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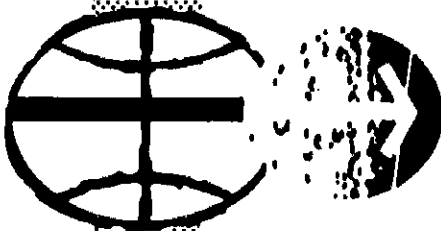
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**APOLLO MISSION TECHNIQUES
MISSION H-2 AND SUBSEQUENT
TRANSLUNAR MIDCOURSE CORRECTIONS
AND LUNAR ORBIT INSERTION
AVAILABLE TO NASA AND
NASA CONTRACTORS ONLY**

**TECHNIQUES DESCRIPTION
FINAL ISSUE**



**APOLLO SPACECRAFT PROGRAM OFFICE
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS**

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Approved by



Philip C. Shaffer, Chief
Apollo Data Priority Coordination

FOREWORD

This Translunar Midcourse and Lunar Orbit Insertion 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
- Lunar Orbit Activities
- Lunar Descent
- Abort from Lunar Powered Descent and Subsequent Rendezvous
- Lunar Surface Activities
- Manual Ascent
- Powered Ascent
- 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 the compatibility of all related MSC and supporting contractor activities.

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

FOREWORD (Continued)

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

This is the final issue of the Translunar Midcourse Corrections and Lunar Orbit Insertion 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

ARIA	Apollo Range Instrumentation Aircraft
AOH	Apollo Operations Handbook
AOS	acquisition of signal
ASCP	attitude set control panel
ASPO	Apollo Spacecraft Program Office
BAP	best adaptive path
BMAO	body mounted attitude gyro
BRC	basic reference coordinate system
BSS	boresight star (PAD data)
BT	burn time (PAD data)
GDR	commander
CLA	contingency landing area
CM	command module
CMC	command module computer
CMP	command module pilot
COAS	crew optical alignment sight
CSM	command and service module
DSKY	CMC display and keyboard
EMS	entry monitoring system
EPO	earth parking orbit
EPT	earliest possible time
FDAI	flight director attitude indicator
FOV	field-of-view

NOMENCLATURE (Continued)

FPS	feet per second
FR	free return
FSD	Flight Support Division
g. e. t.	ground elapsed time
GET 0.05 g	ground elapsed time to 0.05 g entry condition (PAD data)
GETI	ground elapsed time of ignition (PAD data)
GDC	gyro display coupler
GNCS	CSM guidance, navigation, and control system
ΔH	CMC horizon bias
H_A	apogee altitude
H_P	perigee altitude
h_p	perilune altitude
IMU	inertial measurement unit
IRIG	inertial rate integrating gyroscope
IU	instrument unit (S-IVB)
LAT	latitude of resultant landing point after abort maneuver (PAD data)
LLOS	landmark line-of-sight
LM	lunar module
LMP	lunar module pilot
LOI	lunar orbit insertion
LONG	longitude of resultant landing point after abort maneuver (PAD data)
LOS	loss of signal

NOMENCLATURE (Continued)

LVDX	X-velocity component in local vertical coordinate system
LVDY	Y-velocity component in local vertical coordinate system
LVDZ	Z-velocity component in local vertical coordinate system
MCC	midcourse correction(s)
MCC-H	Mission Control Center - Houston
MGA	middle gimbal angle
MNVR	maneuver
MPL	mid-Pacific landing
MSFN	Manned Space Flight Network
NAV	navigation
NBD	null bias drift
NR	North American Rockwell
ORDEAL	orbital rate drive device (to establish local vertical FDI display in pitch)
P23	Cislunar Navigation Program
P27	Update Program
P30	External ΔV Program
P40	SPS Thrust Program
P41	RCS Thrust Program
P47	Thrust Monitor Program
P52	IMU Realign Program
PAD	data voiced to crew from ground and recorded by crew for future use

NOMENCLATURE (Continued)

PC	pericynthian
PIPA	pulse integrated pendulous accelerometer
PLA	planned landing area
PTC	passive thermal control
P _{TRIM}	SPS pitch trim gimbal angle (PAD data)
RCS	reaction control system
REFSMMAT	transformation matrix from BRC reference to CSM stable member inertial coordinates
R, P, Y	roll, pitch, and yaw IMU gimbal angles (PAD data)
RSS	root sum square
RTACF	Real-Time Auxiliary Computing Facility
RTCC	Real-Time Computer Complex
RTGO	range to go for entry maneuver (EMS) (PAD data)
SC	spacecraft
SCS	stabilization and control system
SCT	scanning telescope
SFT	shaft angle for SXTS (PAD data)
SM	service module
SXT	sextant
SXTS	sextant star for ignition attitude check (PAD data)
S-IVB	third stage of Saturn launch vehicle
SPA	BSS pitch angle (COAS)
SPS	service propulsion system
SV	state vector

NOMENCLATURE (Continued)

SXP	BSS X-position (COAS)
TD&E	transposition, docking, and LM extraction
THC	translational hand controller
TIG	time of ignition
TL	translunar
TLI	translunar injection
TM	telemetry
TRN	trunnion angle for SXTS (PAD data)
UNZAP	state vector transfer from LM locations in CMC to CSM locations
VI	P47 DSKY display of inertial velocity
VIO	inertial velocity setting for entry maneuver (EMS) (PAD data)
WT	CSM weight (PAD data)
W-matrix	error transition matrix used in the CMC Navigation Updating Program (P23)
Y_{TRIM}	SPS yaw trim gimbal angle (PAD data)
ZAP	state vector transfer from CSM location in CMC to LM location
ΔR	P23 display of magnitude of the difference between the CMC position vector before and after incorporation of star measurement
ΔV	velocity correction, P23 display of magnitude of the difference between the CMC velocity vector before and after incorporation of star measurement
ΔVC	EMS ΔV counter setting for maneuver (PAD data)
ΔVT	total impulsive ΔV (PAD data)
$\Delta V_X, \Delta V_Y, \Delta V_Z$	P30 velocity to be gained components in local vertical coordinates

1. INTRODUCTION

The following text and flow charts present the guidance and navigation events and real-time decisions which must be made for the H-2 (Apollo 13) mission beginning from translunar injection cutoff through the lunar orbit insertion maneuver.

The objective of this report is to document a standard acceptable procedure for verification and usage of navigation and guidance data together with alternate or backup procedures in the event of a primary guidance, navigation, and control system (GNCS) failure. Routine procedures and operations not pertinent to the objectives are omitted for the sake of clarity.

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

- a) Mission Control Center - Houston (MCC-H) always provides all maneuver targeting for midcourse corrections and LOI.
- b) All burns (midcourse corrections and LOI) will use the GNCS external ΔV mode.
- c) The service propulsion system (SPS) will be used for all MCC's, if possible, in order to conserve reaction control system (RCS) fuel.
- d) A properly operating GNCS is mandatory for LOI.

Figure 1-1 shows the sequence of events for the translunar and lunar orbit insertion phases of the H-2 mission.

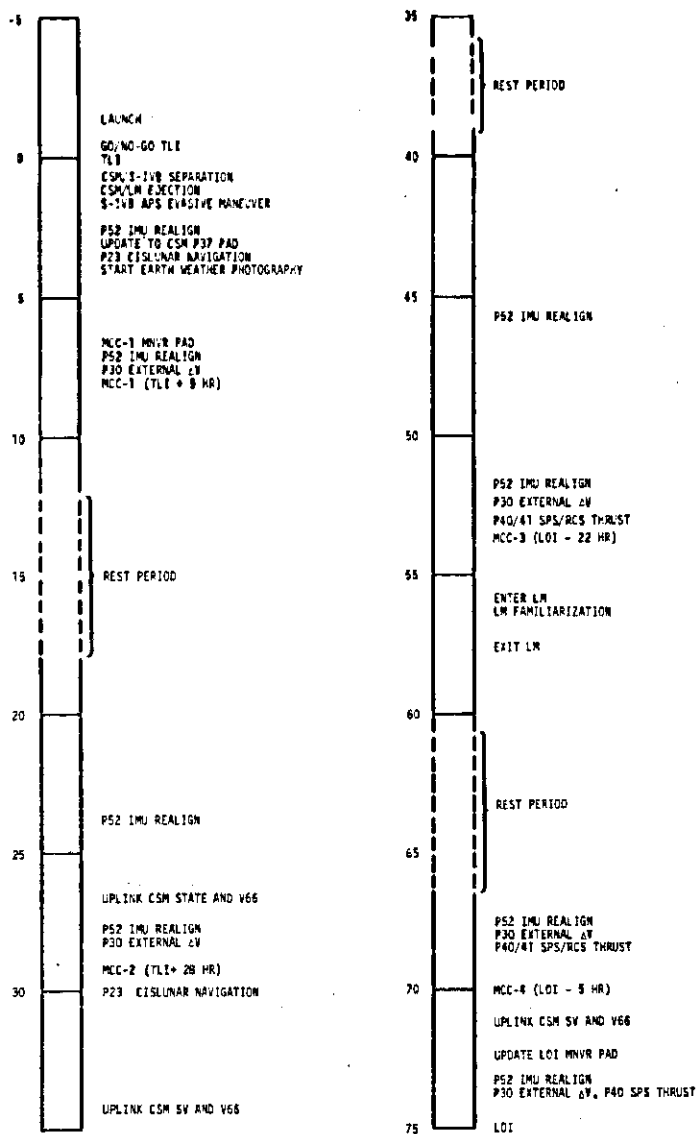


Figure 1-1. Typical H-2 Mission Sequence of Events for TL MCC's and LOI

2. LOI GO/NO-GO PROCEDURE

Prior to committing to the lunar orbit insertion (LOI) burn, the GNCS must be evaluated to ascertain if it is operating within specified limits (Reference 1). This is accomplished in a manner similar to the translunar injection (TLI) go/no-go procedure. The technique makes use of velocity component strip charts during TLI and vector comparison display data during translunar coast. The strip chart data consist of a comparison between the S-IVB and GNCS velocity components in the inertial measurement unit (IMU) coordinates. Changes in trends or a large gradual divergence (beyond established limits) between the two systems are cause to suspect that one system is malfunctioning. To determine the system that is malfunctioning, orbital parameter differences between Manned Space Flight Network (MSFN) tracking and GNCS telemetry (TM) sources are compared by use of the vector comparison display during translunar coast. The strip chart parameters also include a comparison between the S-IVB and GNCS inner, middle, and outer gimbal angles.

2.1 GNCS AND S-IVB IU TLI VELOCITY COMPARISONS

The velocity difference strip charts consist of a set of four charts which indicate the difference between the S-IVB IU and GNCS total (ΔV_c) and component velocities ($\Delta \dot{X}_c$, $\Delta \dot{Y}_c$, $\Delta \dot{Z}_c$) at any time during the TLI burn. The comparisons are made in IMU stable member coordinates after the velocity vectors have been time synchronized. The velocity differences will be forced to zero at the start of the TLI burn, and the gravitational integral effects are removed in order to detect the sensed velocity errors.

Table 2-1 shows the acceptable strip chart limits at TLI cutoff that are used to determine a satisfactory GNCS/IU comparison (Reference 3).

2.2 GNCS AND MSFN ORBITAL PARAMETER COMPARISONS

During the translunar coast the orbital decision parameters are evaluated using the vector comparison display data. Three comparisons between the IMU navigated state and the MSFN tracked state are used to determine the IMU performance during the TLI maneuver. For detecting

Table 2-1. Typical LOI Go/no-go Limits*

<u>Decision Parameter</u>	<u>Definition</u>	<u>Limit</u>
ΔV_c	Saturn-spacecraft G&N velocity differences in IMU stable member coordinates	24 ft/sec**
$\Delta \dot{X}_c$		69 ft/sec**
$\Delta \dot{Y}_c$		66 ft/sec**
$\Delta \dot{Z}_c$		66 ft/sec**
Δa	MSFN-G&N difference in semi- major axis	130×10^6 ft***
$\Delta \gamma_0$	MSFN-G&N argument of perigee	0.15 deg***
$\Delta \dot{w}_{\max}$	MSFN-G&N difference in nodal crossrange velocity	30 ft/sec***

*These numbers may be revised prior to the mission.

**Based on RSS value of

- 1) IU: 3 σ hardware errors TLI, and 3 σ constant gyro drift and errors at EOI since lift-off to TLI
- 2) IMU: 9 σ TLI, 3 σ constant gyro drift since IMU realign in EPO at 54 min GET

***Based on RSS value of (2) above, that is IMU uncertainties only.

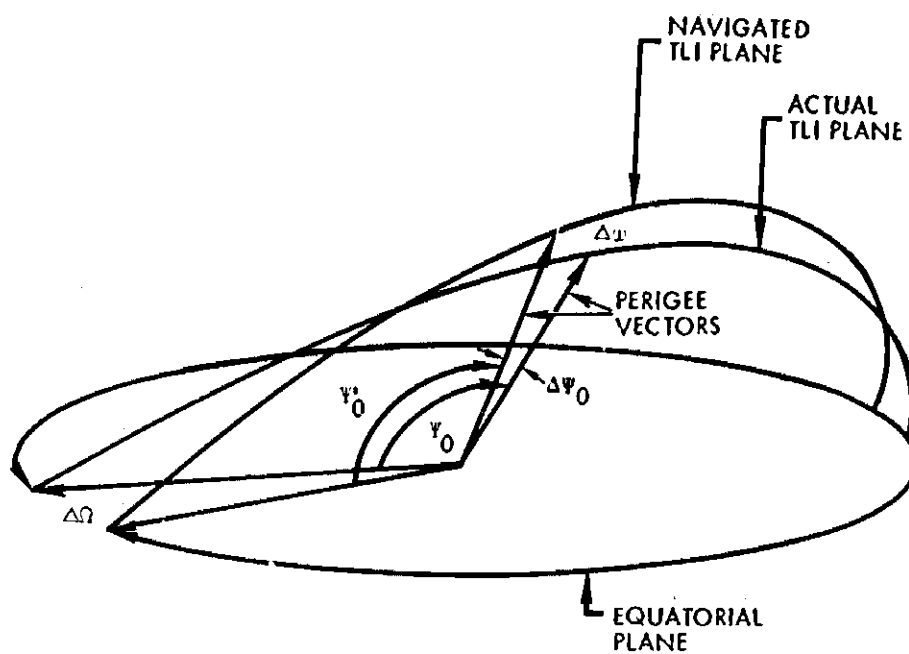
velocity magnitude errors, resulting from in-plane accelerometer biases or scale factors, the semimajor axis difference (Δa) is used. For detecting in-plane errors that are normal to the thrusting direction, resulting from Y-axis gyro drifts, the difference in argument of perigee ($\Delta \dot{\tau}_0 = \dot{\tau}_0 - \dot{\tau}_0'$) is used (Figure 2-1). Crossrange errors are detected by a parameter related to the wedge angle ($\Delta \omega$) between the IMU estimated TLI conic plane and MSFN tracked TLI conic plane. The wedge angle ($\Delta \omega$) will provide a clear indication of cross range velocity errors that occur during the TLI maneuver. The parameter displayed is the estimated nodal cross range velocity ($\Delta \dot{w}_{\max}$) between the IMU estimated TLI plane and the MSFN tracked TLI plane.

The LOI no-go limits for the $\Delta \dot{\tau}_0$ and $\Delta \dot{w}_{\max}$ orbital decision parameters are 0.15 degree and 30 feet per second, respectively (Table 2-1). The Δa no-go limit is a function of the ground elapsed time (g. e. t.) of TLI ignition (Reference 3). A typical no-go value for Δa for the nominal lift-off time is 130 million feet.

