NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MSC INTERNAL NOTE NO. 66-FM-140

November 21, 1966

MANUAL ABORT MANEUVERS DURING THE TRANSLUNAR COAST PHASE OF A LUNAR MISSION

By Charles E. Foggatt
Flight Analysis Branch

MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

MSC INTERNAL NOTE NO. 66-FM-140

PROJECT APOLLO

MANUAL ABORT MANEUVERS DURING THE TRANSLUNAR COAST PHASE OF A LUNAR MISSION

By Charles E. Foggatt
Flight Analysis Branch

November 21, 1966

MISSION PLANNING AND ANALYSIS DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

Approved: C. R. Hicks Jr.
Claiborne R. Hicks, Jr., Chief
Flight Analysis Branch

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

FIGURES

MANUAL ABORT MANEUVERS DURING THE TRANSLUNAR COAST PHASE OF A LUNAR MISSION

By Charles E. Foggatt

SUMMARY

A manual abort maneuver has been studied for aborts initiated during the translunar coast phase of a lunar mission. The earth viewed through the Apollo docking reticle was used to orient the thrust vector.

The results showed that an onboard manual abort capability may exist for a large portion of the translunar coast phase.

INTRODUCTION

If the decision were made to terminate the mission, the abort solution would be transmitted to the spacecraft, and the crew would initiate the abort maneuver. This study investigated a manual abort maneuver that could be used if the crew were unable to perform the maneuver using the solution supplied by the ground and the use of a manual backup procedure were required. The method used is referred to as the earth monitor method because in it the earth is viewed through the Apollo docking reticle to orient the thrust vector.

NOTATION

ΔV	-	velocity increment
T_{AL}	-	time from abort to landing
TTT	-	total trip time from translunar injection to landing
t_{abort}	-	time of abort measured from end of translunar injection
SPS	-	service propulsion system
V_r	-	inertial reentry velocity
γ_r	-	reentry flight-path angle measured from local horizontal

ANALYSIS

In investigating manual aborts, a precise knowledge of the orientation of the thrust vector is necessary. For inplane, survival aborts an error in the spacecraft attitude can cause dispersions which result in incorrect reentry conditions. It is advantageous, therefore, for a manual abort procedure to have a simple but accurate method to align the thrust vector prior to abort initiation.

One such method would be to align the service propulsion system (SPS) thrust vector along the radius vector of the earth. When a ΔV is added along the radius vector, an inplane abort maneuver is assured, and the manual abort procedure is greatly simplified.

To faciliate the spacecraft alignment, the Apollo docking reticle may be used. At distances greater than approximately 40 000 n. mi., the entire earth is visible in the field of view of the reticle. Figure 1 shows the earth when viewed through the reticle at 11, 21, 31, 41, 51, and 61 hours on the translunar coast. By aligning the earth in the field of view, it appears possible to accurately orient the thrust vector.

For this study it was noted that the offset center of gravity of the spacecraft will cause the thrust vector to be aligned slightly off the centerline of the spacecraft. However, this slight offset could be accounted for in the initial positioning of the earth in the reticle. Also, the complete earth will probably not be visible due to the shadow, but it is not expected to cause major misalignment problems.

The guidelines for this study were as follows:

a. The only objective considered was the return of the spacecraft to earth in an acceptable reentry corridor. No attempt was made to land in a preselected landing area.

b. Only spacecraft abort capability after an abort decision has been made was studied. The onboard capability to recognize an abort situation was not included.

c. Only dispersions in abort ΔV were considered. No errors in thrust vector direction were assumed.

d. It was assumed that the lunar module was jettisoned prior to the manual maneuver.

The "AS-504 Preliminary Reference Trajectory" (ref. 1) was used as the reference for this study. Simulated manual aborts were performed at points 11, 21, 31, 41, 51, and 61 hours on the translunar coast. The state vector from a point on the translunar coast was used as the preabort vector, and the postabort vector was obtained by adding an impulsive ΔV along the earth's radius vector. The position and azimuth of the preabort state vector remained unchanged. The postabort state vector was propagated to perigee using a precision integrator program.

RESULTS

Figure 2 is a plot of the perigee radius of an unperturbed ellipse following a manual abort employing the associated ΔV. Data is shown for aborts initiated at points 11, 21, 31, 41, 51, and 61 hours on the translunar coast. Also represented is the radius of the earth and the range of perigee radii which result in a reentry within the acceptable reentry corridor. From this figure it appears that the only successful abort possible must be initiated at 41 hours on the translunar coast and must use a ΔV of between 7500 and 8250 fps.

However, for a true representation of the resulting abort path, the perturbations due to the moon and the sun must be included. Figure 3 is a plot of the actual perigee resulting from a manual abort at the associated ΔV from the graph. For high values of ΔV the plot is very similar to figure 2, but as the abort ΔV decreases the perturbation effect becomes more evident. The flight times associated with the lower abort ΔV become very large and the moons perturbation has a large effect. It is seen that sucessful aborts can be initiated for all the points on the translunar coast investigated rather than the limited region of figure 2. Also, for an abort initiated 31 hours after translunar injection, there are two possible abort solutions.

For aborts performed with the ΔV in the center of the perigee "corridor" the resulting data can be tabulated.

t_{abort}	ΔV	T_{AL}	TTT
11 hr	2000 fps	88.1 hr	99.1 hr
21 hr	3000 fps	76.5 hr	97.6 hr
31 hr (first solution)	4750 fps	57.2 hr	88.2 hr

t_{abort}	ΔV	T_{AL}	TTT
31 hr (second solution)	9500 fps	28.2 hr	59.2 hr
41 hr	1930 fps	145.5 hr	186.5 hr
51 hr	2365 fps	135.5 hr	186.5 hr
61 hr	2900 fps	130.0 hr	191.0 hr

The abort paths associated with these aborts and the nominal free return trajectory from reference 1 are shown in figure 4.

From the above figures the translunar coast phase can be divided into two regions for the purpose of discussion of the earth-monitor, manual abort procedure.

