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PRELIMINARY CONTINGENCY PROCEDURES FOR THE TRANSLUNAR INJECTION MANEUVER

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PROJECT APOLLO

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PRELIMINARY CONTINGENCY PROCEDURES FOR THE TRANSLUNAR INJECTION MANEUVER

By Bobbie D. Weber

SUMMARY

This paper presents the procedures to be followed if a contingency develops during or immediately following the translunar injection (TLI) maneuver. Also presented are sufficient trajectory data to substantiate the procedures and a discussion of the philosophy which led to the development of the procedures.

It will be seen that procedures for aborting following a contingency during TLI are straightforward and the events leading to an abort maneuver can be timelined and rehearsed preflight.

INTRODUCTION

The preliminary contingency procedures presented in this report are for contingencies that occur either during or immediately after TLI. These procedures are considered preliminary only because they have not been tested in simulations by the flight controllers and crew. Descriptions of alternate missions being considered for contingencies occurring during TLI are not within the scope of this document, but may be found in reference 1.

Changes to the procedures presented will be given in the minutes to the meetings of the Apollo Abort Working Group (AAWG), and the final procedures will be documented in the operational abort documents for the particular missions to which the procedures apply.

The nominal translunar injection maneuver is a near-Hohmann type maneuver performed with the S-IVB booster transferring the Apollo spacecraft from a stable near-earth parking orbit to a stable earth-centered, high-apogee ellipse which intersects the moon's gravitational influence. For any given time of S-IVB cutoff during the nominal TLI or for any of the free-flight trajectories resulting from booster cutoffs due to the violation of the suggested attitude deviation and attitude rate limits presented in reference 2, immediate corrective action will not be required (except for rate damping maneuvers). The limits suggested in reference 2 are more restrictive than any trajectory limits required to achieve an earth intersecting ellipse, which would be required to produce trajectory limits such as excessive entry loads or insufficient time to prepare the command module (CM) for entry. Figure 1, which was taken from reference 3, shows TLI trajectories resulting from several S-IVB instrument unit (IU) gyro drifts about the pitch axis. The points at which the trajectory would be terminated based on the total pitch attitude deviation limit (15°) from nominal are indicated. Please note that for none of the terminal points does the osculating perigee altitude indicate an earth intersecting ellipse. Therefore, the contingencies which would require S-IVB shutdown and immediate corrective action (abort) do not include trajectory limits related to crew safety. Furthermore, any contingency originating within the booster and requiring booster shutdown would not require the crew to perform any immediate corrective action except for rate damping maneuvers or possibly an emergency CSM/S-IVB separation.

The contingency procedures presented herein and the problems with which this paper is concerned are those possible spacecraft subsystems problems which can be isolated either immediately during TLI or immediately following TLI and which could result in catastrophe if immediate corrective action is not taken. Possibly spacecraft systems failures which might cause S-IVB shutdown and an abort to be initiated are given in table I (ref. 4).

Detection and verification of a system failure during the brief duration of the TLI maneuver is quite unlikely. Even if a system failure is indicated, it is possible that a degradation rather than an outright failure has occurred or that the instrumentation indicating the failure is at fault. Therefore, it is advisable, if verification of an indicated failure cannot be made, the TLI maneuver be continued to the time of nominal S-IVB cutoff. At that time, the crew can perform the normal malfunction checks (as will be outlined in the "Apollo Operations Handbook" for the lunar mission) with ground assistance.

In both instances, if the crew detects and verifies a failure during TLI severe enough to initiate booster cutoff and an immediate abort maneuver, or if the crew elects to continue the TLI maneuver to the time of nominal cutoff and perform an abort maneuver subsequent to the malfunction checks, the service propulsion subsystem (SPS) will be the primary propulsion system. Practically, the SPS will be the only propulsion system in either instance as the severity of the situation will preclude transposition and docking (T&D) with the lunar module (LM) or waiting in the preabort orbit until the service module (SM) reaction control subsystem (RCS) could effect deorbit.

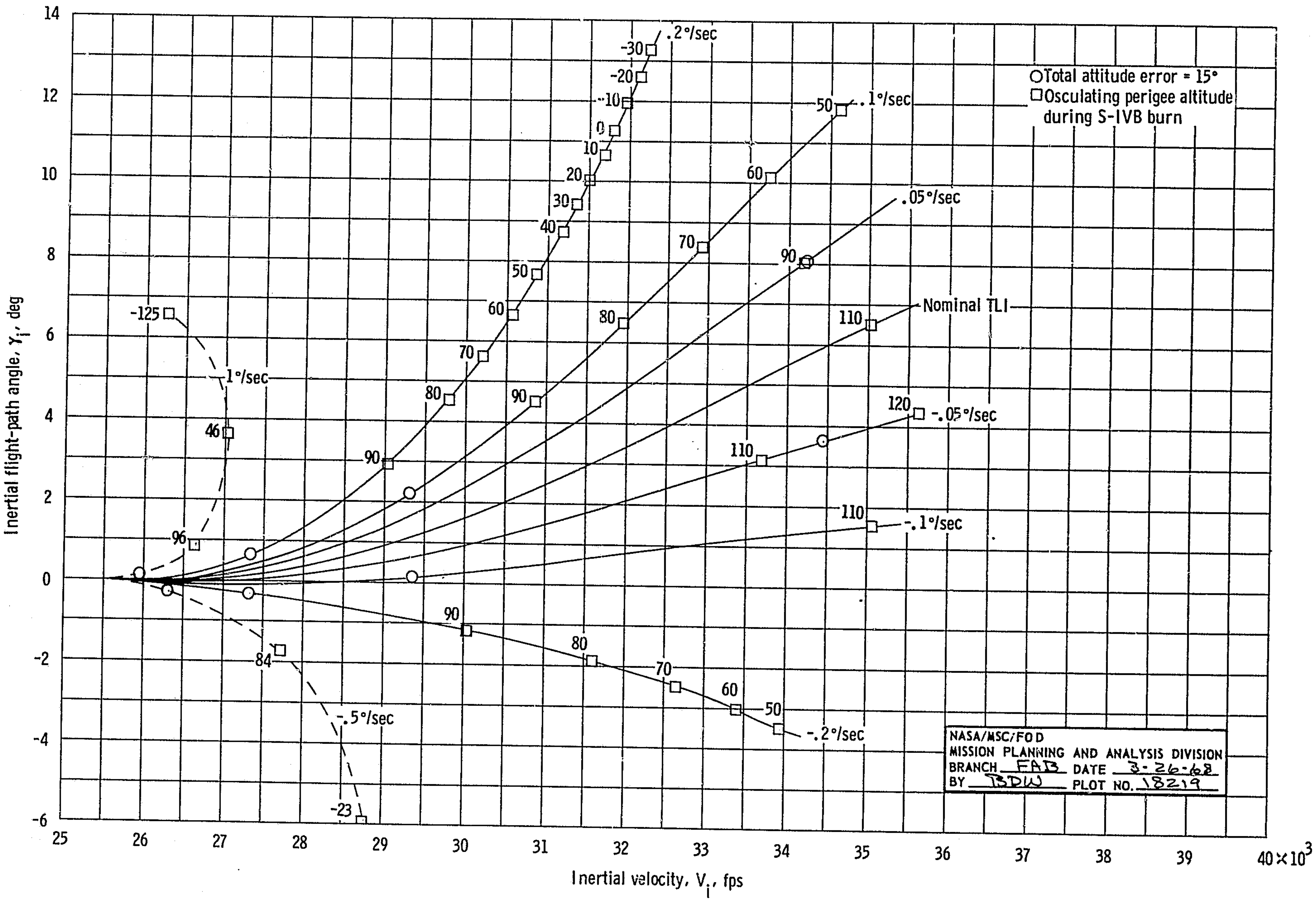

Figure 1.- Osculating perigee altitude as a function of inertial velocity and inertial flight-path angle resulting from IU gyro-drift about the pitch axis during translunar injection.

TABLE I.- SPACECRAFT SUBSYSTEMS FAILURES WHICH COULD CAUSE A FIXED ATTITUDE ABORT TO BE INITIATED

Failure	Verification time, minutes	Return time required, hours
1. Loss of all three fuel cells caused by loss of O_2 or H_2 or all three bus disconnects.	1 to 2	3
2. Loss of O_2 or H_2 caused by plumbing rupture.	5 to 10	3
3. Primary and secondary coolant loop failures caused by a double plumbing failure.	1 to 2	2
4. Both suit compressors fail caused by loss of all ac.	1	18
5. No ac due to failure of three inverters or both main buses.	1	2

4

There exists only one plausible instance when the crew might use the LM descent propulsion subsystem (DPS) as a backup to the SPS for aborts from TLI. Should the malfunction checks immediately following TLI indicate the SPS is inoperable, and some other system has failed requiring that the crew be returned to earth immediately, the LM DPS would be required to perform the abort maneuver. Although this represents a multiple-failure situation, it is possible such a contingency could occur. The procedures required will not be considered herein, as the procedures for early translunar coast (TLC) will be applicable.

CONTINGENCY PROCEDURES

Preliminary Display Limits and Crew Monitoring Considerations for TLI

Reference 1 presents suggested total attitude deviation and attitude rate limits and associated crew monitoring considerations for TLI. Recent AAWG meetings have indicated that the propellant-to-oxidizer mixture ratio (M/R) shift which occurs during TLI may cause the limits suggested in reference 1 to be exceeded. Action is being taken to determine if this event (M/R shift) is predictable and to determine to what degree it would affect the vehicle attitude (ref. 5).

Fixed Attitude Abort Procedures

Should a contingency occur during TLI, such as the systems failures noted in table I, requiring the S-IVB to be shut down and an immediate return of the crew to earth, the abort maneuver will be performed at a fixed time from S-IVB cutoff and at a fixed attitude with respect to the pilot's line of sight (LOS) to the earth's horizon (fig. 2). The purpose of this maneuver will be to achieve a target near the center of the entry corridor which will be defined as a function of inertial velocity (V_{EI}) and inertial flight-path angle (γ_{EI}) at 400 000 ft (fig. 3). Landing site control will not be provided by this procedure since the abort attitude and the time of abort initiation are fixed. The landing site will be a function of the time of booster cutoff (fig. 4).

