmark Tracking Program
P27	CMC, LGC Update Program
P30	External ΔV Program
P40	SPS Thrust Program
P52	IMU Realignment Program
P57	LGC Lunar Surface Alignment Program
P66	Landing Phase (Rate of Descent) Program

NOMENCLATURE (Continued)

P68	Landing Confirmation Program
P71	APS Abort Program
P_{TRIM} , Y_{TRIM}	pitch and yaw trim SPS gimbal angles (PAD data)
PAD	data voiced to crew from ground
PDI	powered descent initiation
PFP	RTCC Powered Flight Processor
PGNCS	LM primary guidance, navigation and control system
PIPA	pendulous integrating pulse accelerometer
PRO	proceed
R05	S-band Antenna Routine
R11	Abort Discretes Monitor Routine
R_{ALIGN} , P_{ALIGN} , Y_{ALIGN}	backup GDC or IMU alignment angles
R, P, Y	roll, pitch, and yaw gimbal angles (PAD data)
RCS	reaction control system
Rdot	PGNCS insertion radial rate
REFSMMAT	transformation matrix from basic reference system to IMU coordinate system
RHC	rotational hand controller
$\underline{R}_{\text{LS}}$	LM position vector on the lunar surface in moon-fixed coordinates
RR	rendezvous radar
rss	root sum squared
RTCC	Real-Time Computer Complex
RTGO	range to go

NOMENCLATURE (Continued)

SC	spacecraft
SCS	CSM stabilization and control system
SFT	sextant shaft angle
SPA	COAS BSS pitch angle (PAD data)
SPS	service propulsion system
SXP	COAS BSS X-position (PAD data)
SXT	sextant
SXTS	sextant star
T(align)	same as t_L
T_1	latest lift-off time for first stay/no-stay decision
T_2, T_3	lift-off time for the second and third preferred lift-off times, respectively, after touchdown (PAD data)
t_L	time corresponding to landing site REFSMMAT
TRN	sextant trunnion angle
TD	touchdown
TFLO	time from lift-off
TIG	time of ignition
TM	telemetry
TPI	terminal phase initiation
TSTD	time since touchdown
V	verb
vg	velocity to be gained
V_H	PGNCS horizontal velocity at insertion

NOMENCLATURE (Continued)

VI, VT	velocity magnitude
VIO	EMS inertial velocity for entry
WT	CSM weight (PAD data)
XGTA } YGTA } ZGTA }	X-, Y-, Z-gyro torquing angles
α_L	semimajor axis
ΔT	time interval
ΔV	delta velocity
ΔVC	EMS ΔV computer input (PAD data)
ΔVT	total inertial velocity impulse (PAD data)
ΔVX	X-velocity component of external ΔV (PAD data)
ΔVY	Y-velocity component of external ΔV (PAD data)
ΔVZ	Z-velocity component of external ΔV (PAD data)
$\Delta \delta$	AGS azimuth correction
8J	AGS lower limit of insertion orbit semimajor axis
9J	AGS upper limit of insertion orbit semimajor axis

1. INTRODUCTION

The guidance and navigation sequence of events, flow of data, and real-time decisions which must be made during the H-2 (Apollo 13) mission lunar surface phase are presented in this document.

Logic flow diagrams are used to show the recommended procedures in making stay/no-stay decisions and to establish the prime guidance system and alignment mode for lunar ascent. A discussion of the flow chart rationale precedes a timeline and the flows.

The procedures shown in the charts reflect the following key ground rules:

- a) The AGS and PGNCS will be powered down (AGS, LGC and IMU to STANDBY) as soon as necessary systems checks have been performed.
- b) The CSM IMU will be ON during the entire mission.
- c) The detection of a PGNCS or AGS failure does not necessitate a lift-off at the next opportunity.
- d) If the GNCS or SCS fails, it is not necessary to lift-off at the next opportunity.

2. DISCUSSION OF THE FLOW DIAGRAMS

2.1 POSTTOUCHDOWN PHASE

The posttouchdown phase begins when the LM contacts the lunar surface. Touchdown is expected to occur at about 11-3/4 minutes after powered descent initiation (PDI + 11-3/4 minutes).

For mission planning, the LM will not lift off during the time interval from approximately touchdown +9 minutes until approximately touchdown +115 minutes. Precise lift-off times are selected in real time before PDI. Table 1 shows the PAD data onboard the LM at the time of touchdown.

The procedure to make the decision to stay on the moon for at least one CSM revolution consists of two steps:

- a) First stay or no-stay decision - After touchdown, the crew terminates the DPS thrust and monitors the LM attitude and rates, while the flight control personnel perform system checks using TM data. Considering the range of expected LM hover time, there will be 1 to 3 minutes available after touchdown for systems evaluation. The time of launch from the first no-stay decision is any time prior to about PDI +15 minutes (T_1).
- b) Second stay or no-stay decision - A second stay or no-stay decision will be made based on more detailed evaluation of the LM systems. If the decision is no-stay, lift-off will occur at approximately PDI +20-3/4 minutes (T_2).

The latest lift-off time for the first stay/no-stay decision will be obtained from the crew checklist. The second stay/no-stay lift-off time will be provided by MCC-H prior to PDI (Table 1).

Variable insertion targeting will be in effect through T_1 ; the target orbit for the T_1 and T_2 lift-off times will be a 10- by 30-nautical mile orbit. The target orbit for lift-off at the nominal time after the first CSM revolution is a 9- by 45-nautical mile orbit. The primary reason the

lower orbit was chosen for the T_1 and T_2 lift-off times is that it has a faster catch-up rate for rendezvous with the CSM and, thereby, provides an additional 3 minutes on the lunar surface, which is used to evaluate the LM systems and to prepare for lift-off. The lower orbit also reduces the probability of APS propellant depletion which is somewhat more likely in an abort, because the equipment to be left on the lunar surface has not yet been jettisoned (Reference 1). A lunar surface lift-off between touchdown and T_1 uses the nominal rendezvous sequence provided by variable insertion targeting. A lift-off at the T_2 opportunity, however, requires a two-revolution rendezvous sequence. This sequence involves a 10-foot per second perilune raising maneuver near the first apolune passage and a height adjust maneuver one-half period later followed by the nominal CSI/CDH sequence one-half period after that.

2.1.1 First Stay/No-Stay Decision

Immediately at touchdown the Engine Stop button is depressed. After the LM has stabilized on the lunar surface, the CDR monitors the LM attitude indicated on his FDAI* to determine if the vehicle tilt is within the abort limit of 30 degrees (GAEC recommended tilt limit). Then the crew will perform the following operations:

- a) CDR pushes PRO on the DSKY to prevent RCS firings.
- b) PGNCS Mode Control switch is placed in AUTO.
- c) The Descent Engine Command Override switch is set to OFF.
- d) The Engine Arm switch is set to OFF.
- e) Make the DEDA entry 413 + 10000 (Reference 2) which does the following:
 - 1) Stores the AGS landing azimuth for future lunar align
 - 2) Sets the abort electronics assembly (AEA) lunar surface signal

* Another more direct indication of tilt may be obtained by displaying the AGS a_{11} direction cosine (DEDA address 130), which is the cosine of the angle between the X-body axis and the AGS X-inertial axis.

- 3) Inhibits AGS accelerometer calibration
- 4) Enables lunar surface navigation

During the first stay/no-stay period, the LGC is still at a point in P66 (rate of descent) waiting for a keyboard entry. The crew can ABORT STAGE (a procedure which provides launch without any external targeting) at any time during this time interval using the APS abort program P71 (Reference 3).

2.1.2 Second Stay/No-Stay Decision

If the first decision given by MCC-H and crew is stay, the crew will perform the following postlanding operations to prepare for possible lift-off about 5 minutes later (PDI + 20-3/4 minutes) using P12:

- a) Turn LR off.
- b) Make a DEDA entry of 414 + 20000. This loads into the AGS LM state vector locations the targeted landing site which was entered into buffer locations via the DEDA at about PDI -5 minutes.
- 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) which terminates the landing programs and initializes the LGC for lunar surface operation (Reference 3). The LGC performs the following:
 - 1) Zero attitude errors.
 - 2) Terminate average-g integration. The average-g integration during the first 5 minutes after touch-down introduces a small error in the state, but the error is acceptable.

* Steps (b) and (c) provide an independent AGS alignment and an independent AGS state vector compatible with the alignment, so that in the event of a lift-off at T₂ the AGS is capable of a safe insertion even if the PGNCs alignment and state vector are grossly in error.

- 3) Reset abort enable flag for use by the abort discrete monitor routine (R11) and APS (P71) abort program.
- 4) Set the lunar surface and APS flags. The APS flag initiates the transfer of the APS data to the digital autopilot (DAP).
- 5) Store present position vector (\underline{R}_{LS}) in lunar fixed coordinates.
- 6) Display the LGC calculated \underline{R}_{LS} coordinates (latitude, longitude, altitude). These coordinates are recorded by the crew.
- 7) Store the LM Y- and Z- body axes in moon-fixed coordinates after the CDR keys in PROCEED. This step is taken to insure that the data are available in case the IMU is turned off without having been realigned after touchdown.
- 8) Select minimum impulse mode.

The CDR then keys in the Ascent Program, P12, and inputs the desired lift-off time obtained from the pre-PDI PAD data (T_2 in Table 1). After exiting the descent program (P66), immediate lift-off is no longer possible; the crew must use P12 for launch.

Just prior to the second stay/no-stay decision, lunar align is exited by DEDA entry of 400 + 10000 which enables guidance steering. At this time the AGS is configured for lift-off at T_2 if necessary.

Approximately 7 minutes after touchdown, the ground makes the second stay/no-stay decision. For a stay decision the crew exits P12 and remains on the lunar surface for at least one CSM revolution.

2.2 SYSTEMS CHECKOUT PHASE

After the decision has been made to remain on the lunar surface for at least one CSM revolution, the crew prepares to perform AGS and PGNCS systems checks, which include alignments of both systems. The alignment data will be used by the ground to provide an additional estimate of LM position on the moon.

This section is divided into the following four subsections:

- a) Alignments
- b) Drift Checks
- c) State Vector Updates
- d) Determination of \underline{R}_{LS}

2.2.1 Alignments

The PGNCS lunar surface alignments (Table 2) are performed as part of the Lunar Surface Alignment Program (P57). The desired IMU orientation is selected by the LM crew (Reference 3); the orientation options available are given below.

<u>Orientation Options</u>	<u>Desired REFSMMAT</u>
1 (preferred)	A previously uplinked REFSMMAT is used.
3 (REFSMMAT)	The present REFSMMAT is used.
4 (landing site)	A REFSMMAT is computed onboard based on \underline{R}_{LS} , $T(\text{align})$, and the CSM angular momentum vector.

There are four choices of IMU alignment vectors available to the crew while on the lunar surface. These vectors are selected through various alignment techniques in P57 (Reference 4) and are listed below.

<u>Alignment Technique (AT)</u>	<u>Vectors Used for Alignment</u>
0	LM Y- and Z-body axis
1	LM Z-body axis and the measured gravity vector
2	Two AOT vectors
3	AOT vector and the measured gravity vector

When alignment technique 1, 2, or 3 is selected and the REFSMMAT is present (the REFSMMAT flag is set), the LM body axes are updated, and an initial alignment is made with this stored LM attitude data (AT-0). The AT-0 portion of an alignment reorients the platform by an amount equal to the angular difference between the old and desired REFSMMAT's. The final alignment is made with the alignment vectors required by the technique selected. The gyro torquing angles are a measure of the difference between the alignment obtained with AT-0 and the alignment using AT-1, 2, or 3.

During AT-1 or 3 the gravity vector is measured, and the angular difference between the new gravity vector and the previously stored gravity vector is displayed. This angular difference is an accurate measure of vehicle tilt since the previous alignment. During the first gravity alignment, the displayed vector difference is the angle between the vehicle X-axis and the measured gravity vector. The AGS pseudo-gimbal angles are monitored by the ground during a gravity alignment to determine LM tilt during the alignment. Tilt during a gravity alignment will degrade the alignment accuracy, and thus will require a realignment.

