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955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

B70 12019

SUBJECT: Translunar and Lunar Orbit Abort Trajectories for Apollo 14 - Case 310

DATE: December 7, 1970

FROM: D. R. Anselmo
M. K. Baker

ABSTRACT

The maximum return-to-earth time from a point on the translunar trajectory for the Apollo 14 mission, assuming a LM descent propulsion abort maneuver, is approximately 110 hours. This occurs for an abort at 37 hours ground elapsed time (GET) from launch. If a ΔV limit of 8000 fps is employed for aborts performed using the SPS, the maximum return time is only 40 hours for an abort at a GET of 67 hours. The 8000 fps limit is assumed by MSC as a guideline so that a large midcourse reserve is maintained.

Aborts to nominal earth entry conditions are possible using both SM and LM RCS for about 25 hours after the hybrid maneuver (up to 55 hours GET). For a short period just after the hybrid maneuver it is possible to obtain nominal entry conditions using the SM RCS only.

Return to earth from lunar orbit may or may not be possible using the LM descent propulsion prior to DOI depending on the previous history of SPS propellant usage. The descent plus ascent propulsion can provide a return to earth any time during the lunar orbit stay prior to powered descent.

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MEMORANDUM FOR FILE

Two types of abort trajectories are considered for the Fra Mauro mission to be launched on January 31, 1971: minimum ΔV and minimum return time. Minimum-ΔV abort trajectories are designed from any point on the nominal trajectory such that a minimum expenditure of propellants places the spacecraft on a return-to-earth trajectory meeting the reentry requirements. Minimum return-time abort trajectories, on the other hand, are computed such that the time from the abort point to reentry is minimized for some maximum ΔV available.

From translunar injection (TLI) to the hybrid maneuver (TLI + 28 hours), the Apollo 14 spacecraft is nominally on a free return trajectory. If no additional maneuver is made, the spacecraft will return to earth at 168 hours GET. After the hybrid maneuver is executed (72.5 fps), the spacecraft is nominally on a non-free return trajectory and from this point on, if a contingency should arise, a propulsive maneuver would have to be made to obtain a safe earth return.

Minimum-ΔV Aborts

Three types of minimum-ΔV aborts to achieve a safe return are considered:

1. Maneuver to place the spacecraft on a trajectory which returns to an unspecified landing point on earth.

2. Maneuver to place the spacecraft on a trajectory which returns to an unspecified landing point on earth and make a second maneuver five hours after pericynthian to assure landing in the midpacific recovery area at 170° W longitude.

3. Stay on the non-free return trajectory through pericynthian and make a maneuver to place the spacecraft on a safe earth return trajectory landing in the midpacific recovery area at 170° W longitude.

The first case above represents the minimum ΔV abort possible since adding the constraint to land at a specific point will always result in additional ΔV cost.

Figure 1 illustrates the ΔV costs and system capabilities for these three strategies for minimum-ΔV aborts.

The cost of the abort maneuver increases as the time elapsed from the hybrid maneuver increases. The splashdown points of the unrestricted-landing-point trajectories vary continuously from 165° W for an abort at two hours after the hybrid maneuver to 15° W for aborts close to pericynthian. In the region of 76.3-78.3 hours GET, a minimum-ΔV abort would place the landing on South America. However, the landing point could be shifted to produce a water landing by subsequent trajectory corrections, by expending more ΔV than required by the minimum maneuver, or simply by delaying the maneuver.

After the hybrid maneuver the SM RCS ΔV capability is approximately equal to the minimum abort ΔV of 75 fps. This restricts the SM RCS abort capability to a short period immediately after the hybrid maneuver. The RCS ΔV capability is based upon the results of a previous study (Reference 1) for which the computation included an allowance for post-abort course corrections and attitude control. The 75 fps capability represents about 75 precent of the total RCS usable propellant. The LM RCS (with the APS tank interconnect closed) can provide approximately 56 fps with a four-jet translation burn lasting about 425 seconds. With the tank interconnect open the APS propellant may be used by the RCS. However, there are thermal constraints on the LM descent stage and on the CSM due to plume impingement. The maximum allowable continuous thruster operation is about 500 seconds with accumulated time not to exceed 1000 seconds. If both 75 fps of SM RCS and 56 fps of LM RCS ΔV capability were used, RCS abort capability would be available until at least 25 hours after the hybrid maneuver (55 hours GET). The DPS ΔV available on the translunar leg is $\sim$2000 fps. Retaining a 100 fps midcourse allowance, this ΔV provides return-to-earth capability until 97 hours GET for docked CSM + LM configuration in the case of the unrestricted landing point and 95 hours GET for landing in the midpacific.