2.3 LOI GO/NO-GO PROCEDURE

The LOI go/no-go procedure consists of the following steps:

- a) Decision parameter differences are revised to reflect initial misalignments determined in earth parking orbit (input required from gimbal angle strip charts processed during parking orbit) (Reference 4).
- b) MCC-H will calculate and evaluate accelerometer bias observed during the coasting period. An accelerometer bias compensation is updated if the bias error is greater than 0.003 foot per second squared. LOI is no-go when the bias error is greater than 0.164 foot per second squared (Reference 5). The velocity strip charts and orbital parameter limits are revised to compensate for the known bias.
- c) MCC-H will calculate and evaluate constant gyro drift errors and initial misalignments calculated during translunar coast. If this error indicates that a GNCS failure is evident (greater than 1.5 degrees per hour), then LOI is no-go (Reference 5). If the drift error is greater than 0.045 degree per hour, then a gyro compensation update is performed (Reference 5). The calculated drift values are used to update orbital parameters and strip chart limits.



Δx - WEDGE ANGLE

$\Delta \psi_0$ - ARGUMENT OF PERIGEE DIFFERENCE ($\psi'_0 - \psi_0$)

$\Delta \Omega$ - RIGHT ASCENSION DIFFERENCE

Figure 2-1. Angular Relationship Between Orbital Decision Parameters

- d) After the strip chart velocity component limits have been compensated for known accelerometer biases, platform misalignments, and gyro drifts (if necessary), the data are examined to determine if the allowable limits have been violated and if definite trend changes exist. If the data are acceptable, then LOI is go at this point. If the data limits are exceeded or unfavorable trend changes exist, then a temporary LOI no-go is given until the orbital decision parameters have been investigated.
- e) It is not necessary for MCC-H to evaluate the orbital decision parameters (differences between GNCS and MSFN tracking) unless the strip chart limits are violated. These parameter differences will be revised to include the effects of initial platform misalignment (Reference 4). If the orbital parameter differences are within limits, then LOI is go at this point.
- f) The vector comparison display will be used to evaluate GNCS performance after each midcourse correction is completed. If the trajectory is determined to have been significantly perturbed and if it is determined that a GNCS failure is the cause of the perturbation, then LOI is no-go.

A program which generates the required velocity and gimbal angle strip charts has been developed for use in the RTCC (Reference 7). S-IVB and GNCS velocity vectors and gimbal angles will be processed, and strip charts generated. The strip charts will be used to make the LOI go/no-go decision.

If a ground station or ship is in sight of the TLI burn, then the required data can be obtained real time. If Apollo Range Instrumentation Aircraft (ARIA) data must be used, then they will be transmitted sometime during translunar coast. If all TLI data are lost, LOI is go if all other checks are favorable. Flight Support Division (FSD) can process the requested data within 3 hours after they are received. The ARIA data will probably be available to the RTCC within 11 hours after TLI. This will provide adequate time to process and analyze the results in order to make the LOI go/no-go decision.

2.4 S-IVB EVASIVE MANEUVER AFTER TD4E

CSM/LM ejection from the S-IVB occurs at TLI cutoff + 1:20. The CSM initiates a RCS -X 4-jet translation maintaining its attitude. The CSM translation is terminated at a $\Delta V = 0.4$ foot per second. The minimum total ejection $\Delta V = 1.2$ feet per second (0.8 foot per second for the spring actuator).

The CSM/LM views the S-IVB through the hatch window after ejection. The initial viewing attitude aligns the CSM/LM in the backup RCS evasive attitude. This attitude depends on the launch day (Reference 7).

At the time of the S-IVB APS evasive maneuver, the S-IVB is located approximately 500 feet south, 600 feet ahead, and 50 feet below the CSM/LM at a range of approximately 800 feet. The ground sends a command to the S-IVB to orient at 0.3 degree per second to the APS evasive maneuver attitude. The gimbal angles at the maneuver attitude are pitch (IGA) = 49.6 degrees, yaw (MGA) = 40.0 degrees, and roll (OGA) = 177.9 degrees. The S-IVB maneuvers out of plane toward the south from the CSM/LM. In the event the S-IVB APS evasive maneuver fails, the CSM will perform a 6-second +X 4-jet RCS backup evasive maneuver in the S-IVB viewing attitude. The S-IVB APS evasive maneuver is terminated after an 80-second burn and a $\Delta V = 9.3$ feet per second. Approximately 500 seconds later, the S-IVB initiates the maneuver to lunar impact burn attitude and maintains this attitude.

3. TRANSLUNAR MIDCOURSE PHILOSOPHY

The purpose of translunar (TL) midcourse corrections is to maintain the SC as close as practical to the nominal trajectory. During the translunar phase the SC will probably never be exactly on a free return trajectory intersecting the entry corridor. This is because the Manned Space Flight Network uncertainty in estimating the vehicle state vector can propagate into entry flight-path angles which lie far outside the entry corridor. Since the lunar module (LM) provides a perfect communications backup and also an SPS backup, it is not imperative that the SC always be on a free return trajectory within the entry corridor. This allows the MCC techniques to be designed so that the MCC RCS propellant expenditure is minimal and also allows a more flexible MCC technique.

Four TL-MCC's are planned for the H-2 mission. The scheduled times are TLI + 9, TLI + 28, LOI - 22, and LOI - 5 hours. The dispersions in perilune from 60 nautical miles, due to a 1-foot-per-second velocity error are shown in Table 3-1.

Table 3-1. Perilune Altitude Sensitivity for Mission H-2*

<u>Time (hr)</u>	<u>Horizontal (n mi/fps)</u>	<u>Out of plane (n mi/fps)</u>	<u>Radial (n mi/fps)</u>	<u>Most Sensitive Direction (n mi/fps)</u>
TLI	277.087	-0.658	36.319	279**
TLI + 28	4.223	-8.361	25.755	26** (after hybrid maneuver)
LOI - 22	0.154	-3.948	9.845	10***
LOI - 5	2.791	0.024	0.096	2.8***

* Data provided by MPAD - Lunar Mission Analysis Branch (References 8 and 9)

** Along the velocity vector

*** Along the local horizontal (nominally referenced)

The three-sigma MSFN velocity uncertainties for the translunar coast phase are shown in Table 3-2.

A typical trajectory and procedural profile for the translunar MCC and navigation sightings is shown in Figure 3-1. The typical MCC sequence is shown in Figure 3-2.

There are three modes of targeting available for the H-2 mission (Reference 10); the first is the best adaptive path (BAP), FR or NFR. The objective of this mode of targeting is to reduce the sum of the ΔV 's required for the translunar MCC's and the LOI maneuver to the smallest possible value which will result in the desired lunar orbit. Generally this mode will not be used beyond TLI + 30 hours for the following reason: As the MCC maneuver point gets close to LOI, the ΔV tradeoff between performing a given plane change at a MCC or at LOI becomes significant concerning translunar phase ΔV optimizations; that is, a given plane change ΔV at a MCC can reduce the plane change ΔV at LOI by an ever increasing amount as the lunar sphere of influence is approached. Therefore, the BAP mode of targeting (which recognizes the small potential ΔV savings) would produce the corresponding plane change tradeoff. Thus the situation could occur where the BAP MCC ΔV would begin growing in magnitude even though the previous MCC had been executed perfectly. The situation would be comparable to preplanning a nominal multi-impulse translunar MCC/LOI combination to save ΔV . Since ΔV is not that critical and because it is operationally desirable to freeze the nominal flight profile as early as possible, the BAP mode for the latter portion of the translunar coast is generally undesirable.

Beyond the scheduled time of MCC-2, nodal (XYZ and T) MCC targeting is normally used. This type of MCC is targeted for the position vector and time of arrival at the nominal node between the lunar approach hyperbolic plane and the desired lunar orbit plane, thus providing a direct coupling with the desired lunar orbit. These nominal nodal targeting objectives are defined by the last previous BAP targeting computation; i. e., if the previous BAP MCC were executed perfectly (including navigation), the actual ΔV required for a subsequent nodal targeted MCC would be zero.

Table 3-2. Typical Three-Sigma Uncertainty of MSFN Velocity Measurement (Reference 11)

Time from TLI Cutoff (hr)	Velocity Uncertainties (fps)		
	\dot{u}^*	\dot{v}^*	\dot{w}^*
2.00	0.42	1.02	2.85
6.00	0.24	0.81	1.59
10.00	0.18	0.72	1.20
15.00	0.15	0.63	0.96
20.00	0.12	0.51	0.72
25.00	0.22	0.24	0.69
30.00	0.09	0.39	0.54
35.00	0.09	0.36	0.50
40.00	0.09	0.33	0.45
45.00	0.07	0.28	0.36
50.00	0.06	0.24	0.32
55.00**	0.06	0.20	0.28
60.00**	0.14	0.06	0.14
65.00**	0.15	0.06	0.33

* \dot{u} is MSFN three-sigma uncertainty in radial direction.

\dot{v} is MSFN three-sigma uncertainty in horizontal direction.

\dot{w} is MSFN three-sigma uncertainty in out-of-plane direction.

** \dot{u} , \dot{v} , and \dot{w} are in moon reference (earth reference prior to 55 hours).

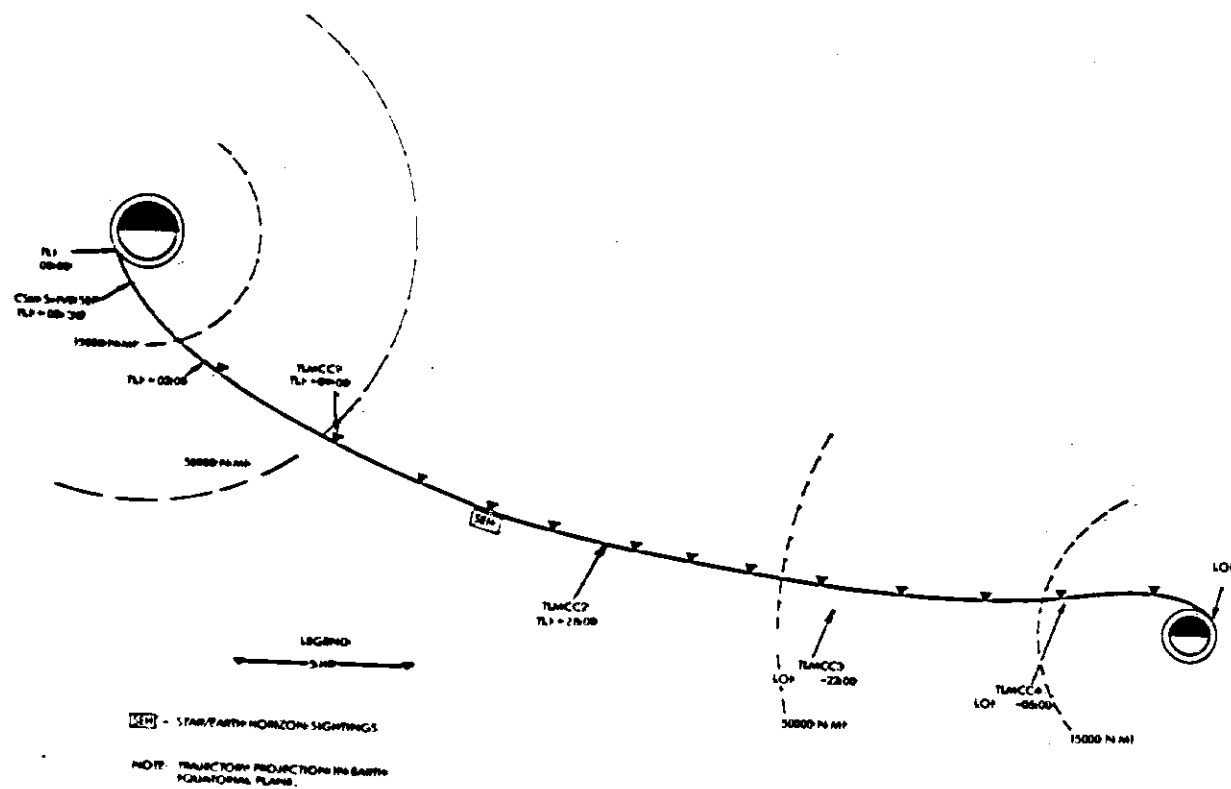


Figure 3-1. Typical Trajectory and Procedural Profile

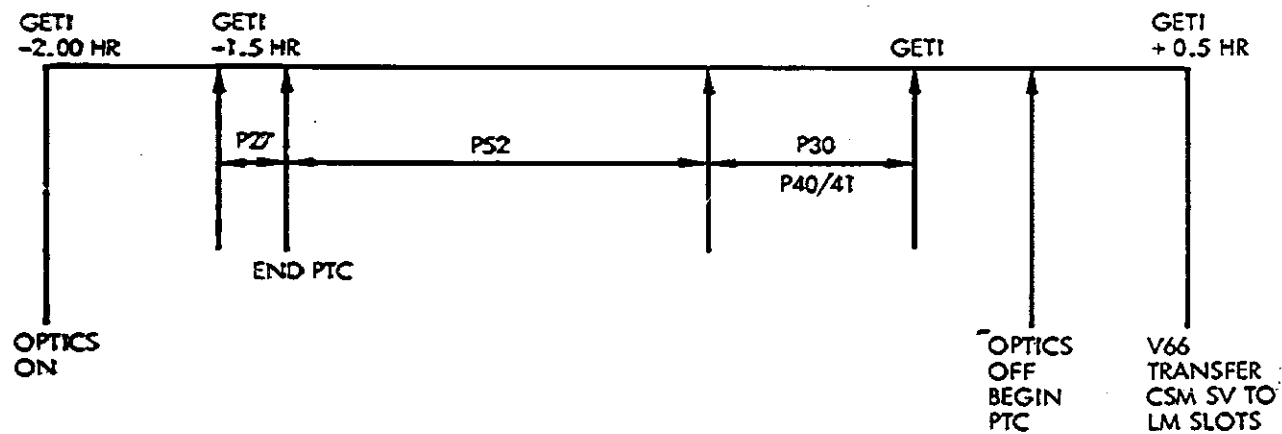


Figure 3-2. Typical MCC Sequence

A third mode of MCC targeting, free-return flyby, is available throughout the translunar coast phase as a backup to the BAP and nodal modes. Its target objectives are a specified perilune altitude and latitude and earth return flight-path angle for a circumlunar trajectory. The primary disadvantage of using this third mode for MCC for a lunar orbit mission is that it is decoupled from any specified or desired lunar orbit orientation. Thus, it will normally be used for targeting a flyby alternate mission. In the unlikely event the flyby mode were used due to some contingency, it would still be possible to target and execute a LOI maneuver based on the resulting lunar approach trajectory if the perilune altitude has been kept reasonably low, but it may be impossible to obtain the exact desired lunar orbit orientation.

3.1 TRANSLUNAR MIDCOURSE CORRECTIONS

The translunar MCC execution criteria are as follows:

- a) SPS MCC's should be greater than 3 seconds. (It is undesirable to perform an SPS burn less than 3 seconds (\approx 20 feet per second).)
- b) MCC-2 and MCC-4 are preferred execution points.
- c) Considering the above, the first midcourse will be delayed until MCC-2 if cost is not prohibitive*.
- d) For a nominal hybrid mission, the maneuver to go nonfree return will be executed at MCC-2.

3.2 FIRST AND SECOND MIDCOURSE CORRECTIONS

MCC-1, if performed, or MCC-2 will be executed with the SPS. The VOX burn residual will be trimmed to 0.2 foot per second if VOX < 2 feet per second. Burn residuals greater than 2 feet per second will not be trimmed. The VOY and VOZ burn residuals will not be trimmed. It is

* Real-time decision based on SPS reserves

desirable to trim the VGX burn residual during the MCC-1 or MCC-2 opportunities, because these should result in an RCS maneuver (i. e., < 3 feet per second) for MCC-3 or MCC-4.

3.3 THIRD MIDCOURSE CORRECTION

The third midcourse is scheduled for LOI - 22 hours. If MCC-3 ΔV is such that the resulting ΔV for MCC-4 is not prohibitive, MCC-3 is not executed. If MCC-3 is required, the SPS burn residuals are trimmed using the same criteria as for MCC-1 and MCC-2. This should ensure that MCC-4 will not be required because post MCC-3 residual errors in pericynthian altitude will nominally be corrected during the LOI maneuver.

