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APOLLO 11 (MISSION G)
SPACECRAFT DISPERSION ANALYSIS
VOLUME II
TRANSLUNAR AND
TRANSEARTH PHASES

Lunar Mission Analysis Branch

MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER
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PROJECT APOLLO

APOLLO 11 (MISSION G) SPACECRAFT DISPERSION ANALYSIS VOLUME II - TRANSLUNAR AND TRANSEARTH PHASES

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APOLLO 11 (MISSION G) SPACECRAFT DISPERSION ANALYSIS

VOLUME II - TRANSLUNAR AND TRANSEARTH PHASES

By G. C. Hitt, S. M. Kindall, and J. D. Yencharis

SUMMARY

The results of the spacecraft dispersion analyses for the translunar and transearth phases of Apollo (Mission G) are presented in this document. The analyses were performed based on the Apollo 11 (Mission G) operational trajectory which has a July 16, 1969, launch date and a 72° launch azimuth (ref. 1).

Of the 200 translunar phase and 200 transearth phase simulations which were performed, the worst cases resulted in total service propulsion system (SPS) ΔV expenditures of 53.6 fps and 17.2 fps for the translunar and transearth phases, respectively. Worst-case reaction control system (RCS) ΔV expenditures were 5.5 fps for the translunar phase and 14.6 fps for the transearth phase.

Trajectory deviations at lunar orbit insertion (LOI) and at entry are smaller than those obtained from preflight analyses for the Apollo 10 mission and appear to be acceptable. However, it appears, that deviations at LOI could be reduced significantly if a midcourse correction were not allowed at MCC-3 (LOI minus 22 hr).

This analysis was conducted within the guideline of MCC logic established in the most recent Mission Techniques documents (refs. 2 and 3). However, recent changes in that logic will necessitate a revision of this dispersion analysis. On translunar coast, an entirely different philosophy in MCC logic which will emphasize MCC-2 and MCC-4 instead of MCC-1 and MCC-3 is currently evolving. On transearth coast, the time for the middle midcourse (MCC-6) maneuver has been moved from EI minus 15 hours to EI minus 22 hours. Another cause for revision of the analysis is an update of one error source (the CSM TVC pointing error) which is used for the analysis.

MISSION DESCRIPTION

The nominal time lines for the translunar and transearth phases of Apollo 11 (Mission G), as specified in reference 1, are shown below.

Translunar phase

Event	Time, day:hr:min, g.e.t.	Time from TLI cutoff, hrs
Translunar injection (TLI) cutoff	0:02:50	0
MCC-1	0:11:50	9
MCC-2	1:02:50	24
MCC-3	2:05:55	51.1 (LOI minus 22 hr)
MCC-4	2:22:55	68.1 (LOI minus 5 hr)
LOI ignition	3:03:55	73.1
Nodal passage	3:03:58	73.1

Transearth phase

Event	Time, day:hr:min, g.e.t.	Time from TEI cutoff, hrs
Transearth injection (TEI) cutoff	5:11:31	0
MCC-5	6:02:31	15
MCC-6	7:12:01	48.5 (entry minus 15 hr)
MCC-7	8:00:01	60.5 (entry minus 3 hr)
Entry	8:03:01	63.5

SIMULATION DESCRIPTION

The dispersion analyses for the translunar and transearth phases of Apollo 11 (Mission G) were performed with the linear Monte Carlo dispersion analysis programs described in references 4 and 5.

Translunar Simulations

Each translunar simulation was initialized with a set of sample state vector deviations (actual deviations) after the evasive maneuver at TLI cutoff plus 6601.4 seconds and was terminated at the nominal time of nodal passage. Simulated midcourse corrections were targeted to node (X, Y, Z and time at the node of the approach hyperbola and the lunar orbit plane) and included the effects of MSFN navigation errors, errors in the estimated values for the gravitational constants of the earth and moon, and midcourse execution errors.

Transearth Simulations

Transearth simulations were initialized with a set of sample actual state deviations at TEI cutoff plus 15 seconds and were terminated at entry interface (400 000 ft). Simulated transearth midcourse corrections were targeted to an entry fight-path angle of -6.509° (with longitude and latitude of the entry point unconstrained) and included the effects of MSFN navigation errors, errors in the estimated values for the gravitational constants of the earth and moon, and midcourse execution errors.

In both the translunar and the transearth simulations, MSFN tracking data taken during the 2-hour period immediately prior to a planned midcourse correction were not included in the calculation of the required ΔV.

ERROR SOURCES

Navigation Errors

MSFN tracking normal matrices and state transition matrices for the translunar and transearth phase dispersion analyses were prepared by MSC/TRW task A-153 using the TAPP IV program. Navigational error sources whose effects were included in both the translunar and transearth analyses were tracking data noise and biases, MSFN tracking station

location errors, error in the estimated value for the gravitational constant of the earth, and error in the estimated value for the gravitational constant of the moon. The value of the standard deviation for each of these errors was specified by the Mathematical Physics Branch of Mission Planning and Analysis Division. Venting effects were not included in the Apollo 11 (Mission G) simulations. Navigational errors for Apollo 11 (Mission G), the effects of which are considered in this analysis, are summarized in reference 6.

Midcourse Execution Errors

Translunar and transearth midcourse maneuvers were modeled as impulsive corrections, and it was assumed that all maneuvers are performed with the primary guidance system. The effects of the errors listed below were included in simulated midcourse maneuvers; the errors were modeled to have a normal distribution with mean and standard deviation as indicated.

Error	Mean	Standard deviation
Initial thrust vector pointing error		
Pitch, deg	0.0	0.30
Yaw, deg	0.0	0.30
IMU platform alinement error at midcourse burn initiation[a]		
Pitch, deg	0.0	1.87×10^{-2}
Roll, deg	0.0	1.87×10^{-2}
Yaw, deg	0.0	1.87×10^{-2}
IMU accelerometer bias		
X-axis, ft/sec^2	0.0	6.56×10^{-3}
Y-axis, ft/sec^2	0.0	6.56×10^{-3}
Z-axis, ft/sec^2	0.0	6.56×10^{-3}
IMU accelerometer scale factor		
X-axis	0.0	1.16×10^{-4}
Y-axis	0.0	1.16×10^{-4}
Z-axis	0.0	1.16×10^{-4}
Error in SPS thrust magnitude, lb	0.0	147.2
Error in RCS thrust magnitude (one jet), lb	-0.7	1.2
SPS tailoff impulse error (equivalent time at full thrust), sec	0.0	0.04

[a]Includes an initial misalinement of 1.11×10^{-2}° (1σ) and one-half hour of drift at a rate of 3.0×10^{-2} deg/hr. The RMS of these two values yielded 1.87×10^{-2}° (1σ).

In addition to these errors, initial vehicle pitch, roll, and yaw attitude errors at maneuver ignition were simulated with these errors assumed to be uniformly distributed between -0.5° and 0.5° (the deadband constraints for attitude hold prior to ignition). Also, the fact that ΔV sensed onboard accumulates in discrete steps of 0.19 fps rather than as a continuous function of actual ΔV, was accounted for in the simulation.

Nominal weights and engine performance data for the CSM were assumed to be as follows.

Nominal CSM weight (dry), lb	22 831
Nominal LM weight, lb	33 276
Nominal propellant weights after TLI, lb	40 498
Nominal propellant weights after TEI, lb	3 755
Nominal thrust for SPS, lb	20 880
Nominal specific impulse for SPS, sec	313.8
Nominal thrust (one jet) for RCS, lb	102.8
Nominal specific impulse for RCS, sec	277.3

Nominal performance values, standard deviations for errors, and curves which relate ΔV errors (caused by initial thrust vector pointing error) to midcourse burn time were all obtained from reference 7. Nominal weights were obtained from reference 8.

Injection Errors

The covariance matrices of actual postinjection state deviations which were used to generate sample initial state deviations for the translunar and transearth phase simulations are presented in table I. These matrices were generated by the Guidance and Performance Branch of Mission Planning and Analysis Division.