The alignment of the IMU must be accurate in the pitch axis, since misalignments in that direction reflect directly into flight-path angle errors at insertion which degrade the rendezvous and, if sufficiently large, could result in an impacting insertion orbit. An accurate IMU alignment with respect to a local vertical coordinate system will allow a correct flight-path angle at insertion, even if LM position (\underline{R}_{LS}) errors cause the alignment to be inaccurate with respect to the basic reference coordinate system (BRCS). A gravity alignment (AT-1 or 3) for lift-off will orient the IMU accurately with respect to the vertical, regardless of \underline{R}_{LS} errors (assuming gravity anomalies are small). However, the misalignment with respect to the BRCS would degrade the navigation accuracy during rendezvous if not corrected. (Present plans allow for an AOT IMU alignment (P52) approximately 5 minutes after insertion.) It is believed that the local gravity vectors can be measured more accurately than star vectors, so an AT-3 is recommended for planned lift-off.

Approximately 20 minutes after touchdown, the crew enters P57 and selects AT-1, option 3. The crew will exit the program following the gravity direction measurement before enabling the displayed gyro torquing angles. The gravity vector is stored in the LGC in LM body coordinates.

Approximately 30 minutes after touchdown, the crew enters P57 once again and selects AT-2, option 3. After the IMU is aligned to the pre-PDI REFSMMAT, the crew requests the LGC to calculate the landing site vector, \underline{R}_{LS} . The \underline{R}_{LS} is calculated from the gravity vector measured in AT-1 (Reference 3) and it is displayed to the crew; MCC-H then determines if the displayed values should replace the \underline{R}_{LS} presently stored in the LGC. After the above is completed, P57 is reentered and an AT-2, option 3 is performed to provide additional star data for the off-line RTCC weighted least squares \underline{R}_{LS} processor of Reference 5, which is discussed in Section 2.2.4.

After completion of the second P57 AT-2, the AGS is aligned to the PGNCS and the two systems remain inertial until they are powered down. Immediately following the AGS to PGNCS align^{*}, the improved AGS azimuth is stored (DEDA entry of 413 + 10000) and the crew reads the new AGS azimuth data (DEDA addresses 047 and 053) to MCC-H.

In the event that only one celestial body (star, planet, sun, earth^{**}) is visible through the AOT, the sequence of IMU alignment techniques during the systems checkout phase will be 1-3. In this case, an AOT vector is suitable if it is separated by at least 20 degrees from the gravity vector (Reference 3, Routine 59). For the 20-degree separation case, the alignment accuracy in azimuth will be degraded by a factor of approximately 2.5 from the ideal, or 90-degree vector separation case (Reference 6). The pitch axis alignment will not be degraded by small vector separation. If no suitable celestial bodies are available, the AT sequence for systems checkout is 1-1. The alignment sequence with degraded AOT capability is summarized in Table 3.

* Each AGS to PGNCS align will be preceded by a CDU zero (V40N20) to reduce the probability of a CDU transient spoiling the alignment.

** The LGC earth vector may be in error by as much as 1.4 degrees. The ground must supply earth vector data which will be entered with planet code 00.

The CSM is fine aligned to the pre-PDI REFSMMAT in preparation for sextant sightings on the LM. The gyro torquing angles are a measure of gyro drift from the previous alignment. This alignment will be used for rendezvous if lift-off at T_3 is required.

2.2.2 Drift Checks

A LM IMU drift test, using gyro torquing angle data, is performed because the ground cannot distinguish between platform drift and LM settling rates by observing the PGNCS gimbal angles. Furthermore, a drift test provides data to check the status of the AGS. If PGNCS is marginal, the drift test data can be used to select the best system (PGNCS or AGS) for lift-off.

The P57 AT-2 option 3 alignment performed shortly after landing is used to determine IMU drift. The AT-2 gyro torquing angles will be a measure of the drift since the last pre-PDI alignment at about PDI - 85 minutes.

The AGS gyros are calibrated using the Lunar Surface Gyro Calibration Routine (DEDA entry 400 + 60000) at about 15 minutes after touchdown. The gyro bias coefficients are updated automatically in the routine and both the old and new values are displayed to the crew. If the indicated drift is greater than 2.0 degrees per hour then the gyro has failed. The relative drift between the AGS and PGNCS is monitored after the AGS to PGNCS align which follows the second AT-2 alignment.

2.2.3 State Vector Updates

For the first 1-1/2 hours after touchdown, the CSM state vector in the CMC will be the one obtained from MSFN on the pass prior to PDI (time tagged at PDI - 10 minutes). The next CSM state vector is determined using the PDI pass data and is uplinked to the CMC 1-1/2 hours after LM touchdown (time tagged at touchdown + 1 hour 40 minutes) (Figure 1). The LM position vector (\underline{R}_{LS}) is also updated in the CMC at this time. These vectors are used for sextant tracking or for rendezvous if lift-off is necessary after one CSM revolution. The lunar surface flag in the CMC will have been set by a V44 entry at about TD + 10 minutes.

The LM state vector in the LGC at touchdown will be the navigated state through powered descent. It will be in error by at least the descent targeting offsets. In the event of loss of communication, the crew can set the radius of the landing site equal to the pre-PDI estimate by inputting via the DSKY the $\Delta |R_{LS}|$ from the pre-PDI pad (Table 1).

A value for R_{LS} will be computed in the LGC following each of the AT-2 alignments. MCC-H will make the recommendation on the acceptance of the new R_{LS} values for storage in the LGC.

Approximately 1 hour after touchdown the ground will select a best estimate of R_{LS} and uplink this value to the LGC with an updated CSM state vector (time tagged at touchdown + 1 hour 40 minutes). A discussion of the ground determination of R_{LS} follows in Section 2.2.4.

2.2.4 Determination of R_{LS}

It is planned that several data sources for R_{LS} determination will be available on the ground prior to the uplinking of the best value at approximately touchdown + 1 hour. The sources and their estimated three-sigma accuracies are as follows:

<u>R_{LS} Source</u>	Estimated Three-Sigma Accuracy		
	ϕ (Latitude) (ft)	λ (Longitude) (ft)	R(Radius) (ft)
Adjusted PGNCS navigated state vector	4,800	2,300	-
Adjusted AGS navigated state vector	*	*	-
Adjusted PFP state vector at TD	4,500	1,500	1,500
Map + crew survey**	6,000 (9,000)***	1,500 (9,000)***	1,500 (13,500)***
AOT + PGNCS gravity	13,500	13,500	-
AOT + AGS gravity	18,000	18,000	-

* AGS accuracy is believed to be slightly less than PGNCS

** Crew estimation errors are not included

*** Not well surveyed site (H-2 mission site is well surveyed)

Methods Using AOT and Gravity Vector (Longitude and Latitude only)

This \underline{R}_{LS} determination method (Reference 7) uses the gravity vector in body coordinates, the PGNCS gimbal angles, and the REFSMMAT used with the AT-2 alignment. A similar computation has previously been performed onboard (during P57, AT-2). An analogous technique can be used with the AGS gravity in body coordinates to give another estimate of LM position. Both of these methods are independent of the CSM trajectory.

Method Using Map and Crew Survey Data

This method uses the crew estimate of their position (longitude and latitude) obtained by locating prominent terrain features on their map during powered descent. These data will be voiced to the ground. The crew will also tell the ground how confident they are of this estimate. The pre-PDI SXT data may be used by the ground to improve the accuracy of map longitude and latitude.

Methods Using PGNCS, AGS, and PFP* State Vectors

In these methods, a correction is applied to the three touchdown state vectors to remove initial state vector position errors at PDI. The best estimate of the PDI position will not be known until after PDI and, therefore, cannot be used to initialize the three systems for descent. For these three methods, the three components of \underline{R}_{LS} will be computed by the FDO from the vector equation:

$$(\underline{R})_i = (\underline{R}_{PDI})_{best} + [(\underline{R}_{TD})_i - (\underline{R}_{PDI})_i]$$

*The PFP 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.

where:

i = One of the following data sources:

- a) PFP (LM powered flight tracking data processor)
- b) PGNCS
- c) AGS

$(\underline{R})_i$ = Source i's best estimate of \underline{R}_{LS} (in selenographic coordinates); this estimate will be available after the second stay/no-stay decision and before TD + 1:00 (hr:min).

$(\underline{R}_{PDI})_{best}$ = Best estimate of LM position in selenographic coordinates at time of PDI based on MSFN pre-PDI data which are processed after TD. This estimate uses the data from AOS to PDI for inplane information while constraining the LM plane to the "best" plane available determined by Data Select.

$(\underline{R}_{TD})_i$ = Source i's value of \underline{R}_{LS} at time of TD obtained as hard copy of RTCC on-line output and pneumatically tubed to FDO.

$(\underline{R}_{PDI})_i$ = Source i's estimate of LM position (in selenographic coordinates) at time of PDI. These three vectors as well as $(\underline{R}_{PDI})_{best}$ will be made available to FDO on the vector comparison display.

The choice of the best estimate for \underline{R}_{LS} at touchdown + 1 hour will be a real-time decision based on the data which were processed and the confidence in its accuracy. This best value of \underline{R}_{LS} will be uplinked to the LGC (if different from onboard value) and will be used as the LM lift-off vector if necessary at T_3 .

Prior to the first CSM pass over the landing site following LM touchdown, the CMP will orient the SC for sextant acquisition, select the Landmark Tracking Program (P22), and track on a predetermined landmark. At least 25 seconds (Reference 8) should be allowed between each of the sighting marks. The LM will concurrently track the CSM with the RR. The SXT and RR data will be processed in the RTCC program LSD, which will yield moon-fixed latitude, longitude, and radius components

for the landmark and LM, respectively. The a priori position of the landmark is assumed to be well known; therefore, the difference between the a priori value and the sextant value is assumed to be directly attributable to the CSM state vector uncertainty. The RR estimate of the LM position will be corrected by this difference to yield another estimate of \underline{R}_{LS} . In addition, the AT-2 star sighting data and PGNCS measured gravity vectors will be processed in the RTCC off-line weighted least squares processor (Reference 5) to provide an \underline{R}_{LS} estimate which is independent of the CSM orbit plane uncertainty and more accurate than the LGC AOT + g program which uses only two star sightings. Prior to ascent these estimates and the others will be compared and a best estimate of \underline{R}_{LS} will be chosen and uplinked to the LGC before lift-off.

2.3 CSM PLANE CHANGE

Since the CSM orbit will be inclined 5.3 degrees to the lunar equator, the CSM must perform a plane change so that its orbit will pass over the LM at lift-off time. The plane change will require an SPS burn of about 184 feet per second; the LM will yaw steer out any remaining errors during ascent.

On the revolution before the plane change burn (revolution 18), the ground will uplink its best estimate of \underline{R}_{LS} , the CSM ephemeris data and the preferred REFSMMAT, and voice up the maneuver PAD. The CSM will then perform an IMU alignment (P52, option 1) which is checked using auto-optics to a third star.

Prior to the plane change on revolution 19, P30 and P40 are executed. The CMP monitors the CSM auto maneuver to the burn attitude and adjusts the outer gimbal angle to the P30 maneuver PAD value (Table 4). The auto optics is used to drive the sextant to the sextant star (PAD data). The trunnion angle must indicate the PAD value within 1 degree in order to proceed with the GNCS in control. If this 1-degree optics check is failed, the burn is executed later with the SCS if the GNCS problem cannot be resolved. The CMP has the option to use the boresight star and the COAS to verify the SC attitude.

After the ignition attitude is verified, the GDC is aligned to 0-0-0. The BMAG's 1 are then uncaged. The CMP will monitor these attitude references to determine if the CSM is drifting while under GNCS control. The SC is drifting if both the SCS attitude references indicate a drift greater than their respective three-sigma limits in any axis (SCS/GDC - 10 degrees per hour; BMAG's 1 - 1.7 degrees per hour).