3.4 FOURTH MIDCOURSE CORRECTION

The decision to do MCC-4 is coupled with LOI in that if the nodal and pericynthian altitude errors can be corrected within the LOI targeting constraints then MCC-4 will not be done. Nominally, any predicted nodal and pericynthian altitude deviations at MCC-4 will be small enough to be nulled during LOI. In the unlikely event that this is not the case, the MCC-4 will be performed at LOI - 5 hours. A MCC ΔV of less than 3 feet per second which cannot be corrected during LOI will be nulled to within 1 foot per second using the RCS. Nodal targeting (XYZ and T) is used for this correction, but generally only the X component, which adjusts hp, is used. If the MCC ΔV is greater than 3 feet per second, a SPS burn may be required and the residuals will be trimmed to within 1 foot per second.

4. TRANSLUNAR NAVIGATION

The basic ground rule is for MCC-H to provide the navigation function as long as communications are maintained with the SC. Nominally, the MCC's will be performed under GNCS control using the external ΔV mode and the MSFN state vector. The typical program sequence around a MCC will be P52, P27, and P30/P40 (41), as shown in Figure 3-2. The MSFN vector and external ΔV target parameter are uplinked to the CMC prior to each MCC. The vector is placed in the CSM slots, and the ground then transfers the vector from the CSM slots to the LM slots prior to the burn in order to store an unaltered state vector onboard. After the burn, the CMP transfers the CSM vector to the LM slots to keep a redundant state vector onboard.

In addition to the maneuver target loads, state vector, and CMC PAD data sent to the SC by the ground, block data maneuver PAD's will also be sent. In the unlikely event that communication is lost in both the CSM and LM, these data will be used for an abort. If an abort is required, P23 will be selected after the burn, the W-matrix initialized, and navigation sightings taken to perform the backup navigation function required for subsequent MCC's.

Star/earth horizon sightings scheduled at TLI + 3.5 hours are evaluated by MCC-H to determine the earth horizon bias (ΔH) above the Fischer ellipsoid used by the CMC. Such sightings are scheduled again at TLI + 28.5 hours, when ΔH errors are negligible, to establish sextant biases, if any, that may have influenced the earlier determination of ΔH . If the ΔH determined from the first sightings is different from that in the E-memory of the CMC by more than 5.0 KM, then the ΔH will be updated in the CMC. This uplink will occur at approximately TLI + 55.5 hours. A summary of the translunar navigation sighting schedule is shown in Table 4-1.

Table 4-1. Typical Navigation Sighting Schedule*

<u>Time of Sightings (hr: min)</u>	<u>Sightings</u>	<u>Stars Used (Octal)</u>	<u>Number of Marks</u>
TLI + 3:30	Star/Earth Horizon	33, 221, 125, 40, 42	5 sets of 3
TLI + 28:30	Star/Earth Horizon	37, 221, 212, 44, 77	5 sets of 3

*Reference 12

5. DISCUSSION OF FLOW DIAGRAMS

The following checks and procedures are followed for the translunar midcourse and lunar orbit insertion phases of the H-2 mission.

5.1 IMU ALIGNMENTS AND REFSMMAT'S

Periodic IMU alignments (P52) to particular REFSMMAT's will be made during the H-2 mission. All realignments are verified with auto optics to a third star. If at any time the gyro torquing angles indicate an off-nominal IMU drift, frequent P52's are performed to assess the drift performance. The LOI no-go compensated gyro drift limit has been set at 1.5 degrees per hour (Reference 5). That is, the GNCS will be considered failed if the IMU drift shifts more than 1.5 degrees per hour from the initial compensated value. The compensation is updated if the drift rate exceeds 0.045 degree per hour (Reference 5).

Different REFSMMAT's will be used throughout the translunar coast phase. The launch pad alignment REFSMMAT will be used for launch, TLI, and TDE. The PTC REFSMMAT will be used for midcourse corrections 1 through 4. This REFSMMAT places the X-axis in the ecliptic plane and perpendicular to the earth-moon line projection in the ecliptic plane at the average time of transearth injection for the monthly launch window and azimuth range. The Z-axis is then perpendicular to the ecliptic and directed south. At the beginning of the PTC mode, during TLC, the spacecraft will maneuver at an FDAI display of roll 0 degree, pitch 90 degrees, and yaw 0 degree.

If the middle gimbal angle is predicted to be > 60 degrees for a particular MCC maneuver, a preferred REFSMMAT will be used. The platform is realigned to the PTC REFSMMAT after MCC-1 to MCC-3. After MCC-4, the platform is aligned to the aligned to the landing site REFSMMAT. The landing site REFSMMAT at the time of lunar landing is defined as follows:

- X-axis is along the positive lunar radius vector through the landing site.

- Z-axis is in the direction of flight parallel to the CSM orbital plane and perpendicular to the X-axis.
- Y-axis completes the right-handed system.

This REFSMMAT will be computed and uplinked by MCC-H after MCC-4 for use in the CSM.

5.2 PIPA BIAS UPDATE

Periodic checks are made by MCC-H of the PIPA bias values. A change of 0.003 foot per second per second in any axis requires an update (Reference 5). The LOI no-go limit on the PIPA bias is 0.166 foot per second per second (Reference 5). That is, the GNCS will be considered failed if the PIPA bias shifts more than 0.166 foot per second from the initial compensation.

5.3 BLOCK DATA MESSAGES

Frequent block data PAD messages are voiced to the crew. These data consist of the Maneuver Pad (Table 5-1) and the P37 block data (Table 5-2). The nominal block data times are shown in Table 5-3. The external ΔV solutions and P37 first guesses during TLC result in direct (noncircumlunar) trajectories with landing in the primary area. The LOI + 5 hours abort is targeted for a circumlunar trajectory to the primary contingency landing area (CLA) and with a perilune between 60 and 1500 nautical miles. The perilune + 2 hours solution is targeted for the fastest return to a CLA.

During earth orbit, two abort maneuver PAD's will be voiced to the crew. The first will be an abort for TLI + 90 minutes to be used for SC systems problems. The second will be the first P37 PAD to be used for the LOI + 8 hour abort. Block data solutions and P37 PAD's will be corrected for trajectory updates as required. Block data for burn attitude gimbal angles will be for the appropriate REFSMMAT. The case of loss of communications while the CMG has other than the nominal REFSMMAT will only result in the PAD gimbal angle data for monitoring not being usable. The ΔV data are not affected since they are in local vertical (P30) coordinates.

Table 5-1. Maneuver Pad

COMMENTS		MANEUVER									
											PURPOSE 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
											ΔV_X N81
											ΔV_Y
ULLAGE											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						SXIS
		+						0			SFT
		+						0	0		TRN
		X	X	X							BSS
		X	X								SPA
		X	X	X							SXP
OTHER			0								LAT N61
											LONG
		+									RTGO
		+									VIO EMS
											GET .050

Table 5-1. Maneuver Pad (Continued)

Notes

- PURPOSE is the name of the maneuver.
- PROP/GUID is propulsion and guidance selected.
- WT is the CSM weight (lb).
- PTRIM and YTRIM 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.
- RALIGN, PALIGN, YALIGN 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 5-2. P37 PAD

P37 BLOCK DATA									
									GETI (HR:MIN)
X					X				ΔVT
X					X				LONG
									GET _{400K} (HR:MIN)
									GETI (HR:MIN)
X					X				ΔVT
X					X				LONG
									GET _{400K} (HR:MIN)
									GETI (HR:MIN)
X					X				ΔVT
X					X				LONG
									GET _{400K} (HR:MIN)
									GETI (HR:MIN)
X					X				ΔVT
X					X				LONG
									GET _{400K} (HR:MIN)
									GETI (HR:MIN)
X					X				ΔVT
X					X				LONG
									GET _{400K} (HR:MIN)
									GETI (HR:MIN)
X					X				ΔVT
X					X				LONG
									GET _{400K} (HR:MIN)
									GETI (HR:MIN)
X					X				ΔVT
X					X				LONG
									GET _{400K} (HR:MIN)

Table 5-3. Translunar Coast and Lunar Phase Block Data

<u>Time of Block Data Transmission (hr:min, g.e.t.)</u>	<u>Description of Block Data</u>	<u>GETI of Abort Maneuver (hr:min, g.e.t.)</u>	<u>Type of Data Transmitted</u>	<u>Return Mode</u>
1:40	TLI + 90 MIN LO + 8	4:11 8:00	Complete P30 Pad* P37 Pad**	Direct to AOL Direct to MPL
6:00	LO + 15 (W/O MCC-1)	15:00	↓	↓
12:30	LO + 25	25:00		
	LO + 35 (W/MCC-2)	35:00		
	LO + 45	45:00		
	LO + 60	60:00		
35:00	LOI - 5 FLYBY	72:25	Complete P30 Pad	Circumlunar to MPL
71:10	PC + 2 (W/MCC-4)	79:28	Partial P30 Pad***	Direct to MPL
74:30	TEI 1 (W/LOI) TEI 4 (W/O DOI)	79:41 86:08	↓	Circumlunar to MPL ↓

* See Table 5-1.

** See Table 5-2 (spacecraft weight and SPS engine pitch- and yaw-trim angles added as a comment of first pad).

*** Only GETI, ΔV_x , ΔV_y , ΔV_z , pitch-gimbal angle will be provided (spacecraft weight and SPS engine pitch- and yaw-trim angles provided on first pad and updated only if necessary).

5.4 SCS DRIFT CHECK

Periodically the IMU gimbal angles are compared to the SCS gimbal angles (GDC/BMAG's 2). The allowable limit (three-sigma) for the SCS drift check is 10 degrees per hour for all axes (Reference 10). If the GDC fails to indicate the IMU attitude within the allowable limits, the SCS is switched to the backup rate mode (BMAG's 1) and the GDC is realigned to the IMU. The test is then repeated. If the SCS FDAI (using BMAG's 1) does not indicate the allowable SCS drift, then the GDC is probably operating greater than three sigma (the IMU could be drifting). If the GDC drift is within the data acceptance limits after switching to BMAG's 1, BMAG's 2 are operating greater than three sigma. The BMAG/GDC failure limit is 15 degrees per hour. After the test, the GDC (if operational) is aligned periodically to the IMU.

5.5 EMS TEST

Nominally, before MCC's, a test of the EMS ΔV counter and accelerometer bias is made (AOH procedures). The accelerometer bias failure limit is 0.1 foot per second per second (Reference 11). Failure to pass the test prior to the LOI burn does not inhibit LOI, since time is used to manually backup SPS cutoff and is also adequate to backup the SPS cutoff for TEI.

5.6 CMC UPDATES

The CMC update program, P27, is selected by either MCC-H or the crew to update the CMC. The update may include state vectors, target parameters, PIPA and IRIG biases, REFSMMAT's, etc. In between maneuvers, the state vector is uplinked to the CMC CSM slots at the discretion of MCC-H. The PIPA and IRIG bias are uplinked whenever their allowable limits are exceeded. The REFSMMAT's that are uplinked are described in Section 5.4. The REFSMMAT is always sent up last whenever the CMC is updated with other data to ensure a correct REFSMMAT in the CMC, as other uplinked data may result in destroying the REFSMMAT within the CMC.

5.7 PREBURN PROCEDURES FOR ALL SCHEDULED BURNS

This section describes the typical preburn activities for scheduled GNCS controlled translational maneuvers. The first activity consists of performing an IMU alignment (P52). The alignment is checked using auto-optics to a third star. Following the CMC update (P27) and the maneuver PAD message, the External ΔV Program is exercised. The thrust program is either P40 or P41.

The crew monitors the CMC auto maneuver to the burn attitude and adjusts the outer gimbal angle to the PAD value. The SFT and TRN angles are set to PAD values. If the SXTS is in the SXT FOV then the GNCS is go. If the SXTS is not in the SXT FOV, then the auto optics is used to drive the SXT to the SXTS (PAD data). The TRN angle must indicate the PAD value within 1 degree in order to proceed with the GNCS. For LOI if this 1-degree optics check is failed, LOI is no-go. For MCC's however, the burn is executed with the SCS if the GNCS problem cannot be resolved.

After the ignition attitude is verified, the GDC is aligned to 0-0-0 for MCC's and to 0-180-0 for LOI burn. The BMAG's 1 are then uncaged. The crew will monitor these attitude references to determine if the SC 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).

The preburn sequence of events for the LOI burns are shown in Figure 5-1. The typical sequence for a MCC has been shown previously in Figure 3-2.

5.8 LOI BURN MONITOR

This section presents the burn monitor functions during the GNCS controlled LOI burn of the H-2 mission. Data limits included in these charts are supplied by MPAD (Reference 12).

It is assumed that certain undetected double failures (both sets of BMAG's or one of the BMAG sets and the primary control system) will

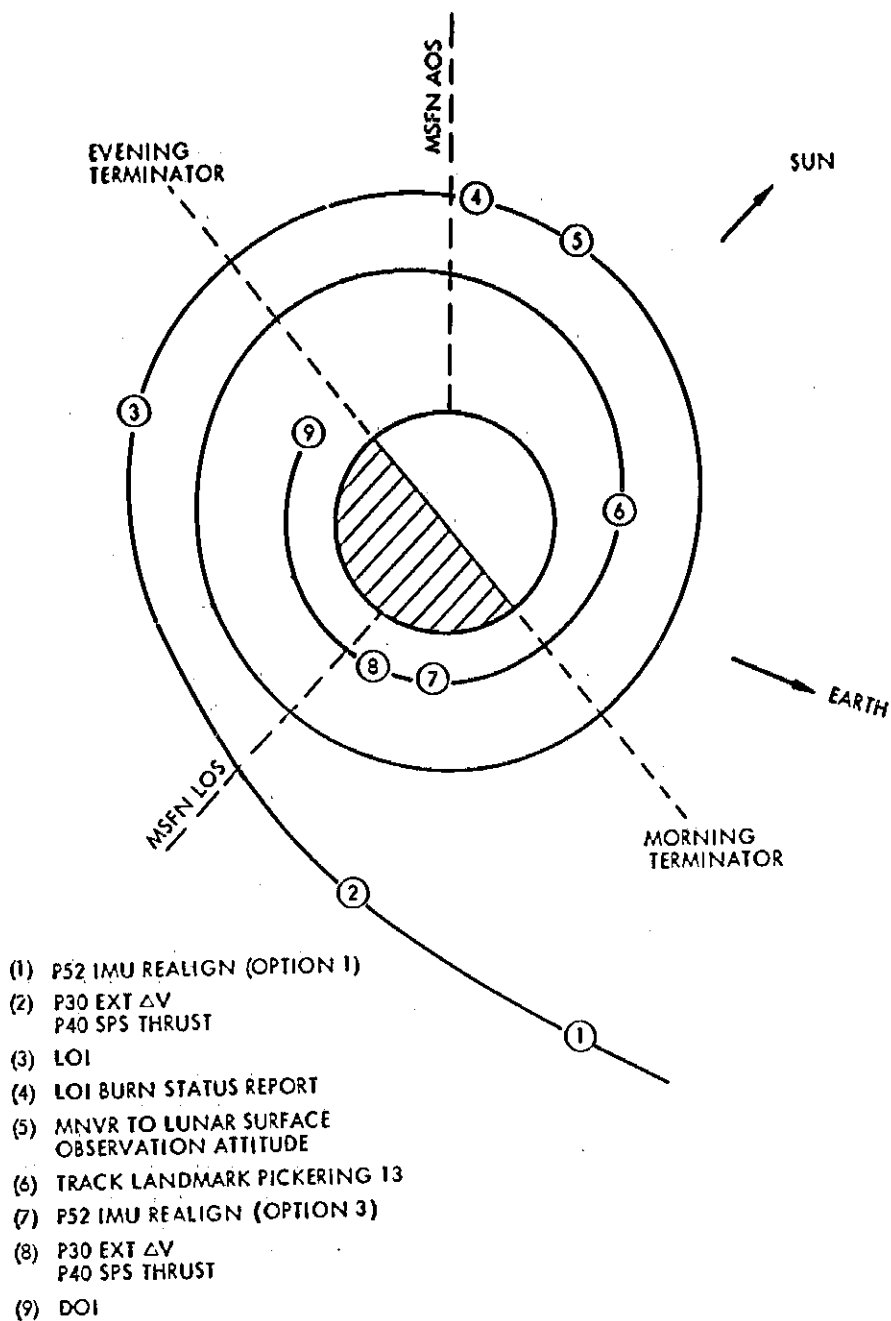


Figure 5-1. Typical LOI to DOI Sequence of Events

not occur during a single SPS burn. This means that if the BMAG's display disagree, the one that is not nominal is assumed to be failed. If both BMAG's displays are off-nominal, the GNCS is assumed failed.

