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RATIONALE FOR USING THE SATURN MONITOR AND ABORT CREW CHARTS FOR APOLLO 10 (MISSION F)

Flight Analysis Branch
MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER
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PROJECT APOLLO

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By Contingency Analysis Section
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MISSION PLANNING AND ANALYSIS DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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HOUSTON, TEXAS

Approved: ______________________
Charlie C. Allen, Chief
Flight Analysis Branch

Approved: ______________________
John P. Mayer, Chief
Mission Planning and Analysis Division

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RATIONALE FOR USING THE SATURN MONITOR AND ABORT CREW CHARTS FOR APOLLO 10 (MISSION F)

By Contingency Analysis Section

1.0 SUMMARY

The purpose of this document is to explain the crew charts that the Flight Analysis Branch has prepared for Apollo 10 (Mission F). The operational abort plan for Apollo 10 (Mission F) (ref. 1) includes a complete description of abort modes, philosophy, and constraints used in the generation of these crew charts.

The following sections include copies of the applicable crew charts as well as a discussion of the situations that require their use. Finally, the procedure for using each of the charts is included.

2.0 INTRODUCTION

The crew charts contained in this document were prepared by the Flight Analysis Branch for the F mission launched May 18, 1969. Changes required to update the crew charts because of variations in launch date are discussed in each section where applicable. The crew charts included are listed below along with the responsible Flight Analysis Branch personnel.

(a) Launch abort, section 4.0: E. M. Henderson

(b) TLI monitoring, section 5.1: C. T. Hyle

(c) TLI abort, section 5.2: C. J. Laetz

(d) LOI abort, section 6.0: C. E. Foggatt

3.0 ABBREVIATIONS

CM	command module
CMC	command module computer

COAS	crew optical alinement sight
COI	contingency orbit insertion
CSM	command and service modules
DPS	descent propulsion system
DSKY	display keyboard
DVM	ΔV magnitude
EMS	entry monitoring system
EPO	earth parking orbit
ESS	early S-IVB staging
FDAI	flight director attitude indicator
g	entry load
g.e.t.	ground elapsed time
h	altitude
IGA	inner gimbal angle
IMU	inertial measurement unit
IU	instrument unit
LOI	lunar orbit insertion
LOI-1	first LOI burn into a 60- by 170-n. mi. altitude orbit
LOI-2	lunar orbit circularization burn into a 60-n. mi. altitude orbit
MCC	midcourse correction
MGA	middle gimbal angle
MSFN	Manned Space Flight Network
OGA	outer gimbal angle

RCS	reaction control system
REFSMMAT	transformation matrix from inertial to stable member (IMU)
SC	spacecraft
S-IC	launch vehicle first stage
SCS	stabilization and control subsystem
S-II	launch vehicle second stage
S-IVB	launch vehicle third stage
SPLERROR (ΔR)	difference between the onboard predicted landing point and the mode III target point
SPS	service propulsion subsystem
TAR	time from abort to reentry
THC	translational hand controller
TLC	translunar coast
TLI	translunar injection
t_B	burn time
t_{ff}	time of free fall
t_{IG}	time of ignition
V_i	inertial velocity
ΔR	SPLERROR
ΔV	total sensed velocity change

Subscripts:

p	perigee
IG	ignition

i inertial

b body axis system

4.0 LAUNCH PHASE CHARTS

To facilitate trajectory monitoring during the launch phase, the crew uses the FDAI and DSKY displays with two onboard crew charts. The first chart (crew chart 1) presents the nominal launch profile along with the abort trajectory limits and the orbital capability regions. This chart would be used by the crew to help determine when an abort would be required for trajectory deviations and to determine what action (abort mode) would be required if an abort should occur. Normally, the ground control will inform the crew when trajectory limits are violated and will advise the crew on the appropriate abort action. However, if voice communications were lost during launch, the crew would have to depend on crew chart 1 and on the onboard displays for this information. The second chart (crew chart 2) lists the planned trajectory parameters for the nominal launch. This chart will be used by the crew to monitor the trajectory parameters during launch, and the data would provide the launch vehicle steering parameters if the crew manually takes over after a launch vehicle platform failure during the S-II and the S-IVB portions of the launch.

The nominal launch profile and the associated abort trajectory limits and capability lines are shown as functions of inertial velocity and altitude rate in crew chart 1. The chart has a dual function.

(a) To determine when an abort is necessary for trajectory deviations

(b) To determine what capability exists if the launch vehicle shuts down

For the first function, if the actual flight trace violates the structural limit, the heating limit (invalid for engine out), or the 16g maximum entry load factor limit, the crew would be required to initiate an abort. If the trace approaches the 100-second free-fall limit, the crew would initiate an abort when the DSKY display of free-fall time is 100 seconds and decreasing. Note that the ground control normally would inform the crew both by voice and by command of the abort light for trajectory violations if voice communications and command capability exist.

For the second function of the first chart (i.e., to determine what capability exists if the launch vehicle shuts down), several possibilities exist based on the boundaries crossed by the flight trace.

(a) ESS to COI tick - the crew could manually upstage to the S-IVB and could achieve the mode IV COI region.

(b) ESS to orbit tick - the crew could manually upstage to the S-IVB and achieve earth parking orbit.

(c) Mode IV, COI boundary - the crew could use the SPS manually to achieve orbit (either a two-impulse, a single impulse, or an apogee kick maneuver).

(d) Mode II/mode III line or $\Delta R > -400$ n. mi. - if a suborbital abort were required, the crew would use lift control or an SPS burn or both to obtain an Atlantic landing.

(e) GO/NO-GO line - no action would be required by the crew (except for an overspeed); a safe orbit has been achieved; $h_p > 75$ n. mi. Again, these capabilities would be relayed from ground control when voice communications exist.

The second chart for the launch phase, crew chart 2, lists the SC IMU pitch gimbal angle, inertial velocity, altitude rate, and altitude as functions of ground elapsed time for the nominal planned profile. These parameters will be compared to the actual flight values as an estimate of the trajectory status during the launch. The primary function of this chart will be to provide crew steering parameters if a manual takeover should occur (stick steering) after launch vehicle IU platform failure. The SC computer will provide steering commands for the first stage (S-IC) portion of the flight, and the crew will manually provide steering commands for the second and third stage (S-II and S-IVB) portions of the launch. The crew will use the parameters in crew chart 2 in conjunction with the FDAI and DSKY displays. After comparison of the inertial velocity on the DSKY with the inertial velocity on the chart, the crew will command the appropriate pitch gimbal angle to achieve the desired altitude rate and altitude profile and will continually check the results with the chart until orbital insertion is achieved. Note that this procedure and these parameters assume a normally functioning launch vehicle except for the platform failure.

5.0 TRANSLUNAR INJECTION CREW CHARTS

5.1 Translunar Injection Monitoring Crew Charts

Next to insuring crew safety, the primary objective after a problem develops during TLI, as well as during all other mission phases, is to perform an alternate mission. Therefore, the extent of allowable deviated flight conditions must be determined in advance to insure that the desired alternate mission capability will exist. Also, due consideration must be given to the provision of reasonable initial conditions for performance of an abort maneuver. These things have been done by the development of a crew monitoring procedure which includes appropriate S-IVB shutdown limits.

The crew must be able to monitor and evaluate TLI without ground support because the maneuver can occur off the MSFN tracking range. A schematic of the basic crew monitoring technique (fig. 1) shows that an abort can be performed for S-IVB attitude rate problems, for attitude deviation problems, and for SC system problems. Because S-IVB problems normally would result in an alternate mission, only a critical SC system problem is likely to require an abort.

Several significant items can be noted about the TLI monitoring technique.

1. The TLI maneuver will be inhibited if the launch vehicle attitude before ignition is more than 10° from nominal as determined by horizon reference.