After the SPS thrust is terminated, the residuals are not trimmed. Although this is the first SPS burn in the undocked configuration, the expected residuals are not large enough to significantly affect the ascent and rendezvous. Prior to loss of signal (LOS) of revolution 19, the ground uplinks the lift-off REFSMMAT to the CSM, and the CMP pulse torques the IMU to the uplinked REFSMMAT.

2.4 PRELAUNCH PHASE*

2.4.1 CSM Activities

Approximately 4 hours before lift-off, the CSM pilot begins preparations for ascent (Figure 2). The G&N activities are started at this time to allow the CMP time to perform an IMU alignment to the lift-off REFSMMAT and perform sextant sightings on a landmark. The P52 alignment is performed to the lift-off REFSMMAT about 3 hours 40 minutes before lift-off. The CSM and LM perform concurrent P22 sextant and RR tracking, respectively, at about 2 hours 5 minutes prior to lift-off; the CSM will track a predetermined landmark, and the LM will track the CSM. The optical data are nominally used only for postflight analysis. MSFN data are used to target the LM for yaw steering into the CSM orbit plane.

The CSM lunar surface flag reset, the CSM state vector, and the nominal LM insertion vector (time tagged at insertion + 18 minutes) are uplinked to the CMC prior to LOS on the last revolution before lift-off (revolution 30).

* In the event of a premature lift-off at some preferred lift-off time (T_N) between T_3 and the nominal lift-off time, the nominal ascent preparation procedures will be followed.

The CSM will attempt to track the LM with the SXT on the LM lift-off revolution. At about LO -30 minutes the CSM will maneuver to an inertial attitude ($R = 0$ degrees, $P = 301$ degrees, $Y = 0$ degrees). P22 will be entered, and the CMP will track the LM in the ORB RATE mode until the SXT trunnion angle equals about 22 degrees, at which time the CMP will select minimum impulse control and attempt to null the LM line-of-sight rates.

2.4.2 LM Activities

At approximately 3 hours before lift-off, the LM crew starts preparing for lift-off. The AGS and PGNCS are powered up, the CSM state vector and R_{LS} are updated in the LGC, and systems tests are performed. The RR system is turned on, and the radar self-test is performed. The IMU is aligned using P57, AT-3, and option 4 for RR tracking of the CSM on the last CSM pass prior to lift-off. The AGS is then aligned to PGNCS, the AGS gyro calibration is performed, and AGS is realigned to PGNCS. The AGS azimuth is stored and voiced to the ground. The AGS and PGNCS remain inertial until the final P57 alignment.

The CDR selects the Lunar Surface Navigation Program (P22 in Mode II) to obtain data for postflight analysis. This program controls the rendezvous radar, auto acquisition, and downlinks the IMU gimbal angles, the shaft and trunnion angles, and the range and range rate data. During this tracking period, the program is in the no-update mode to increase the frequency that the data are telemetered to the ground. The RR data consist of the following:

- Shaft and trunnion angles
- LM IMU gimbal angles associated with the observations
- Range and doppler observations
- Observation times

The RR is turned off following the P22 tracking, and remains off during ascent.

The AGS time is initialized (K = 130 hours), and an AGS state vector update is performed (V47 and 414 + 10000).

At about 1-1/2 hours before lift-off, MCC-H voices up the ascent PAD (Table 5), and the AGS ascent parameters are loaded and verified.

In preparation for lift-off the IMU is realigned to the lift-off REFSMMAT using P57 AT-3 at lift-off -45 minutes. The drift check data which have been gathered from the PGNCS and AGS realignments will be used by the crew and ground to select the best system for lift-off.

If LM communications with the ground fail (considered an unlikely event), the LM crew can compute lift-off time using the time (g. e. t.) of CSM closest approach and certain PAD data. The time of closest approach is determined by noting the time when RR range rate goes to zero during a CSM overpass. Lift-off time is determined by the following:

$$\text{lift-off (g. e. t.)} = t_1 \text{ (g. e. t.)} + \text{NAAF}^*$$

The time of CSM closest approach, one revolution prior to lift-off, is t_1 . NAAF is the CSM orbital period plus the nominal time interval from the time the CSM passes over the LM until the desired lift-off time.

The RTCC has the backup capability to estimate LM azimuth using RR shaft and trunnion data (Reference 9). These data and gravity can be used to determine an actual REFSMMAT for the IMU. By uplinking this actual REFSMMAT, the IMU can be realigned to the LGC calculated desired REFSMMAT for lift-off by using AT-0 or 1 of P57. This method of alignment could become prime should optical data (AOT) not be available and the LGC stored azimuth be questionable. Without optical data, this RTCC processor provides the only method for determining a direct measure of IMU azimuth. An alternative is to use AT-1 of P57 with the REFSMMAT flag unset. This would mean that the final alignment would have an azimuth error (probably small) equal to the IMU misalignment at the time the LM body vectors were stored.

After the completion of the final IMU alignment, the AGS will be aligned to the PGNCS, and the new azimuth will be stored for use in the

* NAAF is known by the LM crew prior to LM descent (PAD data - Table 1).

following AGS lunar align. The ground has the option to request that the ascent PAD values be used for the azimuth in the lunar align if the AGS to PGNCS align appears to be in error.

The crew will then enter the Ascent Program (P12) and input the PGNCS targeting parameters (V_H , $Rdot$, CROSSRANGE) from the crew checklist and the ascent PAD.

About 30 minutes before lift-off the crew will enter 400 + 40000 in the DEDA (AGS Lunar Align). At TIG -10 minutes the AGS state vectors will be initialized from the PGNCS downlink (DEDA 414 + 10000 and DSKY V47) and at TIG -2 minutes AGS guidance steering will be entered (DEDA entry 400 + 10000). At TIG -10 seconds the ABORT STAGE button will be pressed to enable the LGC redundant engine on circuitry and staging.

Table 1. LM Pad Data at Touchdown (Pre-PDI)

TPI_0 (hr:min:sec)	g. e. t. of TPI time for abort from powered descent
T_2 (hr:min:sec)	g. e. t. of the preferred lift-off time for second stay/no-stay decision after touchdown (\approx touchdown +9 minutes)
T_3 (hr:min:sec)	g. e. t. of lift-off time after the first CSM revolution
P (hr:min:sec)	CSM period (used for backup lift-off time and TPI times)
NAAF (hr:min:sec)	CSM orbital period plus the nominal time interval from the time the CSM passes over the LM until the desired lift-off time
$\Delta R_{LS} $ (n mi)	Correction to the landing site radius (PGNCS)
$ R_{LS} $ (ft)	Landing site radius (AGS)

Table 2. Summary of Nominal P57 Alignments

-
- Alignment Technique 1, Option 3 (TD + 20 min)
 - a) Objective is to measure gravity vector.
 - b) Gyro torquing angles are displayed to crew, but torquing is not enabled.
 - c) Gravity error angle displayed in V06N04 indicates tilt of the LM.
 - Alignment Technique 2, Option 3 (TD + 30 min)
 - a) Gyro torquing angles displayed in V06N93 indicate drift since pre-PDI alignment.
 - b) R_{LS} is calculated using the gravity vector measured in AT-1.
 - c) The above alignment is repeated to provide data for ground determination of R_{LS} .
 - Alignment Technique 3, Option 4 (T(Align) = TIG) (LO - 2 hr 30 min)
 - a) This alignment is done in preparation for use of RR in P22.
 - b) The gravity error angle displayed in V06N04 is a good check on LM tilt resulting from settling since the AT-1.
 - Alignment Technique 3, Option 4 (T(align) = TIG) (LO - 45 min)
 - a) This is the lift-off alignment.
 - b) The gyro torquing angles displayed in V06N93 are a gross drift check since the previous AT-3 alignment.
-

Table 3. Alignment Sequence with Degraded AOT Visibility

<u>AOT Capability</u>	<u>Systems Checkout</u>	<u>Actual Countdown</u>
Two celestial bodies available	1-2-2	3-3
One celestial body available	1-3	3-3
No celestial body available	1-1	1-1

Table 4. P30 Maneuver PAD

P30 MANEUVER									
					PURPOSE				
SET STARS					PROP/GUID				
					/				
+							WT N47		
R	ALIGN	—	—	—	0	0	.	P _{TRIM} N48	
P	ALIGN	—	—	—	0	0	.	Y _{TRIM}	
Y	ALIGN	—	—	—	+	0	0	HRS GETI	
					+	0	0	0	MIN N33
					+	0		.	SEC
ULLAGE								.	ΔV_X N81
								.	ΔV_Y
								.	ΔV_Z
					X	X	X		R
					X	X	X		P
					X	X	X		Y
					+			.	H _A N44
								.	H _P
					+			.	ΔVT
HORIZON/WINDOW					X	X	X	.	BT
					X			.	ΔVC
					X	X	X	X	SXTS
					+			.	0 SFT
					+		.	0 0	TRN
					X	X	X		BSS
					X	X		.	SPA
					X	X	X	.	SXP
OTHER						0		.	LAT N61
								.	LONG
					+			.	RTGO EMS
					+			.	V10
						.	.	.	GET 0.05G

Table 4. P30 Maneuver PAD (Continued)

Notes

- PURPOSE is the name of the maneuver
- PROP/GUID is propulsion and guidance selected
- WT is the CSM weight (lb)
- P_{TRIM} and Y_{TRIM} are respectively the pitch and yaw trim SPS gimbal angles (deg)
- GETI is the time of ignition
- ΔV_x , ΔV_y , ΔV_z are the P30 velocity to the gained components in local vertical coordinates (fps)
- R, P, Y are the IMU gimbal angles at the time of ignition for the maneuver (deg)
- H_A , H_p are the altitude of apogee and perigee, respectively above launch pad radius (n mi)
- ΔVT is the total inertial velocity impulse (fps)
- BT is the burn time (min:sec)
- ΔVC is the EMS ΔV counter input
- SET stars are for backup GDC align
- R_{ALIGN} , P_{ALIGN} , Y_{ALIGN} are the backup GDC or IMU alignment angles
- SXTS is the sextant star to be used for the SC ignition attitude check.
- SFT is the sextant shaft angle for the SXTS (deg).
- TRN is the sextant trunnion angle for the SXTS (deg).
- BSS is the boresight star for an ignition attitude check using the COAS (as required).
- SPA is the BSS pitch angle (COAS) (as required) (deg).
- SXP is the BSS X position (COAS) (as required) (deg).
- LAT and LONG are, respectively, the latitude and longitude of the resultant landing point following the abort maneuver (deg).
- RTGO is the range to go for the entry maneuver (EMS) (n mi).
- VIO is the EMS inertial velocity for the entry maneuver (fps).
- GET .05 g is the estimated ground elapsed time to the 0.05 g level of acceleration for the entry maneuver (hr:min:sec).

The last five items of the maneuver PAD are essentially an abbreviated entry PAD.