Since presently LOI is not considered no-go if either BMAG's 1 or BMAG's 2 fail prior to the burn, both SCS attitude displays may not be available for LOI monitoring. If either SCS attitude display is not available, the crew will attempt to use an external reference (stars) as a gross third vote, if required.

For confirmed rates greater than 10 degrees per second, the commander (CDR) will turn the translation hand controller clockwise. This places the secondary attitude control system (SCS rate CMD mode) in command. It also places the secondary SPS actuator system in the TVC control loop and activates the automatic EMS ΔV cutoff. The ΔV counter must be initialized with ΔVC from the PAD data which are compatible with an SCS auto mode burn.

The vehicle attitudes are also monitored by the CDR and CMP. If any attitude errors exceed the allowable limit and are confirmed, the backup mode is selected. The allowable attitude limit is computed by MCC-H and will not exceed 10 degrees excluding the start transient. This limit was chosen to insure a safe perilune.

If an SPS burn is taken over, control may be switched to SCS auto for completion if the peak attitude excursion is under 17 degrees. If the peak attitude excursion exceeds 17 degrees, the BMAG's 1 are no longer properly aligned, so the burn must be completed with SCS RATE CMD control. With this control mode the SCS FDAI total attitude will be used for steering.

The advantages of continuing the LOI burn under SCS control when a GNCS problem is detected are:

- a) It would be a standard procedure regardless of the type of GNCS problem.
- b) It would provide as much time as needed to analyze and verify the failure.

- c) A premature shutdown during the first half of the LOI burn could require a time-critical burn since the abort ΔV would be increasing continuously with time.
- d) The abort block data would be more nearly applicable.
- e) The nominal timeline would be maintained so that some or all of the lunar orbit mission objectives could be attained if the G&N could be fixed.

The GNCS controlled LOI burn will be shut down manually when the burn time exceeds $BT + 10$ seconds. This limit was chosen to make it extremely probable that the GNCS would automatically shut down the SPS if it is going to, and also to assure a safe perilune.

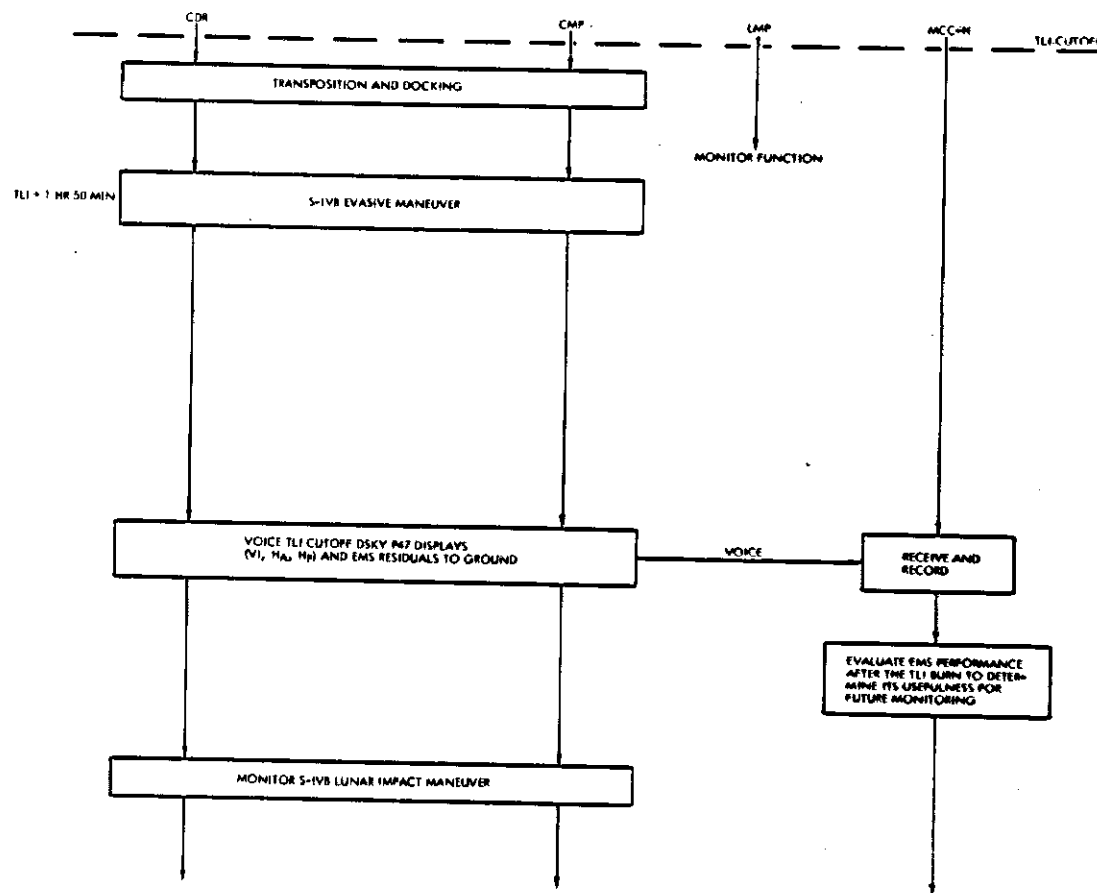
5.9 SPS MIDCOURSE CORRECTION BURN MONITOR

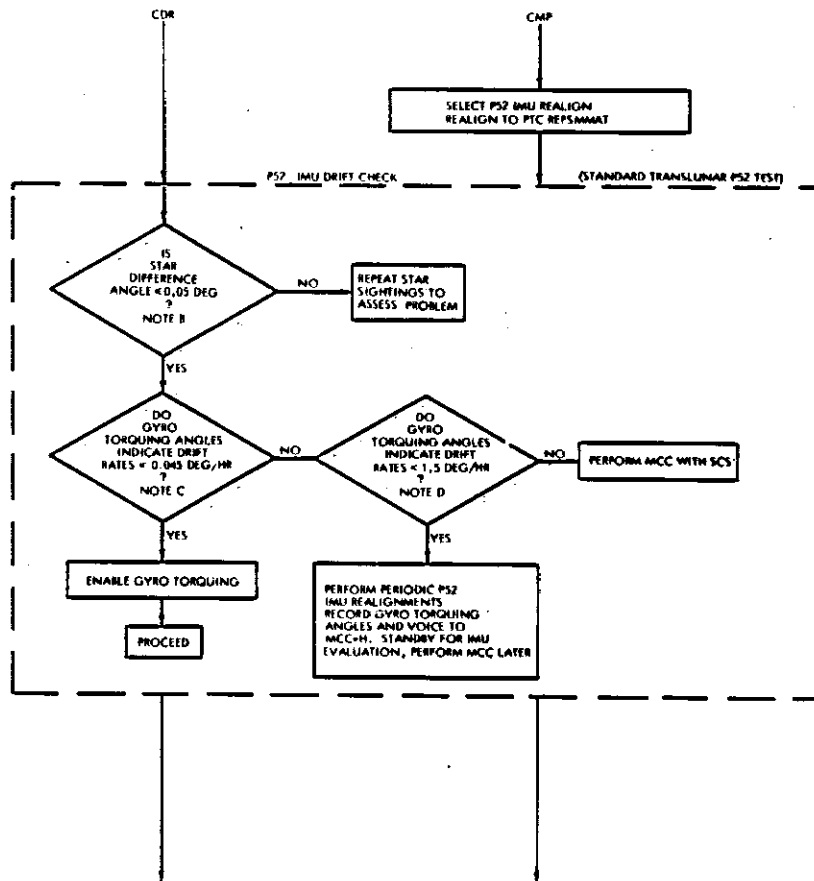
The SPS MCC burn monitoring procedures are similar to those described for the LOI burn monitor (Section 5.8). In the event the attitude or rate limits (10 degrees and 10 degrees per second excluding the starting transient) are exceeded, the procedure is to switch to SCS RATE CMD mode, damp rates, and terminate the burn. The SPS MCC burns will also be manually terminated if the nominal burn time (PAD data) is exceeded by 1 second.

5.10 ABORT (BLOCK DATA) BURN MONITOR

The block data abort burn monitoring procedures are very similar to those described for the LOI burn monitor (Section 5.8). In the event the attitude or rate limits (10 degrees and 10 degrees per second excluding the starting transient) are exceeded, the procedure is to switch to SCC RATE CMD mode and damp rates. The burn may then be completed with either the SCS RATE CMD mode or the SCS AUTO mode. Before the burn, ΔVC will be slewed into the EMS ΔV counter. The burn will be terminated manually if the EMS ΔV counter reads less than -70 feet per second and the burn time is greater than $BT + 10$ seconds.

For TEI 1 and 4 block data maneuvers (no communications), the burn will be terminated if the EMS ΔV counter reads less than -40 feet per second and the burn time is greater than $BT + 10$ seconds.





MCC-H

TL1-3 HR

NOTE B

- CURRENT VALUE BASED ON: SIGHTING ACCURACY
- RESPONSIBILITY: MIT
- DATE AVAILABLE: 26 SEPTEMBER 1988
- REFERENCE: 4

NOTE C

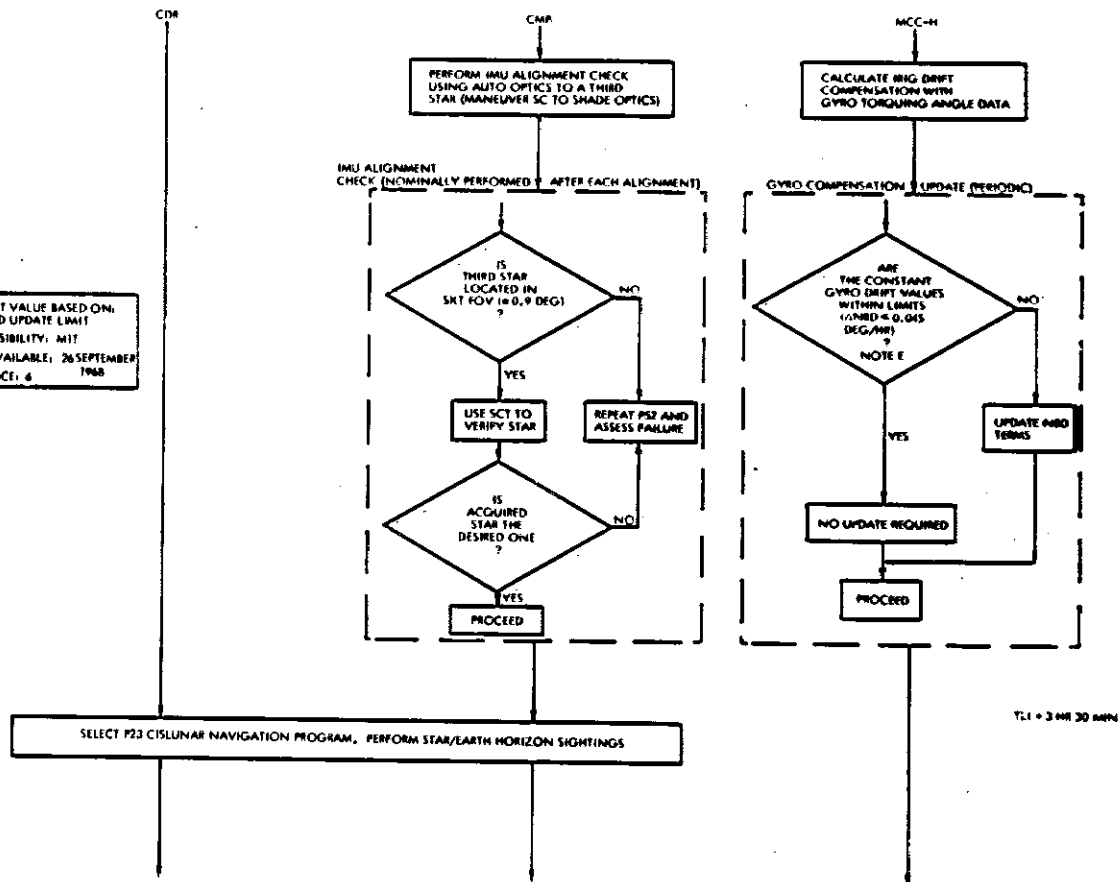
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- RESPONSIBILITY: MIT
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- REFERENCE: 4