The rationale for using such a procedure is that the time from the abort maneuver to atmospheric entry (TAR) increases rapidly with respect to the time the maneuver is delayed from booster cutoff. If time were taken to track the spacecraft, align the IMU, compute an abort solution, and prepare to execute the abort with the primary guidance navigation and control subsystem (PGNCS), TAR would far exceed the lifetime of the system which failed and caused the abort to be initiated.

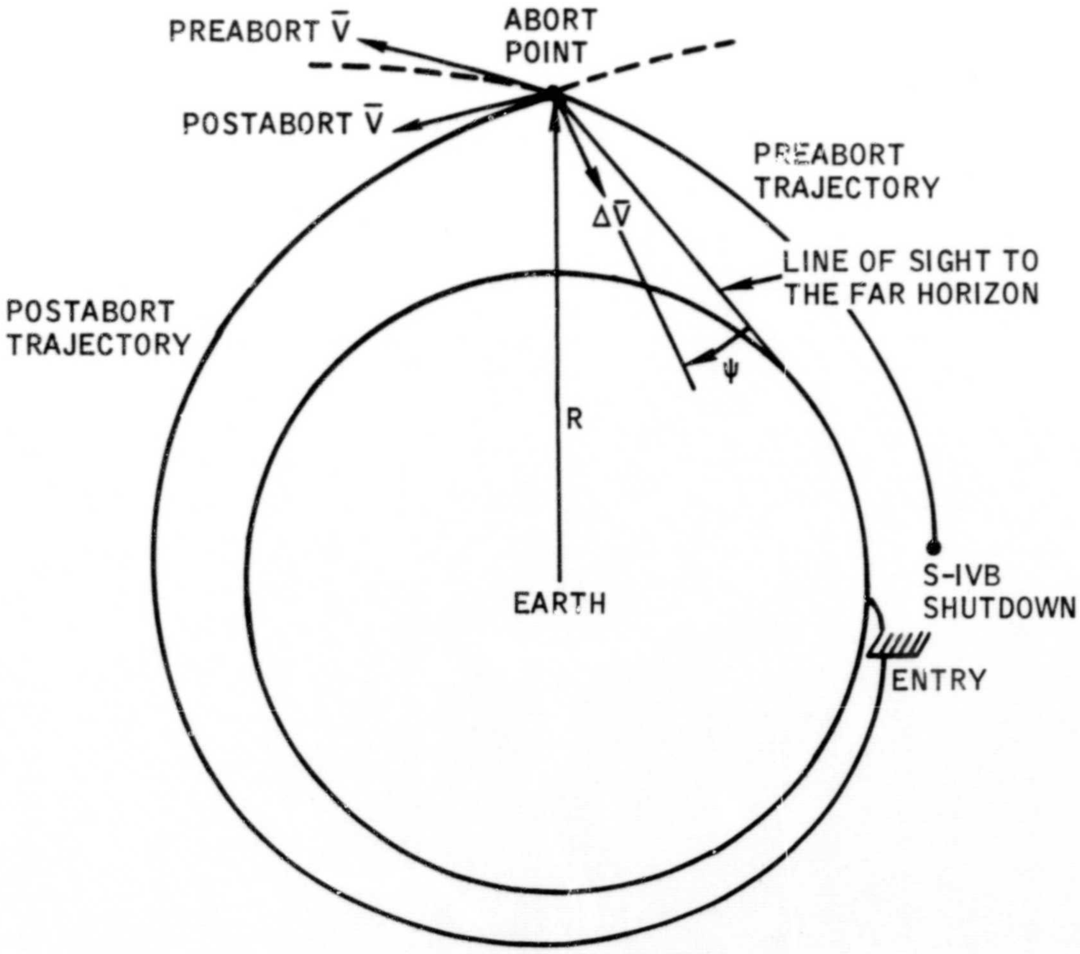

Figure 2.- Basic geometry of a horizon reference abort.

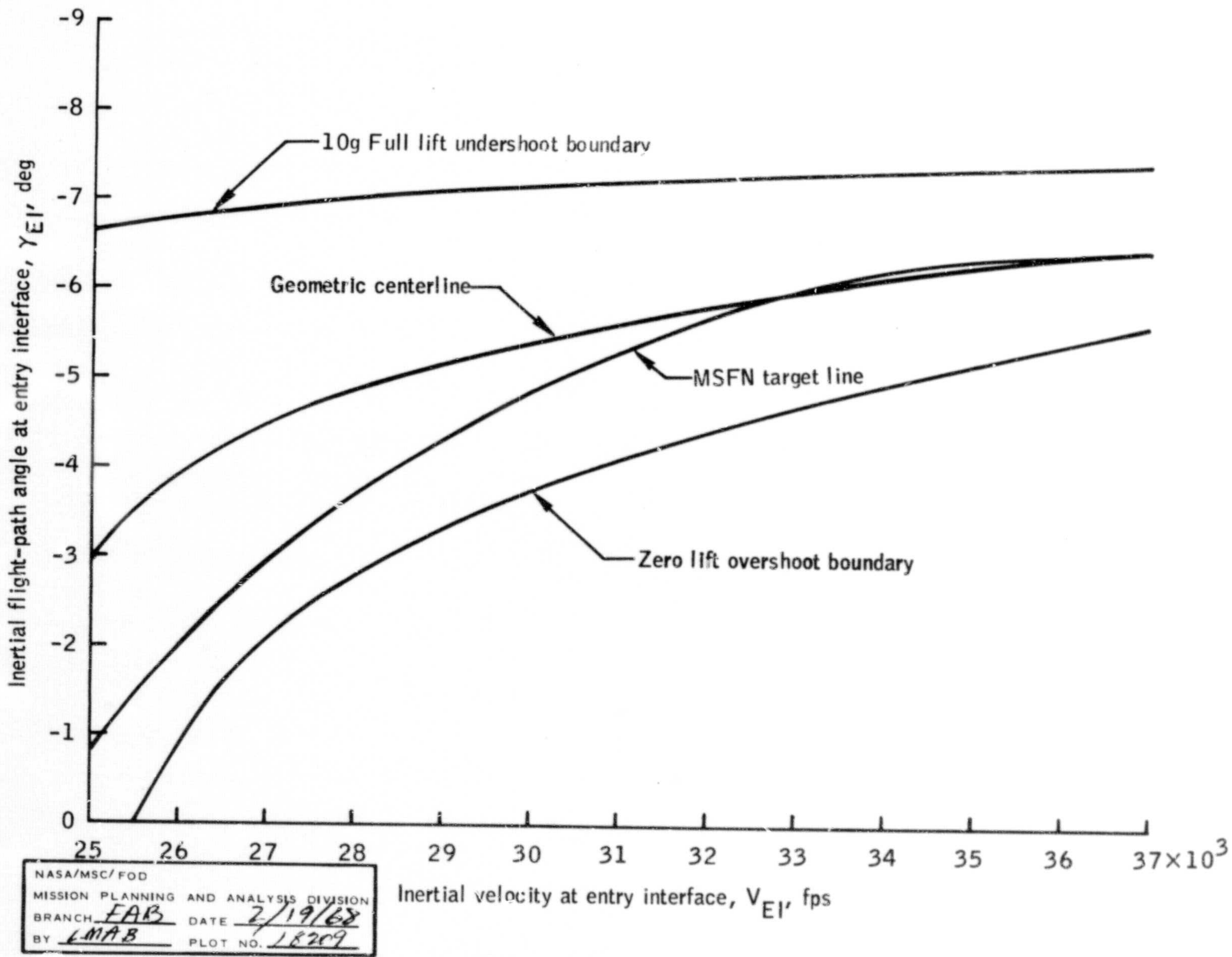

Figure 3.- Entry corridor and target line definition.

