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REPLY TO ATTN OF: 71-FM62-28

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MEMORANDUM

TO: Informal Distribution

FROM: FM6/Orbital Mission Analysis Branch

SUBJECT: Postflight Summary of the Apollo 14 Rendezvous

REFERENCES

1. Bell, J. A. and Hartley, L. D., MSC Memorandum 70-FM62-3, "Preliminary analysis of an early rendezvous technique being investigated for future Apollo lunar landing missions, dated January 14, 1970.

2. Hartley, L. D., MSC Memorandum 70-FM62-49, "Dispersion analysis results on the tweak maneuver for the Apollo 14 early rendezvous," dated April 7, 1970.

3. Hartley, L. D., MSC Memorandum 70-FM62-140, "Effect on the Apollo 14 early rendezvous of applying the nominal TPI," dated November 15, 1970.

INTRODUCTION

The basic rendezvous maneuver plan for the Apollo 14 mission was designed to be executed within the first revolution following LM insertion. To accomplish this, the CSI and CDH maneuvers were removed from the previous rendezvous sequences leaving only the TPI and TPF terminal phase intercept and braking maneuvers. However, from the dispersion analysis performed in references 1 and 2, a tweak maneuver was scheduled following orbit insertion to protect the final approach against various undesirable conditions resulting from incorrect lift-off times and insertion dispersions. The purpose of this memorandum is to discuss the tweak maneuver, the TPI solutions, and the rendezvous plan in general. The results are based upon real-time data or on data generated using the PGNCS onboard state vectors. A best estimate of trajectory (BET) for the rendezvous sequence was not available; hence, detailed trajectory data will not be available.

DISCUSSION

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, pre-mission analysis (see reference 2) 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 I with the PGNCS tweak being executed. It is of interest to point out what caused this tweak maneuver. Presented in Table II is a summary of the parameters contributing to the tweak. One of these shown 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 was indicated by an 8,000 ft. downrange insertion dispersion. This downrange dispersion was shown on the vector comparison display after insertion. These two dispersions together 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 post-insertion trim added to the tweak maneuver as shown in Table II.

Table 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 which updated the LM position by approximately 8 n.mi. Table 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.

FINAL TPI SOLUTIONS

The PGNCS, GNCS, and MSFN TPI solutions are shown in Table 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. It is interesting to note how much the final PGNCS TPI solution differed from the initial PGNCS TPI solution after the tweak; i.e., it differs by 2.3 fps in ΔVX and 10.1 fps in ΔVZ. However, based on pre-mission analysis (reference 3), these differences are shown to be within one-sigma. 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 value of this rendezvous technique was demonstrated; hence, it should be used for future Apollo lunar missions.

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5 Enclosures

Distribution:
(See attached list)

FM6:LDHartley:sas:4/02/71:5276

TABLE I

TWEAK SOLUTIONS

	PGNCS	AGS	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 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 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
ΔVY	-0.9	ΔVY	-0.7
ΔVZ	76.7	ΔVZ	22.0
ΔV_{TOTAL}	98.1	ΔV_{TOTAL}	29.1

TPI ELEVATION ANGLE = 27.9 DEG

FINAL APPROACH ANGLE = -49.1 DEG

b. Same case with tweak

TPI, FPS		TPF, FPS	
ΔVX	64.4	ΔVX	18.5
ΔVY	-0.2	ΔVY	0.0
ΔVZ	73.2	ΔVZ	26.0
ΔV_{TOTAL}	97.5	ΔV_{TOTAL}	31.9

TPI ELEVATION ANGLE = 26.5 DEG

FINAL APPROACH ANGLE = -54.6 DEG

NOMINAL TPI ELEVATION ANGLE = 26.6 DEG

NOMINAL APPROACH ANGLE = -52.3 DEG

TABLE 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 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

MCC1 ≈2.0 FPS

MCC2 ≈1.0 FPS