2. The TLI maneuver will be terminated by the crew for S-IVB initiated rates of 10 deg/sec.

3. The TLI maneuver will be terminated by the crew with the abort handle for attitude deviations of 45° from the nominal attitude, which are determined by onboard charts of the nominal pitch and yaw gimbal angle histories.

4. A backup to the S-IVB guidance cutoff signal will be performed by the crew if the S-IVB has not shut down at the end of the predicted burn time plus a 2σ dispersion of 6.0 seconds and if the nominal inertial velocity displayed by the SC computer has been achieved.

The crew charts mentioned in item 3 are shown in crew charts 3 and 4. The double scale on the pitch chart (crew chart 3) indicates the TLI ignition gimbal angle for a 72° launch azimuth. For any other day or launch azimuth, the crew will renumber the scale by changing the zero point to the ignition pitch gimbal angle uplinked by the ground control during EPO. After an S-IVB shutdown by use of these charts, the crew will receive alternate mission midcourse requirements from the ground. The rationale for the monitoring procedures and for the determination of the previously discussed limits are documented in references 2, 3, and 4.

If a tumbled S-IVB inertial platform exists during TLI, the crew may assume manual control of the burn with the hand controller. In this case, the IMU would be used to obtain reference information, and the crew charts could be used to obtain reference information. A ground rule for manual takeover requires illumination of the guidance failure lights when the S-IVB platform is tumbled. The 45° attitude deviation limits are required for protection against other S-IVB malfunctions.

Although the recommended procedure to shut down the S-IVB involves use of the above chart, the same end could be accomplished by the crew mentally computing differences between the actual attitude and values from a preflight table of attitudes at discrete times.

A comparison of the nominal pitch gimbal angle with pitch gimbal angle variations for several malfunctioning TLI burns is provided in figure 2.

5.2 TLI Abort Crew Charts

The 10-minute fixed attitude abort is designed to enable the crew to return to earth as rapidly as possible, without regard to landing location, if a catastrophic SC subsystem problem should occur which could be isolated during the TLI burn. It has been recommended that, if the situation permits, the crew should allow the S-IVB to complete TLI, at which time the ground could assist in performance of a system malfunction analysis. As yet, no single point failures are known which would require the crew to shut down the S-IVB manually and to execute this abort maneuver immediately.

The following time line has been recommended for the 10-minute fixed attitude abort. The actual time line will be presented in the Apollo Abort Summary for Apollo 10 (Mission F) to be prepared by the Crew Safety Section, Crew Safety and Procedures Branch, Flight Crew Support Division.

Time from S-IVB cutoff, min:sec, g.e.t.	Event
00:00	S-IVB burn time is recorded; THC is turned counterclockwise to initiate S-IVB shutdown; inertial velocity (V_i) is recorded from the DSKY; the four +X RCS jets are turned on
00:03	CSM/S-IVB separation occurs
00:13	The four +X RCS jets are turned off; the crew begins to pitch up ($+X_b$ down) to -r (down the radius vector), with the earth used as the visual reference to determine -r
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
01:08	The four -X RCS jets are turned off; the crew begins maneuvers to the abort maneuver thrusting attitude (fig. 3) after having driven to the following IMU gimbal angles: OGA = 180° MGA = 0.0° IGA = ground computed in EPO
04:00	The crew selects the abort ΔV from a chart of ΔV versus V_i and S-IVB t_B (crew chart 5) and enters this value in the ΔV counter; the crew begins preparations for an SCS automatic maneuver
05:00	The COAS elevation angle is reset to 0°; the CDR adjusts his position on the couch to view the horizon through the COAS reticle image
09:30	The spacecraft is alined to the required horizon referenced attitude (fig. 3)
10:00	The SPS is ignited and the burn is controlled by SCS automatic

The crew will have a second chart, crew chart 6, to enable them to determine if sufficient time remains after the abort to perform a MCC prior to entry. In both crew charts 5 and 6, S-IVB burn time and S-IVB EMS ΔV have been provided as independent backup parameters.

Typical TLI burn groundtracks and landing point loci are shown in figure 4. For the abort to be as insensitive as possible to execution errors, the maneuver is targeted to achieve the contingency target line, which is the same as the entry target line that is stored in the CMC. Therefore, subsequent midcourse corrections determined onboard will be targeted to the entry target line used to determine the abort ΔV.

Previous studies have shown that this maneuver is relatively insensitive to execution errors in abort ΔV and ignition time. However, this abort maneuver is very sensitive to attitude errors for aborts performed after approximately 200 seconds into the TLI burn. Nevertheless, sufficient time prior to entry remains after this time to perform a midcourse correction.

6.0 LUNAR ORBIT INSERTION ABORT CREW CHARTS

6.1 Nominal Mission (CSM/LM) Crew Charts

During the LOI burn, failure of the SPS engine would require LM activation followed by one or more docked DPS burns to inject the SC on the transearth coast. A complete description of the LM abort modes is presented in reference 1. Monitoring of SPS systems during the burn, however, would permit termination of the LOI burn before an SPS burn capability is lost.

Because specific SPS problems during the burn can be identified and the LOI burn terminated, the SPS engine may be available for an abort maneuver after manual shutdown. In general, however, the SPS problems considered in the Apollo 10 (Mission F) mission rules are associated with decaying propellant tank pressure. For this reason, an immediate SPS abort capability would be desirable because the pressure decay might preclude SPS restarts if an extended coast period occurred prior to abort. Although the DPS has the capability to return the SC to earth for any early LOI shutdown during Apollo 10 (Mission F), LM activation and possibly two DPS burns are required.

The 15-minute crew chart developed for Apollo 8 (when no DPS backup was available) is included for Apollo 10 because the relatively simple procedure could reduce the crew activity required if SPS problems of the type previously mentioned became evident.

For the F mission, the SPS ΔV available in the docked configuration is such that the 15-minute abort is available for only a portion of the LOI burn. The applicable region of the LOI burn is discussed in the following paragraphs.

Basically, the procedure for use of the 15-minute crew chart is as follows.

1. After manual SPS shutdown, the crew maneuvers the CSM/LM combination to a set of gimbal angles relative to the CM IMU orientation. These gimbal angles are contained on the chart and are the same regardless of LOI burn duration.

2. The abort ΔV magnitude is read from the chart (crew chart 7) and is a function of the DVM read from the DSKY after shutdown. The burn time can be used as a backup.

3. An SPS/SCS burn is initiated at $LOI\text{-}1_{IG}$ plus 15 minutes. Therefore, a constant time of ignition results.

4. If the SPS cannot be restarted, the normal DPS abort procedure is followed.

It is recommended that the 15-minute abort be used for LOI shutdowns prior to 3^m00^s although the chart will be extended until 4^m00^s when the abort ΔV is approximately 500 fps less than the available SPS ΔV (a nominal SPS performance is assumed). At 3^m00^s into the LOI burn, a stable lunar ellipse with a period of 15 hours has been achieved. The preabort periods in this region of the LOI burn are shown on the crew chart. For the remainder of the LOI burn, a mode III DPS abort can be initiated after one revolution, and immediate LM activation is not required. As a point of interest, if the chart is used at 2^m50^s into LOI, the total SPS burn time (LOI plus abort) is approximately 20 seconds longer than if the LOI burn had been continued to nominal shutdown.

Basically, the 15-minute crew chart provides the crew the capability to target an SPS burn onboard to return to the free-return trajectory after manual SPS shutdown.

6.2 Alternate Mission (CSM only) Crew Charts

One of the alternate missions planned for contingencies that could arise during the nominal F mission is a CSM-only lunar orbital mission. This alternate mission is similar to the Apollo 8 mission in that the

LM backup to an SPS failure is not available. In general, this alternate mission would occur if a failure of LM extraction occurred after TLI. This alternate mission could also be caused by an early TLI shutdown followed by a large SPS MCC to return the CSM/LM to a free-return TLC. Then the LM would have to be jettisoned because of its ΔV penalty, and an Apollo 8 type mission would be flown.