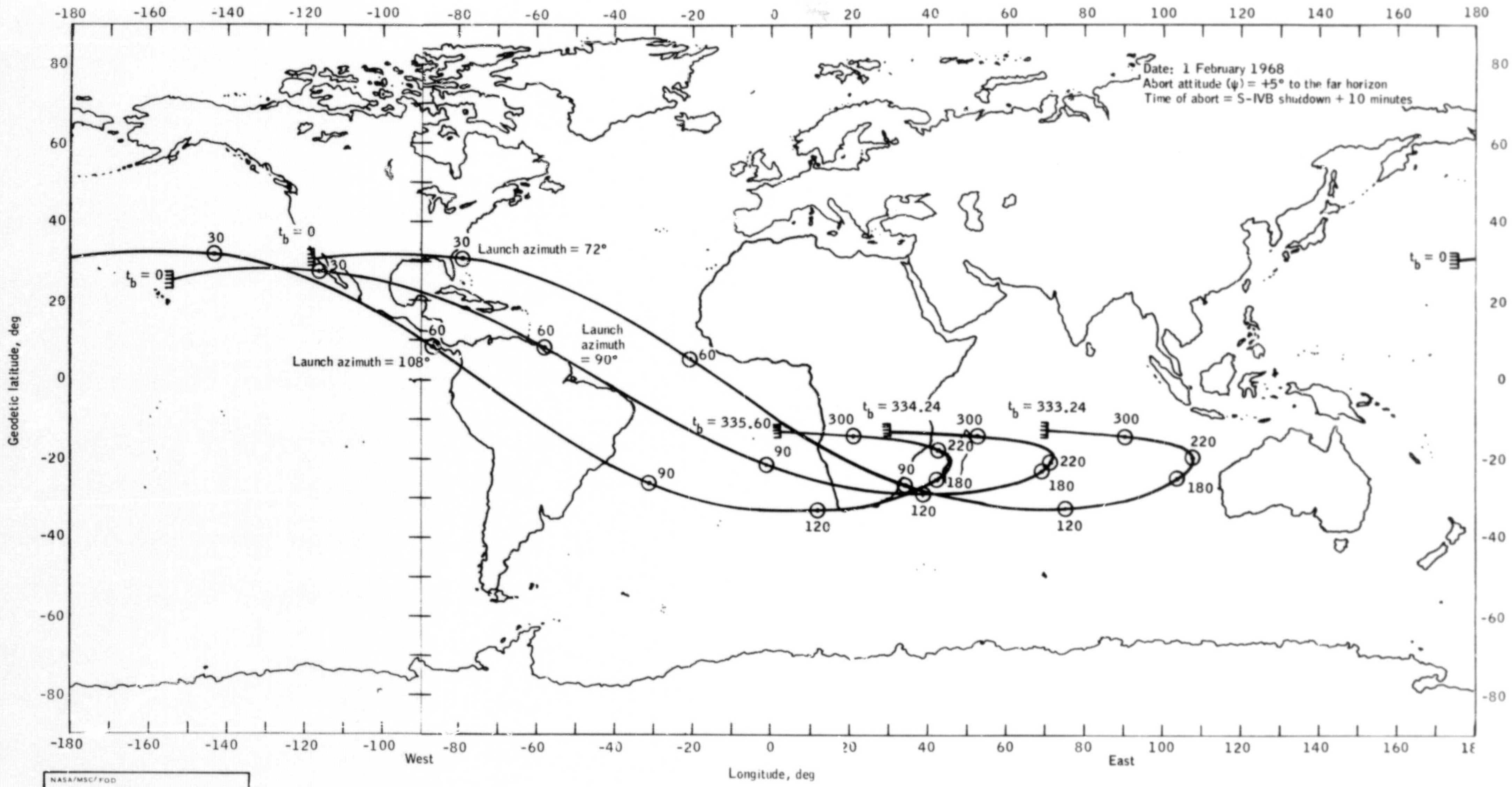

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Figure 4.- Fixed attitude abort landing locations.

One factor which is a prerequisite to this procedure is that the docking reticle, or crew optical alignment sight (COAS), shown in figure 5, be mounted on the left forward viewing window prior to TLI. The COAS will be the prime attitude reference source for the fixed attitude abort maneuver. Although it has been noted in reference 6 that the COAS can be mounted in about 3 minutes, it was agreed in the AAWG meeting that this time could be used to provide more useful support to the abort maneuver preparations.

Table II presents the sequence of events from S-IVB cutoff to SPS ignition for the fixed attitude abort maneuver. Note that table II indicates the thrust monitor program (P-47) will not be terminated after S-IVB cutoff. This program is active for two reasons: first, P-47 will keep track of the changes in the spacecraft state caused by the separation maneuvering and second, the display and keyboard (DSKY) parameters used in conjunction with preflight crew charts are the only sources for solutions to the abort maneuver.

The thrust monitor program will remain active to monitor the acceleration provided by the subsequent abort maneuver. The current procedures do not require the three components of velocity from P-47 be used to evaluate the maneuver. This program remains active to track the spacecraft state because the subsequent midcourse and entry will be performed normally without realigning the IMU or receiving a state vector update.

The abort maneuver will be performed using the automatic stabilization and control subsystem (SCS) mode in which the thrust vector is held fixed inertially. At the initiation of the abort maneuver, the crew will have aligned a marking (to be determined) on the COAS reticle and the earth's far horizon (horizon west of the subsatellite point). Also, the crew will be heads-up with respect to the LOS to the horizon. During the maneuver, the horizon will appear to move across the window as the spacecraft's center of gravity (c.g.) shifts.

As indicated previously, the only sources which will be available to the crew to provide solutions for the abort maneuver are the DSKY parameters in P-47 (inertial velocity, V; altitude, h; and altitude rate, $\dot{h}$) and crew charts prepared preflight. The Real-Time Computer Complex (RTCC) will not be required to provide solutions for the fixed attitude abort maneuvers. Several charts will be provided the crew preflight. They will include: (1) "Abort ΔV as a function of inertial velocity at booster cutoff". This chart will provide the ΔV for the ΔV monitor as indicated in table II. Solutions which result in land landings will be indicated on the charts (fig. 6). (2) "Time from abort to entry as a function of inertial velocity". Besides providing support data, this chart will indicate whether or not the crew would be expected to perform a subsequent midcourse maneuver. A midcourse maneuver will always be performed with RCS trim if there is sufficient TAR; that is, if TAR > $\sim$ 1.5 hours (fig. 7).

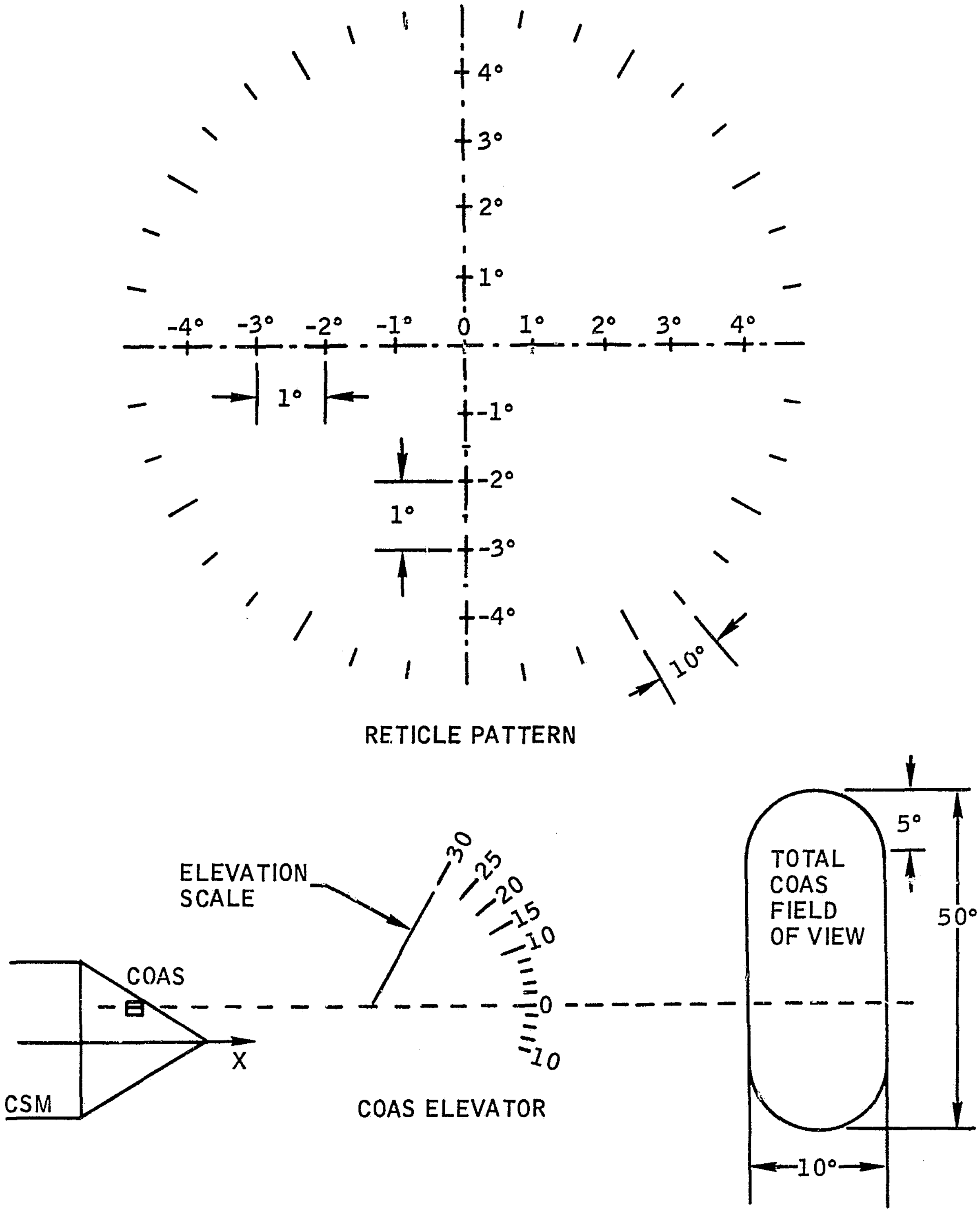

Figure 5.- COAS field of view, reticle plus elevator pattern.

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TABLE II.- SEQUENCE OF EVENTS FOR THE

FIXED ATTITUDE ABORT MANEUVERS

Time from booster cutoff, min:sec	Event
00:00	Terminate S-IVB thrust, SM/RCS +X thrusters on. Continue CMC in P-47. Select V, h, $\dot{h}$ display and record.
00:03	CSM/S-IVB separation.
01:30[a]	Separation completed, SM/RCS +X thrusters off.
04:00	ΔV monitor set to correct value from charts. Prepare for SCS ΔV auto maneuver.
05:00	CMDR pilot in position to view horizon through COAS. If in contact, the ground will verify the pitch and yaw gimbal angles and ΔV in the counter (from ground charts).
09:30	FDAI align
09:45	Ullage
10:00	SPS ignition

[a]Separation maneuvers have not been defined. It is desirable that separation maneuvers be completed by this time.

