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POSTFLIGHT EVALUATION OF THE APOLLO 14 SPACECRAFT TRAJECTORIES

Mission Planning Support Office

MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER

HOUSTON, TEXAS

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Edited by E. Dixon Murrah
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POSTFLIGHT EVALUATION OF

THE APOLLO 14 SPACECRAFT TRAJECTORIES

Edited by E. Dixon Murrah

SUMMARY

This document was compiled to provide a summary of the postflight trajectory analyses that have been performed by the Mission Planning and Analysis Division. The total mission from earth launch to earth landing is discussed, with emphasis on the lunar module descent and the rendezvous phases.

The CSM and LM encountered no significant maneuver planning or execution problems except for a post-TLI docking problem. Prior to launching, overcast and rain in the launch area caused a 40-minute, 2.9-second hold. This delay caused the flight azimuth to shift from 72° to 75.55° and necessitated that the ground elapsed time (g.e.t.) clocks on board the spacecraft and in the control center be updated (update performed at 54:53:36 AET). The update was necessary so that the flight plan events measured in g.e.t. would agree with clock g.e.t.

The accuracy of the lunar landing (within 175 ft of target) and of the earth landing (within 1 n. mi.) indicates that the overall mission performance was well within expected dispersions. A summary of events is given in table I. The primary source for the times associated with this table was reduced telemetry data; the times, therefore, can be expected to differ from the times that appeared on the real-time displays in the Mission Control Center.

INTRODUCTION

Data for this document were contributed largely by the Landing Analysis Branch, Flight Analysis Branch, Mathematical Physics Branch, Orbital Mission Analysis Branch, and Planetary Mission Analysis Branch. In addition, contributions were made by TRW Systems under MTCP task A-50. For detailed analyses on various parts of the mission and for background reference material, a bibliography is provided; it is also a complete list of the source material for this document. Data are derived from

both real-time determinations and postmission reconstructions of the major trajectory events.

All times given in the text, unless otherwise identified, are in Apollo elapsed time (AET), that is, time in hours:minutes:seconds that has elapsed from lift-off.

DEFINITIONS

AET	Apollo elapsed time
ALSEP	Apollo Lunar Surface Experiment Package
APS	auxiliary propulsion system (S-IVB)
CSM	command and service modules
DOI	descent orbit insertion
EI	entry interface
g.e.t.	ground elapsed time
G.m.t.	Greenwich mean time
IU	instrument unit
LM	lunar module
LOI	lunar orbit insertion
MCC	midcourse correction
MSFN	Manned Space Flight Network
PDI	powered descent initiation
RTCC	Real-Time Computer Complex
RCS	reaction control system
SPS	service propulsion system
TLI	transular injection
ΔV	change in velocity

ΔV_g	velocity to be gained
γ	entry flight-path angle
λ (table II)	longitude
ϕ (table II)	latitude
R	entry
X,Y,Z	coordinate components

MISSION EVENTS

Launch

The Apollo 14 spacecraft was launched, after a 40-minute, 2.9-second hold, at $21^h03^m02^s$ G.m.t. (3:03 p.m. c.s.t.) on a flight azimuth of 75.55°.

Translunar Injection (TLI)

Translunar injection (TLI) was performed in a near-nominal manner with ignition at 2:28:32.4. The resulting perilune altitude was 2022 n. mi., which compares with a prelaunch planned perilune altitude of 2030 n. mi. The actual TLI burn time was 350.8 seconds, which compares with a real-time plan of 348.5 seconds. The difference was primarily due to an uncertainty in the Real-Time Computer Complex (RTCC) thrust model.

Transposition and Docking

Actual CSM separation from the LM/S-IVB occurred at 3:02:29.4. Because of a problem with the docking probe, actual hard docking did not occur until 4:56:56, approximately 1 hour 45 minutes later than was nominally planned.

CSM/LM Separation from S-IVB

Actual CSM/LM separation from the S-IVB occurred at 5:47:14.4. The actual burn time and ΔV of the separation maneuver were 6.9 seconds and 0.8 fps, as compared with a prelaunch plan of 3.0 seconds and 0.4 fps. The resulting perilune altitude was lowered to 1980 n. mi., as compared to the prelaunch nominal 2030-n. mi. altitude.

S-IVB Evasive Maneuver

Because of the problems in docking the CSM with the LM/S-IVB, the final CSM/LM ejection was delayed until 5:47:14.4, thus eliminating the possibility of performing the APS-1 maneuver on schedule (fig. 1). The auxiliary ascent propulsion system (APS) evasive maneuver was executed at 6:04:20, but because the S-IVB instrument unit (IU) telemetry was inoperative at that time, the maneuver performance was difficult to determine. Later Manned Space Flight Network (MSFN) tracking data indicate the maneuver was performed in a near-nominal manner (burn time of 80 sec and ΔV of 9.5 fps).

S-IVB Liquid Oxygen Dump

The S-IVB expelled through the J-2 engine the liquid oxygen remaining in its tanks at approximately 6:25:00. Following the LOX dump, the behavior of the Doppler tracking data began to indicate that some type of thrusting was occurring on board the S-IVB, probably in the form of a continuous vent. By the time (08:15:00) a target vector for APS-1 was required, the trajectory had been perturbed to such an extent that the MSFN orbit solutions were no longer reliable.

S-IVB APS-1 Maneuver

The docking problem caused the time (fig. 1) for the APS-1 maneuver to slip from its scheduled time of 6:30:00 to 9:00:00 and the APS-2 maneuver was cancelled. As a result of the apparent S-IVB venting following the LOX dump and its effect on the MSFN tracking data, the APS-1 burn target was necessarily based on the MSFC estimate of the trajectory, which was obtained by updating the best earth-orbit state vector with telemetered accelerometer data to model TLI and subsequent maneuvers. APS-1 was performed successfully at 9:00:00.

Midcourse Correction 1 (MCC-1)

MCC-1 was never computed in the RTCC nor performed because the predicted MCC-2 ΔV was well within the expected range (70 to 90 fps, depending on whether a constant G.m.t. or g.e.t. at LOI was desired). A predicted MCC-2 ΔV of 71.4 fps would correspond to an MCC-1 ΔV of approximately 38 fps, based on preflight experience.

Midcourse Correction 2 (MCC-2)

The final real-time plan for the hybrid transfer (MCC-2) had an ignition time of 30:36:07. This maneuver was designed to set up the lunar

approach hyperbola from which, after lunar orbit insertion (LOI), an orbit could be achieved that

a. began rev. 2 at 84:05:10.07 AET, and that

b. resulted in no flight-path angle change at descent orbit insertion (DOI).

Midcourse correction 2 was targeted using a state vector computed from Bermuda tracking (BDAX132). The maneuver was to be a 71.4-fps SPS burn that would place the spacecraft on a trajectory with the closest approach to the moon occurring at 82:00:36.97 g.e.t. and an altitude of 60.3 n. mi. above the radius of the lunar landing site.

The burn was executed on time (30:36:07.9) and the comparison between the planned and actual midcourse maneuver is best seen in terms of the component ΔV_g values.

	Vg_x	Vg_y	Vg_z
Real-time plan	+34.58 fps	-62.26	+2.89
Actual MCC-2	34.3 fps	-62.2	+3.2

In accordance with mission rules the small MCC-2 residuals were not trimmed out with the RCS.

The confirmed maneuver gave the time of closest approach as 82:00:45 g.e.t. with perilune altitude being 67.05 n. mi. Although the burn residuals were small in the body coordinate system, they were predominantly along the z direction when transformed into external ΔV values. This was overcome by MCC-4.

Midcourse Correction 3 (MCC-3)

No MCC-3 maneuvers were computed in the RTCC because the predicted MCC-4 ΔV was within a reasonable range (1.7 to 3.8 fps, depending on whether perilune altitude control only or a reoptimization BAP-4 MCC was desired). A predicted MCC-4 ΔV of 3.8 fps would correspond to an MCC-3 ΔV of approximately 1.0 fps, based on preflight experience.

Clock Update

At 54:53:36 the spacecraft onboard clocks and the ground g.e.t. clocks were changed by adding 40 minutes 2.9 seconds. This change was made so that the mission g.e.t. agreed with the flight plan g.e.t.

Midcourse Correction 4 (MCC-4)

Because of the prediction of a rather high incoming perilune altitude (65.17 n. mi.), which would have required large lunar orbit apsidal rotations for the LOI maneuver, MCC-4 was performed. In order to conserve RCS fuel, the decision was made to perform a BAP-4 MCC (3.8 fps) with the SPS. Normally, perilune altitude is the only desired parameter to be controlled (ΔV = 1.7 fps for altitude control only); but, in this situation, a larger MCC-4 ΔV was desired so that a minimum impulse SPS burn could be used. The actual time of MCC-4 was 76:58:12, and the Ascension tracking vector (ACNX264) was used to target it. The actual burn time was 0.65 seconds and the resulting perilune altitude was 60.7 n. mi. Both of these figures are very close to the real-time plan (0.69 sec and 60.6 n. mi.), which indicates a near-nominal burn was executed and no RCS trim was performed.

Lunar Orbit Insertion (LOI)

The final lunar orbit insertion plan had an ignition time of 82:36:42.7 g.e.t. (81:56:39.8 AET). This maneuver was designed to set up the lunar parking orbit such that

a. the spacecraft began rev 2 at 84:44:53.15 g.e.t. (84:04:50.25 AET)

b. there would be no flight-path angle change at DOI

c. time of PDI would be 108:41:46 g.e.t. (108:01:43.1 AET).

Lunar orbit insertion was targeted using the Guaymas tracking state vector (GWMX300). The LOI burn was to be a 3021.8-fps (372.28-sec burn time) SPS maneuver that would place the spacecraft into a 58.1- by 169.3-n. mi. lunar orbit.

The LOI burn was performed perfectly. In terms of component ΔV_g values,

	V_{g_X}	V_{g_Y}	V_{g_Z}	Burn time
Real-time plan	-599.34	-1645.02	+2463.99	372.28 sec
Actual LOI	-599.1	-1645.0	+2463.7	370.8 sec

The confirmed LOI maneuver showed the orbit to be 58.4 n. mi. by 169.0 n. mi. with perfect conditions for DOI.

S-IVB Lunar Impact

The S-IVB impacted the moon at 82:37:52.2 at longitude 26.023° W (±0.03°) and latitude 8.093° S (±0.15°). The lunar radius at the point of impact was calculated to be 937.045 n. mi. ± 0.745 n. mi. This point is 159 n. mi. from the target point and well within the expected 3σ impact dispersion ellipse (fig. 2).

The nominal target for the S-IVB impact has been at west longitude 33.25° and south latitude 1.596°. The impact point as determined in real time was at longitude 26.0° W (±0.2°) and latitude 7.81° S (±0.4°), which was 155.5 n. mi. from the target point. The close agreement between the real-time estimate and the impact point as determined post-mission adds confidence to the real-time estimate technique.