1. Region I - Aborts initiated from 6 to 35 hours on the translunar coast.

2. Region II - Aborts initiated from 35 to 61 hours on the translunar coast.

Region I is the obvious region for the initiation of the manual abort for two reasons:

1. A substantial reduction in total trip time can be achieved as compared to nominal circumlunar free return total trip time of 146.5 hr.

t_{abort}	TTT ABORT	TTT REDUCTION
11 hr	99.1 hr	47.4 hr
21 hr	97.6 hr	48.9 hr
31 hr (first solution)	88.2 hr	58.3 hr
31 hr (second solution)	59.2 hr	87.3 hr

2. The allowable dispersions in abort ΔV which will keep the spacecraft in the reentry corridor are high.

t_{abort}	ALLOWABLE DISPERSION	%ACCURACY REQUIRED
11 hr	± 40. fps	± 2.00 %
21 hr	± 70. fps	± 2.34 %
31 hr (first solution)	± 225. fps	± 4.74 %
31 hr (second solution)	± 450. fps	± 4.74 %

Region II would be a very unlikely region in which the manual abort would be initiated for two reasons:

1. The total trip times associated with earth monitor aborts exceed those of the nominal free return.

t_{abort}	TTT ABORT	TTT INCREASE OVER TTT_{FR}
41 hr	186.5 hr	40.0 hr
51 hr	186.5 hr	40.0 hr
61 hr	191.0 hr	44.5 hr

2. The allowable dispersions in abort ΔV which will keep the spacecraft in the reentry corridor are low.

t_{abort}	ALLOWABLE DISPERSION	% ACCURACY REQUIRED
41 hr	± 7. fps	± 0.37 %
51 hr	± 5. fps	± 0.21 %
61 hr	± 5. fps	± 0.17 %

In region I of the translunar coast it can be seen that the allowable dispersions in abort ΔV increase as the abort initiation is delayed. This effect can be seen in figure 3. The slope of the perigee radius curves decreases and the corresponding ΔV range to remain in the reentry corridor increases. It would appear that an optimum time of abort would exist to maximize the allowable ΔV variation.

The optimum time of abort is shown on figure 3 as an abort initiated 33.5 hours on the translunar coast. The range of ΔV becomes 5450 fps to 8750 fps and the percentage of accuracy has increased to ± 22.0%.

As a result of this wide range of abort ΔV allowable an additional manual abort capability exists. Since the time from abort to landing is a function of the abort ΔV and since the landing point is determined by the amount of earth rotation prior to landing, the crew now has the ability to choose a landing point by varying the abort ΔV. This could be very advantageous in that a water landing near a recovery area in daylight would probably be desired. With the use of onboard data the crew could select the ΔV corresponding to this landing point and initiate the abort. Also in the event of a time-critical contingency the minimum total trip time could be achieved while assuring a water landing.

The data resulting from aborts at this optimum point on the translunar coast are as follows:

t_{abort}	ΔV	V_R	γ_R	TTT_{abort}
33.5 hr	5500. fps	35911. fps	-6.850 deg	84.61 hr
33.5 hr	6000. fps	35933. fps	-6.233 deg	80.38 hr
33.5 hr	6500. fps	35962. fps	-5.885 deg	76.76 hr
33.5 hr	7000. fps	35998. fps	-5.790 deg	73.63 hr
33.5 hr	7500. fps	36040. fps	-5.921 deg	70.90 hr
33.5 hr	8000. fps	36090. fps	-6.237 deg	68.50 hr
33.5 hr	8500. fps	36146. fps	-6.694 deg	66.38 hr

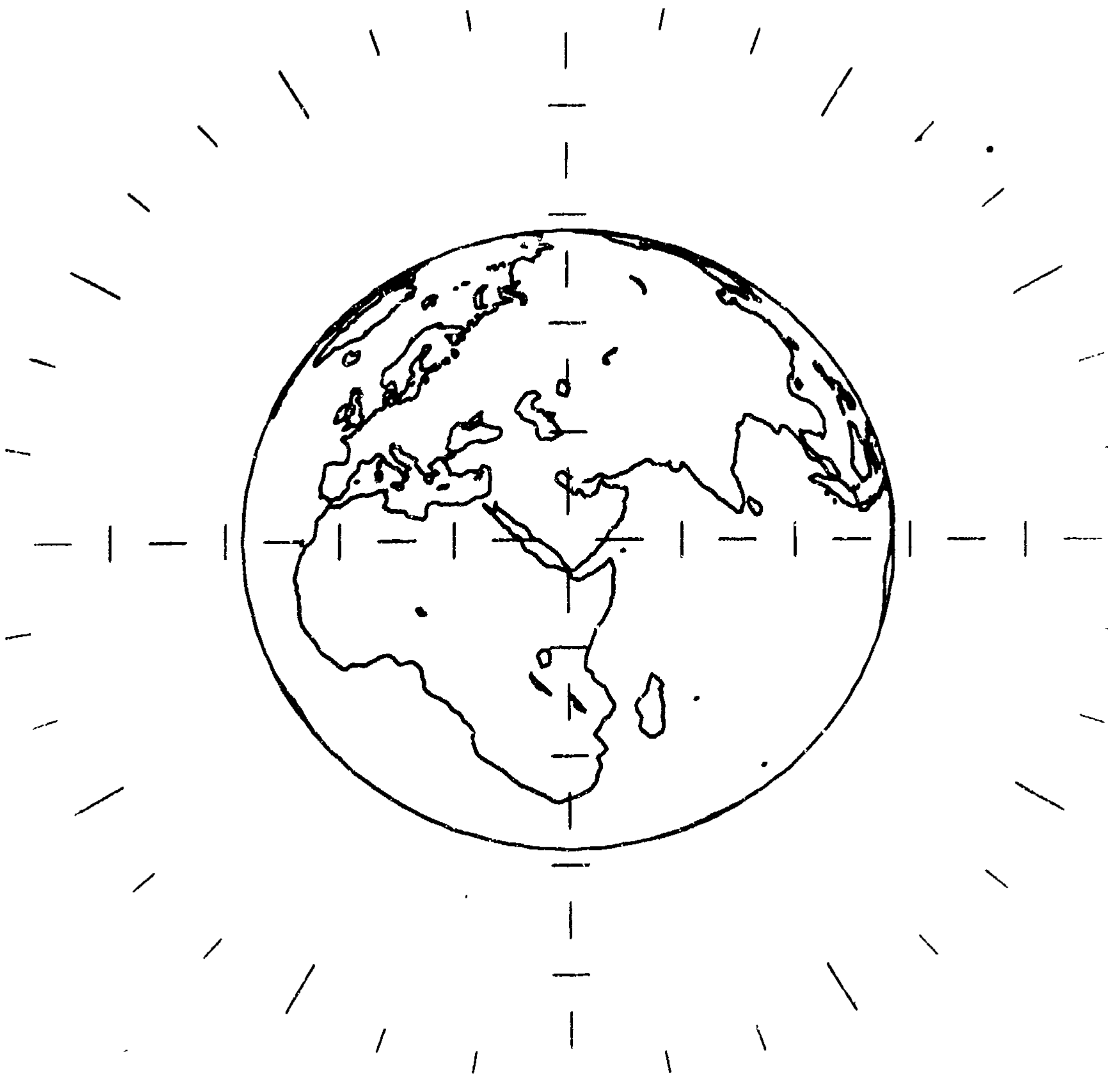
Figure 5 shows the wide range of reentry positions that are available when the abort ΔV is varied. The actual landing points are displaced by the reentry range, but it is evident that at the optimum abort position the crew has the capability to select the landing area.

