FSRR
3-7-72
TRW
SHOOK

LM AGS

FLIGHT PROGRAM 8/APOLLO 16

FLIGHT SOFTWARE READINESS REVIEW

7 March 1972

CONTENTS

FP 8/APOLLO 16

PROGRAM DELIVERABLES

- ACE FILE TAPE ID 3024 0000
- CONSTANTS LISTING, FP 8/LM 11/ASA 013
- BTME TAPE, ID 4047
- UPDATED ABSOLUTE DECK - ID 4047

deliver all items Friday

FP 8 TEST HISTORY

- VERIFIED PROGRAM DELIVERED 28 APRIL 1971
- INDEPENDENT VERIFICATION TESTING BY LEC/GCD
- CONSTANTS UPDATE TESTING FOR APOLLO 15
- FMES/FCI APOLLO 15 MISSION TESTING
- APOLLO 15 FLIGHT
  - PROGRAM EXCERCISED EXCEPT FOR CSI, CDH
  - NO SOFTWARE ANOMALIES (REFERENCE TRW 71:7150.GRS-40)
- FMES/FCI APOLLO 16 MISSION TESTING
- CONSTANTS UPDATE TESTING FOR APOLLO 16

RELATED ACTIVITIES

- DATA PRIORITY SUPPORT
  - AGS NAVIGATION BRIEFING - 12 OCTOBER 1971
    - PGNCS/AGS STATE VECTOR TRANSFERS
    - ALTITUDE/VELOCITY UPDATE
    - RADAR UPDATING
  - RR DATA INPUT ERROR RECOVERY (N49)
    - FILTER CHARACTERISTICS
    - PROCEDURES
  - APOLLO 16 ALTITUDE/VELOCITY UPDATE PROCEDURE
- FMES/FCI
  - APOLLO 16 MISSION TESTING

APOLLO 15 POSTFLIGHT SUMMARY

- ALTITUDE/VELOCITY UPDATE DURING DESCENT

		Altitude Update		Velocity Update		Touchdown
		Pre	Post	Pre	Post	
- AGS-PGNCS	h(ft)	-1018	368	616	616	678
	$\dot{h}$(fps)	-2.4	-2.4	-1.6	-1.0	0.5

  - APOLLO 15 FIRST MISSION WITH VELOCITY UPDATE - PROCEDURE WORKED, HOWEVER LITTLE EFFECT AS AGS ERRORS WERE SMALL

- PGNCS/AGS STATE VECTOR TRANSFERS
  - POSTFLIGHT ANALYSIS ON FOUR TRANSFERS INDICATE
    LARGEST COMPONENT ERROR: 558 ft, .608 fps
    rms: 197 ft, .218 fps
  - REAL TIME MONITORING PROBLEM TRACED TO GROUND PROCESSING
- AGS AZIMUTH ERROR PRE-LIFTOFF
  - INDICATED ERROR OF .12°
  - CORRECTED BY LOADING GROUND COMPUTED VALUE
  - PROBLEM DUE TO TRANSFERRING PGNCS AZIMUTH AT T_{IG} -30 MIN WITHOUT ACCOUNTING FOR YAW ANGLE CHANGE BETWEEN TRANSFER AND LIFTOFF
  - APOLLO 16 WILL LOAD GROUND COMPUTED VALUES

APOLLO 15 POSTFLIGHT SUMMARY (continued)

- AGS WARNING AND MASTER ALARM
  - TWO OCCURANCES - SECONDS AFTER INSERTION, AFTER LM JETTISON
  - PROBLEM TRACED TO AEA/C&W INTERFACE - NOISE ON TEST MODE FAIL RTN LINE - HARDWARE FIX FOR LM 11
  - POSTFLIGHT ANALYSIS BOUNDED FAILURE CAUSE TO AEA OUTPUT SWITCH, INTERFACE BETWEEN AEA AND C&W, OR C&W LATCHING CIRCUITS
- AUTO RR UPDATING AND RR FILTER
  - PERFORMED AS EXPECTED - NO ANOMALIES NOTED
  - GUIDANCE SOLUTIONS AGREED WELL WITH PGNCS, CSM
  - USED MOSTLY AUTO UPDATING WITH SOME MANUAL UPDATES BEFORE MCC1 AND 2
- ASA PERFORMANCE
  - INERTIAL INSTRUMENT PERFORMANCE WAS EXTREMELY GOOD

CONSTANTS SUMMARY

- CHANGES FROM APOLLO 15
  - 13 ASA HARDWARE CONSTANTS
  - 15 MISSION CONSTANTS

    1K28 - LUNAR ALIGN CONSTANT (FUNCTION OF RLS)