However, current analysis has indicated the feasibility of a DPS LOI-1 burn as an alternate mission (ref. 5). Because this alternate mission would take precedence over a CSM-only lunar orbital mission (after a large SPS MCC on the TLC), it was assumed that all the SPS propellant remained prior to the CSM-only LOI burn for which the CSM-only crew charts were prepared.

If SPS problems occur during LOI which indicate an approaching SPS failure (such as a decay in the propellant tank pressures), the recommended procedure is to shut down the SPS engine manually. The subsequent crew action will be an SPS restart by use of the 15-minute crew chart. However, if inadvertent SPS shutdown occurs during LOI and ground communications are lost, either the mode I 5-hour crew charts or the mode III crew charts will be used (based on the time of LOI shutdown).

Basically, the procedure for use of the crew charts is as follows.

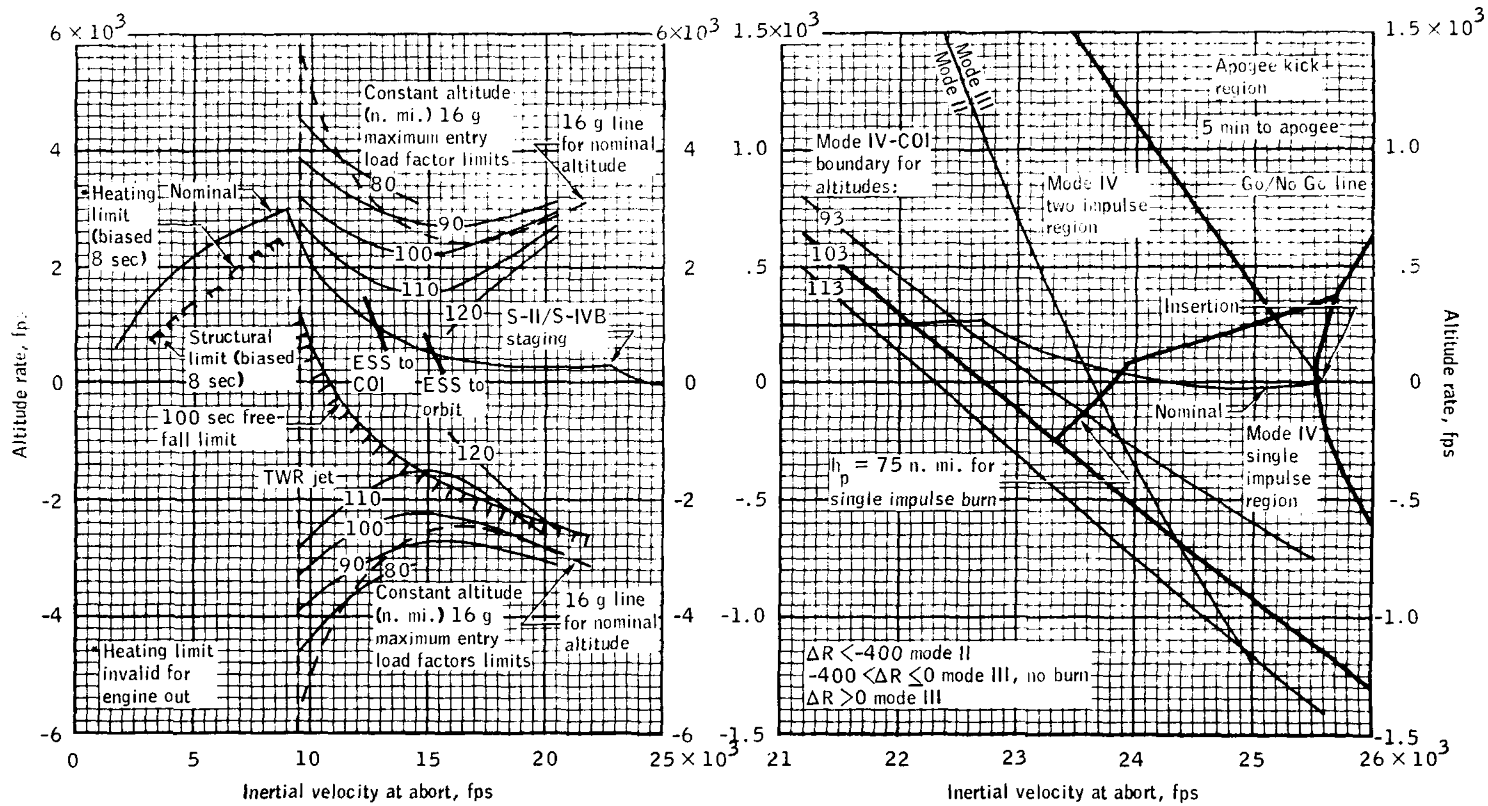
1. The crew maneuvers the CSM to a set of gimbal angles relative to the CM IMU orientation. These gimbal angles are included on each chart and are the same for a particular mode, regardless of LOI burn duration.

2. The abort ΔV magnitude is read from the chart and is a function of the DVM read from the DSKY after LOI shutdown. (The LOI burn time can be used as a backup.)

3. The time of ignition is determined from the crew chart. For the mode I 15-minute chart and the 5-hour chart (crew chart 8), the g.e.t. of ignition is a constant. For the mode III chart (crew chart 9), the selenographic longitude of ignition is read and converted to the time of ignition by use of CMC P21 (which requires iteration on time of ignition). An estimate of the time of ignition is provided by an additional scale on the mode III chart.

4. At the correct time of ignition, an SPS/SCS burn of the required ΔV magnitude is initiated.

The possibility of such a CSM-only lunar orbital alternate mission is of low probability. In addition, the system problems that would require the use of these alternate mission crew charts can be considered at least a double failure situation. On the other hand, because of the relative simplicity of the charts and of the fairly low work level required for their preparation, they are included among those recommended by the Flight Analysis Branch.



Crew chart 1.- Launch abort curves.

Time from first motion, g.e.t., min:sec	SC IMU pitch gimbal angle, θ, deg	DSKY displays		
		Inertial velocity, V_i, fps	Altitude rate, ḣ, fps	Altitude, h, n. mi.
00:00.0	90	1 340	0	0.0
00:30.0	87	1 390	296	0.7
01:00.0	69	1 847	828	3.3
01:30.0	48	3 051	1486	9.0
02:00.0	33	5 127	2200	18.2
02:15.0*	27	6 567	2582	24.1
02:30.0	23	7 928	2822	30.7
02:39.9**	22	8 998	3009	35.5
03:00.0	22	9 239	2626	44.8
03:30.0	29	9 805	2153	56.6
04:00.0	26	10 449	1801	66.4
04:30.0	23	11 190	1474	74.5
05:00.0	20	12 030	1178	81.1
05:30.0	17	12 976	916	86.2

*S-IC center-engine cutoff (TB_2)