Each of the matrices in table I is actually a combined covariance and correlation matrix with covariance elements σ_{ij} in the lower triangular portion and correlation coefficients ρ_{ij} above the diagonal, as shown on the following page.

$$\begin{bmatrix} (\sigma_x)^2 & & & & & \\ & (\sigma_y)^2 & & & & \\ & & (\sigma_z)^2 & & & \\ & & & (\sigma_{\dot{x}})^2 & & \rho_{ij} \\ & & & & (\sigma_{\dot{y}})^2 & \\ \rho_{ij}\sigma_i\sigma_j & & & & & (\sigma_{\dot{z}})^2 \end{bmatrix}$$

where σ_i = standard deviation of the ith component of the state vector deviation

ρ_{ij} = correlation coefficient for the ith and jth components

MIDCOURSE DECISION LOGIC

In the translunar and transearth simulations, the decision to make or not to make a midcourse correction at each of the specified nominal midcourse times was based on the magnitude of the required ΔV relative to several different threshold values. The first of these thresholds was the midcourse correction threshold (MCCT). A maneuver was not performed unless the magnitude of the required ΔV exceeded this threshold. If $|\overline{\Delta V}_{REQ}| \geq$ MCCT, then a midcourse correction was performed. If $|\Delta V_{REQ}| \geq$ SPST, the SPS threshold, then the maneuver was performed with the SPS[a]; otherwise, the maneuver was performed with the RCS.

[a]For transearth simulations, all SPS MCC's included an RCS ullage maneuver equal to 4.0 fps. Ullage maneuvers were not performed during the translunar phase.

TABLE I.- COVARIANCE MATRICES OF ACTUAL POST-INJECTION STATE DEVIATIONS

Covariance matrix of actual state deviations at TLI + 1 hour, 50 minutes, 3.43 seconds (ft, ft/sec; geocentric UVW coordinates)[a]

	1	2	3	4	5	6
1	$(3.3717432+04)^2$	-1.5011460-02	5.7422775-02	1.4251941-02	-2.3579744-01	7.5779104-02
2	-1.0032280+08	$(1.9820847+05)^2$	-3.4915464-02	-9.5088803-01	9.9517175-01	-4.2222569-02
3	1.5644683+08	-5.5920126+08	$(8.0803116+04)^2$	4.9680848-02	-3.8191559-02	9.8747229-03
4	6.5910705+03	-2.5851101+06	5.5061062+04	$(1.3716000+01)^2$	-9.2971453-01	5.4760074-02
5	-1.7056103+05	4.2316182+06	-6.6203620+04	-2.7356675+02	$(2.1452911+01)^2$	-4.6940838-02
6	1.4204781+04	-4.6526187+04	4.4359191+03	4.1756307+00	-5.5984483+00	$(5.5594341+00)^2$

Covariance matrix of actual state deviations at TEI +14 seconds (ft, ft/sec; selenocentric UVW coordinates)[a]

	1	2	3	4	5	6
1	$(1.6189723+03)^2$	-2.4510579-01	-1.5737061-01	2.7156627-01	-7.2629032-01	-8.8137394-02
2	-3.8237334+06	$(9.6358519+03)^2$	2.5729362-01	-9.6520166-01	4.3018826-01	4.1660106-02
3	-7.8058718+05	7.5958693+06	$(3.0637855+03)^2$	-2.4741354-01	1.5681319-01	9.0758863-01
4	5.3935249+03	-1.1409474+05	-9.2990647+03	$(1.2267539+01)^2$	-4.1486117-01	-1.8330775-02
5	-2.7609925+03	9.7333922+03	1.1281231+03	-1.1950217+01	$(2.3480994+00)^2$	3.3527596-02
6	-1.9450769+03	5.4720195+03	3.7903956+04	-3.0653173+00	1.0731369+00	$(1.3631296+01)^2$

[a] Elements above the diagonal are correlation coefficients.

After a midcourse correction with the SPS, the magnitude of $\overline{\Delta V}_{RES}$, the residual ΔV ($\overline{\Delta V}_{RES} = \overline{\Delta V}_{REQ} - \overline{\Delta V}_{SENSED}$), was compared with the trim threshold TRIMT, and an RCS trim maneuver was performed if $|\overline{\Delta V}_{RES}| \geq$ TRIMT. However, the residual ΔV was not trimmed down to zero but down to the value of TRIMT, in accordance with a policy established by the Data Priority Techniques Working Groups.

A diagram of the midcourse decision logic is shown in figure 1. The values of MCCT, SPST, and TRIMT for the four translunar midcourse corrections are given in table II. The values for the three transearth midcourse corrections are shown in table II.

TABLE II.- TRANSLUNAR MIDCOURSE DECISION THRESHOLDS

Threshold	MCC-1	MCC-2	MCC-3	MCC-4
MCCT, fps	3.0	3.0	0.5	1.0
SPST, fps	3.0	3.0	3.0	3.0
TRIMT, fps	a	a	0.5	1.0

TABLE III.- TRANSEARTH MIDCOURSE DECISION THRESHOLDS

Threshold	MCC-5	MCC-6	MCC-7
MCCT, fps	1.0	0.5	1.0
SPST, fps	14.0	14.0	14.0
TRIMT, fps	.2	.2	.2

[a]Trim not allowed.

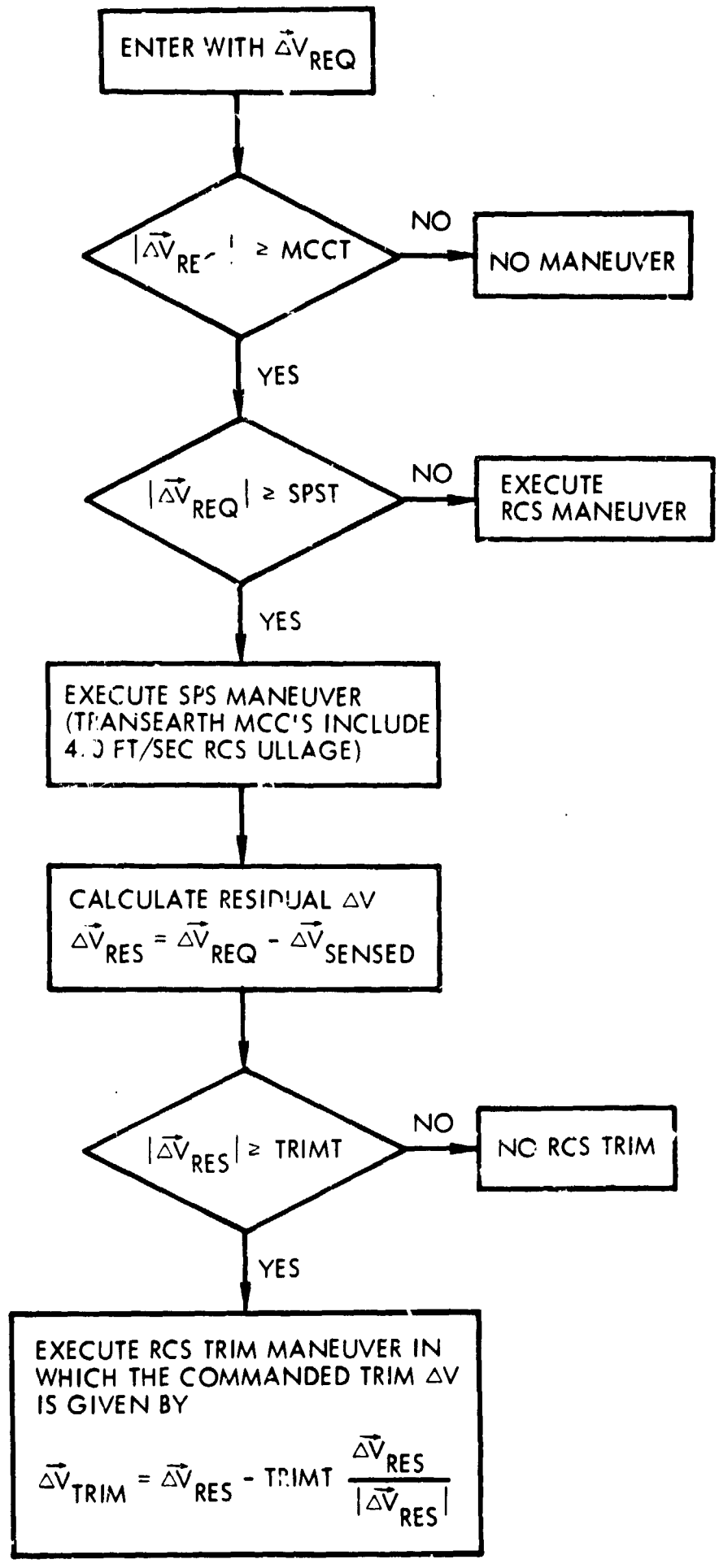


Figure 1. Midcourse Decision Logic

RESULTS

Detailed results from simulations of the translunar and transearth phases of Apollo 11 (Mission G) are tabulated in appendixes A and B, respectively.

Summary of Translunar Results

As shown in table A-V in appendix A, the largest total ΔV commanded for Apollo 11 (Mission G) was 56.2 fps. The largest total SPS usage was 53.6 fps and the largest total RCS usage was 5.5 fps.

