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FEBRUARY 27, 1970

APOLLO MISSION TECHNIQUES  
MISSION H-2 AND SUBSEQUENT  
CONTINGENCY PROCEDURES

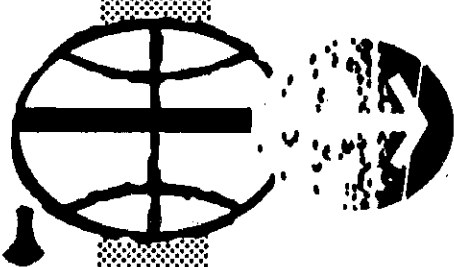
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APOLLO SPACECRAFT PROGRAM OFFICE  
MANNED SPACECRAFT CENTER  
HOUSTON, TEXAS

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February 27, 1970

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

Approved by

*Philip C. Shaffer*  
Philip C. Shaffer, Chief  
Apollo Data Priority Coordinator

## FOREWORD

This Contingency Procedures 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
- Lunar Surface
- Manual Ascent
- Powered Ascent
- Lunar Orbit Activities
- Transearth Injection, Midcourse Corrections, and Entry
- Tracking Data Selection Controllers 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 activities and develop agreed upon mission techniques.

## FOREWORD (Continued)

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 Contingency Procedures 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

APS	ascent propulsion system
ASAP	as soon as practicable
BMAG	body mounted attitude gyro
CDR	Crew Commander
CLA	contingency landing area
CM	command module
CMC	Command Module Computer
CMP	Command Module Pilot
CO	cutoff
COI	contingency orbit insertion
CSM	command service module
DEDA	data entry and display assembly
DET	digital event timer
DPS	descent propulsion system
DSKY	CM display and keyboard
DVM	delta velocity magnitude
ECS	environmental control system
EI	entry interface
EMS	entry monitoring system
EPO	earth parking orbit
EPS	electrical power system
ESS	early S-IVB staging
FDAI	flight director attitude indicator

## NOMENCLATURE (Continued)

GDC	guidance display coupler
g. e. t.	ground elapsed time
GETI	ground elapsed time of ignition
GMT	Greenwich mean time
GNCS	CSM primary guidance, navigation, and control system
G&N	guidance and navigation system
$\dot{h}$	rate of change in altitude (measured in feet per second)
$h_a$	Keplerian apogee altitude (measured in nautical miles above a spherical reference body-earth of pad radius or moon)
$h_p$	Keplerian perigee altitude (measured in nautical miles above a spherical reference body-earth of pad radius or moon)
HR	hour
IMU	inertial measuring unit
IU	Saturn launch vehicle instrument unit
KSC	Kennedy Space Center
LET	launch escape tower
LM	lunar module
LLOS	landmark line of sight
LO	lift-off
LOI	lunar orbit insertion
LV	launch vehicle
MCC	midcourse correction
MCC-H	Mission Control Center - Houston

# NOMENCLATURE (Continued)

MIN	minute
MPL	Mid Pacific Landing Area
MSFN	Manned Space Flight Network
PC	pericynthian
PGNCS	LM primary guidance, navigation, and control system
PLA	planned landing area
PTC	passive thermal control
RCS	reaction control system
REFSMMAT	transformation matrix from earth centered inertial reference to stable member inertial coordinates
RTCC	Real-Time Computer Complex
RTEAP	return-to-earth abort processor
SC	spacecraft
SCS	stabilization control system
S-IC	Saturn V first stage booster
S-II	Saturn V second stage booster
S-IVB	Saturn V third stage booster
SPS	service module propulsion system
SXT	sextant
$t_B$	burn duration
TD&E	transposition, docking, and LM extraction
TE	transearth
TEC	transearth coast
TEI	transearth injection

# NOMENCLATURE (Continued)

THC	translational hand controller
TIG	time of ignition
TLC	translunar coast
TLI	translunar injection
V or $V_I$	inertial velocity
$\Delta V$ , $\Delta V_M$	velocity increment

## 1. INTRODUCTION

The H-2 (Apollo 13) hybrid mission profile, targeted for the Fra Mauro landing site, consists of the following:

- a) Launch and boost to earth parking orbit (EPO) 11 April with other launch opportunities 10 and 12 May; the configuration is AS-508-LY/CSM-109/LM-7.
  - Daylight launch from KSC Launch Complex on a variable flight azimuth of 72 to 96 degrees dependent on launch time
  - S-IVB/IU/CSM/LM inserted into a nominal 100-nautical mile circular EPO after completion of S-IC, S-II, and partial S-IVB stage burns
- b) Coast in EPO for two or three orbits during which time launch vehicle (LV) and SC systems checkout will take place
- c) Translunar injection (TLI)
  - S-IVB engine restarted over the Pacific Ocean during either the second or third orbits (first and second injection opportunities, respectively)
  - S-IVB/IU/CSM/LM injected into a free-return translunar trajectory
- d) Translunar coast (TLC)
  - CSM separation from S-IVB/IU/LM
  - CSM transposition and docking (T&D) with the LM
  - LM extraction and CSM/LM separation from S-IVB
  - S-IVB evasive maneuver followed by dump of residual propellants to achieve slingshot\*

\*The S-IVB slingshot consists of placing the S-IVB on a close approach lunar trajectory; whereby, the S-IVB stage is nominally transferred to a solar orbit.

- SPS burn to transfer CSM/LM to a hybrid trajectory
- Midcourse corrections (MCC's) executed as required

e) Lunar phase

- Service module propulsion system (SPS) burn to transfer the CSM/LM to a 60- by 170-nautical mile lunar orbit (LOI); after two orbits, a second SPS retrograde burn produces an 8-by 60-nautical mile orbit (DOI).
- After approximately 11 orbits, the CSM and LM separate, and the CSM performs an SPS burn to attain a 60-nautical mile circular orbit.
- During lunar orbit 14, the LM descends to the lunar surface, and subsequent to the lunar surface activities, ascends (orbit 31) and rendezvous with the CSM (orbit 33).
- Following approximately 46 orbits, an SPS post-grad burn to transfer the CSM to a transearth trajectory (TEI) is executed.

f) Transearth coast

- Midcourse corrections executed as required

g) Earth entry

This document defines trajectory and systems monitoring techniques and resultant contingency procedures (excluding alternate mission possibilities and undocked lunar activities) which involve real-time decisions by the crew and ground (MCC-H) during the mission. Figure 1 presents an overall view of the contingency procedure options, and a contingency procedures timeline is presented in Figure 2. The contingency procedure modes shown in Figure 2 read vertically down in their order of priority (i. e., the top contingency mode is the one which would be executed before considering the next lower mode, etc.). In addition, those contingency modes shown on the same level for different mission phases are assumed to be approximately equal in likelihood of ever being required.

The monitoring techniques and contingency procedure options are presented in flow charts which depict the necessary crew and corresponding Mission Control Center-Houston (MCC-H) real-time decisions. The contingency procedures contained in these flow charts are based on References 1 through 8. Detailed discussions of these procedures are presented in Sections 2 through 7 of this document. Launch phase contingency procedures are presented in the Mission H-2 and Subsequent Launch Phase Aborts document (Reference 1) and so are not discussed in detail herein. The earth entry phase shown in Figure 2 is not discussed in this report. A detailed account is given in Reference 9.

## 2. LAUNCH PHASE CONTINGENCY PROCEDURES

Launch phase contingencies consist of launch abort and contingency orbit insertion (COI) maneuvers. The initiation of a contingency maneuver is determined from specific displays which are monitored by the ground and crew throughout the launch phase.

- a) Mode I aborts utilize the launch escape tower (LET) to remove the CM from the LV. Mode I aborts are possible from just prior to lift-off until the LET is jettisoned (nominally 3 minutes 20 seconds g. e. t.). Mode I aborts may be initiated automatically by the emergency detection system or manually.
- b) Mode II aborts which employ a full-lift entry profile into the Atlantic Continuous Recovery Area. These aborts are nominally possible from LET jettison until about 10 minutes 2 seconds g. e. t. (Full-lift down-range landing distance equals 3200 nautical miles).
- c) Mode III aborts which employ an SPS retro burn followed by an approximate half-lift entry profile into the Atlantic Discrete Recovery Area. These aborts are nominally possible at any time after the mode II region until EPO insertion.

The COI modes consist of:

- a) Manual takeover which permits the crew to fly the booster to the desired orbit. Takeover is possible any time that an IU platform failure is indicated by the LV guidance light.
- b) Early S-II/S-IVB staging (ESS) which may be accomplished any time that the S-IVB plus SPS is capable of completing insertion into the nominal or a contingency orbit. This maneuver will be executed if S-II malfunctions do not permit continued S-II powered flight. The earliest that ESS could occur is 5 minutes 45 seconds g. e. t. when the S-IVB plus SPS is capable of achieving a contingency orbit. At 6 minutes 35 seconds g. e. t., the S-IVB is capable of achieving nominal insertion.
- c) Mode IV which permits the crew to fly the CSM into a safe orbit ( $h_p \geq 75$  nautical miles). This SPS post-grade maneuver can nominally be executed at any time after 9 minutes 1 second g. e. t., until EPO insertion.



- d) Apogee kick mode (AK) which utilizes a postgrade SPS burn at apogee to raise perigee altitude to 75 nautical miles.

The COI maneuvers are prime whenever the capability for their execution exists. Figure 3 describes the availability of each abort mode and contingency maneuver. A detailed discussion of these abort and COI procedures and monitoring techniques may be found in Reference 1.

### **3. EPO CONTINGENCY PROCEDURES**

EPO contingency procedures consist of monitoring critical SC systems and those LV systems required for TLI in order to determine whether or not to proceed with the TLI phase. In the event TLI is no go, the following alternatives are available:

- a) Execution of potential alternate mission
- b) Premature earth entry at some time during EPO. Depending on the time criticality of the malfunction which precludes TLI, the entry could be required immediately or within a time frame sufficient to land in a planned recovery area. Detailed retro-fire and entry procedures are presented in Reference 10 for the C-prime (earth orbit) D, F, and G missions. In the event of a critical SPS failure or unusable SPS propulsion system, the reaction control system (RCS) propulsion system can be employed as a backup deorbit technique.

#### 4. TLI THROUGH TD&E CONTINGENCY PROCEDURES

The TLI burn injects the S-IVB/IU/CSM/LM onto a free-return translunar trajectory, nominally, on the second EPO revolution. Contingency studies have shown that if the TLI burn is completed within established attitude and attitude rate limits, alternate mission capabilities are enhanced without endangering the crew. Since there is little possibility of a catastrophic CSM failure that would require an immediate S-IVB engine shutdown followed by a time-critical abort, any decision to return to earth because of degrading spacecraft systems performance can be made more reliably after TLI with MCC-H support. Consequently, a decision has been made to no longer consider the 10-minute abort mode (Reference 11).

Because MSFN tracking is not always available during TLI, the crew must be able to monitor and evaluate TLI without ground support. Translunar injection burn monitoring procedures are presented in Figure 4 where primary and backup monitoring techniques and limits are defined. (Detailed information is provided in References 2 and 5.) Onboard tabular data are provided, similar to that shown in Table 1, to monitor the burn (Reference 12). These data consist of pad-referenced pitch-and yaw-gimbal angles, inertial velocity, and altitude and altitude rate as functions of time from TLI ignition. If during the burn the attitude deviates more than  $\pm 45$  degrees from the nominal gimbal angles shown on the crew chart, the crew will manually shutdown the S-IVB engine. Manual shutdown will also occur if attitude rates greater than  $\pm 10$  degrees per second are experienced. Criteria are also defined for an altitude check prior to TLI ignition and for manual shutdown at injection if nominal cutoff does not occur (Figure 4).

The foregoing discussion is related to S-IVB problems and does not require an abort. The TLI plus 90 minute and lift-off plus 8-hour abort modes provide for return to earth should spacecraft systems problems be identified during the TLI burn or post TLI through TD&E. Therefore, the contingency procedures applicable from TLI ignition through TD&E are:

- a) Crew takeover and manual completion of the TLI burn if LV Guide Light lights; or if attitude or attitude rate limits are exceeded, manual shutdown of S-IVB engine. An alternate mission would result for a premature manual S-IVB shutdown.
- b) TLI plus 90-minute abort mode; return to earth because of spacecraft systems problems identified during TLI or after TLI through TLI plus 25 minutes. Return solution is based on onboard block data (provides first guess for P37) if no-voice or MCC-H with communications.
- c) Lift-off plus 8-hour abort mode; return to earth because of spacecraft systems problems or loss of communications during period from TLI plus 25 minutes through TD&E.