CONCLUSIONS

The earth monitor manual abort maneuver suggested in this document appears to provide a simplified manual procedure to terminate a lunar mission over a substantial range of the translunar coast phase. In the event of a nonnominal translunar coast, it would appear feasible for the ground to send a revised set of abort solutions to the spacecraft for use if a manual abort is required later in the mission.

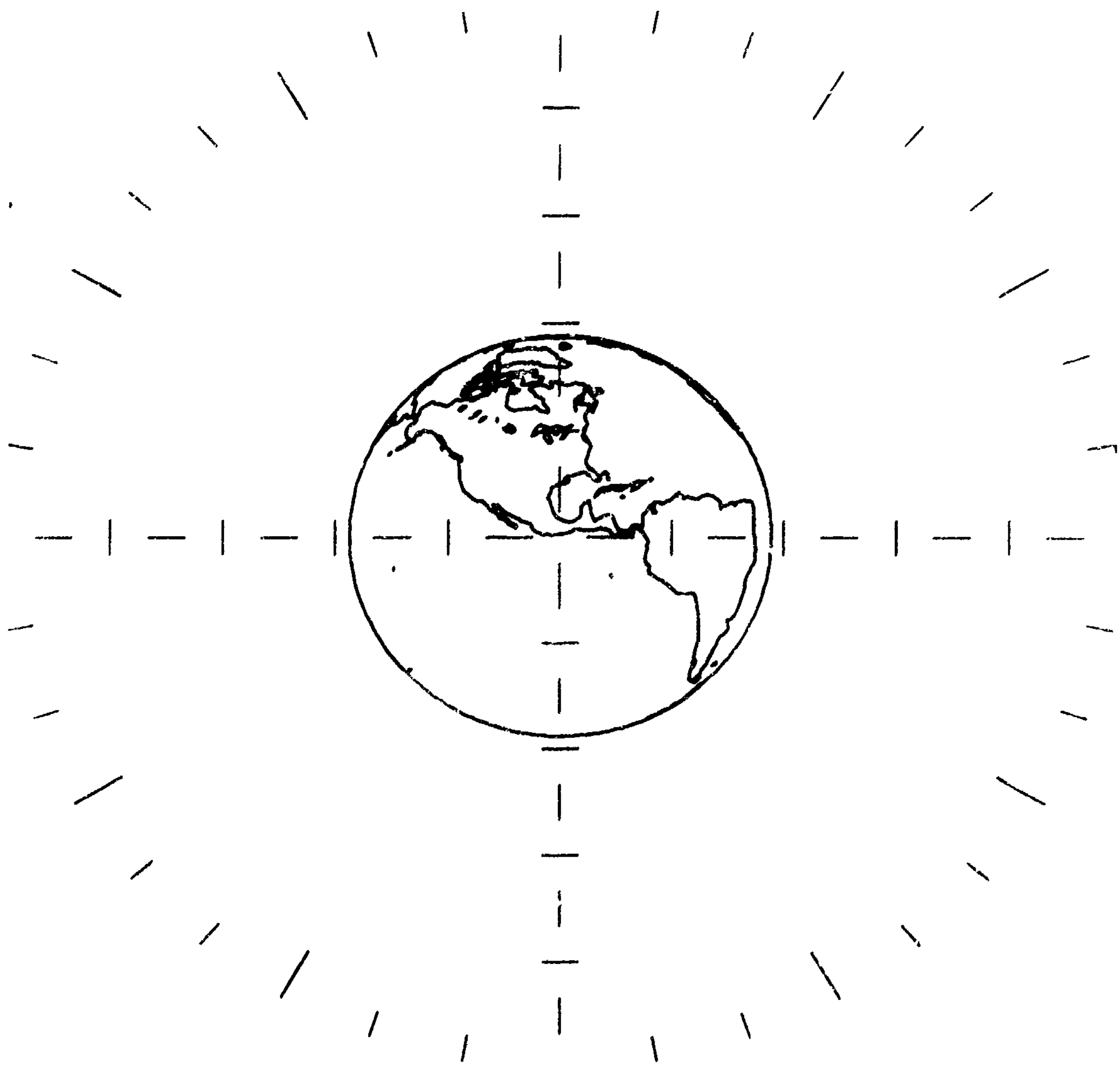
Finally, there is an optimum point along the translunar coast to perform the earth monitor manual abort. At this abort "station" the allowable variation in abort ΔV which will keep the spacecraft in the reentry corridor is high, the total trip time can be minimized, and the crew can choose the longitude of the resulting landing point.

It is noted that dispersions in thrust vector direction were not considered in this study. Further analysis is currently being performed to investigate the required accuracy in initial alignment and to determine if the earth-monitor manual abort is operationally feasible.