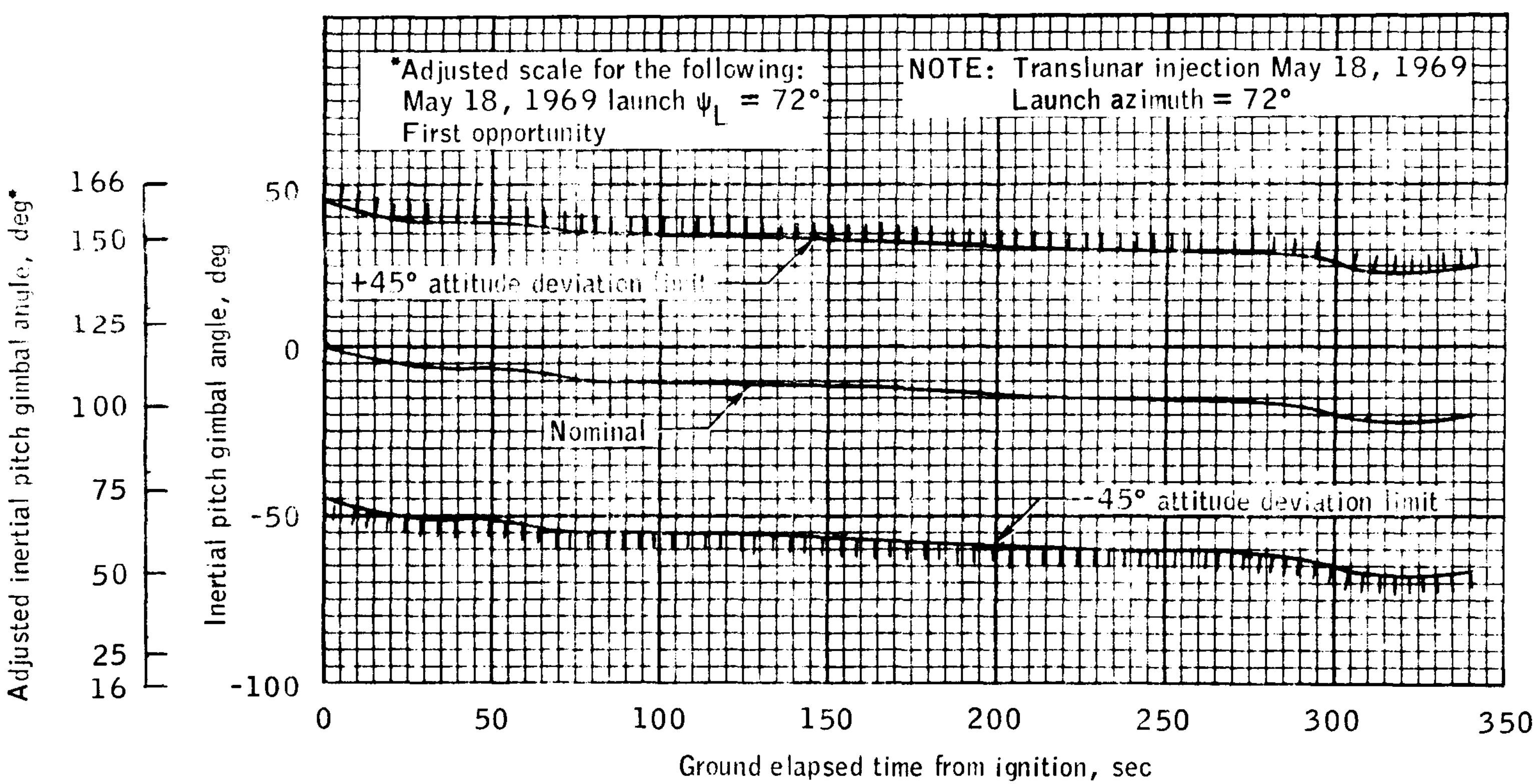
**S-IC outboard-engine cutoff (TB_3)

Time from first motion, g.e.t., min:sec	SC IMU pitch gimbal angle, θ, deg	DSKY displays		
		Inertial velocity, V_i, fps	Altitude rate, ḣ, fps	Altitude, h, n. mi.
06:00.0	14	14 038	691	90.2
06:30.0	10	15 230	507	93.2
07:00.0	7	16 574	369	95.4
07:30.0	3	18 097	289	97.1
08:00.0	3	19 566	267	98.4
08:30.0	0	20 801	248	99.8
09:00.0	356	22 053	256	101.0
09:13.9***	354	22 682	280	101.7
09:30.0	350	22 872	207	102.3
10:00.0	346	23 426	103	103.1
10:30.0	343	24 011	27	103.5
11:00.0	341	24 625	-13	103.5
11:30.0	339	25 269	-19	103.4
11:43.2****	339	25 562	0	103.4

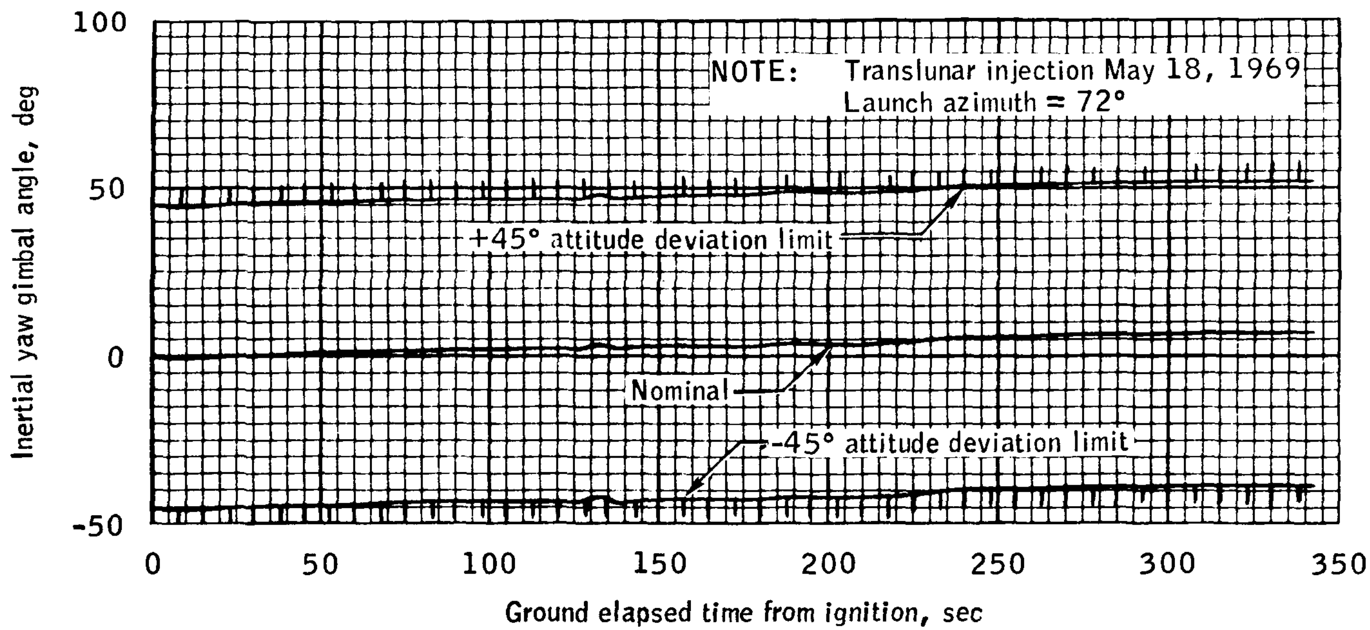
***S-II engine cutoff (TB_4)