Minimum-Time Returns

In the event of an emergency which requires the quickest safe return to earth, there are several abort modes available. All are dependent on the available propulsion systems and the GET at which the minimum-time return is initiated. Four strategies for fast earth returns for various ΔV capabilities were considered:

1. A direct return to earth without going around the moon.

2. A minimum ΔV maneuver to put spacecraft on a free return trajectory at the time of the emergency and a second maneuver after pericynthian to speed up the vehicle.

3. Stay on post-hybrid trajectory until after pericynthian and then make a maneuver to return to earth as quickly as possible.

4. Stay on the initial post-TLI free return trajectory and speed up after passing pericynthian.

Options (2) and (3) are applicable only after the hybrid maneuver. Option (4) is applicable only up to the hybrid maneuver. Option (1) is applicable before and after the hybrid maneuver.

The maximum ΔV capabilities of the various propulsion systems that might be available for an abort are summarized in Table I. These ΔV capabilities include in usable propellant the 3σ dispersion propellant currently allotted for the DPS and the SPS. To obtain an estimate of the return-to-earth trajectories that would always be achievable, an allowance for midcourse and dispersions was subtracted from the capabilities listed. When the return-to-earth maneuvers were calculated, 100 fps was allotted for midcourse corrections and the nominal mission dispersion propellants were not considered usable. For the cases plotted in Figure 2 the ΔV capabilities become 1860 fps for DPS, 5120 fps for SPS and 11,626 fps for SPS plus DPS. The data show the minimum return-to-earth times for these three propulsion configurations. The first two cases return the CSM and LM, the last drops the LM prior to performing the SPS maneuver. These correspond to cases 1, 2 and 4 respectively in Table I.

Examination of Figure 2 shows that the minimum return time for direct aborts increases as a function of GET while return time decreases for circumlunar aborts. Thus there is a point at which the return time is the same for the circumlunar and the direct abort. This point is designated in what follows as the critical point.

The critical point for the DPS abort case occurs at 37 hours GET with a corresponding return-to-earth time of 110 hours. For the SPS case the critical point occurs at 59 hours GET with a return-to-earth time of 58 hours. The SPS + DPS case yields a critical point within the lunar sphere of influence at about 74 hours GET and provides a maximum return time of 30 hours.

An additional curve is shown in Figure 2 for a ΔV capability of 8000 fps. This curve is shown as a limit based on informal information received from the Flight Control Division at MSC (Reference 2). This limit would reserve a ΔV of about 1800 fps for midcourse corrections in the case of SPS aborts performed after jettisoning the lunar module (Case 5 in Table I). The reasoning is that a direct abort would probably be made in a deteriorating situation and large dispersions could result, particularly if a PGNCS problem were involved, hence the large midcourse allowance is provided.

Aborts for minimum return time are constrained by the maximum allowable reentry velocity. The entry velocity limit is established in the RTCC at 37,500 fps. In addition, the on-board program for computing direct aborts (P-37) will not compute a trajectory resulting in an entry velocity above 38,000 fps. The lower curve in Figure 2 corresponding to the use of the DPS plus SPS for direct aborts does not result in an entry velocity as large as 37,500 fps, thus propulsion is not constrained for direct aborts. Circumlunar aborts, however, can result in entry velocities greater than 37,500 fps using all available propulsion. This limit constrains aborts employing post-pericynthian speed-up maneuvers to about 8000 fps maximum.