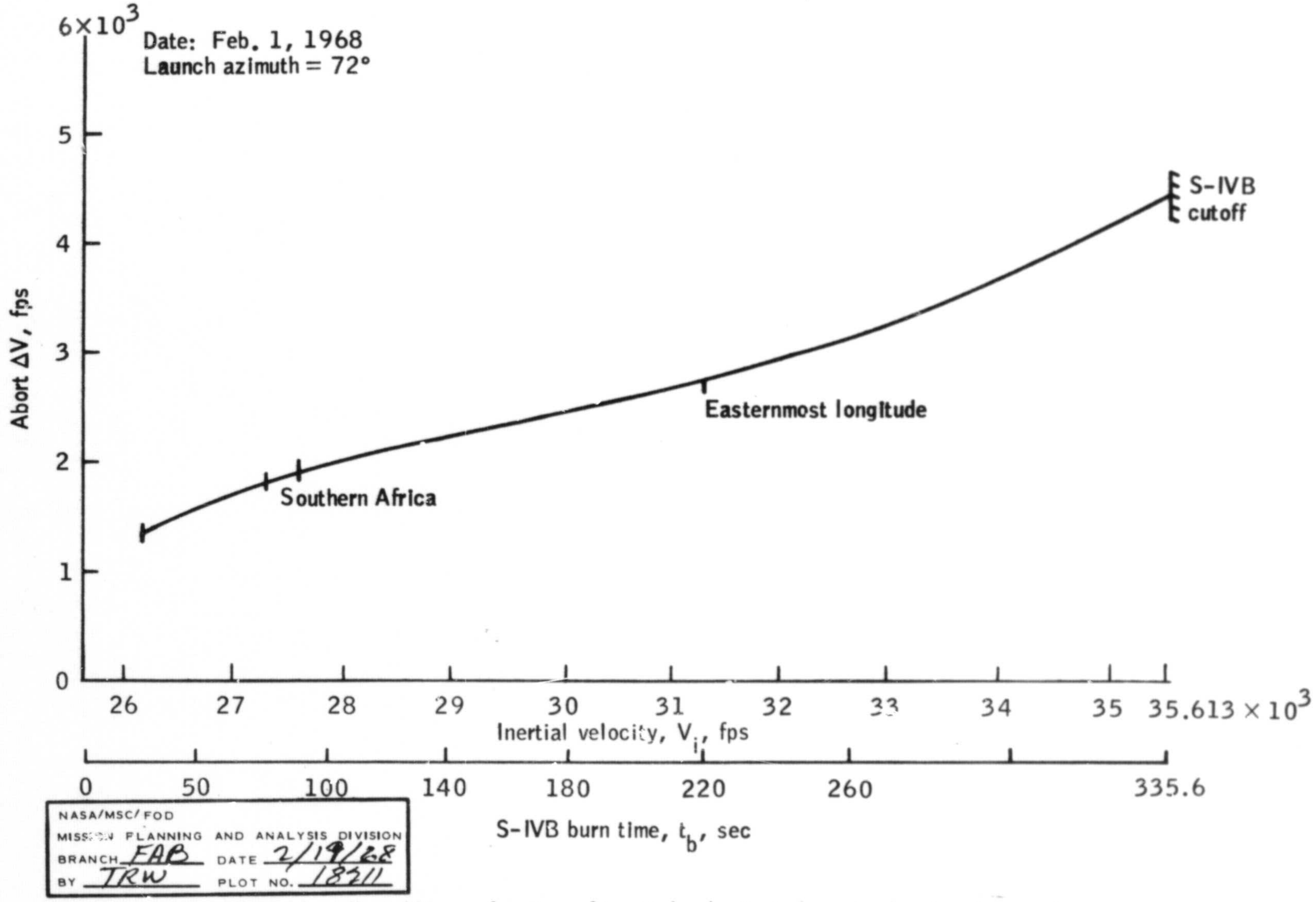

Figure 6.- Abort ΔV as a function of inertial velocity to be gained at booster cutoff.

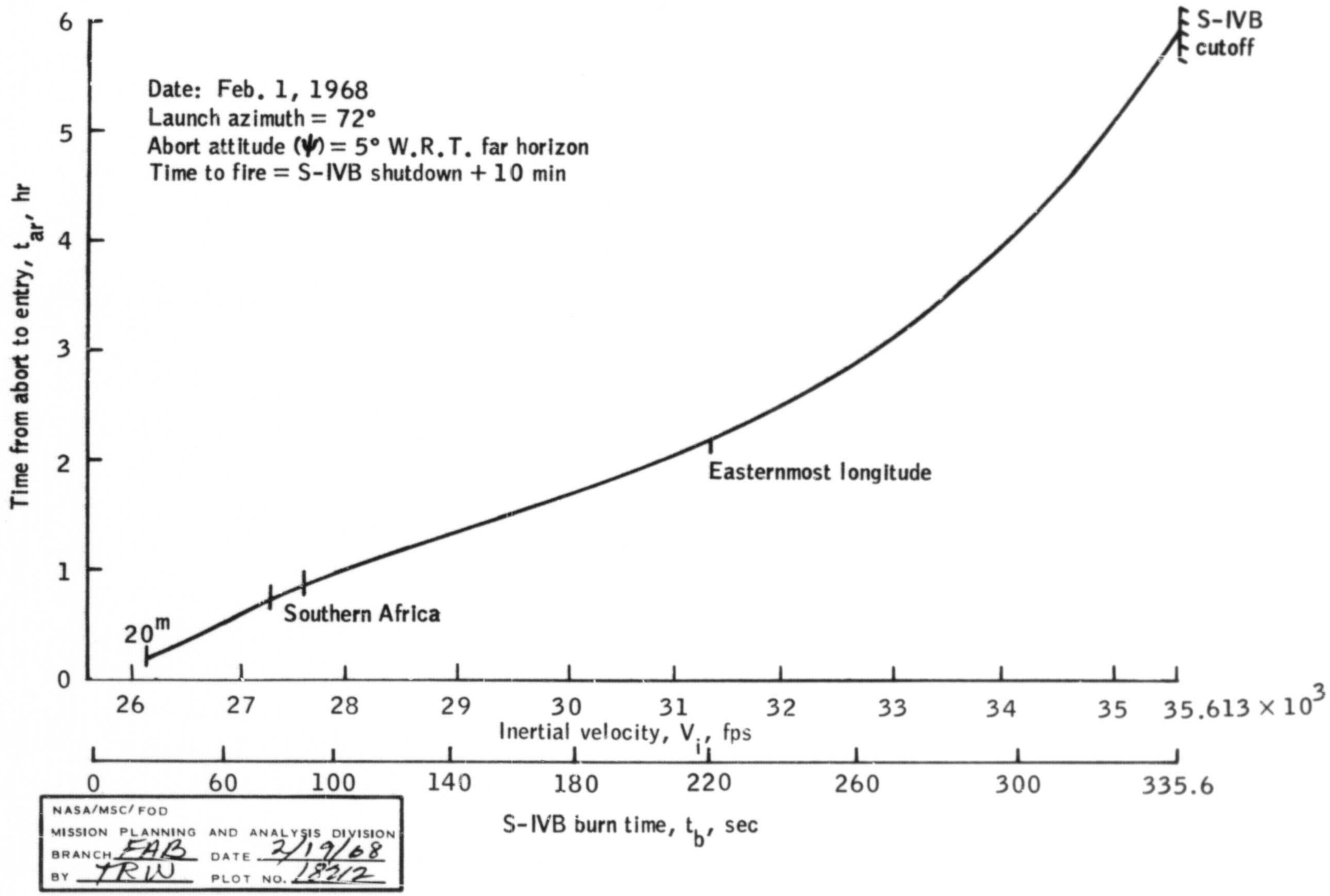

Figure 7.- Time from abort to entry as a function of inertial velocity to be gained at booster cutoff.

Figures 6 and 7 are the results of conic solutions to the abort problem in which the angle between the thrust vector and the LOS to the horizon is assumed to be 5° (thrust vector below LOS). As indicated in reference 3, this angle has yet to be finalized based on analyses of finite thrusting, c.g. offset, and dispersion analysis. Figures 8 and 9 give comparisons of the finite solution (for 5° between the thrust vector and the LOS to the horizon) and the conic solutions. Further comparisons are given in reference 7.

For approximately the last third of the TLI burn, it is anticipated that midcourse maneuvers will be required following the fixed attitude aborts. References 8, 9, and 10 give a good indication of the expected midcourse ΔV requirements.

Table III gives the midcourse and entry guidance modes following the fixed attitude aborts from TLI. As indicated, if the ground has voice and command contact with the spacecraft, the midcourse maneuver will be computed in the RTCC using the RTCC return to earth abort program (RTEAP) and the CMC entry target line which will be near the center of the entry corridor shown in figure 3. The pad message sent to the crew and the procedures for executing the midcourse will be similar to the message and procedures for the abort at TLI cutoff-plus-90-minutes (to be discussed).

If the ground could not contact the spacecraft, the crew would perform the midcourse using the onboard return-to-earth abort program P-37.

Primary Abort Procedures for TLI

As indicated previously, there are two types of malfunctions or contingencies which could cause an abort to be initiated from the TLI maneuver. The first would consist of a gross subsystem failure which could be detected and verified immediately. The second type of failure is that which could be verified by the crew by performing the standard malfunction procedures as outlined in the Apollo Operations Handbook. Also, the results of the malfunction procedures may indicate that the suspect system is performing satisfactorily but the instrumentation which indicated the malfunction is at fault. Many of the malfunction procedures will require the participation of all crew members and the procedures may require as long as 30 minutes to perform. Therefore, the primary procedure following the detected indication of a system malfunction will be to continue the TLI maneuver to the time of nominal cutoff and then perform the malfunction procedures. Table IV shows the procedures that will be performed on both the ground and onboard following booster cutoff. At booster-cutoff-plus-30-minutes, the crew and ground will have completed the malfunction procedures and a GO - NO-GO decision for T&D will be made. If the malfunction procedures verify that a spacecraft

