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(*70-28644)
MSC-O1522



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MSC INTERNAL NOTE

FEBRUARY 9, 1970

APOLLO MISSION TECHNIQUES MISSION H-2 AND SUBSEQUENT LUNAR POWERED ASCENT

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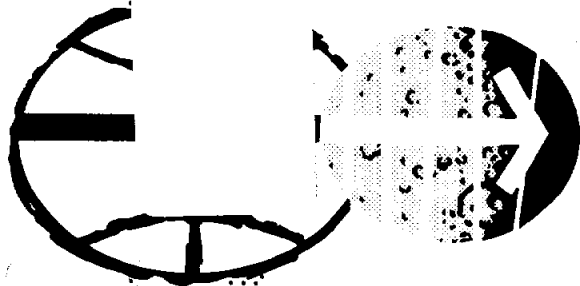
TECHNIQUES DESCRIPTION

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

FINAL ISSUE

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

AVAILABLE TO NASA AND
NASA CONTRACTORS ONLY



MSC INTERNAL NOTE

APOLLO MISSION TECHNIQUES
MISSION H-2 AND SUBSEQUENT
LUNAR POWERED ASCENT

February 9, 1970

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

Approved by:



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

FOREWORD

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

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

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 ensure compatibility of all related MSC and supporting contractor activities.

For each mission phase, a Data Priority Working Group has been established under the direction of Chief, Apollo Data Priority Coordination, ASPO. These groups, which are comprised of representatives of MSC and support contractors, hold frequent meetings to coordinate their various associated activities and develop agreed-upon mission techniques. TRW assists in the development of the techniques and documents them for ASPO. After formal review by ASPO, E&DD, FCOD, FOD, GAEC, MDC, MIT, NR, and TRW, a document such as this one is issued.

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

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NOMENCLATURE

AEA	abort electronics assembly
AGS	abort guidance system
ALT	altitude
ALT RT	altitude rate
APS	ascent propulsion system
ASC	ascent
AT-3	P57 star/gravity IMU alignment technique
BAL CPL	balanced couple
CDR	commander
CR	crossrange
CRSFD	cross feed
CSI	concentric sequence initiation
CSM	command service module
DEDA	data entry and display assembly
DSKY	display and keyboard
FDAI	flight director attitude indicator
g	acceleration of gravity
G&N	guidance and navigation
GUID CONT	guidance control
H	altitude
\dot{H}	altitude rate
H_P	pericynthion altitude (measured relative to launch site)
IMU	inertial measurement unit
LM	lunar module
LMP	lunar module pilot

NOMENCLATURE (Continued)

LVLH	local vertical, local horizontal
MCC-H	Mission Control Center-Houston
MON	monitor
MSFN	Manned Space Flight Network
PFP	Powered Flight Processor
PGNCS	primary guidance navigation and control system
PRO	proceed
PROG	program
P12	Powered Ascent Guidance Program
P47	Thrust Monitor Program
P57	Lunar Surface Alignment Program
R	range
\dot{R}	range rate
RCS	reaction control system
RGO	range to go
RNG	range
RR	rendezvous radar
RTCC	Real-Time Computer Complex
R40	DPS/APS Thrust Fail Routine
SEL	selection
SOV	shutoff valve
TFI	time from ignition
TIG	time of ignition
TGO	time to go
T/M	telemetry

NOMENCLATURE (Continued)

VGX	velocity-to-be-gained in body X-direction
VGY	velocity-to-be-gained in body Y-direction
VGZ	velocity-to-be-gained in body Z-direction
VHF	LM-CSM voice communications and ranging device
V_I	inertial velocity magnitude
V_{MSFN}	velocity obtained from MSFN data
\dot{Y}	crossrange velocity
\dot{Z}	downrange velocity
γ	flight-path angle
ΔH	delta altitude
ΔV	delta velocity
ΔW_P	wedge angle
$\Delta \dot{X}_A, \Delta \dot{Y}_A, \Delta \dot{Z}_A$	differences between AGS and PGNCS (AGS-PGNCS) estimated velocity components in local vertical coordinates, where X is downrange, Y is out of plane, and Z is radial
$\Delta \dot{X}_L, \Delta \dot{Y}_L, \Delta \dot{Z}_L$	differences between PFP and PGNCS (PFP-PGNCS) estimated velocity components in the same local vertical coordinates as defined above
$\Delta \dot{\rho}_{RRP}$	difference between rendezvous radar measured range rate (LM to CSM) and PGNCS estimate of rendezvous radar range rate (RR-PGNCS)
$\Delta \dot{\rho}_{MP}$	difference between MSFN measured range rate and PGNCS estimate of MSFN to LM range rate (MSFN-PGNCS)

1. INTRODUCTION

The guidance and navigation sequence of events, flow of data, and real-time decisions which must be made for the lunar ascent phase of the H-2 (Apollo 13) lunar landing mission are presented in this document. The recommended procedures are presented in flow charts which are preceded by a description of the rationale involved.

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

The mission techniques for the period just preceding the lunar ascent are presented in the lunar surface phase document, Reference 1. The mission techniques for the period following insertion are presented in the lunar orbit activities document, Reference 2.

2. DISCUSSION

The ascent phase of the H-2 mission starts when the lunar module (LM) lifts off the lunar surface and terminates when the LM achieves targeted orbit conditions. The ascent trajectory consists of a vertical rise for about 10 seconds during which the LM is yawed to the proper azimuth. The LM is then pitched along a flight path targeted to insert the vehicle in a 9- by 45-nautical mile lunar orbit in-plane with the command service module (CSM).

Assuming the PGNCS operates properly, the PGNCS program P12 (which controls the LM without astronaut assistance) will be used throughout the ascent. The astronauts are required only to monitor the trajectory and system parameters. Should the PGNCS fail or if its performance becomes sufficiently degraded to cause an unsafe orbit, LM control will be switched to the abort guidance system (AGS). In the event both PGNCS and AGS are not operational, a backup manual guidance procedure will be used. This procedure is presented in the manual ascent techniques description document, Reference 3.

The procedures presented herein are designed to ensure a safe orbit which is defined as having a pericynthion altitude greater than 30,000 feet and a wedge angle less than 1 degree.* These procedures are based on the following ground rules:

- The AGS and PGNCS systems are maintained independently (except for their initial state vectors) for ascent. An AGS lunar alignment is used prior to lift-off to preclude a common misalignment error which could (but normally would not) go undetected by ground monitoring prior to lift-off.
- There is virtually no "launch window" for powered ascent. That is, any problem detected prior to ascent propulsion system (APS) engine ignition which would result in an even slightly delayed lift-off is sufficient reason to delay the lift-off until the next opportunity approximately 2 hours later.

*The 30,000- H_p constraint (measured relative to the launch site) was selected to protect against a possible lunar impact. The 1-degree ΔW_p constraint was chosen to ensure that a LM rendezvous would always be possible in the event that the LM should become inactive after insertion.

- S-band high bit rate communications with the ground (MCC-H) are available during ascent to assess guidance systems performance.
- The crew is responsible for detecting and isolating system problems that require immediate action.
- The ground (MCC-H) is responsible for detecting insidious, slow-drift malfunctions. There is no accepted method for onboard isolation of insidious malfunctions which can result in an unsafe orbit. This is an acceptable situation because to get in trouble the PGNCS has to fail insidiously and ground communication capability has to be lost.
- Guidance control will be continued on PGNCS if it can attain a safe orbit, even if AGS might provide a better insertion orbit. The situation in which the LM is being controlled with a degraded PGNCS (but still inside switchover constraints) is acceptable because it is judged more desirable to insert into a degraded safe orbit and perform a subsequent "tweak" maneuver than to switch systems during ascent (relays, etc. should work, but may not).

In performing the lunar ascent, the following major functions must be accomplished by the crew and MCC-H:

- Preignition activity
- Monitor APS ignition
- Monitor yaw and pitch maneuvers
- Monitor guidance/control performance
- Monitor engine cutoff conditions
- Null velocity residuals

A timeline of these functions is presented in Table 1. Section 2.1 presents those preignition procedures which are directly related to the ascent phase of the mission and are included to provide continuity between the lunar surface and ascent phases of the mission. Section 2.2 presents the crew onboard monitoring procedures and rationale. Section 2.3 presents the ground (MCC-H) monitoring procedures and rationale. Section 3 presents the ascent flow charts.

Table 1. Typical Abbreviated Timeline of the Lunar Ascent Guidance and Navigation Activities

<u>Time from Ignition</u>	<u>LM</u>
-2 hrs 55 min	AGS power up CSM and LM state vector update Pad data uplink
-2 hrs 30 min	Align IMU (P57, AT-3 to previous REFSMMAT) Align AGS to PGNCS, DEDA (400 +30000)
-2 hrs 5 min	Initialize AGS time Select P22
-45 min	Align IMU (P57, AT-3 to landing site) Align AGS to PGNCS, DEDA (400 +30000) Store azimuth, DEDA (413 +10000)
-30 min	Enter AGS lunar align, DEDA (400 +40000)
-20 min	Select P12 RR off, positioned along X-axis in Mode 2 Verify or update: TIG, $CR \leq 8$ n mi, Z and R
-18 min	Record pitch and yaw angles Set event timer with TFI Initialize AGS CSM and LM state vectors Verify AGS targets Verify balanced couple: ON Main SOV (2): CLOSE ASC feed (4): OPEN CRSFD: OPEN
-2 min	Enter AGS guidance steering and exit lunar align, DEDA (400 +10000)
-10 sec	Push abort stage Master arm: ON Engine arm: ASC
-5 sec	Push PRO on DSKY

Table 1. Typical Abbreviated Timeline of the Lunar Ascent
Guidance and Navigation Activities (Continued)

0 sec (lift-off)	<p>Push engine start (after engine is verified on)</p> <p>Monitor yaw maneuver</p>
10 sec	<p>Monitor pitch maneuver</p>
20 sec	<p>Call V_I display on DEDA (address 433)</p> <p>Balanced couple: OFF</p>
20 sec through insertion	<p>Monitor vehicle attitude, rates, error needles, and horizon angle</p> <p>Yaw right 30 deg (H-2 only) as soon as practical (S-band communications)</p>
6 min 15 sec	<p>Key in V16N85E on DSKY for VGX display</p> <p>Call VGX display on DEDA (address 500)</p> <p>Close RCS/APS interconnect when VGX = 500 ft/sec</p> <p> Main SOV (2): OPEN</p> <p> ASC Feed (4): CLOSE</p> <p>Set Engine Arm to OFF when VGX = 200 ft/sec</p> <p>Monitor shutdown</p>
7 min 10 sec (Orbit Insertion)	<p>Null VGX or perform "tweak" burn (tweak burn is only performed when insertion is with a degraded system)</p>

2.1 PREIGNITION PHASE

The detailed preignition procedures are documented in Reference 1. Those procedures which are directly related to the ascent phase of the mission are presented here to provide continuity between the two phases of the mission.