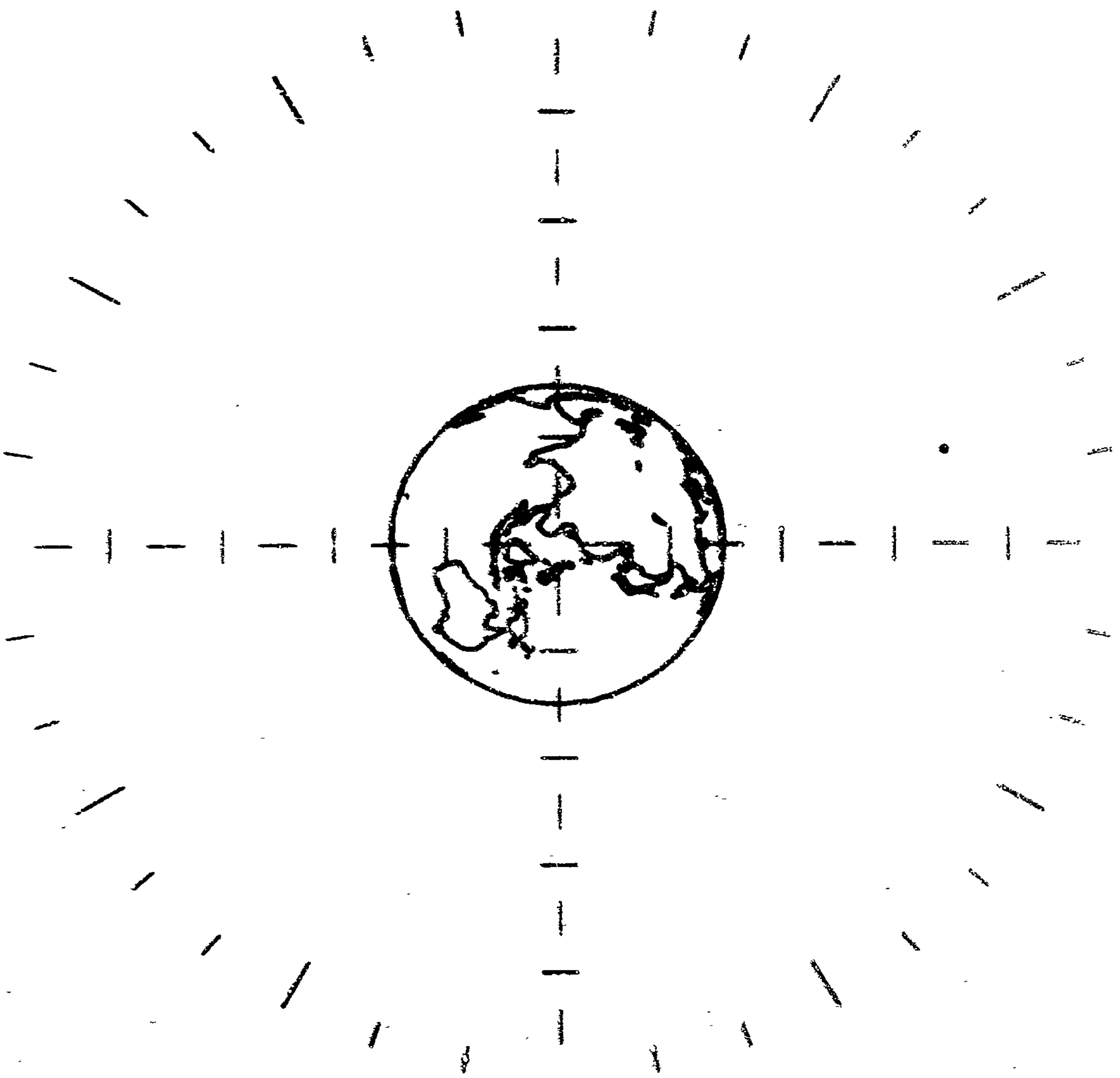
(a) At 11 hours (65 648 n.mi. altitude).

Figure 1.- Earth viewed through docking reticle on translunar coast.



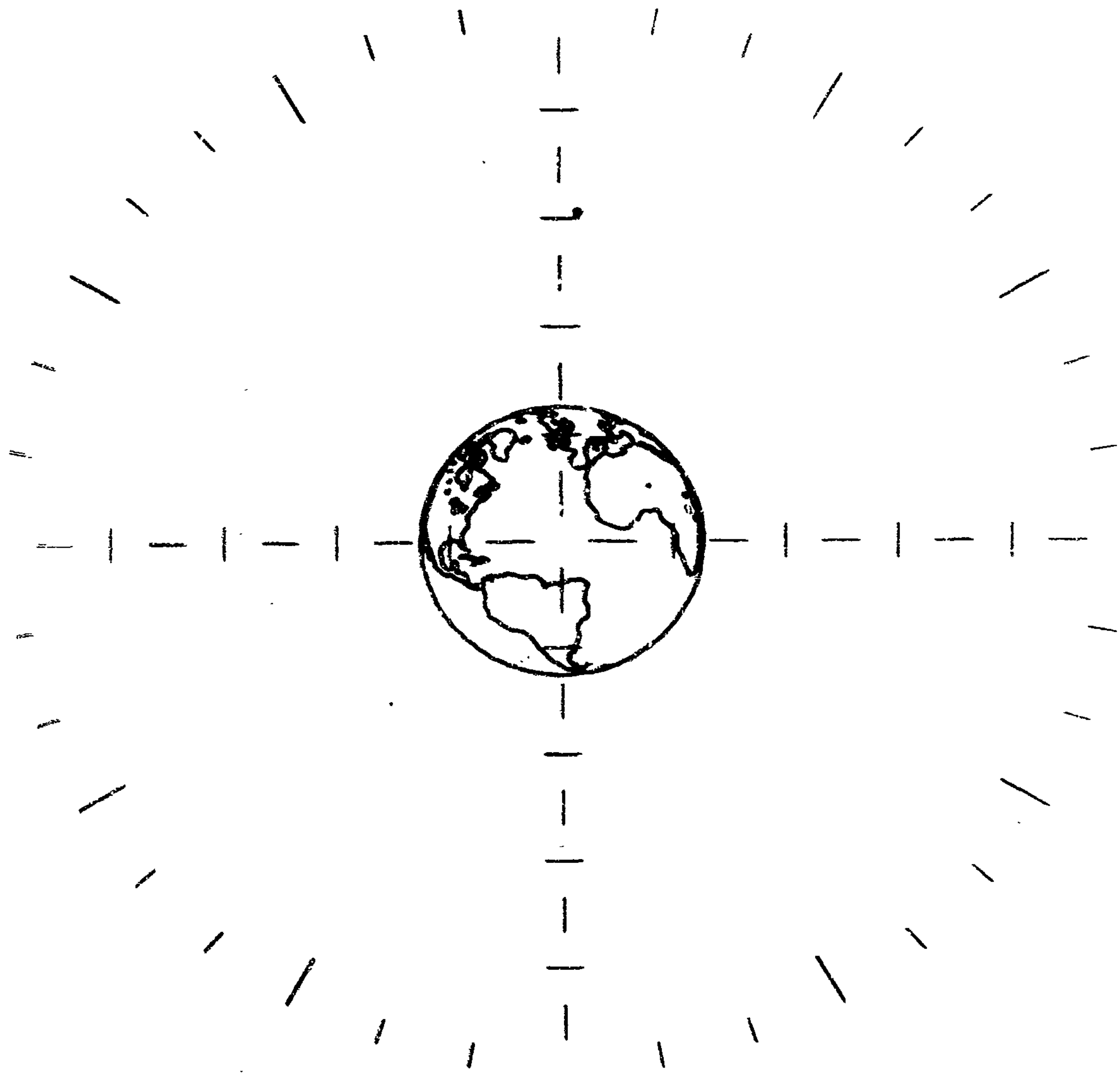
(b) At 21 hours (101 218 n.mi. altitude).