Descent Orbit Insertion (DOI)

Because LOI was performed so well, the real-time planned DOI maneuver was essentially the one used in targeting LOI. The DOI ignition was 86:10:53. The final plan was based on state vector GWMX334. The DOI burn was a 205.7-fps (20.77-sec burn time) SPS burn, and it placed the spacecraft into a 9.1- by 58.8-n. mi. lunar orbit.

The DOI burn was executed on time and, in terms of external ΔV, it had the following:

	ΔV_x	ΔV_y	ΔV_z	Δt_b
Pre-LOI	-207.1 fps	0.0	+1.1	
Real-time plan for DOI	-206.4	0.0	-3.7	20.77 sec
Actual DOI	-205.7	0.0	-3.5	20.8 sec

CSM/LM Undocking and CSM Separation

The CSM separation maneuver took place at 103:47:41.6. An actual burn time of 2.7 seconds and a ΔV of 0.8 fps achieved an orbit shape of 7.8 n. mi. by 60.2 n. mi., which was very close to the prelaunch plan orbit of 8.2 n. mi. by 59.5 n. mi.

CSM Circularization

The CSM circularization burn occurred on time at 105:11:46.1. A 2-fps overburn from the planned 76.2-fps maneuver was noted by the crew, but 1 fps of this overburn was immediately trimmed out with the RCS, resulting in an actual ΔV of 77.2 fps. This slight overburn resulted in an actual orbit shape of 56.0 n. mi. by 63.9 n. mi., instead of the real-time plan orbit of 55.6 n. mi. by 63.3 n. mi.

Powered Descent Initiation (PDI)

The powered descent was initiated at 108:02:26.5 by ignition of the descent propulsion system. During the descent a ΔRLS update of +2800 feet and one landing point redesignation of approximately 350 feet left (for smoother terrain) were made. After these two corrections the LM was still about 1400 feet short of the desired landing point (table IV). This distance, which was flown out manually by the crew, apparently resulted from incorrect map offset points used in targeting the LM guidance system. A total ΔV of 6997 fps was expended in this descent and landing as compared to a predicted prelaunch ΔV of 6637.6 fps.

Landing

The LM touched the lunar surface at 108:15:09.3 at south latitude 3.6733° and west longitude 17.4653°. This point (fig. 2) was 174 feet from the premission target point. During the subsequent extravehicular activity the Apollo Lunar Surface Experiment Package (ALSEP) was deployed 164 feet north and 577 feet west of the LM. The map coordinates of the LM and ALSEP are given in table IV.

CSM Plane Change

The plane change was initiated at 117:29:33.1 and utilized an 18.5-second (370.5 fps) SPS burn. The maneuver was nominal and no problems were encountered.

Ascent

The LM lifted off from the lunar surface at 141:45:40. Its performance during the ascent was as near nominal as has been seen in the Apollo program. The LM lifted off on the precise time that had been given the crew; however, on the portion of the CSM pass just prior to lift-off, tracking revealed that the LM should have lifted off

1 second later than the crew had been instructed. It was decided that no change in lift-off time should be sent to the LM. This error in lift-off time coupled with normal performance dispersions (8000 ft down range) produced an error in the LM orbit insertion conditions. A postinsertion trim burn of $\Delta VX = -1.2$ fps and $\Delta VZ = -2.5$ fps was executed to correct the insertion dispersions.

Tweak

The tweak maneuver was initiated at 141:56:49.4, 4 minutes after insertion, and it provided the desired nominal rendezvous offsets for the estimated TPI solution.

Rendezvous

With the exception of some CSM VHF problems, which are discussed in appendix B, the direct rendezvous was executed as planned and performed within the expected 1σ dispersions. The terminal phase was initialized at 142:30:51 and finalized at 143:13:29.1.

Docking

The LM and CSM docked at 143:32:50.5 and no problems were encountered with the docking mechanism.

LM Jettison and Separation

The LM/CSM was oriented along the radius vector with the LM away from the moon and the CSM toward the moon. When this orientation was achieved, the LM was jettisoned at 145:44:58. Five minutes later, at 145:49:42.5, the CSM performed the separation burn.

LM Deorbit

The LM ascent stage deorbit burn was initiated at 147:14:16.9. This RCS burn lasted for 76.2 seconds and was performed in the inertial attitude defined at LM jettison.

LM Ascent Stage Impact

The LM ascent stage impacted the lunar surface at 147:42:23.4 with impact coordinates of 3.420° S latitude and 19.667° W longitude.

This point was about 7 n. mi. from the prelaunch target, 36 n. mi. from Apollo 14 lunar landing site, and 62 n. mi. from the Apollo 12 lunar landing site.

Transearth Injection (TEI)

The TEI maneuver occurred on rev 34 at 148:36:02.3. The maneuver was targeted to land at 171°30' W longitude at 216:37:06 g.e.t. (215:57:03.1 AET). The planned burn of 3460.6 fps was generated on the GDSX60 vector. This vector consisted of rev 32 postdocking data and rev 33 preseparation data. The premission plan was to use a vector composed of all the rev 32 data, but during the mission the predocking and postdocking data could not be fitted. Premission data indicated that the worst case MCC-5 ΔV associated with using a preseparation vector for TEI targeting was 12.6 fps. The planned TEI was executed (frozen) on a rev 34 vector (BDAX578) and indicated a 5.6-fps MCC-5 ΔV. Columns 2 and 3 of table VI present selected parameters for the planned and frozen TEI. Column 1 presents the corresponding data for the premission operational trajectory. Column 4 presents the executed TEI obtained by confirming the burn with trimmed ΔV_g residuals. The crew reported a good burn, which is also indicated by column 4. The postburn 20-minute tracking vector (HAWX587) (column 5) indicated a transearth coast that had an entry with a flight-path angle of -7.34°. Apparently, the execution of the TEI almost compensated for the difference between the Goldstone and Bermuda vectors. The predicted MCC-5 ΔV on the Hawaii (HAWX587) vector was 1.3 fps.

Transearth Midcourses

The first transearth midcourse (MCC-5) was scheduled to occur at approximately 17 hours after TEI. The planned MCC-5 was targeted on the Carnarvon (CROX638) vector to correct only the entry corridor error. As presented by column 3 of table VII, the entry flight-path angle γ of the CROX638 vector was -6.97° and the vacuum perigee altitude h_{vp} was 12.6 n. mi. The planned MCC-5 is presented in table VIII. The required maneuver ΔV to correct the γ back to -6.50° was 0.7 fps. The midcourse was executed even though the ΔV was less than 1 fps, the nominal ΔV threshold value for MCC-5 execution. The then current vector indicated that if MCC-5 were not executed, MCC-6 would be required (ΔV approximately 1.4 fps). If possible, MCC-6 was to be avoided because the oxygen flow-rate test would create an uncertainty in the quality of the state vector that would be available at that time.

The maneuver was initiated on time (165:34:56.7), but the residuals indicated a maneuver ΔV of 0.5 rather than the desired 0.7 (column 2 of table VIII). The executed MCC-5 yielded a γ of -6.63°. Subsequent

vectors (for example, MADX730, column 4 of table VII) predicted a more shallow γ of about -6.35°. The best pre-MCC-5 vector (CROX646) predicted a γ of -6.80°. The executed MCC-5 on this vector would yield a γ of -6.46° while the planned MCC-5 would yield a γ of -6.33°.

MCC-6, based upon MADX730, required 0.3 fps. The predicted γ at MCC-7 time (HSKX823) was -6.38°. Since both of these values were below their respective maneuver threshold values, they were not executed.

Entry and Landing

The command module separated (215:32:42.2) from the service module 15 minutes prior to entry. Entry occurred at 215:47:45.3 at latitude 36.36° S and longitude 165.80° E. Landing occurred at 216:01:58.1 at latitude 27.01° S and longitude 172.65° W, which represented a miss distance of 0.62 n. mi. (fig. 4).

CONCLUSIONS

The CSM and LM encountered no serious maneuver planning or execution problems during the mission other than the initial docking problem shortly after TLI. The mission went essentially as planned and the LM was landed within 175 feet of the desired target on the moon. Then the crew was returned safely to a point on the earth within 1 n. mi. of the target.

TABLE I.- TRAJECTORY PARAMETERS

Event	Reference body	Apollo elapsed time, hr:min:sec	Latitude, deg	Longitude, deg	Altitude, miles above rev. body	Space-fixed velocity, fps	Space-fixed flight-path angle, deg	Space-fixed heading angle, deg E of N
Translunar phase								
Translunar injection	Earth	02:34:31.9	29.89 S	113.50 E	103.5	25 582.6	0.01	77.52
Command and service module/S-IVB separation	Earth	03:02:29.4	19.23 N	153.41 W	4297.0	24 089.2	46.84	65.41
Docking	Earth	04:56:56	30.43 N	137.99 W	20 603.4	13 204.1	66.31	84.77
Command and service module/lunar module ejection from S-IVB	Earth	05:47:14.4	30.91 N	114.74 W	26 299.6	11 723.5	68.54	87.76
Midcourse correction #2								
Ignition	Earth	30:36:07.9	28.87 N	130.33 W	118 515.0	4 437.9	76.47	101.98
Cutoff	Earth	30:36:18.1	28.87 N	130.37 W	118 522.1	4 367.2	76.95	102.23
Midcourse correction #4								
Ignition	Moon	76:58:12.0	0.56 N	61.40 W	11 900.3	3 711.4	-80.1	295.57
Cutoff	Moon	76:58:12.6	0.56 N	61.40 W	11 899.7	3 713.1	-80.1	295.65
Lunar orbit phase								
Lunar orbit insertion								
Ignition	Moon	81:56:40.7	2.83 N	174.81 W	87.4	8 061.4	-9.97	257.31
Cutoff	Moon	82:02:51.5	0.10 N	161.58 E	64.2	5 458.5	1.3	338.18
S-IVB impact	Moon	82:37:52.2	8.09 S	26.02 W				
Descent orbit insertion								
Ignition	Moon	86:10:53.0	6.58 N	173.60 W	59.2	5 484.8	-0.08	247.44
Cutoff	Moon	86:11:13.8	6.29 N	174.65 W	59.0	5 279.5	-0.03	246.94
Command and service module/lunar module separation	Moon	103:47:41.6	12.65 S	87.76 E	30.5	5 435.8	-1.52	241.64
Command and service module circulation								
Ignition	Moon	105:11:46.1	7.05 N	178.56 E	60.5	5 271.3	-0.1	248.58
Cutoff	Moon	105:11:50.1	7.04 N	178.35 E	60.3	5 342.1	0.22	248.36
Powered descent initiation	Moon	108:02:26.5	7.38 S	1.57 W	7.8	5 565.6	0.08	290.84
Landing	Moon	108:15:09.3	3.67 S	17.47 W				