A failure of the IU does not rule out TLI. An ST-124 inertial platform located in the IU is used as the inertial attitude reference during the TLI burn. The outputs from the platform are monitored by the launch vehicle digital computer (LVDC) and are tested for reasonableness. Successive failures of the reasonableness test will cause the LVDC to issue the last commands repetitiously to the end of TLI. The LV Guide Light in the CSM will also light. Should this light come on prior to TLI, the crew will flip the IU/CMC switch to the CMC position and begin preparations for manual completion of the TLI burn. This is accomplished by torquing the flight director attitude indicator (FDAI-1 in ORDEAL mode) at a constant pitch rate representative of the nominal TLI guided maneuver. The crew then manually maintains constant pitch and yaw angles with respect to the torquing attitude indicator. The burn is monitored with FDAI-2 and CM display and keyboard (DKY) outputs with manual shutdown based on data provided in the pre-TLI pad message (Table 2). More detailed procedures are presented in Table 3 (Reference 12). If the light comes on during the TLI burn, the crew will flip the IU/CMC switch to the CMC position and takeover and manually complete the remaining portion of the burn.

It is possible for the IU to fail and the LV Guide Light to remain dark. Just prior to TLI ignition, this would be detected by the preignition burn attitude check, and TLI ignition would be inhibited. If this happens during TLI, and FDAI indicated attitudes or rates exceed specified limits, the S-IVB will be shutdown manually. An alternate mission will then be determined in real time.

The TLI plus 90-minute abort mode is designed to return the spacecraft to a contingency landing area, with a return flight time of 18 hours or less. An evaluation of spacecraft systems is made after TLI and a go/no-go decision is made at TLI plus 25 minutes as to whether or not an abort will be executed. If an abort maneuver is required, MCC-H transmits a solution (if required) at TLI plus 60 minutes that updates the pre-TLI block data solution (Table 4). If communication with MCC-H is not possible, the pre-TLI block data solution will be used as first guess input to the Return-to-Earth Targeting Program (P37). The following abort sequence is initiated at TLI plus 25 minutes by turning the THC counterclockwise (Reference 13).

<u>Digital Event Timer (DET)</u> <u>(hr:min:sec)</u>	<u>Event</u>
00:00:00	The translational hand controller (THC) is turned counterclockwise, initiating CSM/S-IVB separation. The four +X RCS jets are turned on.
00:00:03	CSM/S-IVB separation occurs.
00:00:13	The four +X RCS jets are turned off, and the crew begins pitching up (+X, down) to -r (down the radius vector) using the earth as the visual reference to determine -r.
00:01:00	The four -X RCS jets are turned on to initiate an evasive maneuver to provide clearance between the CSM and S-IVB for the abort maneuver.
00:01:08	The four -X RCS jets are turned off and the crew begins maneuvering to abort maneuver thrusting attitude.
01:05:00 (Equivalent Impulsive, TIG)	SPS ignition (fixed inertial attitude retro burn)

Detailed TLI plus 90-minute procedures are presented in Figure 5.

In the event that voice communications are lost after TLI plus 25 minutes and TD&E cannot be accomplished, the crew will prepare to execute a lift-off plus 8-hour abort maneuver. This maneuver is executed following the nominal CSM separation sequence and results in a return to a contingency landing area. A P37 solution (Table 5) is passed to the crew during EPO (assuming a nominal TLI burn) and, if required, is updated by MCC-H at TLI plus 60 minutes. In any event, the transmitted solution is used as a first guess to recompute the solution using P37.

## 5. TLC CONTINGENCY PROCEDURES

If it is determined by MCC-H and the crew that an abort maneuver should be performed during TLC, MCC-H will provide the solution and specify the configuration and propulsion system to be used. Because a number of options are available, a real-time assessment of the contingency situation is required to select the best return mode for the particular situation. Sufficient time exists to make an evaluation since long return trip times are unavoidable. Nominally, the maneuver will be performed in the external  $\Delta V$  mode, although it could be executed in the stabilization control system (SCS) auto mode in the CSM or a manual mode in the LM.

Possible return options, as shown in Figure 2, are:

- a) Lunar flyby targeted to the Mid Pacific Landing Area (MPL) or the prime contingency landing area (CLA) with pericynthian altitude between 60 and 1500 nautical miles (Reference 14), and performed at LOI minus 5 hours (option generally used in a non-time critical situation).
- b) Pericynthian passage plus 2-hour abort targeted to any CLA. (This option is generally used to perform a docked abort maneuver after 60 hours g. e. t. to provide a minimum time return. The entry velocity constraint of 37,500 feet per second defines the minimum return time).
- c) Direct return targeted to a CLA (option provides a minimum return time for aborts initiated prior to 60 hours g. e. t.)

Direct returns will usually be performed undocked, while circum-lunar returns will include the LM.

During translunar coast, MCC-H will periodically provide block data abort solutions to the crew for use should communications in both the CSM and LM be lost. Since this situation is somewhat remote, a minimum number of solutions are provided, and where possible, a minimum amount of data are transmitted as shown in Table 6. While outside of the lunar sphere of influence, where P37 can be used to compute direct returns,

only first guess information is provided (Table 5). Inside the sphere prior to LOI, two block data solutions (Table 4) are provided. As shown in Table 6, they are:

- a) A non-time critical, lunar flyby solution targeted to a prime CLA and executed at LOI minus 5 hours.
- b) A fast return solution targeted to a CLA and executed at pericynthian passage plus 2 hours.

Figure 6 shows the TLC abort procedures.

SPS and docked DPS abort burn monitoring procedures are described in Figures 7 and 8, respectively.

For direct return aborts with the CSM alone, the LM separation procedure is as follows:

- a) Orient the CSM +X axis 180 degrees away from the abort direction (+X axis up the radius vector).
- b) Execute LM jettison and perform CSM -X RCS translation for a net separation velocity of 1.0 foot per second.
- c) Coast for 30 minutes, orient to the abort attitude.
- d) Perform the SPS abort maneuver.



## 6. LOI AND LUNAR ORBIT CONTINGENCY PROCEDURES

The LOI maneuver transfers the CSM/LM from the non-free return translunar trajectory to a 60- by 170-nautical mile lunar orbit (LOI) and after approximately two revolutions, a second SPS burn (DOI) produces an 8- by 60-nautical mile lunar orbit. (The contingency procedures relating to the DOI burn are not discussed herein but are detailed in Reference 15.) Since the LOI burn occurs behind the moon, the crew must be able to monitor and evaluate the burn without ground support. Figure 7 defines the real-time decision logic for use in monitoring the SPS, G&N, and critical spacecraft systems. In addition, it defines the manual SPS shutdown logic when a contingency is identified by the monitoring procedures. The burn monitoring procedures are similar to those for TLI in that the prime objective is to complete the LOI burn so long as attitude and attitude rate limits are not violated. The attitude and attitude rate and SPS shutdown monitoring rationale is discussed in detail in References 3 and 16. The SPS system monitoring portion is presented to indicate when LOI aborts (and TEI aborts discussed in Section 7) would be initiated. Generally, the burn monitoring logic is applicable for all major SPS burns including various SPS abort maneuvers which may occur during TIG or TEC.

Four possible contingency areas have been identified for an SPS burn:

- a) Guidance and control: platform misalignment, drift, etc.
- b) Non-SPS related: ECS, EPS, etc.
- c) SPS related: sustained pressure decay, low chamber pressure, large pressure differential between fuel and oxidizer tanks, etc.
- d) Inadvertent SPS shutdown: all contingencies which can be identified with an SPS failure however remote.

If G&N problems result in violation of the preignition attitude check LOI is no go; if attitude or attitude rate limits (10 degrees and 10 degrees per second, respectively, excluding start transients) are violated during

the burn, crew takeover and completion of the burn (at the nominal ignition attitude) is accomplished under SCS control (Figure 7).

For non-SPS related problems that might develop during LOI, the procedure is to complete the burn and, after establishing contact with MCC-H, jointly assess the situation.

Manual shutdown for SPS related problems (Reference 17) would occur during the first 105 seconds or the last 128 seconds of the LOI burn if SPS operating limits that permit a subsequent burn (tight limits) are exceeded. Between 105 seconds and 228 seconds, manual shutdown would occur only if the SPS operating limits that do not permit a subsequent burn (loose limits) are exceeded. Tight and loose limits are defined by the mission rules as:

#### Tight Limits

- Loss of one GN2 tank pressure (less than 1500 psia) associated with a decay in the other
- Delta pressure between fuel and oxidizer greater than 20 psia (confirmed by low chamber pressure)
- SPS propellant tank pressure less than 160 psia (confirmed by low chamber pressure)
- Chamber pressure less than 80 psia or decay of 10 psia during burn
- Any ball valves that fail to open or close prematurely (verify by shutting good tank off)

#### Loose Limits

- Chamber pressure less than 70 psia
- Propellant tank pressure less than 115 psia (confirmed by chamber pressure)
- Physiological indication of problems

If manual shutdown is necessary, an LOI abort will be executed.

Should an inadvertent SPS shutdown occur, a restart will be attempted. If unsuccessful, an LOI abort will be executed.

Return-to-earth abort procedures, using LM propulsion as a backup to the SPS, are shown in the LOI Abort Flow Chart (Figure 8) and are summarized in the following table:

<u>LOI-3 Burn Duration (sec)</u>	<u>Abort Mode</u>	<u>Propulsion System</u>	<u>Number of Burns</u>	<u>QIN Mode</u>	<u>Source of Solution</u>	<u>Return Target*</u>	<u>Time of Ignition (hr)</u>
0 - 105	I	DPS	1	PONCS	MCC-H	MPL	LOI IGN + 2.0
105 - 170	II	DPS	2	1st PONCS 2nd PONCS	MCC-H MCC-H	** MPL	LOI IGN + 2.0 RTCC GETI
170 - 1ns	III	DPS	1	PONCS	MCC-H	MPL	RTCC GETI

Modes I, II, and III are the standard LOI abort modes:

- a) Mode I - A single-impulse, return-to-earth maneuver normally executed 2 hours after a premature LOI shutdown. The preabort, moon-centered orbit is hyperbolic.
- b) Mode II - A two-impulse maneuver with the first executed 2 hours after a premature LOI shutdown, to provide a stable lunar orbit with a pericynthian altitude of at least 40 nautical miles. The second maneuver occurs some 15 to 40 hours later and injects the spacecraft on return trajectory.
- c) Mode III - A single-impulse, return-to-earth maneuver executed some 2 to 15 hours after a premature LOI shutdown. The preabort orbit is a stable lunar ellipse.

\* If required for circumlunar aborts, an SPS burn will be executed to raise pericynthian altitude to at least 40 nautical miles. Also, the return maneuver will be targeted to a CLA where possible. At minimum, returns will be constrained to water landings.

\*\* Corrective maneuver: Real-Time Computer Complex (RTCC) specified  $\Delta V$  targeted down the radius vector to produce a stable lunar orbit with pericynthian altitude  $\geq 40$  nautical miles.

In addition to the more familiar mode I, II, and III abort modes, Reference 18 describes additional abort modes which may, for certain trajectories, be required to provide continuous abort capability during LOI.

Burn monitoring procedures for docked DPS abort burns under PGNCs control are presented in Figure 9. Similar information for manually executed DPS and APS docked maneuvers is presented in Figure 10.

Just prior to LOI and during lunar orbit (before LM separation and after rendezvous), MCG-H will periodically provide block data solutions (premature TEI solutions) to the crew should communications in both the CSM and LM be lost. Since this situation is extremely remote, a minimum amount of data are transmitted as shown in Table 6. The crew uses the abort message pad shown in Table 4 to record these block data solutions which would be used only if communications with MCG-H were lost.