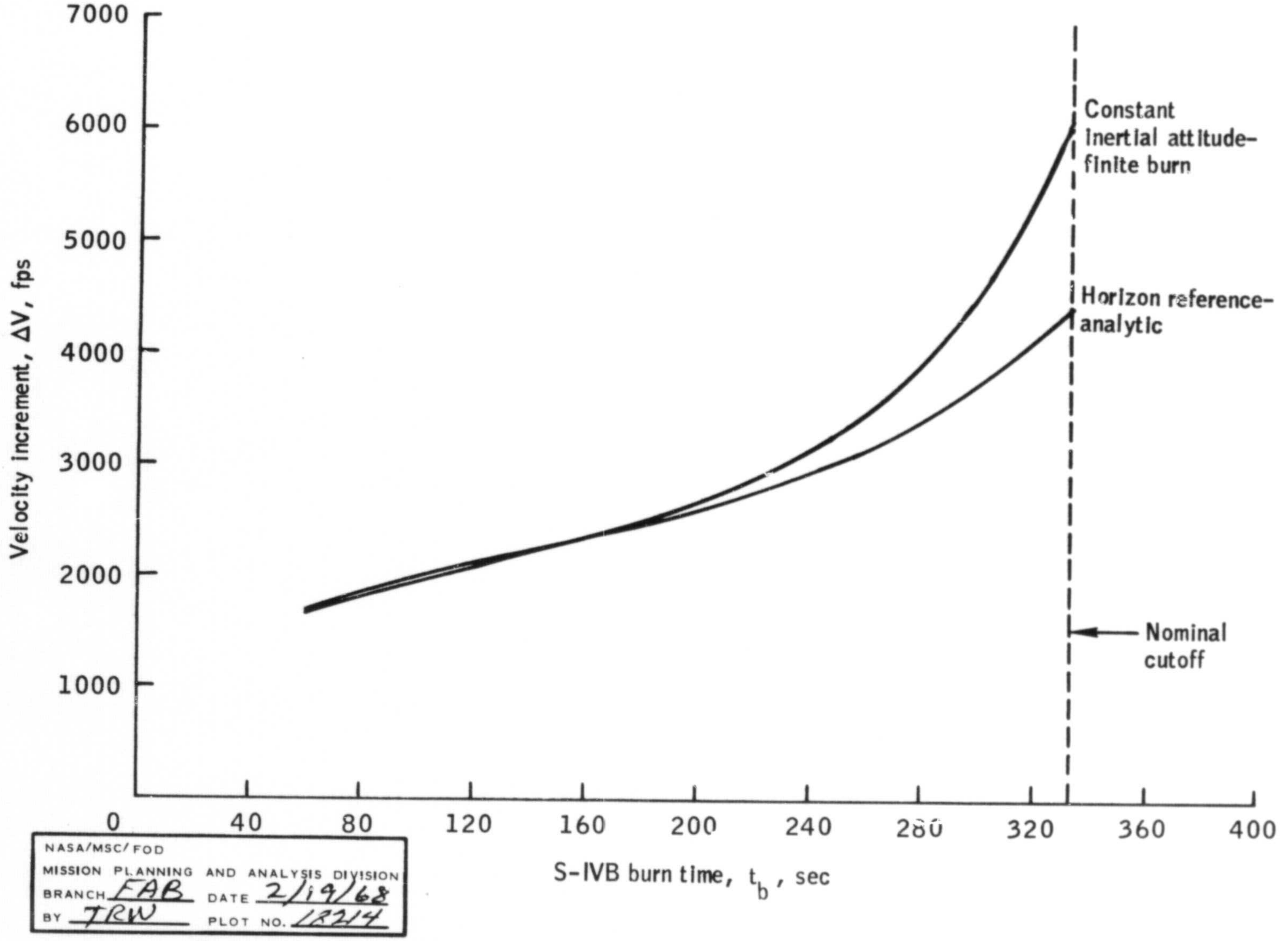

Figure 8.- Comparison of finite and impulsive abort ΔV solutions for the fixed attitude aborts.

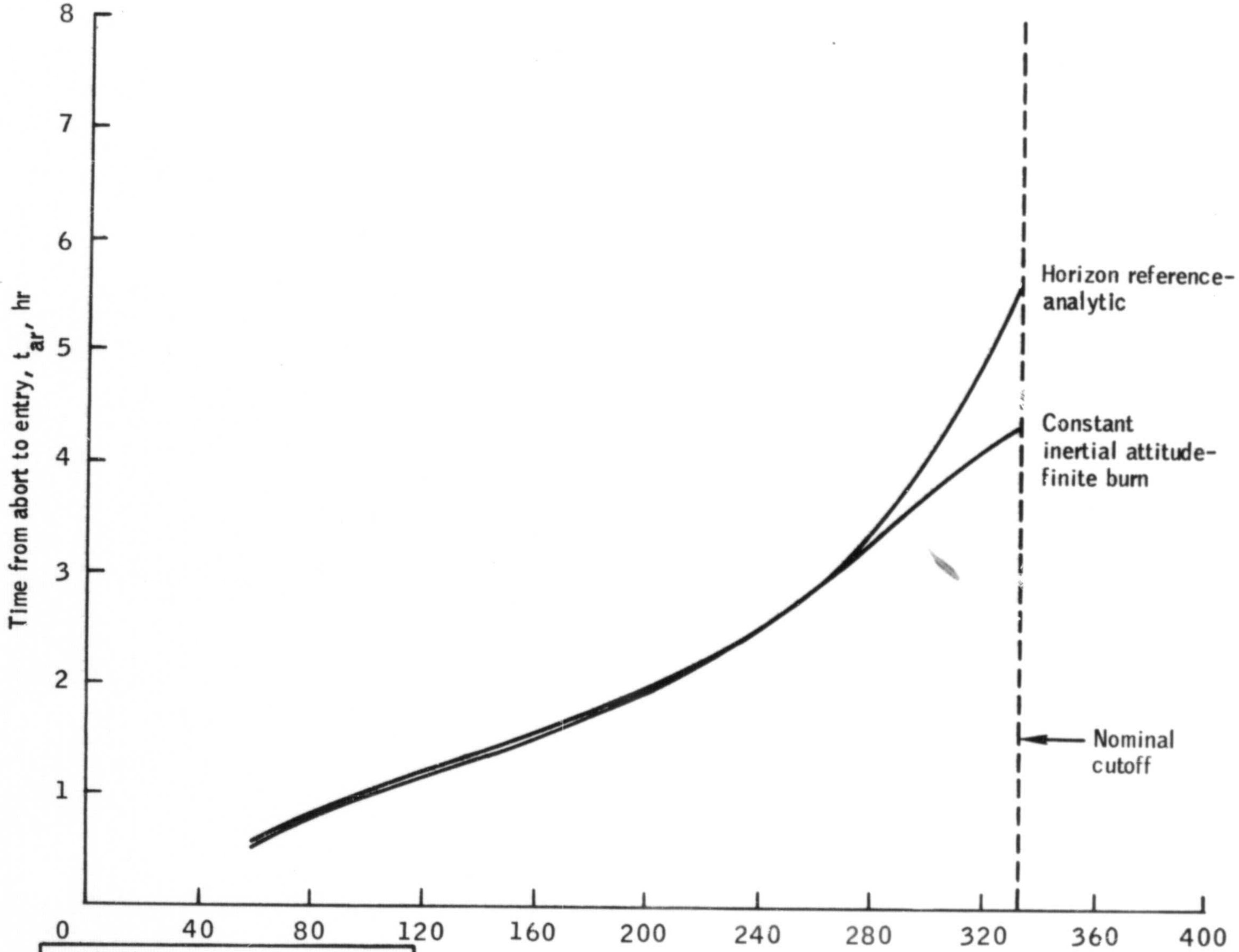

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Figure 9.- Comparison of finite and impulsive times to entry solutions for the fixed attitude aborts.

TABLE III.- MIDCOURSE AND ENTRY GUIDANCE MODES

FOLLOWING FIXED ATTITUDE ABORTS DURING TLI

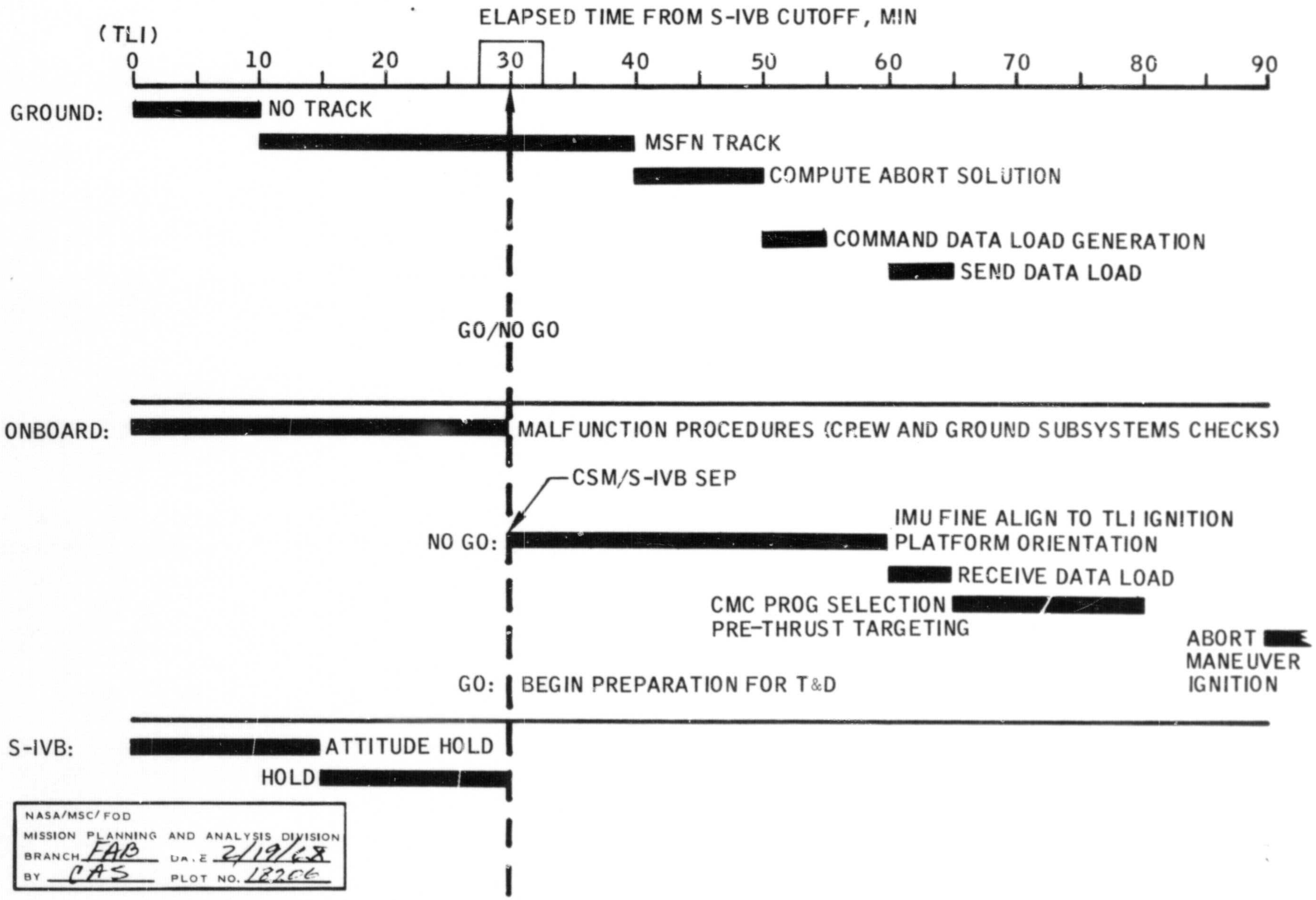
Commo status	Midcourse		Entry
	Attitude	Maneuver	
Voice and CMD	IMU[a]	Optimum using RTEAP/RTCC	G&N control with EMS monitor landing point update is possible.
	GDC/BMAGS optics[b]	Optimum using RTEAP/RTCC	Backup entry with EMS monitor.
No voice or CMD	IMU[c]	Optimum using RTEAP/onboard	G&N control with EMS monitor. Backup entry would be constant g using EMS.