****S-IVB guidance cutoff signal

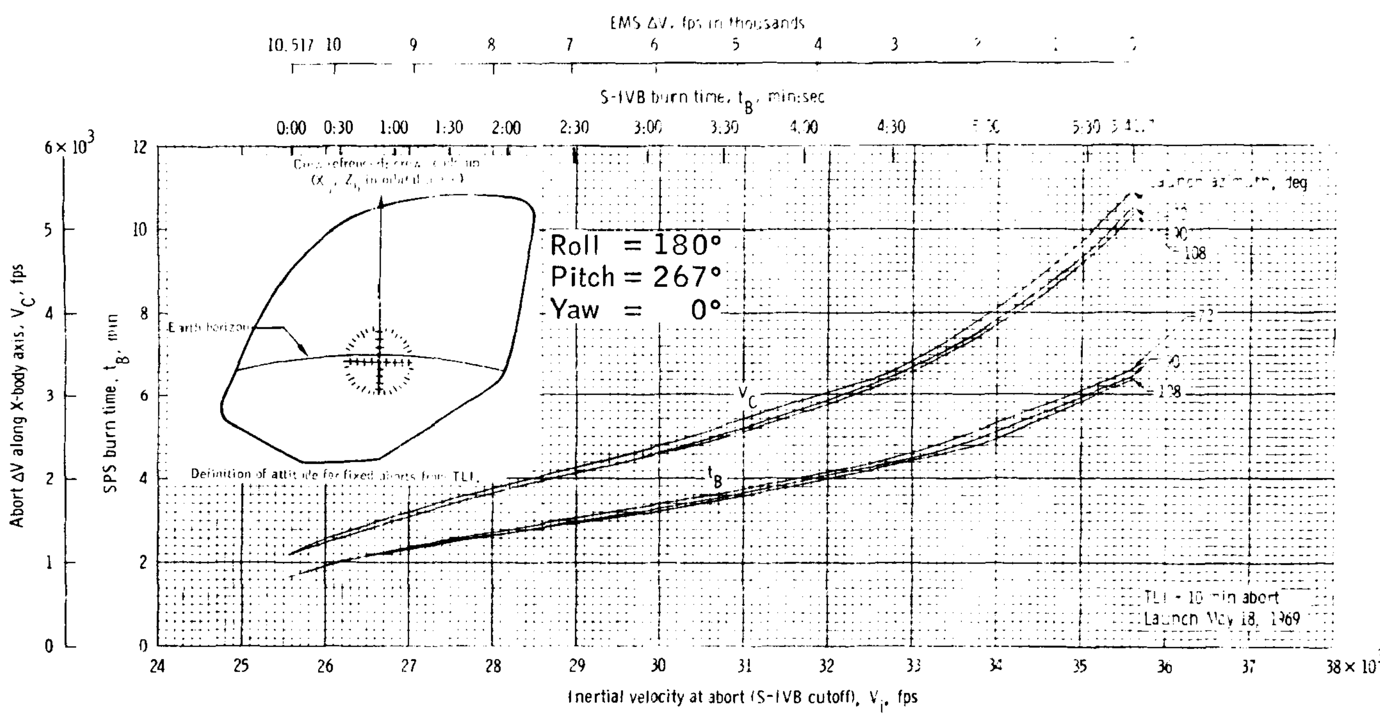
Crew chart 2. - Listing of planned launch trajectory parameters.



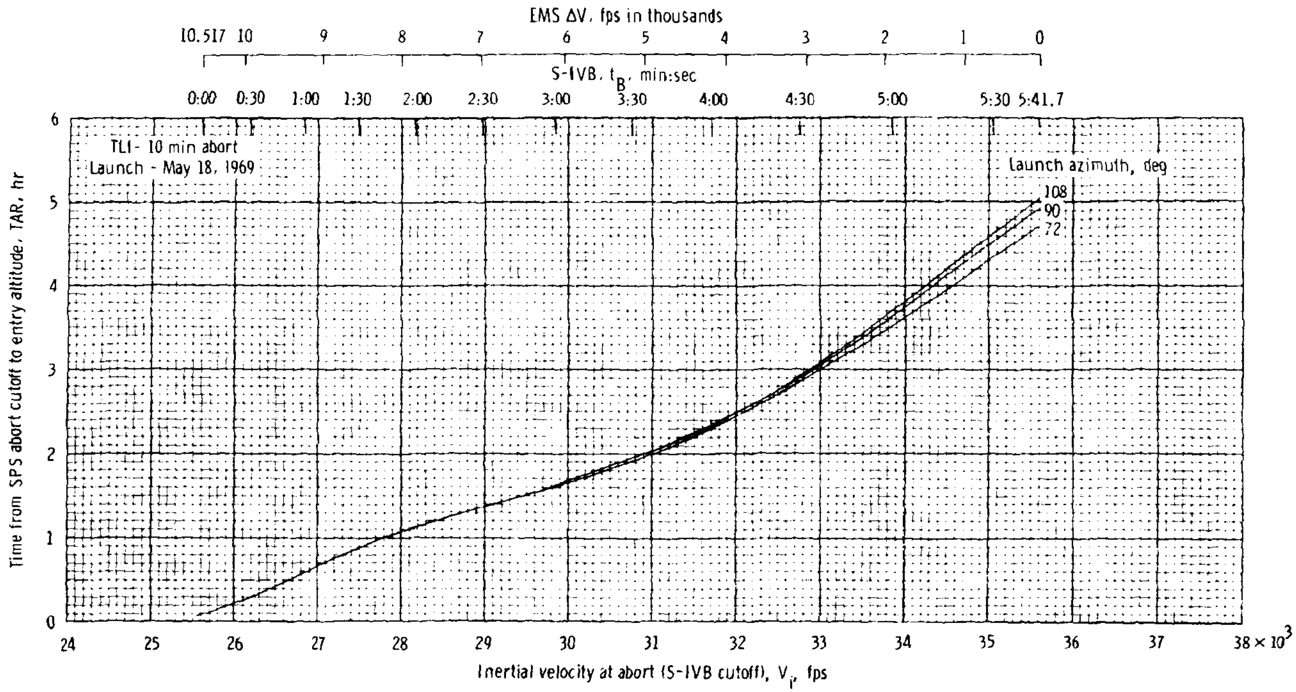
Crew chart 3.- TLI pitch gimbal angle history and attitude deviation limits for first opportunity.



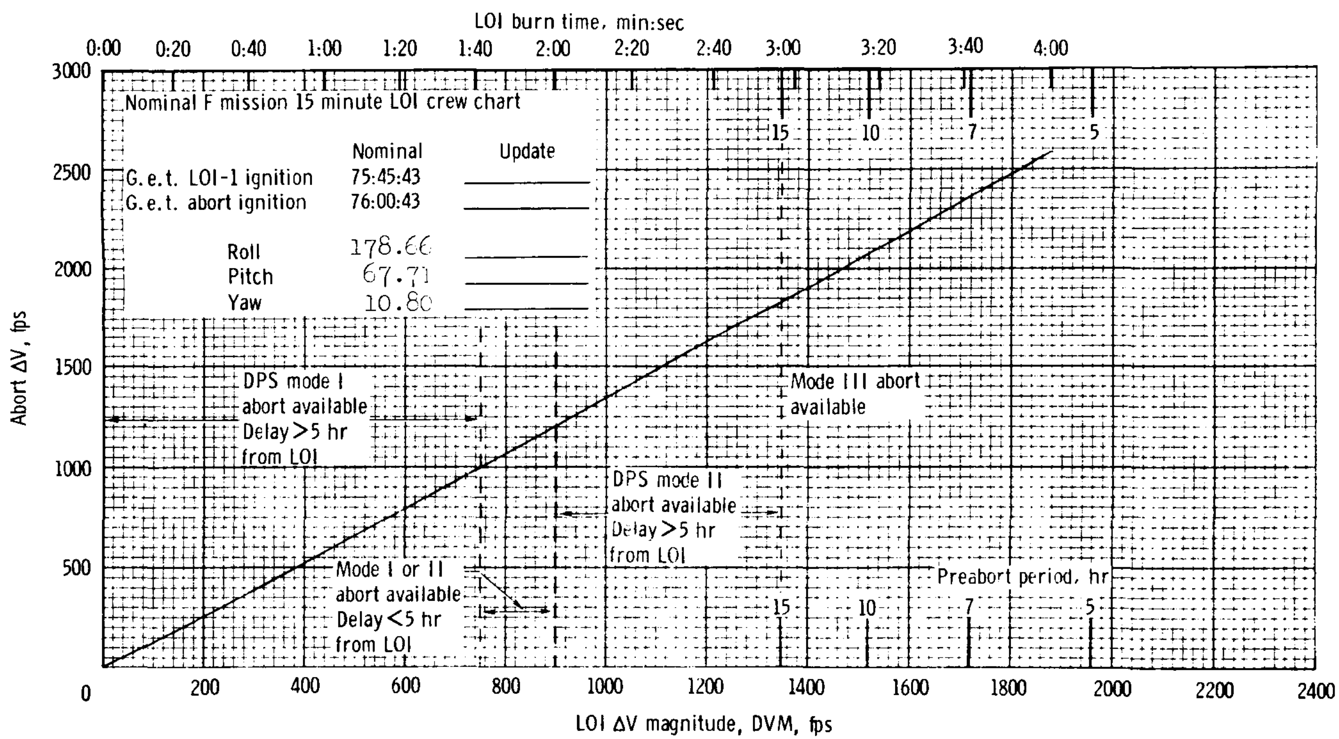
Crew chart 4.- TLI yaw gimbal angle history and attitude deviation limits for first opportunity.