The engine usage histories of all 200 translunar simulations (fig. 2), indicates that the most probably translunar sequence of maneuvers is as follows.

a. A first MCC at TLI plus 9 hours made with the SPS

b. No MCC at TLI plus 24 hours

c. A second MCC at LOI minus 22 hours made with the RCS

d. A third MCC at LOI minus 5 hours made with the SPS

The final 1σ dispersion in altitude at node was 2.99 n. mi. The largest positive deviation in altitude at node was 8.2 n. mi., and the largest negative deviation was -8.2 n. mi. The dispersion in altitude at node for Apollo 11 (Mission G) is smaller than it was for the Apollo 10 mission. The final deviation in altitude at node caused directly by execution error at MCC-4 is not large (e.g., table A-IV); the deviation is primarily the result of error in the pre-MCC-4 estimate of required ΔV caused by state vector uncertainty.

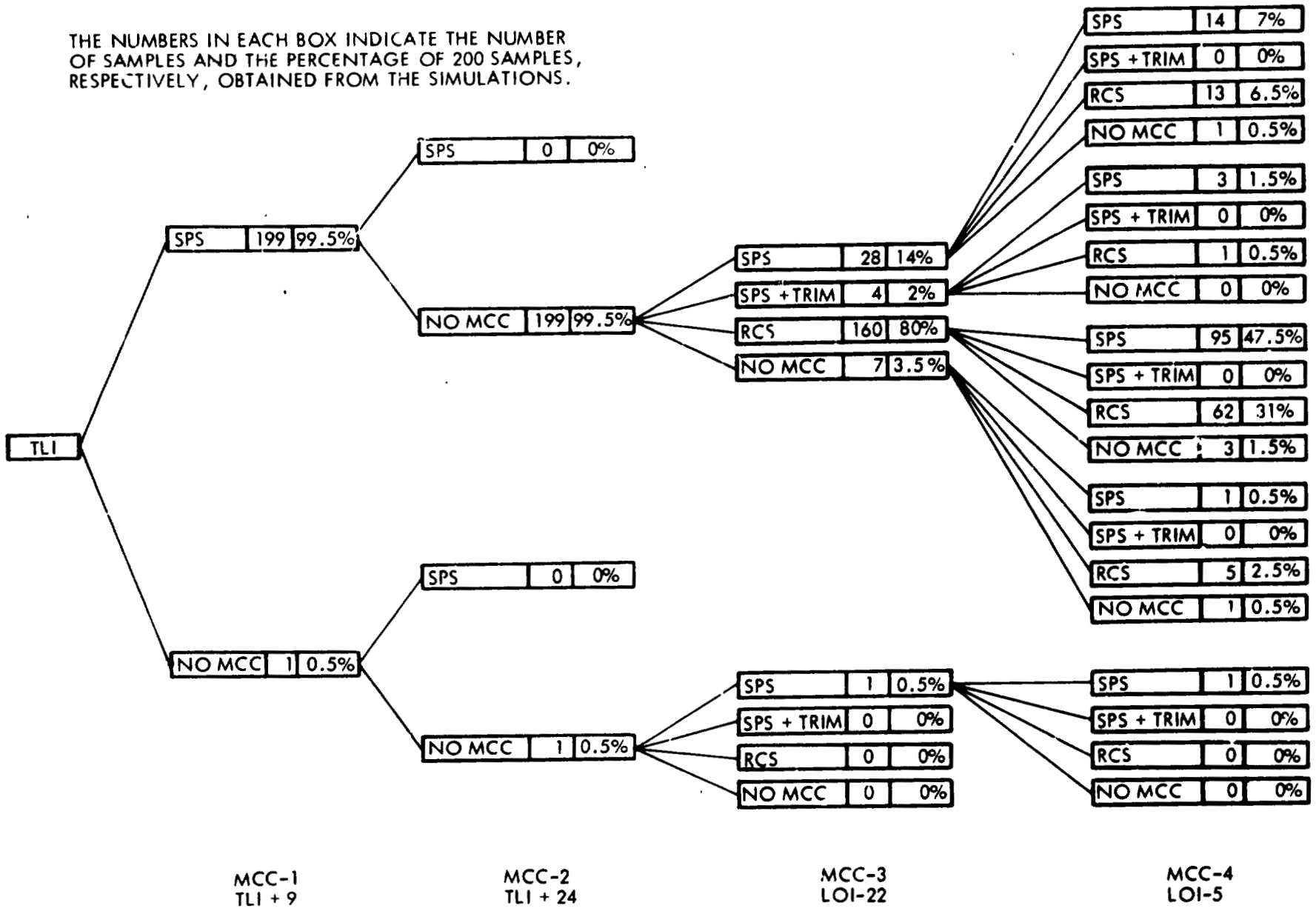


Figure 2. Engine Usage for Translunar Simulations

Summary of Transearth Results

Analysis of the transearth phase indicates that injection errors incurred during the TEI burn are small and correctable (targeting for a flight-path angle at entry of -6.509°) at a small cost of midcourse ΔV. One of the 200 transearth simulations which were performed required no midcourse correction at all, and approximately 28 percent of the simulations accumulated a total ΔV of 3.0 fps or less. The SPS was used only five times during the simulations. All five SPS maneuvers occurred at MCC-5 (TEI plus 15 hr); the SPS was never required at MCC-6 (entry minus 15 hr) or at MCC-7 (entry minus 3 hr). The largest cumulative ΔV (RCS) obtained was 22.8 fps.

As indicated in table B-V of appendix B, midcourse corrections during the transearth phase were always in a direction very nearly perpendicular to the geocentric position vector of the vehicle and in the plane of the trajectory.

The transearth maneuver sequence followed by each of the 200 transearth simulations is presented in figure 3. At any time in the mission, given the sequence of maneuvers which preceded that time, data in figure 3 indicate the probable sequence of maneuvers which will follow. Thus, prior to MCC-5, the most probable sequence of transearth maneuvers is the following.