[a]Assumes platform not tumbled prior to or during fixed attitude abort maneuver.

[b]Assumes platform not available for attitude reference.

[c]IMU must be available for crew to perform the midcourse calculations, etc., onboard.

TABLE IV.- PROCEDURES TIME LINE FOLLOWING A MALFUNCTION DETECTION DURING TLI



system has failed and requires the immediate return of the crew to earth, preparations will begin leading to an abort maneuver at booster-cutoff-plus-90-minutes (c.o. + 90 abort). The c.o. + 90 abort will be an in-plane maneuver to an alternate target point (contingency landing area). The abort solution will be constrained by requiring the return flight time from S-IVB cutoff to entry to be less than 18 hours.

It was noted in table I that there existed a readily identifiable failure which could require the return of the crew within 18 hours. The abort ΔV required to return the crew within this time (from S-IVB cutoff to entry) is approximately 4200 fps. To provide a procedure which will return the crew within this time to an alternate target point (ATP) and reserve sufficient SPS propellant for a subsequent midcourse correction (MCC), a minimum ΔV has been established for the abort maneuver to insure entry within 18 hours, and a maximum ΔV has been established to insure landing point control to land at an ATP and still reserve propellant for a MCC. Upon examining the ATP's for the lunar mission, it was found that the greatest distance between the ATP's was about 105° longitude. If the established minimum ΔV (4200 fps) lands at one ATP and there exists another ATP 105° longitude to the east, the additional ΔV required to achieve the other ATP is that ΔV required to shorten the return time by 7 hours. Thus defined, the maximum ΔV for the TLI-plus-90-minute abort is about 6250 fps and the return time is 11 hours. There does exist one area on the earth where possible land landings may result from the TLI-plus-90-minute abort (i.e. the distance between ATP's is greater than 105° longitude). If an abort using the minimum ΔV (4200 fps) results in a landing between latitudes of 15° N to 40° N and longitudes between 30° W eastward to 45° E, the maximum ΔV (6250 fps) cannot achieve an ATP. Also, the maximum ΔV available (10 000 fps) in some instances cannot achieve an ATP. For landings in that area, ΔV's less than 4200 fps, which would result in return times greater than 18 hours, would need to be employed. Preliminary results indicate landings in that area would require TLI to occur north of about 25° N in a northeasterly direction. Studies are currently being conducted to determine the precise TLI conditions required for landings in that area and if any operational planning coincides with those conditions.

Prior to TLI the ground will have provided the crew with a solution to the c.o. + 90 abort. The pad message (message sent via voice) for the c.o. + 90 abort is given in table V.

As noted in table IV, a new abort solution will be sent, following TLI, updating the pre-TLI pad message. Both solutions as well as the onboard solution will be targeted to the CMC entry target line.

TABLE V.- PAD MESSAGE FOR CUTOFF-PLUS-90-MINUTES ABORT

Parameter	Description
GETI	Ground elapsed time of abort maneuver ignition, hr:min:sec
ΔV_c	Change in velocity magnitude, fps
ϕL	Latitude of resultant land point, + north
λ_L	Longitude of resultant landing point, + east
T_{FF}	Transit time from GETI to 400 000-ft altitude, hr:min:sec
V_{EI}	Inertial velocity at 400 000-ft altitude
γ_{EI}	Inertial flight-path angle at 400 000-ft altitude
P, Y, R	IMU gimbal angles at SPS ignition attitude
COAS EL	COAS elevation angle for in-plane horizon at ignition attitude
Reticle	Reticle point where in-plane horizon should be aligned at ignition attitude

Upon receipt of the pad message the crew will select the onboard RTEAP (P-37), perform P-37 using GETI and ΔV from the pad message, and compare P-37 output to the remainder of the pad message. This action will not only generate the Lambert's targeting parameters for the SPS thrusting program (P-40) but also provide verification that the PGNCS is operating properly. If the P-37 results do not agree with the pad message, the crew can perform a manual attitude maneuver to align the visual references on the COAS and check the IMU gimbal angles from the pad message to verify the inertial measurement unit (IMU) alignment.

If it is finally established that the PGNCS results are unacceptable, the abort maneuver will be performed in the SCS automode using the ΔV_c from the pad message for the ΔV monitor and either the IMU gimbal angles provided by the ground (if it is verified by the optical check that the IMU is aligned properly) or the COAS visual references for the SPS ignition attitude.

Logical Flow Diagrams

Figure 10 presents logical flow diagrams summarizing the contingency procedures presented in this paper. Although "no-voice" considerations were not presented on the logical flow diagrams the following assumptions concerning voice communications were made:

1. No ground-to-air voice communications, ground-to-air telemetry, or MSFN track will exist during TLI to TLI-plus-10-minutes.

2. Ground-to-air communications status will not affect the fixed attitude abort procedures.

3. The only change effected by "no-voice" following TLI would be that the ground would not be able to update the TLI-plus-90-minute abort.

Other assumptions made affecting the validity of the procedures and the logical flow diagrams are:

1. The crew will be provided preflight the necessary charts to support the fixed attitude abort maneuver.

2. In earth parking orbit, the crew will be provided a solution to the TLI-plus-90-minute abort.

3. The crew will be provided preflight a chart enabling them to determine the inplane point of the earth's horizon for the TLI-plus-90-minute abort.

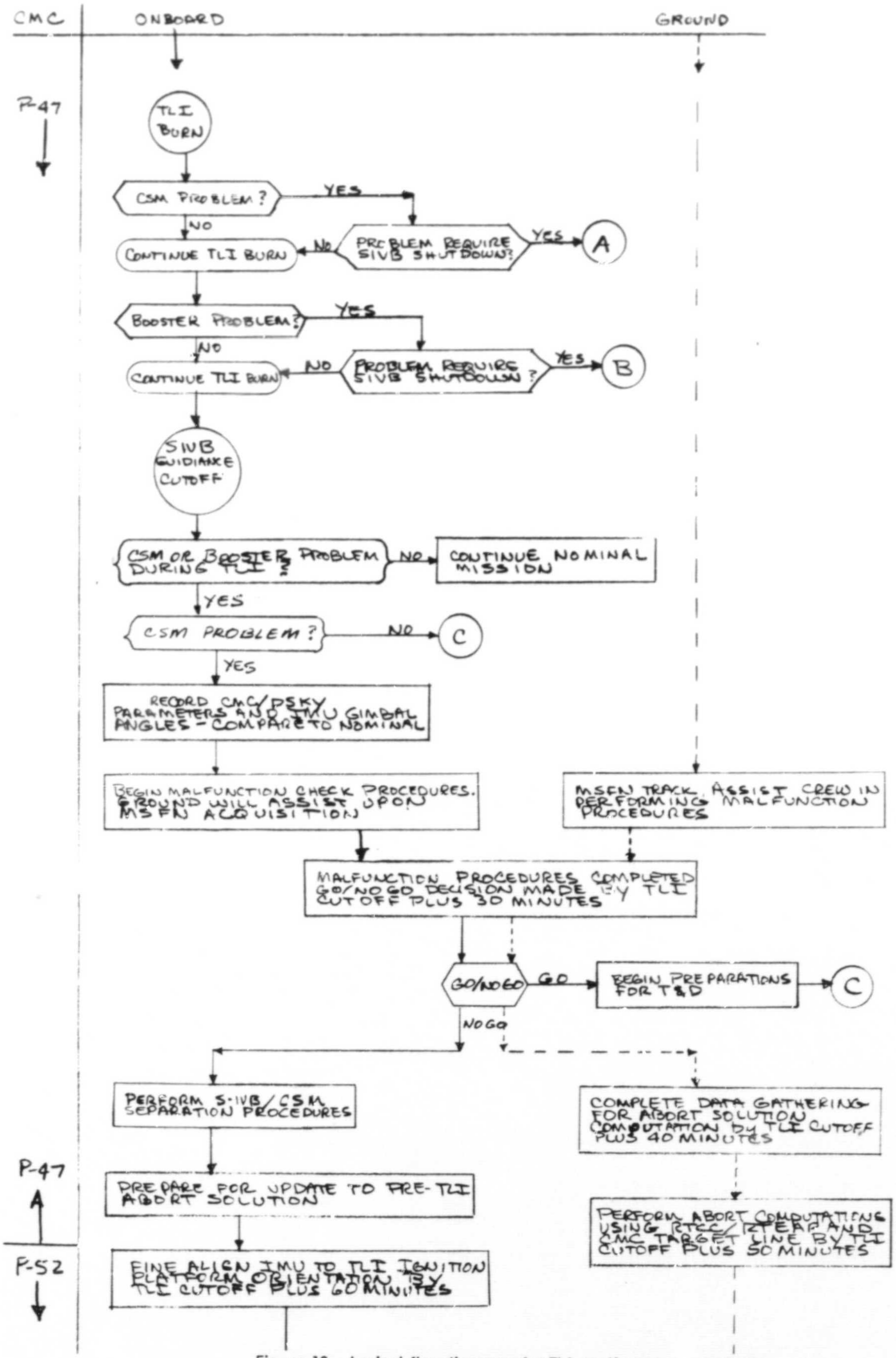


Figure 10. - Logical flow diagrams for TLI contingency procedures.