TABLE I.- TRAJECTORY PARAMETERS - Concluded

Event	Reference body	Apollo elapsed time, hr:min:sec	Latitude, deg	Longitude, deg	Altitude, miles above rev. body	Space-fixed velocity, fps	Space-fixed flight-path angle, deg	Space-fixed heading angle, deg E of N
Command and service module plane change								
Ignition	Moon	117:29:33.1	10.63 S	96.31 E	62.1	5 333.1	-0.04	237.61
Cutoff	Moon	117:29:51.6	10.78 S	95.40 E	62.1	5 333.3	0.01	241.79
Ascent	Moon	141:45:40						
Tweak	Moon	141:56:49.4	0.5 N	37.1 W	11.1	5 548.5	0.52	282.1
Terminal phase initiation	Moon	142:30:51	11.1 N	149.6 W	44.8	5 396.6	0.73	265.0
Terminal phase final	Moon	143:13:29.1	11.3 S	76.7 E	58.8	5 365.5	-0.002	265.5
Docking	Moon	143:32:50.5	10.18 S	161.87 W	58.6	5 353.5	0.11	268.06
Lunar module jettison	Moon	145:44:58.0	3.208 S	21.803 W	59.9	5 344.6	0.133	281.9
Command and service module separation	Moon	145:49:42.5	0.622 N	39.579 W	60.6	5 341.7	0.119	282.3
Lunar module ascent stage deorbit								
Ignition	Moon	147:14:16.9	11.918 S	67.434 E	57.2	5 358.7	0.038	267.3
Cutoff	Moon	147:15:33.1	12.122 S	63.526 E	57.2	5 177.0	0.019	267.7
Lunar module ascent stage impact	Moon	147:42:23.4	3.420 S	19.667 W	0.0	5 504.9	-3.685	281.7
Transearth injection								
Ignition	Moon	148:36:02.3	7.41 N	81.55 W	60.9	5 340.6	-0.17	260.81
Cutoff	Moon	148:38:31.5	6.64 N	168.85 E	66.5	8 505.0	5.29	266.89
Transearth coast phase								
Midcourse correction #5	Earth	165:34:56.7	25.77 N	46.43 E	176 713.8	3 593.2	-79.61	124.88
Command module/service module separation	Earth	215:32:42.2	31.42 S	94.38 E	1 965.0	29 050.8	-36.62	117.11
Entry and landing phases								
Entry	Earth	215:47:45.3	36.36 S	165.80 E	66.8	36 170.2	-6.37	70.84
Landing	Earth	216:01:58.1	27.01 S	172.65 W				

TABLE II.- S-IVB IMPACT TARGETING

	Latitude, deg	Longitude, deg	G.m.t.
Pre-APS-1 best estimate (MSFC)	-3.205	-110.355	103:09:01.38
Last RTCC vector before vector selection	-2.800	-106.400	103:20:58.0
Last RTCC vector before APS-1	-5.764	-84.374	103:10:31.55
Best post-APS-1 estimate MILX112	-9.240	-25.600	103:40:13.41
Nominal post-APS	-1.593	-33.33	103:28:50.0
Final real-time IP	-7.81	-26.00	103:40:54.7

TABLE III.- S-IVB IMPACT COORDINATES

Prelaunch target

1.596° south latitude

33.25° west longitude

Reference: LOC July 2, 1969

1:2,500,000

Actual impact

8.093° ± 0.15° south latitude

26.023° ± 0.03° west longitude

973.045 n. mi. ± 0.745 n. mi. radius

82:37:52.17 AET ± 0.02 sec

Target point miss distance = 159 n. mi.

Actual impact distance from Apollo 14 landing site = 158 n. mi.

Actual impact distance from Apollo 12 landing site = 93 n. mi.

TABLE IV.- APOLLO 14 MAP COORDINATES

Prelaunch target point

Latitude south	3°40'19" (3.6719°)
Longitude west	17°27'46" (17.4628°)
Radius	1 736 680 meters (937.732 n. mi.)

Reference: MSL Apollo 12 triangulation

Actual LM landing point

Latitude south	3°40'18" (3.6717°)
Longitude west	17°27'55" (17.4653°)
Radius	1 736 565 meters (937.670 n. mi.)

Actual ALSEP location

Latitude south	3°40'18" (3.6717°)
Longitude west	17°28'16" (17.4712°)

NOTE: These coordinates are related to the 1:25 000 scale Lunar Topographic Photomap, Third Edition, November 1970, compiled from Apollo 12 photography and are not necessarily interchangeable to other map products of comparable scales. As an example, this same LM position is at latitude 3°35'31" S and longitude 17°21'55" W on the 1:25 000 scale Lunar Photomap (III 5-23, First Edition, Aug. 1969).

TABLE V.- LM ASCENT STAGE IMPACT COORDINATES

Prelaunch target point

Latitude south 3°30' (3.50°)

Longitude west 19°16' (19.27°)

Reference: LOC July 2, 1969 1:2,500,000

Impact time = 148:20:58.1 g.e.t.

Actual impact point

Latitude south 3°25'12" (3.420°)

Longitude west 19°40'12" (19.667°)

Impact time = 148:22:26.3 g.e.t. (147:42:23.4 AET)

TABLE VI.- TEI COMPARISON TABLE

	Premission	Planned (pad)	Preburn frozen	Executed	Postburn 20-minute vector
Vector		GDSX560	BDAX578	BDAX578	HAWX587
Ignition time, g.e.t.	149:16:42	149:16:04.3	149:16:04.3	149:16:04.3	
G.m.t. ignition	169:39:42	169:39:04.3	169:39:04.3	169:39:04.3	
ΔV, fps	3450.5	3460.6	3460.6	3460.6	
Burn time, min:sec	2:29.3	2:28.1	2:28.1	2:28.1	
Entry time, g.e.t.	216:24:05	216:23:05			216:26:59
V_R, fps	36 171	36 171			36 171
γ_R, deg	-6.50	-6.50			-7.34
I_R, deg	40.0	40.0	40.4	40.4	40.2
Landing time, g.e.t.	216:38:05	216:37:06			
Landing latitude	27:15S	27:02S			
Landing longitude	171:30W	171:30W			
Perigee altitude, n. mi.		19.5	73.2	73.7	7.0
Perigee time, g.e.t.		216:25:19	216:31:05	216:31:25	216:29:29
MCC-5 ΔV, fps	0	0	5.6	5.6	1.3

TABLE VII.- ENTRY AND PERIGEE PARAMETERS FROM SELECTED TEC STATE VECTORS

Parameter	Planned TEI target values	Post-TEI 20-minute track vector	Pre-MCC-5	MCC-6	MCC-7	Entry
ID		HAWX 587	CROX 638	MADX 730	HSKX 823	
EI, g.e.t.	216:23:05	216:26:59	216:27:18	216:27:47	216:27:47	216:27:47
γ_R, deg	-6.50	-7.34	-6.97	-6.35	-6.38	-6.37
I_R, deg	40.0	40.2	40.3	40.3	40.3	
VP, g.e.t.	216:25:19	216:29:29	216:29:41	216:29:57	216:29:58	
H_{VP}, n. mi.	19.5	7.0	12.6	21.5	21.2	

TABLE VIII.- MIDCOURSE 5 COMPARISON

	Planned MCC-5	Executed MCC-5
Vector	CROX638	CROX638
Ignition time, g.e.t.	166:14:58.5	166:14:58.5
Ignition time, G.m.t.	186:37:58.6	186:37:58.6
ΔV, fps	0.7	0.5
Burn time, sec	2.9	2.2
Entry time, g.e.t.	216:27:35	216:27:31
V_R, fps	36 170	36 170
γ_R, deg	-6.50	-6.63
I_R, deg	40.3	40.3
Landing time, g.e.t.	216:41:34	216:41:38
Landing latitude, deg:min	27:02S	27:02S
Landing longitude, deg:min	172:37W	172:37W
Perigee altitude, n. mi.	19.4	17.6
Perigee time, g.e.t.	216:29:49	216:29:47

TABLE IX.- COMPARISON OF EVENT TIMES

Event	Premission g.e.t.	Actual		Civil time	
		g.e.t.	AET	Day	CST
Launch	00:00:00	00:00:00	00:00:00	Jan. 31	3:03 p.m.
TLI	02:36:43.8	02:34:31.9	02:34:31.9	Jan. 31	5:37 p.m.
SC ejection	03:56:34	05:47:14.4	05:47:14.4	Jan. 31	8:50 p.m.
MCC-2	30:36:07	30:36:07.9	30:36:07.9	Feb. 1	9:39 p.m.
MCC-4	77:36:58.4	77:38:14.9	76:58:12	Feb. 3	8:01 p.m.
LOI	82:36:58.4	82:36:43.6	81:56:40.7	Feb. 4	1:00 a.m.
S-IVB impact	83:03:03.5	83:17:55.1	82:37:52.2	Feb. 4	2:41 a.m.
DOI	86:50:41.3	86:50:55.9	86:10:53	Feb. 4	5:13 a.m.
Circ	105:46:48.5	105:51:49	105:11:46.1	Feb. 5	12:14 a.m.
PDI	108:42:01.1	108:42:29.4	108:02:26.5	Feb. 5	3:05 a.m.
LM landing	108:53:32.6	108:55:12.2	108:15:09.3	Feb. 5	3:17 a.m.
LOPC	118:09:40.2	118:09:36	117:29:33.1	Feb. 5	12:32 p.m.
Ascent	142:24:29.2	142:25:42.9	141:45:40	Feb. 6	12:48 p.m.
Docking	144:10:00	144:12:53.4	143:32:50.5	Feb. 6	2:36 p.m.
LM jettison	146:23:30.5	146:25:00.9	145:44:58	Feb. 6	4:48 p.m.
LM deorbit	147:52:58.9	147:54:19.8	147:14:16.9	Feb. 6	6:17 p.m.
LM ascent impact	148:20:58.1	148:22:26.3	147:42:23.4	Feb. 6	6:45 p.m.
TEI	149:14:50.1	149:16:05.2	148:36:02.3	Feb. 6	7:39 p.m.
MCC-5	166:40:19.4	166:14:59.6	165:34:56.7	Feb. 7	12:38 p.m.
Entry	216:24:05.4	216:27:48.2	215:47:45.3	Feb. 9	2:50 p.m.
Landing	216:37:59.8	216:42:01	216:01:58.1	Feb. 9	3:05 p.m.