Earth landing points for the minimum time returns sweep across the major landmasses: Australia, Africa, and South America. Thus, in some cases to avoid land landings a slightly longer than minimum return time must be employed or the abort must be delayed. For a maximum abort ΔV of 8000 fps the required delay can be as long as two hours.

Aborts From Lunar Orbit

The ΔV costs of aborts to earth entry from lunar orbit are somewhat more expensive than the aborts from translunar coast. In this case the energy expended during LOI must be expended again to depart from the vicinity of the moon. The major events in lunar orbit for the nominal Apollo 14 mission are summarized below:

1. LOI 1 - spacecraft in a 60 x 170 nm orbit (82:38 GET)

2. DOI - spacecraft in a 60 x 8 nm orbit (86:56 GET)

3. Separation (104:28 GET)

4. Circularization - 60 x 60 nm orbit (105:46 GET)

5. Landing (108:53 GET)

6. CSM plane change (118:09 GET)

7. Rendezvous (144:10 GET)

8. Nominal TEI (149:14 GET)

Figure 3 illustrates the return-to-earth ΔV cost (or TEI cost) as a function of GET. The vehicle remains in a 60 x 170 nm orbit for about four hours. It is during this period that the TEI cost is the lowest. The DPS alone is barely capable of providing a return to earth during this period as shown by the DPS capability line. In the case of aborts prior to LOI an allowance was subtracted for midcourse corrections and dispersions, however, for aborts from lunar orbit the maximum available ΔV is shown. After the DOI maneuver the ΔV costs to get out of orbit increase roughly by an amount equal to the DOI maneuver or 200 fps. At the same time, because of the reduction in total spacecraft weight by the propellant expended for DOI the DPS capability increases by about 65 fps. After the DOI maneuver has been performed, DPS return from lunar orbit is no longer possible. A small maneuver with the APS or the SM RCS and LM RCS could provide the additional ΔV required, which is on the order of 130 fps.

After the circularization maneuver (establishing a 60 nm circular orbit), the TEI cost drops but after the CSM plane change TEI cost again increases. The DPS plus APS propulsion will provide enough ΔV (≈3900 fps) capability for return-to-earth at any time in lunar orbit* as illustrated by the TEI costs shown in Figure 3. The ΔV capabilities for the various propulsion systems after the performance of LOI are given in Table I.

Summary

The minimum ΔV abort capability and the minimum return time capability represent the extremes of return-to-earth time available during the mission. In the event of a contingency

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*Nominally LM separation and descent begin 22 hours after LOI and the LM propulsion is no longer available for earth return. It is possible if an abort were required shortly after the start of powered descent, that rendezvous could be performed and sufficient DPS plus APS propulsion remain for the TEI maneuver.

during a mission a continuous range of return-to-earth times between these boundaries would be available. The specific choice would have to depend on real-time factors such as choice of landing area, condition of spacecraft systems and the condition of the crew.

D. R. Anselmo

M. K. Baker

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Attachments

REFERENCES

1. Preliminary Evaluation of SM/RCS Capability to Abort to Earth Entry from the Relaxed Free Return Profile, Bellcomm Memorandum for File B70 09084, September 30, 1970, R. J. Stern.

2. Informal Communication - Phil Shaffer, MSC/FC, October, 1970.

TABLE I

Option	Source of Propulsion	Post Abort Configuration	ΔV	
			Pre-LOI	Post-LOI (Pre-DOI)
1	DPS	CSM + LM	2000 fps	2040 fps
2	SPS	CSM + LM	5200 fps	2260 fps
3	DPS + SPS	CSM + LM	9040 fps	6000 fps
4	DPS + SPS	CSM	11870 fps	7520 fps
5	SPS	CSM	9865 fps	4780 fps
6	SPS + DPS	CM + LM	10150 fps	7170 fps
7	DPS	CM + LM	4850 fps	4910 fps
8	DPS + APS	CSM + A/S	2715 fps	3880 fps