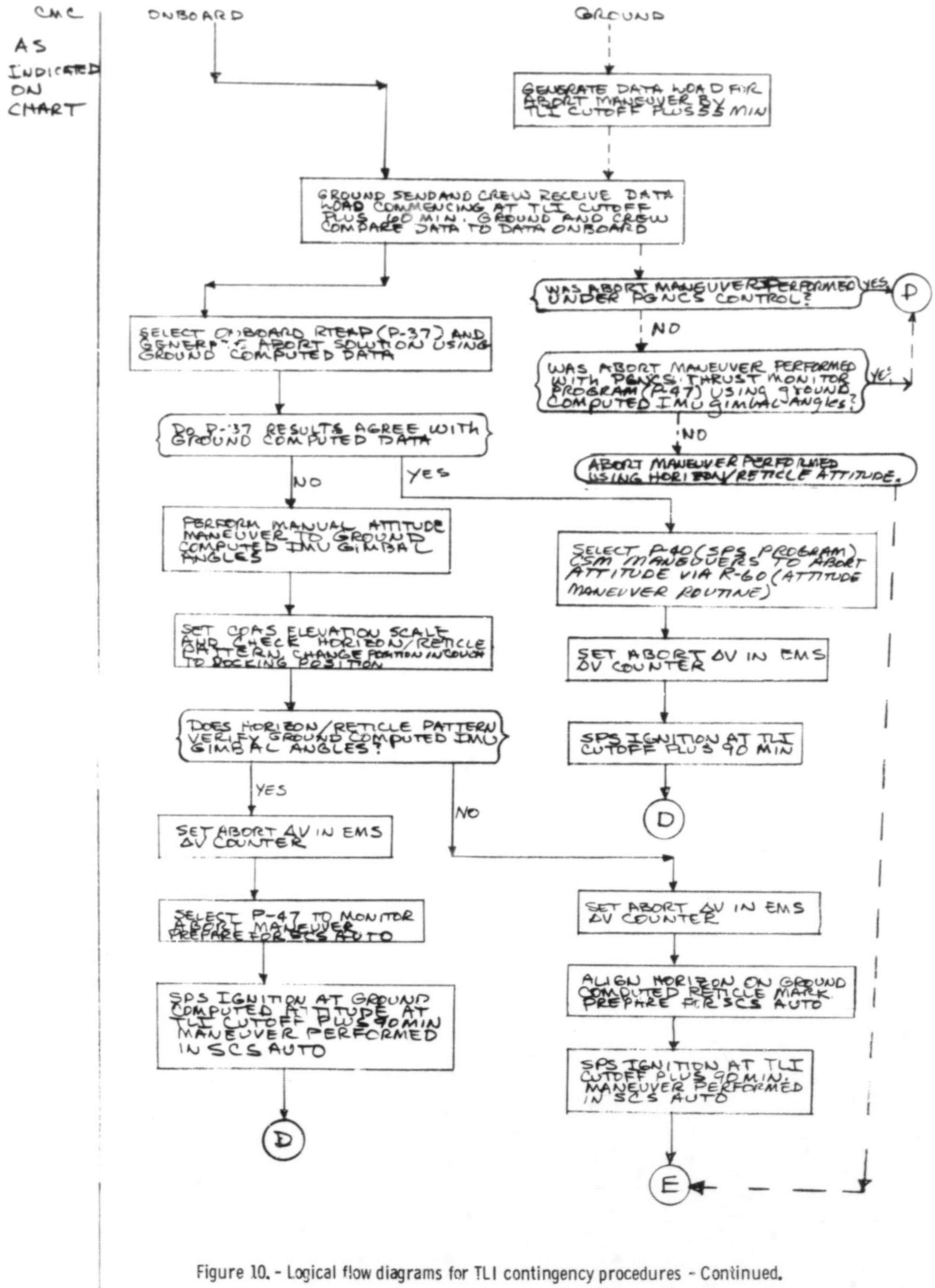


Figure 10. - Logical flow diagrams for TLI contingency procedures - Continued.

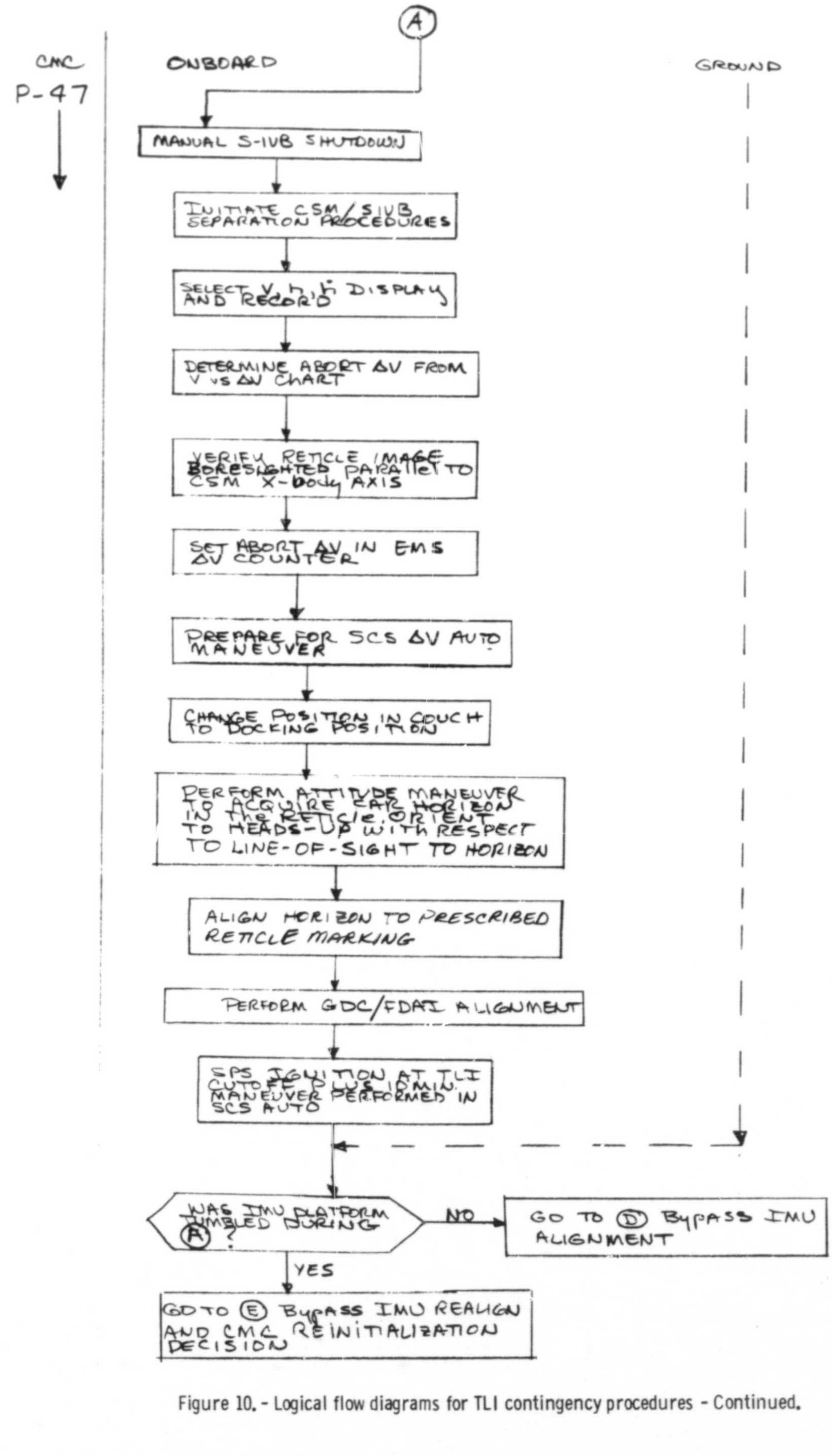


Figure 10. - Logical flow diagrams for TLI contingency procedures - Continued.

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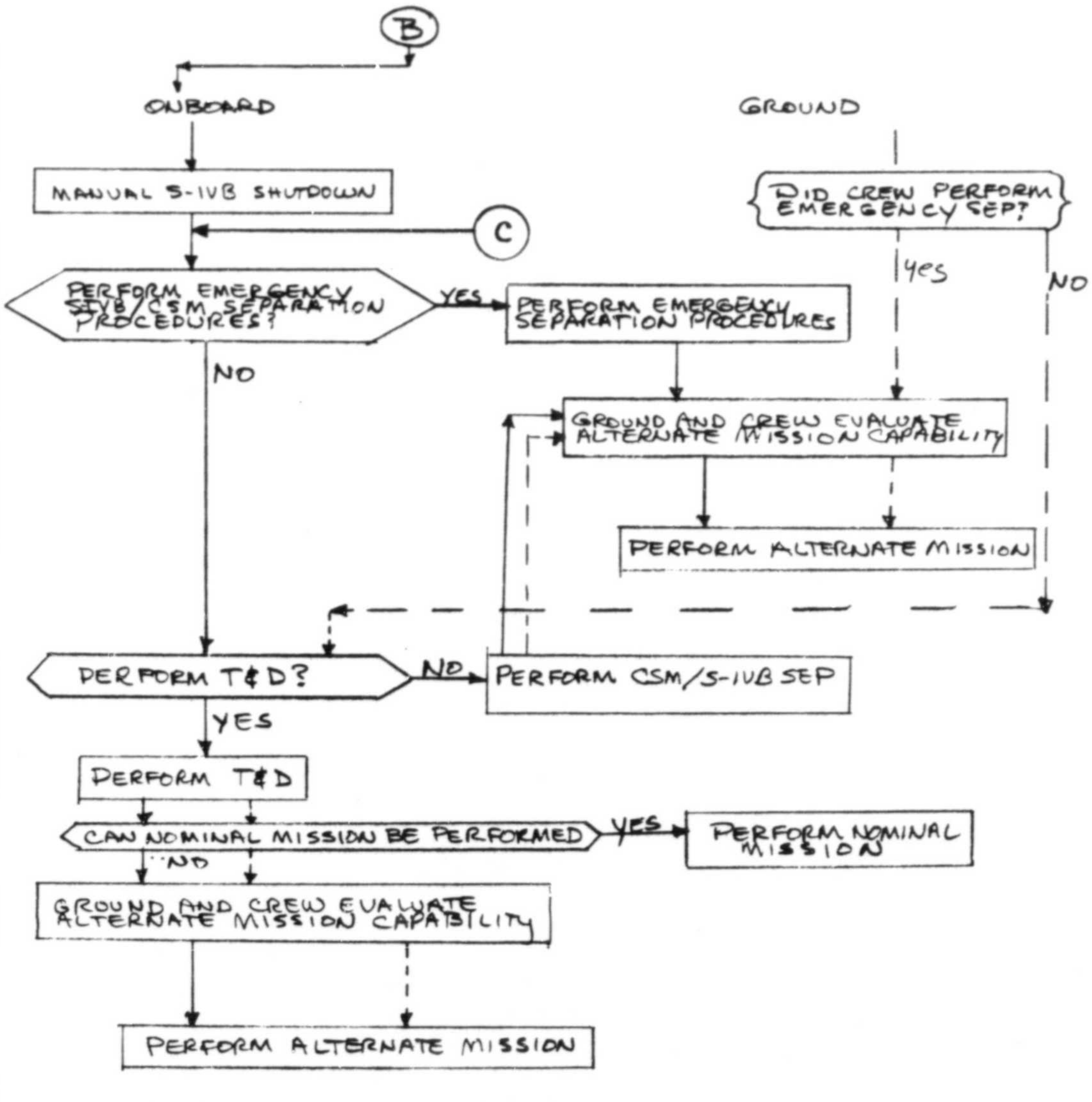