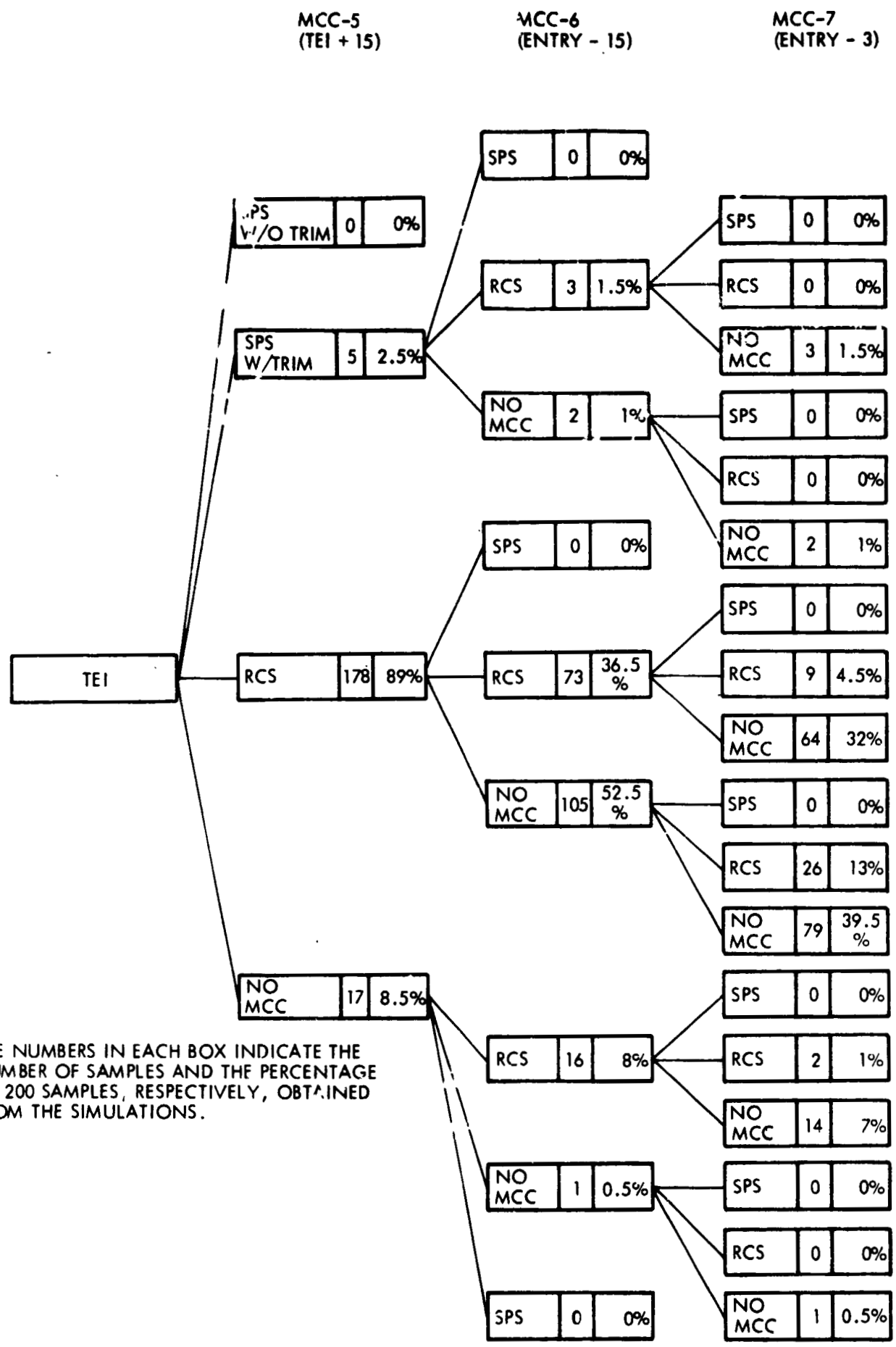
a. MCC-5: RCS maneuver

b. MCC-6: no maneuver

c. MCC-7: no maneuver

Note that some of the branches of the tree in figure 3 were followed in only a very few cases. On these branches the reliability of a predicted maneuver sequence would not be very high because the prediction would be based on results from such a small number of samples.

Entry parameters (actual) from the transearth simulations ranged between the values shown in the following table.



THE NUMBERS IN EACH BOX INDICATE THE NUMBER OF SAMPLES AND THE PERCENTAGE OF 200 SAMPLES, RESPECTIVELY, OBTAINED FROM THE SIMULATIONS.

Figure 3. Engine Usage for Transearth Simulations

Actual Entry Parameters

Parameter	Nominal	Low	High
Flight-path angle, deg	-6.509	-6.674	-6.366
Azimuth deviations, deg	0.00	-.90	.96
Longitude deviations, deg	0.00	-1.89	1.61
Latitude deviations, deg	0.00	0.36	.36
Speed deviations, fps	0.00	-11.6	16.2

Note that the entry flight-path angle range is well within the entry corridor of -5.25° (overshoot) to -7.34° (12g undershoot) defined in reference 1. Entry longitude and latitude deviations, which were not constrained in the calculation of midcourse corrections, result in landing points which are within the relocation capability of the recovery ship during transearth coast.

An MCC never accomplished its purpose to completely null deviations in the target parameter(s), in this case, flight-path angle γ at entry. There are two classes of errors which cause this failure: error in the pre-MCC estimate of γ at entry, which leads to an erroneous calculation of the required ΔV, and error in the execution of the maneuver. The contribution of each of these classes of error to the post-MCC deviation in γ at entry is shown in the Trajectory Characteristics sections of tables B-I, B-II, and B-III in appendix B. Note that the final deviation in γ at entry is caused primarily by the pre-MCC-4 error in the estimate of γ rather than execution error at MCC-4.

In summary, entry conditions obtained from the Apollo 11 (Mission G) transearth simulations appear to be completely acceptable.

CONCLUSIONS

The following conclusions may be drawn from this analysis.

a. The translunar midcourse philosophy would benefit from any change which deemphasizes MCC-3.

b. Total ΔV costs, translunar and transearth, are entirely acceptable.

c. Entry interface conditions are well within acceptable bounds.

It should also be pointed out that this analysis reflects only officially documented procedures which were in effect at the time the study was initiated. A revision of the document will be forthcoming shortly. It will reflect the most current operational procedures.

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TABLE A-I.- STATISTICAL SUMMARY OF MIDCOURSE CORRECTION 1 (TLI + 9 Hours)

		Maneuver Characteristics				
Item	Nominal	Mean	σ	Low	High	Sample Size
ΔV required (ft/sec)	0.0	15.9	9.2	1.2	50.2	200
Total ΔV commanded (ft/sec)		15.9	9.2	3.2	50.2	199
Total SPS ΔV commanded (ft/sec)		15.9	9.2	3.2	50.2	199
Total RCS ΔV commanded (ft/sec)		-	-	-	-	0
RCS ΔV commanded (MCC) (ft/sec)		-	-	-	-	0
RCS ΔV commanded (trim) (ft/sec)		-	-	-	-	0
Actual SPS propellant expended (lb)		152.6	88.1	29.6	480.8	199
Actual RCS propellant expended (lb)		-	-	-	-	0
Actual SPS burn time (sec)		2.29	1.32	.45	7.15	199
Actual RCS burn time (sec)		-	-	-	-	0
ΔV_u sensed (ft/sec)		-0.4	12.4	-30.8	30.1	199
ΔV_v sensed (ft/sec)		0.6	12.8	-32.7	39.9	199
ΔV_w sensed (ft/sec)		0.02	4.6	-12.9	9.8	199
ΔV_x residual[a] (ft/sec)		0.09	0.4	-1.04	1.14	199
ΔV_y residual[a] (ft/sec)		0.01	0.1	-0.6	0.9	199
ΔV_z residual[a] (ft/sec)	0.0	0.003	0.1	-0.8	0.6	199

Number of SPS MCC's - 199
Number of RCS ullages - 0
Number of RCS MCC's - 0
Number of RCS trims - 0

[a] ΔV commanded minus ΔV sensed in control axis coordinates

TABLE A-I.- STATISTICAL SUMMARY OF MIDCOURSE CORRECTION 1 (TLI + 9 Hours) - Concluded

Item		Nominal	Mean	σ	Low	High	Sample Size
		Trajectory Characteristics					
Actual speed (ft/sec)	Pre	7796	7796	7.3	7778	7814	200
	Post	7796	7796	2.27	7790	7802	200
Actual flight-path angle (deg)	Pre	74.25	74.25	0.02	74.19	74.30	200
	Post	74.25	74.25	0.09	73.95	74.50	200
Actual azimuth (deg)	Pre	119.96	119.96	0.09	119.70	120.17	200
	Post	119.96	119.96	0.07	119.75	120.14	200
Actual deviation in perilune altitude (ft)	Pre	0.0	-3.22+06	3.71+06	-9.02+06	12.88+06	200
	Post	0.0	3564	77,347	-294,568	231,130	200
Actual deviation in perilune arrival time (sec)	Pre	0.0	-5.73	441.20	-660.98	820.18	200
	Post	0.0	2.62	34.81	-80.02	110.62	200
Actual deviation in altitude at node due to estimation error	Post	0.0	2936	53,591	-126,427	169,716	199
Actual deviation in altitude at node due to execution error	Post	0.0	-1260	48,214	-133,897	167,030	199

TABLE A-II.- STATISTICAL SUMMARY OF MIDCOURSE CORRECTION 2 (TLI + 24 Hours)

	Maneuver Characteristics					
Item	Nominal	Mean	σ	Low	High	Sample Size
ΔV required (ft/sec)	0.0	0.9	0.5	0.1	2.6	200
Total ΔV commanded (ft/sec)		-	-	-	-	0
Total SPS ΔV commanded (ft/sec)		-	-	-	-	0
Total RCS ΔV commanded (ft/sec)		-	-	-	-	0
RCS ΔV commanded (MCC) (ft/sec)		-	-	-	-	0
RCS ΔV commanded (trim) (ft/sec)		-	-	-	-	0
Actual SPS propellant expended (lb)		-	-	-	-	0
Actual RCS propellant expended (lb)		-	-	-	-	0
Actual SPS burn time (sec)		-	-	-	-	0
Actual RCS burn time (sec)		-	-	-	-	0
ΔV_u sensed (ft/sec)		-	-	-	-	0
ΔV_v sensed (ft/sec)		-	-	-	-	0
ΔV_w sensed (ft/sec)		-	-	-	-	0
ΔV_x residual[a] (ft/sec)		-	-	-	-	0
ΔV_y residual[a] (ft/sec)		-	-	-	-	0
ΔV_z residual[a] (ft/sec)	0.0	-	-	-	-	0

Number of SPS MCC's - 0
Number of RCS ullages - 0
Number of RCS MCC's - 0
Number of RCS trims - 0