Separation procedures for jettisoning either the total LM or LM ascent stage during lunar orbit are:

- a) Orient the CSM +X-axis along the postgrade local horizontal
- b) Perform LM jettison
- c) Perform CSM -X translation retrograde for a net velocity increment of 1.0 foot per second
- d) Coast for at least 30 minutes (preferably 1 hour) to TEI
- e) Execute TEI

When the LM is retained after a mode I, II, or III abort, the LM is jettisoned during TEC prior to 3 hours before reaching entry interface, using the following technique:

- a) Orient the CSM +X axis along the postgrade local horizontal (earth reference)
- b) Perform CSM +X RCS translation postgrade to target for a 70-nautical mile vacuum perigee
- c) Execute LM jettison
- d) Perform -X RCS translation retrograde to null the first CSM maneuver and thus lower vacuum perigee.

## 7. TEI AND TEC CONTINGENCY PROCEDURES

The TEI maneuver is a critical SPS burn in that it has no backup and is mandatory for return to earth. Therefore, the primary objective is to complete the burn if at all possible. Since TEI also occurs behind the moon, the crew must be able to monitor and evaluate the burn without ground support. Consequently, the burn monitor procedures, discussed in Section 6 and shown in Figure 7, apply to the TEI burn. It is emphasized that manual shutdown will not be initiated for any CSM systems problems since completion of the burn is mandatory. Guidance, navigation, and control problems which produce violation of attitude or attitude rate limits, result in crew takeover and completion of the burn (at TEI ignition attitude) under SCS control. The crew will manually terminate the burn at nominal cutoff plus 2 seconds, provided the EMS  $\Delta V$  counter indicates that the desired  $\Delta V$  has been applied. Should an inadvertent SPS shutdown occur, a restart will be made within 30 seconds. If a restart is not possible within this period, the crew will receive a solution from MCC-H after communications are reestablished.

The options available for inadvertent SPS shutdowns during TEI are presented in Figure 11. These options assume an operable GNCS although an abort maneuver could be executed in one of the SCS modes. The abort modes applicable to TEI are:

<u>TEI Burn Duration</u> <u>(sec)</u>	<u>Abort Mode</u>	<u>Comments</u>
0 - 80	III	RTCC computed external $\Delta V$ solution targeted to a water landing or MPL
80 - 96	II	Two maneuvers: first maneuver executed as soon as possible to achieve a stable lunar orbit; second maneuver targeted to a water landing or MPL. Both are external $\Delta V$ solutions computed by the RTCC.

<u>TEI Burn Duration (sec)</u>	<u>Abort Mode</u>	<u>Comments</u>
121 - Injection	1	RTCC computed external $\Delta V$ solution targeted to a water landing or MPL. Maneuver executed as soon as possible.

Should communications be lost during lunar orbit, the block data solutions discussed in Section 6 would be used for the TEI solution. If communications are lost after TEI, P37 can be used to compute any necessary maneuvers once the lunar sphere is exited.

Aborts during TEC would be initiated only if a shorter flight time was required because of degrading life support systems. Any required solution would normally be provided by MCC-H, or if communications were lost, P37 could be used.

## 8. NAVIGATION

The basic ground rule is for MCC-H to provide the navigation function as long as communications are maintained with the spacecraft. If communications are lost, the navigation function must be performed onboard in accordance with an appropriate navigation schedule. Midcourse corrections will be performed under GNCS control using the external  $\Delta V$  mode and a P37 solution. The typical program sequence around a MCC will be P52, P23, P37, P40(41), and P23 as shown in Figure 12. After the burn and before P23 is called, the CMP will transfer the CSM state vector to the LM slots (V66). This will ensure a redundant state vector onboard in the event that the state vector in the CSM slots is destroyed.

Onboard navigation procedures are discussed in detail in Appendix A (Reference 19). Typical onboard data consisting of sighting schedules and star availability crew charts are included for the following no-communications contingencies (a complete set of onboard data is presented in Reference 19):

- a) Lift-off plus 8-hour return-to-earth abort maneuver from translunar coast
- b) Return-to-earth abort maneuvers from lunar orbit
- c) Nominal transearth coast (nominal lunar stay time)

In addition, general procedures and rules are defined to facilitate onboard navigation should a situation develop that is not specifically covered by the onboard data. A summary of sextant constraints relating to navigation sightings is also included.

Table 1. Typical TLI Burn Monitor Crew Charts

SIVB TLI - NOMINAL

November 14, 1969 AZ 72° FIRST OPPORTUNITY					
$\theta$	$\gamma$	DET	$V_I$	$\dot{H}$	H
59	1.0	0:00	25559	9	106
56	-2.0	0:30	26116	24	106
55	0.0	1:00	26727	85	106
54	2.5	1:30	27364	206	107
53	3.0	2:00	28092	399	108
53	6.8	2:30	28903	681	111
52	8.7	3:00	29754	1057	115
51	10.6	3:30	30649	1534	122
50	12.5	4:00	31594	2122	131
48	14.3	4:30	32595	2819	143
46	15.9	5:00	33664	3633	159
41	17.6	5:30	34819	4536	179
41	17.5	5:44	35426	5026	190

SIVB TLI - MANUAL

November 14, 1969 AZ 72° FIRST OPPORTUNITY					
$\theta$	$\gamma$	DET	$V_I$	$\dot{H}$	H
57	8.0	0:00	25559	9	106
56	8.0	0:30	26116	24	106
55	8.0	1:00	26727	85	106
54	8.0	1:30	27364	206	107
53	8.0	2:00	28092	399	108
52	8.0	2:30	28903	681	111
51	8.0	3:00	29754	1057	115
50	8.0	3:30	30649	1534	122
49	8.0	4:00	31594	2122	131
48	8.0	4:30	32595	2819	143
47	8.0	5:00	33664	3633	159
45	8.0	5:30	34819	4536	179
45	8.0	5:44	35426	5026	190



Table 2. TLI Message Pad

TLI															
X						X						TB6P			
X	X	X				X	X	X				R	TLI		
X	X	X				X	X	X				P			
X	X	X				X	X	X				Y			
X	X	X				X	X	X				BT			
												ΔVC			
+						+						VI			
X	X	X				X	X	X				R	SEP		
X	X	X				X	X	X				P			
X	X	X				X	X	X				Y			
X	X	X				X	X	X				R	EXTRACTION		
X	X	X				X	X	X				P			
X	X	X				X	X	X				Y			
COMMENTS															

Table 2 Notes

- TB6p is the predicted time the SII Second Plane Separation Light will go out (TB6 + 37 seconds) (MSFC provides data)
- R, P, Y are the predicted spacecraft IMU gimbal angles at TLI ignition (deg).
- BT is the predicted duration of the TLI burn. (MSFC provides data)
- ΔVC' is the value set into the EMS ΔV counter which includes predicted longitudinal ΔV plus tailoff (fps). (MSFC provides data)
- R, P, Y SEP are the predicted spacecraft IMU gimbal angles at the post-TLI separation attitude (S-IVB cutoff + 15 minutes).
- R, P, Y EXTRACTION are the IMU gimbal angles to perform LM extraction.

Table 3. TLI Backup Guidance Procedures

TB5	KEY V46E LV GUID - CMC ORDEAL ALT = 300 NM EARTH/LUNAR = LUNAR MANEUVER LV TO START ATT: $R = 180^\circ$ , $P = 107.9^\circ$ , $Y = 0^\circ$ (1st OPP) KEY V16 N20E (DSKY R2 = $107.9^\circ$ , NULL LV RATES ORDEAL FDAI #1 = ORB RATE ORDEAL MODE - FAST/HOLD SLEW FDAI #1 TO $P = 0^\circ$ INSURE R2 = $107.9^\circ$ ) CMC TB6 LOAD** V96E V25 N33E LOAD GET of TB6 V25 N26E (LOAD R1, R2, R3) V30E F 06 34 (TIME FROM TB6)
TB6	S-II SEP LT - ON
	V37E 00E
51:00	S-II SEP LT - OFF
	START DET COUNTING UP FROM 51:00
57:00	KEY V37E 47E, CHECK BIAS N20E
	INSURE FDAI #1 $P = 0^\circ$ & $R2 = 107.9^\circ$ , $R3 = 0^\circ$
57:20	ORDEAL MODE - OPERATE/SLOW (STARTS ORDEAL TORQUING)
58:20	EMS MODE - NORMAL
58:36	S-II SEP LT - ON
58:38	LV ULLAGE START
59:42	S-II SEP LT - OFF (IGN - 18 SEC)
59:52	SIVB FUEL LEAD
59:55	LV ULLAGE TERMINATES
59:59	ENG #1 LT - ON
00:00	IGNITION
00:02	ENG #1 LT - OFF FLY $P = 0^\circ$ , $Y = 4^\circ$ N 62E
05:45 (1st)	CUTOFF ON PAD VI
05:29 (2nd)	LV STAGE SW - SII/SIVB

\* The times and angles shown are only typical of those for the H-2 mission.

\*\* If P20, P23, P3x, P4x, P6x or P7x is inadvertently called prior to TB6, manual TB6 must be used.

Table 4. Typical P30 Message Pad

P30 MANEUVER										
SET STARS										PURPOSE
										PROP/GUID
					+					WT N47
R ALIGN	---	---	---		0	0				P <sub>TRIM</sub> N48
P ALIGN	---	---	---		0	0				Y <sub>TRIM</sub>
Y ALIGN	---	---	---		+	0	0			HRS GETI
					+	0	0	0		MIN N33
					+	0				SEC
ULLAGE										$\Delta V_X$ N81
										$\Delta V_Y$
										$\Delta V_Z$
					X	X	X			R
					X	X	X			P
					X	X	X			Y
					+					H <sub>A</sub> N44
										H <sub>P</sub>
					+					$\Delta VT$
HORIZON/WINDOW					X	X	X			BT
					X					$\Delta VC$
					X	X	X	X		SXTS
					+				0	SFT
					+				0 0	TRN
					X	X	X			BSS
					X	X				SPA
P37 FOR L/O +8					X	X	X			SXP
				GETI		0				LAT N61
X				$\Delta VT$						LONG
X				LONG	+					RTGO EMS
				GET <sub>400K</sub>	+					V10
										GET 0.05G

#### Table 4 Notes

- PURPOSE is the name of the maneuver
- PROP/GUID is propulsion and guidance selected (SPS/P30)
- WT is the CSM weight (lb)
- PTRIM and Y-TRIM are respectively the pitch and yaw trim SPS gimbal angles (deg)
- GETI is the time of ignition
- $\Delta V_x$ ,  $\Delta V_y$ ,  $\Delta V_z$  are the P30 velocity to be gained components in local vertical coordinates (fps)
- R, P, Y are the IMU gimbal angles at the time of ignition for the abort maneuver (deg)
- $H_A$ ,  $H_p$  are the altitude of apogee and perigee, respectively above launch pad radius (n mi)
- $\Delta VT$  is the total inertial velocity impulse (fps)
- BT is the burn time (min:sec)
- $\Delta VC$  is the EMS  $\Delta V$  counter input
- SXTS is the sextant star to be used for the abort 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)
- SPS 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)
- P37 for L/O + 8 is a P37 first guess for the lift-off plus 8-hour abort.

Table 5. Typical P37 Pad

P37 BLOCK DATA									
									GETI (HR:MIN)
X				X					ΔVT
X				X					LONG
									GET <sub>400K</sub> (HR:MIN)
									GETI (HR:MIN)
X				X					ΔVT
X				X					LONG
									GET <sub>400K</sub> (HR:MIN)
									GETI (HR:MIN)
X				X					ΔVT
X				X					LONG
									GET <sub>400K</sub> (HR:MIN)
									GETI (HR:MIN)
X				X					ΔVT
X				X					LONG
									GET <sub>400K</sub> (HR:MIN)
									GETI (HR:MIN)
X				X					ΔVT
X				X					LONG
									GET <sub>400K</sub> (HR:MIN)
									GETI (HR:MIN)
X				X					ΔVT
X				X					LONG
									GET <sub>400K</sub> (HR:MIN)
									GETI (HR:MIN)
X				X					ΔVT
X				X					LONG
									GET <sub>400K</sub> (HR:MIN)

Table 6. Translunar Coast and Lunar Phase Block Data

Time of Block Data Transmission (hr:min, g.e.t.)	Description of Block Data	GETI of Abort Maneuver (hr:min, g.e.t.)	Type of Data Transmitted	Return Mode
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 LO + 35 (W/MCC-2) LO + 45 LO + 60	25:00 35:00 45:00 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 LOI)	79:41 86:08		Circumlunar to MPL
80:55	TEI 5 (W/DOI)	87:33		
84:10	TEI 11	98:48		
95:45	TEI 35	145:54		
144:20	TEI 40	155:49		
153:10	TEI 42	159:35		
158:10	TEI 44	163:33		
161:05	TEI 46	167:30		
164:50	TEI 46 (Nominal-Preliminary)	167:30	Complete P30 Pad	
166:10	TEI 46 (Nominal-Final) TEI 47	167:30 169:28	Partial P30 PAD	

\* See Table 4.