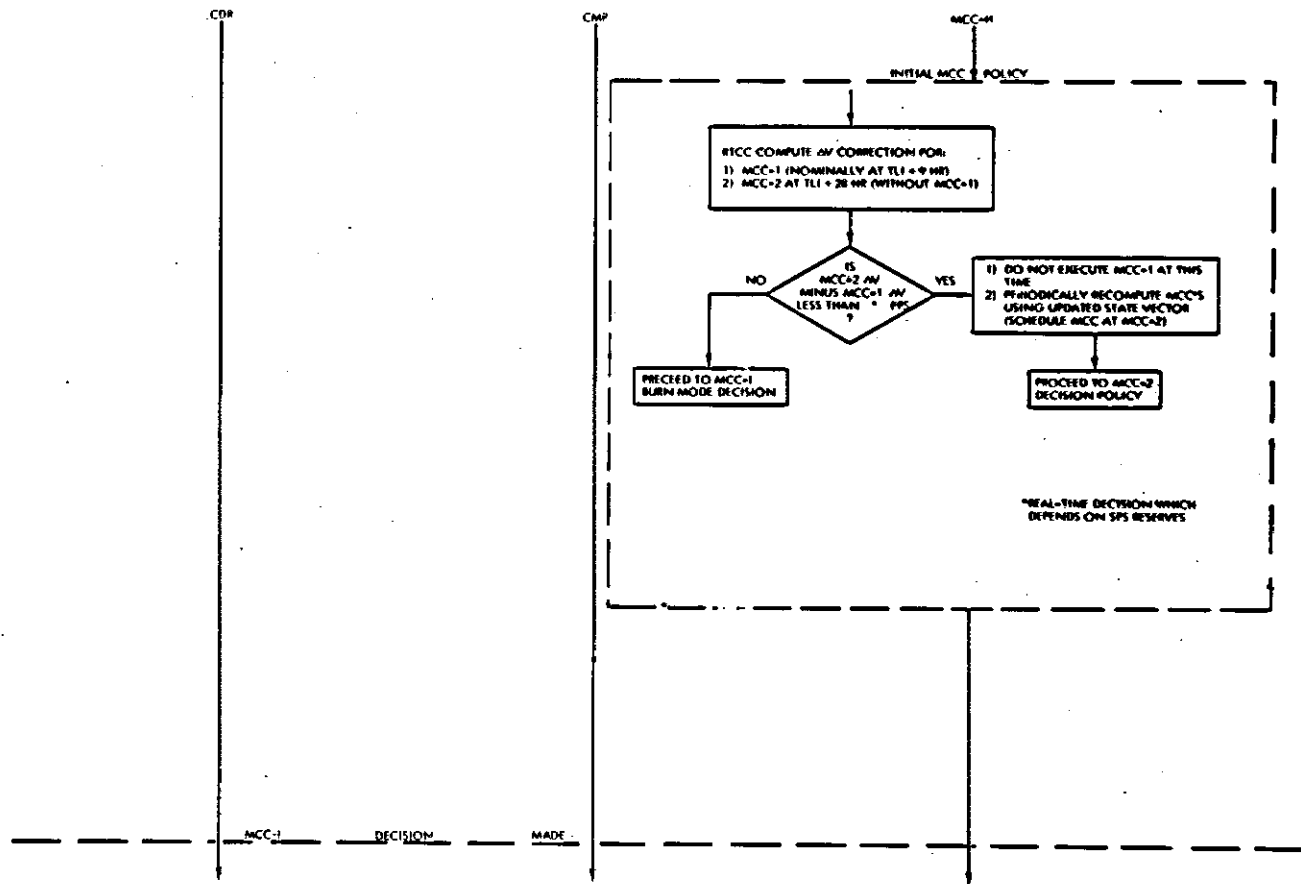
NOTE D

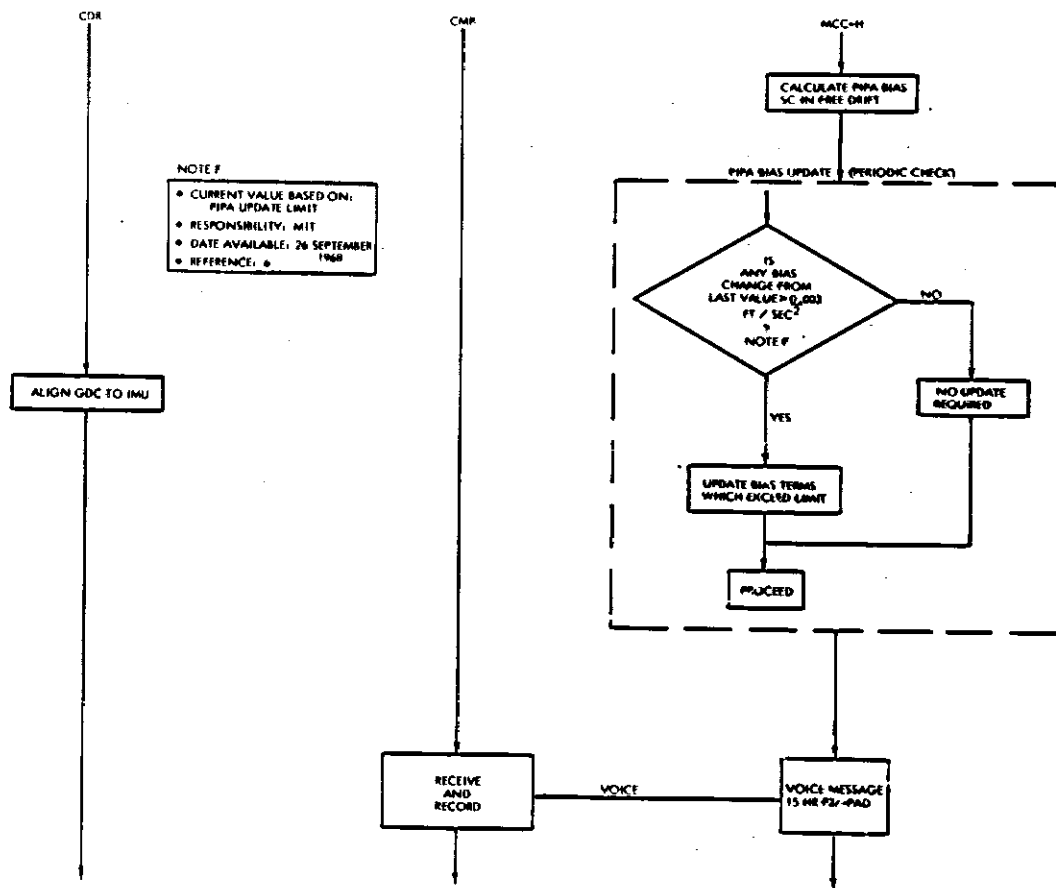
- CURRENT VALUE BASED ON: ALLOWABLE GYRO DRIFT RATE
- RESPONSIBILITY: MIT
- DATE AVAILABLE: 27 NOV. 1988
- REFERENCE: 5

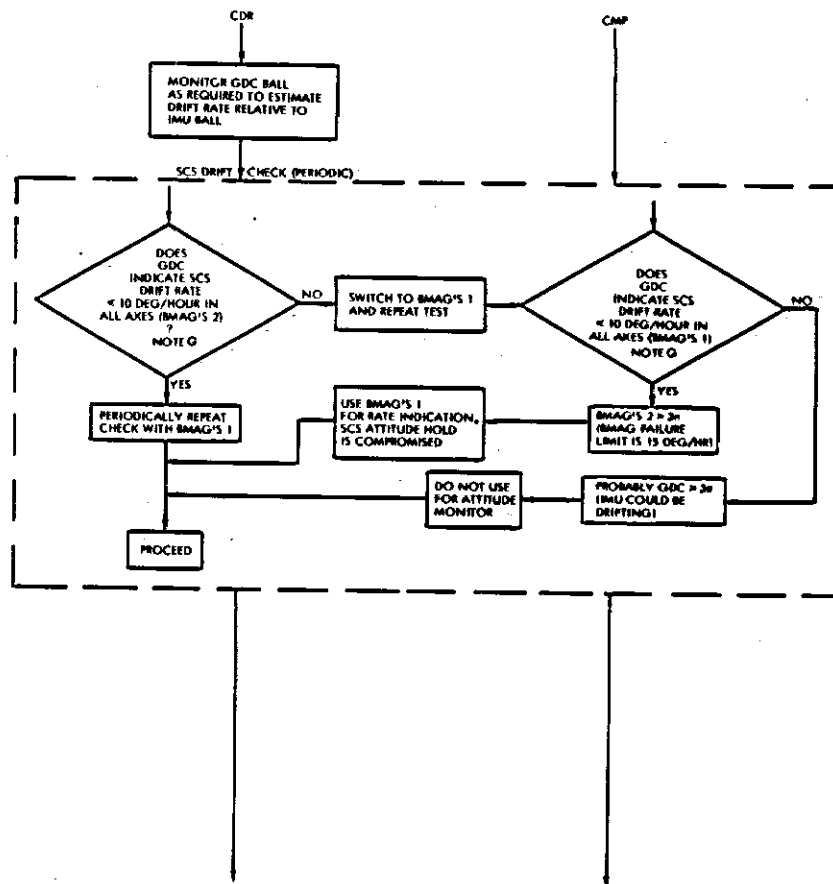
NOTE E

- CURRENT VALUE BASED ON: AND UPDATE LIMIT
- RESPONSIBILITY: MIT
- DATE AVAILABLE: 26 SEPTEMBER 1968
- REFERENCE: 4







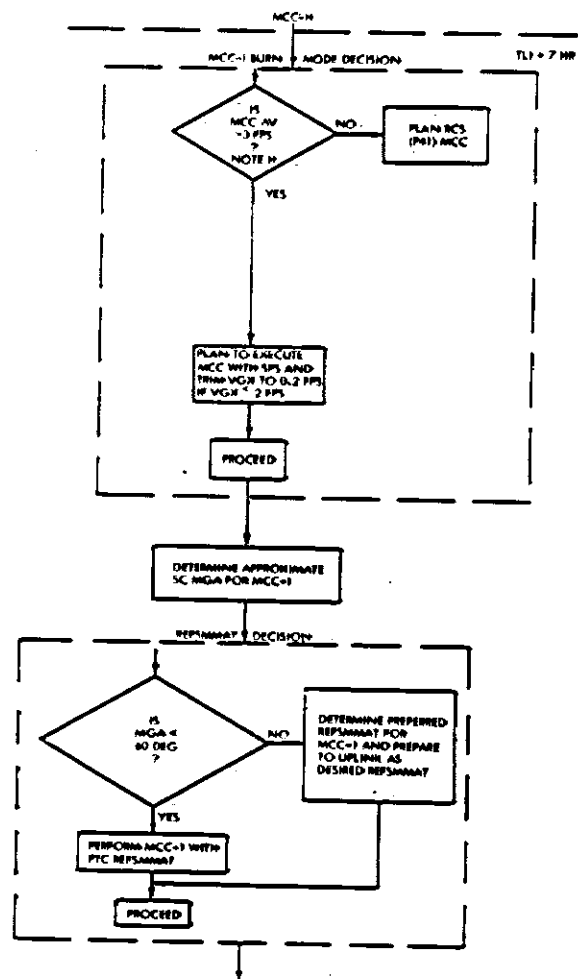


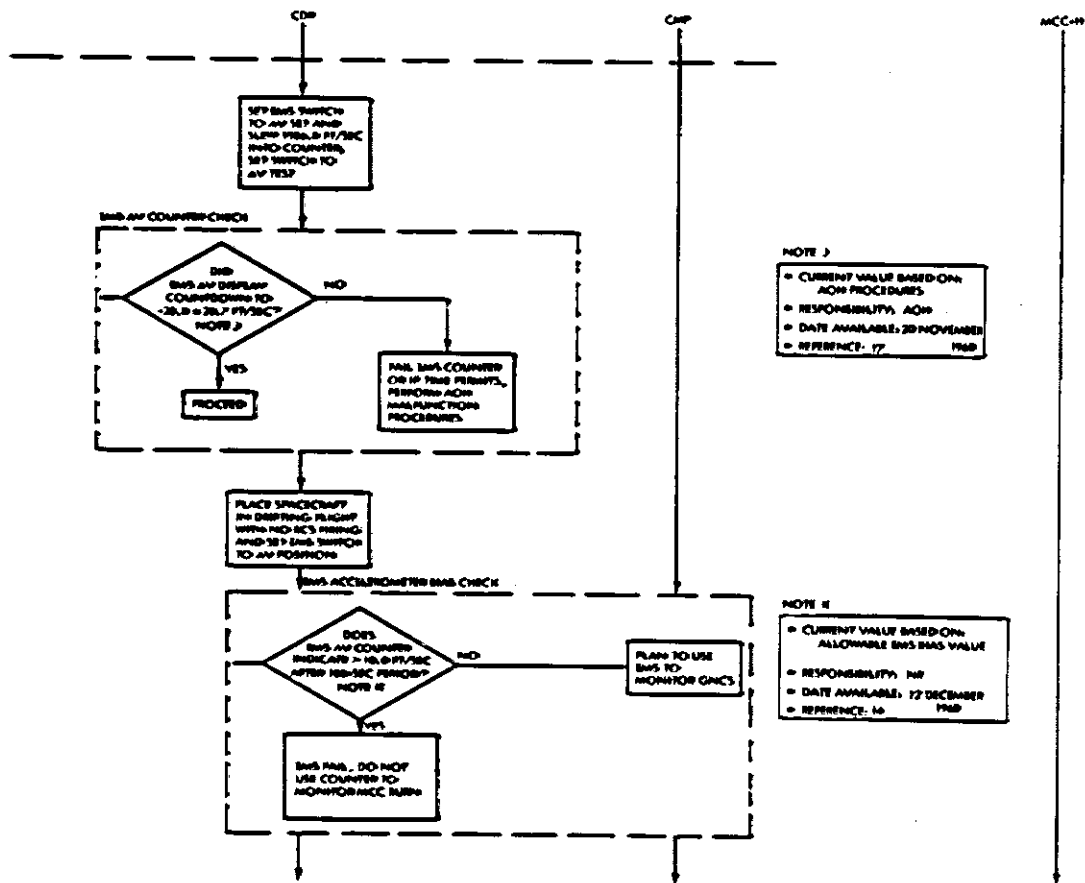
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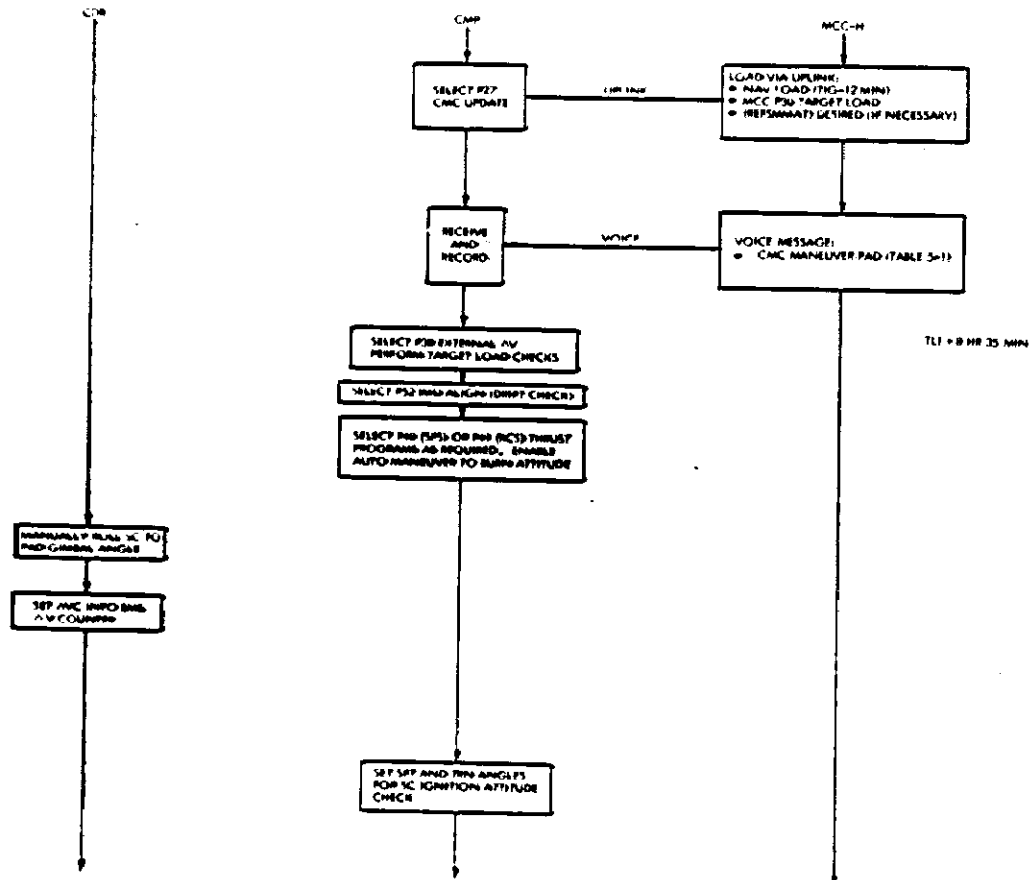
- CURRENT VALUE BASED ON:
30 SCS DRIFT LIMIT
- RESPONSIBILITY: NR
- DATE AVAILABLE: 14 NOV 1968
- REFERENCE: 43

