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REPLY TO ATTN OF: 71-FM54-41

Mar. 1, 1971

MEMORANDUM TO: Informal distribution

FROM : FM5/Planetary Mission Analysis Branch

SUBJECT : Postflight analysis of CSM maneuvers during Apollo 14

Reference is made to MSC Memorandum No. 70-FM54-185, "AV effect of performing TEI from the pre-separation vector for an Apollo 14 mission launched January 31, 1971," by Gordon L. Norbraten, dated July 29, 1970.

### Introduction

The following analysis was made by the Maneuver Analysis Section of the Planetary Mission Analysis Branch. A brief summary of the enclosed information has previously been provided to the Postflight Analysis Group of the Mission Planning Support Office to be submitted as part of their report for inclusion in the MSC Mission Evaluation Report for Apollo 14.

All of the data, information, and comments found in this analysis were accumulated during this section's support in the Flight Dynamics SSR and MPL (Mission Planning Laboratory) during the mission.

Following is a narrative which generally summarizes the postflight analysis and real-time data which were gathered.

#### Translunar Phase

<u>Translunar Injection</u> - TLI was performed in a near-nominal manner with ignition at a g.e.t. of 2:28:30.1. The resulting perilune altitude after TLI was 2022 n.m. which compares with a prelaunch planned perilune altitude of 2030 n.m. The actual TLI burn time was 351.2 secs. which compares with a real-time plan of 348.5 secs. This difference was primarily due to an error in the RTCC thrust model.

<u>Transposition and Docking</u> - Actual CSM separation from the IM/S-IVB occurred at a g.e.t. of 3:02:32. Because of a problem incurred with the docking probe, actual hard docking did not occur until 4:57:00 g.e.t., approximately 1 hour 45 minutes later than was nominally planned.

CSM/IM Separation from S-IVB - Actual CSM/IM separation from the S-IVB occurred at 5:47:25 g.e.t. The actual burn time and  $\Delta V$  of the separation

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maneuver were 6.9 secs. and 0.8 fps as compared with a prelaunch plan of 3.0 secs. and 0.4 fps. The resulting perilune altitude was lowered to 1980 n.m. as compared to the prelaunch nominal 2030 n.m.

<u>S-IVB Evasive Maneuver</u> - The S-IVB evasive maneuver took place at 6:04:20 g.e.t. Because the S-IVB IU telemetry was inoperative at that time, it was difficult to determine how well the maneuver was performed, although MSFN data indicate the maneuver was performed in a near-nominal manner (burn time of 80 secs. and  $\Delta V$  of 9.5 fps).

<u>MCC-1</u> - MCC-1 was never computed in the RTCC because the predicted MCC-2  $\Delta V$  was well within the expected range (70 - 90 fps, depending on whether a constant G.m.t. or g.e.t. at LOI was desired). A predicted MCC-2  $\Delta V$  of 71.4 fps would relate to a MCC-1  $\Delta V$  of approximately 38 fps, based on preflight experience.

<u>MCC-2</u> - The final real-time plan for the hybrid transfer (Midcourse-2) had an ignition time of 30:36:07 g.e.t. This maneuver was designed to set up the lunar approach hyperbola such that a LOI could be done into an orbit which: (a.) began rev. 2 at 105:08:12.07 G.m.t. and (b.) result in no gamma change at DOI.

Midcourse-2 was targeted using state vector BDAX132. The maneuver itself was to be a 71.4 fps SPS burn which placed the spacecraft on a trajectory with a closest approach to the moon occurring at 82:00:36.97 g.e.t. and an altitude of 60.3 n.m. above the radius of the lunar landing site.

The burn was executed "on time" and the comparison between the planned and actual midcourse maneuver is best seen in terms of the component  $\Delta V_g$ 's.

	Vgx	Vgy	Vgz
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 time of closest approach as 82:00:45 g.e.t. with perilune altitude being 67.05 n.m. Although the burn residuals were small in the body coordinate system, they were predominately along the z direction when transformed into external  $\Delta V$ 's. This was overcome by Midcourse-4.

 $\underline{\text{MCC-3}}$  - No MCC-3 maneuvers were computed in the RTCC because the predicted  $\underline{\text{MCC-4}}$   $\Delta V$  was within a reasonable range (1.7 - 3.8 fps, depending on whether perilune altitude control only or a reoptimization BAP-4 MCC was

desired). A predicted MCC-4  $\Delta V$  of 3.8 fps would relate to a MCC-3  $\Delta V$  of approximately 1.0 fps, based on preflight experience.

MCC-4 - Due to the rather high predicted incoming perilune altitude (65.17 n.m.), which would call for some rather large lunar orbit (LPO-1) rotations for the LOI maneuver, it was decided to perform MCC-4. In order to conserve RCS fuel, it was decided to perform a BAP-4 MCC (3.8 fps) with the SPS. Normally, perilune altitude is the only desired parameter to be controlled ( $\Delta V = 1.7$  fps for altitude control only); but in this situation, a larger MCC-4  $\Delta V$  was desired so that a minimum impulse SPS burn could be used. The actual time of MCC-4 was 77:38:14 g.e.t., and the vector used was ACNX264. The actual burn time was 0.64 secs. and the resulting perilune altitude was 60.7 n.m. Both of these figures are very close to the real-time plan (0.69 secs. and 60.6 n.m.) which indicates a near-nominal burn was executed. No RCS trim was performed.