TABLE X.- APOLLO 14 TRANSLUNAR AND TRANSEARTH MANEUVER SUMMARY AS OBTAINED IN REAL TIME

MANEUVER	GROUND ELAPSED TIME (G.E.T.) AT IGNITION (HR:MIN:SEC)			BURN TIME (SECONDS)			VELOCITY CHANGE (FPS)			G.E.T. OF CLOSEST APPROACH HT (N. MI.) OF CLOSEST APPROACH			EVENT TIME IN CIVIL TIME	
	PRELAUNCH PLAN	REAL-TIME PLAN	ACTUAL	PRELAUNCH PLAN	REAL-TIME PLAN	ACTUAL	PRELAUNCH PLAN	REAL-TIME PLAN	ACTUAL	PRELAUNCH PLAN	REAL-TIME PLAN	ACTUAL	DATE	C.S.T.
TLI (S-IVB)	02:30:38	02:28:30.1	02:28:30.1	355.7	348.5	355.0	10 353.1	10 355.8	10 346.5	82:39:29 2030	82:10:50 2022	82:10:50 2022	1-31-71	5:31 p.m.
CSM SEP	03:01:34	02:59:23	03:02:30	3.0			0.5			82:39:29 2030	82:10:50 2022	82:10:50 2022	1-31-71	6:05 p.m.
CSM DOCK	03:11:34	03:13:56	04:57:00	N.A.[a]	——	——	N.A.	——	——	82:39:29 2030	82:10:50 2022	82:10:50 2022	1-31-71	8:00 p.m.
CSM/LM SEP	03:56:34	03:56:00	05:47:25	3.0	3.0	6.9	0.4	0.3	0.8	82:39:29 2030	— — —	82:15:19 1980	1-31-71	8:50 p.m.
S-IVB EVASIVE	04:19:35	06:04:20	06:04:20	80.2	80.0	80.0	9.7	9.5	9.5	83:03:04 0	— — —	82:38:03 0	1-31-71	9:07 p.m.
MCC-1 (SPS)	11:36:34	N.P.[b]	N.P.	0.0	N.P.	N.P.	0.0	N.P.	N.P.	82:39:29 2030	N.P.	N.P.	N.P.	N.P.
MCC-2 (SPS)	30:36:07	30:36:07	30:36:07	11.1	10.3	10.2	73.4	71.4	71.1	82:40:58 59.9	82:00:37 60.3	82:00:45 67.1	2-1-71	9:39 p.m.
MCC-3	60:38:14	N.P.	N.P.	0.0	N.P.	N.P.	0.0	N.P.	N.P.	82:40:58 59.9	N.P.	82:40:48 65.8	N.P.	N.P.
MCC-4	77:38:14	77:38:14	77:38:14	0.0	0.7	0.6	0.0	3.8	3.5	82:40:58 59.9	82:40:35 60.7	82:40:36 60.7	2-3-71	8:01 p.m.
LUNAR ORBIT MANEUVERS	LUNAR ORBIT MANEUVERS GIVEN ON SEPARATE TABLE									G.E.T. OF ENTRY INTERFACE (EI) VELOCITY (FPS) AT EI FLIGHT-PATH ANGLE (DEG) AT EI				
TEI (SPS)	149:14:50	149:16:04	149:16:04	149.2	148.1	148.1	3 449.5	3 460.6	3 460.6	216:24:05 36 170.7 -6.5	216:23:05 3 460.6 -6.5	216:31:25 36 126.9 -7.3	2-6-71	7:39 p.m.
MCC-5	166:17:17	166:14:59	166:14:59	0.0	2.9	2.2	0.0	0.7	0.5	216:24:05 36 170.7 -6.5	216:27:18 36 170.5 -6.97	216:27:31 36 170.4 -6.63	2-7-71	12:38 p.m.
MCC-6	194:24:05	N.P.	N.P.	0.0	N.P.	N.P.	0.0	N.P.	N.P.	216:24:05 36 170.7 -6.5	— — — — — —	— — — — — —	N.P.	N.P.
MCC-7	213:24:05	N.P.	N.P.	0.0	N.P.	N.P.	0.0	N.P.	N.P.	216:24:05 36 170.7 -6.5	— — — — — —	— — — — — —	N.P.	N.P.
CM/SM SEP	216:09:05	216:12:47	216:12:50	N.A.	——	——	N.A.	——	——	N.A. N.A. N.A.	— — — — — —	— — — — — —	2-9-71	2:35 p.m.
ENTRY	216:24:05	216:27:47	216:27:47	N.A.	——	——	N.A.	——	——	216:24:05 36 170.7 -6.5	216:27:47 36 170 -6.4	216:27:47 36 170 -6.4	2-9-71	
SPLASH	216:38:00	216:41:38	216:42:01	N.A.	——	——	N.A.	——	——	N.A. N.A. N.A.	— — — — — —	— — — — — —	2-9-71	3:05 p.m.

[a] N.A. - not applicable.

[b] N.P. - not performed.

TABLE XI.- APOLLO 14 LUNAR ORBIT SUMMARY AS OBTAINED IN REAL TIME

MANEUVER	GROUND ELAPSED TIME (G.E.T.) AT IGNITION (HR:MIN:SEC)			BURN TIME (SECONDS)			VELOCITY CHANGE (FPS)			RESULTING APOLUNE/PERILUNE (N. MI.)			EVENT TIME IN CIVIL TIME	
	P ELAUNCH PLAN	REAL-TIME PLAN	ACTUAL	PRELAUNCH PLAN	REAL-TIME PLAN	ACTUAL	PRELAUNCH LAN	REAL-TIME PLAN	ACTUAL	PRELAUNCH PLAN	REAL-TIME PLAN	ACTUAL	DATE	C.S.T.
LOI	82:36:58	82:36:43	82:36:43	369.5	372.3	372.2	2986.5	3022.7	3022.4	169.3/58.4	169.3/58.1	169.0/58.4	2-4-71	1:00 a.m.
DOI	86:50:41	86:50:55	86:50:55	21.6	20.8	20.7	206.7	206.4	205.7	58.5/ 9.8	58.8/ 9.1	58.8/ 9.6	2-4-71	5:13 a.m.
UNDOCKING	104:27:31	———	———	N.A.[a]	———	———	N.A.	———	———	59.5/ 8.2	———	———	———	———
CSM SEP	104:27:31	104:27:31	104:28:00	3.2	3.2	2.7	1.0	1.0	0.8	59.5/ 8.2	60.2/ 7.8	60.2/ 7.8	2-4-71	10:51 p.m.
CSM CIRC	105:46:49	105:51:48	105:51:48	3.9	3.8	3.8	72.5	76.2	77.2	63.5/56.0	63.3/55.6	63.9/56.0	2-5-71	12:14 a.m.
PDI	108:42:01	108:42:29	108:42:29	691.5	693.5	693.5	6638	6639.1	6639.1	0	0	0	2-5-71	3:05 a.m.
LANDING	108:53:33	108:54:02	108:54:02	N.A.	———	———	N.A.	———	———	N.A.	———	———	2-5-71	3:17 a.m.
CSM LOPC	118:09:40	118:09:35	118:09:32	18.6	18.5	18.4	360.7	370.0	370.5	61.7/57.4	62.1/57.2	62.1/57.6	2-5-71	12:32 p.m.
ASCENT	142:24:29	142:25:42	142:25:42	430.7	432.0	432.0	6053.4	6066.1	6066.1	51.0/9.1	52.1/ 9.2	52.1/ 9.2	2-6-71	12:48 p.m.
TWEAK	142:34:40	142:36:51	142:36:51	0			0	10.0	10.0	50.3/ 9.1	52.0/ 9.2	52.3/ 8.8	2-6-71	1:00 p.m.
TPI	143:09:40	143:10:54	143:10:54	4.0	3.6	3.6	92.2	92.0	88.5	61.0/44.6	60.0/45.5		2-6-71	1:34 p.m.
DOCKING	144:10:00	144:15:00	144:13:00	N.A.	———	———	N.A.	———	———	60.2/58.7	———	———	2-6-71	2:36 p.m.
LM JETT	146:23:31	146:25:00	146:25:00	N.A.	———	———	N.A.	———	———	60.6/58.7	63.4/56.8	63.4/56.8	2-6-71	4:48 p.m.
CSM SEP	146:28:31	146:30:00	146:30:00	6.0	6.0	7.0	1.0	1.0	1.2	60.2/58.3	61.8/56.9	62.3/56.8	2-6-71	4:53 p.m.
ASC DEORB	147:52:59	147:54:19	147:54:19	77.0	75.4	75.4	183.7	186.1	186.1	58.4/-63.9	57.3/-63.1	58.9/-44.4	2-6-71	6:17 p.m.
ASC IMPACT	148:20:58	148:22:25	148:22:25	N.A.	———	———	N.A.	———	———	N.A.	———	———	2-6-71	6:45 p.m.
TEI	149:14:50	149:16:04	149:16:04	149.2	148.1	148.1	3449.5	3460.6	3460.6	N.A.	———	———	2-6-71	7:39 p.m.

[a] N.A. - not applicable.

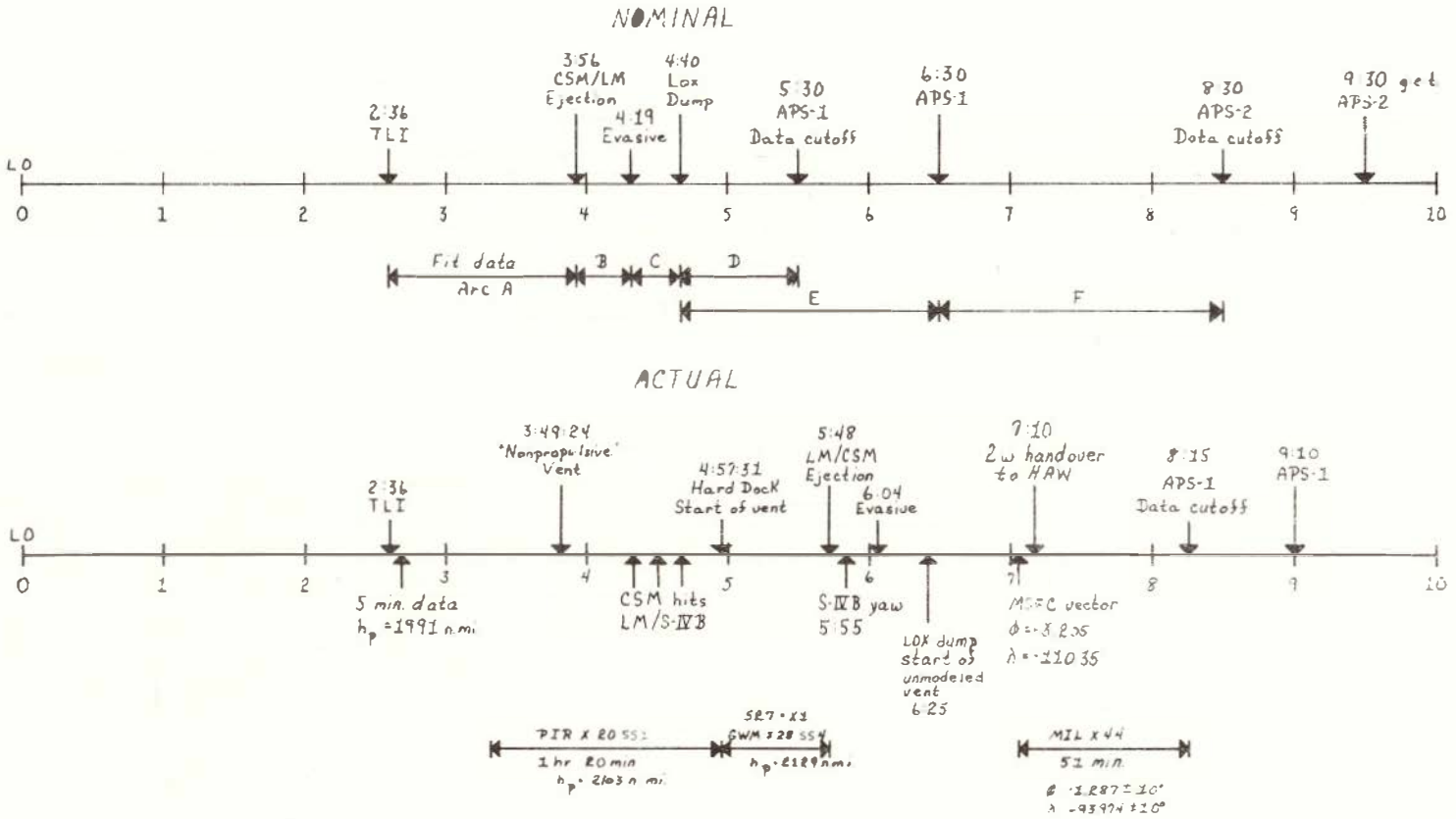

Figure 1.- S-IVB targeting time line.