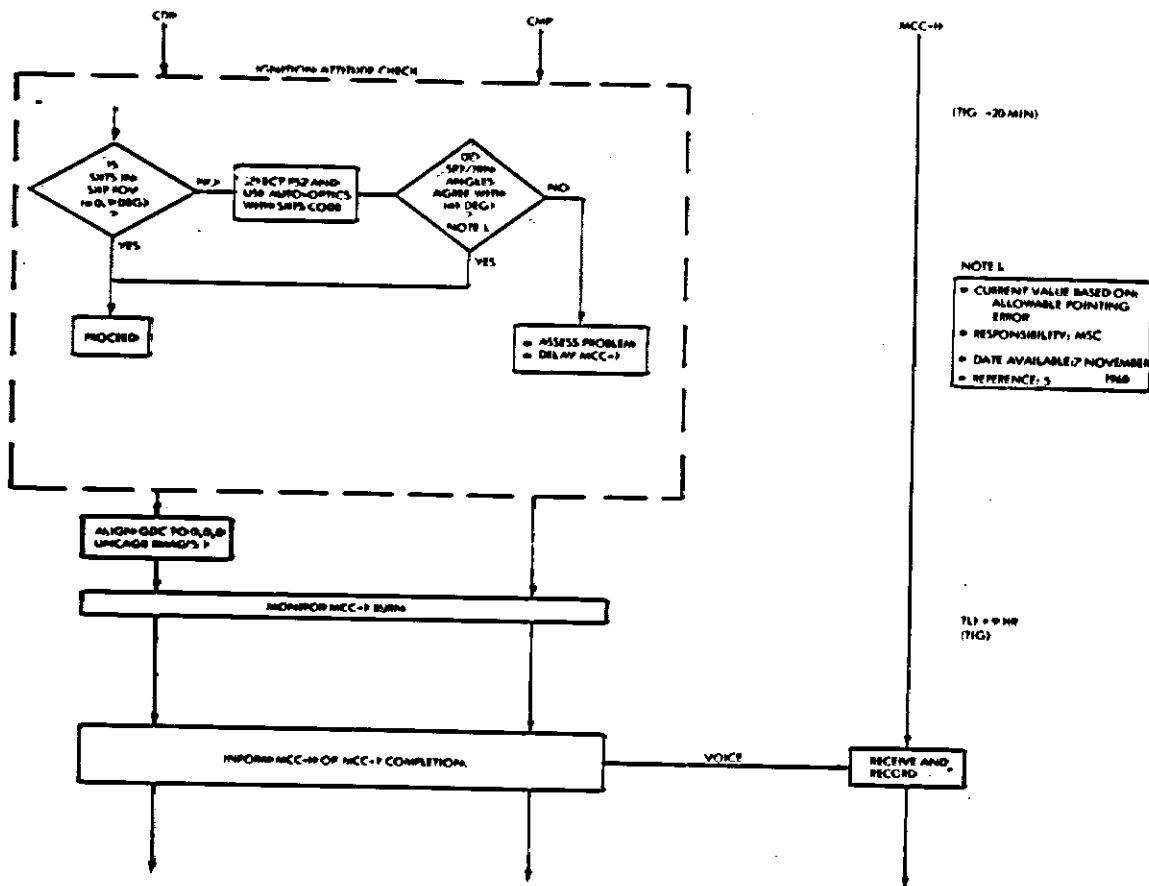
NOTE 11

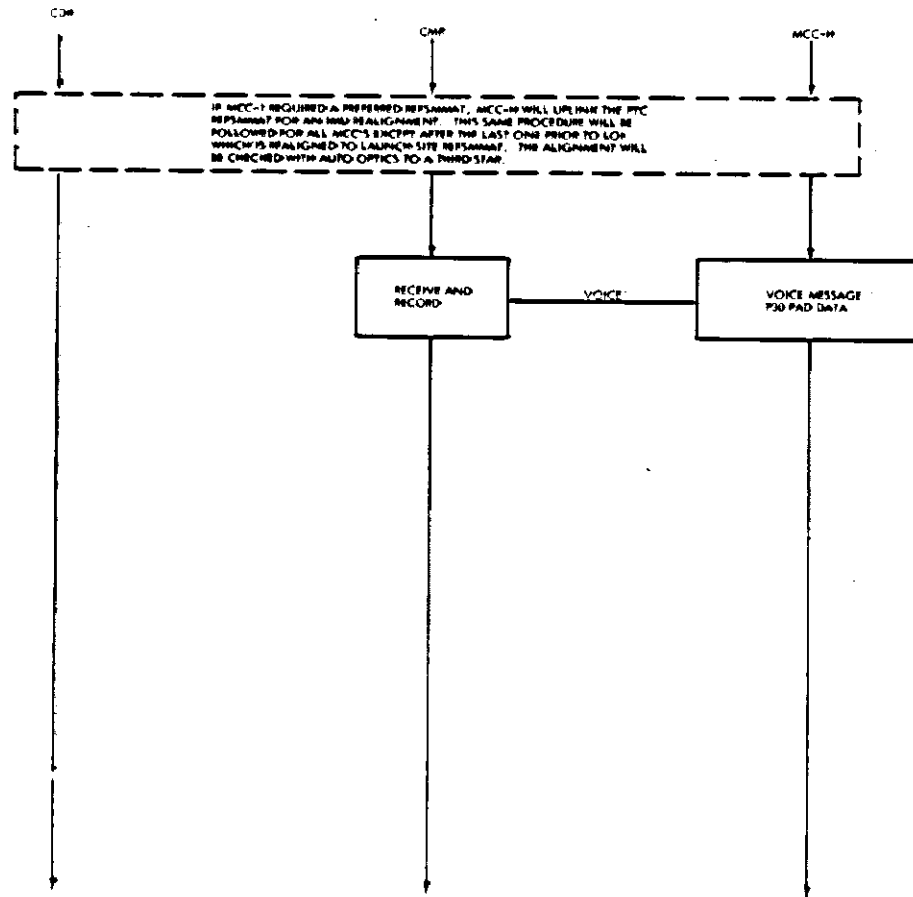
- CURRENT VALUE BASED ON SPS VS. RCS CROSSOVER
- RESPONSES: PPS, WPPD, GUIDANCE AND PERFORMANCE BRANCH
- DATE AVAILABLE: 10 MAY 1969
- REFERENCES: 68-0483-12a











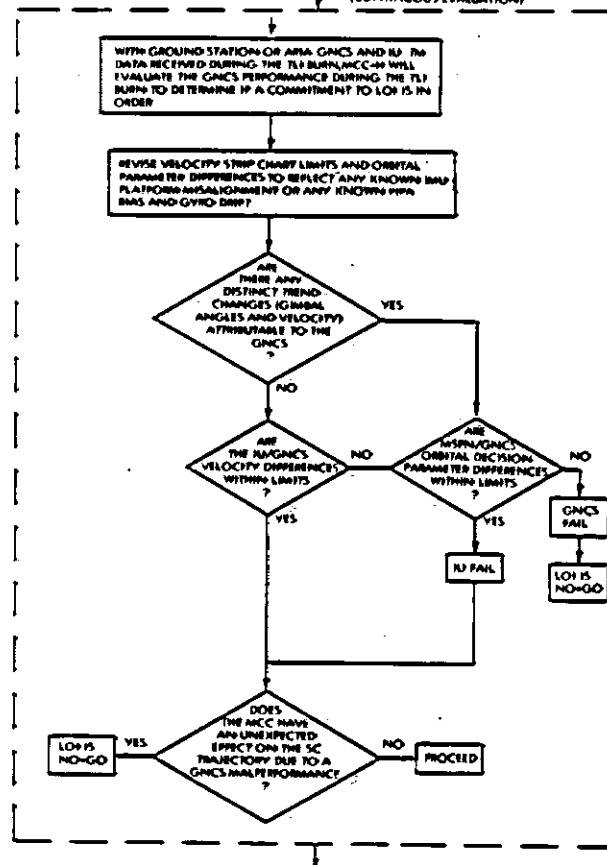
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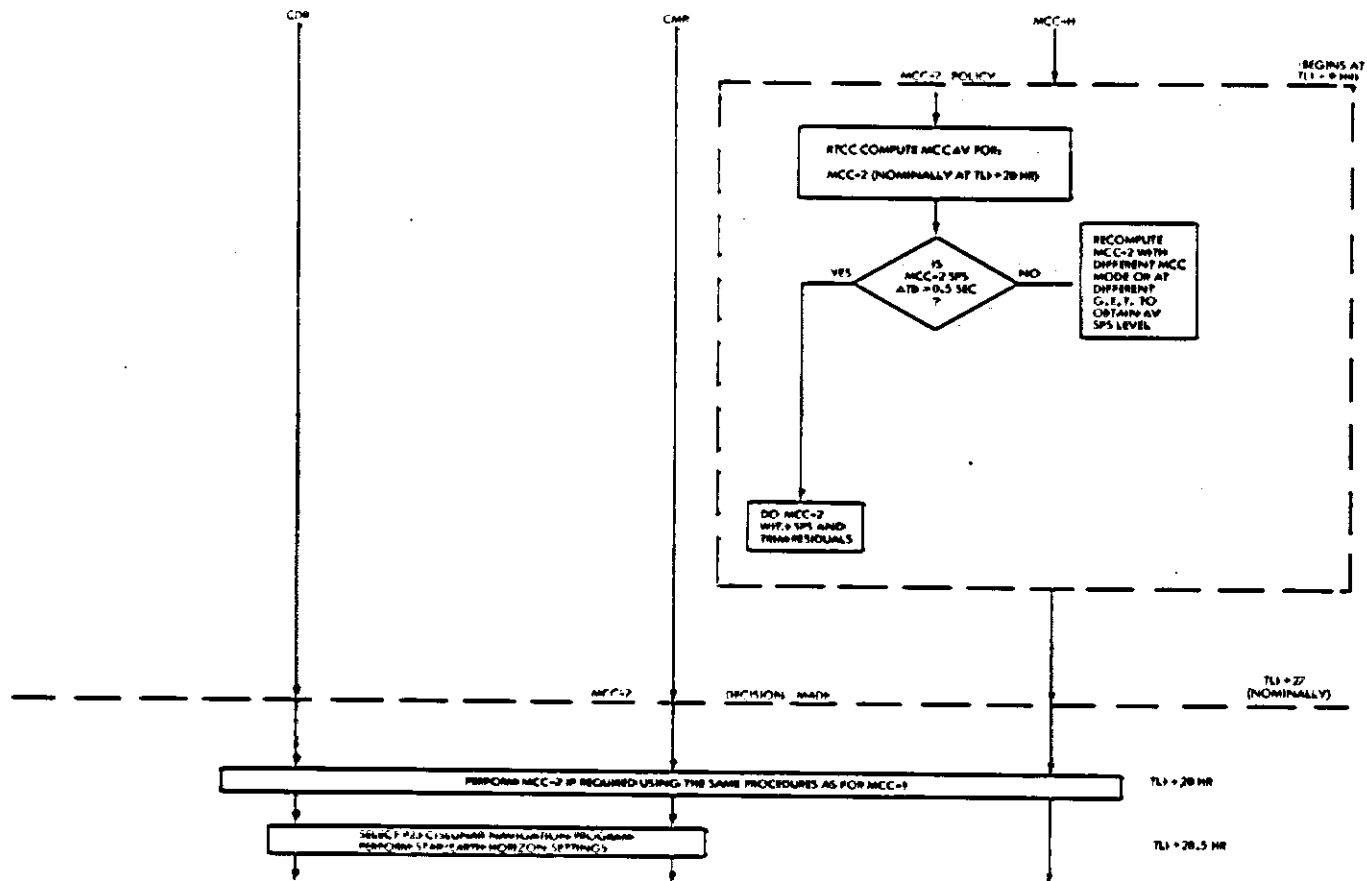
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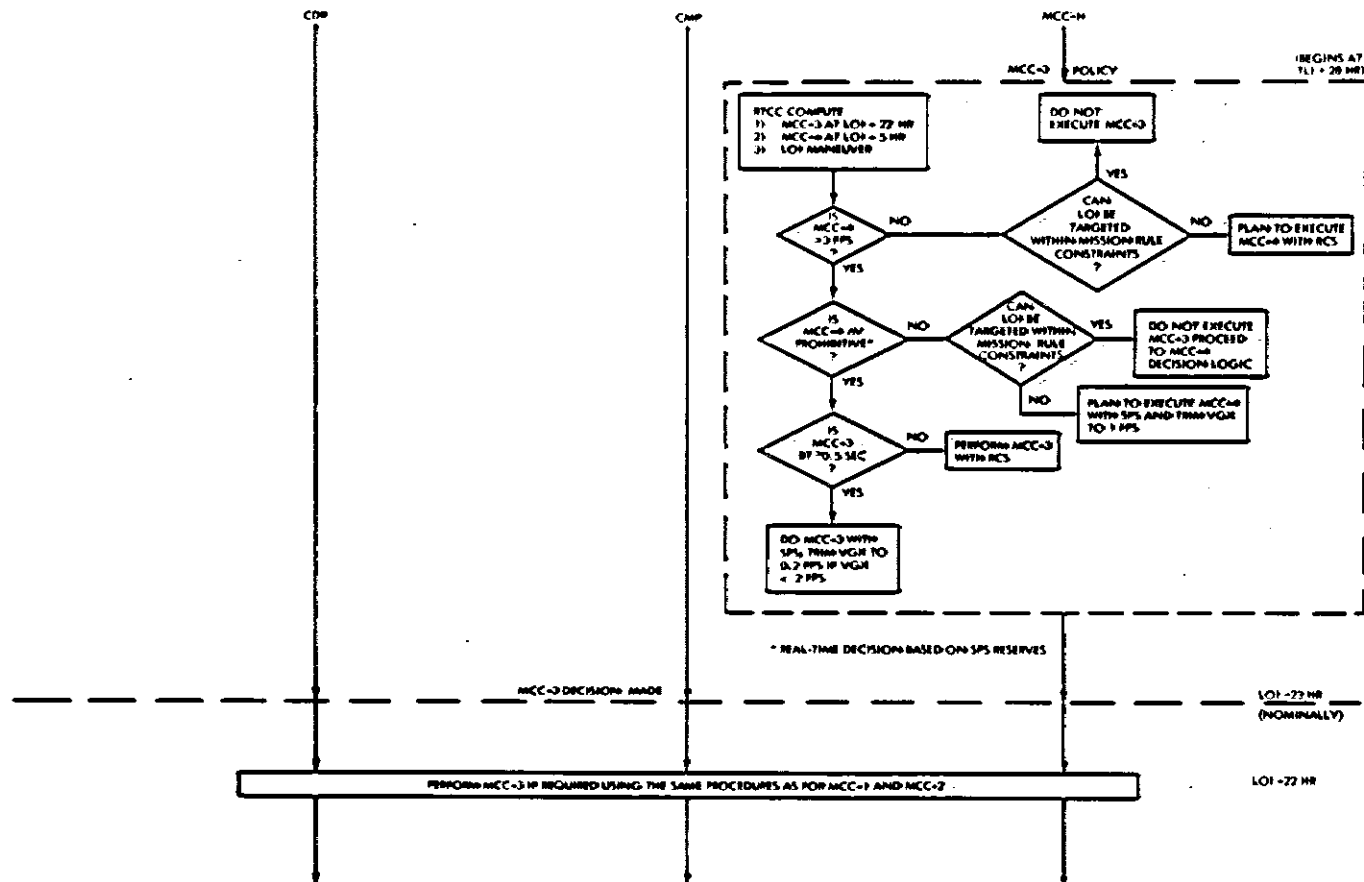
MCC-H