## Lunar Orbit Phase

Lunar Orbit Insertion - The final lunar orbit insertion plan had an ignition time of 82:36:42.7 g.e.t. This maneuver was designed to set up LPO-1 such that: (a.) the spacecraft began rev. 2 at 84:44:53.15 g.e.t., (b.) there would be no gamma change at DOI, and (c.) time of PDI would be 108:41:46 g.e.t.

LOI was targeted using state vector GWMX300. The LOI burn was to be a 3021.8 fps (372.28 second burn time) SPS maneuver which placed the spacecraft into a 58.1 n.m. x 169.3 n.m. lunar orbit.

The LOI burn was performed perfectly. In terms of  $\Delta V_g$ 's:

	Va	Vg	Vg	Burn Time
	x	<u>y</u>	Z	
Real-time plan	-599.34	-1645.02	+2463.99	372.28 secs.
Actual LOI	-599.1	-1645.0	+2463.7	372.23 secs.

The confirmed LOI maneuver showed the orbit to be 58.4 n.m. x 169.0 n.m. with everything set up perfectly for DOI.

Descent Orbit Initiation - The real-time planned DOI maneuver was essentially the one used in targeting LOI because LOI was performed so well.

DOI ignition was 86:51:06 g.e.t. The final plan was based on state GWMX334. The DOI burn was a 205.7 fps (20.77 second burn time) SPS burn which placed the spacecraft into a 9.1 n.m. x 58.8 n.m. lunar orbit.

The DOI burn was "on time". In terms of external  $\Delta V$ 's we had:

	$\nabla \Lambda^{X}$	$\overline{\nabla \Lambda^{\Lambda}}$	$\overline{\nabla \Lambda^{\Sigma}}$	Δt <sub>b</sub>	
Pre-LOI	-207.1 fps	0.0	+1.1		
Real-time plan for DOI	-206.4	0.0	-3.7	20.77 secs.	
Actual DOI	-205.7	0.0	-3.5	20.70 secs.	

The confirmed DOI showed the lunar orbit to be 9.6 n.m. x 58.8 n.m.

<u>CSM/IM Undocking and CSM Separation</u> - CSM separation took place at 104:28:00 g.e.t. An actual burn time of 2.7 secs. and  $\Delta V$  of 0.8 fps resulted in an orbit shape of 7.8 n.m. by 60.2 n.m. which was very close to the prelaunch plan orbit of 8.2 n.m. by 59.5 n.m.

<u>CSM Circularization</u> - The CSM circularization burn occurred on time at a g.e.t. of 105:51:48. 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  $\Delta V$  of 77.2 fps. This slight overburn resulted in an actual orbit shape of 56.0 n.m. by 63.9 n.m. instead of the real-time plan orbit of 55.6 n.m. by 63.3 n.m.

#### Transearth Injection

The transearth injection (TEI) occurred on rev. 34 at 149 hours 16 mins. 4.3 secs. g.e.t. The maneuver was targeted to land at 171°30' west with a landing time of 216 hours 37 mins. 6 secs. g.e.t. The planned burn of 3460.6 fps was generated on the GDSX560 vector. This vector consisted of rev. 32 post-docking data and rev. 33 pre-separation data. The premission plan was to use a vector composed of all the rev. 32 data but during the mission the pre-docking and post-docking data could not be fit. Premission data (reference) indicated that the worst case MCC-5  $\Delta V$  associated with using a pre-separation vector for TEI targeting was 12.6 fps. The planned TEI executed (frozen) on a rev. 34 vector (BDAX578) indicated a 5.6 fps MCC-5  $\Delta V$ . Columns 3 and 4 of Table I present selected parameters for the planned and frozen TEI while columns 1 and 2 present the corresponding data for the premission operational trajectories. Column 5 presents the executed TEI obtained by confirming the burn with trimmed  $\Delta V_{\rm g}$  residuals. The crew reported a good burn which is also indicated by column 5. The post-burn 20 minute tracking vector (HAWX 587) indicated a transearth coast having an entry with a flight path angle of -7.34°. Apparently the execution of the TEI compensated almost exactly for the difference between the Goldstone and Bermuda vectors. The predicted MCC-5  $\Delta V$  on the HAWX587 vector was 1.3 fps.

#### Transearth Midcourses

The first transearth midcourse (MCC-5) was scheduled to occur at approximately 17 hours past TEI. The planned MCC-5 was targeted on the CROX638

vector to correct only the entry corridor error. As presented by column 3 of Table II the CROX638 vector's entry flight path angle ( $\gamma_R$ ) was -6.97 and the vacuum perigee altitude (hvp) was 12.6 n.m. The planned MCC-5 is presented in Table III. The required maneuver delta velocity ( $\Delta V$ ) to correct the  $\gamma_R$  back to -6.50 is 0.7 fps. The midcourse was executed even though the  $\Delta V$  was less than 1 fps, the nominal  $\Delta V$  threshold value for MCC-5 execution. The then current vector indicated that if MCC-5 were not executed, MCC-6 would be performed ( $\Delta V$  approximately 1.4 fps). One wished to avoid executing MCC-6 because of the uncertainty in the quality of the state vector that would be available at that time due to the oxygen flowrate test. Thus prior to the test one wished to be as near to the center of the corridor as possible.