Table 5. PAD Data for LM Ascent

LGC

1. TIG (hr:min:sec) _____
2. V_H (ft per sec) _____
3. CROSSRANGE _____ LOAD 8 MILES IF CROSSRANGE
 > 8 nautical miles
4. R _____
5. P _____ FDAI Reading at TIG (deg)
6. Y _____
7. TIG (CSI) _____ (hr:min:sec)
8. TIG (TPI) _____ (hr:min:sec)

DEDA

9. 047_____ (octal) (as required)
10. 053_____ (octal) (as required)
11. 225 and 226 (ft)

Definitions

- | | |
|--------------|--------------------------------------------------------------------------------------------------------------------|
| TIG | - Time of ignition for ascent |
| V_H | - LM horizontal velocity at insertion |
| Crossrange | - The distance between the LM orbital plane after ascent injection and the LM position vector on the lunar surface |
| P
Y
R | - Pitch, yaw, and roll on the FDAI |
| TIG (CSI) | - Time of ignition for CSI |
| TIG (TPI) | - Time of ignition for TPI |
| 047 + XXXXXX | - (sin of AGS azimuth for lift-off) |
| 053 + XXXXXX | - (cos of AGS azimuth for lift-off) |
| 225 + XXXXXX | - AGS lower limit of α_L |
| 226 + XXXXXX | - AGS upper limit of α_L |

Table 6. Abbreviated Timeline of the Lunar Stay G&N Activities

<u>CSM</u>	<u>LM</u>
Time (hr:min)	Time (hr:min)
POSTTOUCHDOWN PHASE	POSTTOUCHDOWN PHASE
Touchdown = 0:00	Touchdown = 0:00
	Depress Engine Stop button
	Monitor FDAI for tilt over abort
	Push PRO on the DSKY to prevent RCS firings
	Mode Cont (PGNCS) - AUTO
	Descent Engine Command Override - OFF
	Engine Arm - OFF
	Enter 413 + 10000 on DEDA for AGS lunar surface confirmation
	First stay/no-stay decision
	0:03.5 T ₁
	Turn LR off
	Load AGS LM state vector (414 + 20000)
	Enter AGS Lunar Align (400 + 40000)

Table 6. Abbreviated Timeline of the Lunar Stay G&N Activities (Continued)

<u>CSM</u>		<u>LM</u>	
Time (hr:min)		Time (hr:min)	
			Select P68, Lunar Surface Confirmation Program
			Select P12, input lift-off time from pre-PDI pad
		0:07	Exit AGS Lunar Align and enable guidance steering (400 + 10000)
			Second stay/no-stay decision (for one CSM revolution)
0:10	Set CMC lunar surface flag (V44)	0:09	T ₂
			Mode Cont (AGS) - OFF
			Mode Cont (PGNCS) - ATTITUDE HOLD
0:15	Select P52-IMU realign to pre-PDI REFSMMAT	0:15	Perform AGS Lunar Surface Gyro Calibration (400 + 60000)
			Set AGS insertion altitude rate to 32 feet per second (address 465)

Table 6. Abbreviated Timeline of the Lunar Stay G&N Activities (Continued)

<u>CSM</u>	<u>LM</u>
Time (hr:min)	Time (hr:min)
	0:20
	Select P57, AT-1, option 3 - gravity measurement with no gyro torquing
	Crew survey estimate of \underline{R}_{LS} voiced to ground
	0:30
	Select P57, AT-2, option 3 - align IMU to pre-PDI RESFMMAT using two celestial bodies. Compute updated \underline{R}_{LS} . Repeat the above.
	1:00
	Align AGS to PGNCS (400 + 30000)
	Store the updated AGS azimuth (413 + 10000)
	Readout AGS azimuth (address 047 and 053) to the ground
	Enter AGS insertion targeting (225 and 226 for 9 x 45 insertion orbit)
	Receive uplinked \underline{R}_{LS} (if different from onboard) and CSM state vector (TD + 1:40)

Table 6. Abbreviated Timeline of the Lunar Stay G&N Activities (Continued)

<u>CSM</u>		<u>LM</u>	
Time (hr:min)		Time (hr:min)	
1:20	Confirm stay/no-stay for nominal lunar stay Receive LM <u>R_{LS}</u> and CSM state vector (TD + 1:40)	1:20	Confirm stay/no-stay for lunar stay. Receive recommendation of best guidance system for launch
1:45	Select P22 - SXT tracking of landmark	1:45	Select P22 - RR tracking of CSM
		2:00	Power down the RR. AGS, LGC, and IMU to STANDBY

Table 6. Abbreviated Timeline of the Lunar Stay G&N Activities (Continued)

Time (hr:min)	<u>CSM</u>	Time (hr:min)	<u>LM</u>
	LUNAR STAY PHASE		LUNAR STAY PHASE
7:30	Receive uplinked CSM state vector and REFSMMAT for plane change. Also receive P30 data and maneuver PAD update.		(Periodically update the CSM state vector in the LGC during the lunar stay. This state vector is time tag biased so that it will be correct at the nominal lift-off time)
8:00	Select P52 - IMU align to preferred REFSMMAT		
9:20	Perform plane change burn* (Revolution 19)		
10:00	Receive lift-off REFSMMAT, pulse torque to lift-off REFSMMAT		

* If GNCS fails, perform plane change with SCS on a later revolution.

Table 6. Abbreviated Timeline of the Lunar Stay G&N Activities (Continued)

Time From Lift-off (hr:min)	<u>CSM</u>	Time From Lift-off (hr:min)	<u>LM</u>
	PRELAUNCH PHASE		PRELAUNCH PHASE
-3:40	Select P52 - IMU align to REFSMMAT uplinked after plane change		
		-2:55	Power up the AGS and PGNCS
			Receive uplinked CSM state vector (LO) and \underline{R}_{LS}
			Perform RR self test (V63)
		-2:30	Select P57, AT-3 option 4 - align IMU to landing site REFSMMAT (T(align) = TIG)
			Align AGS to PGNCS after completion of P57 (400 + 30000)
			Perform AGS gyro calibra- tion (400 + 60000)
			Align AGS to PGNCS (400 + 30000)
			Store AGS azimuth (413 + 10000)
			Read azimuth data (047 and 053) to the ground

Table 6. Abbreviated Timeline of the Lunar Stay G&N Activities (Continued)

Time From Lift-off (hr:min)	<u>CSM</u>	Time From Lift-off (hr:min)	<u>LM</u>
-2:05	Select P22 - SXT tracking of LMK	-2:05	Select P22 - Lunar Surface Navigation Program, track CSM in no update mode. Turn RR off
-1:40	Receive P27 update - lunar surface flag reset, CSM state vector (LO) and nominal LM insertion vector (time tag is insertion +18 min)		Initialize AEA time bias and perform CDU zero with AGS state vector update (V47 and 414 + 10000)
-1:30	Select P52-IMU realign to REFSMMAT	-1:30	Receive ascent PAD Load AGS ascent PAD values Verify AGS ascent parameters

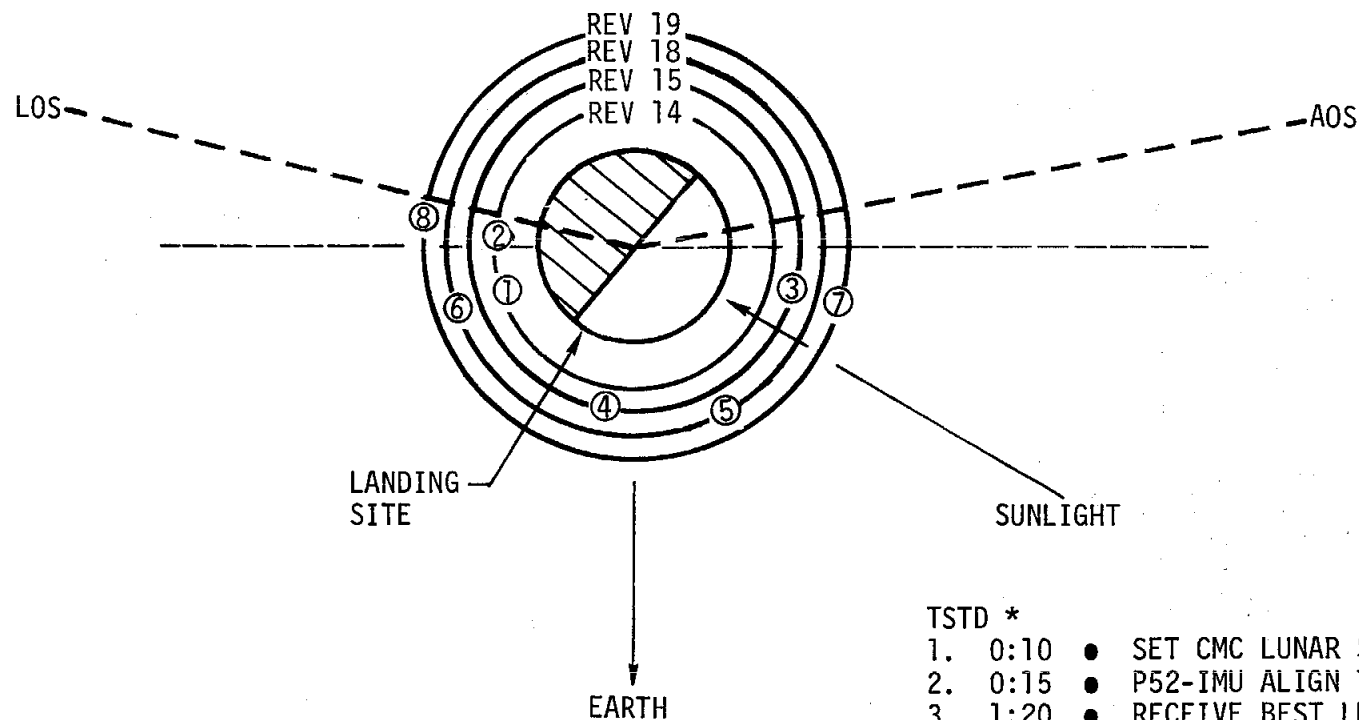
Table 6. Abbreviated Timeline of the Lunar Stay G&N Activities (Continued)

<u>CSM</u>		<u>LM</u>	
Time from Lift-off (hr:min)		Time from Lift-off (hr:min)	
		-0:45	Select P57, AT-3, option 4 - align IMU to t(align) REFSMMAT at TIG Align AGS to PGNCS (400 + 30000) Store updated AGS azimuth (413 + 10000) Read AGS azimuth (047 and 053) to MCC-H Receive LGC gyro compen- sation (if necessary)
-0:20	Maneuver to preliminary tracking attitude (R = 0 degrees, P = 301 degrees, Y = 0 degrees)	-0:30	Enter AGS lunar align (400 + 40000) Select P12 - load PGNCS ascent targeting parameters
-0:10	Select P22 and ORB RATE attitude control in preparation for SXT tracking of the LM	-0:10	Initialize AGS state vectors from PGNCS downlink (DEDA 414 + 10000 and DSKY V47)

Table 6. Abbreviated Timeline of the Lunar Stay G&N Activities (Continued)

<u>CSM</u>		<u>LM</u>
Time from Lift-off (hr:min)	Time from Lift-off (hr:min)	
	-0:02	Exit lunar align and enter AGS guidance steering (400 + 10000)
	-10 sec	Arm [*] ascent engine and press Abort Stage button at TIG -10 seconds to enable LGC redundant engine on circuitry and staging.

* If AGS is used for lift-off, verify Guidance Control switch in the AGS position and the AGS Mode Control switch is in AUTO. Verify that Engine Stop button is not depressed, and then depress the Abort Stage button at TIG.