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

\*\*\* Only GETI,  $\Delta V_x$ ,  $\Delta V_y$ ,  $\Delta V_z$ , 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)

MISSION PHASE	CONTINGENCY PROCEDURE OPTIONS
LAUNCH PHASE	MANUAL COMPLETION ESS COI MODE I LAUNCH ABORT MODE II LAUNCH ABORT MODE III LAUNCH ABORT
EPO PHASE	ALTERNATE MISSION PREMATURE ENTRY
TLI PHASE (THROUGH TRANSPPOSITION, DOCKING AND LM EXTRACTION) LM EXTRACTION)	MANUAL COMPLETION ALTERNATE MISSION TLI + 90 MIN TLC ABORT LIFTOFF + 8 HR TLC ABORT
TLC PHASE	ALTERNATE MISSION TLC ABORT
LUNAR PHASE	MANUAL COMPLETION ALTERNATE MISSION MODE I LOI ABORT MODE II LOI ABORT MODE III LOI ABORT PREMATURE TEI
TEI PHASE	MANUAL COMPLETION MODE III TEI ABORT MODE II TEI ABORT MODE I TEI ABORT

Figure 1. Overall Mission H-2 Contingency Procedure Options

[illegible]



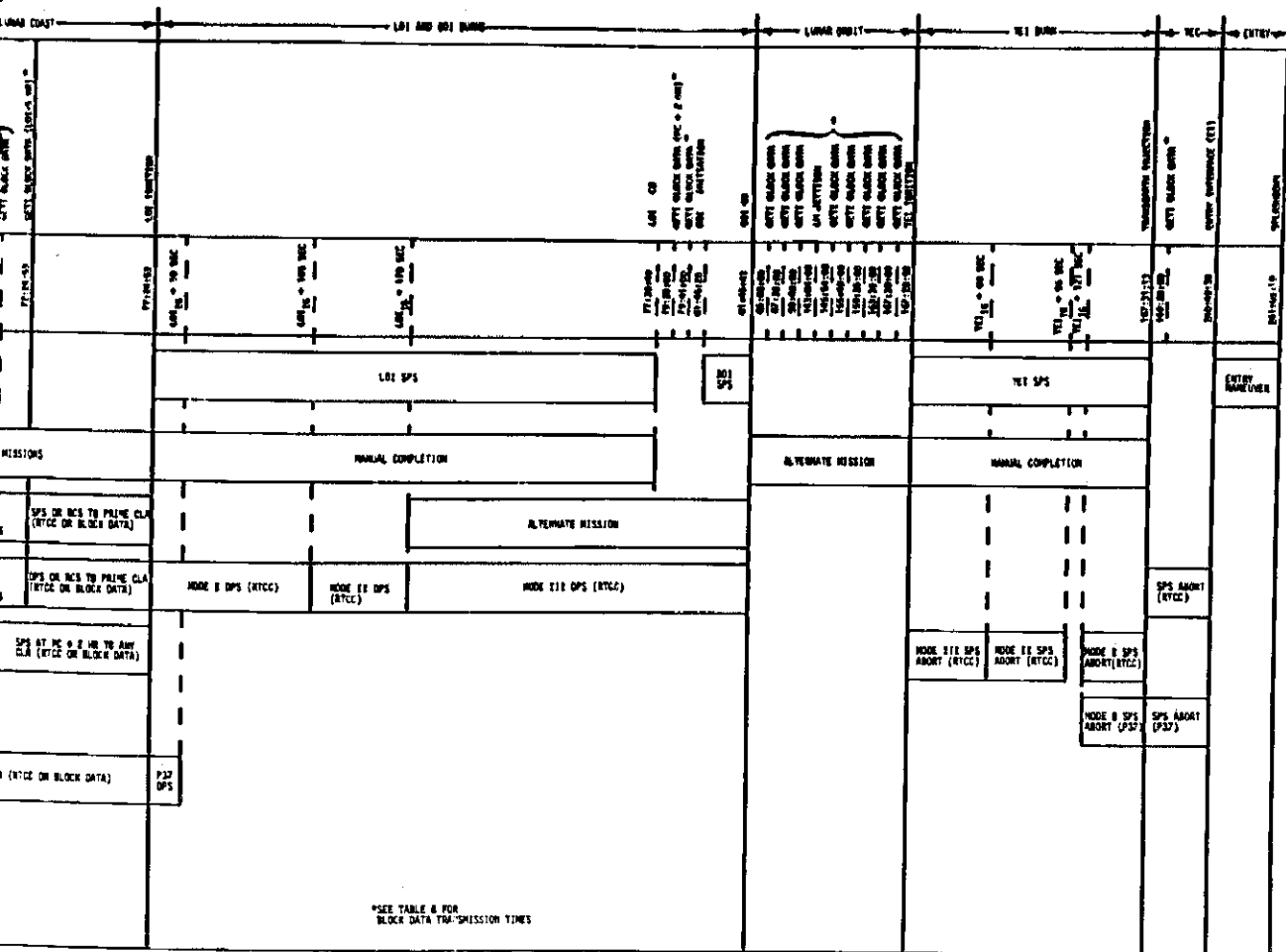


Figure 2. Overall Mission H-2 Contingency Procedures Timeline

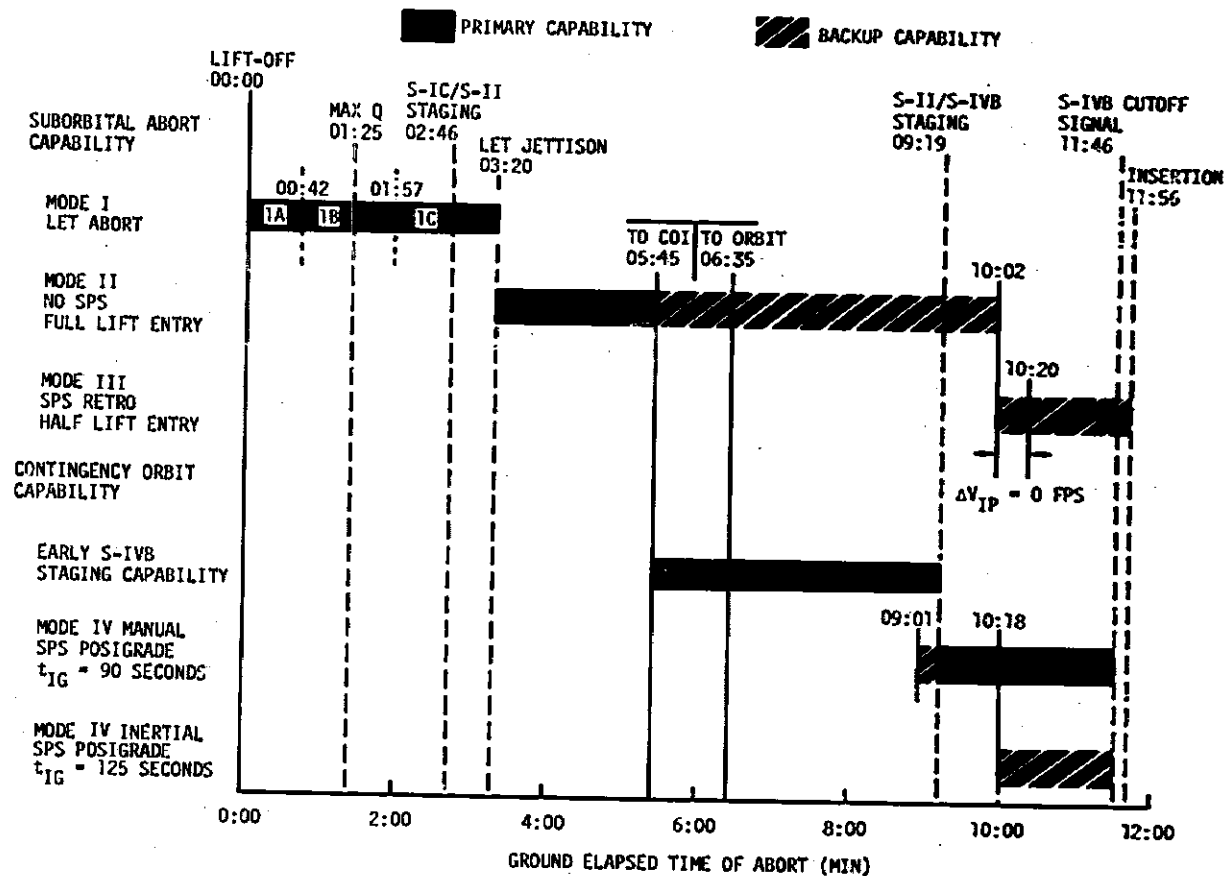
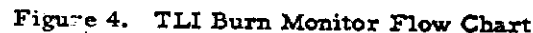