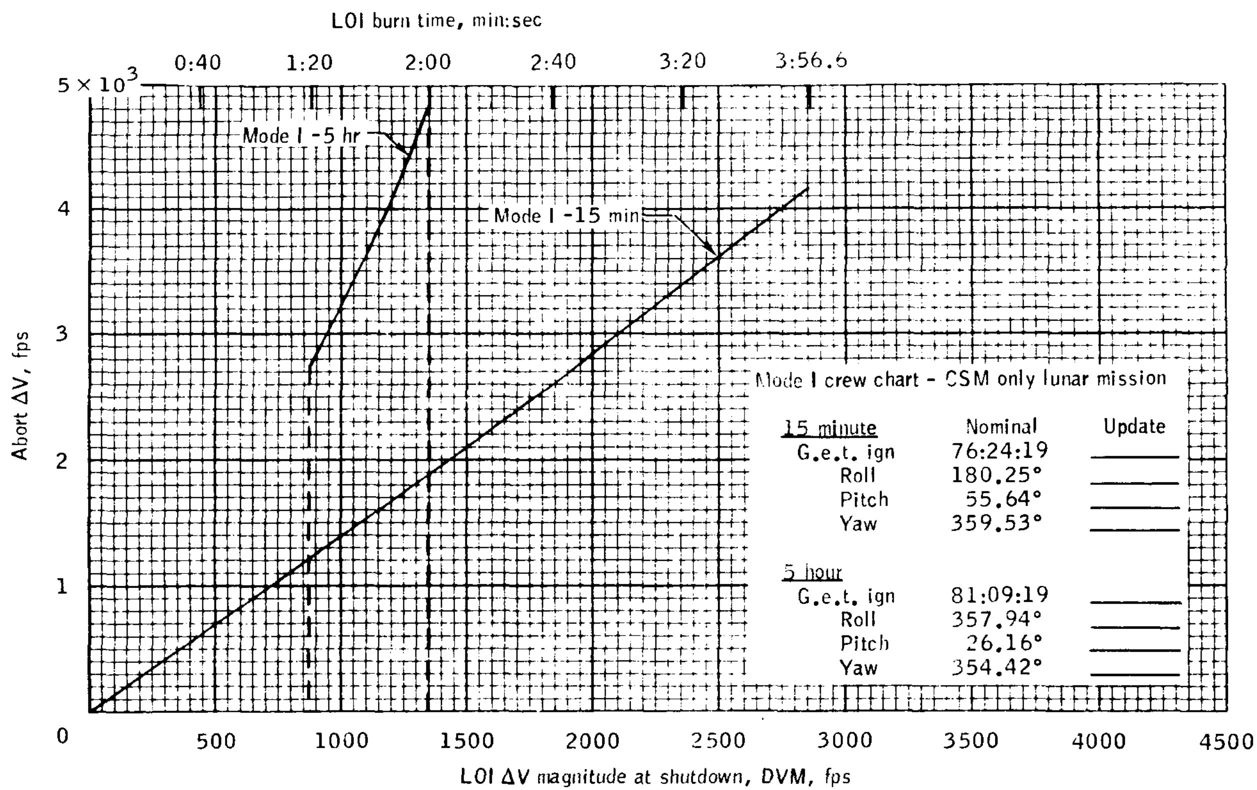
Crew chart 5.- TLI plus 10 minute abort crew chart; abort ΔV and SPS burn time versus inertial velocity.



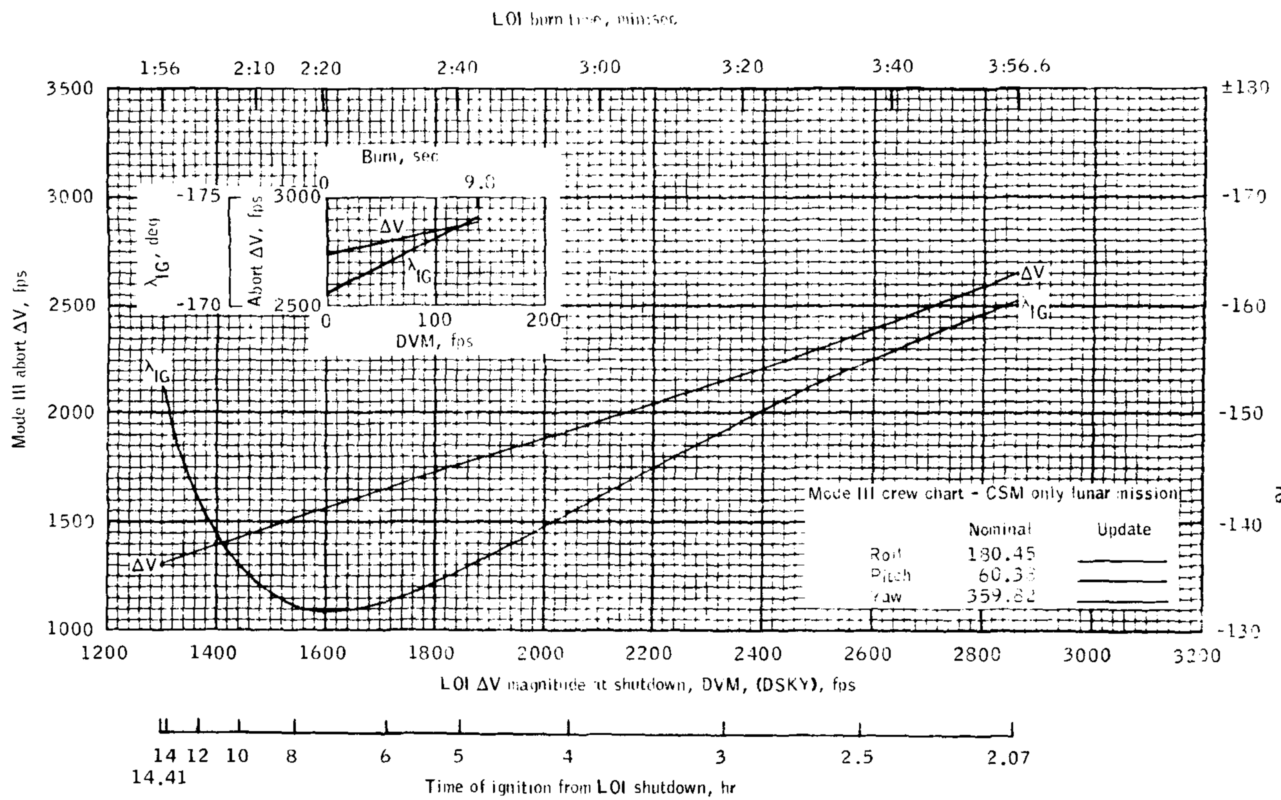
Crew chart 6.- TLI plus 10 minute abort crew chart; TAR versus inertial velocity.



Crew chart 7.- Nominal LOI 15-minute abort (CSM/LM).



Crew chart 8.- CSM-only lunar orbital alternate mission LOI abort; 15-minute and 5-hour abort curves.



Crew chart 9.- CSM-only lunar orbital alternate mission LOI abort; mode III crew chart.