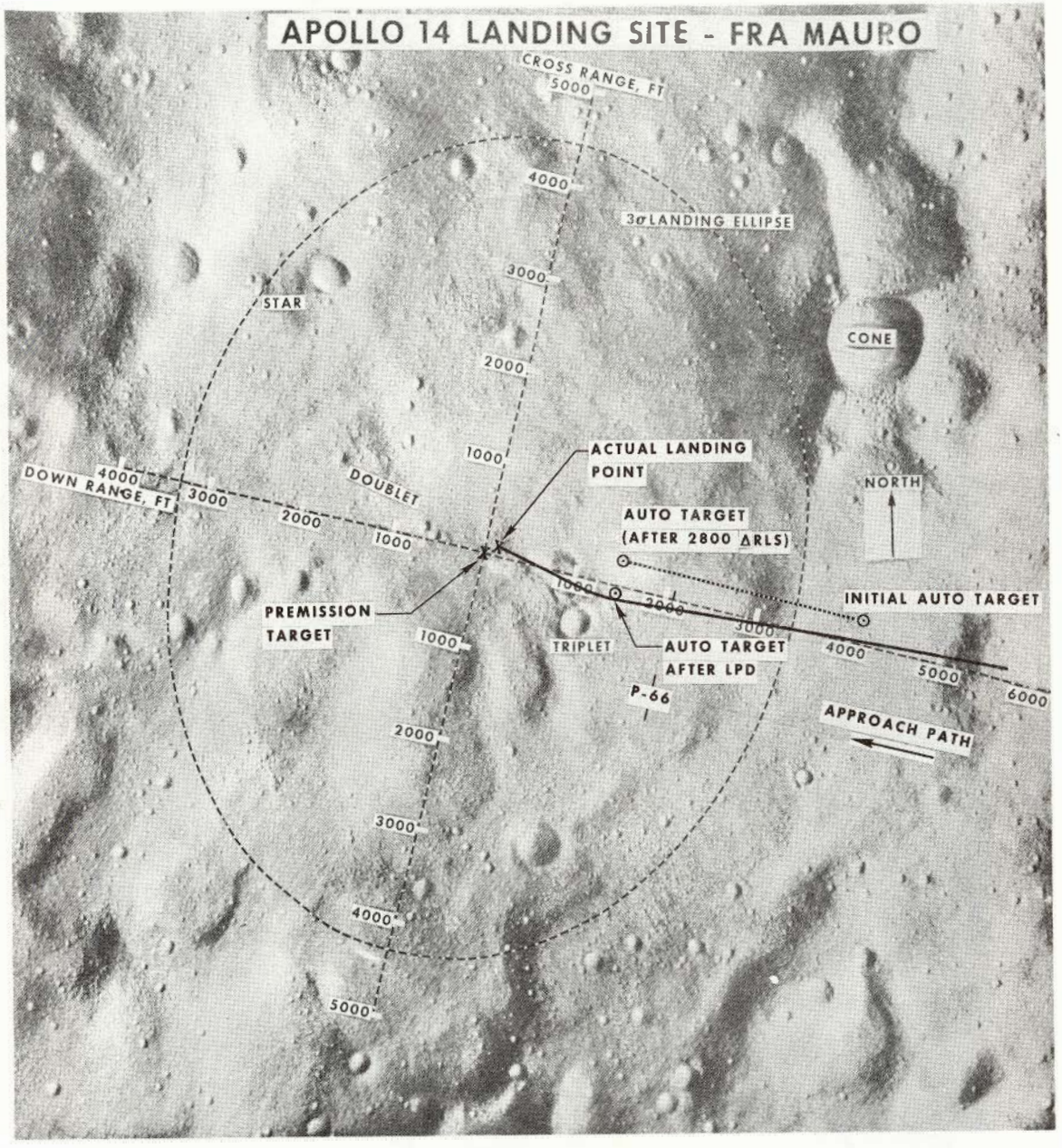

Figure 2.- Apollo 14 groundtrack.

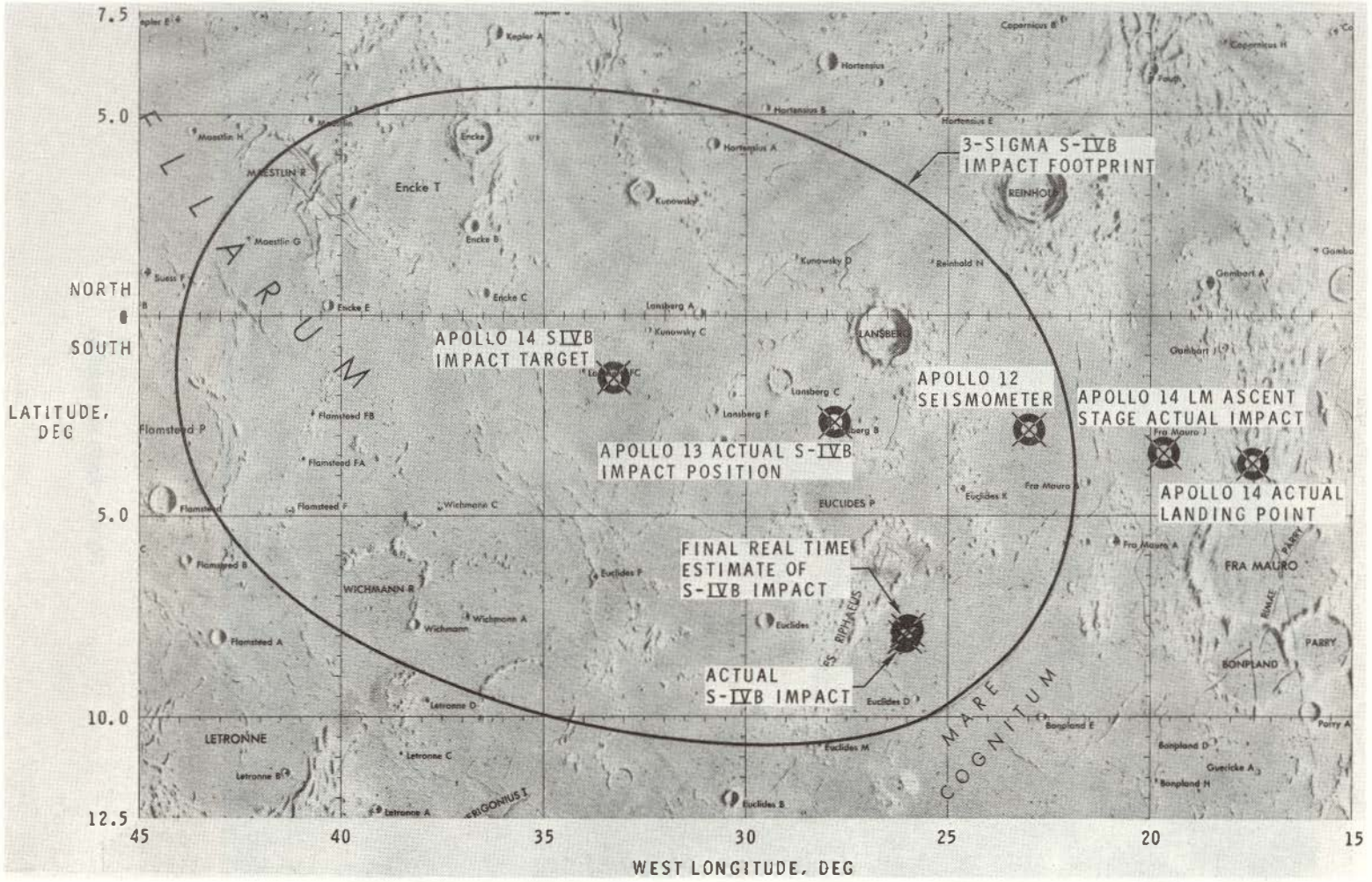

Figure 3. - Apollo 14 discarded S-IVB impact dispersion.