Figure 1.- Continued.



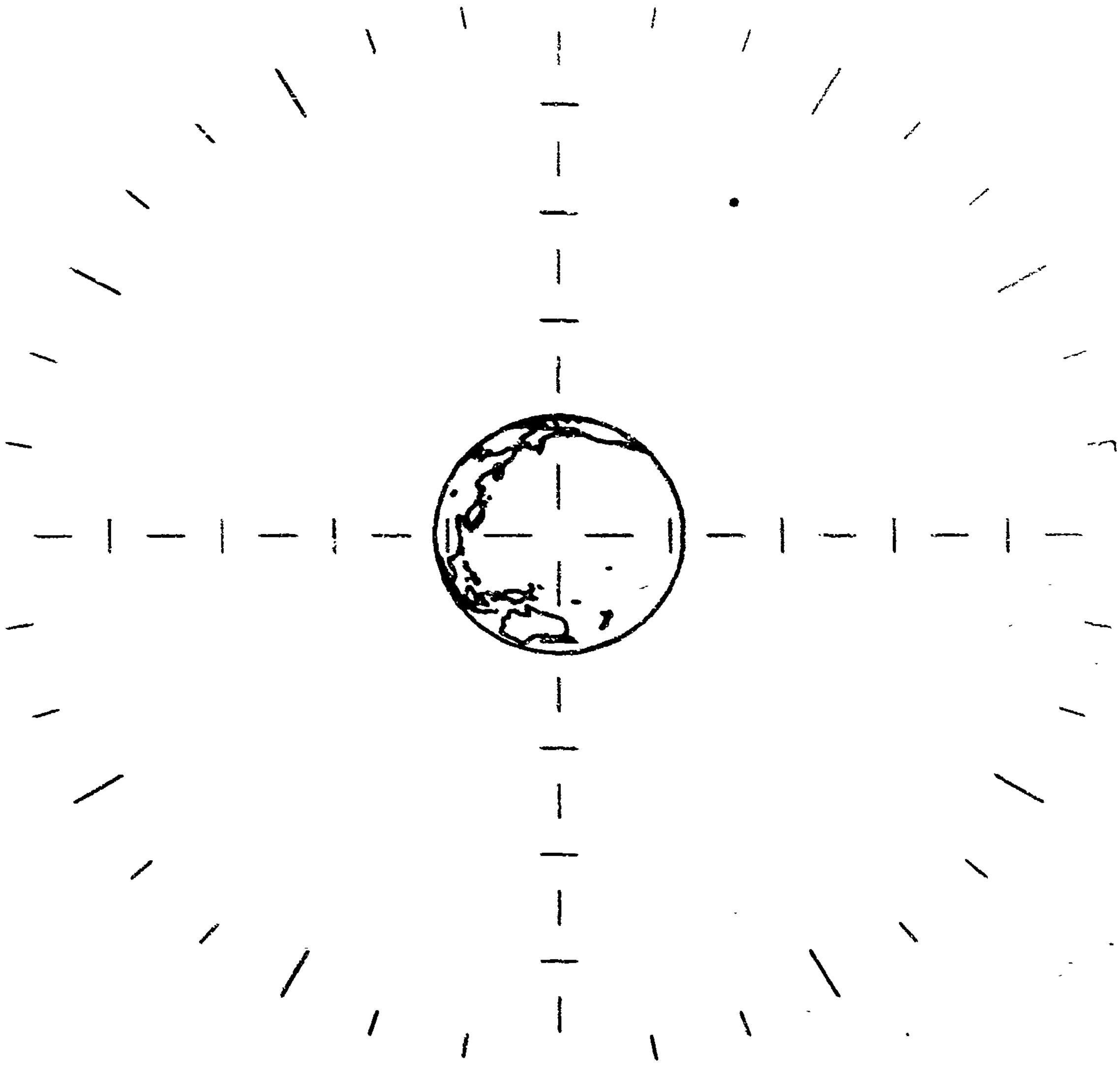
(c) At 31 hours (129 483 n.mi. altitude).

Figure 1. - Continued.