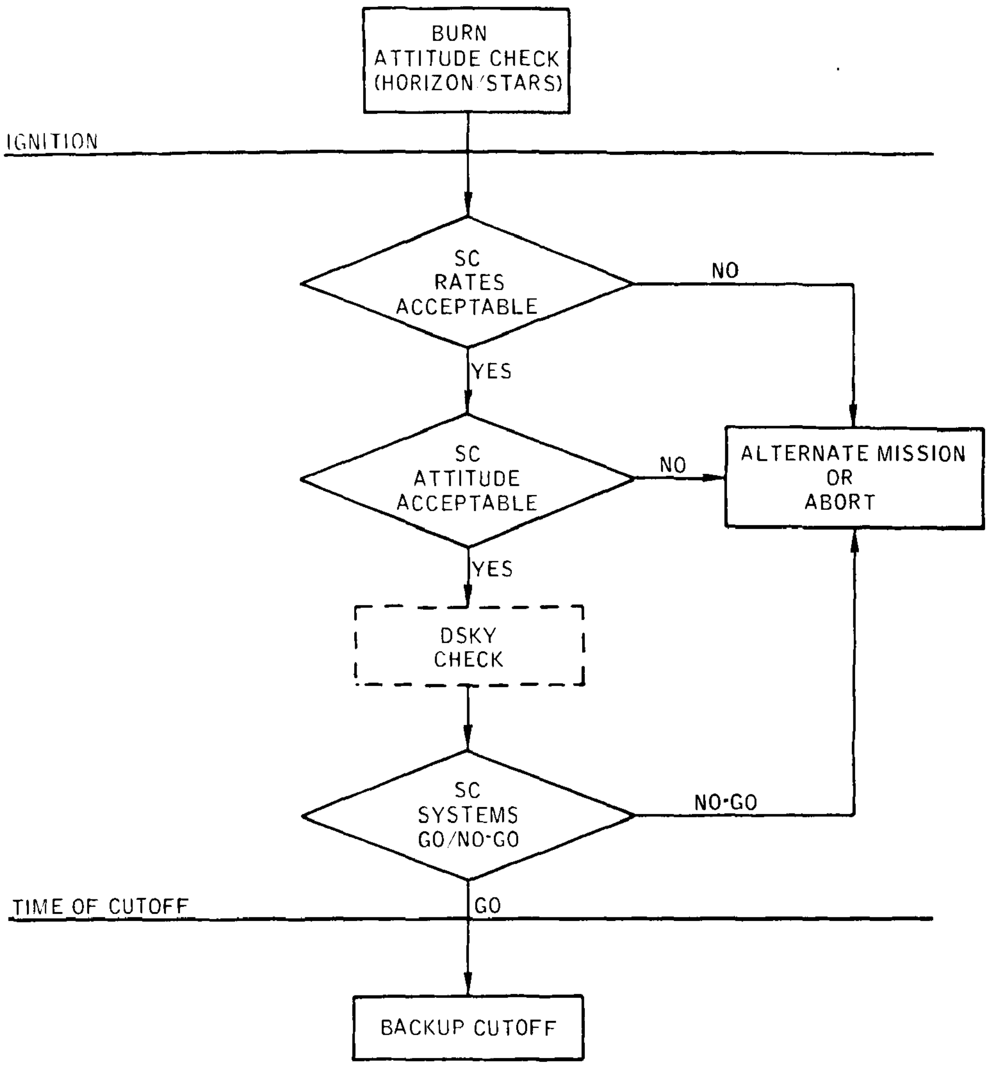


Figure 1.- Basic crew maneuver monitoring technique.

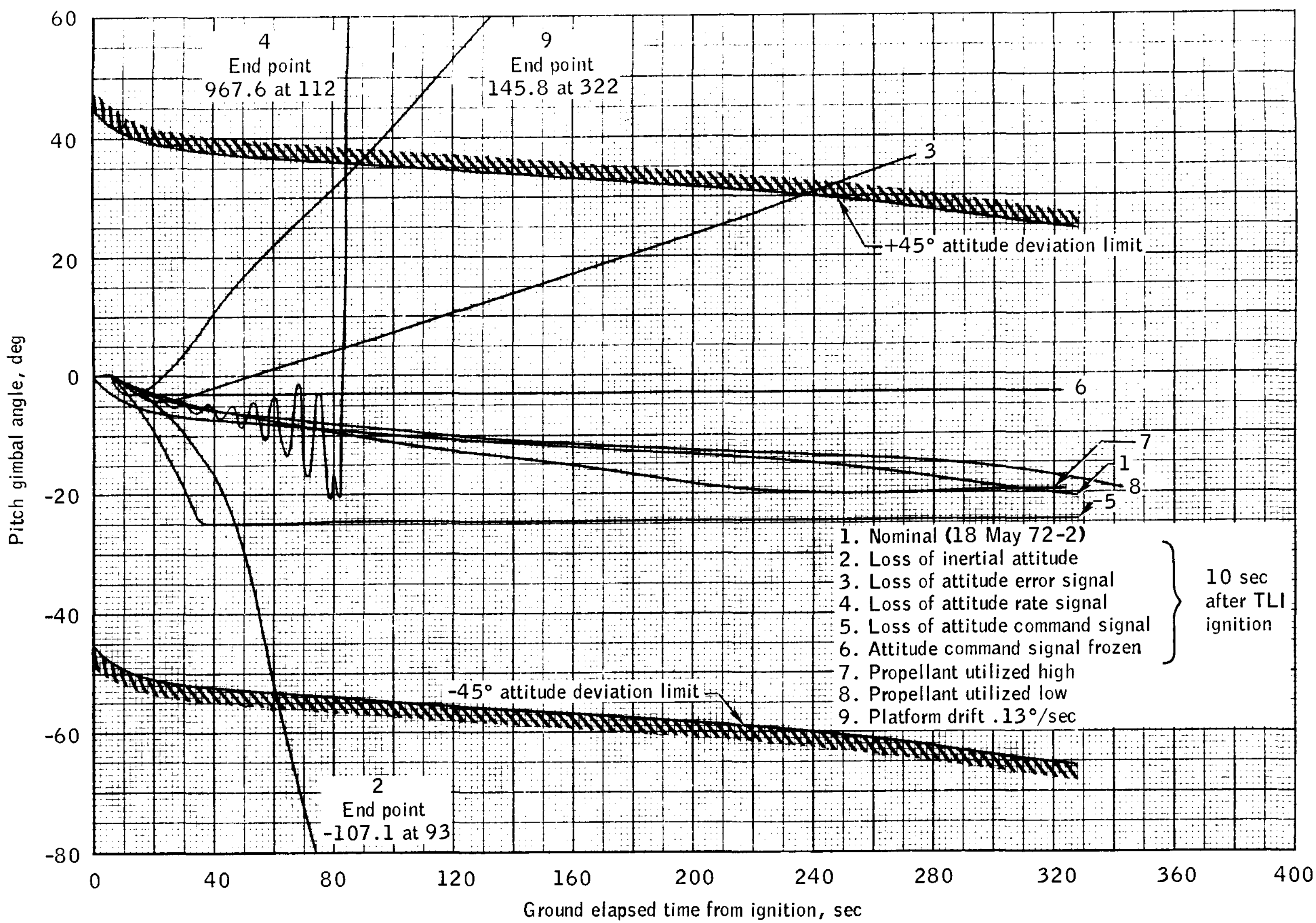


Figure 2.- Pitch gimbal angle versus ground elapsed time from ignition.