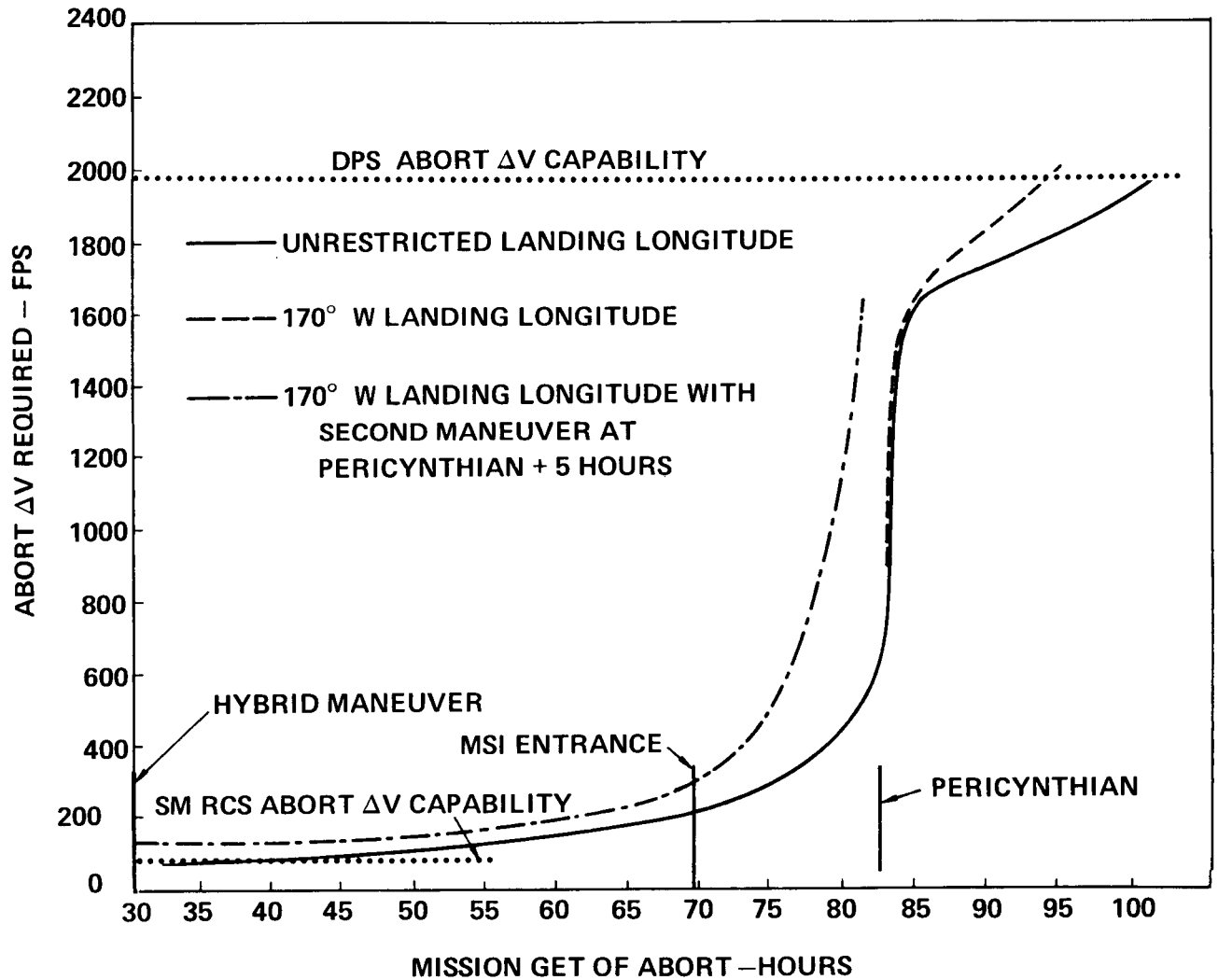

FIGURE 1 - MINIMUM ΔV ABORT REQUIREMENTS FOR FRA MAURO MISSION
LAUNCH JANUARY 31, 1971

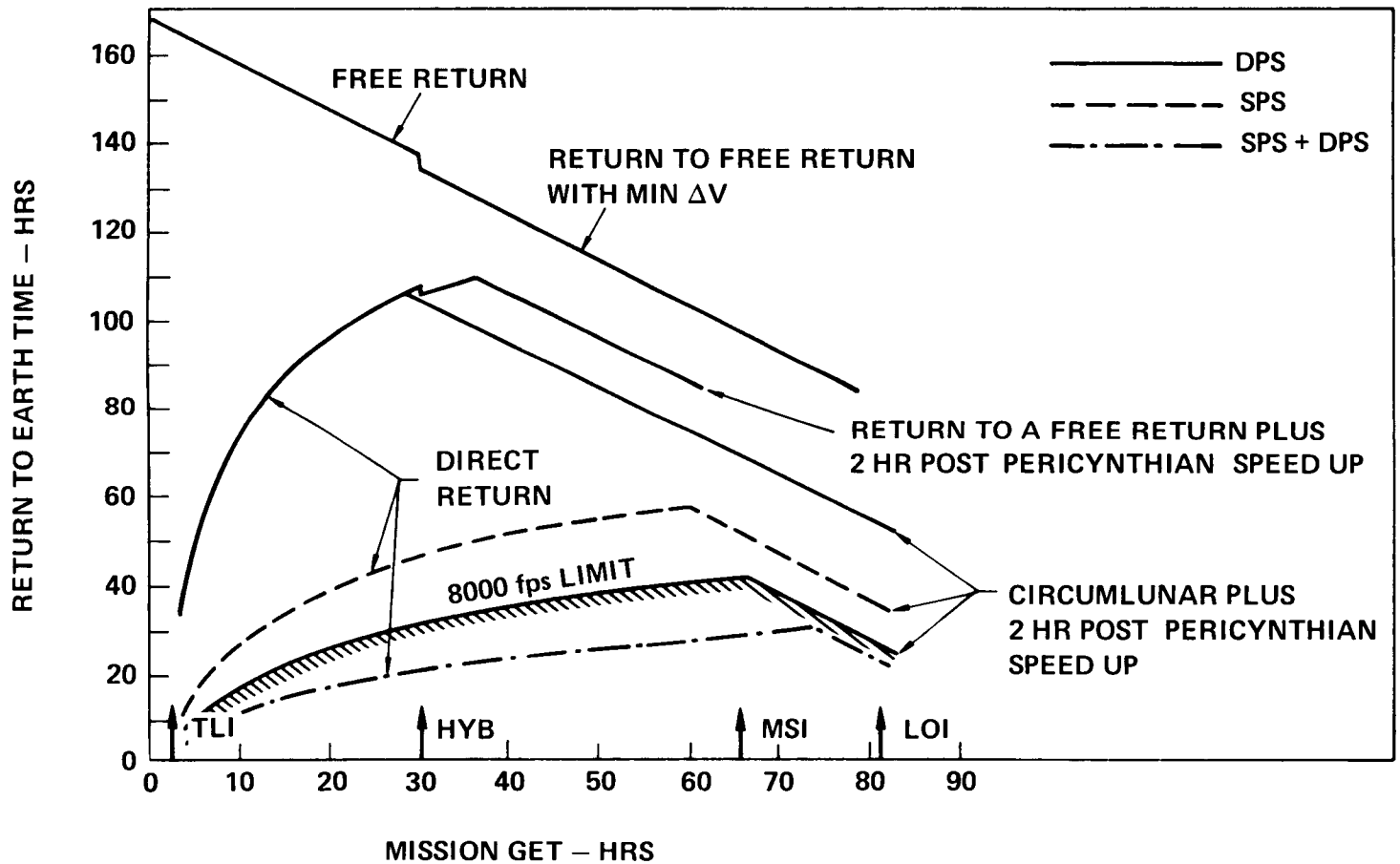