The LM and CSM state vectors are updated in both the PGNCS and AGS. The inertial measurement unit (IMU) is aligned using the Lunar Surface Alignment Program (P57) and the AGS is initially aligned to the PGNCS to allow MCC-H to monitor the gyro drift performance of both systems. Approximately 30 minutes before lift-off, a separate AGS lunar alignment is made which protects against a common misalignment error in PGNCS and AGS. The crew will key in the Powered Ascent Guidance Program (P12) on the display and keyboard (DSKY) approximately 20 minutes prior to ignition. The rendezvous radar (RR) is left off with the antenna positioned along the X-axis (Mode 2). The crew monitors the DSKY display of time from ignition (TFI) and the crossrange (CR) distance from the launch site to the CSM orbital plane that will be removed during the ascent maneuver. The crew updates the PGNCS and AGS ascent targets as required and initializes the event timer and the abort electronics assembly (AEA) clock. In addition, the following angles displayed on the DSKY are monitored and recorded: the flight director attitude indicator (FDAI) yaw angle that should be present on the FDAI at the end of vertical rise phase prior to pitchover and the FDAI pitch attitude that should be present after the pitchover has been completed. The following switch settings are required:

- "GUID CONT": PGNS
- PGNCS "MODE CONT": AUTO
- AGS "MODE CONT": AUTO
- CDR FDAI "ATTITUDE MON": PGNS
- LMP FDAI "ATTITUDE MON": AGS
- tape meter "MODE SEL": AGS
- tape meter "RNG/ALT MON": ALT/ALT RT
- Call DEDA H display (address 367)

"BAL CPL": ON
"MAIN SOV" (2): CLOSE
"CRSFD": OPEN
"ASC FEED" (4): OPEN

Since the phasing for rendezvous is time dependent, the lift-off must occur on time (i. e., no launch window). There are four decisions made between TIG - 40 seconds and TIG to determine if lift-off will occur on time or if TIG will be slipped one CSM revolution. Three of these decisions are based upon P12 displays ("PROG" warning light, V97N74, or lack of any display on DSKY). The fourth is whether or not APS ignition occurred. After the APS starts, the engine start button is pushed to protect against a premature guidance commanded shutdown during ascent.

2.2 ONBOARD MONITORING PROCEDURES

The crew onboard monitoring procedures are based upon the assumption that MCC-H will detect and isolate insidious system degradations which are generally impossible to detect onboard. The crew is prime in situations that require immediate action.

2.2.1 Lift-off Through Pitchover Monitoring (flow charts, pages 3-5 and 3-6)

Physiological or visual cues are prime during and immediately following APS ignition (TIG through TIG + 15 seconds), when insufficient time exists for extensive monitoring. After TIG, the commander (CDR) confirms that the LM is stable and that the altitude is increasing by looking out the window. He then compares a shadow or prominent landmark with a mark on the forward window to establish that the LM yaw maneuver is reasonable. If the PGNCS ΔV thrust monitor routine (R40) fails to recognize APS thrusting, P12 will inhibit guidance steering and hold attitude (this is indicated by a V97 display on the DSKY). In this event, the crew should not immediately switch to AGS but wait until they have determined that the PGNCS will not control the spacecraft properly, i. e., yawing to the proper launch azimuth and pitching over as programmed. When these cues have confirmed lack of PGNCS guidance and AGS is confirmed good, the crew should switch to AGS without attempting to recycle the PGNCS. To verify AGS during this period, the LM pilot (LMP) is watching H and \dot{H} on the tape meter (AGS driven), \dot{H} on the data entry and display assembly (DEDA), and spacecraft attitude on the LMP FDAI (AGS driven).

If the ΔV thrust monitor alarm comes on and control was switched to AGS, R40 is recycled in order to make PGNCS useful for monitoring the remainder of ascent, or for switch back if AGS should fail.

2. 2. 2 Onboard Powered Ascent Monitoring (flow chart, page 3-7)

After the pitchover maneuver is completed, the LM maintains a slowly changing attitude (average pitch rate of about 0.1 degree per second). It is during this period that the crew (and MCC-H) should be able to perform their first good check of PGNCS performance. The crew checks FDAI attitudes, attitude errors, and attitude rates. The horizon angle through the overhead window can be used as a gross check to isolate large PGNCS/AGS differences. For confirmed attitude errors exceeding 10 degrees and rates exceeding 10 degrees per second, the crew switches to AGS control. The 10 degrees per second was chosen as the attitude rate error switchover criterion because 10 degrees per second is the maximum commanded attitude rate about any axis (a smaller value was not acceptable because rate error needle deflections of 6 degrees per second may occur during ascent). The 10 degrees was chosen as the attitude error switchover criterion because attitude error variations due to vehicle DAP response characteristics of about ± 5 degrees may occur during ascent. In addition, the high attitude rates would cause an attitude error of 10 degrees in a very short period.

S-band high-gain antenna communication should be maintained automatically during the first 2 minutes of the ascent (automatic acquisition occurs after pitchover). As soon as practical after pitchover, however, the CDR will yaw right 30 degrees to ensure S-band lock. If lock is lost, an attempt will be made to acquire manually.

2. 2. 3 Engine Shutdown Monitoring (flow chart, page 3-8)

Ground monitoring verifies the navigation accuracy of the PGNCS and AGS. Because of this, APS shutdown monitoring is performed on-board simply by observing the velocity-to-go display of the verified system which is controlling the ascent. When TFI is approximately 6 minutes 15 seconds, the DEDA display is changed from inertial velocity (V_I) to velocity to-be-gained in body X-direction (VGX), and the DSKY

display is changed from V_I , altitude (H), and altitude rate (\dot{H}) to VGX, velocity to-be-gained in body Y-direction (VGY), and velocity to-be-gained in body Z-direction (VGZ) by keying in V16N85E. When VGX reaches 500 feet per second with the engine on, the reaction control system (RCS)/APS interconnect is closed (the two RCS main SOV's are first opened to ensure a continuous propellant supply to the RCS engines when the four ASC propellant valves are closed). When VGX reaches 200 feet per second, the engine arm switch is turned off to enable a PGNCS controlled cutoff. (If premature engine shutdown occurs, the engine arm switch will be returned to the ON position. In this situation, a manual shutdown is required when $VGX = 0$.) The CDR monitors VGX as it approaches zero. If VGX reaches zero and the engine is still on, he will push the engine stop button. The LMP is also monitoring VGX on the DEDA near insertion.

If engine shutdown inadvertently occurs with the RCS/APS interconnect open, the two RCS main SOV's are opened to force the helium out of the lines before the ASC feed valves are closed. If the APS will not restart, the CDR advances the thrust/translation controller to initiate RCS + X thrusting to obtain a safe orbit. In the unlikely event VGX exceeds approximately 360 feet per second, the AGS will be used for the maneuver. This is desirable because the AGS continues to cycle through the guidance equations after receiving the initial engine shutdown discrete.

If the VGX is greater than 600 feet per second (Reference 4), the RCS propellant will not provide a safe orbit, thus requiring that the RCS/APS interconnect be reopened.

2.2.4 Nulling Velocity Residuals (flow chart, page 3-9)

Within 30 seconds following insertion, MCC-H will advise the flight-crew whether to null residuals or prepare for a "tweak" burn. For normal insertion conditions, only the X-axis (downrange) velocity residual will be trimmed. These are trimmed to maintain the rendezvous concentric delta altitude (ΔH) near nominal (a 10-foot per second overburn or underburn changes ΔH by about 5 nautical miles). Cross-axis and radial residuals have little effect on ΔH and can be more accurately removed during rendezvous maneuvers which incorporate rendezvous navigation data.

If insertion was performed with a degraded PGNCS or AGS, the MCC-H will provide a "tweak" burn ΔV_X and TIG within 30 seconds after insertion. The PGNCS Program P47 will be used for the burn, which is performed nominally 4 minutes after insertion.

2. 2. 5 Onboard Post-Insertion Monitoring - LM Communication Failure

The flow chart on page 3-10 presents the technique used to determine whether an acceptable insertion orbit was obtained when no communications with the LM exist. The chart assumes that the PGNCS downrange residual VGX has been nulled and that no PGNCS control problems have occurred. (That is, the PGNCS estimate of radial and downrange velocities at insertion is near nominal; control problems would have resulted in a switch to AGS.)

After insertion, if PGNCS and AGS agree within 10 feet per second in downrange velocity and within 50 feet per second in radial velocity, no action is taken to adjust the insertion orbit by the crew. The 10 foot-per-second downrange limit, if the PGNCS were wrong by that amount, would result in a rendezvous ΔH dispersion of about 5 nautical miles, which is acceptable; and at the same time, does not result in an unsafe orbit. Also, downrange errors greater than 10 feet per second can be isolated using the RR as shown in the flow chart.

Radial errors of ± 50 feet per second or less have little effect on ΔH (< 2 miles variation). This limit was selected to be consistent with obtaining a safe orbit and yet be large enough that the RR might provide failure isolation capability. For a positive radial error of 50 feet per second ($H \approx 80$ feet per second), the resultant pericynthion is less than 30,000 feet but occurs behind the LM. In this case, the CSI burn (which occurs near apocynthion) would make the orbit safe. Radial errors of ± 50 feet per second ($H \approx -20$ feet per second) result in a safe orbit.

There is a reasonably good possibility that radial errors greater than 50 feet per second can be isolated using the RR, and so the crew should

attempt to do so as shown in the flow chart. If isolation problems are encountered, however, when AGS indicates a marginal negative radial rate (H AGS about -50 feet per second or worse, which is a PGNCS/AGS difference of about 80 feet per second or more), a radial burn to ensure a safe orbit could be performed at the discretion of the crew.

There are no techniques for post-insertion isolation of out-of-plane differences between PGNCS and AGS. Delaying the plane correction until after a period of rendezvous navigation results in less propellant being used.

2.3 GROUND MONITORING

The ground (MCC-H) is responsible for detecting and isolating insidious guidance and navigation (G&N) systems malfunctions which would result in either a pericynthion altitude (H_p) $< 30,000$ feet or wedge angle (ΔW_p) > 1.0 degree and, on reaching a limit, for recommending the required action to the LM crew. The ground monitoring procedures (Reference 5) are designed to protect against errors which would violate these constraints, and at the same time minimize the possibility of switching from a good PGNCS to AGS. In most instances, the PGNCS malfunctions required to reach a switchover limit (which reflects either or both of the above constraints) greatly exceeds the 3σ performance.

The following paragraphs present the ground monitoring procedures and rationale. Section 2.3.1 describes the available data sources (Real-Time Computer Complex (RTCC) monitoring displays) and Section 2.3.2 describes the ground monitoring rationale. Additional information concerning ground monitoring procedures can be obtained from Reference 5.

2.3.1 Ascent Monitoring Data Sources (RTCC Displays)

The prime data displays for the ground ascent monitoring procedures are the velocity strip charts, the predicted pericynthion versus predicted wedge angle plotboard display (predictor), the V_I versus flight-path angle (γ) and H versus \dot{H} plotboard displays, and the range rate residuals plotboard display, each described in Table 2. Other data sources used for cues are the local vertical, local horizontal (LVLH) pitch versus yaw plotboard, PGNCS/AGS attitude angle residuals, H versus range-to-go (RGO)

Table 2. MCC-H Ascent Monitoring Displays

Velocity differences strip charts $\Delta\dot{X}_A, \Delta\dot{Y}_A, \Delta\dot{Z}_A$ $\Delta\dot{X}_L, \Delta\dot{Y}_L, \Delta\dot{Z}_L$	Six individual strip charts; one set of three displaying downrange, crossrange, and radial velocity differences AGS - PGNCS, and the other set displaying PFP - PGNCS velocity differences
Pericynthion and wedge angle predictor H_P versus ΔW_p	The predicted value of pericynthion altitude versus the predicted value of wedge angle, plotboard display, driven by PFP or PGNCS or AGS state vector
Inertial velocity versus flight-path angle V_I versus γ	Analog display available on plotboard, any two of AGS, PGNCS, or PFP values are displayed simultaneously
Altitude versus altitude rate H versus \dot{H}	Analog display available on plotboard, any two of AGS, PGNCS, or PFP values are displayed simultaneously
MSFN Doppler, range rate residuals $\Delta\dot{\rho}_{MP}$ $\Delta\dot{\rho}_{MA}$	Displayed on plotboard MSFN (Doppler) - PGNCS MSFN-AGS range rate to earth residuals
RR range rate residuals (post- insertion display) $\Delta\rho_{RRP}$ $\Delta\rho_{RRA}$	Displayed on plotboard RR - PGNCS and RR - AGS range rate to CSM residuals

plotboard, PGNCS and AGS attitude errors, digitals, and selected discretes.