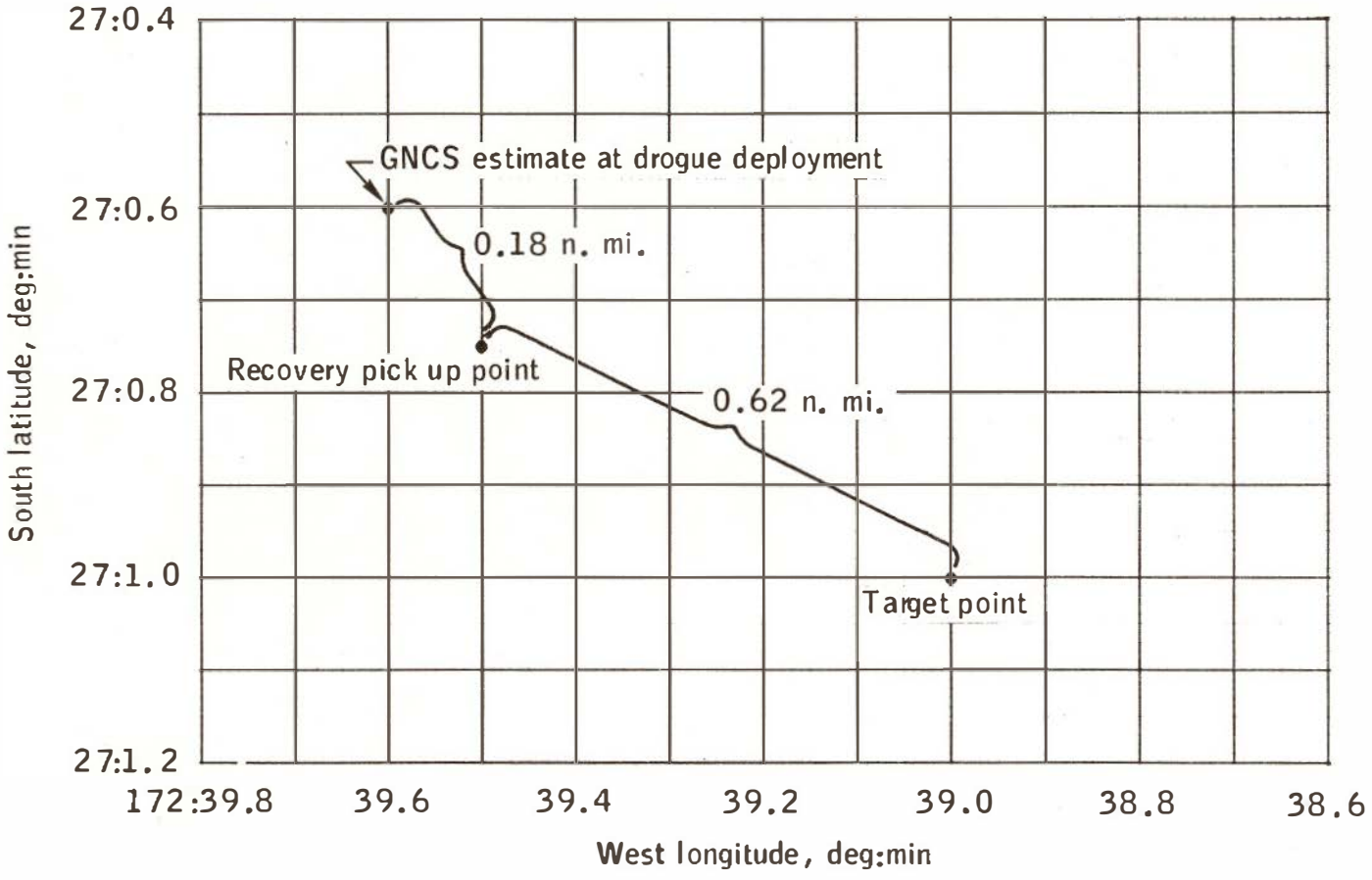

Figure 4.- Apollo 14 entry landing point.

APPENDIX A

LM DESCENT PHASE

APPENDIX A

LM DESCENT PHASE

Abort Discrete

The abort discrete was discovered to be unintentionally set (believed to be switch contamination) during the front-side pass of revolution 12. It was turned off by pressing the abort switch twice. The discrete reappeared on revolution 13, and this time it was reset by tapping the abort switch. Procedures were developed to prevent the abort discrete from causing a guidance program transfer from P63 to P70 (abort guidance) which would have caused an immediate abort (loss of descent guidance). The abort discrete did not reappear after it was reset on revolution 13.

Landing Radar (LR) Discretes

Telemetry data show two LR discretes, data good and low scale, being set prior to PDI. The LR data good discrete was set intermittently beginning at approximately PDI minus 9 minutes 40 seconds and ending at approximately PDI minus 6 minutes 22 seconds, at which time it was off. The outer, inner, and middle gimbal angles, when the first LR data good appeared, were approximately 1°, 111°, and 3°, respectively. At this attitude, LR beams 1, 2, 4 would intercept the lunar surface. Efforts are being directed toward determining an accurate groundtrack which would make it possible to determine the area on the lunar surface that the beams intercepted prior to PDI.

The LR low-scale discrete appeared at approximately PDI minus 4 minutes 50 seconds and remained set until the LR circuit breaker was cycled at PDI plus 6 minutes 24 seconds. To speculate on the causes of these discretes being set is beyond the scope of this report.

Powered Descent Initiation

The DPS ignition occurred automatically, but a manual throttle up was needed by the procedures that were used to disable P70. Table A-I indicates that the manual throttle up was on time, resulting in a 26-second trim phase. Ignition attitude was maintained in the primary guidance and navigation control system (PGNCS) attitude hold mode for

46 seconds after ignition. No appreciable attitude excursions were experienced during the transition from attitude hold to guidance steering.

Thrust Command

The procedures mentioned previously led to guidance steering enable at 46 seconds after ignition, as shown in table A-I. The small step seen on the thrust command time history at approximately 2 minutes into the burn is a result of the +2800 NOUN 69 entry. A comparison of the telemetry data and preflight data in figure A-1 indicates that throttle recovery occurred early during the mission. Table A-I shows that this difference is 12 seconds. This early throttle recovery increased the throttle margin from 120 to 140 seconds. The increase in this margin is attributed to the positive NOUN 69 entry and the DPS thrust that was approximately 70 pounds higher than preflight predictions while operating at the fixed-throttle position. A 3σ uncertainty in thrust is approximately 120 pounds, which indicates that the engine was operating within 3σ bounds.

Altitude and Altitude Rate Profile

A comparison of the preflight and actual flight altitude versus altitude rate profiles (fig. A-1) indicates that the descent orbit perilune altitude was lower than nominal, being 47 355 feet instead of the nominal value of 50 000 feet. The difference, however, is well within the expected dispersions and caused no problems.

Landing Radar Altitude Updates

The delta H time history shows an initial delta H of approximately 11 500 feet. This large initial delta H is attributable to a false radar output; however, the altimeter quickly converged to a valid delta H of approximately 1000 feet. Table A-I shows that the commander accepted the altitude data 7 minutes 10 seconds into the burn. At this time the delta H was approximately 500 feet and the PGNCS altitude was approximately 20 000 feet. The altitude at which LR was updated was much lower than predicted premission. This can be attributed to the LR low-scale discrete problem discussed previously. Table A-I shows that the LR low-scale discrete reappears at an altitude of approximately 2800 feet. This implies that if the LR circuit breaker had not been cycled to set the high-scale discrete, the LR may not have locked on until this altitude. Mission rules in this case would have called for an abort at a PGNCS altitude of 10 000 feet.

Landing Point Redesignation (LPD)

Table A-I indicates that a landing site redesignation was made at an altitude of approximately 2700 feet. The redesignation was one click left (south of track) or approximately 350 feet left. In the guidance and navigation debriefing the commander mentioned that this redesignation was made to achieve smoother landing terrain. Figure A-2, which plots cross range versus down range, shows that approximately half this amount of the redesignation was taken back out with a maneuver in P66.

Also in the crew debriefing, the commander mentioned that, after P64 pitchover, the LPD was showing that they were heading for the landing site. Not until they were at a much lower altitude did they realize that the automatic guidance was taking them short of the actual landing point. If this had been discovered at higher altitudes, a landing site redesignation of approximately 1400 feet down range could have been made to correct the problem. Instead, the commander elected to use manual control in P66 to reach the landing point (this is discussed in a subsequent section). The air-to-ground communications transcript indicates that only two LPD callouts were made during the approach phase, which are much fewer than in previous missions. A closer check on the LPD angle may be desirable on future missions.

Approach Phase Altitude versus Range Profile

Figure A-2 plots the altitude versus range profile from the point of the redesignation to landing. Accelerometer data dropout between the LPD redesignation point and P64 prevented the use of reverse integration beyond this point. This plot clearly shows that the automatic guidance was targeted to a point that is approximately 1400 feet short of the actual landing point.

Landing Phase Trajectory Profile

Figure A-3 plots the landing phase portion of the trajectory data in figure A-4 on an expanded scale. The altitude range plot shows approximately 50 seconds of almost level flight. This, as mentioned before, was necessary to achieve the desired landing point. This figure also shows that the down-range distance traveled in P66 was 2000 feet and that flight time was 2 minutes. The difference between the automatic landing point (after +2800-ft ΔRLS) and the actual landing point is approximately 1350 feet down range. The majority of this difference was apparently caused by a landmark offset error.

Propellant Summary

Figure 4 presents the propellant summaries for Apollo 11, 12, and 14. It also includes the Apollo 14 planned propellant summary. The low-level light was activated approximately 1 minute 56 seconds prior to depletion. During the low-level countdown, only the 60 seconds to "Bingo" fuel was called. At touchdown, 46 seconds remained in the count. The time to propellant depletion at landing was 1 minute 6 seconds (as computed from low-level activation). This falls below the 3σ low value as indicated in the Apollo 14 planned propellant summary of figure A-4. The main reason for this "time to depletion" number was the 2000-foot translation maneuver performed in P66, which was required to reach the desired landing point. Table A-II presents the propellant remaining at landing based on the gage readings and on the low-level activation time. A flight time summary is also presented. The total premission and postmission estimates differ by approximately 12 seconds.

Delta Velocity Required

A best estimate for the total ΔV required for the Apollo 14 landing is 6997 fps. This number reflects corrections made to account for truncation error on the downlinked total ΔV.

LM DESCENT PHASE CONCLUSIONS

a. The FTP thrust delivered by the descent engine was higher than nominal, contributing to the 12-second early throttle recovery.

b. A +2800 NOUN 69 entry indicates that the actual trajectory was up range from the desired trajectory by this amount.

c. Activation of the LR low scale prior to PDI delayed LR acquisition.

d. LR acquisition occurred approximately 106 seconds prior to an altitude of 10 000 feet, which is an abort decision point.

e. The LM is estimated to have landed within 175 feet of the desired landing point.

TABLE A-I.- APOLLO 14 POWERED DESCENT

EVENT TIMES AND ATTITUDES

Event	Computer[a] AET, hr:min:sec	TFI, min:sec		h_{IGNCS}, ft
		Actual	Nominal	
LR low-scale discrete set	107:57:35			
AVG G-on	108:01:15	-30	-30	
Engine arm	:02:15			
Ullage	:02:19	-00:08		
Ignition	:02:25	00:00	00:00	47 355
PTP	:02:52	00:27	00:26	47 537
Enable guidance steering	:03:11	00:46		47 503
Disable P70 to P71	:03:33	01:08		46 996
P63 in mode register	:03:47	01:22		46 459
NOUN 69 initiated	:04:21	01:56		44 809
NOUN 69 entered	:04:49	02:24		
X-axis override inhibit	:07:33	04:68		30 015
Throttle recovery	:08:47	06:22	06:34	
LR high-scale discrete set	:08:49	06:24		
LR-V data good	:09:09	06:44		22 657
LR-H data good	:09:11	06:46		22 486
Enable LR-H and LR-V updates	:09:35	07:10		20 331
P64	:11:09	08:44	08:34	8 190
LR antenna position 2 discrete set	:11:15	08:50		
Redesignation enable	:11:51	09:26		2 850
LR low-scale discrete set	:11:51	09:26		
LPD redesignation (350 ft left)	:11:53	09:28		2 699
Low gate (80 sec to auto landing)	:12:59	10:34	10:12	476
Attitude hold	:13:07	10:42		360
P66	:13:09	10:44		333
Low level light	:14:18	11:53		
LR-V reasonability test failed	:14:19	11:54		154
LR-V reasonability test passed	:14:21	11:56		147
LR-V reasonability test failed (Z component)	:14:33	12:08		99
LR-V reasonability test passed (Z component)	:14:37	12:12		95
Terminate LR-H data	:14:59	12:34		39
Landing	:15:09	12:44	11:32	8
Engine disarm	:15:15	12:50		
AVG G-off	:17:19	14:54		

[a]Computer AET time = LGC time minus 40 min 2 sec.