The maneuver was initiated on time but the residuals indicated a maneuver  $\Delta V$  of 0.5 rather than the desired 0.7 (column 2 of Table III). The executed MCC-5 yielded a  $\gamma_R$  of -6.63°. Subsequent vectors (for example, MADX730, column 4 of Table II) predicted a more shallow entry Y of about -6.35 degs. The best pre - MCC-5 vector (CROX646) predicted an entry  $\gamma$  of -6.80 degs. The executed MCC-5 on this vector would yield an entry  $\gamma$  of -6.46 degs. while the planned MCC-5 would yield a -6.33 degs. entry  $\gamma.$ 

Both MCC-6 and MCC-7 were not executed. MCC-6, based upon MADX730, required 0.3 fps. The predicted entry  $\gamma$  at MCC-7 time (HSKX823) was -6.38 degs. Both of these values are below their respective maneuver threshold values and therefore were not executed.

#### Conclusions

Aside from the docking problem after TLI that was mentioned earlier, the CSM encountered no significant maneuver planning or execution problems during the mission. All of the CSM maneuvers were performed within expected tolerances.

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Enclosures

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		Premission O.T.	Premission O.T. Rev. 2	Planned (pad)	Pre-burn frozen	Executed	Post burn 20 minute vector		
Vec	tor			GDSX560	BDAX578	BDAX578	HAWX587		
Ignition t	ime (GET)	149:14:50	149:16:42	149:16:4.3	149:16:4.3	149:16:4.3			
GMT igniti	on	169:34:50	169:39:42	169:39:4.3	169:39:4.3	169:39:4.3			
ΔV	(fps)	3449.5	3450.5	3460.6	3460.6	3460.6			
Burn time	(min:sec)	2:27.2	2:29.3	2:28.1	2:28.1	2:28.1		n de segres per la consegne com actor com como deservado estado	
Entry time	(GET)	216:26:59	216:24:5	216:23:5			216:26:59		
V <sub>R</sub>	(fps)	36170	36171	36171			36171		
Υ <sub>R</sub>	(deg)	-6.50	-6.50	-6.50			-7.34		
IR	(deg)	40.0	40.0	40.0	40.4	40.4	40.2		
Landing ti	me (GET)	216:40:59	216:38:5	216:37:6					
Landing la	titude	27:15 <b>S</b>	27:15 <b>S</b>	27:025	-02				
Landing lo	ngitude	171:30W	171:30W	171:30W				an management of the last statement of the	
Perigee al	titude(n. m	i.)	-	19.5	73.2	73.7	7.0		
Perigee ti	me (GET)			216:25:19	216:31:5	216:31:25	216:29:29		
MCC5 AV	(fps)	0	0	0	5.6	5.6	1.3		
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# TABLE II .- ENTRY AND PERIGEE PARAMETERS FROM SELECTED TEC STATE VECTORS

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Parameter	Planned TEI target values	Post TEI 20 minute track vec- tor	Pre-MCC5	мссб	MCC7	Entry			
ID		HAWX 587	CROX 638	MADX 730	HSKX 823				13.1
GET EI	216:23:5	216:26:59	216:27:18	216:27:47	216:27:47	216:27:47			
Υ <sub>R</sub>	-6.50	-7.34	-6.97	-6.35	-6.38	-6.37			
I <sub>R</sub>	40.0	40.2	40.3	40.3	40.3				
GET VP	216:25:19	216:29:29	216:29:41	216:29:57	216:29:58			· .	
H <sub>vp</sub>	19.5	7.0	12.6	21.5	21.2				
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		Planned MCC5	Executed MCC5						
Brieffing and the state of the State of States									
Vec	or	CROX638	CROX638						
Ignition t:	me (GET)	166:14:58.5	166:14:58.5						
Ignition to	me (GMT)	186:37:58.6	186:37:58.6					-	
ΔV	(fps)	0.7	0.5						
Burn time	(sec)	2.9	2.2					tion discourse and the sec	
Entry time	(GET)	216:27:35	216:27:31						
V <sub>R</sub> .	(fps)	36170	36170						
Υ <sub>R</sub>	(deg)	-6.50	-6.63						
IR	(deg)	40.3	40.3						
Landing ti	ne (GET)	216:41:34	216:41:38				- 10 - 11 - 11 - 11 - 11 - 11 - 11 - 11		
Landing la	titude	27:25	27:25						
Landing lo	ngitude	172:37W	172:37W						
Perigee al	titude (n. mi	.) 19.4	17.6						
Perigee ti	me (GET)	216:29:49	216:29:47						an a
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