    1K9 - ULLAGE REQUIREMENT
    WAS: 5 2-SEC COUNTS (MIN 9.25 SEC)
    IS: 6 2-SEC COUNTS (MIN 11.25 SEC)

    4K25 - APS TAILOFF ΔV

    4K10, 7J, 8J, 10J, 11J, 12J - DESCENT ABORT CONSTANTS

    5J - LANDING SITE RADIUS

    W_{BX}, W_{BY} - YAW STEERING VECTOR
    WAS: 40° YAW RIGHT FOR DESCENT/ASCENT
    IS: 180° FOR POST INSERTION (TPI MANEUVER)

    6J1, 6J2, 6J3 - LUNAR RATE COMPENSATION FOR GYRO CALIBRATION

CONSTANTS SUMMARY (continued)

- KSC LOAD AND VERIFY CHECKS
  - LM DICTIONARY ANALYSIS LISTS DIFFERENCES BETWEEN

    ID 4039 DELIVERED 28 APRIL 1971 - MASTER FILE

    ID 4047 TO BE DELIVERED 15 MARCH 1972 FOR APOLLO 16
  - NON-COMPARES ARE:

    13 HARDWARE CONSTANTS CHANGES
    14 MISSION DEPENDENT CONSTANTS
     1 NEW CHECKSUM

    28 TOTAL

VERIFICATION TESTING FOR CONSTANTS UPDATE ON APOLLO 16

OBJECTIVE:

- VERIFY ALL CONSTANTS FOR PROGRAM AND MISSION COMPATIBILITY
- DEMONSTRATE FLIGHT PROGRAM TAPE CONTAINING FINAL APPROVED CONSTANTS
- DEMONSTRATE ABILITY OF AGS TO PERFORM SPECIFIED MISSION FUNCTIONS
- DEMONSTRATE THAT THE FLIGHT PROGRAM OPERATES PROPERLY WITH THE APPROVED CONSTANTS

TEST REQUIREMENTS:

- DIGITAL SIMULATIONS
  - ICS/FS
  - SFS
  - PERFORMANCE ANALYSIS
- FMES/FCI
  - AGS CONTROLLED
  - NOMINAL FOLLOW-UP

VERIFICATION TESTING AND RESULTS

TEST CASES:

- ICS/FS CASES
  - LUNAR SURFACE OPERATIONS
  - NOMINAL ASCENT
  - TPI MANEUVER (SHORT RENDEZVOUS)
- SFS CASES
  - NOMINAL SHORT RENDEZVOUS
  - SHORT RENDEZVOUS WITH EARLY LIFTOFF (10 SEC EARLY - INCLUDING A TWEAK BURN)
  - SHORT RENDEZVOUS WITH LATE LIFTOFF (10 SEC LATE - INCLUDING A TWEAK BURN)
  - LUNAR LIFTOFF TO RENDEZVOUS INCLUDING CSI AND CDH
  - PDI+180 ABORT
  - PDI+360 ABORT
  - PDI+540 ABORT
  - PDI+720 ABORT
  - PDI+900 ABORT
- ANALYSIS IN WORK (80% COMPLETE)
  - TO BE COMPLETED PRIOR TO PROGRAM DELIVERY ON 10 MARCH
  - VERIFICATION STATEMENT TO BE INCLUDED AS PART OF SOFTWARE DELIVERY COVER LETTER

ICS/FS TEST RESULTS

- LUNAR SURFACE OPERATION
  - VERIFY LUNAR ALIGN MODE AND LUNAR CALIBRATION MODE, CONSTANTS 6J1, 6J2, 6J3, K28
  - RESULTS:
    - ALIGN ERRORS AFTER 60 SEC

	ACTUAL	SHOULD BE
Y	-.089 $\widehat{\text{min}}$	0
P	-2.642 $\widehat{\text{min}}$	2.742 $\widehat{\text{min}}$
R	-.052 $\widehat{\text{min}}$	0

    - GYRO CALIBRATION RESULTS - VERIFIED GYRO BIAS COMPENSATION VALUES
- ORBIT INSERTION
  - VERIFY OI GUIDANCE, NOMINAL ASCENT TARGETING, CONSTANTS 4K25, 5J
  - RESULTS:
    - INSERTION ORBIT CHECKS WITH OT
    - CUT-OFF AT 61000 ft, 35.75 fps RADIAL RATE
    - REQUIRE PLOTS TO COMPLETE ANALYSIS