[a] ΔV commanded minus ΔV sensed in control axis coordinates

TABLE A-II.- STATISTICAL SUMMARY OF MIDCOURSE CORRECTION 2 (TLI + 24 Hours) - Concluded

Trajectory Characteristics

Item		Nominal	Mean	σ	Low	High	Sample Size
Actual speed (ft/sec)	Pre	5003	5003	0.87	5001	5005	200
	Post	5003	5003	0.87	5001	5005	200
Actual flight-path angle (deg)	Pre	77.02	77.02	0.08	76.77	77.23	200
	Post	77.02	77.02	0.08	76.77	77.23	200
Actual azimuth (deg)	Pre	121.13	121.13	0.07	120.93	121.33	200
	Post	121.13	121.13	0.07	120.93	121.33	200
Actual deviation in perilune altitude (ft)	Pre	0.0	3564	77,347	-294,568	231,130	200
	Post	0.0	3564	77,347	-294,568	231,130	200
Actual deviation in perilune arrival time (sec)	Pre	0.0	2.62	34.81	-80.02	110.62	200
	Post	0.0	2.62	34.81	-80.02	110.62	200
Actual deviation in altitude at node due to estimation error (ft)	Post	0.0	-	-	-	-	0
Actual deviation in altitude at node due to execution error (ft)	Post	0.0	-	-	-	-	0

TABLE A-III.- STATISTICAL SUMMARY OF MIDCOURSE CORRECTION 3 (LOI - 22 Hours)

	Maneuver Characteristics					
Item	Nominal	Mean	σ	Low	High	Sample Size
ΔV required (ft/sec)	0.0	1.98	1.1	0.3	5.8	200
Total ΔV commanded (ft/sec)		2.04	1.1	0.53	5.8	193
Total SPS ΔV commanded (ft/sec)		3.9	0.6	3.01	5.8	33
Total RCS ΔV commanded (ft/sec)		1.6	0.7	0.07	2.98	164
RCS ΔV commanded (MCC) (ft/sec)		1.7	0.7	0.53	2.98	160
RCS ΔV commanded (trim) (ft/sec)		0.2	0.1	0.07	0.4	4
Actual SPS propellant expended (lb)		36.6	6.9	26.9	55.3	33
Actual RCS propellant expended (lb)		16.7	8.5	0.69	36.0	164
Actual SPS burn time (sec)		0.55	0.10	0.41	0.82	33
Actual RCS burn time (sec)		22.8	11.1	5.4	48.2	160
ΔV_u sensed (ft/sec)		0.1	1.23	-4.2	5.2	193
ΔV_v sensed (ft/sec)		-0.1	1.6	-4.4	3.5	193
ΔV_w sensed (ft/sec)		0.01	0.95	-2.8	2.1	193
ΔV_x residual[a] (ft/sec)		0.1	0.1	-0.5	0.65	193
ΔV_y residual[a] (ft/sec)		0.0	0.0	0.0	0.0	193
ΔV_z residual[a] (ft/sec)	0.0	0.0	0.0	0.0	0.0	193

Number of SPS MCC's - 33
Number of RCS ullages - 0
Number of RCS MCC's - 160
Number of RCS trims - 4

[a] ΔV commanded minus ΔV sensed in control axis coordinates

TABLE A-III.- STATISTICAL SUMMARY OF MIDCOURSE CORRECTION 3 (LOI - 22 Hours) - Concluded

Trajectory Characteristics

Item		Nominal	Mean	σ	Low	High	Sample Size
Actual speed (ft/sec)	Pre	3265	3265	1.12	3262	3269	200
	Post	3265	3265	1.29	3261	3270	200
Actual flight-path angle (deg)	Pre	78.09	78.09	0.08	77.84	78.30	200
	Post	78.09	78.09	0.08	77.84	78.33	200
Actual azimuth (deg)	Pre	121.83	121.83	0.07	121.61	122.04	200
	Post	121.83	121.83	0.10	121.55	122.15	200
Actual deviation in perilune altitude (ft)	Pre	0.0	3564	77,347	-294,568	231,130	200
	Post	0.0	-755	14,707	- 64,471	45,962	200
Actual deviation in perilune arrival time (sec)	Pre	0.0	2.62	34.81	-80.02	110.62	200
	Post	0.0	-0.87	6.87	-16.68	20.30	200
Actual deviation in altitude at node due to estimation error (ft)	Post	0.0	-469	10,797	-28,844	27,755	193
Actual deviation in altitude at node due to execution error (ft)	Post	0.0	-690	11,962	-62,861	44,028	193

TABLE A-IV.- STATISTICAL SUMMARY OF MIDCOURSE CORRECTION 4 (LOI - 5 Hours)

	Maneuver Characteristics					
Item	Nominal	Mean	σ	Low	High	Sample Size
ΔV required (ft/sec)	0.0	3.7	2.0	0.6	11.3	200
Total ΔV commanded (ft/sec)		3.7	2.0	1.03	11.3	195
Total SPS ΔV commanded (ft/sec)		4.9	1.8	3.0	11.3	114
Total RCS ΔV commanded (ft/sec)		2.1	0.6	1.03	2.99	81
RCS ΔV commanded (MCC) (ft/sec)		2.1	0.6	1.03	2.99	81
RCS ΔV commanded (trim) (ft/sec)		-	-	-	-	0
Actual SPS propellant expended (lb)		46.9	18.0	24.6	107.1	114
Actual RCS propellant expended (lb)		22.7	6.7	10.5	36.9	81
Actual SPS burn time (sec)		0.71	0.27	0.37	1.63	114
Actual RCS burn time (sec)		30.40	8.96	14.13	49.05	81
ΔV_u sensed (ft/sec)		0.2	2.7	-8.6	8.1	195
ΔV_v sensed (ft/sec)		0.04	1.4	-4.3	4.2	195
ΔV_w sensed (ft/sec)		-0.2	2.8	-7.9	6.8	195
ΔV_x residual[a] (ft/sec)		.08	0.23	-0.9	0.7	195
ΔV_y residual[a] (ft/sec)		0.0	0.02	-0.2	0.2	195
ΔV_z residual[a] (ft/sec)	0.0	0.0	0.0	0.0	0.0	195

Number of SPS MCC's - 114
Number of RCS ullages - 0
Number of RCS MCC's - 81
Number of RCS trims - 0

[a] ΔV commanded minus ΔV sensed in control axis coordinates

TABLE A-IV.- STATISTICAL SUMMARY OF MIDCOURSE CORRECTION 4 (LOI - 5 Hours) - Concluded

Item		Nominal	Mean	σ	Low	High	Sample Size
		Trajectory Characteristics					
Actual speed (ft/sec)	Pre	4075	4075	2.41	4068	4081	200
	Post	4075	4075	2.85	4067	4083	200
Actual flight-path angle (deg)	Pre	-81.43	-81.43	0.016	-81.49	-81.38	200
	Post	-81.43	-81.43	0.019	-81.49	-81.38	200
Actual azimuth (deg)	Pre	255.65	255.65	0.15	255.19	256.00	200
	Post	255.65	255.67	0.17	255.21	256.11	200
Actual deviation in perilune altitude (ft)	Pre	0.0	-755	14,707	-64,471	45,962	200
	Post	0.0	131.6	17,688	-47,021	50,222	200
Actual deviation in perilune arrival time (sec)	Pre	0.0	- 0.87	6.87	-16.68	20.30	200
	Post	0.0	- 0.14	8.48	-22.60	22.92	200
Actual deviation in altitude at node due to estimation error (ft)	Post	0.0	64	17,961	-50,102	48,866	195
Actual deviation in altitude at node due to execution error (ft)	Post	0.0	-92	3142	-10,441	10,868	195

TABLE A-V.- STATISTICAL SUMMARY OF RESULTS OF TRANSLUNAR PHASE SIMULATIONS

Parameters	Nominal	Mean	σ	Low	High	Sample Size
Total ΔV commanded (ft/sec)	0.0	21.5	10.2	6.2	56.2	200
Total SPS ΔV commanded (ft/sec)		19.3	10.6	3.2	53.6	200
Total RCS ΔV commanded (ft/sec)		2.2	1.3	0.0	5.5	200
Actual total SPS propellant (lb)		184.6	101.3	29.6	511.4	200
Actual total RCS propellant (lb)		22.9	14.9	0.0	61.2	200
Actual deviation in perilune altitude (ft)		131.6	17,688	-47,021	50,222	200
Actual deviation in arrival time at perilune (sec)	0.0	-0.14	8.48	-22.60	22.92	200

TABLE A-VI.- SAMPLE COVARIANCE MATRICES OF REQUIRED MIDCOURSE ΔV

First Midcourse Correction (TLI+9 Hours)

Sample covariance matrix of required midcourse ΔV (ft/sec; geocentric UVW coordinates)[a]

	1	2	3
1	1.2393220+001	Symmetric	
2	-7.7466724-001	1.2813262+001	
3	-2.9976965-003	3.0124755-003	4.5871587+000

Second Midcourse Correction (TLI+24 Hours)

Sample covariance matrix of required midcourse ΔV (ft/sec; geocentric UVW coordinates)[a]

	1	2	3
1	4.9920259-001	Symmetric	
2	-2.1729862-001	7.3300322-001	
3	7.4920920-002	-6.7872800-001	5.3204486-001

[a] Statistics are based on 200 samples.
Matrices are in normalized form; i.e., the diagonal elements are the standard deviations rather than the variances, and the off-diagonal elements are the correlation coefficients.