The position and velocity data can be obtained from four different sources (PGNCS, AGS, Manned Space Flight Network (MSFN)/doppler, and Powered Flight Processor (PFP)*). The velocity strip charts provide AGS-PGNCS and PFP-PGNCS velocity differences (downrange, cross-range, and radial components). The H versus H and V_I versus γ displays are driven by any two of the following three sources: PFP, PGNCS, or AGS. The predictor display propagates a given state vector through the remainder of powered ascent and computes predicted values of H_p and ΔW_p . This display can be driven by PFP, PGNCS, or AGS state vectors. There are two different range rate residual displays available. The first display is the MSFN to LM range rate residual obtained by the MSFN range rate differenced with PGNCS and AGS estimated range rates based on state vector information. The second display, available only after insertion, is the LM to CSM range rate residual obtained by MCC-H using telemetered rendezvous radar data which is differenced with PGNCS and AGS estimated range rates based on state vector information.

2.3.2 Guidance and Trajectory Monitoring Limits and Rationale

2.3.2.1 Guidance and Navigation Verification

The velocity difference (AGS-PGNCS and PFP-PGNCS) strip charts, illustrated in Figures 1 and 2, represent the prime source for G&N switch-over decisions because these displays detect an impending H_p and/or ΔW_p violation before the pericynthion and wedge angle predictor (as much as 100 seconds). The switchover PFP-PGNCS strip chart limits for each ΔV component are constant values throughout the ascent. The AGS-PGNCS strip chart limits are used to indicate possible AGS or PGNCS problems and are not used as switchover criteria. The range rate difference plot-

*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.

board displays, illustrated in Figure 3, are used to confirm switchover decisions and determine double failures.

Four sets of ΔV limits used in the flow charts to monitor PGNCS and AGS performance are presented in Table 3. The first set, for the AGS-PGNCS strip charts, is used to indicate a possible PGNCS or AGS degradation. These limits are the 3σ AGS-PGNCS velocity component differences near insertion. The second set, for the PFP-PGNCS strip charts, is used to indicate which system may be degraded. These limits are the 3σ PFP-PGNCS velocity component differences near insertion. The third set, also for the PFP-PGNCS strip charts, is used as the PGNCS to AGS switchover criteria. The downrange ($\Delta \dot{X}_L$) and radial ($\Delta \dot{Z}_L$) values were derived to protect against an $H_p < 30,000$ feet and resulted in the use of 3σ PFP and 6σ PGNCS data. These numbers may not protect against a $H_p < 30,000$ feet if the Y-gyro degrades, but the flight-path angle at insertion is positive and the H_p can be raised by the subsequent concentric sequence initiation (CSI) burn. The crossrange ($\Delta \dot{Y}_L$) limit corresponds to a $\Delta W_p = 1$ degree which is the maximum acceptable ΔW_p for LM rendezvous.

The fourth set of numbers are used to indicate an AGS failure. These numbers are based on AGS hardware limits (gyro drift = 2.5 degrees per hour and accelerometer bias = 0.05 feet per second squared). Individual error runs for each AGS gyro and accelerometer were performed using the indicated error magnitudes, and the largest near insertion velocity difference noted from the runs was used to define the limit. In all cases, AGS errors of this magnitude did not violate the pericynthion and wedge angle constraints. All the numbers discussed in this and the preceding paragraph were calculated for a TFI of 400 seconds but are applied throughout the ascent. The 400 seconds correspond with the TGO = 30 seconds beyond which no ground switchover decisions are made.

2.3.2.2 Trajectory Verification

The H versus \dot{H} display, Figure 4, and the V_L versus γ display, Figure 5, are used to verify the trajectory. Action lines are included on the H versus \dot{H} display to protect against situations where the PGNCS guidance is incorrectly steering the LM. These action lines are based

Table 3. Velocity Differences Strip Chart Limits

ΔV (ft/sec)	Degraded PGNCS or AGS Indicated (AGS-PGNCS)	Used After a Degraded PGNCS or AGS Indication to Isolate the Degraded System (PFP-PGNCS)	PGNCS to AGS Switchover Action Criteria (PFP-PGNCS)	AGS Failure Criteria (AGS-PGNCS)
$\Delta \dot{X}$	± 15	± 14	± 24	± 23
$\Delta \dot{Z}$	± 22	± 20	± 37	± 36
$\Delta \dot{Y}$	± 23	± 21	± 90	± 27

upon the 30,000-foot pericynthion constraint and were obtained by simulating the PGNCS $\pm X$ (radial) accelerometer bias errors which just violated that constraint. A check on crossrange velocity (\dot{Y}) provides the same protection in the out-of-plane direction.

A safe orbit line is included on the V_I versus γ plot to indicate when an orbital pericynthion $\geq 30,000$ feet has been obtained. If shutdown occurs before the trajectory trace crosses the safe orbit line, an additional burn is required.

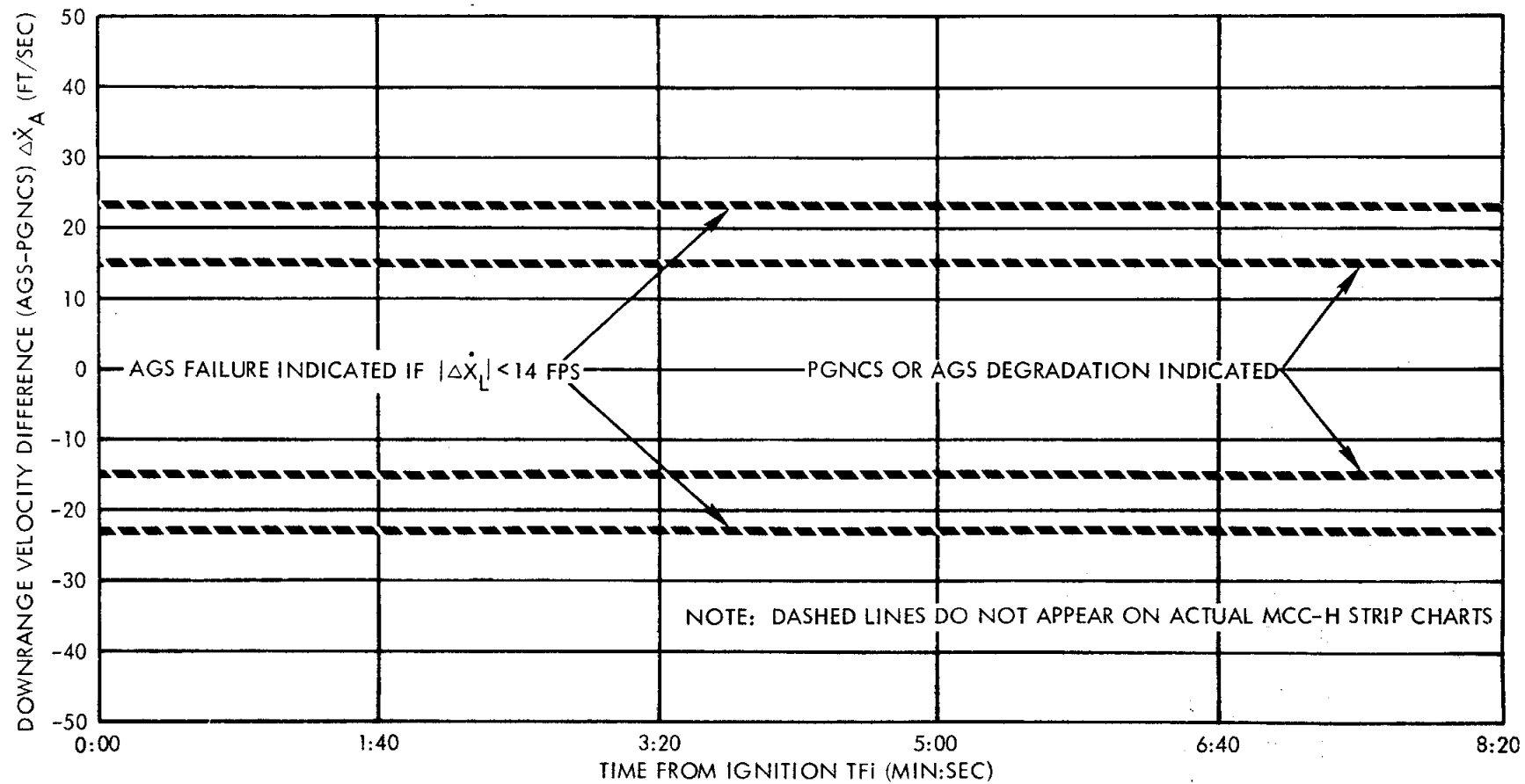


Figure 1. AGS - PGNCs Strip Chart (Typical)

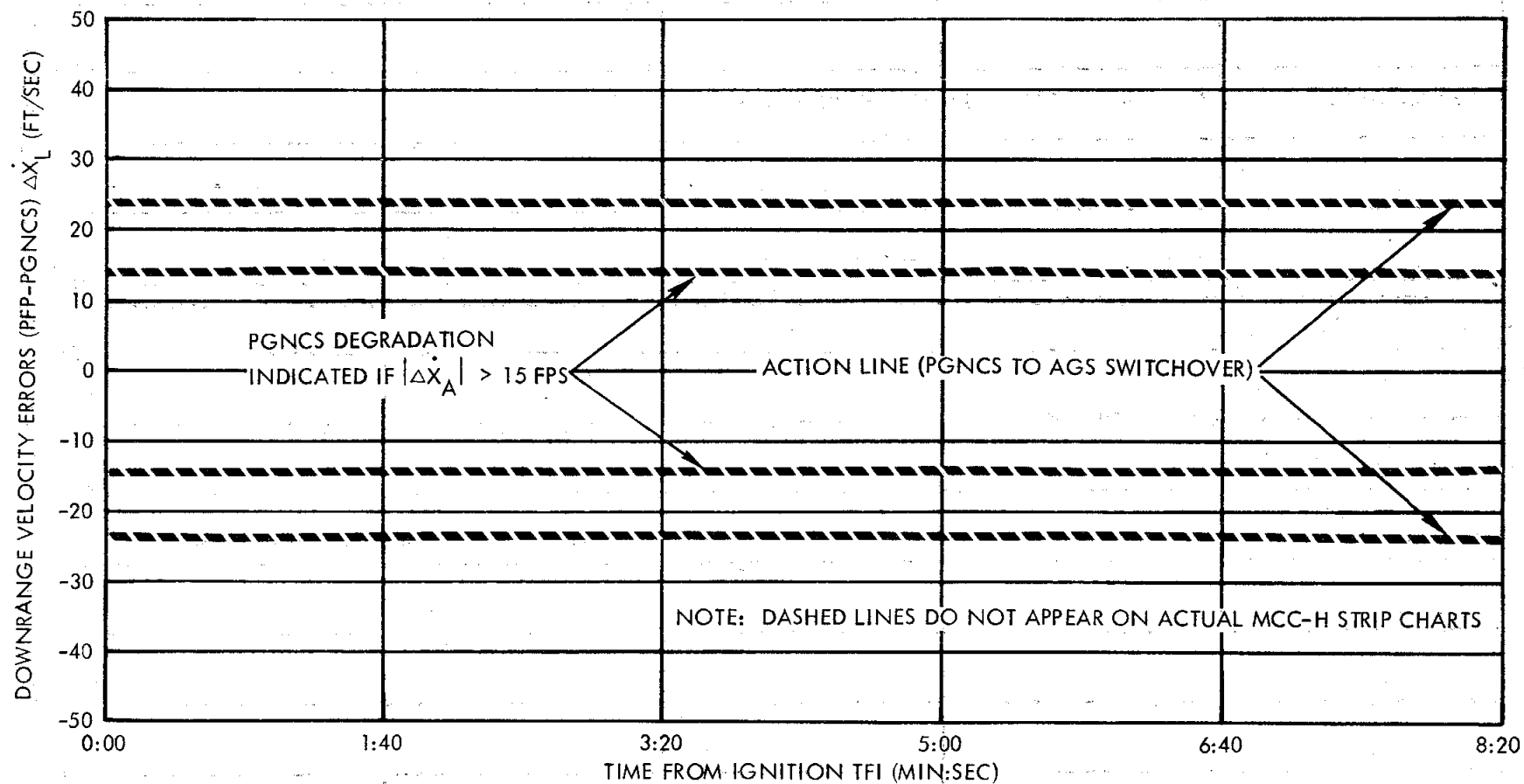


Figure 2. PFP - PGNCS Strip Chart (Typical)