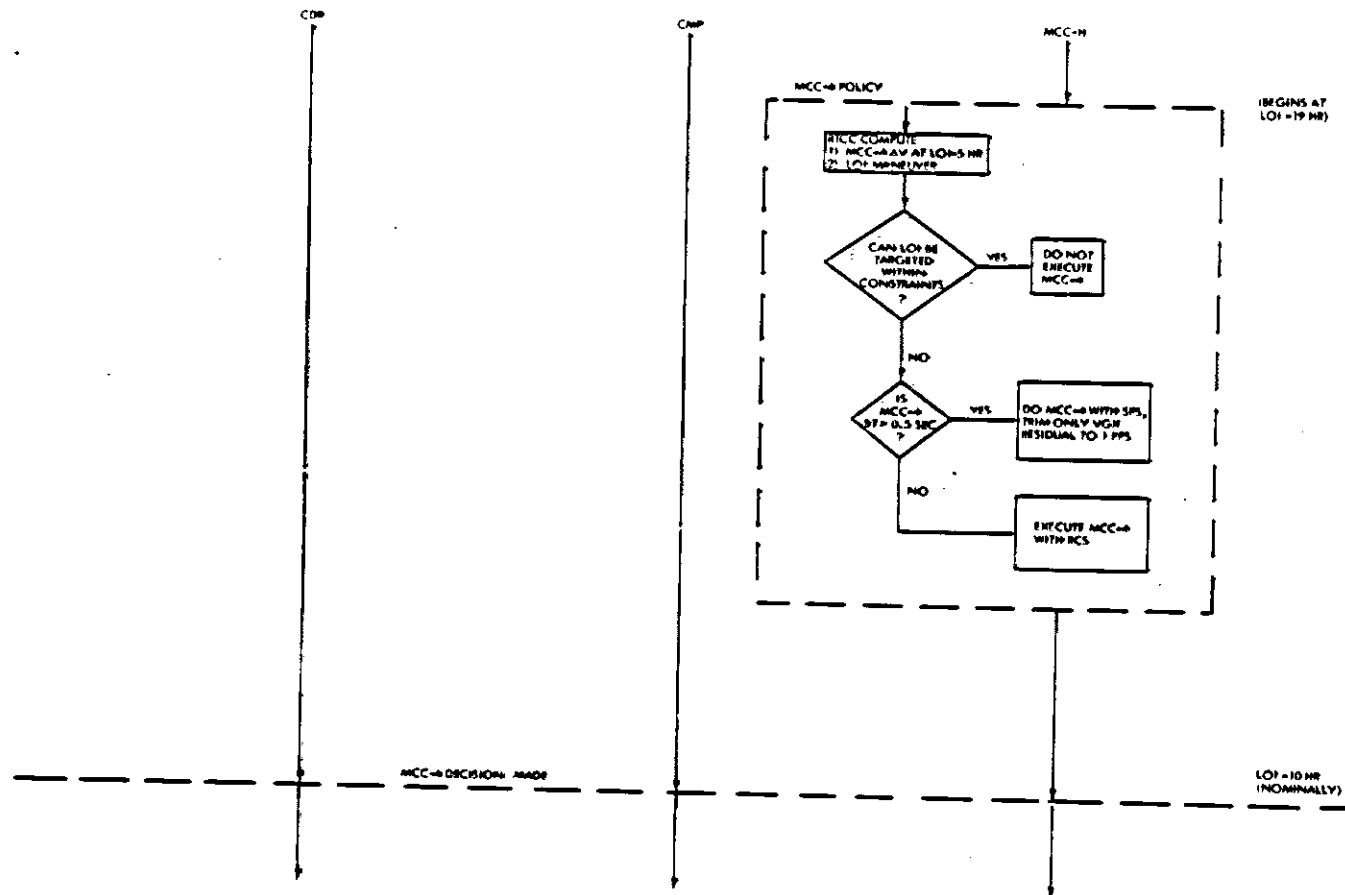
MCC-H LOI GO/NO-GO DECISION

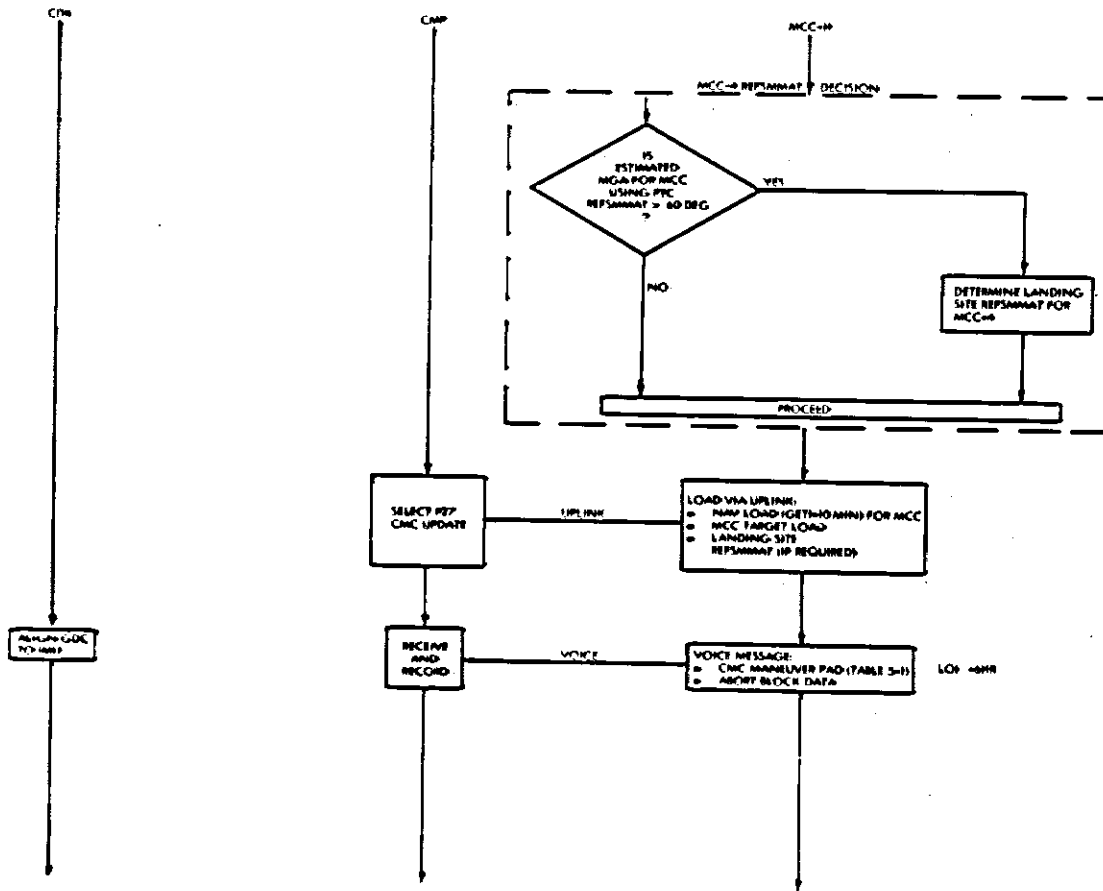
(CONTINUOUS EVALUATION)