FIGURE 2 - RETURN TO EARTH TIMES FOR TRANSLUNAR ABORTS
FRA MAURO MISSION – LAUNCH JANUARY 31, 1971

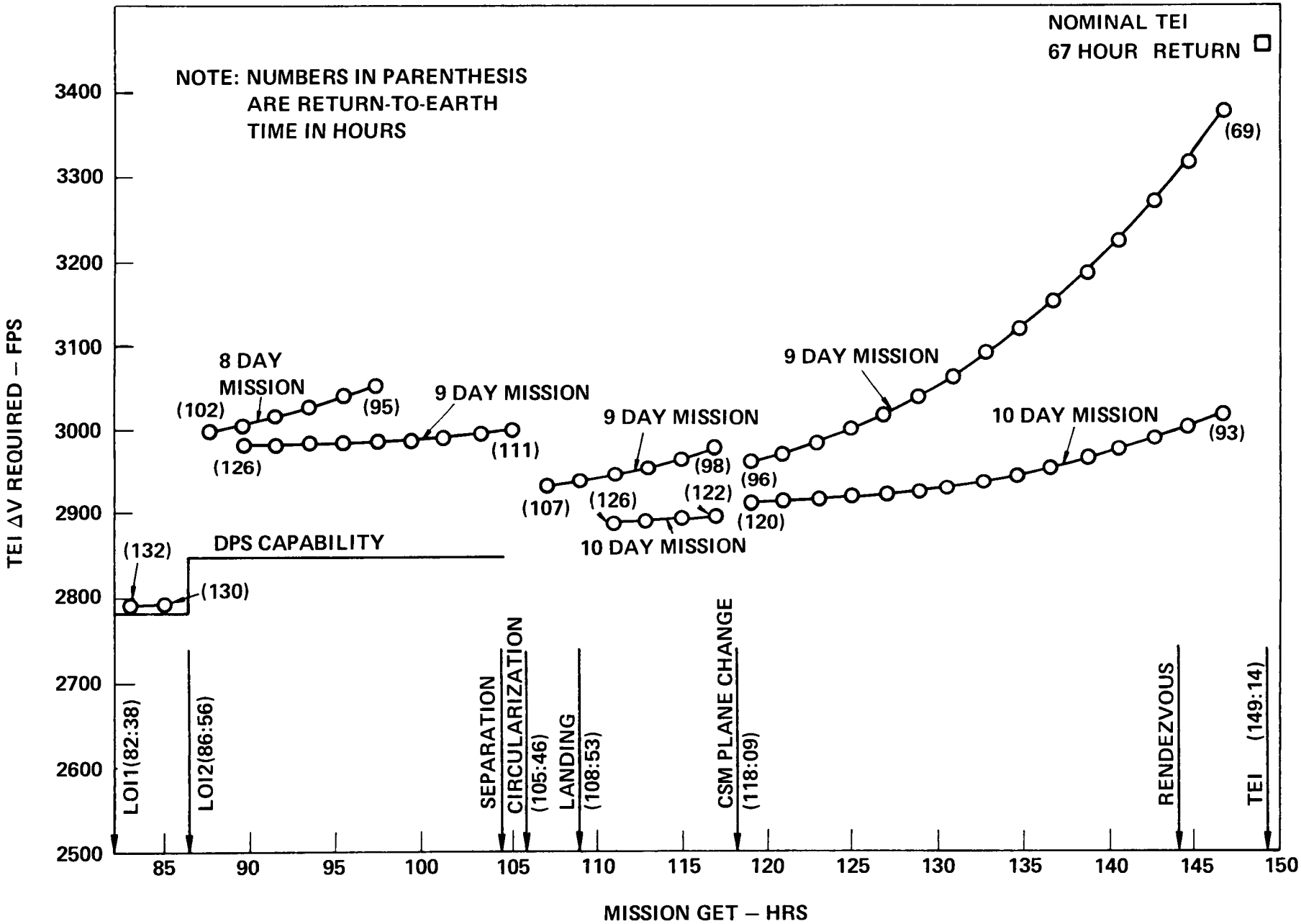

FIGURE 3 - RETURN TO EARTH REQUIREMENTS FROM LUNAR ORBIT
FRA MAURO LAUNCH JANUARY 31, 1971

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M. K. Baker

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