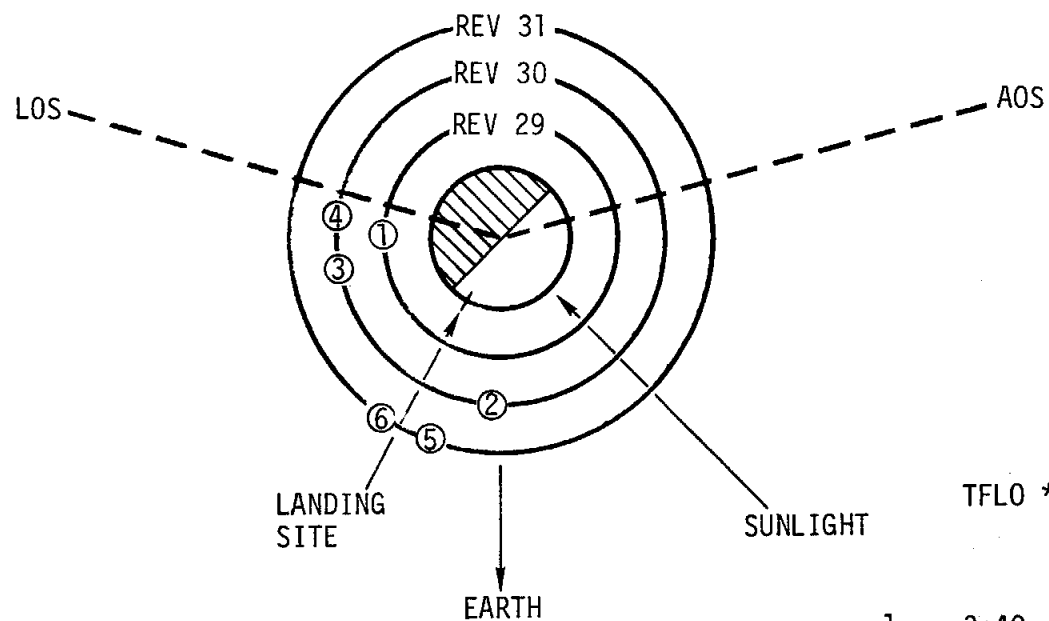


TSTD *

1. 0:10 ● SET CMC LUNAR SURFACE FLAG (V44)
2. 0:15 ● P52-IMU ALIGN TO PRE-PDI REFSMMAT
3. 1:20 ● RECEIVE BEST LM R_{LS}
● CSM STATE VECTOR (TD + 1:40)
4. 1:45 ● SELECT P22, PERFORM SXT SIGHTINGS ON LANDMARK
5. 7:30 ● RECEIVE UPLINKED CSM STATE VECTOR AND REFSMMAT FOR PLANE CHANGE. ALSO RECEIVE PAD DATA.
6. 8:00 ● SELECT P52, IMU ALIGN TO PREFERRED REFSMMAT
7. 9:20 ● PERFORM PLANE CHANGE BURN
8. 10:00 ● RECEIVE LIFT-OFF REFSMMAT
● PULSE TORQUE TO LIFT-OFF REFSMMAT

* TSTD IS TIME SINCE TOUCHDOWN (HR:MIN)

Figure 1. CSM Activities on Touchdown Day



- TFLO *
1. -3:40 • SELECT P52, IMU ALIGN TO LIFTOFF REFSMMAT (THE REFSMMAT UPLINKED AFTER THE PLANE CHANGE)
 2. -2:05 • SELECT P22, PERFORM LMK SXT SIGHTINGS (LM TRACKS WITH RR)
 3. -1:40 • RECEIVE P27 UPLINK - LM INSERTION VECTOR, CSM STATE VECTOR, LUNAR SURFACE FLAG RESET
 4. -1:30 • IMU REALIGN TO REFSMMAT
 5. -0:06 • P22 SXT TRACKING OF LM
 6. 0:00 • LIFT-OFF

* TFLO IS TIME FROM LIFT-OFF (HR:MIN)

Figure 2. CSM Activities on Lift-off Day

HR:MIN
SINCE TOUCHDOWN

CDR

LMP

MCC-H

OMP

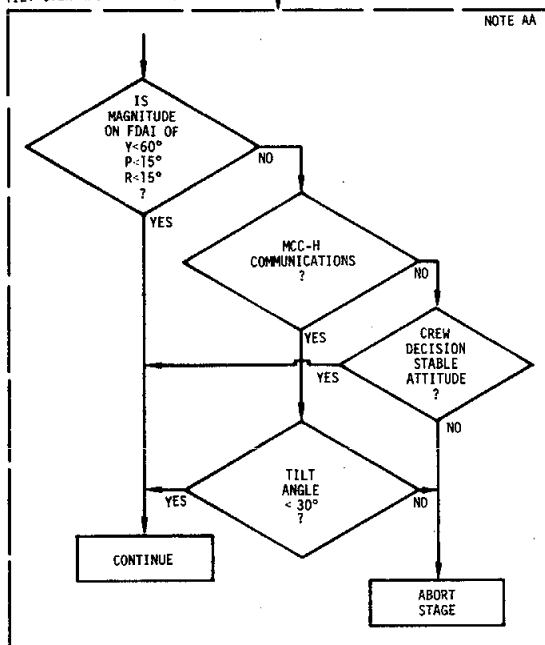
HR:MIN
SINCE TOUCHDOWN

0:00
(PDI+11-3/4 MIN)
POSTTOUCHDOWN PHASE

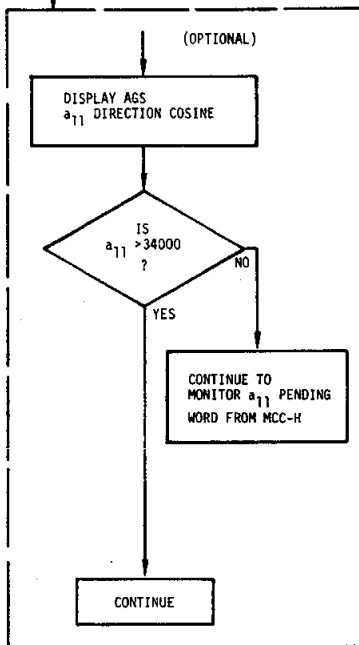
3:00
(PDI+11-3/4 MIN)

TILT OVER ABORT DECISION

NOTE AA



(OPTIONAL)

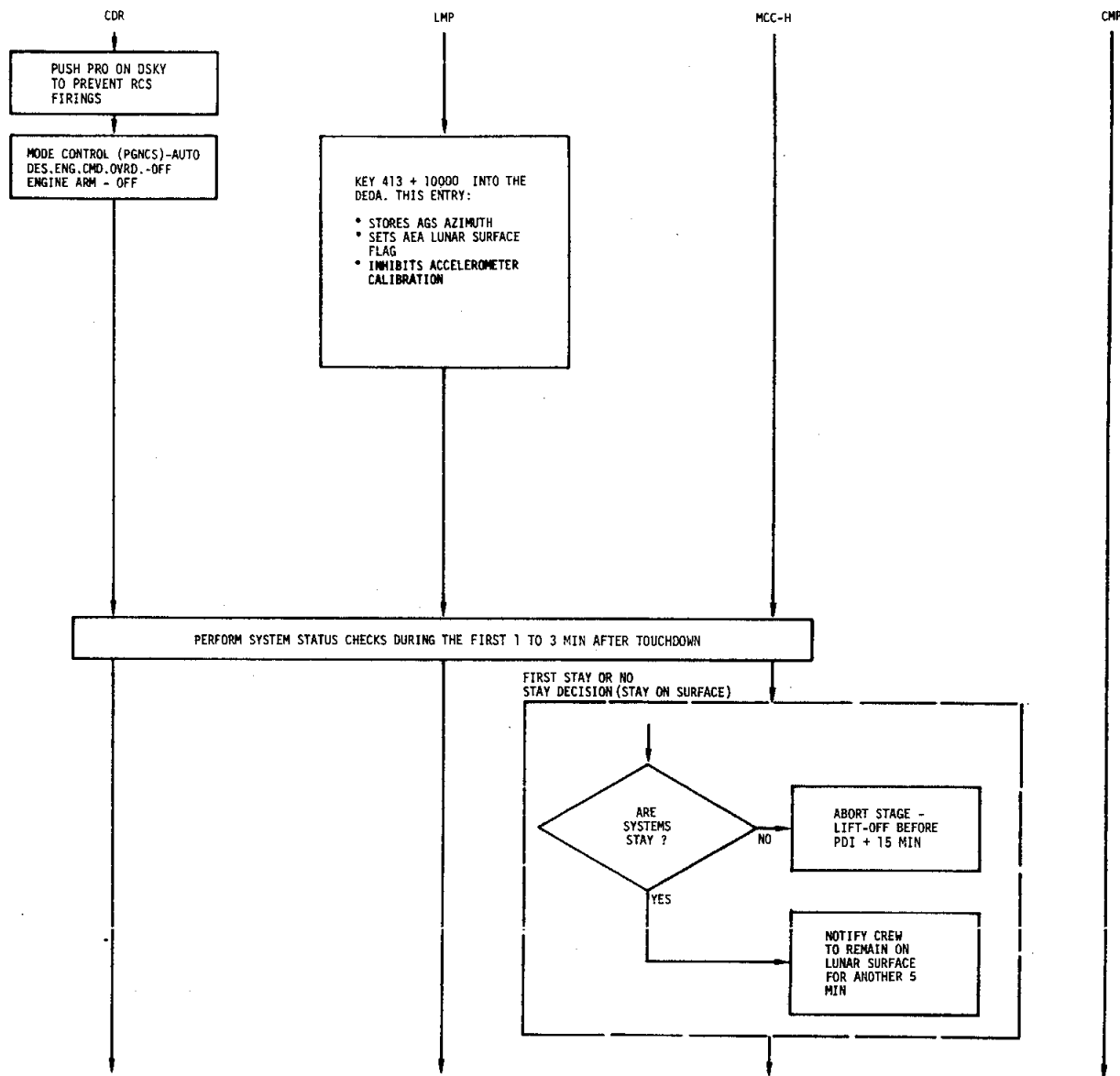


NOTE AA

- CURRENT VALUE BASED ON TILT OVER LIMIT
- RESPONSIBILITY: GAEC
- DATE AVAILABLE: 24 JUNE 1969
- REFERENCE: 10

MONITOR PGNC'S
GIMBAL ANGLES
AND AGS DIRECTION
COSINES (COARSE
EVALUATION OF
PGNC'S FOR "GLITCHES")

LM STABLE ON LUNAR SURFACE



FIRST DECISION IS TO STAY (UNTIL
PDI + 20-3/4 MIN)

LMP

MCC-H

CMP

0:05

0:05

STAY - CREW PERFORMS POSTLANDING CHECKLIST
• TURN OFF LR

KEY IN P68 TO:
•END AVERAGE G
•END ABORT MONITOR
•SET LUNAR SURFACE
FLAG AND APS FLAG
•DISPLAY LATITUDE
LONGITUDE, ALTITUDE
•STORE LM ATTITUDE
•STORE RLS IN MOON-
FIXED COORDINATES
•SELECT MIN IMPULSE
•ZERO ATTITUDE ERRORS

SELECT P12, AND INPUT
LIFT-OFF TIME (PDI +
20-3/4 MIN) FROM
PRE-DDI PAD

KEY IN 414 + 20000
TO INITIALIZE AGS
STATE VECTOR

ENTER IN DEDA 400 + 40000
FOR AGS LUNAR ALIGN

KEY IN 400 + 10000
TO EXIT LUNAR ALIGN
AND ENABLE GUIDANCE
STEERING

SECOND STAY OR NO STAY DECISION

ARE
CRITICAL
SYSTEMS
STAY
?