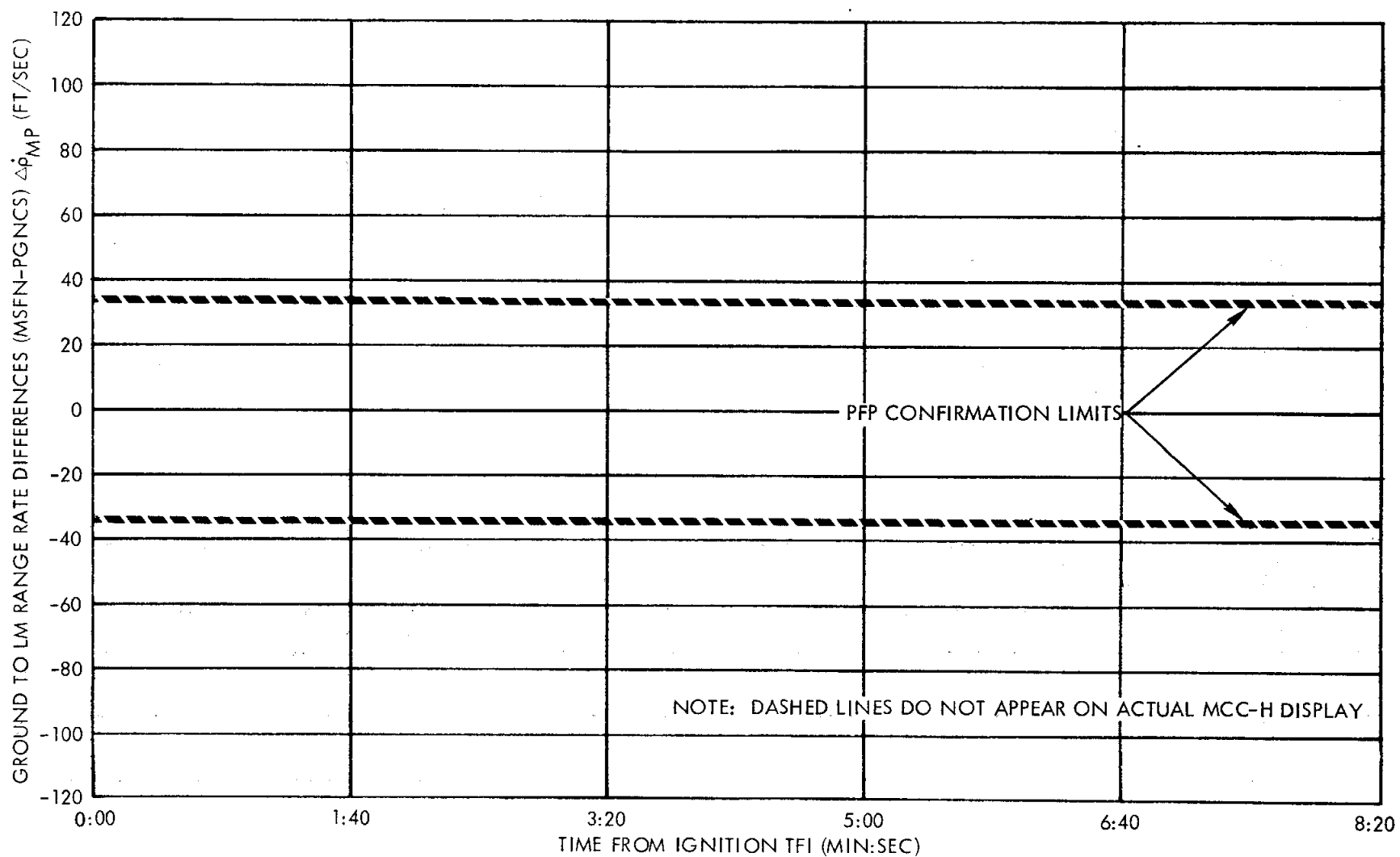


Figure 3. Range Rate Difference Plotboard Display (Typical)