Figure 3. Typical Launch Abort and Contingency Maneuver Availability Chart



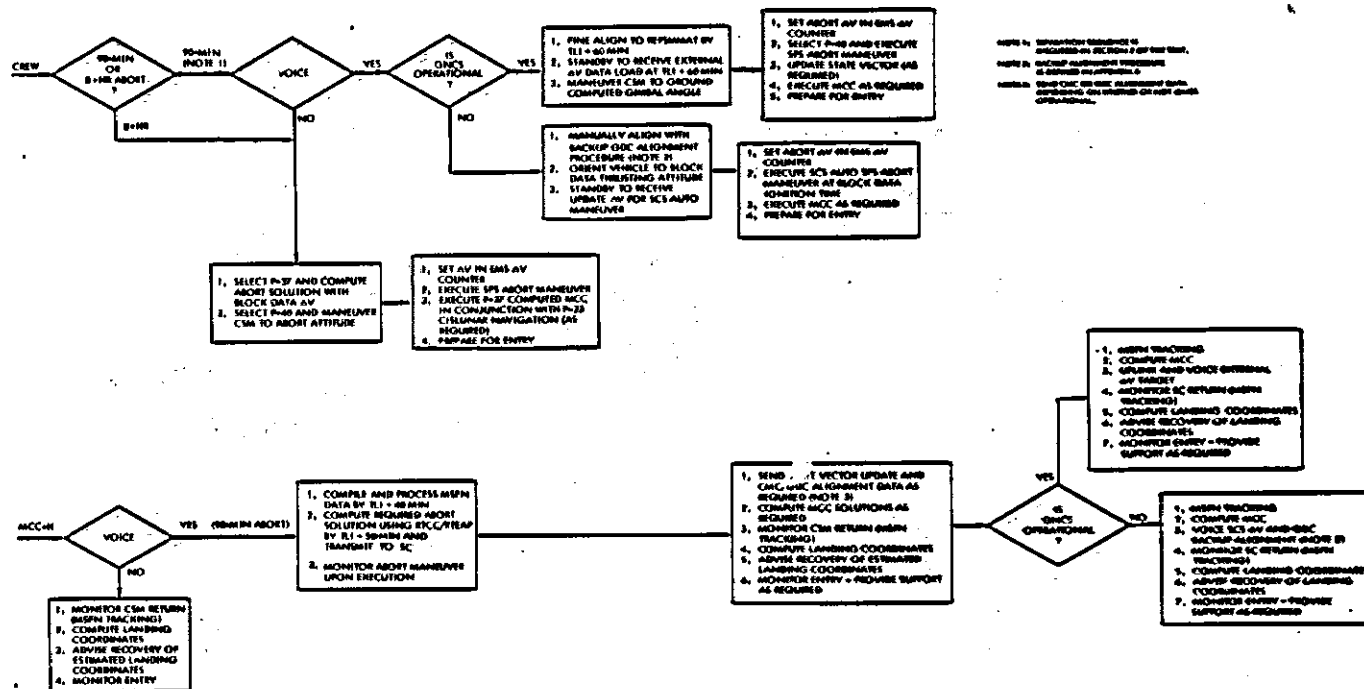


Figure 5. Typical 90-Minute and Lift-off Plus 8-Hour (No Voice) Abort Flow Chart

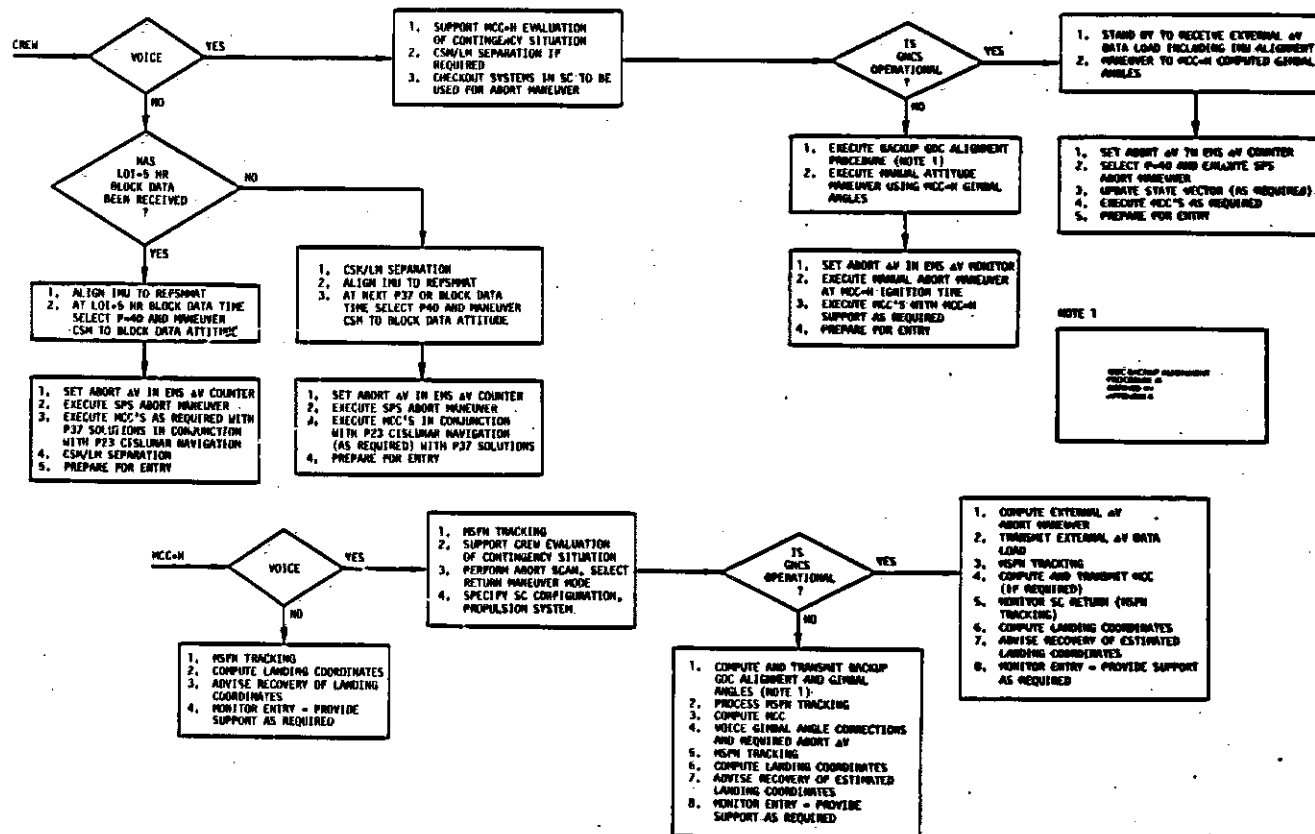


Figure 6. TLC Abort Flow Chart

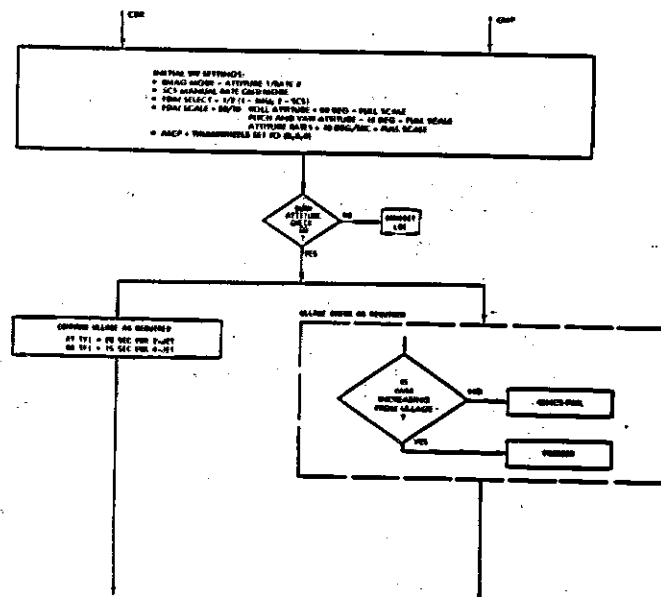
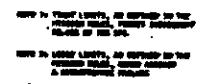


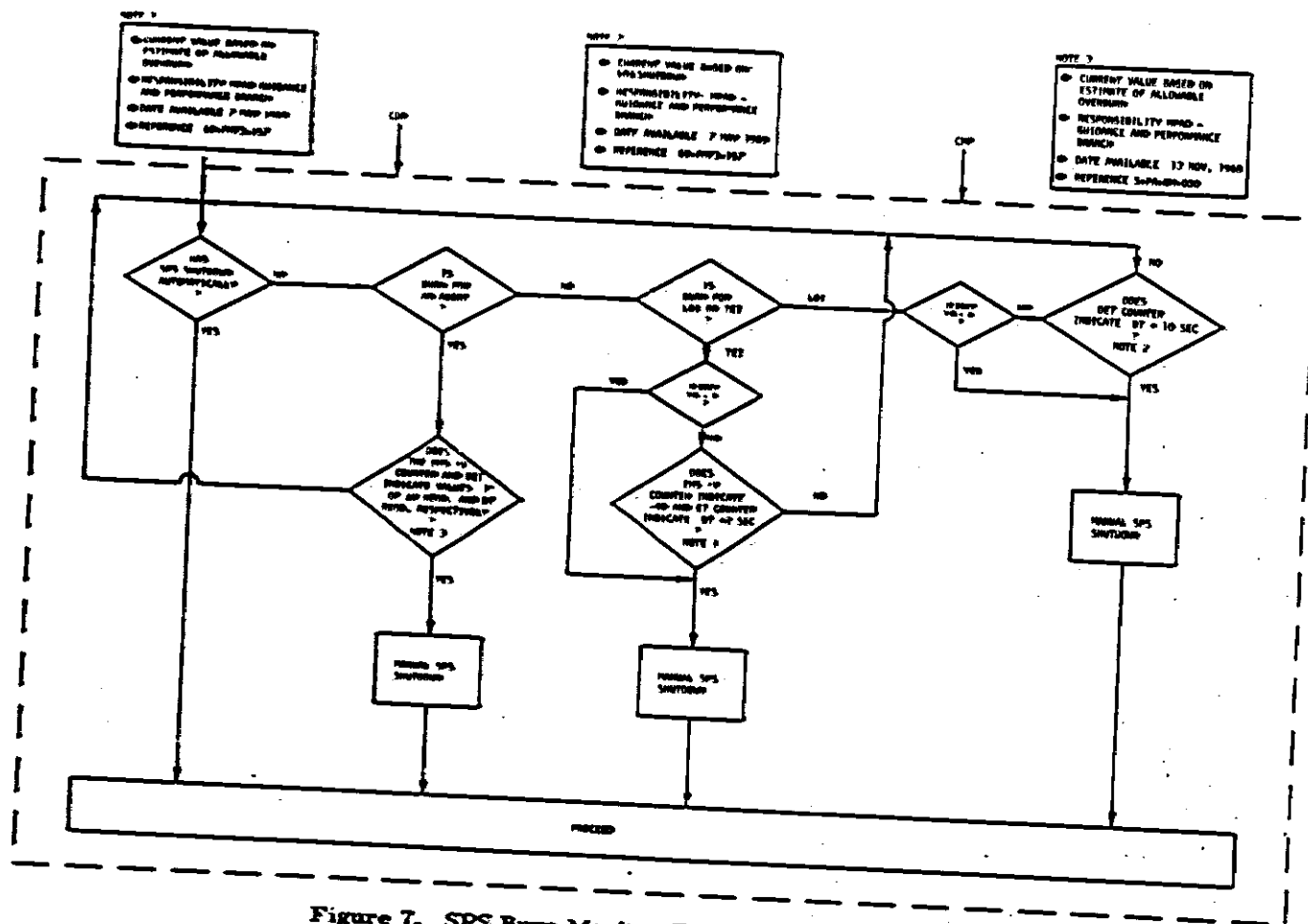
Figure 7. SPS Burn Monitor Flow Chart





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**Figure 8. LOI Abort Flow Chart**

**Figure 9. Docked DPS Abort Burn Monitor Flow Chart**

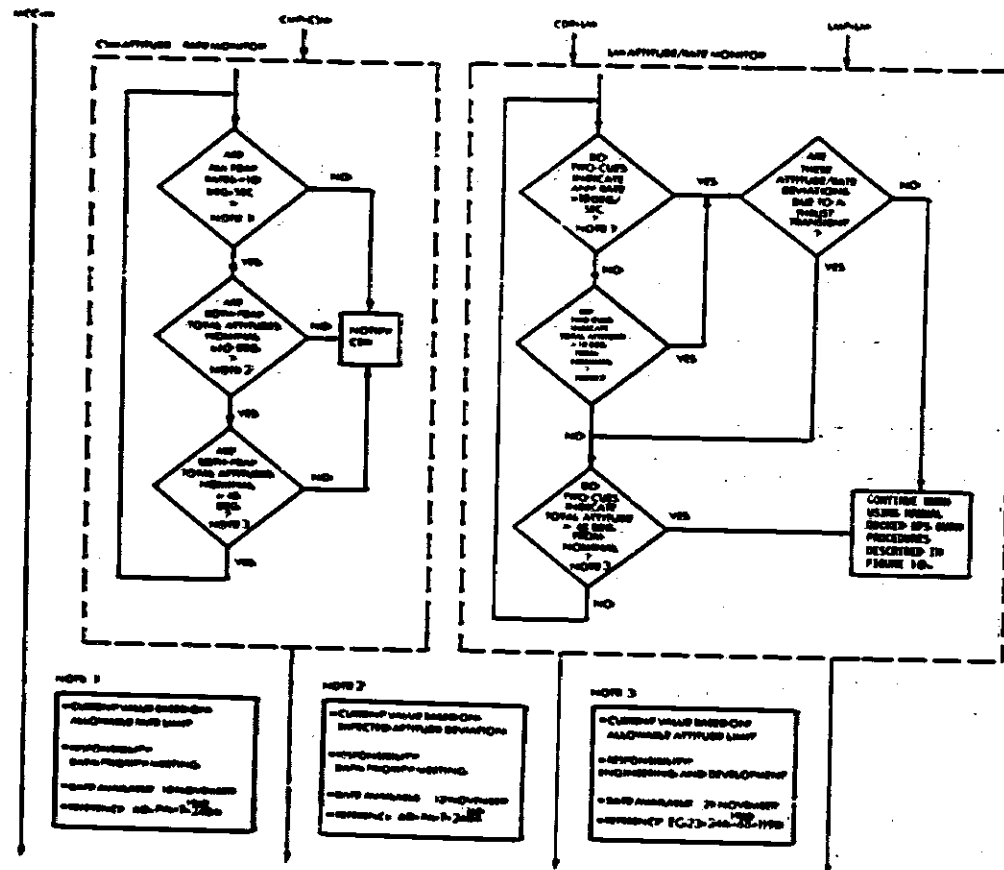


Figure 9. Docked DPS Abort Burn Monitor Flow Chart (Continued)