NO

LIFT-OFF WITH P12
LIFT-OFF AT PRE-
FERRED TIME
(=PDI + 20-3/4 MIN)

YES

NOTIFY CREW TO REMAIN
ON LUNAR SURFACE FOR
AT LEAST ONE CSM
REVOLUTION

SECOND DECISION IS TO STAY FOR ONE CSM REVOLUTION

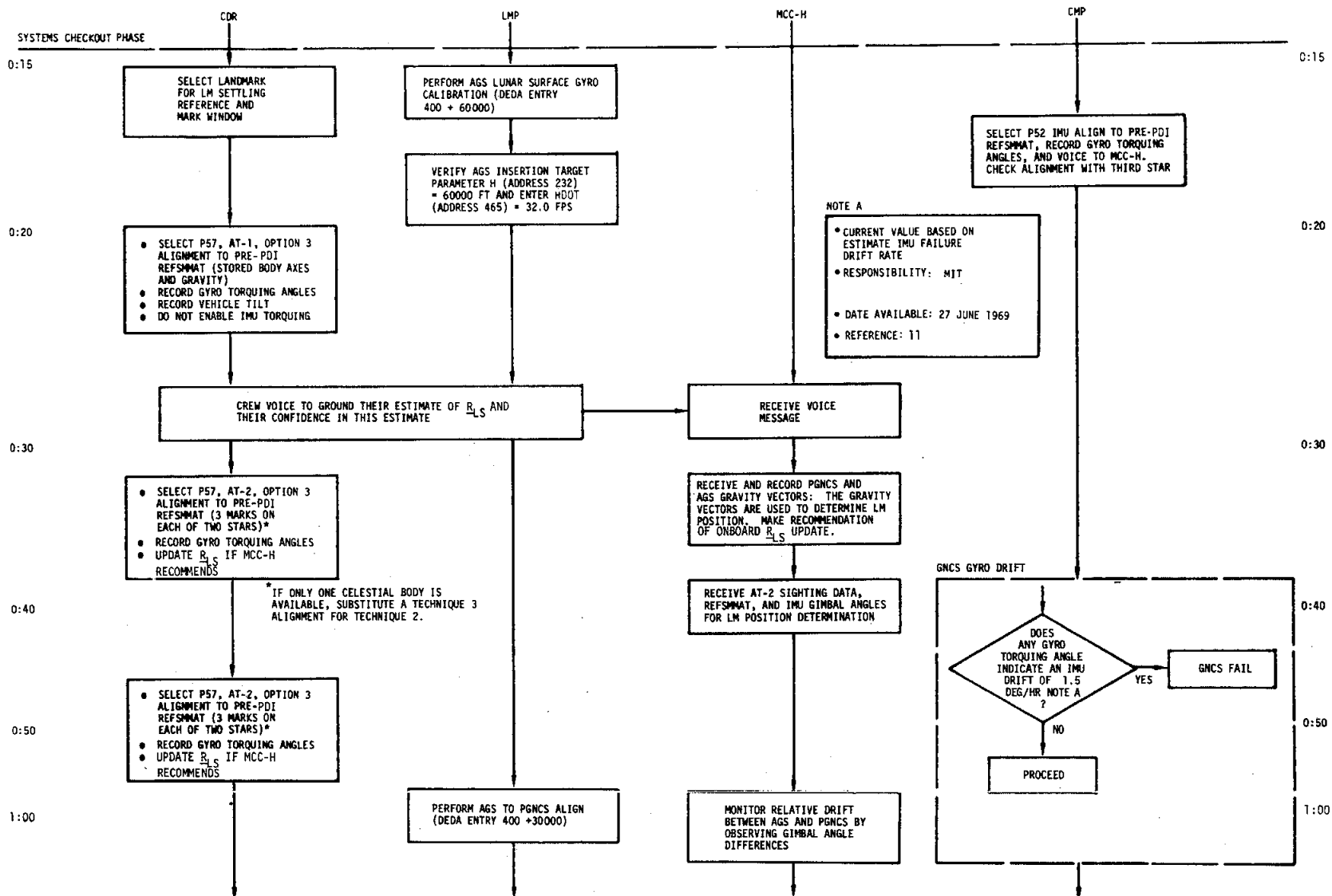
MODE CONTROL (PGNCS) - ATT HOLD
MODE CONTROL (AGS) - OFF

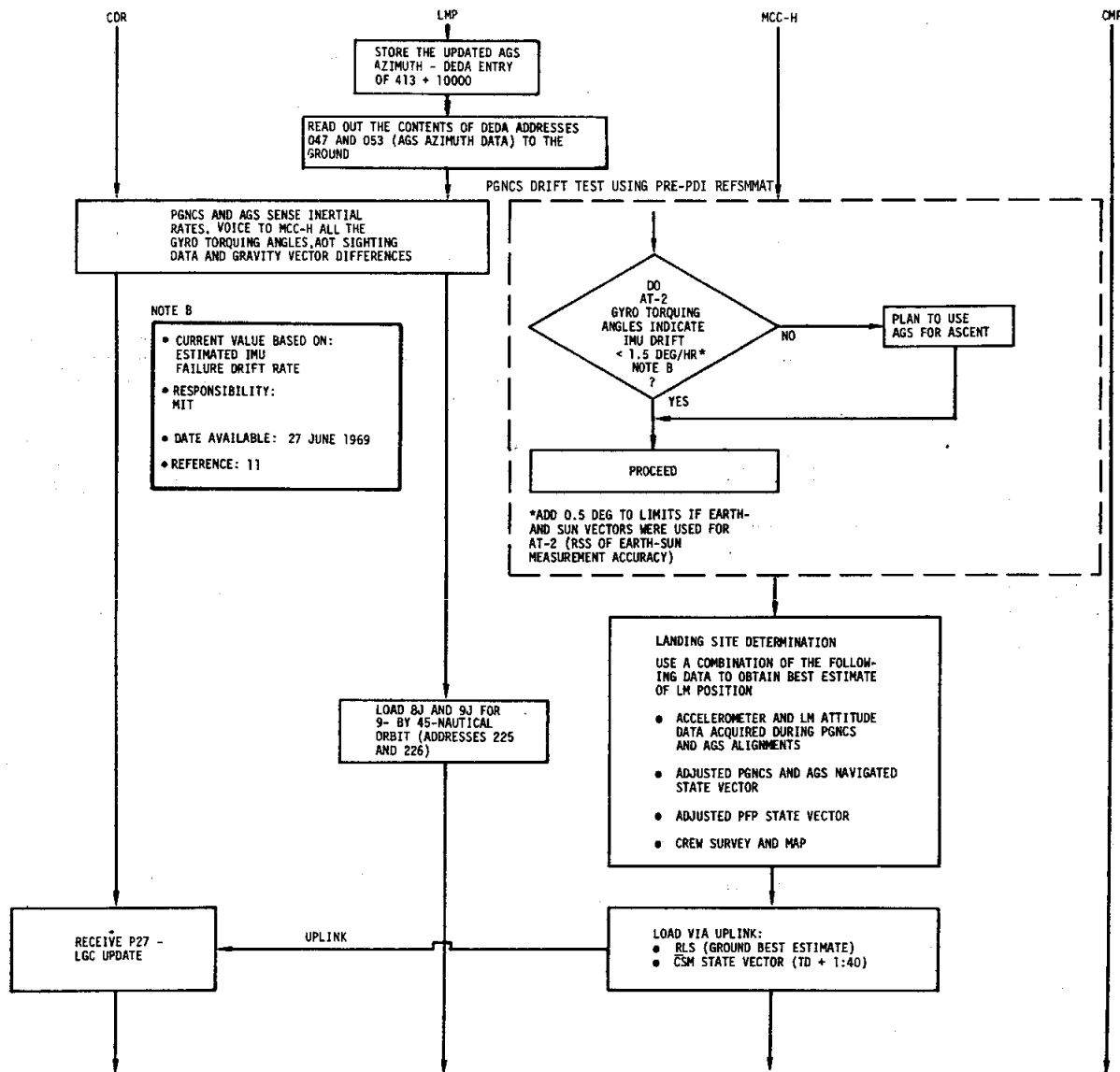
READ OUT THE CONTENTS
OF DEDA ADDRESS 047 AND
053 (AGS AZIMUTH DATA)
TO THE GROUND

SET CMC LUNAR SURFACE
FLAG (V44)

0:10

0:10





NOTE B

- CURRENT VALUE BASED ON: ESTIMATED IMU FAILURE DRIFT RATE
- RESPONSIBILITY: MIT
- DATE AVAILABLE: 27 JUNE 1969
- REFERENCE: 11

LANDING SITE DETERMINATION

USE A COMBINATION OF THE FOLLOWING DATA TO OBTAIN BEST ESTIMATE OF LM POSITION

- ACCELEROMETER AND LM ATTITUDE DATA ACQUIRED DURING PGNCs AND AGS ALIGNMENTS
- ADJUSTED PGNCs AND AGS NAVIGATED STATE VECTOR
- ADJUSTED PFP STATE VECTOR
- CREW SURVEY AND MAP

- LOAD VIA UPLINK:
- RLS (GROUND BEST ESTIMATE)
 - CSM STATE VECTOR (TD + 1:40)

RECEIVE P27 - LGC UPDATE

UPLINK

LOAD 8J AND 9J FOR 9- BY 45-NAUTICAL ORBIT (ADDRESSES 225 AND 226)

READ OUT THE CONTENTS OF DEDA ADDRESSES 047 AND 053 (AGS AZIMUTH DATA) TO THE GROUND

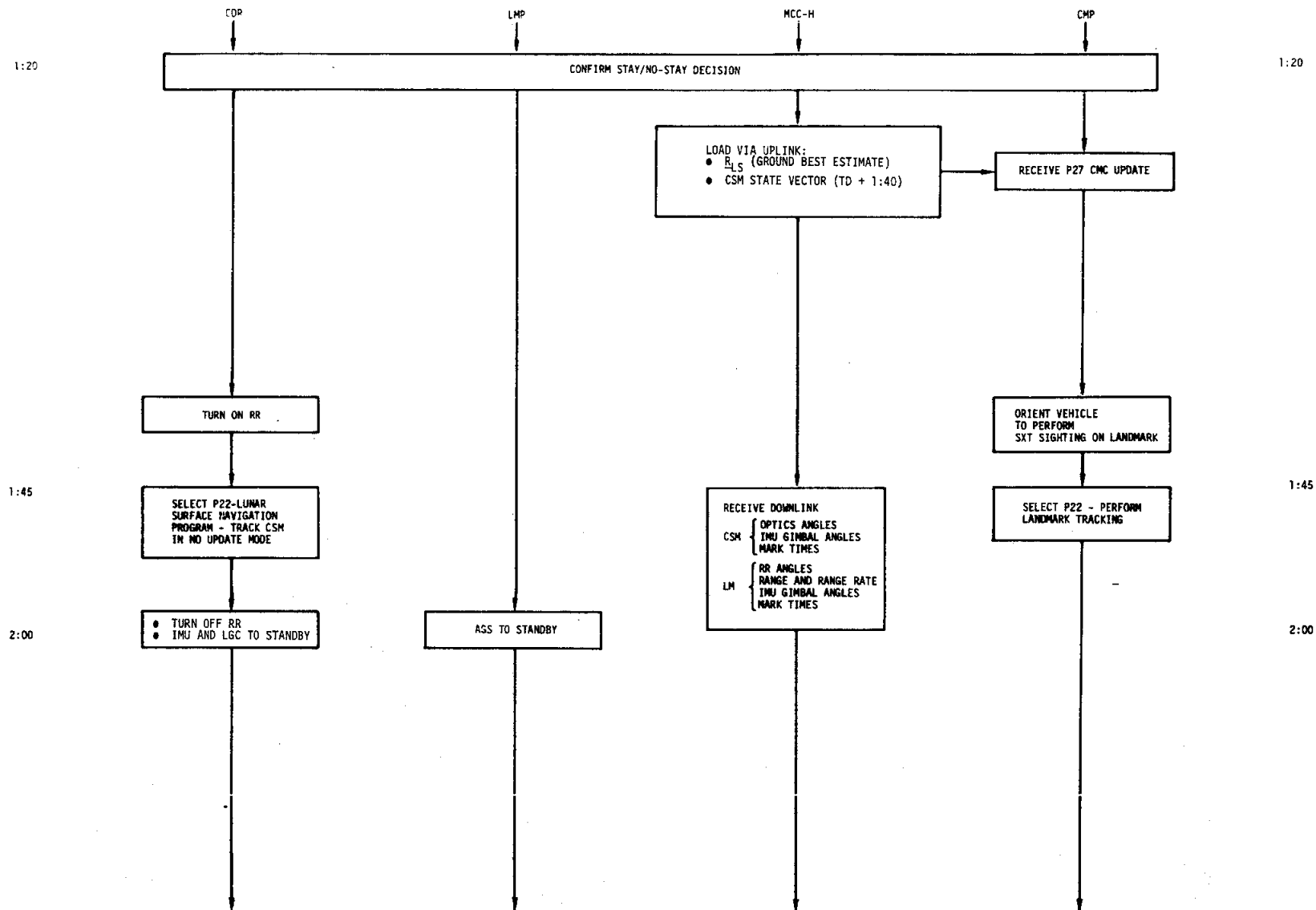
STORE THE UPDATED AGS AZIMUTH - DEDA ENTRY OF 413 + 10000