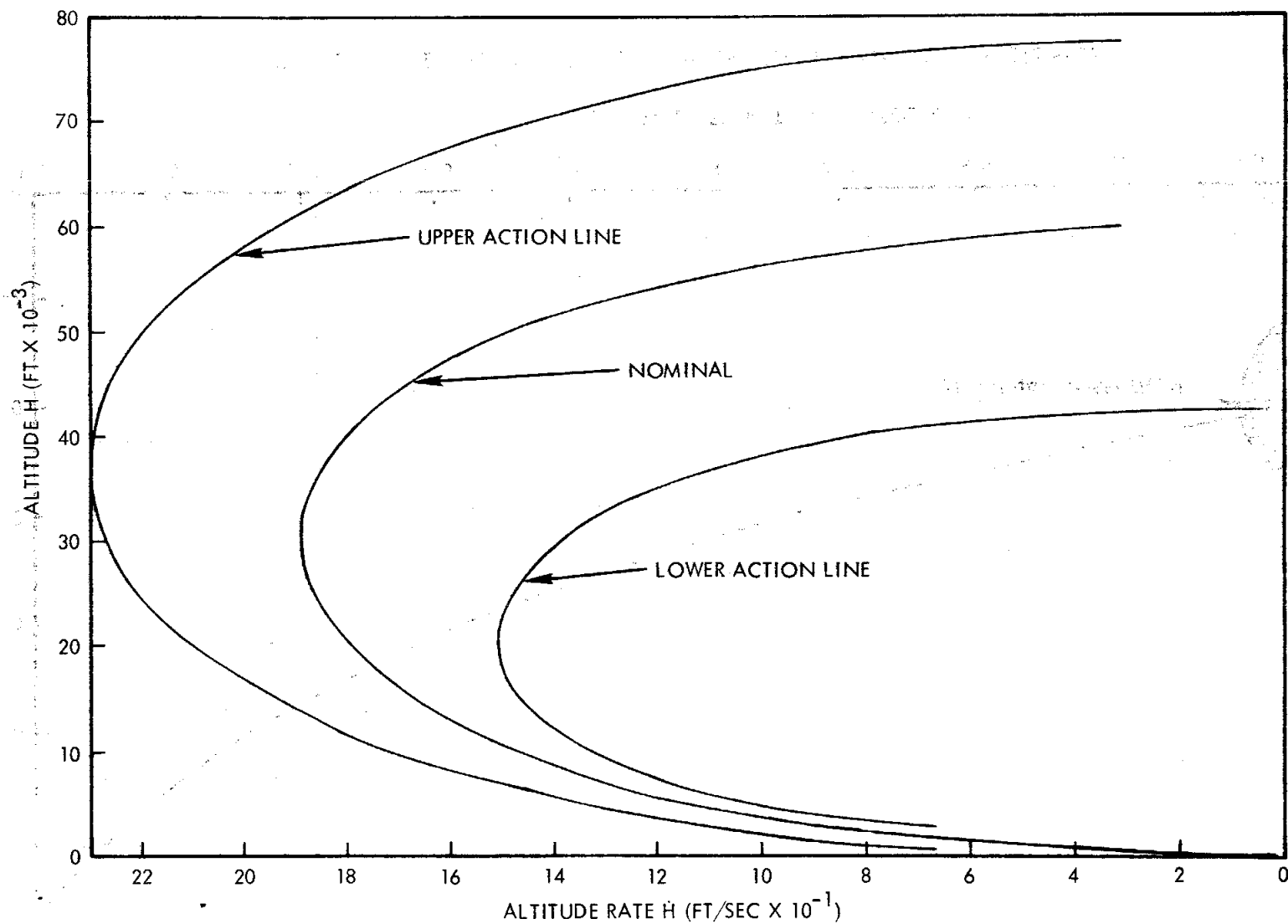


Figure 4. Altitude versus Altitude Rate Display

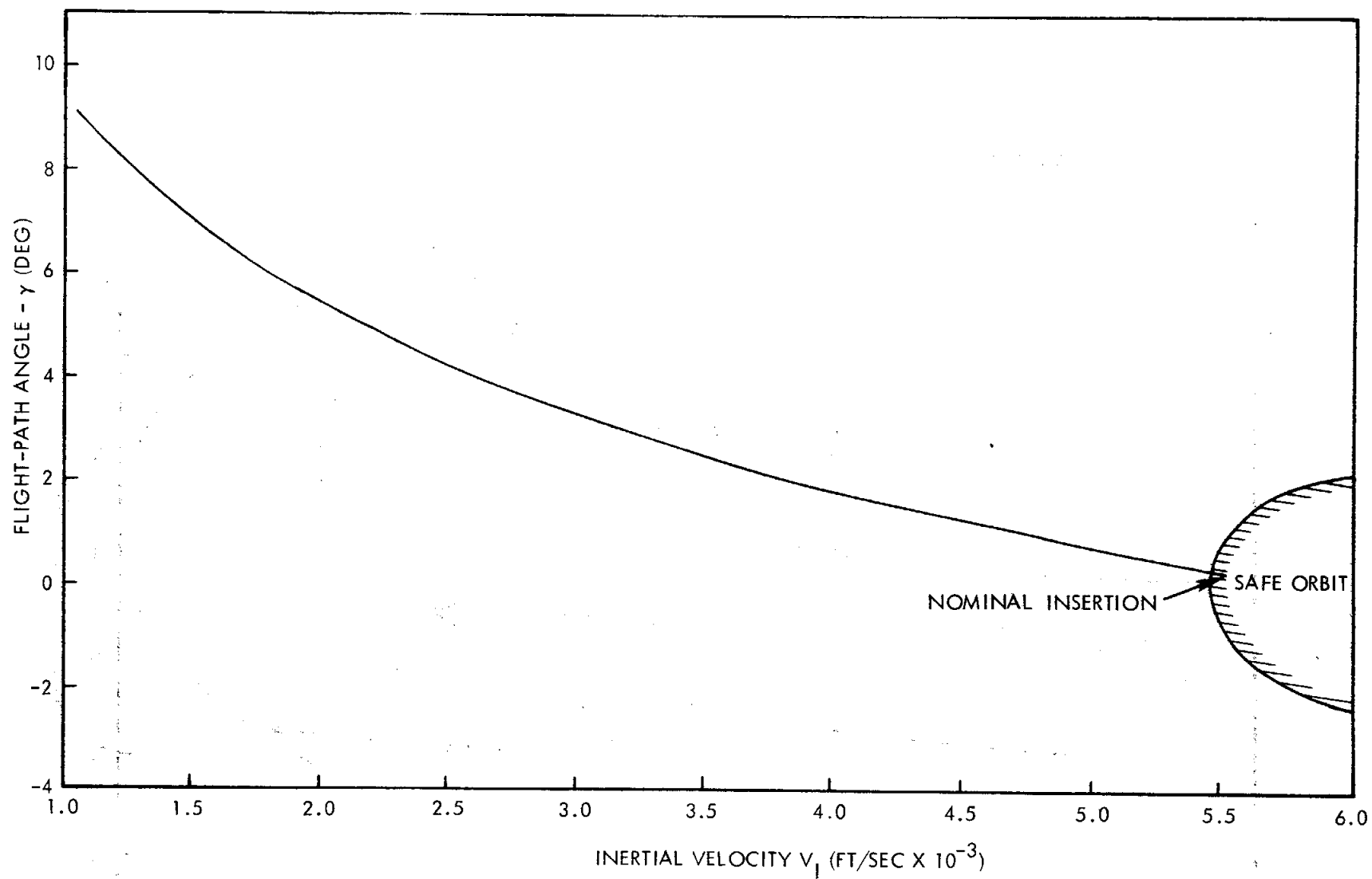


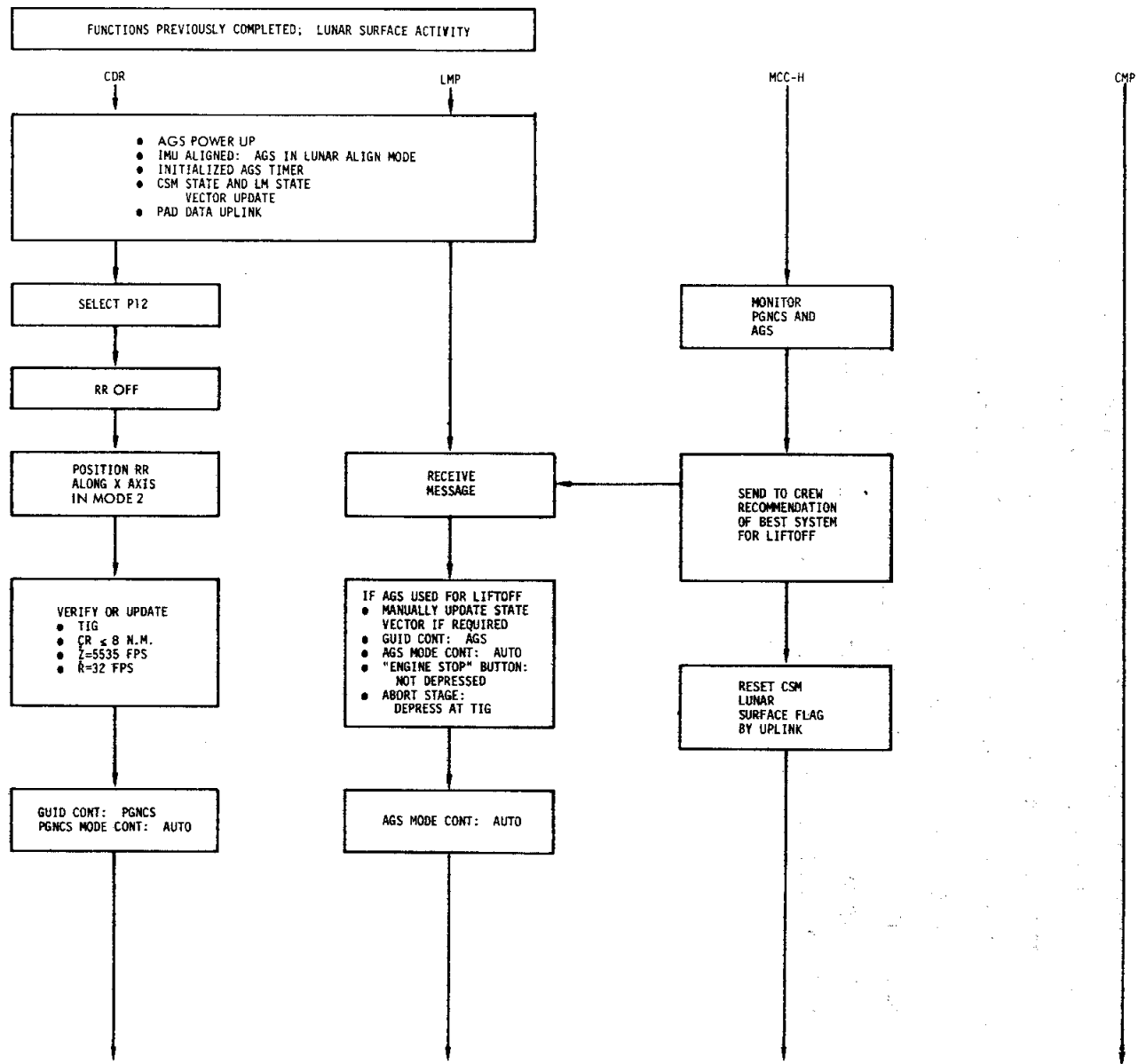
Figure 5. Inertial Velocity versus Flight-Path Angle Display

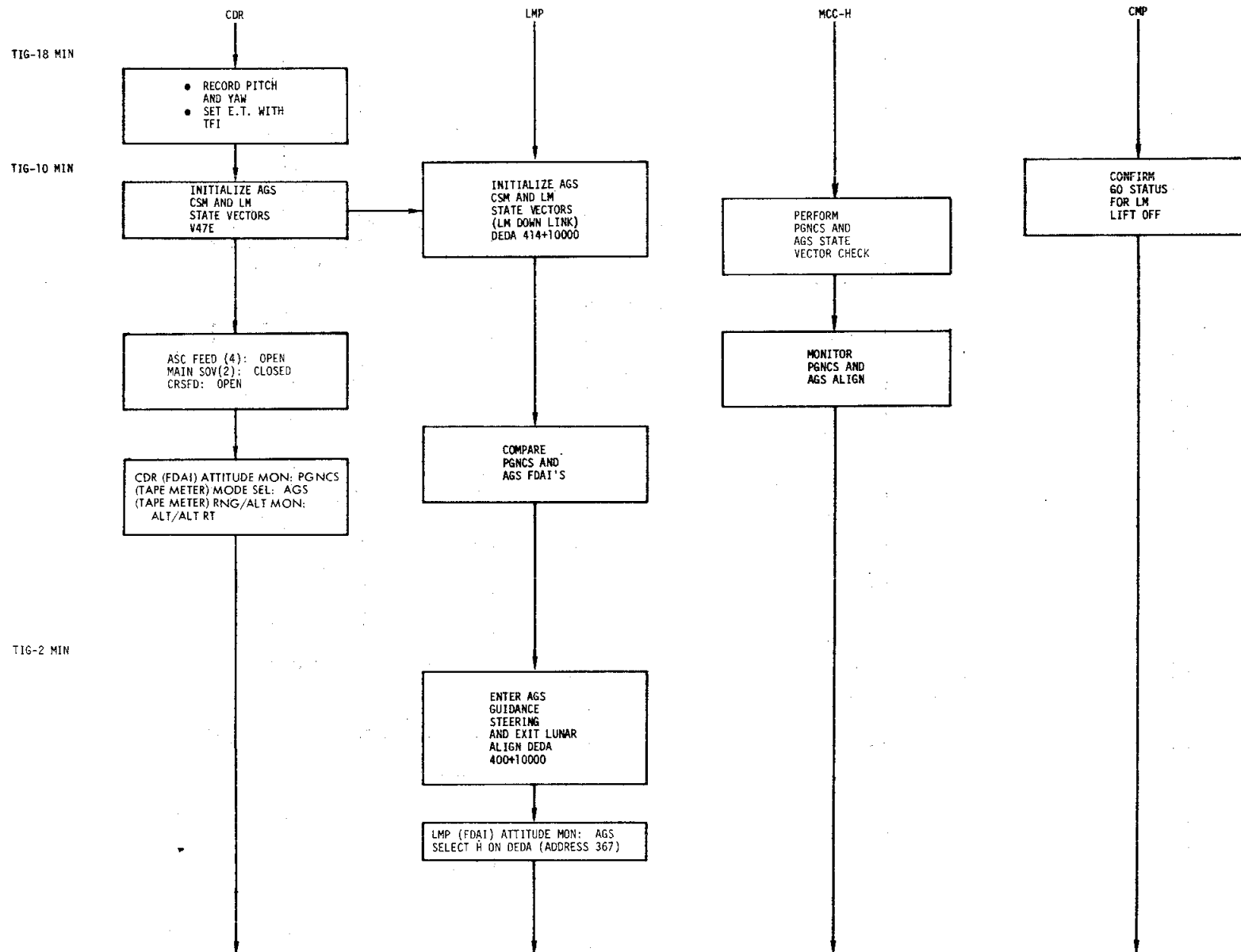
3. LUNAR ASCENT TECHNIQUES

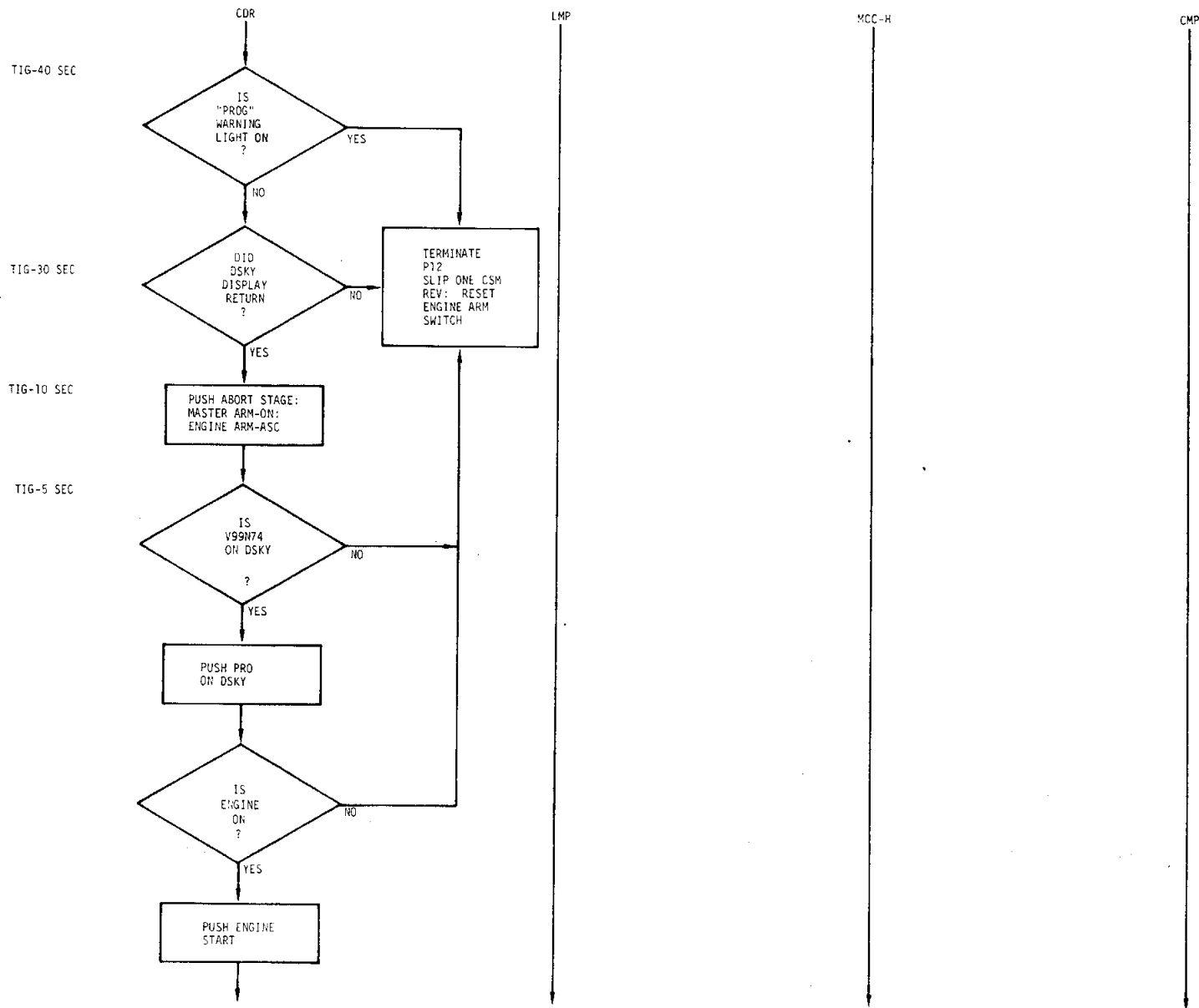
The following flow-chart pages present the approved procedures to be followed for the guidance and control sequence of events, the data flow, and the real-time decision logic for ascent from the lunar surface. All the procedures except yaw and pitch maneuver monitoring and nulling of velocity residuals are cyclic in nature and should be used throughout the ascent.