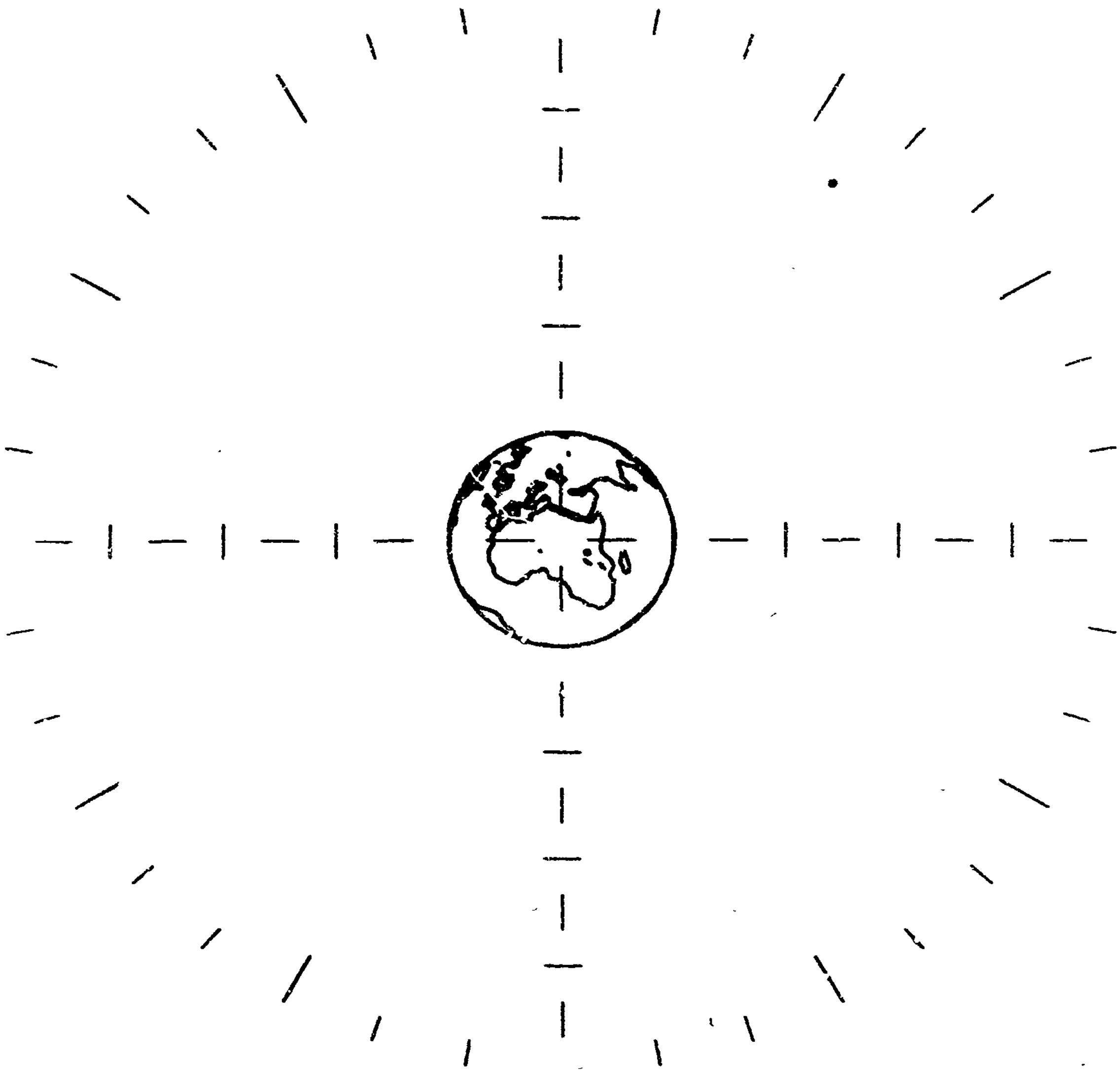
(d) At 41 hours (153 325 n.mi. altitude).

Figure 1.- Continued.



(e) At 51 hours (174 046 n.mi. altitude).

Figure 1.- Continued.



(f) At 61 hours (192 454 n.mi. altitude).

Figure 1.- Concluded.