TGT 32 fps

- TPI BURN
  - VERIFY NOMINAL TPI PROCEDURES, TARGETING, CONSTANTS 1K9, W_B VECTOR, 5J
  - RESULTS:
    - TPI SOLUTION

      OT 72.09

      AGS VG = 72.5 fps
    - POST TPI ORBIT

      OT 61.96 X 44.02

      AGS 61.92 X 44.13

SCIENTIFIC SIMULATION RESULTS

- ASCENT FROM LUNAR SURFACE
  - NOMINAL LIFTOFF
  - 10 SEC EARLY LIFTOFF
  - 10 SEC LATE LIFTOFF

	OT(NOMINAL)	AGS NOMINAL	-10 SEC	+10 SEC
Insertion Orbit(nm)	9.016 x 45.438	9.0 x 45.4	9.0 x 45.4	9.0 x 45.4
Tweak V_X, V_Z			-4.0, -20.0	4.0, 20.0
TPI				
V_G(fps)	72.09	74.4	76.3	77.9
V_{GX}(fps)	-	72.5	76.2	68.9
V_{GY}(fps)	-	0	0	0
V_{GZ}(fps)	-	16.3	-3.1	36.4
$_{LOS}$(deg)	26.9	25.06	25.0	25.0
Braking V(fps)	33.3	33.3	37.2	36.5

SCIENTIFIC SIMULATION RESULTS (continued)

- DESCENT ABORTS

ABORT TIME		INS. ALT. (FT)	ha (nm)	CSI ΔV fps	CDH Δh nm	ΔV_X	ΔV_Z	TPI ΔV_X	ΔV_Y	ΔV_Z	θ_{LOS}	BRAKING ΔV
PDI +3 min	AGS	60,043	133.1	47.6	14.9	-114.8	-36.3	22.4	0	-13.3	26.6	36.2
	LMTL	60,018	132.8	47.7		-113.5	-33.7					
PDI +6 min	AGS	60,039	110.9	46.5	15.6	-87.2	-3.8	23.0	.2	-12.4	26.6	36.7
	LMTL	60,038	109.6	47.5		-84.3	-1.1					
PDI +9 min	AGS	64,433	66.1	44.6	16.1	-28.4	41.2	23.4	.2	-13.9	26.6	38.5
	LMTL	74,096	63.2	43.7		-23.0	43.4					
PDI +12 min	AGS	59,952	59.5	36.4	16.4	-22.3	-22.9	23.7	.4	-11.4	26.6	43.5
	LMTL	62,010	59.9	38.0		-19.8	-23.2					
PDI +15 min	AGS	59,942	42.9	39.6	16.1	-.9	14.7	23.3	0	-11.5	26.6	39.7
	LMTL	60,241	41.7	41.2		2.2	17.4					

PERFORMANCE ANALYSIS SUMMARY

- APOLLO 16, SHORT RENDEZVOUS:
  - SPEC ASA V 172 (mean +3~~σ~~) fps
  - FLIGHT ASA V 167 fps
- APOLLO 16, NOMINAL RENDEZVOUS
  - SPEC ASA V 190 fps
  - FLIGHT ASA V 183 fps
- HOVER ABORT
  - NO CSM UPDATE AFTER INSERTION V 463 fps
    - TRACKING CLOSE TO BURN
  - CSM UPDATE AFTER INSERTION V 367 fps
    - TRACKING TO TIG - 8 MIN
  - EXTENDED TRACKING V 309 fps
    - TRACKING CLOSE TO BURN
  - FLIGHT ASA, CSM UPDATE V 333 fps
    - TRACKING TO TIG - 8 MIN

349 fps ave.!

(mean + 3σ)

NAVIGATION UPDATE SUMMARY

- STANDARD (NO CSM UPDATE FOLLOWING INSERTION)
  - INITIALIZATION ERRORS BASED ON MSFN DATA AT PDI-180°*
    - 1 UNCERTAINTIES AT PDI-180°

U = 2140	$\dot{U}$ = 6.0		1σ
V = 8500	$\dot{V}$ = 1.9		
W = 6100	$\dot{W}$ = 10.9		

  - ALTITUDE UPDATE AT 8000 FT. (DESCENT ABORT)
  - RR UPDATING POST INSERTION THROUGH MCC2
- CSM UPDATE POST INSERTION (DESCENT ABORT)
  - INITIALIZATION, ALTITUDE UPDATE, RR AS ABOVE
  - AGS CSM VECTOR UPDATED AT HAM -35 MIN

U = 2100	$\dot{U}$ = 4.2		1σ
V = 4500	$\dot{V}$ = 1.9		
W = 7300	$\dot{W}$ = 10.3		