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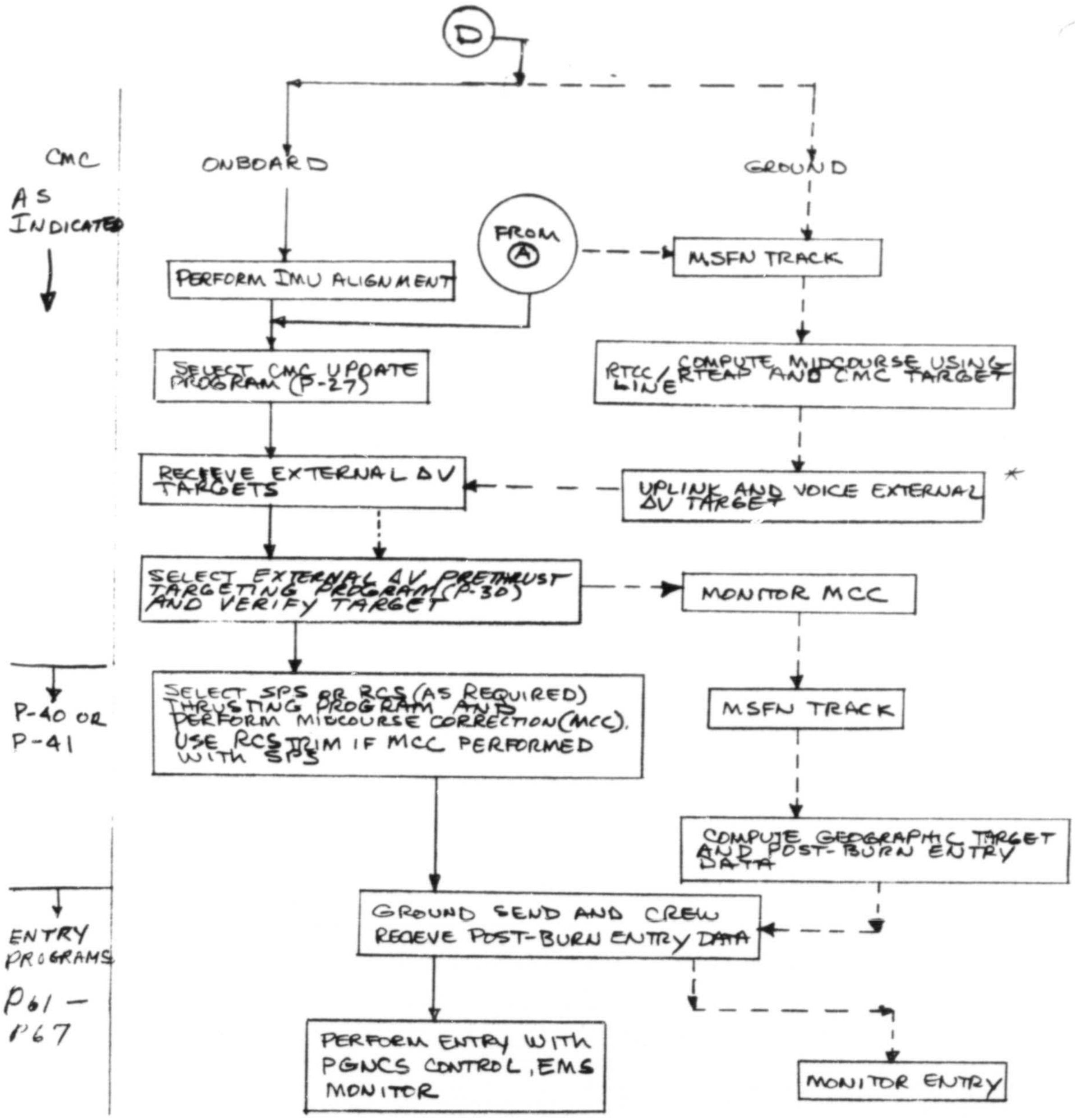

Figure 10. - Logical flow diagrams for TLI contingency procedures - Continued.

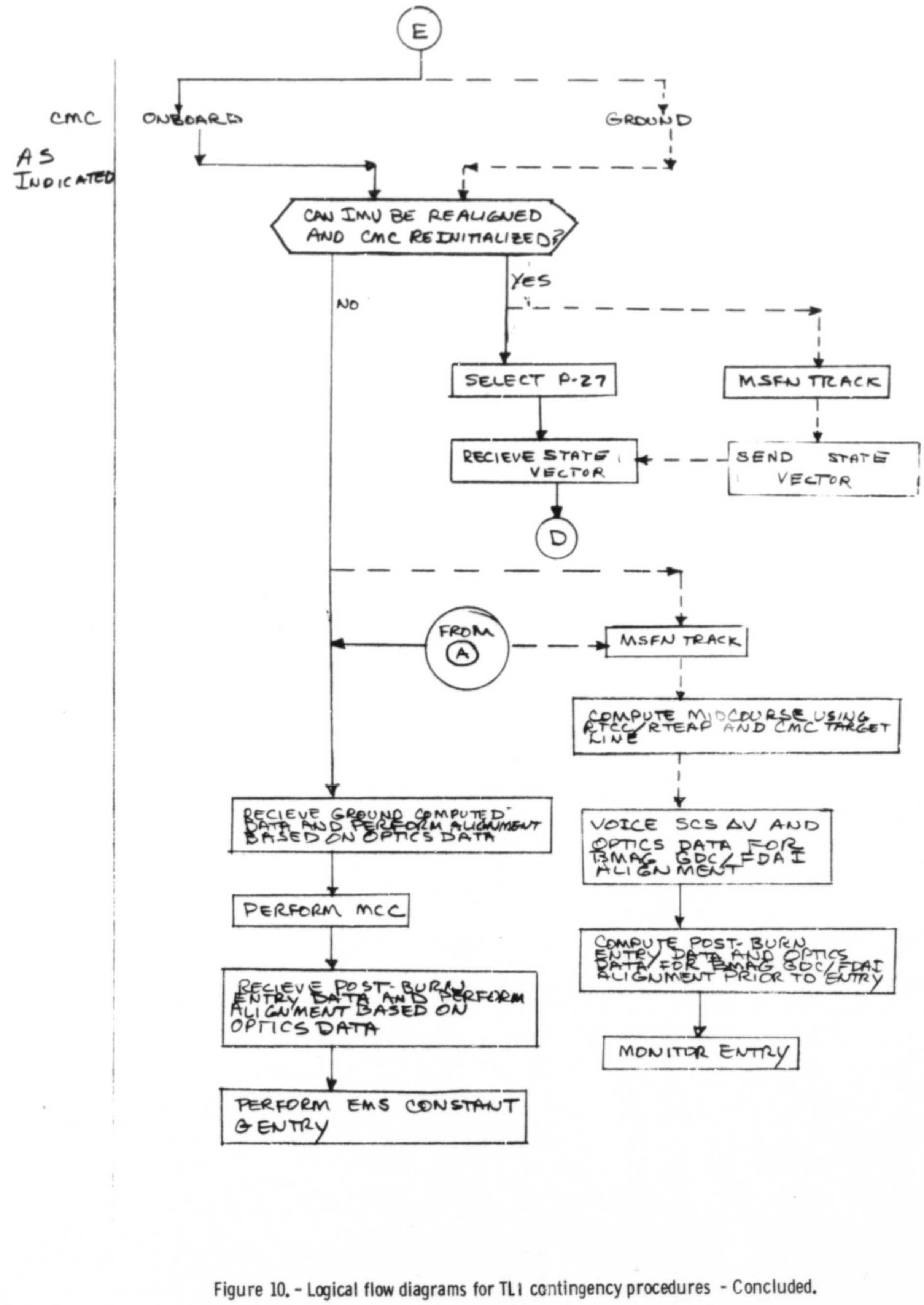

Figure 10. - Logical flow diagrams for TLI contingency procedures - Concluded.

4. Prior to TLI (preflight or in earth parking orbit) the crew will be provided a time history (charts or digital data) of the nominal TLI IMU gimbal angles.

5. Prior to TLI the COAS will be mounted and boresighted parallel to the x-body axis.

6. The thrust monitor program (P-47) will be used to monitor TLI and the pilot can call V, h, and $\dot{h}$ displays at his discretion.

7. The CMC will remain in P-47 and "average g" will continue when an "SPS abort" is initiated during TLI.

CONCLUDING REMARKS

Procedures to be followed in the event a contingency occurs during the translunar injection maneuver have been presented.

The procedures are to be considered preliminary only due to the fact they have not been tested in flight controller, crew simulation exercises.

Changes to the prescribed procedures will be noted in the minutes of the Apollo Abort Working Group meetings and the final procedures will be presented in the operational abort documents of the missions to which the procedures are applicable.

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