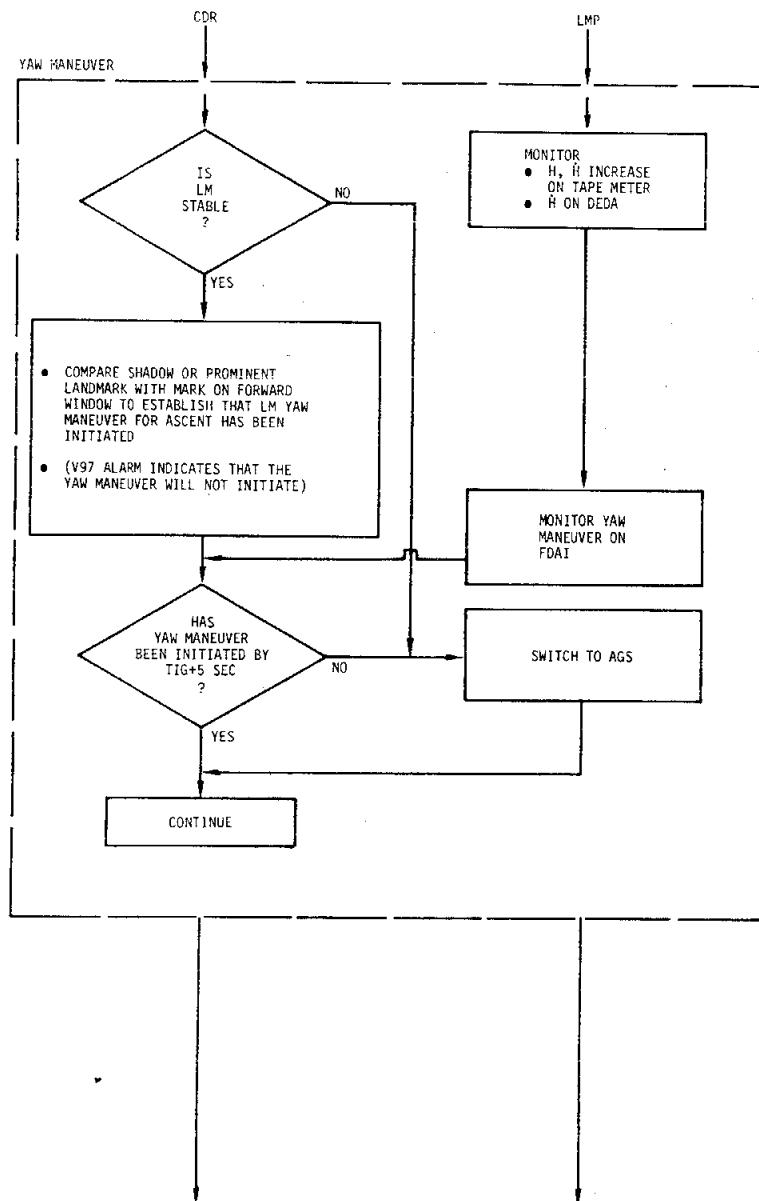
The data limits used for the onboard monitoring procedures are the product of Data Priority Panel Meetings. The limits used for the ground monitoring procedures are from the Guidance and Performance Branch of MPAD, and are documented in Reference 5.