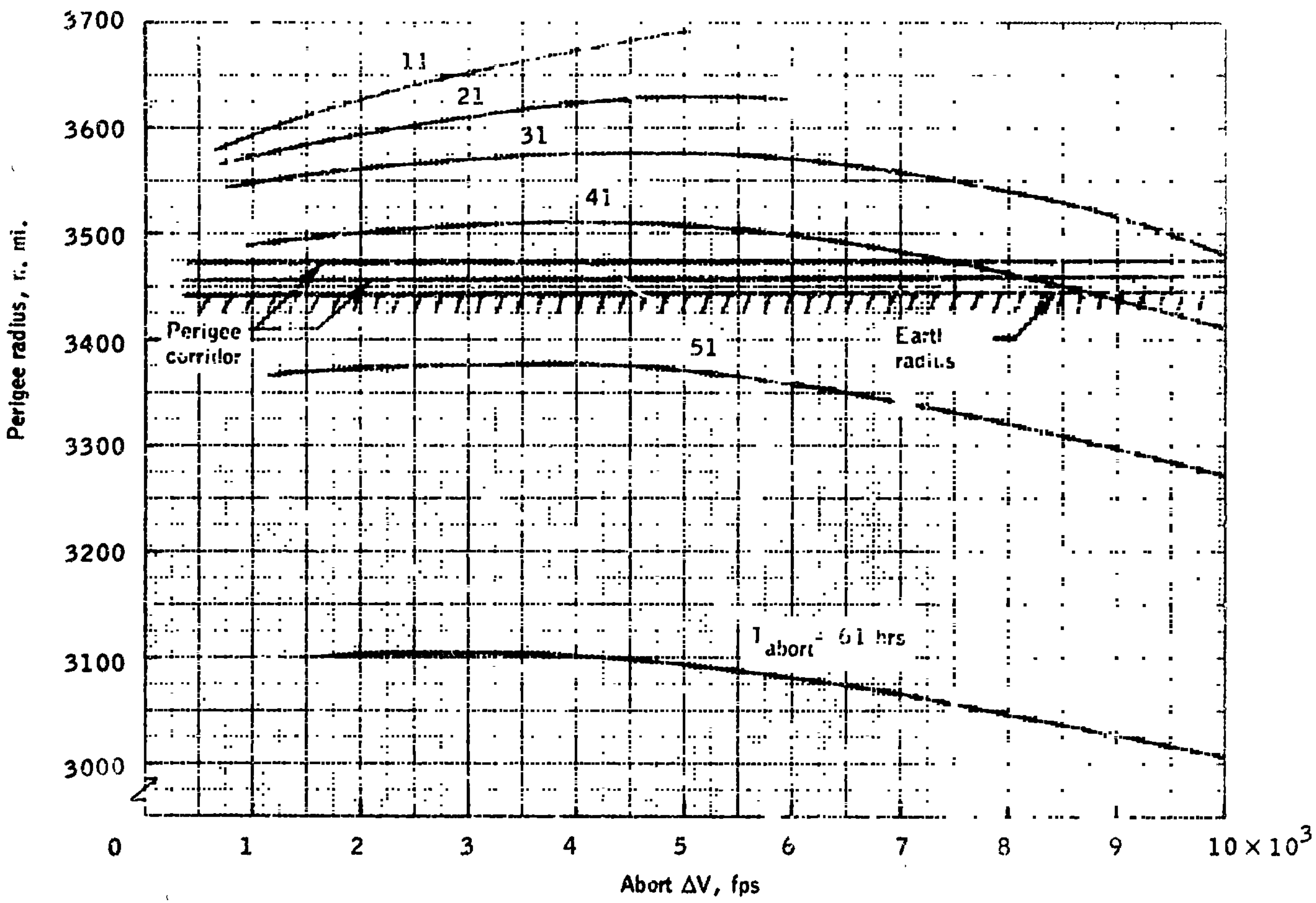


Figure 2.- Unperturbed perigee radius following earth monitor manual abort from translunar coast.

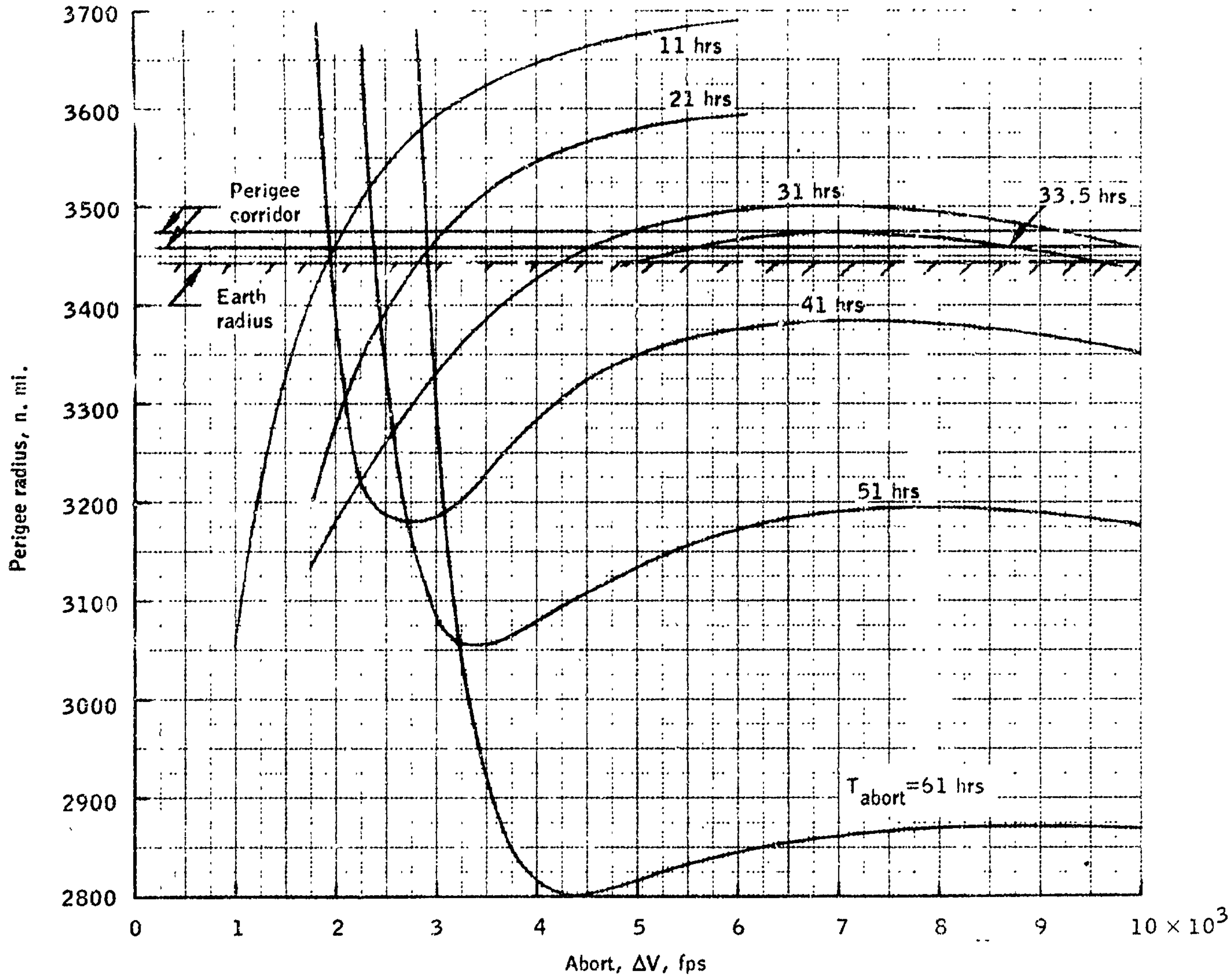


Figure 3.- Perigee radius following earth monitor manual abort from translunar coast.