TABLE A-VI.- SAMPLE COVARIANCE MATRICES OF REQUIRED MIDCOURSE ΔV - Concluded

Third Midcourse Correction (LOI-22 Hours)

Sample covariance matrix of required midcourse ΔV (ft/sec; geocentric UVW coordinates)[a]

	1	2	3
1	1.2541959+000	Symmetric	
2	-2.6476865-001	1.6150671+000	
3	1.1702263-001	-5.4024729-001	9.8136036-001

Fourth Midcourse Correction (LOI-5 Hours)

Sample covariance matrix of required midcourse ΔV (ft/sec; selenocentric UVW coordinates)[a]

	1	2	3
1	2.7511015+000	Symmetric	
2	8.3344487-001	1.4152040+000	
3	5.7080260-001	4.7187215-001	2.8118498+000

[a] Statistics are based on 200 samples.
Matrices are in normalized form; i.e., the diagonal elements are the standard deviations rather than the variances, and the off-diagonal elements are the correlation coefficients.

TABLE A-VIII.- SAMPLE COVARIANCE MATRICES OF POSTMANEUVER STATE DEVIATIONS PROPAGATED TO THE NODE

After First Translunar Midcourse Correction (TLI+9 Hours)

Sample covariance matrix of actual state deviations propagated to the node[a]

	1	2	3	4	5	6
1	$(7.7448610+04)^2$	-5.8577712-01	3.1240073-01	6.5466508-01	-9.9954878-01	-3.1705136-01
2	-1.3782213+10	$(3.0378962+05)^2$	-5.4457992-01	-9.9609869-01	5.7336721-01	5.4576481-01
3	7.5325998+08	-5.1505522+09	$(3.1132875+04)^2$	5.4247385-01	-3.0935970-01	-9.9836485-01
4	9.2544097+06	-5.5232058+07	3.0825772+06	$(1.8252229+02)^2$	-6.4324233-01	-5.4391719-01
5	-3.3188028+06	7.4674034+06	-4.1290182+05	-5.0333180+03	$(4.2871021+01)^2$	3.1346603-01
6	-9.7716110+05	6.5978341+06	-1.2368910+06	-3.9506780+03	5.3478257+02	$(3.9794489+01)^2$

After Second Translunar Midcourse Correction (TLI+24 Hours)

Sample covariance matrix of actual state deviations propagated to the node[a]

	1	2	3	4	5	6
1	$(7.7448610+04)^2$	-5.8577712-01	3.1240073-01	6.5466508-01	-9.9954878-01	-3.1705136-01
2	-1.3782213+10	$(3.0378962+05)^2$	-5.4457992-01	-9.9609868-01	5.7336721-01	5.4576481-01
3	7.5325998+08	-5.1505522+09	$(3.1132875+04)^2$	5.4247385-01	-3.0935970-01	-9.9836485-01
4	9.2544097+06	-5.5232058+07	3.0825772+06	$(1.8252229+02)^2$	-6.4324233-01	-5.4391719-01
5	-3.3188028+06	7.4674034+06	-4.1290182+05	-5.0333180+03	$(4.2871021+01)^2$	3.1346603-01
6	-9.7716110+05	6.5978341+06	-1.2368910+06	-3.9506780+03	5.3478257+02	$(3.9794489+01)^2$

[a] All statistics based on 200 samples. Units are feet and feet per second; selenocentric UVW coordinates. Diagonal elements are variances; elements above the diagonal are correlation coefficients; elements below the diagonal are covariances.

TABLE A-VIII.- SAMPLE COVARIANCE MATRICES OF POSTMANEUVER STATE DEVIATIONS

PROPAGATED TO THE NODE - Continued

After Third Translunar Midcourse Correction (LOI-22 Hours)

Sample covariance matrix of actual state deviations propagated to the node[a]

	1	2	3	4	5	6
1	$(1.4986991+04)^2$	-7.6817630-01	1.6020729-01	8.1140649-01	-9.9149784-01	-1.2534540-01
2	-7.0043633+08	$(6.0840576+04)^2$	-3.1598700-01	-9.9612478-01	7.6510195-01	2.6873731-01
3	2.7240494+07	-2.1811262+08	$(1.1345359+04)^2$	3.1153056-01	-1.6185344-01	-9.7701185-01
4	4.5791339+05	-2.2821148+06	1.3309120+05	$(3.7655673+01)^2$	-8.1129889-01	-2.6265950-01
5	-1.3135687+05	4.1148992+05	-1.6232551+04	-2.7005851+02	$(8.8398841+00)^2$	1.1863498-01
6	-2.7663972+04	2.4077587+05	-1.6323368+05	-1.4565158+02	1.5443688+01	$(1.4726233+01)^2$

After Fourth Translunar Midcourse Correction (LOI-5 Hours)

Sample covariance matrix of actual state deviations propagated to the node[a]

	1	2	3	4	5	6
1	$(1.8189068+04)^2$	-9.8835925-01	5.8582907-01	9.9028383-01	-9.9339642-01	-5.2476119-01
2	-1.3506763+09	$(7.5132182+04)^2$	-5.8572236-01	-9.9874529-01	9.8220064-01	5.2139638-01
3	1.6826411+08	-6.9490902+08	$(1.5791018+04)^2$	5.8882326-01	-6.1879174-01	-9.4914730-01
4	8.3482823+05	-3.4778252+06	4.3094525+05	$(4.6347574+01)^2$	-9.8553624-01	-5.2486764-01
5	-1.9563366+05	7.9898158+05	-1.0579501+05	-4.9454994+02	$(1.0827060+01)^2$	5.5272094-01
6	-1.2822927+05	5.2627053+05	-2.0135332+05	-3.2680737+02	8.0395457+01	$(1.3434300+01)^2$

[a] All statistics based on 200 samples. Units are feet and feet per second; selenocentric UVW coordinates. Diagonal elements are variances; elements above the diagonal are correlation coefficients; elements below the diagonal are covariances.

TABLE A-VIII.- STATISTICAL SUMMARY OF DEVIATION IN ALTITUDE AT NODE

Deviation in Altitude at Node (ft)	
Mean	= - 114.6
Standard deviation	= 18,189.1
Smallest sample	= -49,928.7
25th percentile sample	= -11,050.9
50th percentile sample	= - 716.7
75th percentile sample	= 12,289.6
90th percentile sample	= 23,426.4
95th percentile sample	= 28,870.8
99th percentile sample	= 42,186.2
Largest sample	= 49,720.8

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TABLE B-I.- STATISTICAL SUMMARY OF MIDCOURSE

CORRECTION 5 (TEI + 15 Hours)

Item	Nominal	Mean	σ	Low	High	Sample Size
		Maneuver Characteristics				
ΔV required (ft/sec)	0.0	5.4	3.9	0.1	21.2	200
Total ΔV commanded (ft/sec)		5.9	3.9	1.1	22.8	183
Total SPS ΔV commanded (ft/sec)		13.7	2.9	10.7	17.2	5
Total RCS ΔV commanded (ft/sec)		5.5	3.2	1.1	13.9	183
RCS ΔV commanded (MCC) (ft/sec)		5.5	3.2	1.1	13.9	178
RCS ΔV commanded (trim) (ft/sec)		1.3	0.5	0.7	2.0	5
Actual SPS propellant expended (lb)		36.6	8.0	26.3	48.4	5
Actual RCS propellant expended (lb)		16.1	9.5	2.9	40.6	183
Actual SPS burn time (sec)		0.55	0.12	0.40	0.72	5
Actual RCS burn time (sec)		21.7	13.0	3.8	55.1	178
ΔV_u sensed (ft/sec)		0.00	0.08	-0.38	0.16	183
ΔV_v sensed (ft/sec)		0.28	6.87	-21.37	13.10	183
ΔV_w sensed (ft/sec)		0.01	0.23	-0.91	0.43	183
ΔV_x residual[a] (ft/sec)		0.09	0.07	-0.45	0.27	183
ΔV_y residual[a] (ft/sec)		0.00	0.03	-0.21	0.11	183
ΔV_z residual[a] (ft/sec)	0.0	0.00	0.03	-0.20	0.20	183