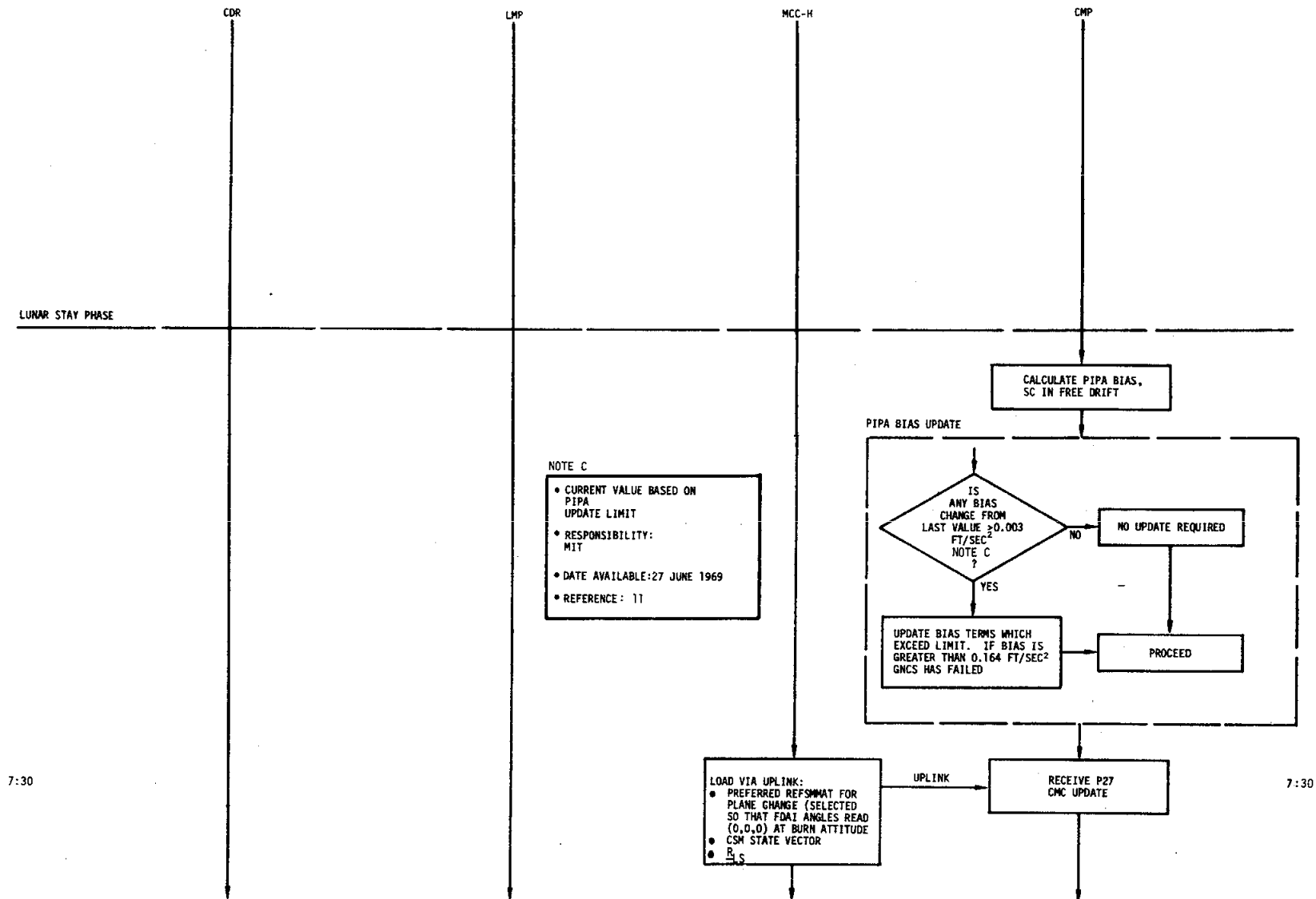
CDR

LMP

MCC-H

OMP





8:00

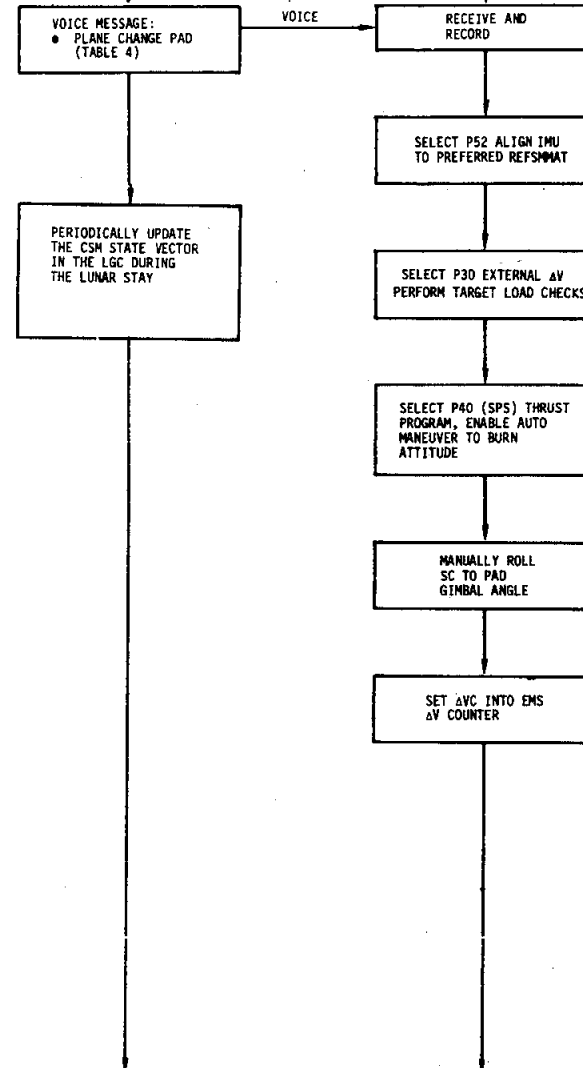
44

CDR

LMP

MCC-H

CMP



8:00

9:20

10:00

CDR

LMP

MCC-H

CMP

NOTE D

- CURRENT VALUE BASED ON ESTIMATE OF ALLOWABLE POINTING ERROR
- RESPONSIBILITY: MIT
- DATE AVAILABLE:
- REFERENCE: APOLLO 8 PROCEDURES

IGNITION ATTITUDE CHECK

SELECT P52 AND USE AUTO-
OPTICS WITH SXTS CODE

DOES
TRUNTON
ANGLE AGREE WITH
PAD (+ 1 DEG)
NOTE D
?

NO

ASSESS PROBLEM: PERFORM BURN
LATER WITH SCS IF NECESSARY

PROCEED

ALIGN GDC TO 0,0,0-UNCAGE
BMAG'S 1

PERFORM PLANE CHANGE
DO NOT TRIM RESIDUALS

RECEIVE P27 CMC UPDATE

SELECT P52 INU ALIGN PULSE
TORQUE TO LIFT-OFF REFSMMAT
(NO FINE ALIGN)