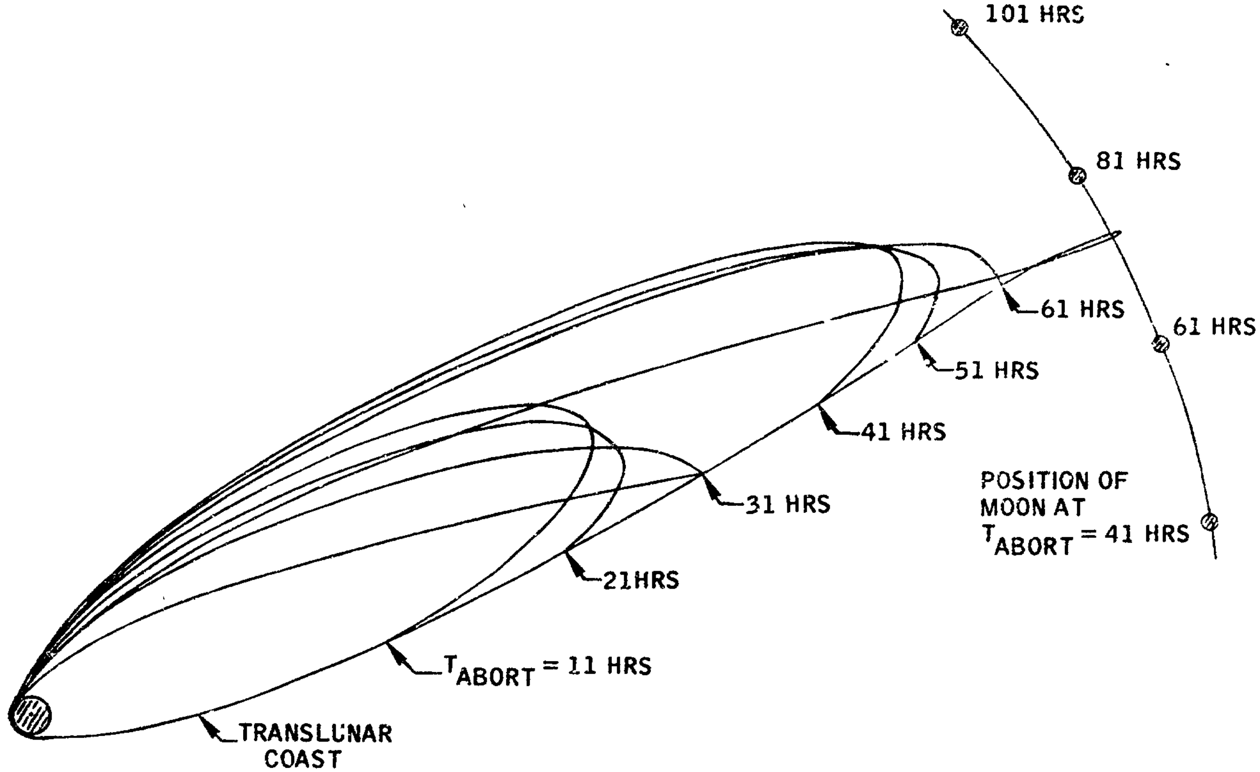


Figure 4.- Abort paths following earth monitor manual aborts initiated along free return translunar coast.

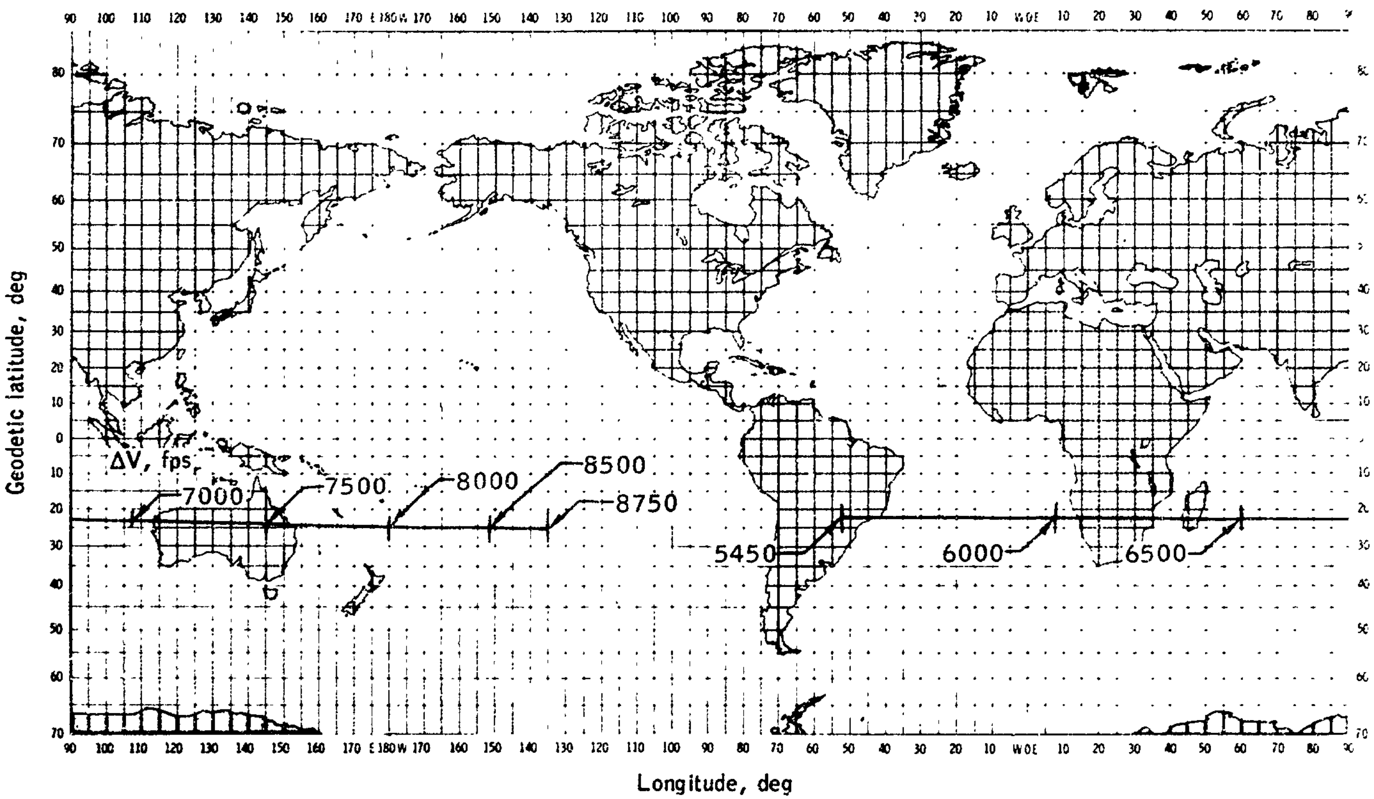


Figure 5.- Reentry po..ts following earth monitor manual abort initiated at 33.5 hours on translunar coast.

REFERENCE

Mission Analysis Branch: AS-504A Preliminary Spacecraft Reference Trajectory, (U) MSC IN 66-FM-70, July 1, 1966. (C)