TIG - 20 MIN

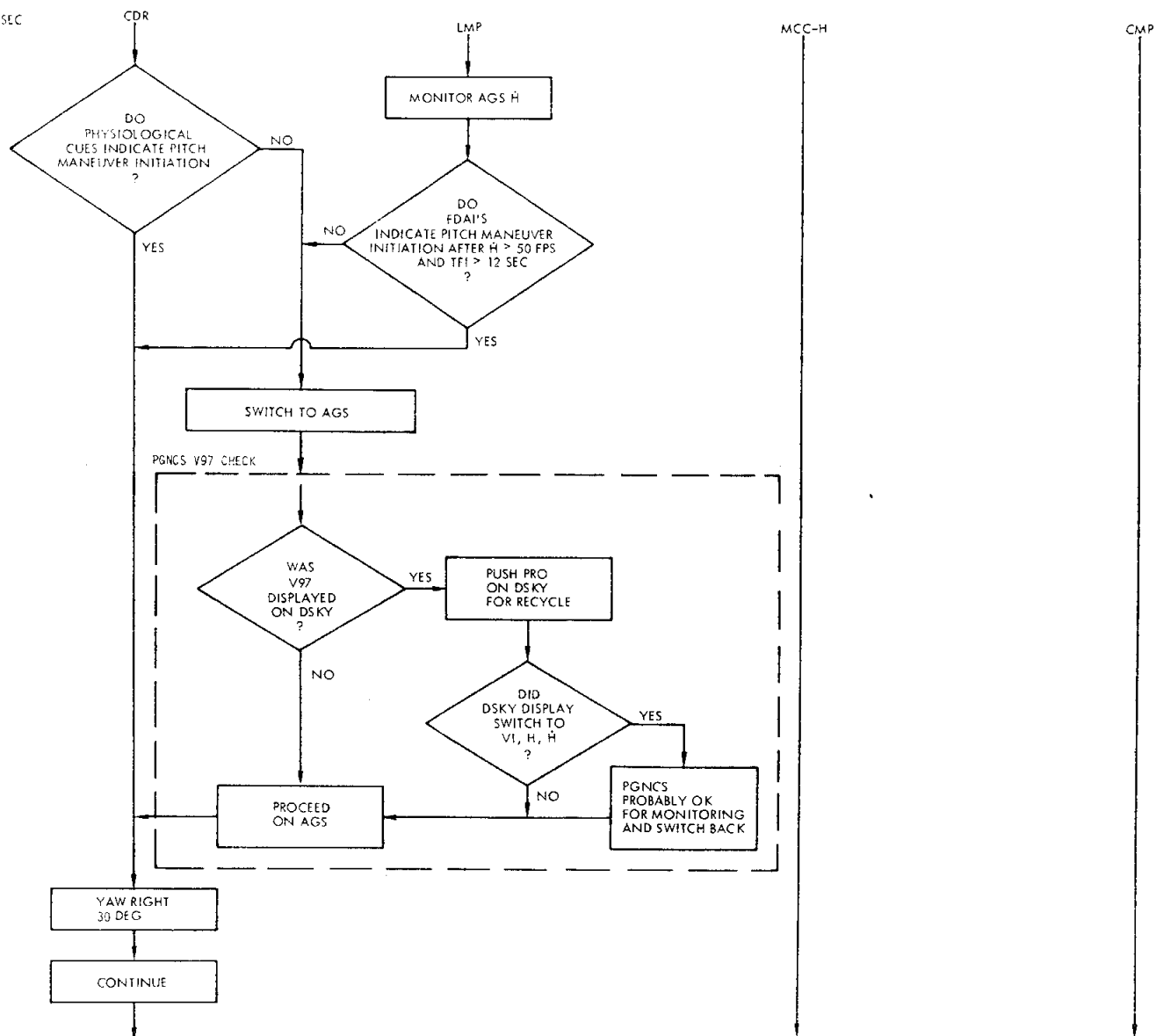


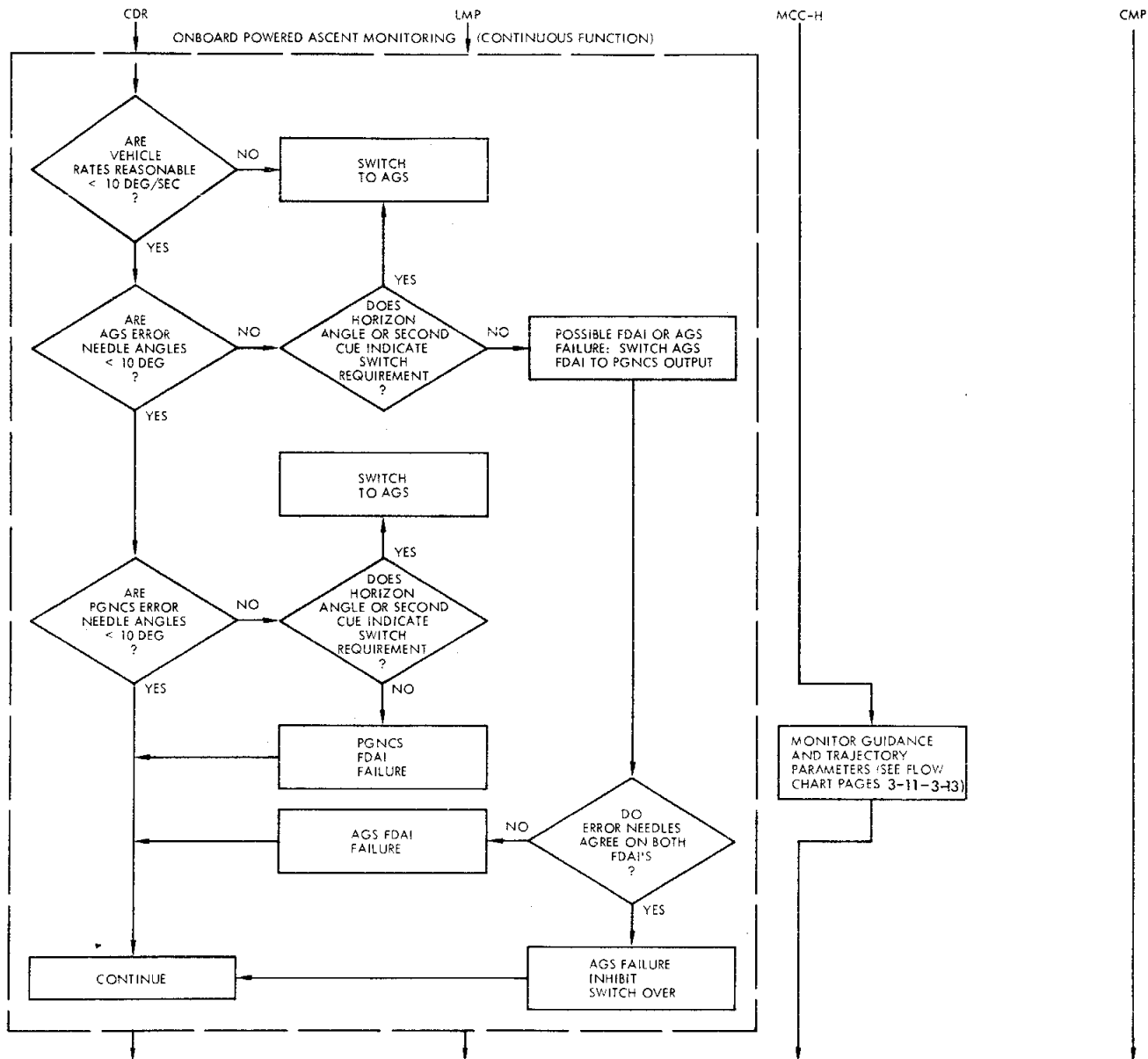


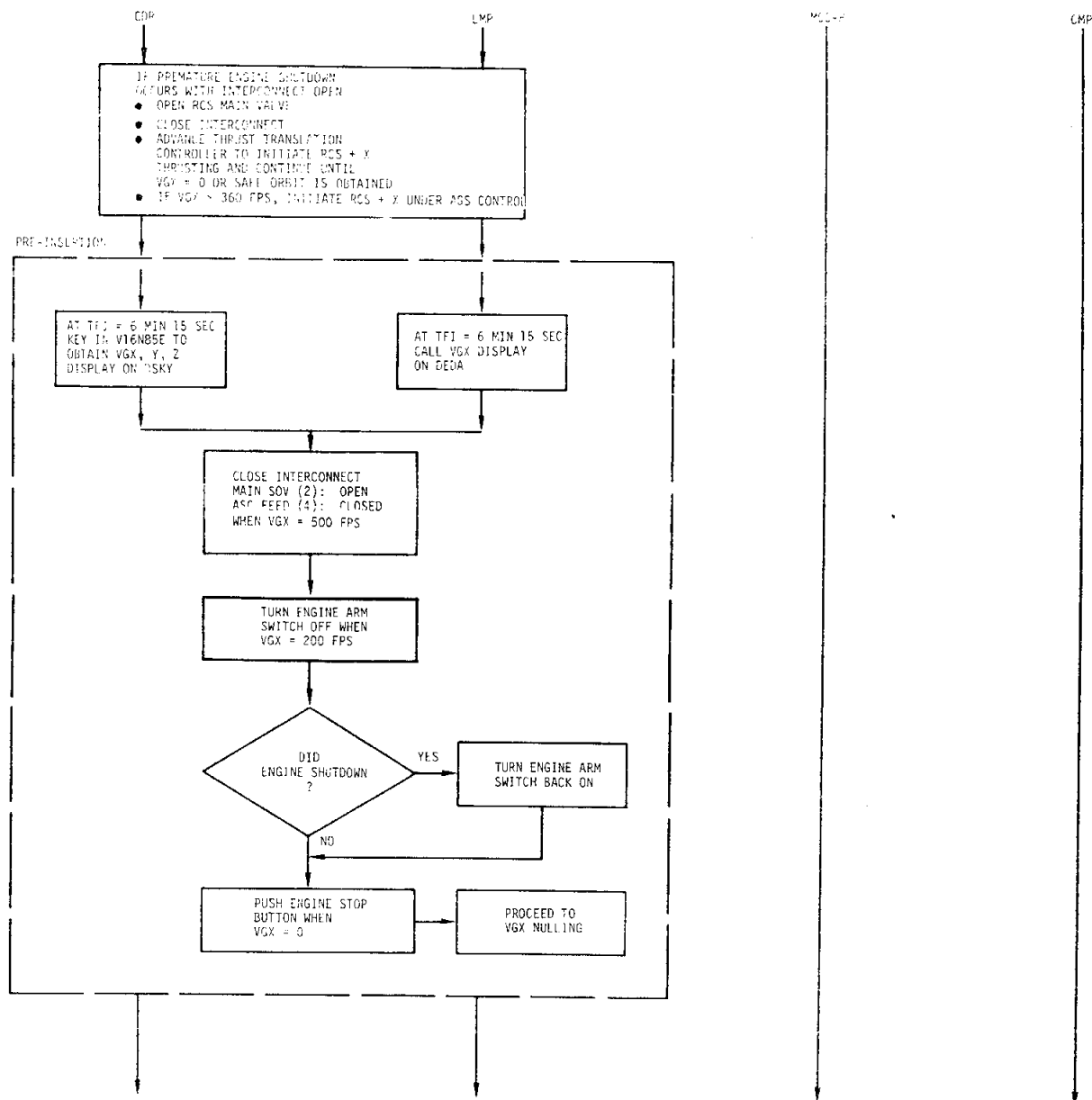


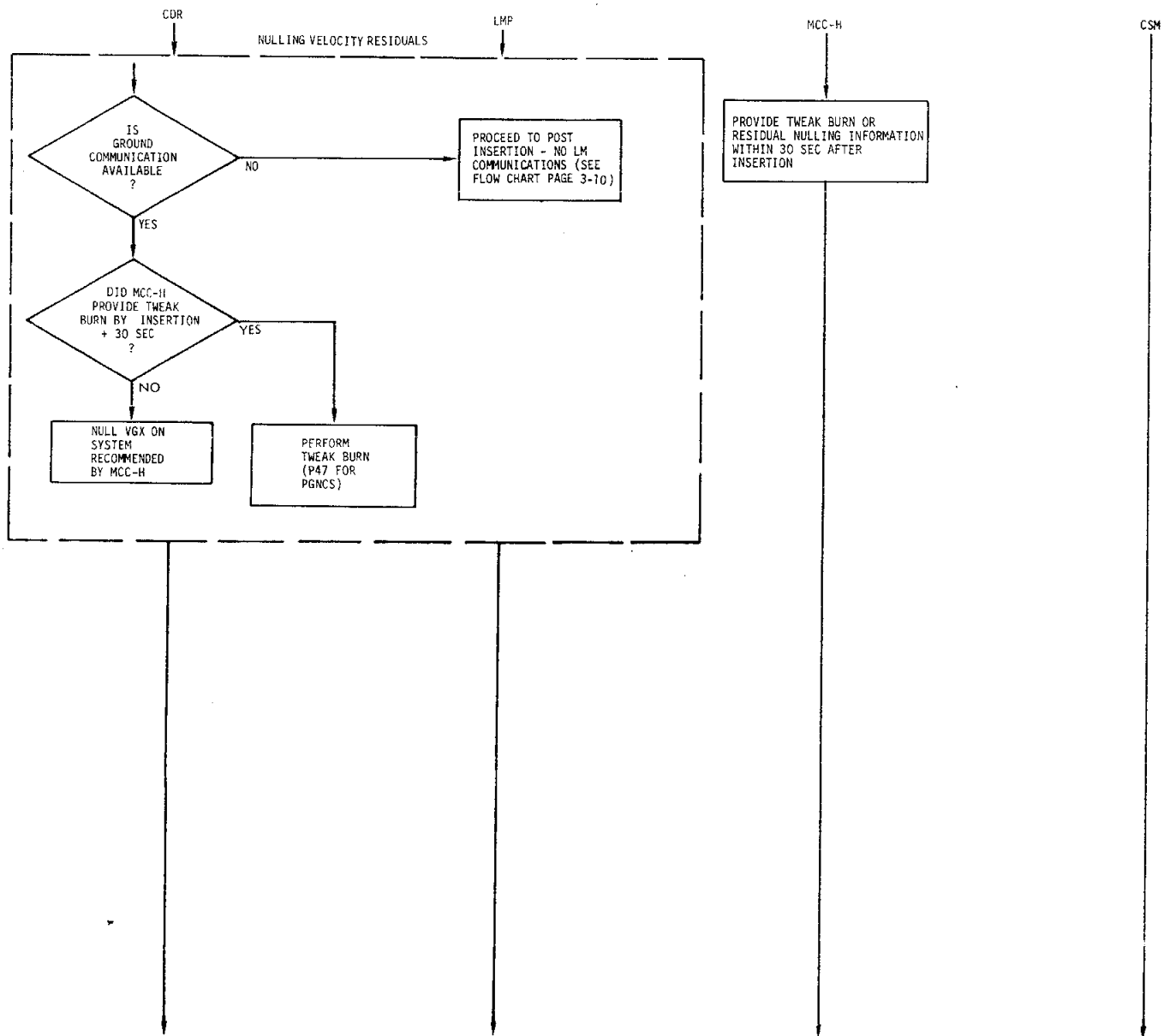


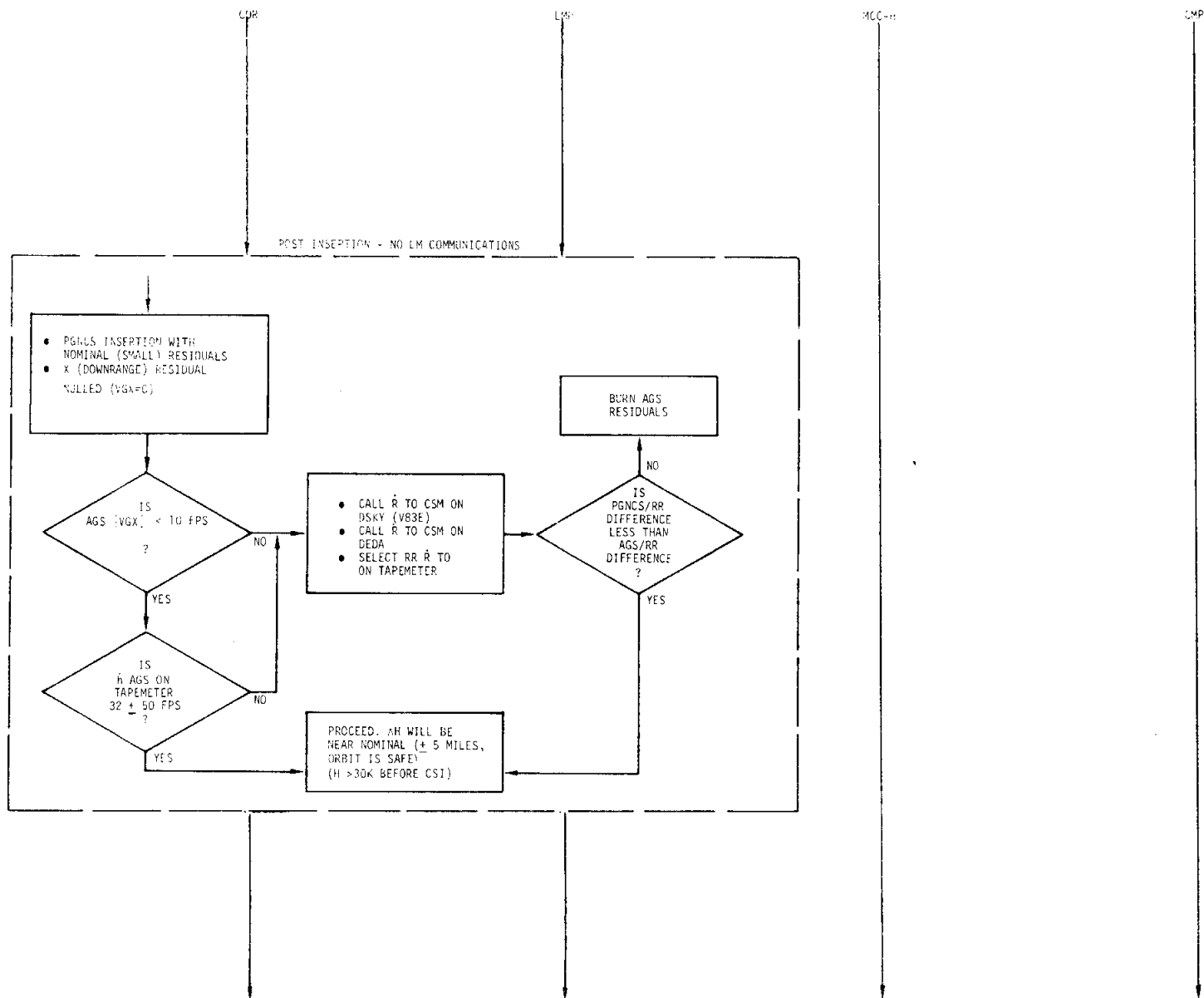
TIG - 10 SEC



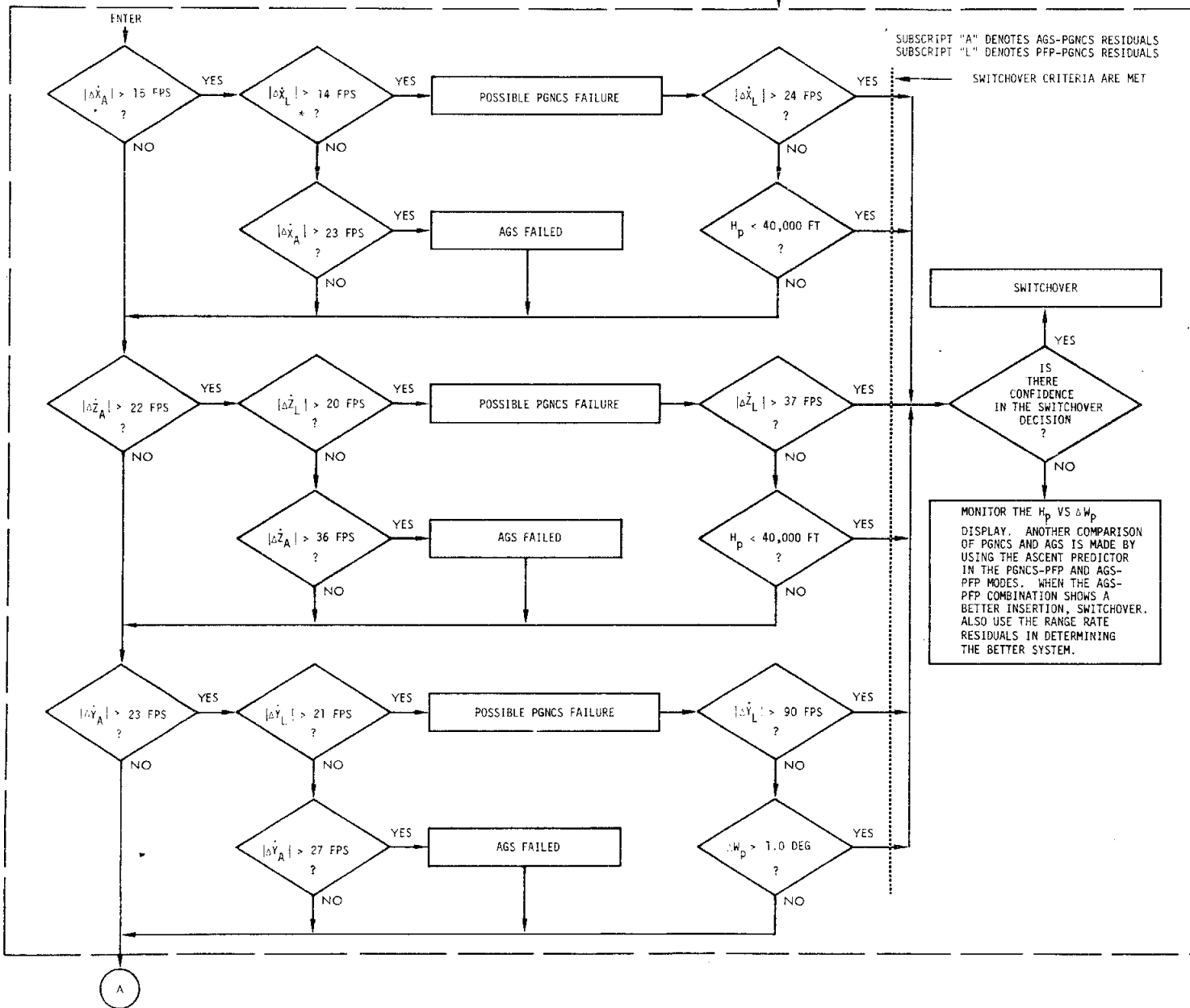




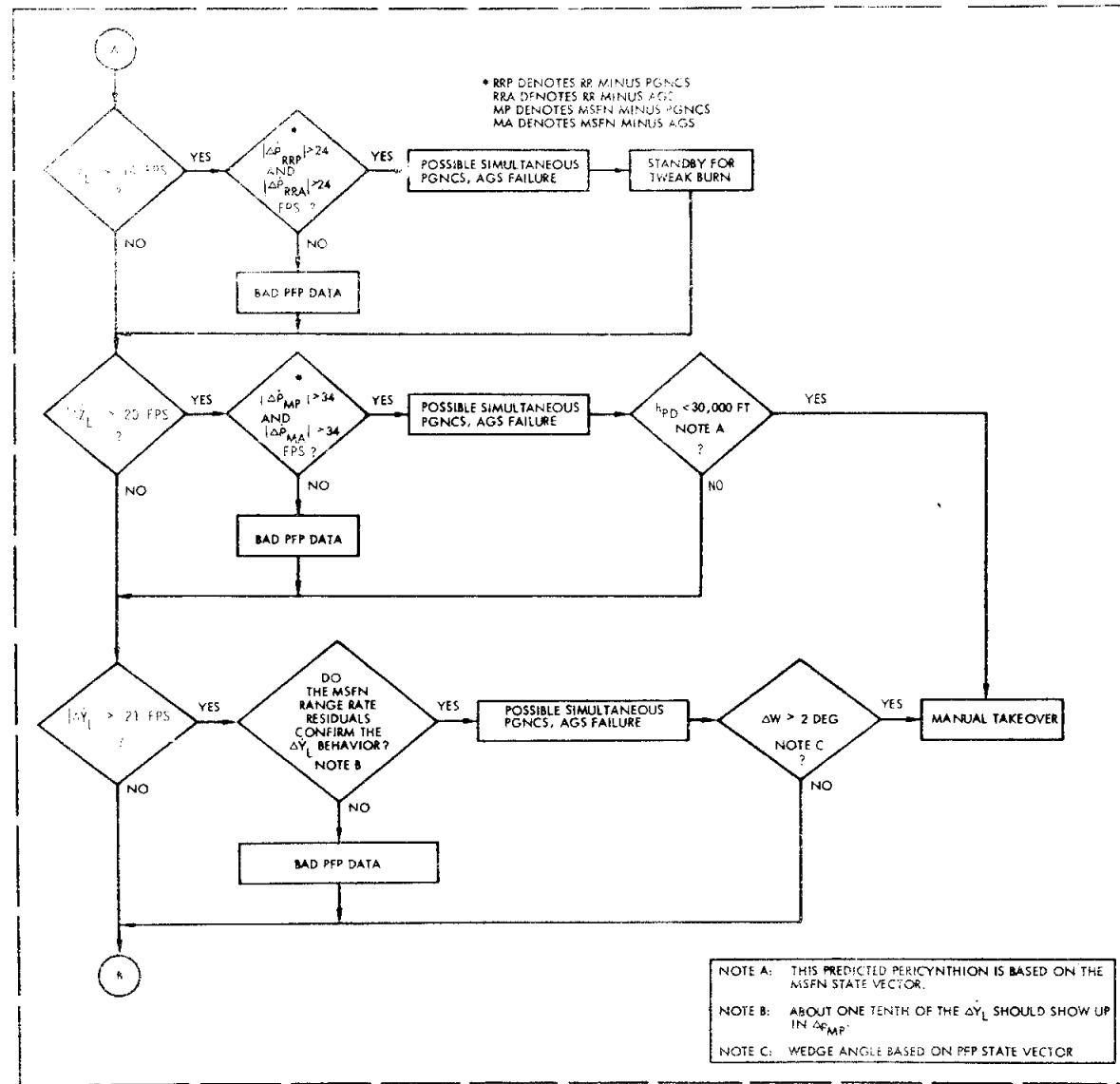


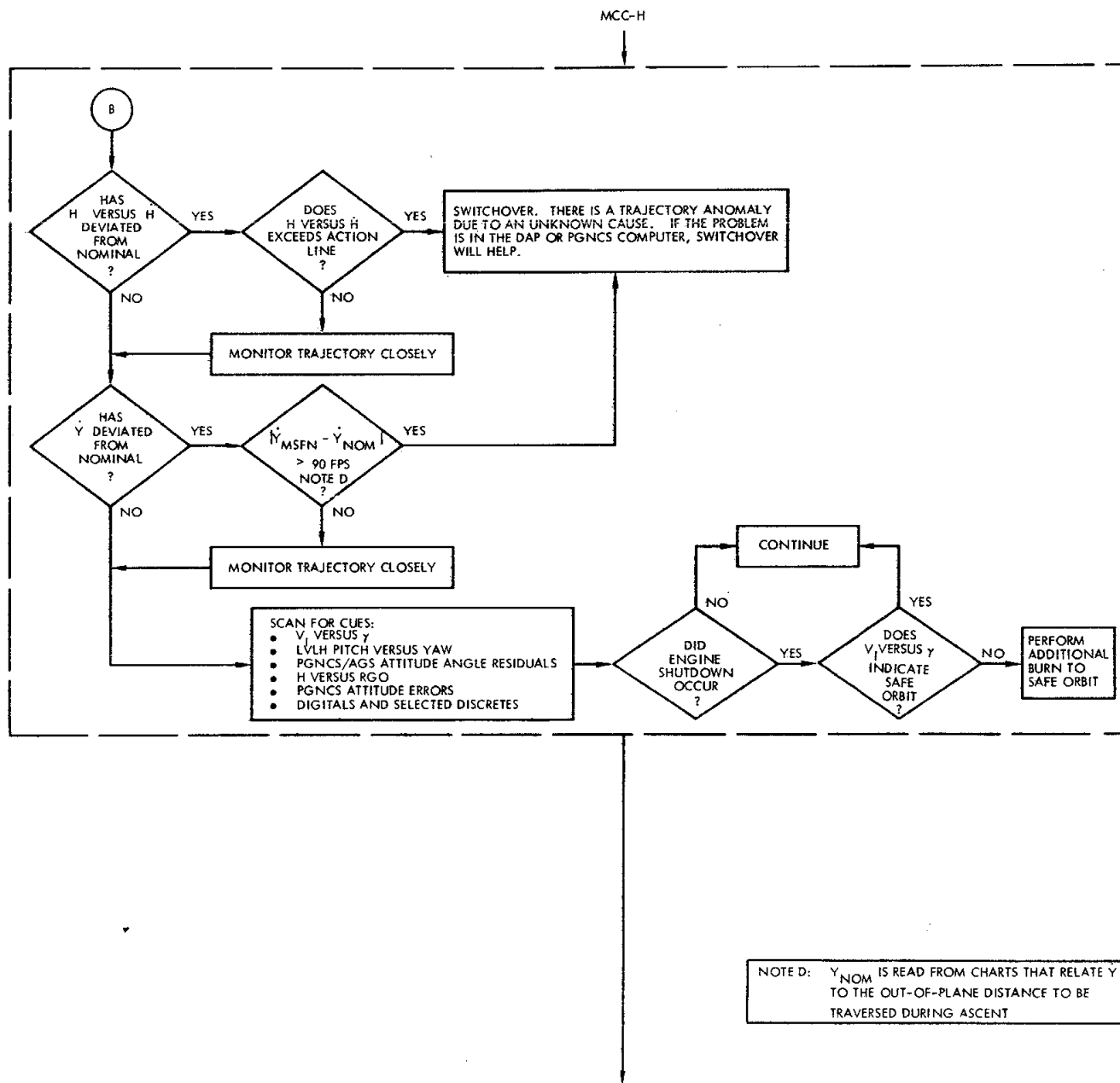


MCC-H



GROUND MONITORING (CONTINUED)





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2. Manned Spacecraft Center: "Apollo Mission Techniques Mission H-2 and Subsequent - Lunar Orbit Activities," MSC Internal Note 01297, 30 January 1970.
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4. B. R. Hurlbut, "RCS Insertion Capability During LM Ascent Employing 3 Different Attitude Histories," TRW Letter 5521. 7-25, 28 March 1969.
5. G. L. Duncan, "Development and Definition of Ground Monitoring Procedures for Powered Ascent from the Lunar Surface," TRW Letter 5524. 6-81, 4 August 1969.