NOTE 1  
 -CHECK THAT DOP-ON  
 -REPAIR, REPAIR PROCEEDS  
 -REPAIRABLE, YES  
 -REPAIR AVAILABLE, YES  
 -REPAIRABLE, NO

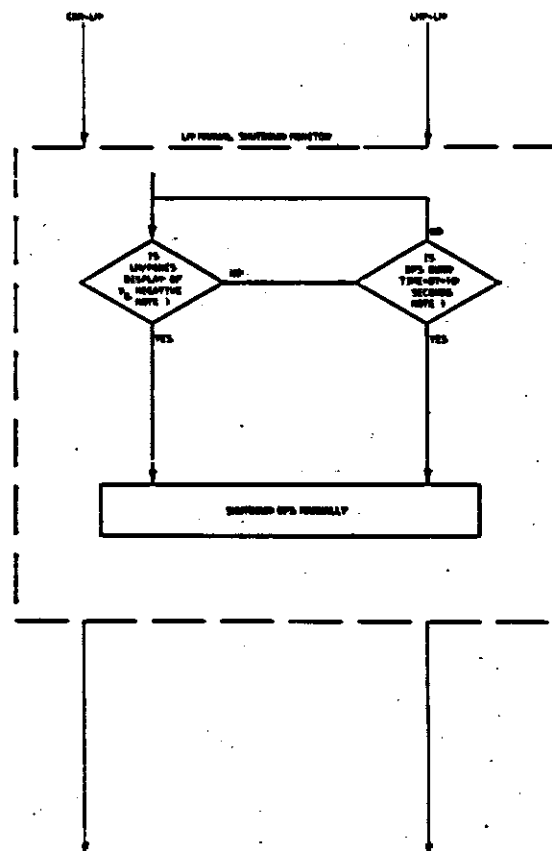


Figure 9. Docked DPS Abort Burn Monitor Flow Chart (Continued)

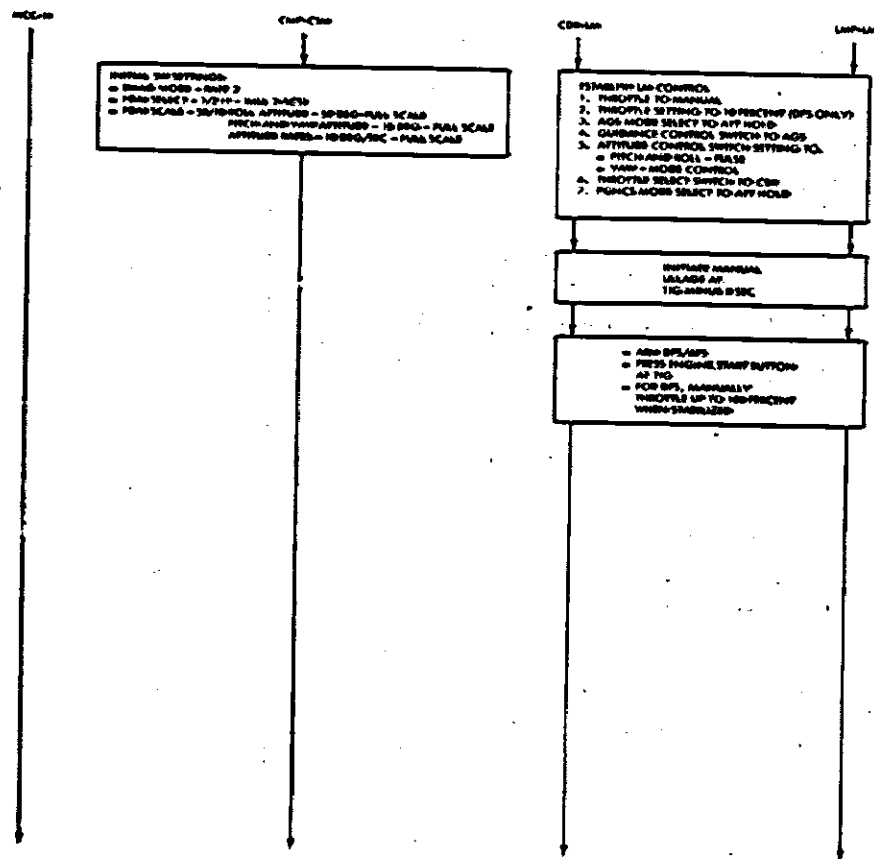


Figure 10. Manual DPS and APS Docked Burn Procedures

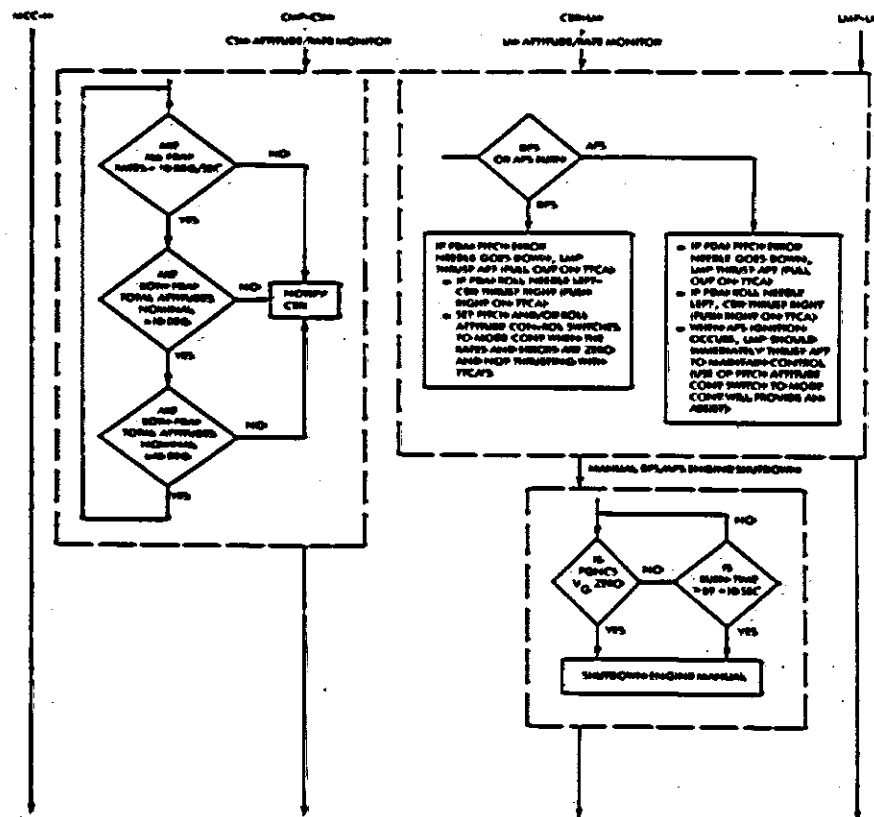


Figure 10. Manual DPS and APS Docked Burn Procedures (Continued)

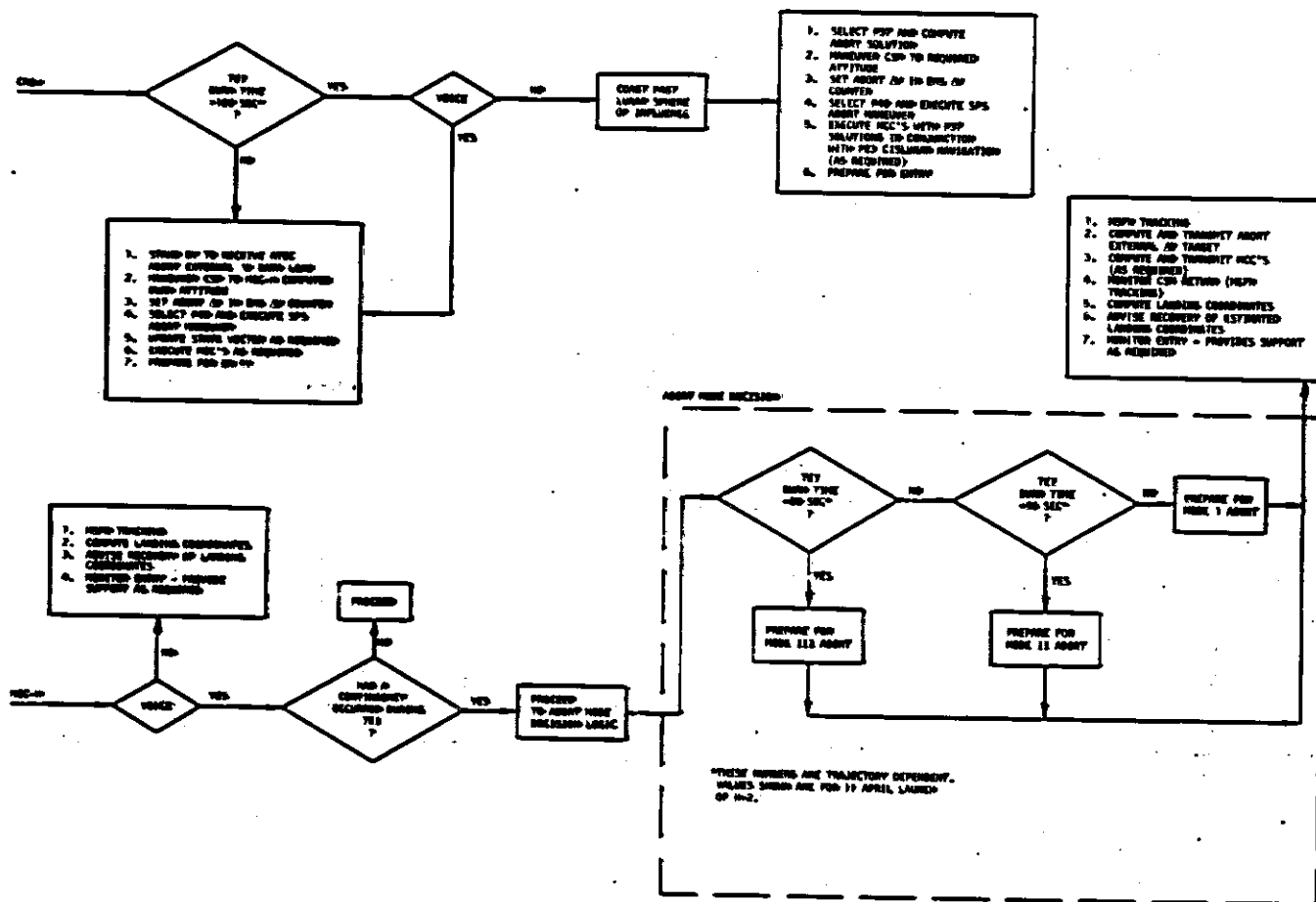


Figure 11. TEI Abort Flow Chart





## APPENDIX A

### LOSS OF COMMUNICATIONS NAVIGATION PROCEDURES

- I. Onboard Navigation after a Lift-off Plus 8-Hour Abort Maneuver From Translunar Coast
  - A. Perform the abort burn.
  - B. Reinitialize the W matrix. Use extended verb 67 and at the V06N99 display, load:  
 $R1 + 80000$  (80,000 feet)  
 $R2 + 00070$  (7.0 feet per second)  
 $R3 + 00003$  (Cislunar Navigation Code)
  - C. Determine the return trip time and look at the corresponding table for the sighting schedule to be followed. For all return trip times less than 20 hours, Schedule 1 (Table A-1)\* should be used. For all return trip times greater than 20 hours, Schedule 2 (Table A-2)\* should be used.
  - D. Times given for each batch of data are referenced to entry interface. (P37 may be used to determine the time reference.)
  - E. Start tracking with the first batch of data following the current time.
  - F. Calibrate optics at the beginning of each batch and every half hour while navigation sightings are in progress. The next sextant calibration will be repeated until agreement of at least two checks (not necessarily sequential ones) are within 1 bit (0.003 degree).
  - G. Large  $\Delta R$ ,  $\Delta V$  values may be expected at the following times:
    1. At the initiation of tracking (the first mark on each star of the first batch of data taken).
    2. After a long period of no sightings.

\*These tables are typical of the ones carried by the crew; the data shown are not necessarily those for the H-2 mission.