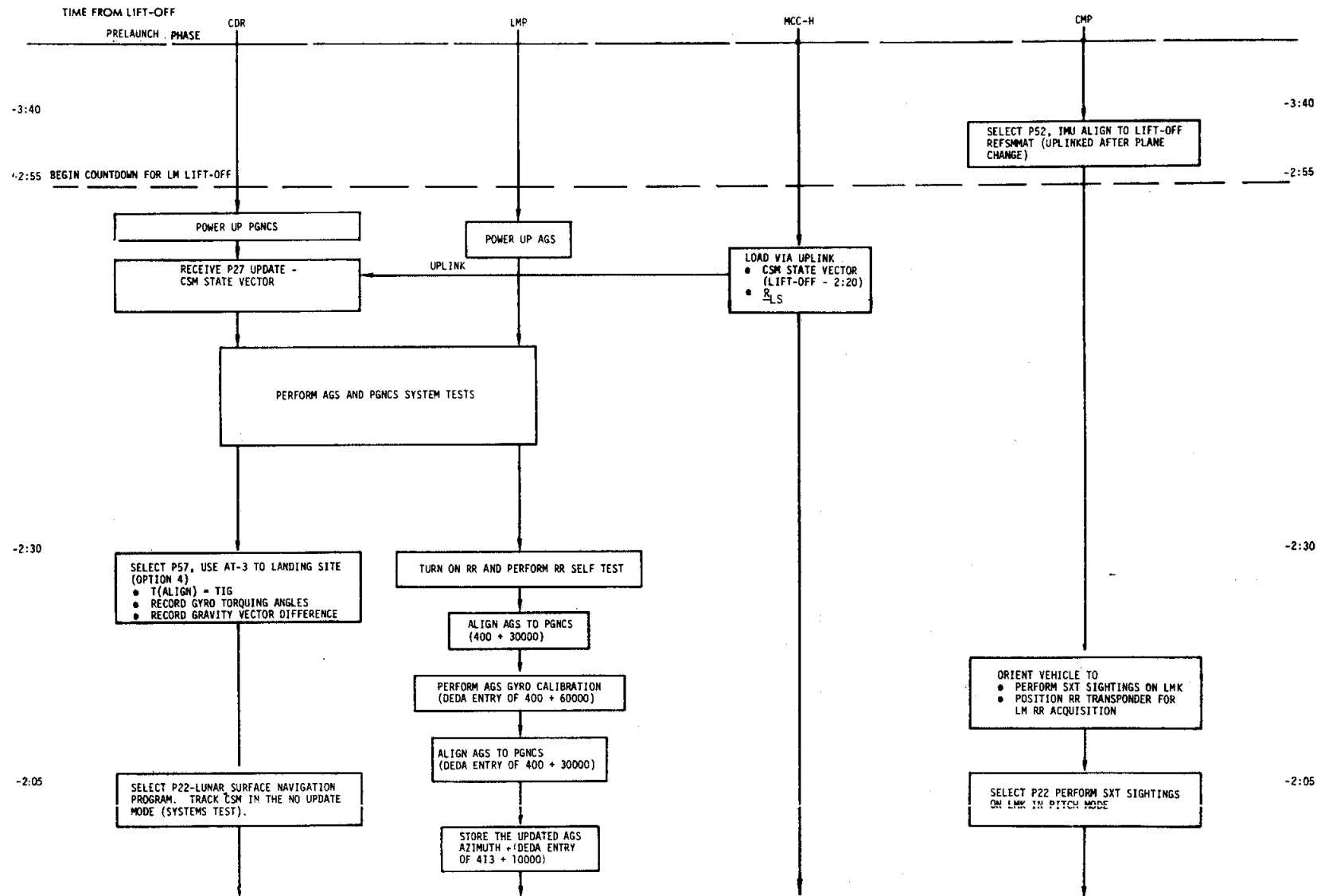
VERIFY BURN

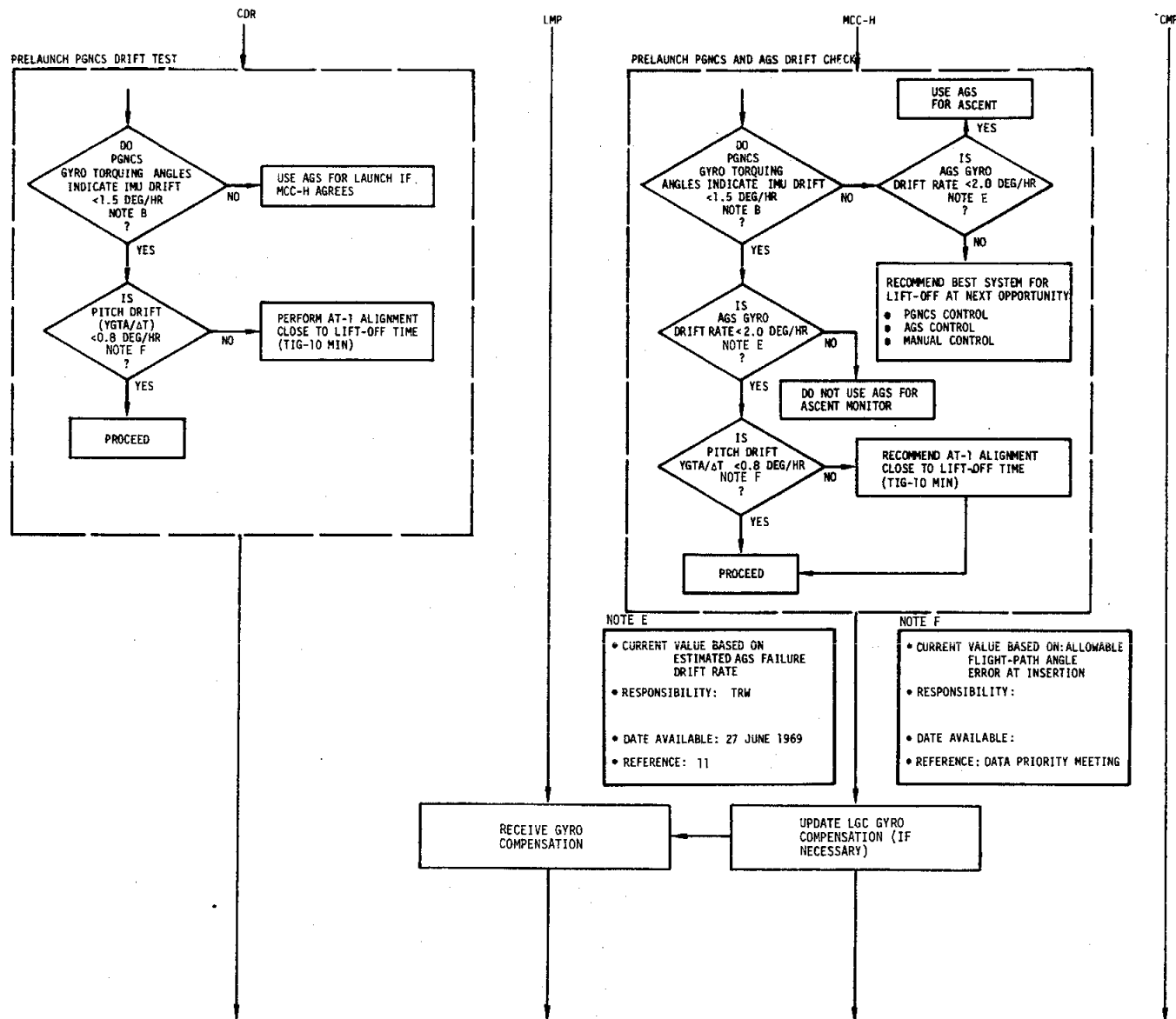
LOAD VIA UPLINK
LIFT-OFF REFSMMAT

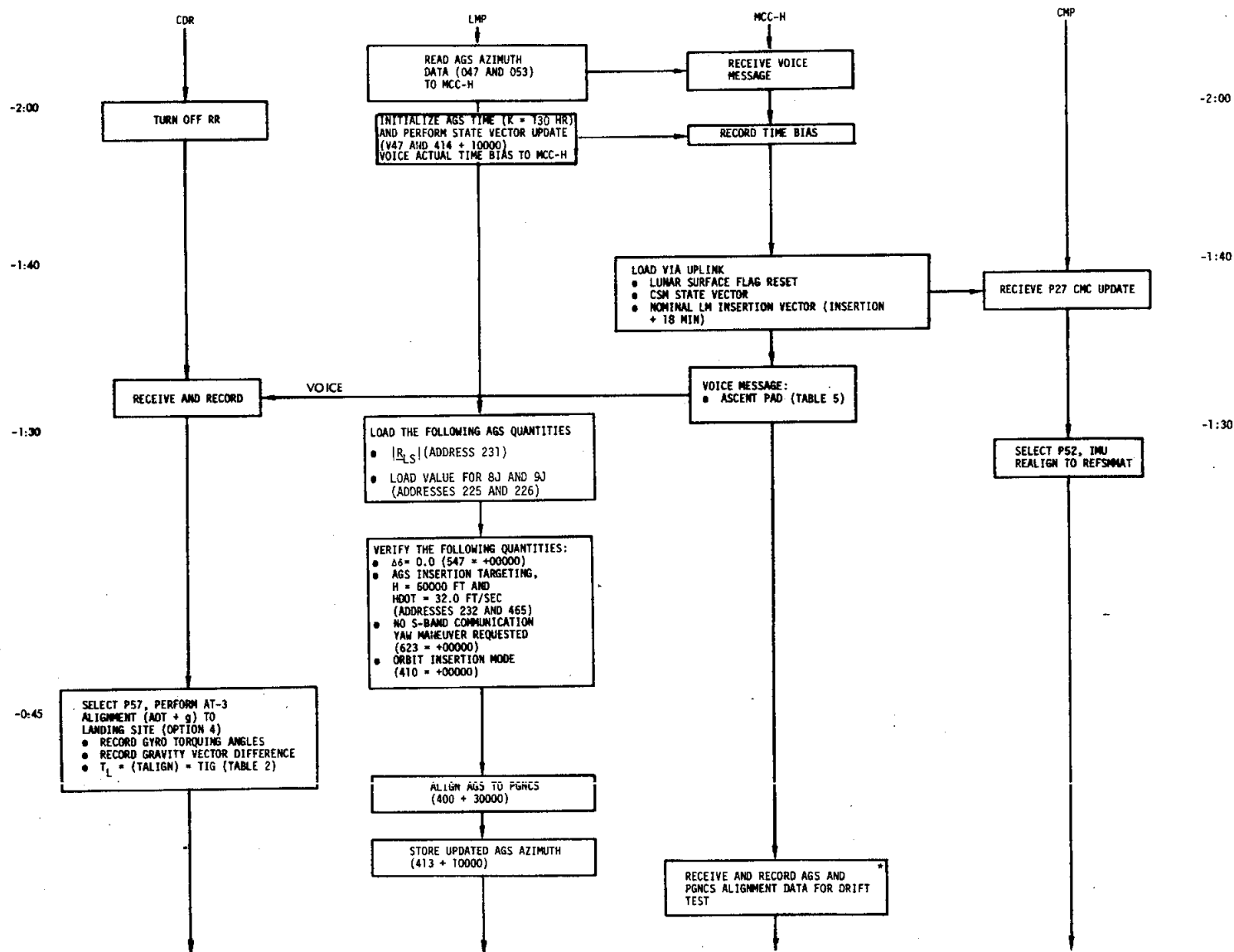
UPLINK

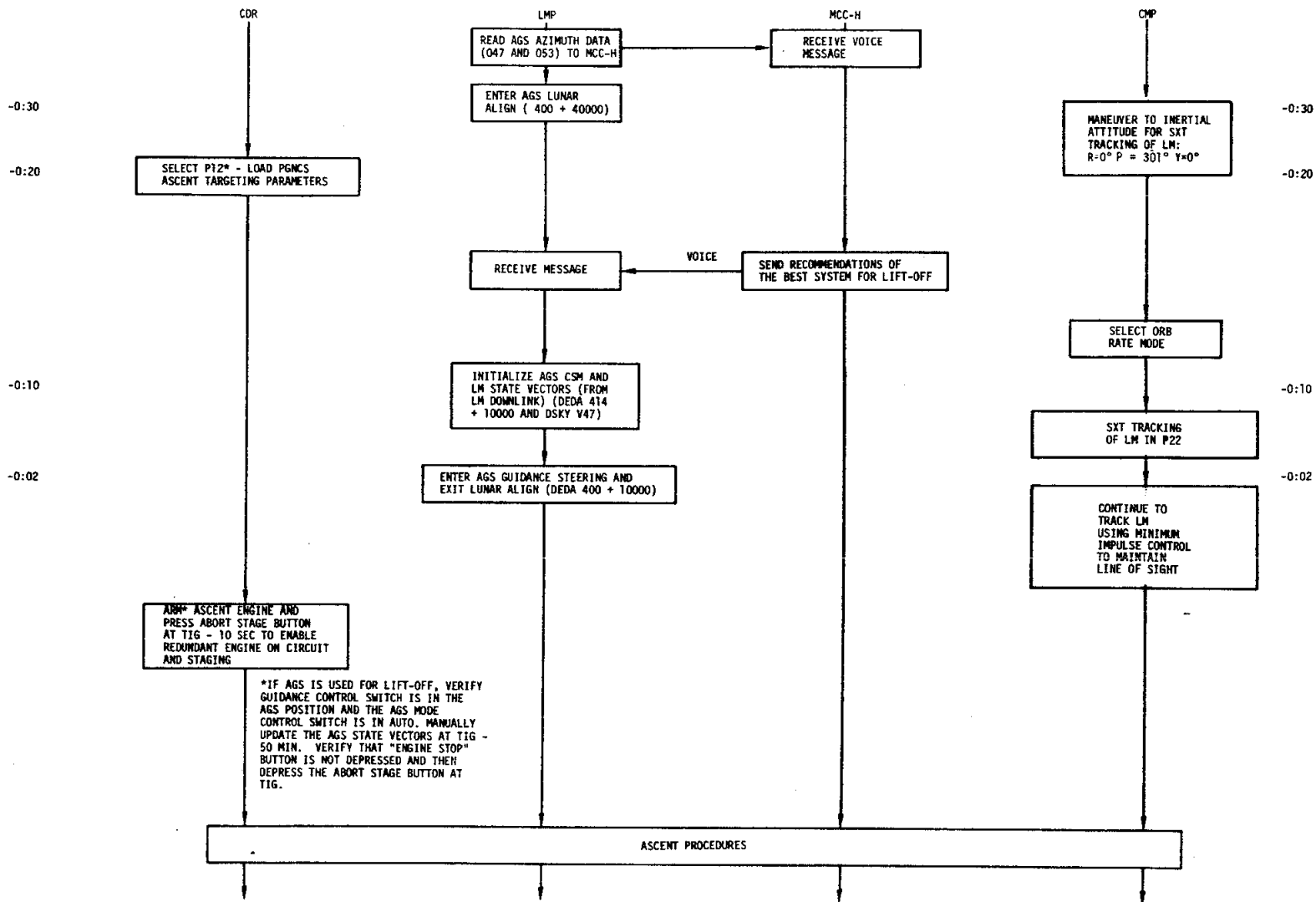
9:20

10:00









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1. "G Lunar Phase Mission Techniques," MSC Memorandum 69-PA-T-22A, 11 February 1969.
2. "LM/AGS Operating Manual, Flight Program 7, "TRW 11176-H405-R0-00, December 1969.
3. "Guidance System Operation Plan," Section 4, LUMINARY 1C, MIT/IL R-567, December 1969.
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5. "LM Position Determination on the Lunar Surface from Multiple Star/Gravity Measurements," MSC Memorandum 69-FM47-355, 7 November 1969.
6. "Effect of Star Sighting Separation Angle on IMU Alignment Accuracy," MIT SGA Memorandum 268, 10 February 1968.
7. "LM Position Determination Using the AOT and the Gravity Vector," MSC Internal Note 68-FM-195, 24 September 1968.
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9. "RTCC Requirements for Mission G: Lunar Module Attitude Determination Using Onboard Observation," MSC Internal Note 68-FM-125, 28 May 1968 (with change pages of MSC Memorandum 68-FM47-408, 6 January 1969).
10. T. J. Stiles, "Stable Attitude Abort Decision," GAEC AVO LAV-500.884, 24 June 1969.
11. Robert G. Chilton, "Gyro Calibration and Accelerometer Bias Update and Redline Values," MSC Memorandum, 27 June 1969.