TABLE A-II.- DPS PROPELLANT AND FLIGHT TIME SUMMARY

(a) DPS propellant remaining

Propellant gage	
Usable, lb	573
Unusable, lb	166
Total remaining, lb	739
Computed from low level (usable), lb	614

(b) Flight time summary

Flight time, min:sec	12:44
Planned auto time, min:sec	11:32
Δt, min:sec	1:12
Premission estimate of total available time, min:sec[a]	14:02
Postmission estimate of total available time, min:sec	13:50
Hover time remaining, min:sec	1:06

[a]These numbers were obtained from the Propulsion Technology Section, TRW.

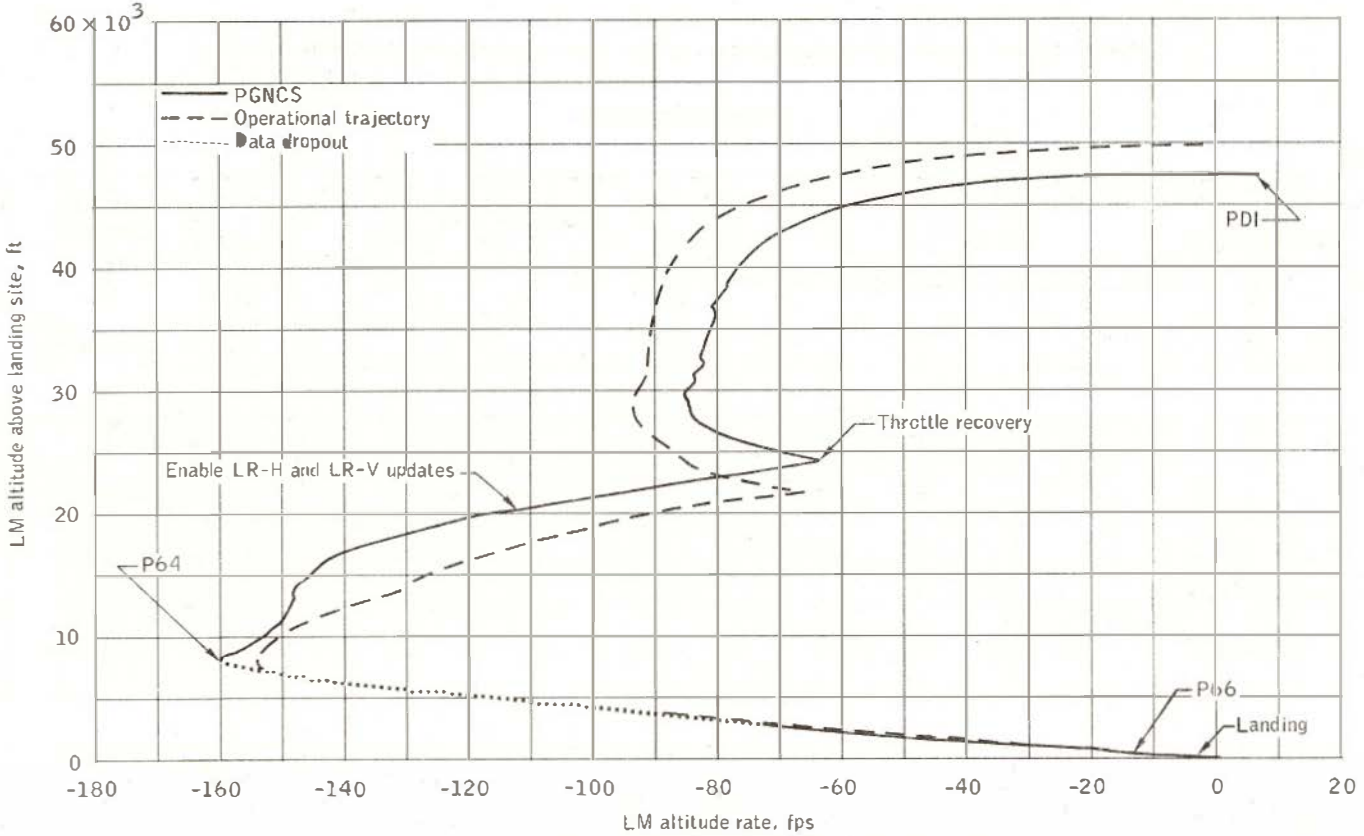

Figure A-1.- Altitude above landing site versus altitude rate.

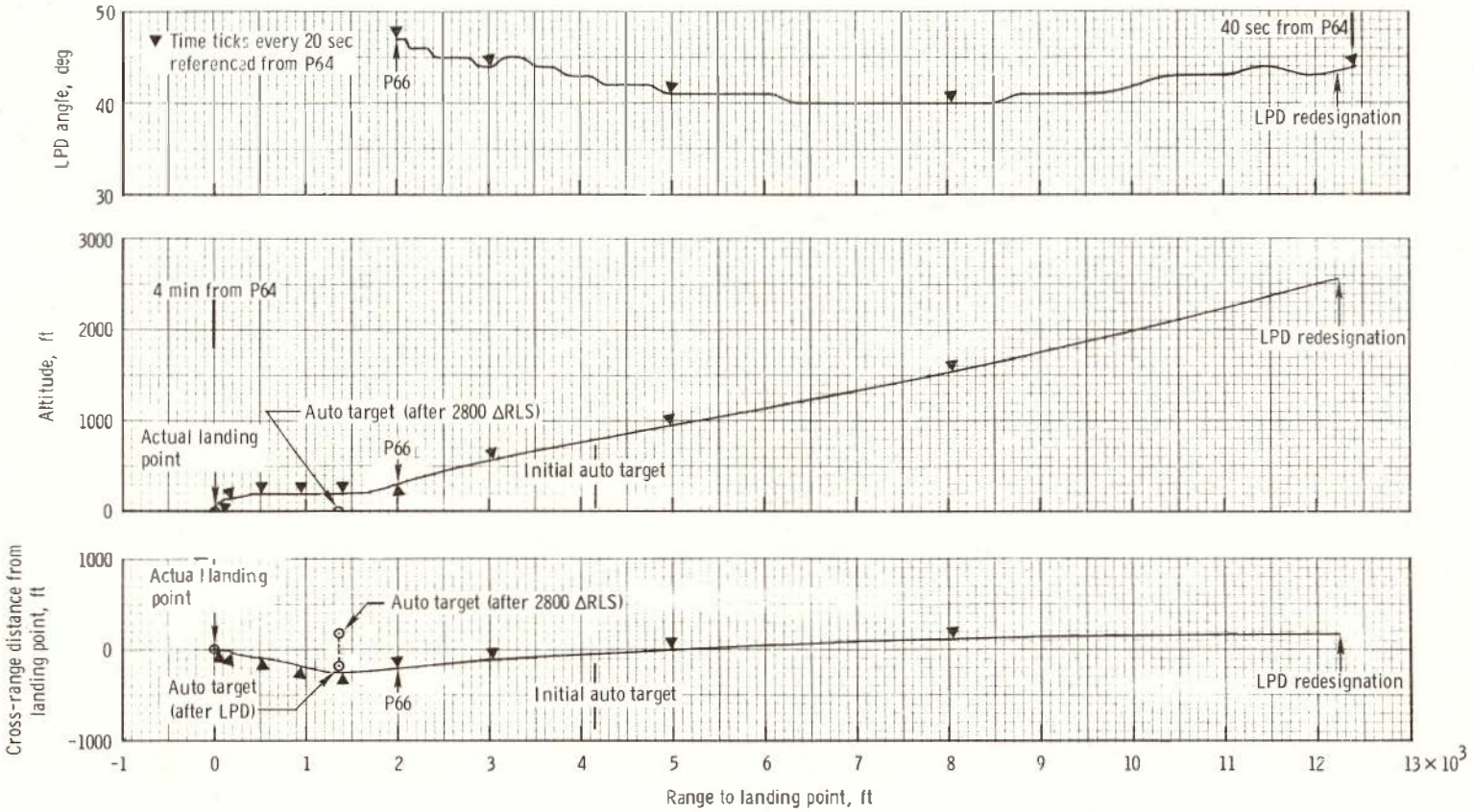

Figure A-2.- Apollo 14 approach phase LPD angle, altitude, and cross-range distance profiles (reverse integration).

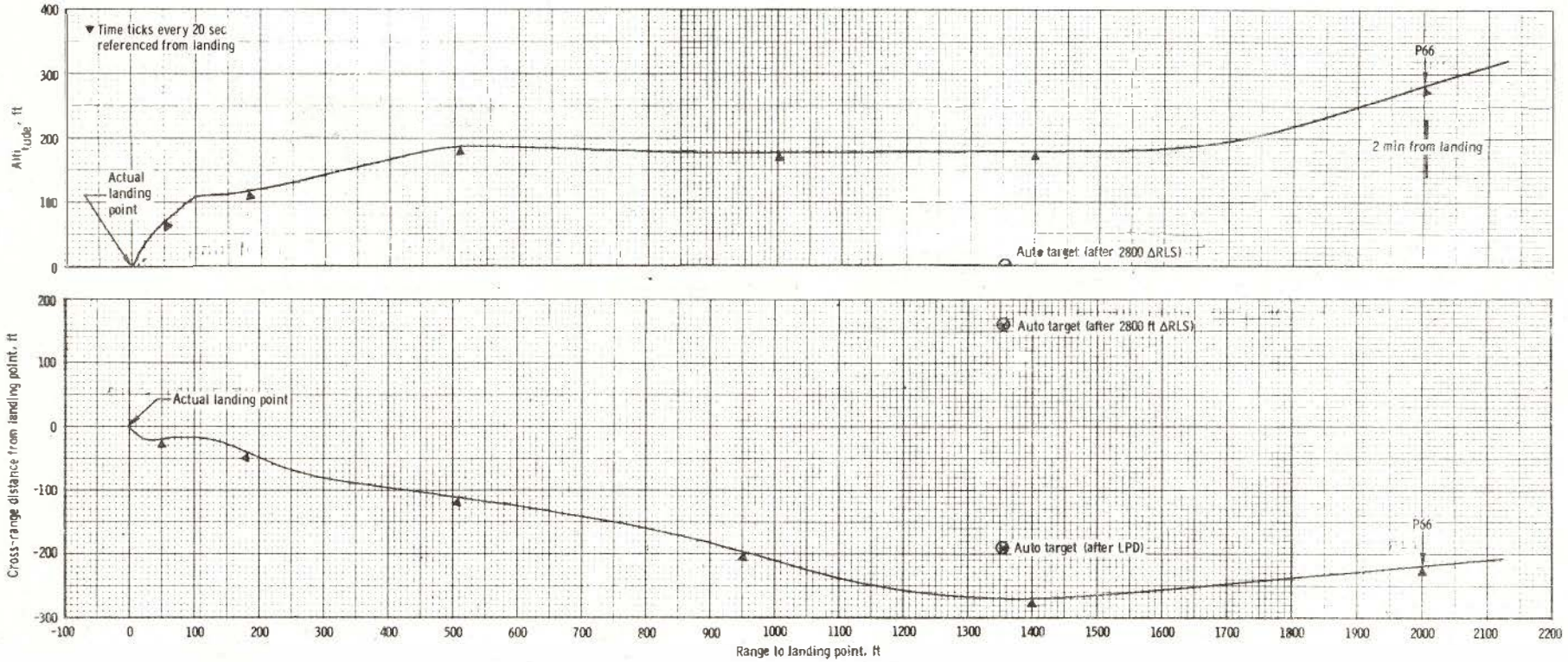

Figure A-3.- Apollo 14 landing phase altitude and cross-range distance profiles (reverse integration).