**3. During the last 6 hours before entry interface.**

If a large state vector correction (greater than 50 nautical miles in position and 50 feet per second in velocity) is displayed during the V06N49 display in P23, the mark should be rejected, the star reselected, and the mark repeated. If the large correction occurs again, it should be accepted and incorporated.

**H. If, for some reason, sightings need to be altered or moved, star availability charts are provided. (A typical crew chart is shown in Figure A-1.) The following comments pertain to these charts:**

**1. The vertical lines represent the stars which are available for use with P23.**

- a) The solid line represents the earliest TLI opportunity for which the chart is valid and is identified by launch azimuth and TLI opportunity.
- b) The dashed line represents the latest TLI opportunity for which the chart is valid and is identified by launch azimuth and TLI opportunity.
- c) If both the solid and dashed lines are present for a given star at a given time, then that star is available for P23 sightings at that time for all TLI opportunities where the earliest is represented by the solid line and the latest is represented by the dashed line.

**2. The numbers at the bottom of each star column represent the angle between the star horizon measurement plane and the orbital plane in degrees. This angle is given for the earliest launch (the solid line) at the acquisition of the star and the loss of the star.**

**3. Star numbers are given in octal.**

**4. The horizon code is:**

EN = earth near horizon  
EF = earth far horizon  
MN = lunar near horizon  
MF = lunar far horizon

II. Onboard Navigation after Return-to-Earth Aborts from Lunar Orbit

A. Aborts from lunar orbit due to communications loss;

1. Perform the abort burn.
2. Reinitialize W matrix. Use extended verb 67 and at the V06N99 display, load:  
 $R1 + 30000$  (30,000 feet)  
 $R2 + 00300$  (30.0 feet per second)  
 $R3 + 00003$  (Cislunar Navigation Code)
3. Determine the day of entry of the abort and look at the corresponding table (similar in content to Table A-1) for the schedule to be followed. Schedules are provided for 20 April and 21 April return dates.
4. Time is referenced from TEI time for the first 35 hours, and EI time thereafter. This is done to provide for varying return trip times.
5. Calibrate optics at the beginning of each batch and every half hour while navigation sightings are in progress. The sextant calibration will be repeated until agreement of at least two checks (not necessarily sequential ones) are within 1 bit (0.003 degree).
6. Large state vector corrections may be expected at the following times:
  - a) At the initiation of tracking (for the first mark on each star of the first batch of data)
  - b) At the first switch of reference bodies
  - c) After a long period of no sightings
  - d) During the last hours of the TE coast when the vehicle is near the earth.

If a large state vector correction (greater than 50 nautical miles in position and 50 feet per second in velocity) is displayed during the V06N49 display in P23, the mark should be rejected and repeated. If the large correction occurs again, it should be accepted and incorporated. (Corrections this large should not be expected in cases other than a and b above.)

7. If a W matrix reinitialization occurs after optical sightings are initiated due to a communications loss, the following procedures should be followed.
  - a) If the reinitialization does not occur while sightings are being taken, the W matrix should be reinitialized at the next batch to the diagonal value associated with that batch.
  - b) If the reinitialization occurs while a batch is in progress, the W matrix should be reinitialized to the diagonal value associated with the batch during which the loss occurred, and the batch restarted immediately. (See Section II-B-3 for values.)
  - c) The current onboard state vector at the time of the W matrix reinitialization is retained.
  - d) The remainder of the optical schedule is followed as if the W matrix reinitialization had not occurred.
8. If sightings need to be altered or moved, star availability charts are provided (chart similar in content to Figure A-1).

B. Communications loss during transearth coast following an abort from lunar orbit.

If the entry pad has been received, then no tracking is performed; if not, then proceed.

1. Check to see if schedules given in Section II-A-3 are applicable. If not, go to Section IV. (In general, very short and very long aborts are not covered by the charts.)
2. Start tracking with the first batch of data following the current time.
3. Reinitialize W matrix. Use extended verb 67 and at the V06N99 display, load:
  - a) Communications loss before Batch 1
    - R1 + 30000 (30,000 feet)
    - R2 + 00300 (30.0 feet per second)
    - R3 + 00003 (Cislunar Navigation Code)

- ( )
- b) Communications loss after Batch 1 with no state vector update after TEI;

R1 + 99000 (99,000 feet)

R2 + 00020 (2.0 feet per second)

R3 + 00003 (Cislunar Navigation Code)

- c) Communications loss after Batch 1 with at least one state vector update after TEI

R1 + 45000 (45,000 feet)

R2 + 00006 (0.6 foot per second)

R3 + 00003 (Cislunar Navigation Code)

4. General rules in Section III for loss of communications during transearth coast are applicable. (See Sections III-B, D, E, and G.)

5. Star Availability Charts are contained in Section II-A-8.

### III. Onboard Navigation after a Loss of Communications during Nominal Transearth Coast (Following Completion of Planned Lunar Stay Time)

( )

If the entry pad has been received, then no tracking is performed; if not, then proceed.

- A. The schedules provided (similar in content to Table A-1) are referenced to launch azimuth and TLI opportunity. For all transearth situations between 72-degree launch azimuth, first TLI opportunity and 99-degree launch azimuth, second TLI opportunity (inclusive), Schedule 1 should be used. For transearth situations from 99-degree launch azimuth, second TLI opportunity and 108-degree launch azimuth, second TLI opportunity, Schedule 2 should be used.

- B. Start tracking with the first batch of data following the current time.

- C. Reinitialize the W matrix. Use extended verb 67 and at the V06N99 display, load:

1. Communications loss before first batch

R1 + 30000 (30,000 feet)

R2 + 00300 (30.0 feet per second)

R3 + 00003 (Cislunar Navigation Code)

2. Communication loss after first batch with no state vector update after TEI:

R1 + 99000 (99,000 feet)

R2 + 00020 (2.0 feet per second)

R3 + 00003 (Cislunar Navigation Code)

3. Communications loss after Batch 1 with at least one state vector update after TEI:

R1 + 45000 (45,000 feet)

R2 + 00006 (0.6 foot per second)

R3 + 00003 (Cislunar Navigation Code)

- D. Calibrate the optics at the beginning of each batch and every half hour while navigation sightings are in progress. The sextant calibration will be repeated until agreement of at least two checks (not necessarily sequential ones) are within 1 bit (0.003 degree).

- E. Large state vector corrections may be expected at the following times:

1. At initiation of tracking. (For the first mark on each star of the first batch of data)
2. At the first switch of reference bodies
3. After a long period of no sightings
4. During the last hours of the TE coast when the vehicle is near the earth

If a large state vector correction (greater than 50 nautical miles in position and 50 feet per second in velocity) is displayed during the V06N49 display in P23, the mark should be rejected and repeated. If the large correction occurs again, it should be accepted and incorporated. (Corrections this large should not be expected in cases other than 1 and 2 above.)

- F. If a W matrix reinitialization occurs after optical sightings are initiated due to a communications loss, the following procedures should be used.

1. If the reinitialization does not occur while sightings are being taken, the W matrix should be reinitialized at the next batch to the diagonal value associated with that batch.

2. If the reinitialization occurs while a batch is in progress, the W matrix should be reinitialized to the diagonal value associated with the batch during which the reinitialization occurred, and the batch restarted immediately. (See Section III-C for values.)
  3. The current onboard state vector at the time of the W matrix reinitialization is retained.
  4. The remainder of the optical schedule is followed as if the W matrix reinitialization had not occurred.
- G. If for some reason, sightings need to be altered or moved, star availability charts are provided (similar in content to Figure A-1). If a star in the regular schedule needs to be replaced, the replacement should be as close to the orbit plane as possible. Do not repeat a set which is already scheduled for that batch.

#### IV. Onboard Navigation Rules for a Do-It-Yourself Sighting Schedule

If the entry pad has been received, then no tracking is performed; if not, then proceed.

##### A. General rules

1. A sighting or set is to consist of three marks.
2. Reinitialize W matrix and schedule a tracking interval as soon as possible after the burn; or in the case of the lunar flyby, about one hour after perilune. If sightings are performed during translunar coast for any reason, reinitialize the W matrix one hour after perilune for transearth sightings. W matrix values are given below in the discussion for each return type. (See Sections B and C.)
3. Star availability is related to GMT, not GET. Therefore, a chart which approximates the GMT of a particular situation can be used as a clue to determine stars available.
4. A batch is to consist of at least three star/ horizon sightings, although as many as five can be advantageous, particularly following a sleep period.
5. All available stars should be used in the sighting schedule. No more than three marks should be taken on a star within a batch of data.



6. Sightings during the last 10 hours before entry interface are important. Five earth horizon sightings should be scheduled at EI-5 hours and three earth horizon sightings should be scheduled following the MCC at EI-3 hours. If no earth horizon sightings are available, lunar horizon sightings should be used.
7. Whenever possible, the navigation batches should be scheduled so that immediately following a time period of length  $\Delta t$  (not to exceed 3 hours) in a non-PTC mode, five times  $\Delta t$  should be spent in a PTC mode (thermal constraints). This rule will be violated most frequently in the following situations: (1) aborts from a translunar trajectory with short return trip times, (2) time critical aborts, and (3) the 10-hour period before entry interface.
8. If possible, both near and far horizons should be included in each batch of data.
9. Calibrate the optics at the beginning of each batch and every half hour while navigation sightings are in progress. The sextant calibration will be repeated until agreement of at least two checks (not necessarily sequential ones) are within 1 bit (0.003 degree).
10. Large state vector corrections may be expected at the following times:
  - a) At initiation of tracking (for the first mark on each star of the first batch of data.)
  - b) At the first switch of reference bodies.
  - c) After a long period of no sightings.
  - d) During the last 10 hours before entry interface.

If a large state vector correction (greater than 50 nautical miles in position and 50 feet per second in velocity) is displayed during the V06N49 display in P23, the mark should be rejected and repeated. If the large correction occurs again, it should be accepted and incorporated. (Corrections this large should not be expected in cases other than a and b above.)

**B. Aborts from a translunar trajectory:**

1. Perform the abort burn.
2. Read the general rules contained in Section IV-A.

3. Initialize the W matrix. Use extended verb 67 and at the V06N99 display, load:

R1 + 80000 (80,000 feet)

R2 + 00070 (7.0 feet per second)

R3 + 00003 (Cislunar Navigation Code)

4. Only star/earth horizon marks will be made.
5. If the return trip time is  $\leq 20$  hours, three sets should be scheduled every 2.5 hours with a batch of five sets at EI-5 hours before the last MCC at EI-3 hours, and three sets after the midcourse.
6. If the return trip time is  $\geq 20$  hours, sleep periods of 8 hours may be provided. Astronauts should be awake the last 10 hours before entry interface. Three sets should be scheduled every three hours while awake with five sets scheduled before each sleep period. Five sets should be taken before the last midcourse at EI-3 hours, and three sets after the midcourse.
7. If a W matrix reinitialization occurs after the optical sightings are initiated, the following procedures should be followed:
  - a) If the reinitialization does not occur while sightings are being taken, the W matrix should be reinitialized at the next batch to the diagonal value given in Section IV-B-3.
  - b) If the reinitialization occurs while a batch is in progress, the W matrix should be reinitialized to the diagonal value given in Section IV-B-3 and the batch restarted immediately.
  - c) The current onboard state vector at the time of the W matrix reinitialization is retained.
  - d) The remainder of the optical schedule is followed as if the W matrix reinitialization had not occurred.

C. Communications loss for flyby, aborts from lunar orbit, etc.

1. Perform the abort burn or wait until perilune.
2. Read the general rules contained in Section IV-A.

3. Reinitialize the W matrix. Use extended verb 67 and at the V06N99 display, load:

a) Communications loss before Batch 1 (at TEI + 1 hour or perilune + 1 hour):

R1 + 30000 (30,000 feet)

R2 + 00300 (30.0 feet per second)

R3 + 00003 (Cislunar Navigation Code)

b) Communications loss after Batch 1 (at TEI + 1 hour or perilune + 1 hour) with no state vector update after TEI:

R1 + 99000 (99,000 feet)

R2 + 00020 (2.0 feet per second)

R3 + 00003 (Cislunar Navigation Code)

c) Communications loss after Batch 1 (at TEI + 1 hour or perilune + 1 hour) with at least one state vector update after TEI:

R1 + 45000 (45,000 feet)

R2 + 00006 (0.6 foot per second)

R3 + 00003 (Cislunar Navigation Code)

4. If return trip time is  $\geq 70$  hours

a) Refer to the sighting schedules of Section III for placement of batches of star/horizon sightings and relate the times given at "TEI + " and "EI -" to the specific trans-earth situation. For each batch scheduled, take three marks on each available star (up to 5 stars).

b) Schedule three earth horizon sightings for every 5 hours between TEI + 32 and EI - 40 hours, or if an additional sleep period is needed for very slow returns, schedule five earth horizon sightings before the sleep period and five earth horizon sightings upon awakening.