Number of SPS MCC's - 5
Number of RCS ullages - 5
Number of RCS MCC's - 178
Number of RCS trims - 5

[a] ΔV commanded minus ΔV sensed in control axis coordinates

TABLE B-I.- STATISTICAL SUMMARY OF MIDCOURSE CORRECTION 5 (TEI + 15 Hours) - Concluded

Item		Trajectory Characteristics Nominal	Mean	σ	Low	High	Sample Size
Actual speed (ft/sec)	Pre	3667.5	3667.4	5.1	3653.4	3681.0	200
	Post	3667.5	3667.4	4.4	3655.7	3678.7	
Actual flight-path angle (deg)	Pre	- 79.87	- 79.88	0.10	- 80.07	- 79.56	
	Post	- 79.87	- 79.87	0.01	- 79.90	- 79.85	
Actual azimuth (deg)	Pre	130.08	130.08	0.43	128.91	131.16	
	Post	130.08	130.08	0.43	128.89	131.18	
Actual entry path angle (deg)	Pre	- 6.509	[a]	[a]	[a]	[a]	
	Post	- 6.509	- 6.497	0.237	- 7.312	- 5.756	
Actual deviation in entry speed (ft/sec)	Pre	0.0	[a]	[a]	[a]	[a]	
	Post		0.9	4.6	- 11.4	16.2	
Actual deviation in entry longitude (deg)	Pre		[a]	[a]	[a]	[a]	
	Post		0.00	0.76	- 2.37	1.96	
Actual deviation in entry latitude (deg)	Pre		[a]	[a]	[a]	[a]	
	Post		0.02	0.31	- 1.17	0.96	
Actual deviation in entry azimuth (deg)	Pre		[a]	[a]	[a]	[a]	
	Post		0.00	0.36	- 0.90	0.99	200
Error in pre-MCC estimate of γ at entry (deg)			- 0.003	0.129	- 0.338	0.360	200
Actual deviation in γ at entry due to MCC execution error (deg)			- 0.011	0.143	- 0.477	0.482	183
Actual post-MCC deviation in γ at entry (deg)		0.0	0.012	0.237	- 0.803	0.753	200

[a] Not calculated.

TABLE B-II.- STATISTICAL SUMMARY OF MIDCOURSE CORRECTION 6 (Entry - 15 Hours)

Item	Nominal	Maneuver Characteristics Mean	σ	Low	High	Sample Size
ΔV required (ft/sec)	0.0	0.5	0.4	0.0	2.3	200
Total ΔV commanded (ft/sec)		0.9	0.4	0.5	2.3	92
Total SPS ΔV commanded (ft/sec)		-	-	-	-	0
Total RCS ΔV commanded (ft/sec)		0.9	0.4	0.5	2.3	92
RCS ΔV commanded (MCC) (ft/sec)		0.9	0.4	0.5	2.3	92
RCS ΔV commanded (trim) (ft/sec)		-	-	-	-	0
Actual SPS propellant expended (lb)		-	-	-	-	0
Actual RCS propellant expended (lb)		2.4	1.1	1.1	6.3	92
Actual SPS burn time (sec)		-	-	-	-	0
Actual RCS burn time (sec)		3.3	1.5	1.4	8.5	92
ΔV_u sensed (ft/sec)		0.00	0.01	-0.01	0.01	
ΔV_v sensed (ft/sec)		-0.08	0.90	-2.09	2.09	
ΔV_w sensed (ft/sec)		0.00	0.00	0.00	0.00	
ΔV_x residual[a] (ft/sec)		0.10	0.06	0.00	0.19	
ΔV_y residual[a] (ft/sec)		0.00	0.00	0.00	0.00	
ΔV_z residual[a] (ft/sec)	0.0	0.00	0.00	0.00	0.00	92

Number of SPS MCC's - 0
Number of RCS ullages - 0
Number of RCS MCC's - 92
Number of RCS trims - 0

[a] ΔV commanded minus ΔV sensed in control axis coordinates

TABLE B-II.- STATISTICAL SUMMARY OF MIDCOURSE CORRECTION 6 (Entry - 15 Hours) - Concluded

Item		Trajectory Characteristics Nominal	Mean	σ	Low	High	Sample Size
Actual speed (ft/sec)	Pre	6406.0	6405.7	9.6	6379.9	6430.5	200
	Post	6406.0	6405.7	9.6	6380.0	6430.3	
Actual flight-path angle (deg)	Pre	- 76.69	- 76.69	0.01	- 76.72	- 76.67	
	Post	- 76.69	- 76.69	0.00	- 76.70	- 76.68	
Actual azimuth (deg)	Pre	126.58	126.58	0.38	125.50	127.56	
	Post	126.58	126.58	0.38	125.50	127.56	
Actual entry path angle (deg)	Pre	- 6.509	- 6.497	0.237	- 7.312	- 5.756	
	Post	- 6.509	- 6.511	0.073	- 6.684	- 6.331	
Actual deviation in entry speed (ft/sec)	Pre	0.0	0.9	4.6	- 11.4	16.2	
	Post		0.6	4.6	- 11.7	16.2	
Actual deviation in entry longitude (deg)	Pre		0.00	0.76	- 2.37	1.96	
	Post		- 0.02	0.67	- 1.92	1.61	
Actual deviation in entry latitude (deg)	Pre		0.02	0.31	- 1.17	0.96	
	Post		0.00	0.14	- 0.36	0.37	
Actual deviation in entry azimuth (deg)	Pre		0.00	0.36	- 0.90	0.99	
	Post		0.00	0.35	- 0.90	0.96	200
Error in pre-MCC estimate of γ at entry (deg)			0.002	0.025	- 0.068	0.074	200
Actual deviation in γ at entry due to MCC execution error (deg)			0.001	0.040	- 0.069	0.066	92
Actual post-MCC deviation in γ at entry (deg)		0.0	- 0.002	0.073	- 0.175	0.178	200

TABLE B-III.- STATISTICAL SUMMARY OF MIDCOURSE

CORRECTION 7 (Entry - 3 Hours)

Maneuver Characteristics

Item	Nominal	Mean	σ	Low	High	Sample Size
ΔV required (ft/sec)	0.0	0.6	0.4	0.0	1.7	200
Total ΔV commanded (ft/sec)		1.3	0.2	1.0	1.7	37
Total SPS ΔV commanded (ft/sec)		-	-	-	-	0
Total RCS ΔV commanded (ft/sec)		1.3	0.2	1.0	1.7	37
RCS ΔV commanded (MCC) (ft/sec)		1.3	0.2	1.0	1.7	37
RCS ΔV commanded (trim) (ft/sec)		-	-	-	-	0
Actual SPS propellant expended (lb)		-	-	-	-	0
Actual RCS propellant expended (lb)		3.6	0.7	2.8	5.0	37
Actual SPS burn time (sec)		-	-	-	-	0
Actual RCS burn time (sec)		4.8	0.9	3.7	6.7	37
ΔV_u sensed (ft/sec)		0.00	0.05	-0.06	0.07	
ΔV_v sensed (ft/sec)		-0.02	1.24	-1.52	1.71	
ΔV_w sensed (ft/sec)		0.00	0.00	0.00	0.00	
ΔV_x residual[a] (ft/sec)		0.10	0.05	0.01	0.19	
ΔV_y residual[a] (ft/sec)		0.00	0.00	0.00	0.00	
ΔV_z residual[a] (ft/sec)	0.0	0.00	0.00	0.00	0.00	37

Number of SPS MCC's - 0
Number of RCS ullages - 0
Numb r of RCS MCC's - 37
Number of RCS trims- 0

[a] ΔV commanded minus ΔV sensed in control axis coordinates

TABLE B-III.- STATISTICAL SUMMARY OF MIDCOURSE CORRECTION 7 (Entry - 3 Hours) - Concluded