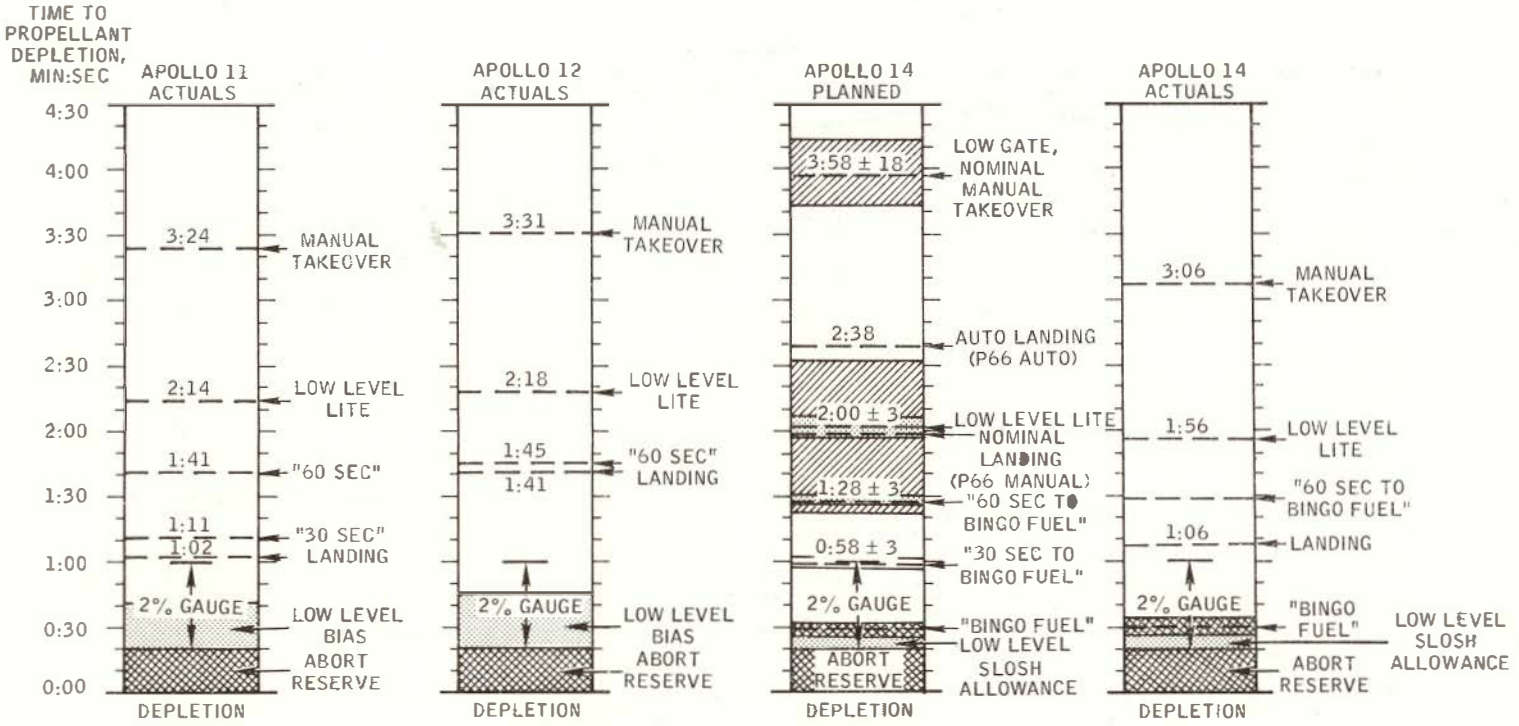

Figure A-4.- Propellant summary for LM landings.

APPENDIX B

RENDEZVOUS

APPENDIX B

RENDEZVOUS

Following insertion into lunar orbit, the first maneuver executed was the tweak maneuver. This maneuver was targeted to provide the nominal offsets at TPI (15 n. mi. below and elevation angle of 26.6°). The tweak would nominally be zero; however, premission analysis showed that a one-sigma PGNCS tweak would be $\Delta VX = \pm 3.5$ fps, $\Delta VY = \pm .9$ fps, and $\Delta VZ = \pm 10.2$ fps. The tweak maneuver actually executed on this flight was $\Delta VX = -4.0$ fps, $\Delta VY = 0.0$ fps, and $\Delta VZ = -9.0$ fps which is about one sigma. The solutions obtained in real time are shown in table B-I with the PGNCS tweak being executed.

The cause of this tweak maneuver is of interest and a summary of the parameters contributing to the tweak is presented in table B-II. One of these is a lift-off time error of about 1 second. This error was determined by obtaining rev 31 (ascent rev) CSM MSFN data and recomputing the LM lift-off time. This updated lift-off time indicated that the actual lift-off time should have been delayed by about 1 second. However, according to previous agreement with the Flight Control Division (FCD), this type of change would not be made in real time prior to ascent.

A second contributor to the tweak is indicated by an 8000-foot down-range dispersion. This down-range dispersion was shown on the vector comparison display after insertion. Together, these two dispersions resulted in a tweak of $\Delta VX = -2.8$ fps, $\Delta VY = 0.0$ fps, and $\Delta VZ = -6.5$ fps at insertion. However, after trimming, the tweak became $\Delta VX = -4.0$ fps, $\Delta VY = 0.0$ fps, and $\Delta VZ = -9.0$ fps. Hence, the postinsertion trim added to the tweak maneuver as shown in table B-II.

Table B-III presents terminal phase data based upon the PGNCS insertion state vector with and without the tweak. The data indicate that the tweak did provide the nominal offsets for this estimated TPI solution. However, it will be shown later that, at this point, the estimated TPI solution was in error.

Rendezvous Navigation

Based upon crew debriefings and real-time data, the PGNCS and AGS rendezvous navigation was performed as planned (19 PGNCS marks and 8 AGS marks). However, the CSM VHF ranging did not perform as expected. Successive large range updates were received for the initial VHF marks, and a mark was accepted that updated the LM position by approximately 8 n. mi. Table B-IV shows the CSM TPI solution based on the CSM state vector shortly after this VHF mark was accepted. The data show that, at that point, the TPI solution was unacceptable.

At some time after the VHF problems were noticed, a request was made that the W-matrix be reinitialized. The rendezvous support personnel felt this request was occurring too late in the tracking interval; hence, the reinitialization should not be made. However, after approximately 8 sextant marks, the W-matrix was reinitialized, and sextant-only tracking was continued resulting in a final TPI solution which was outside the comparison limits but from which a rendezvous could have been accomplished.

Final TPI Solutions

The PGNCS, GNCS, and MSFN TPI solutions are shown in table B-V along with midcourses 1 and 2 total ΔV. The final GNCS solution as shown did not pass the 3 fps ΔVX comparison limit, but it was much improved over the solution that was obtained following acceptance of the bad VHF mark and would have given an acceptable rendezvous, although the midcourse corrections would have been considerably larger. As indicated by the small midcourses, the PGNCS TPI solution was very close to the actual TPI. Note how much the final PGNCS TPI solution differed from the initial PGNCS TPI solution after the tweak; that is, it differs by 2.3 fps in ΔVX and 10.1 fps in ΔVZ. Based on premission analysis (ref. 3), however, this difference is shown to be within one signa. This reemphasizes the need for good rendezvous navigation for the direct rendezvous.

CONCLUDING REMARKS

With the exception of the CSM VHF problems, the Apollo 14 rendezvous was performed as planned within one-sigma system operations. The feasibility of this rendezvous technique was demonstrated; hence, it could be used for future Apollo lunar missions.

TABLE B-I.- TWEAK SOLUTIONS

	PGNCS	ACS	MSFN
ΔVX, fps	-4.0	-1.0	-4.0
ΔVY, fps	0.0	-2.0	-2.0
ΔVZ, fps	-9.0	-12.0	-11.0
ΔV_{TOTAL}, fps	10.0	12.0	12.0

TABLE B-II.- PARAMETERS CONTRIBUTING TO THE TWEAK

LM lift-off time error ≈ 1 sec

$\Delta VX \approx -.5$ fps
$\Delta VZ \approx -2.0$ fps

Down-range insertion dispersion 8000 ft

$\Delta VX \approx -2.0$ fps
$\Delta VZ \approx -5.0$ fps

Postinsertion tweak

$\Delta VX = -2.8$ fps
$\Delta VZ = -6.5$ fps

Posttrim tweak

$\Delta VX = -4.0$ fps
$\Delta VZ = -9.0$ fps

Trim

$\Delta VX \approx -1.2$ fps
$\Delta VZ \approx -2.5$ fps

TABLE B-III.- EFFECT OF TWEAK MANEUVER

UPON THE APOLLO 14 RENDEZVOUS

(a) Rendezvous without trim, tweak, or navigation

TPI, fps		TPF, fps		
ΔVX	61.2	ΔVX	19.1	TPI elevation angle = 27.9°
ΔVY	-0.9	ΔVY	-0.7	
ΔVZ	76.7	ΔVZ	22.0	Final approach angle = -49.1°
ΔV_{Total}	98.1	ΔV_{Total}	29.1	

(b) Same case with tweak

ΔVX	64.4	ΔVX	18.5	TPI elevation angle = 26.5°
ΔVY	-0.2	ΔVY	0.0	Final approach angle = -54.6°
ΔVZ	73.2	ΔVZ	26.0	Nominal TPI elevation angle = 26.6°
ΔV_{Total}	97.5	ΔV_{Total}	31.9	Nominal approach angle = -52.3°

TABLE B-IV.- EFFECT OF VHF MARK ON CSM TPI

TPI after VHF mark

ΔVX = +39.3 fps	Trailing distance 9.8 n. mi.
ΔVY = -.6 fps	ΔH = 33.1 n. mi. below
ΔVZ = -94.5 fps	

Nominal CSM TPI solution

ΔVX = -64.0 fps	Leading distance 29.4 n. mi.
ΔVY = 0 fps	ΔH = 15.1 n. mi. above
ΔVZ = -65.3 fps	

TABLE B-V.- FINAL TPI SOLUTIONS

PGNCS	GNCS	MSFN
62.1	-67.4	62.4
1.0	0.5	2.5
63.1	-69.2	66.5
MCC-1 MCC-2	2.0 fps 1.0 fps	

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