5. If return trip time is  $< 70$  hours

a) Sleep periods of 8 hours should be provided. Astronauts should be awake the last 10 hours before entry interface.

- b) Three sets of star horizon observations should be scheduled every three hours while awake with five sets scheduled before and after each sleep period.
  - 1) A batch of lunar horizon sightings should be taken at TEI + 1 hour or perillune + 1 hour.
  - 2) The second batch of data should consist of earth horizon sightings.
  - 3) The third batch of data should consist of lunar horizon sightings.
  - 4) The remainder of the data should be earth horizon sightings. If no earth horizon sightings are available, lunar horizon sightings should be substituted.
- c) Five earth horizon sets should be scheduled at EI - 5 hours before the MCC (at EI - 3 hours). Three sets should be taken after the midcourse.
- 6. If a W matrix reinitialization occurs after optical sightings are initiated due to a transearth communications loss, the following procedures should be followed.
  - a) If the reinitialization does not occur while sightings are being taken, the W matrix should be reinitialized at the next batch to the diagonal value associated with that batch. (W matrices are given in Section IV-C-3.)
  - b) If the reinitialization occurs while a batch is in progress, the W matrix should be reinitialized to the diagonal value associated with the batch during which the reinitialization occurred, and the batch restarted immediately.
  - c) The current onboard state vector at the time of the W matrix reinitialization is retained.
  - d) The remainder of the optical schedule is followed as if the W matrix reinitialization had not occurred.

#### V. Sextant Constraints

A summary of the SXT constraints relating to navigation sightings follows: (Reference 20)

- A. Trunnion Angle - The trunnion angle must be greater than 2 degrees and less than 50 degrees, unless the sun is within 45 degrees of the landmark line of sight (LLOS), in which case the maximum trunnion angle is 45 degrees.
- B. Star Magnitude - The star must be bright enough to be acquired against the background and tracked across the LLOS target.

#### Minimum Star Magnitude

	<u>Earth</u>	<u>Moon</u>
Horizon	3	3.5
Landmark	1	2.5

- C. Scattered Light - The background illumination due to sunlight scattered off the optical elements must not be so bright that it obscures either the star or the horizon image.
- D. Sun Elevation - The local sun elevation angle at the tangent point for horizon measurements or at the landmark must be high enough to illuminate the target without distortion.

#### Minimum Sun Elevation Angle

	<u>Earth</u>	<u>Moon</u>
Horizon	10 degrees	5 degrees
Landmark	10 degrees	5 degrees

- E. Landmark Slant Angle - Due to optical foreshortening and atmospheric thickness, landmarks with large slant angles are unusable. (The angle is between vertical at the landmark, and the LLOS.) This constraint does not apply to horizon measurements.

#### Maximum Slant Angle

<u>Earth</u>	<u>Moon</u>
45 degrees	60 degrees

Table A-1. \* Sighting Schedules for an Abort at Lift-off Plus 8 Hours  
(No Communications) - Schedule 1, Return Trip Time  
Less Than 20 Hours

<u>Time of Sightings (hr)</u>	<u>Star Identification</u>	<u>Reference Horizon</u>	<u>Register 3 of DSKY</u>
EI - 17.5	23 (Denebola)	Earth/Near	00110
	24 (Gienah)	Earth/Near	00110
	26 (Spica)	Earth/Near	00110
EI - 15.0	21 (Alphard)	Earth/Far	00120
	23 (Denebola)	Earth/Near	00110
	26 (Spica)	Earth/Near	00110
EI - 12.5	21 (Alphard)	Earth/Far	00120
	23 (Denebola)	Earth/Near	00110
	24 (Gienah)	Earth/Near	00110
EI - 10.0	21 (Alphard)	Earth/Far	00120
	23 (Denebola)	Earth/Near	00110
	26 (Spica)	Earth/Near	00110
EI - 7.5	21 (Alphard)	Earth/Far	00120
	26 (Spica)	Earth/Near	00110
	31 (Arcturis)	Earth/Near	00110
EI - 5.0	21 (Alphard)	Earth/Far	00120
	22 (Regulus)	Earth/Far	00120
	24 (Gienah)	Earth/Near	00110
	26 (Spica)	Earth/Near	00110
	31 (Arcturis)	Earth/Near	00110
EI - 2.5	23 (Denebola)	Earth/Far	00120
	31 (Arcturis)	Earth/Near	00110
	32 (Alphecca)	Earth/Near	00110

\* This table is typical of the schedule which the H-2 crew will have.

This chart applies to aborts from the 72-degree launch azimuth, first TLI opportunity through the 90-degree launch azimuth, second TLI opportunity and the 99-degree launch azimuth, second TLI opportunity.

GMT of entry interface = 18:30:00 November 15

Table A-2. Sighting Schedules for an Abort at Lift-off Plus 8 Hours  
(No Communications) - Schedule 2, Return Trip Time  
Greater than 20 Hours

<u>Time of Sightings (hr)</u>	<u>Star Identification</u>	<u>Reference Horizon</u>	<u>Register 3 of DSKY</u>
EI - 39.0	21 (Alphard)	Earth/Far	00120
	23 (Denebola)	Earth/Near	00110
	26 (Spica)	Earth/Near	00110
EI - 36.0	16 (Procyon)	Earth/Far	00120
	21 (Alphard)	Earth/Far	00120
	23 (Denebola)	Earth/Near	00110
	24 (Gienah)	Earth/Near	00110
	26 (Spica)	Earth/Near	00110
EI - 27.0	21 (Alphard)	Earth/Far	00120
	22 (Regulus)	Earth/Far	00120
	24 (Gienah)	Earth/Near	00110
	26 (Spica)	Earth/Near	00110
EI - 24.0	21 (Alphard)	Earth/Far	00120
	26 (Spica)	Earth/Near	00110
	31 (Arcturus)	Earth/Near	00110
EI - 21.0	21 (Alphard)	Earth/Far	00120
	22 (Regulus)	Earth/Far	00120
	26 (Spica)	Earth/Near	00110
	31 (Arcturus)	Earth/Near	00110
EI - 12.0	21 (Alphard)	Earth/Far	00120
	22 (Regulus)	Earth/Far	00120
	31 (Arcturus)	Earth/Near	00110
EI - 9.5	22 (Regulus)	Earth/Far	00120
	23 (Denebola)	Earth/Far	00120
	31 (Arcturus)	Earth/Near	00110
EI - 7.0	22 (Regulus)	Earth/Far	00120
	31 (Arcturus)	Earth/Near	00110
	32 (Alphecca)	Earth/Near	00110
EI - 5.0	23 (Denebola)	Earth/Far	00120
	24 (Gienah)	Earth/Near	00110
	26 (Spica)	Earth/Near	00110
	31 (Arcturus)	Earth/Near	00110
	32 (Alphecca)	Earth/Near	00110
EI - 2.5	26 (Spica)	Earth/Near	00110
	23 (Denebola)	Earth/Far	00120

This chart applies to aborts from the 99-degree launch azimuth, first TLI opportunity and the 108-degree launch azimuth, first and second TLI opportunities.

GMT of entry interface = 19115:00 November 16

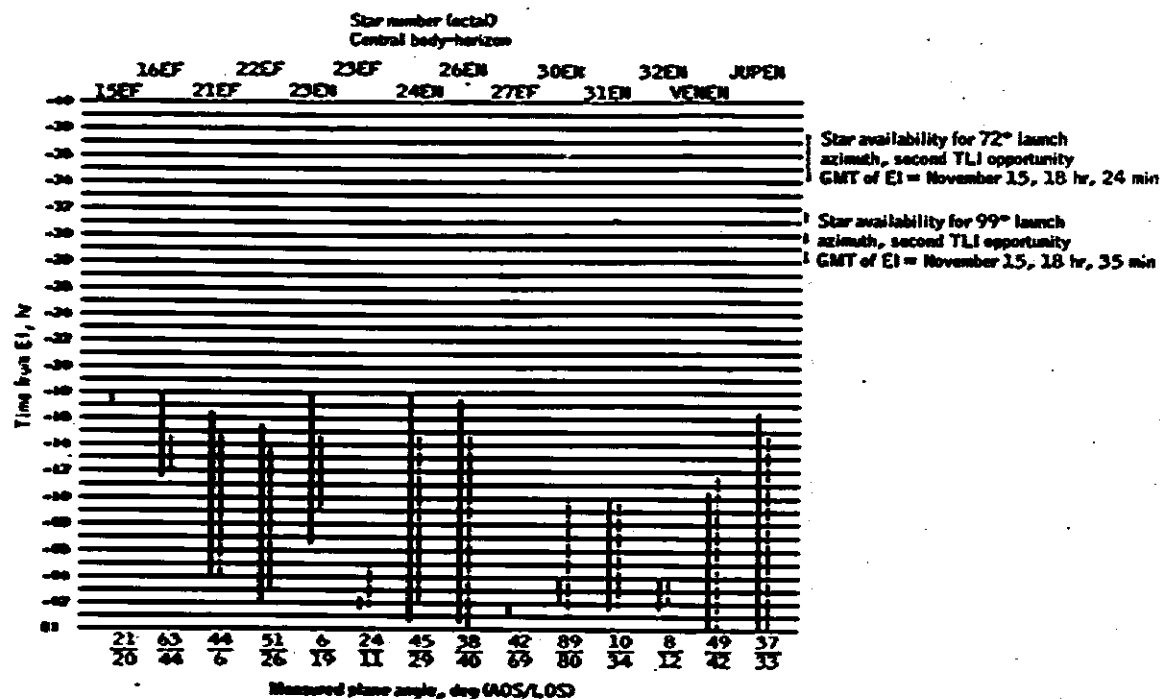


Figure A-1. Star Availability for an Abort from Translunar Coast at 8:00 hours g.e.t., Short Return for a Launch on November 14, 1969 (This chart is similar to that to be carried by the H-2 crew.)



APPENDIX B  
BACKUP GDC ALIGNMENT\*

SCS - On (required)  
CMC - Off or standby

FDAI SELECT - 1

ATT SET - GDC

SC CONT - SCS

RECORD: R, P, Y ALIGN, SXT data, and NAV stars from MCC-H

1. SCT, SFT - 180, TRN - 7.5
2. ATT SET DIALS - R, P, Y ALIGN
3. Cage IMU when near 0, 0, 0
4. Maneuver to stars:

Primary star on 50-degree mark on R line of SCT reticle  
with secondary star on R line

5. GDC ALIGN - push
6. ATT SET DIALS - 0, 0, 0 for preferred orientation or pad maneuver values
7. Maneuver SC to ignition attitude on GDC ball and null error needles
8. Perform SXT star check and adjust in pitch and yaw, if necessary
9. ATT HOLD - Min deadband
10. Uncage IMU if in preferred orientation (0, 0, 0)
11. Realign GDC if necessary  
GDC ALIGN - push

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\*Reference 21

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3. "Preliminary Display Limits and Crew Monitoring Considerations for TLI, LOI and TEI," MSC Internal Note 67-FM-138, 27 September 1967.
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5. "Detailed Crew Procedures for Powered Flight Evaluation of the Translunar Injection Maneuver," MSC Internal Note 68-FM-212, 28 August 1968.
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8. "Operational Abort Plan for Apollo 13 (Mission H-2)," MSC Internal Note 70-FM-27, 17 February 1970.
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19. C. A. Kauffman, "Cislunar Navigation Sighting Data for Alternate and Contingency Checklist for Apollo 12 (Mission H-1), November 14, 1969, " MSC Internal Note 69-FM-288, 12 November 1969.
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