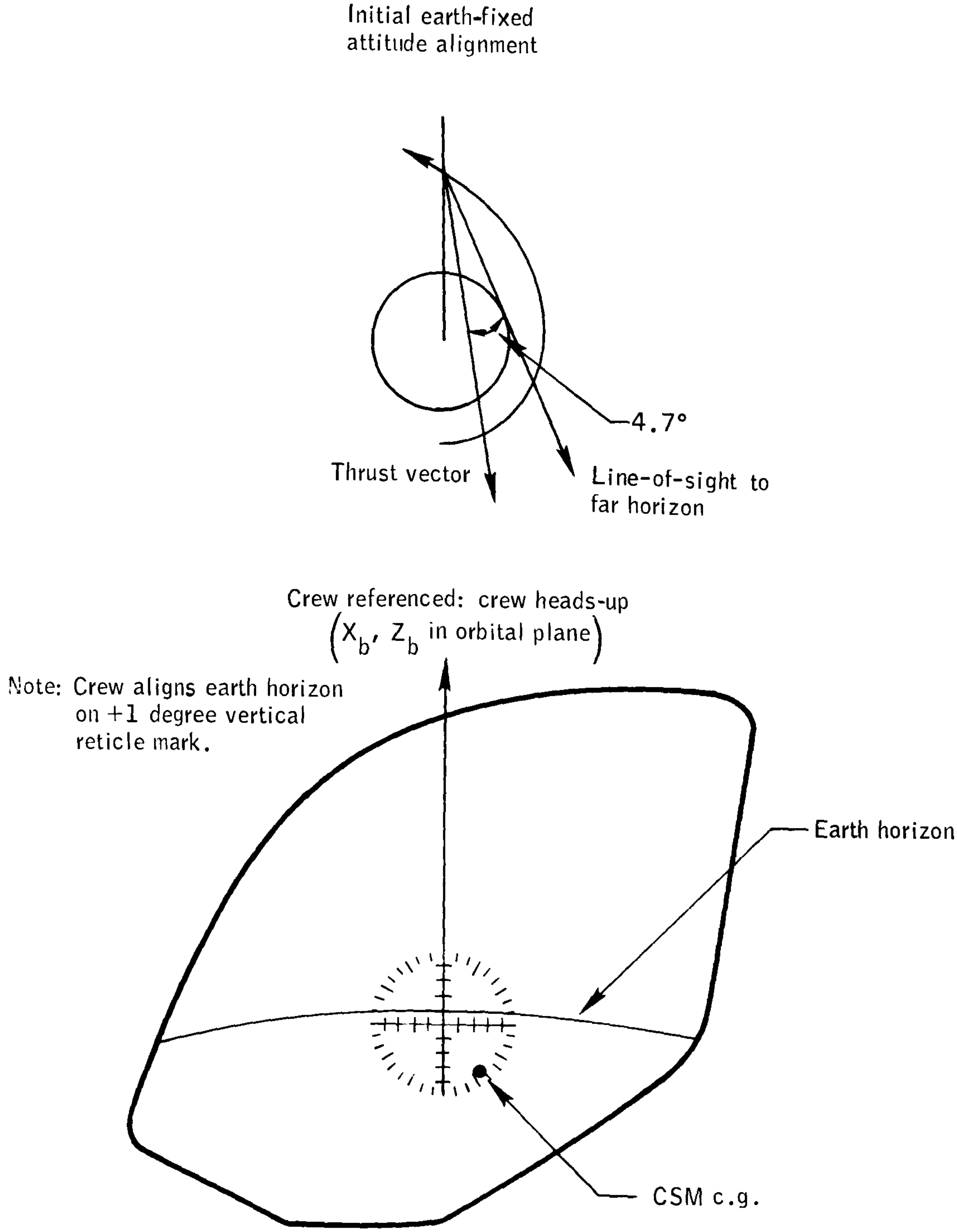


Figure 3.- Definition of attitude for fixed-attitude aborts from TLI.

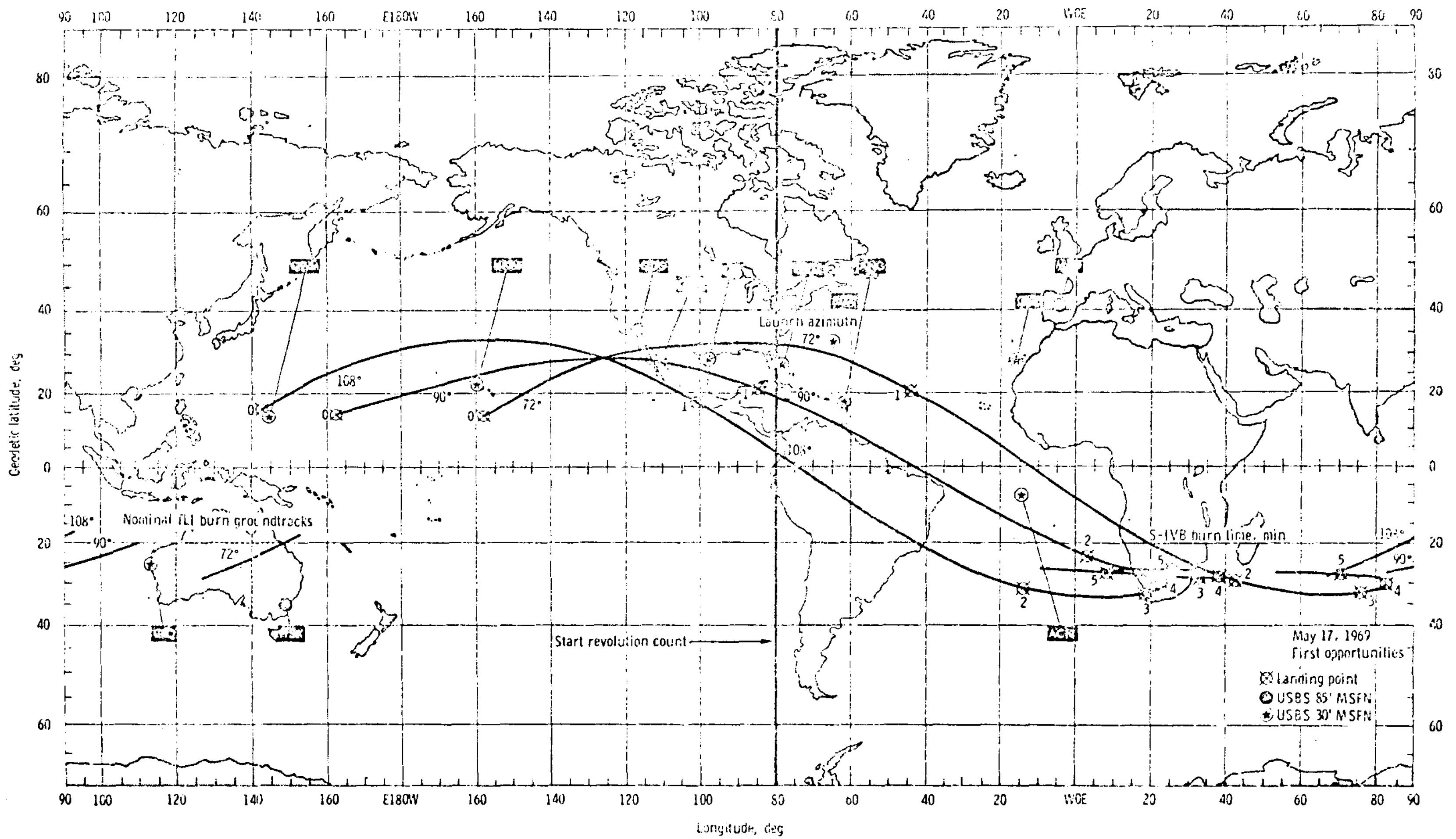


Figure 4.- Typical TLI burn groundtracks and fixed-attitude abort landing point loci.

7.0 REFERENCES

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3. Hyle, Charles T.: and Treadway, Alexander H.: The Determination of Attitude Deviation Limits for Terminating a Nonnominal Translunar Injection Maneuver. MSC IN 68-FM-172, July 17, 1968.

4. Hyle, Charles T.: Detailed Crew Procedures for a Powered Flight Evaluation of the Translunar Injection Maneuver. MSC IN 68-FM-212, August 28, 1968.

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