Item		Trajectory Characteristics Nominal	Mean	σ	Low	High	Sample Size
Actual speed (ft/sec)	Pre	12,189.3	12,187.2	70.6	11,997.6	12,369.2	200
	Post	12,189.3	12,187.2	70.6	11,998.1	13,369.2	
Actual flight-path angle (deg)	Pre	- 68.82	- 68.82	0.10	-69.08	- 68.53	
	Post	- 68.82	- 68.82	0.10	- 69.07	- 68.53	
Actual azimuth (deg)	Pre	119.88	119.88	0.42	118.54	120.85	
	Post	119.88	119.88	0.42	118.54	120.85	
Actual entry path angle (deg)	Pre	- 6.509	- 6.511	0.073	- 6.684	- 6.331	
	Post	- 6.509	- 6.511	0.056	- 6.674	- 6.366	
Actual deviation in entry speed (ft/sec)	Pre	0.0	0.6	4.6	- 11.7	16.2	
	Post		0.6	4.6	- 11.6	16.2	
Actual deviation in entry longitude (deg)	Pre		-0.02	0.67	- 1.92	1.61	
	Post		-0.02	0.66	- 1.89	1.61	
Actual deviation in entry latitude (deg)	Pre		0.00	0.14	- 0.36	0.37	
	Post		0.00	0.12	- 0.36	0.36	
Actual deviation in entry azimuth (deg)	Pre		0.00	0.35	- 0.90	0.96	
	Post		0.00	0.35	- 0.90	0.96	200
Error in pre-MCC estimate of γ at entry (deg)			0.001	0.040	- 0.117	0.130	200
Actual deviation in γ at entry due to MCC execution error (deg)			0.001	0.013	- 0.021	0.026	37
Actual post-MCC deviation in γ at entry (deg)		0.0	-0.002	0.056	- 0.165	0.143	200

TABLE B-IV.- SUMMARY OF RESULTS OF TRANSEARTH PHASE SIMULATIONS

Parameters	Nominal	Mean	σ	Low	High	Sample Size
Total ΔV commanded (ft/sec)	0.0	6.0	4.1	0.0	22.8	200
Total SPS ΔV commanded (ft/sec)		0.3	2.2	0.0	17.2	200
Total RCS ΔV commanded (ft/sec)		5.7	3.5	0.0	14.6	200
Actual total SPS propellant (lb)		0.9	5.8	0.0	48.4	200
Actual total RCS propellant (lb)	0.0	16.5	10.3	0.0	45.1	200
Actual entry flight-path angle (deg)	-6.509	-6.511	0.056	-6.674	-6.366	200
Actual deviation in entry speed (ft/sec)	0.0	0.6	4.6	-11.6	16.2	200
Actual deviation in entry longitude (deg)		-0.02	0.66	-1.89	1.61	200
Actual deviation in entry latitude (deg)		0.00	0.12	-0.36	0.36	200
Actual deviation in entry azimuth (deg)	0.0	0.00	0.35	-0.90	0.96	200

TABLE B-V.- SAMPLE COVARIANCE MATRICES OF REQUIRED MIDCOURSE ΔV

Fifth Midcourse Correction (TEI+15 Hours)

Sample covariance matrix of required midcourse ΔV (ft/sec; geocentric UVW coordinates)[a]

	1	2	3
1	7.8436416-02	Symmetric	
2	1.0000000+00	6.6444158+00	
3	1.0000000+00	1.0000000+00	2.1753580-01

Sixth Midcourse Correction (Entry-15 Hours)

Sample covariance matrix of required midcourse ΔV (ft/sec; geocentric UVW coordinates)[a]

	1	2	3
1	4.6746598-03	Symmetric	
2	1.0000000+00	6.9798748-01	
3	1.0000000+00	1.0000000+00	5.9709009-04

Seventh Midcourse Correction (Entry-3 Hours)

Sample covariance matrix of required midcourse ΔV (ft/sec; geocentric UVW coordinates)[a]

	1	2	3
1	2.8528771-02	Symmetric	
2	1.0000000+00	7.4274422-01	
3	1.0000000+00	1.0000000+00	2.7688235-04

[a] Statistics are based on 200 samples.
Matrices are in normalized form; i.e., the diagonal elements are the standard deviations rather than the variances and the off-diagonal elements are the correlation coefficients. The dominance of the V-component and the high correlation between components indicate that the required ΔV was always in a direction nearly parallel to the V-axis.

TABLE B-VI.- SAMPLE COVARIANCE MATRICES OF POSTMANEUVER STATE DEVIATIONS PROPAGATED TO ENTRY INTERFACE

Midcourse Correction 5 (TEI+15 Hours)

Sample covariance matrix of postmaneuver state deviations (actual) propagated to entry interface[a]

	1	2	3	4	5	6
1	$(1.4384921\text{-}01)^2$	-2.7681526-01	-5.9358153-01	2.7777660-01	2.3540578-01	5.9357483-01
2	-7.0351733+03	$(1.7667589\text{+}05)^2$	-1.4118884-01	-9.9959580-01	-9.6618438-01	1.4037065-01
3	-4.5006813+03	-1.3148254+09	$(5.2709684\text{+}04)^2$	1.4128836-01	1.8875486-01	-9.9945699-01
4	5.9703074+00	-2.6387319+07	1.1127314+06	$(1.4941478\text{+}02)^2$	9.6775724-01	-1.4073935-01
5	5.9308861-01	-2.9897322+06	1.7425431+05	2.5325321+03	$(1.7514389\text{+}01)^2$	-1.9619116-01
6	1.9400025+01	5.6347277+06	-1.1969440+07	-4.7778049+03	-7.8071720+02	$(2.2720575\text{+}02)^2$

Midcourse Correction 6 (Entry-15 Hours)

Sample covariance matrix of postmaneuver state deviations (actual) propagated to entry interface[a]

	1	2	3	4	5	6
1	$(1.4606797\text{-}01)^2$	-1.0997642-01	-7.0668060-01	1.1165938-01	-1.3589476-02	7.0668651-01
2	-8.8843583+02	$(5.5305903\text{+}04)^2$	-8.1798736-02	-9.9557792-01	-7.6386662-01	8.1542520-02
3	-5.4425633+03	-2.3853022+08	$(5.2726062\text{+}04)^2$	8.5799383-02	1.9571418-01	-9.9945607-01
4	7.8368304-01	-2.6456781+06	2.1737008+05	$(4.8049653\text{+}01)^2$	7.7645220-01	-8.6342244-02
5	-1.3897688-02	-2.9578346+05	7.2249108+04	2.6121003+02	$(7.0013995\text{+}00)^2$	-2.1609135-01
6	2.3457114+01	1.0248219+06	-1.1975174+07	-9.4277137+02	-3.4380726+02	$(2.2724419\text{+}02)^2$

[a]Based on 200 samples. Units are feet and feet per second; geocentric UVW coordinates. Elements above the diagonal are correlation coefficients.

TABLE B-VI.- SAMPLE COVARIANCE MATRICES OF POSTMANEUVER STATE DEVIATIONS PROPAGATED TO ENTRY INTERFACE - Concluded

Midcourse Correction 7 (Entry-3 Hours)

Sample covariance matrix of postmaneuver state deviations (actual) propagated to entry interface[a]

	1	2	3	4	5	6
1	$(1.4899481\text{-}01)^2$	-1.6878743-02	-7.3412286-01	1.6798720-02	-1.0684651-01	7.3418336-01
2	-1.0780741+02	$(4.2868408\text{+}04)^2$	-1.0773607-01	-9.9196093-01	-6.8624581-01	1.0872872-01
3	-5.7676011+03	-2.4353075+08	$(5.2729701\text{+}04)^2$	1.1155758-01	2.2216919-01	-9.9945843-01
4	9.4195517-02	-1.6003494+06	2.2137945+05	$(3.7634218\text{+}01)^2$	7.0372903-01	-1.1347482-01
5	-9.8809148-02	-1.8259241+05	7.2711784+04	1.6438191+02	$(6.2067701\text{+}00)^2$	-2.4593819-01
6	2.4858758+01	1.0592180+06	-1.1976331+07	-9.7047898+02	-3.4689286+02	$(2.2724992\text{+}02)^2$

[a] Based on 200 samples. Units are feet and feet per second; geocentric UVW coordinates. Elements above the diagonal are correlation coefficients.

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UNITED STATES GOVERNMENT

Memorandum

NASA - Manned Spacecraft Center
Mission Planning & Analysis Division

TO : See attached list

DATE: JUN 2 4 1969

File No. 69-FM13-353

FROM : FM13/Chief, Mission Planning Support Office

SUBJECT: Apollo 11 (G) Mission Spacecraft Dispersion Analysis, Volume II--Translunar and Transearth Phases

The Dispersion Analysis results for the Apollo 11 translunar and transearth phases are presented in the attached document. Four translunar and three transearth midcourse corrections are covered. The analyses were performed on the Apollo 11 Operational Trajectory (I.N. 69-FM-98) and within the guidelines of MCC logic established in the Mission Techniques documents.

Recent changes in the logic will necessitate a revision of the Dispersion Analysis. In addition, the CSM TVC pointing error has been updated. These revisions are expected to be available by July 8, 1969.

for R. P. Parten

APPROVED BY:

John P. Mayer
Chief, Mission Planning
and Analysis Division

Enclosure

Addressees:
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(Distribution "D")

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