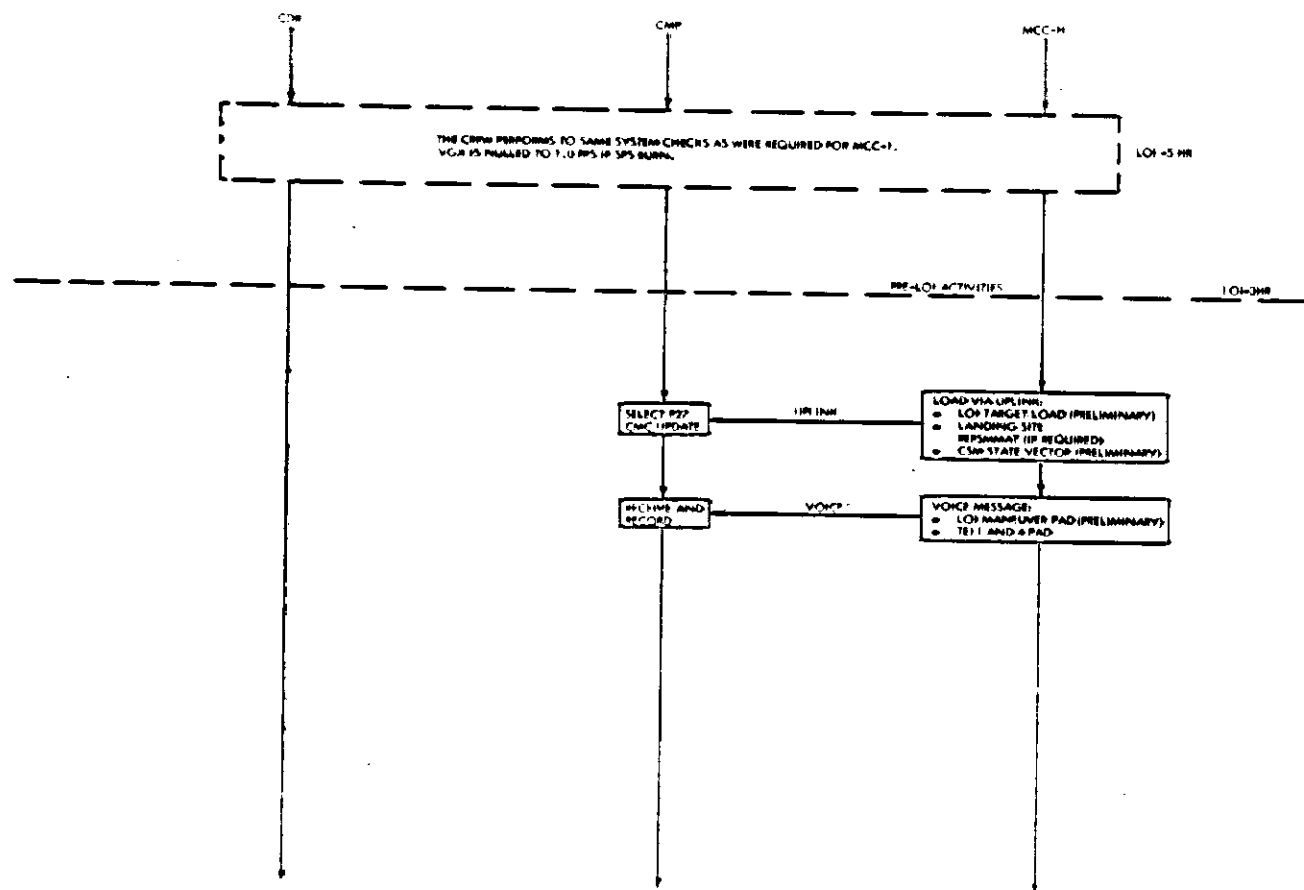


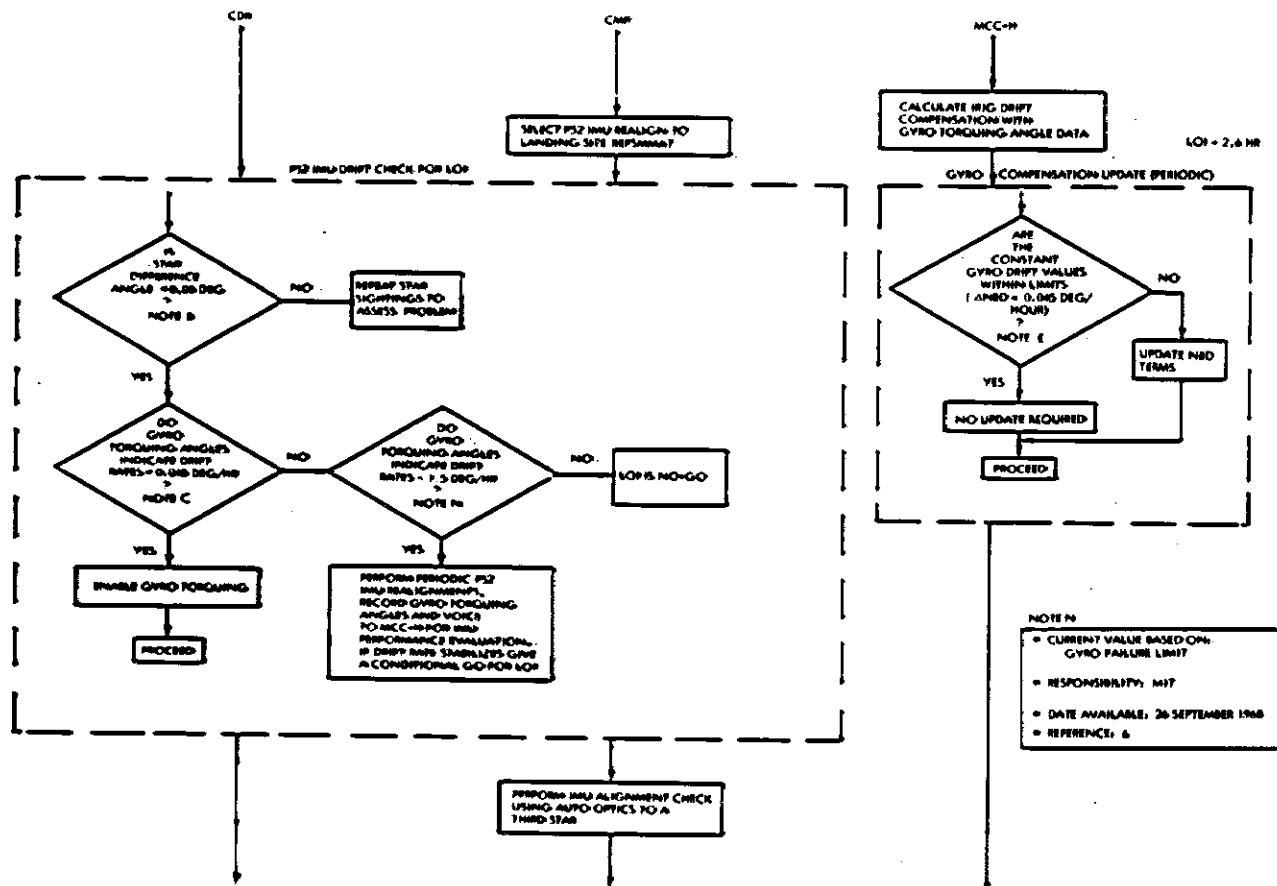


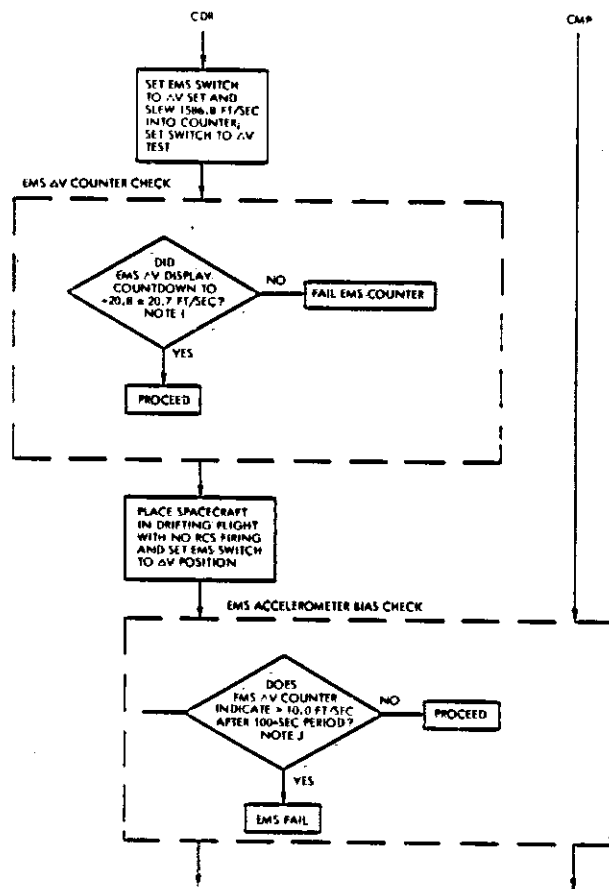


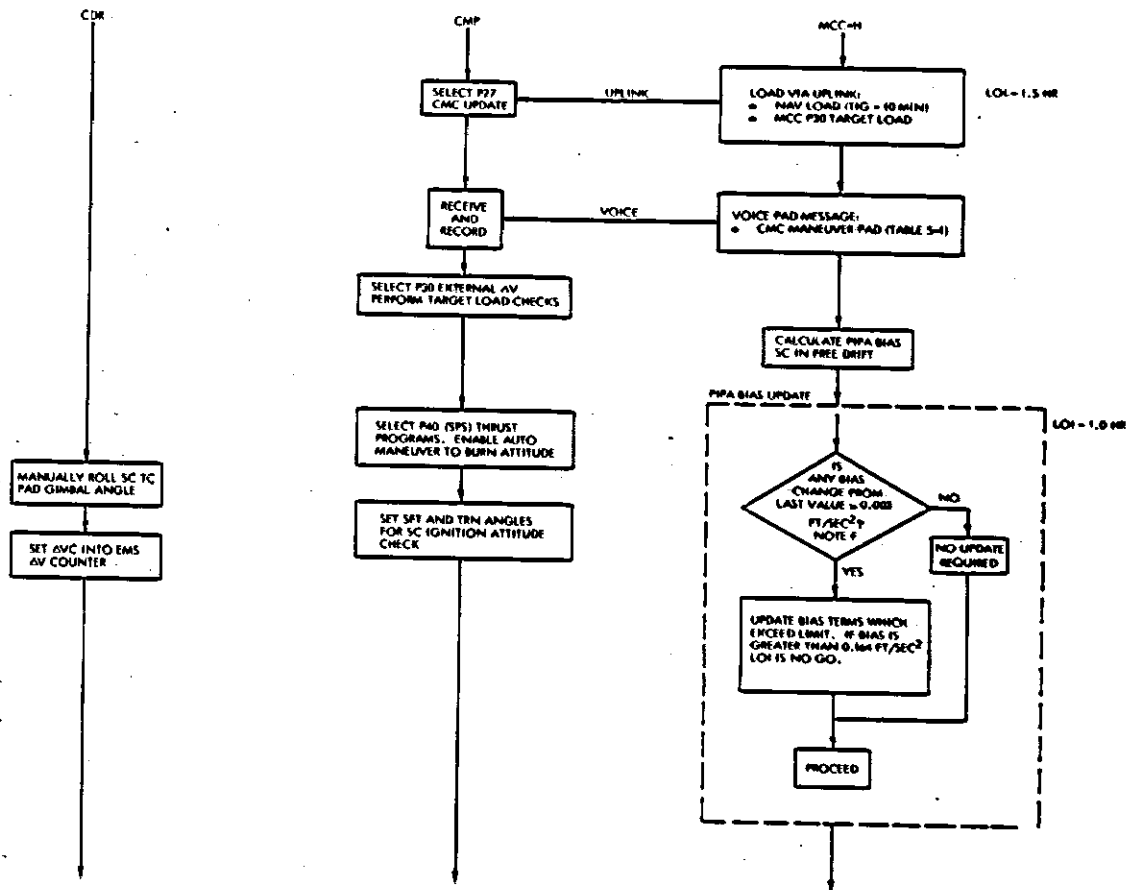


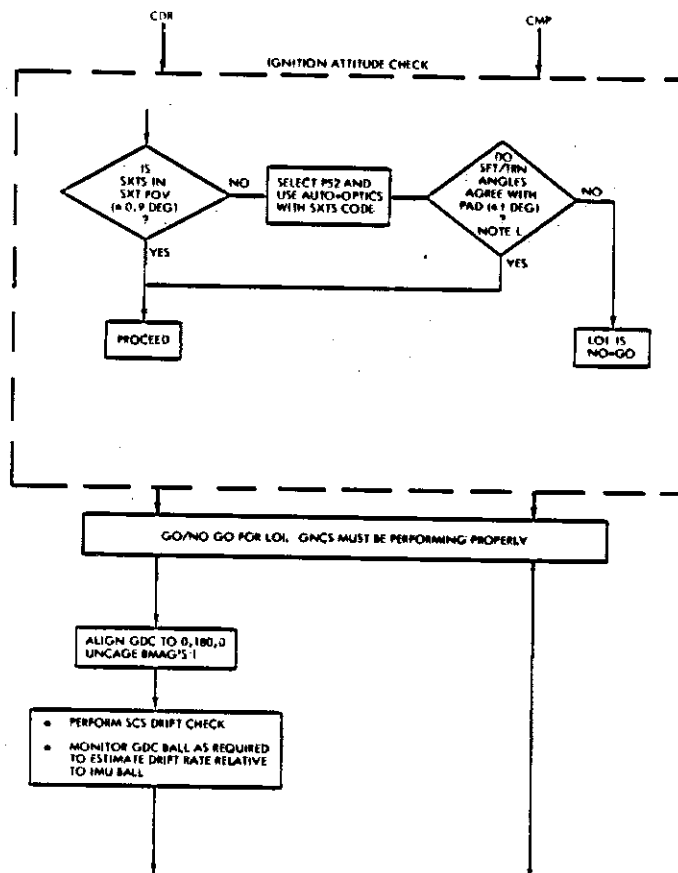










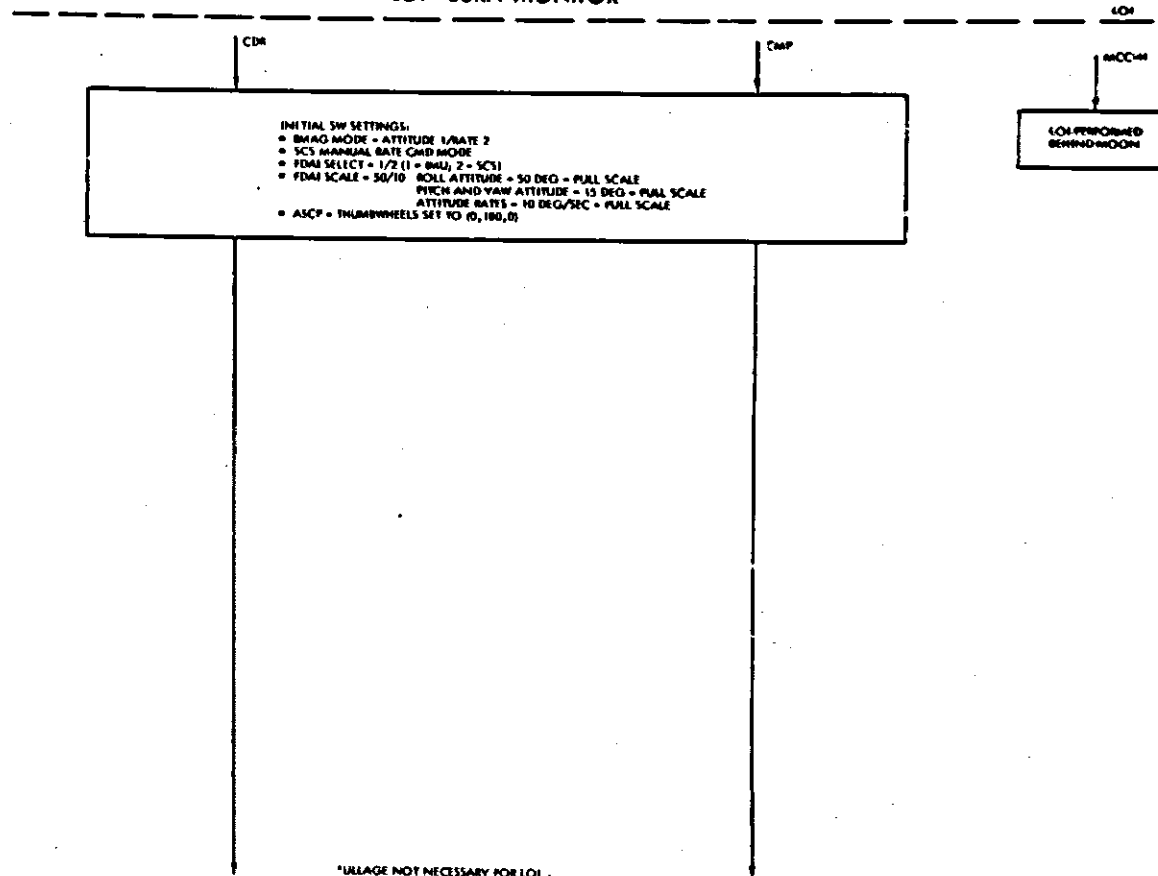


MCC-H

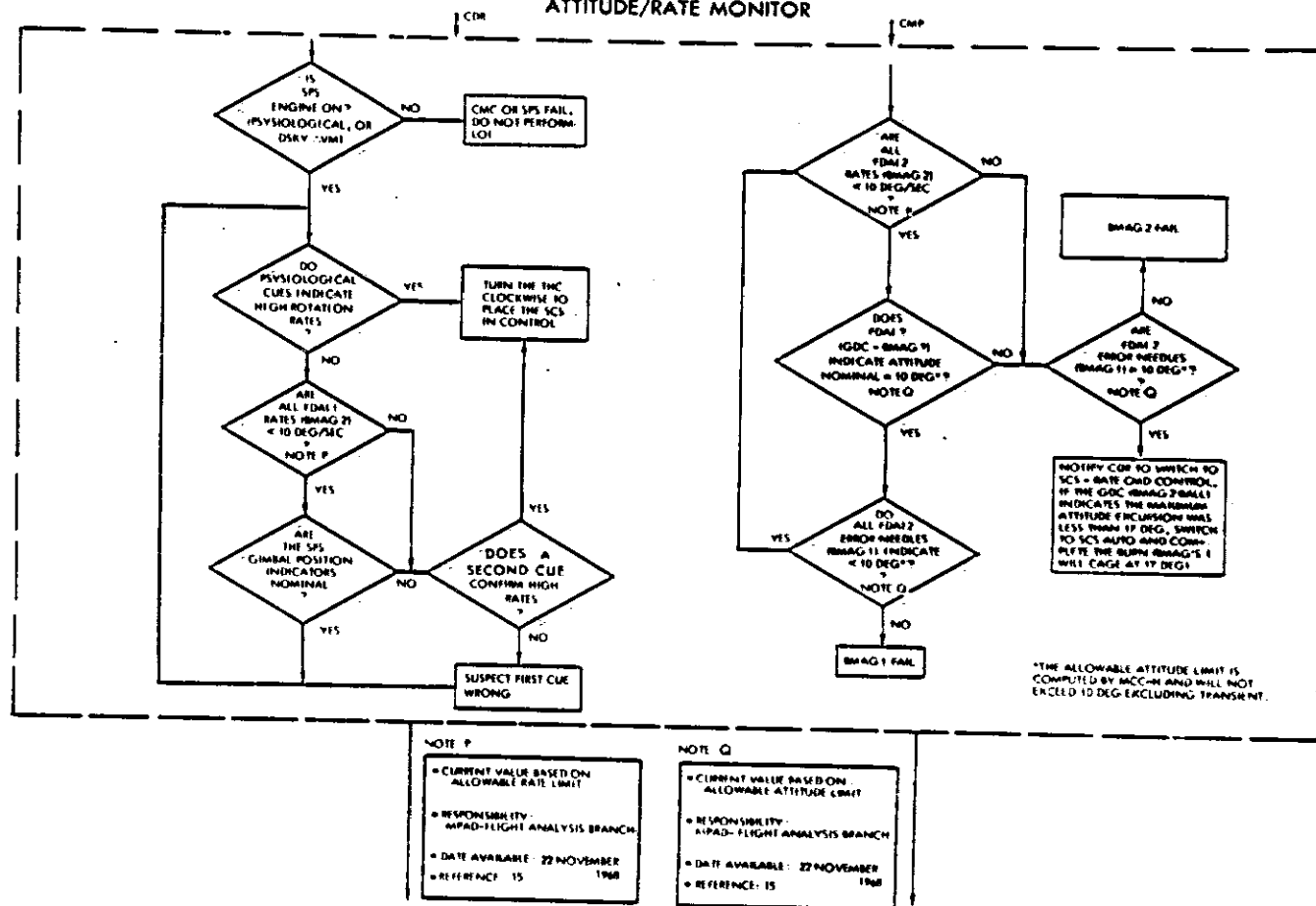
LOI=0,7 HR

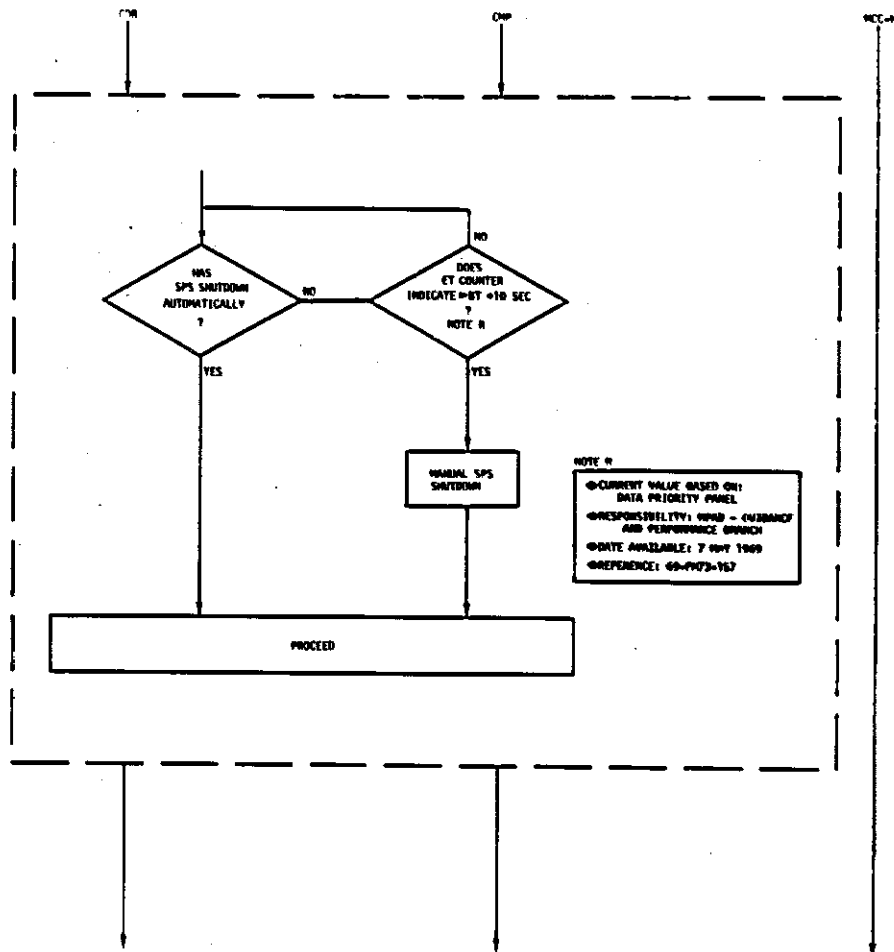
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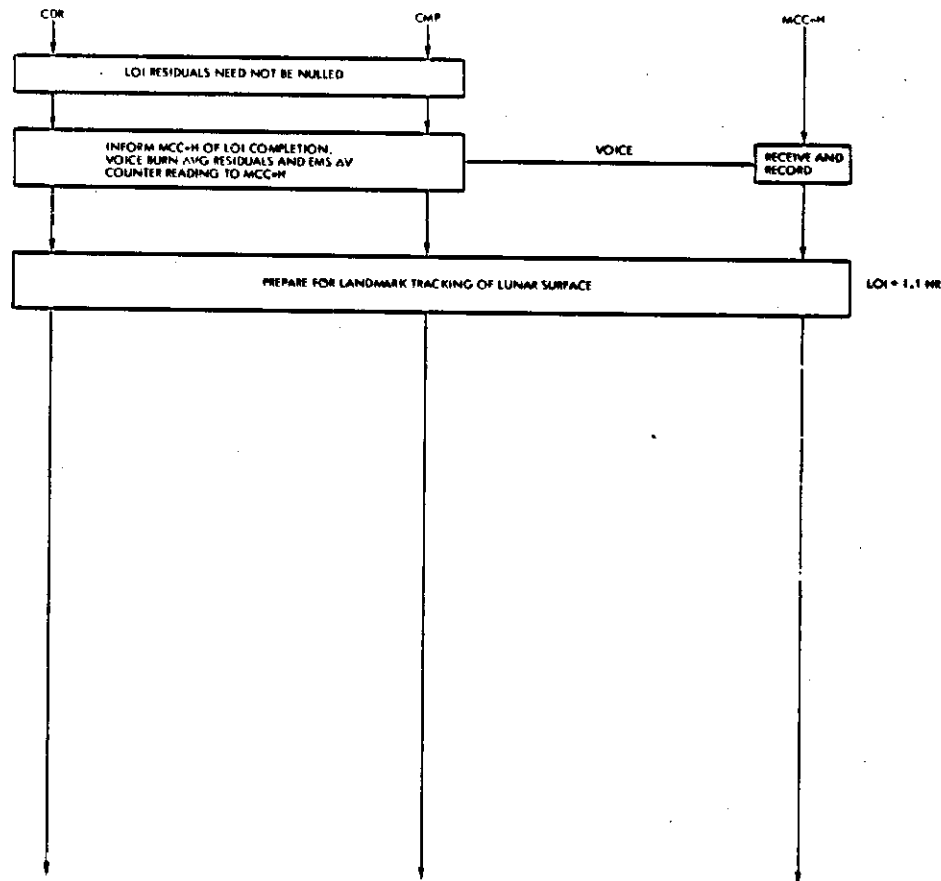
LOI BURN MONITOR



ATTITUDE/RATE MONITOR







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