*MSC 69-FM46-338

APOLLO 16/ASA 013 PERFORMANCE ANALYSIS RESULTS SUMMARY

		Early Rendezvous Lunar Surface Abort		Nominal Lunar Surface Abort		End-of-Hover Abort	
Performance Parameter	Statistical Quantity	P&I SPEC ASA MANUAL RR	ASA 013 MANUAL RR	P&I SPEC ASA AUTO RR	ASA 013 AUTO RR	P&I SPEC ASA MANUAL RR	ASA 013 MANUAL RR
Total ΔV (fps)	Mean σ Mean $+3\sigma$	131. 14. 172.	129. 13. 167.	143. 16. 190.	138. 15. 183.	218. 50. 367.	201. 44. 333.
Pericynthion Altitude (feet)	Mean σ Mean -3σ	53720. 1320. 49760.	53420. 1280. 49580.	41500. 1450. 37150.	41370. 1350. 37320.	56990. 6060. 38810.	57310. 4880. 42670.
Δh at CDH* (n mi)	Mean σ	15.0 1.21	15.1 0.84	15.2 1.15	15.4 1.10	14.6 2.61	14.7 2.38
Δh_{MAX} (n mi)	Mean σ	NA	NA	15.5 1.19	15.7 1.22	15.2 2.84	15.2 2.56
Δh_{MIN}	Mean σ	NA	NA	14.9 1.24	15.2 1.11	14.2 2.63	14.4 2.44
$\Delta\Delta h$ (n mi)	Mean σ	NA	NA	0.52 0.35	0.50 0.34	0.94 0.63	0.84 0.62
$\Delta\theta_{LOS}$** (deg)	Mean σ	0.5 5.4	0.5 4.2	0.4 1.0	-0.2 0.9	0.2 2.9	-0.2 2.5
TPI Time (sec)	Mean σ	NA	NA	9343. 360.	9228. 350.	16440. 555.	16400. 540.

*Δh AT TPI FOR THE EARLY RENDEZVOUS CASES

**$\Delta\theta_{LOS}$ = AGS ESTIMATED LINE-OF-SIGHT ANGLE AT TPI MINUS 26.6 DEGREES (TPI PERFORMED AT A FIXED TIME OF 47 MINUTES AFTER INSERTION FOR THE EARLY RENDEZVOUS CASE).

APOLLO 16/ASA 013 PERFORMANCE ANALYSIS MANEUVER ΔV ERROR SUMMARY

		Early Rendezvous Lunar Surface Abort		Nominal Lunar Surface Abort		End-of-Hover Abort	
Performance Parameter	Statistical Quantity	P&I SPEC ASA MANUAL RR	ASA 013 MANUAL RR	P&I SPEC ASA AUTO RR	ASA 013 AUTO RR	P&I SPEC ASA MANUAL RR	ASA 013 MANUAL RR
CSI ΔV ERROR (fps)	$\sigma_{\dot{T}}$	NA	NA	1.1	1.1	1.3	1.2
CDH ΔV ERROR (fps)	$\sigma_{\dot{T}}$ $\sigma_{\dot{R}}$	NA	NA	0.4 1.4	0.3 1.3	0.5 2.6	0.5 2.5
TPI ΔV ERROR (fps)	$\sigma_{\dot{T}}$ $\sigma_{\dot{N}}$ $\sigma_{\dot{R}}$	0.6 1.6 4.0	0.6 1.0 4.0	0.7 2.9 5.6	0.8 2.0 5.5	1.5 1.4 14.1	1.4 1.1 12.9
MCC1 ΔV ERROR (fps)	$\sigma_{\dot{T}}$ $\sigma_{\dot{N}}$ $\sigma_{\dot{R}}$	1.5 0.8 2.8	1.4 0.8 2.7	0.9 1.6 2.0	1.0 1.3 2.0	1.9 1.2 7.4	1.9 1.0 6.6
MCC2 ΔV ERROR (fps)	$\sigma_{\dot{T}}$ $\sigma_{\dot{N}}$ $\sigma_{\dot{R}}$	1.8 0.6 2.3	1.8 0.6 2.6	1.3 0.8 1.3	1.4 0.7 1.4	2.4 1.0 3.2	2.4 0.8 2.9

APOLLO 16/ASA 013 PERFORMANCE ANALYSIS MANEUVER ΔV SUMMARY

		Early Rendezvous Lunar Surface Abort		Nominal Lunar Surface Abort		End-of-Hover Abort	
Performance Parameter	Statistical Quantity	P&I SPEC ASA MANUAL RR	ASA 013 MANUAL RR	P&I SPEC ASA AUTO RR	ASA 013 AUTO RR	P&I SPEC ASA MANUAL RR	ASA 013 MANUAL RR
BOOST ΔV (fps)	Mean σ	NA	NA	NA	NA	10.0 0.3	10.0 0.2
HAM ΔV (fps)	Mean σ	NA	NA	NA	NA	24.6 17.5	19.5 15.4
CSI ΔV (fps)	Mean σ	NA	NA	49.1 1.7	48.9 1.7	40.5 3.5	40.7 3.3
CDH ΔV (fps)	Mean σ	NA	NA	5.5 3.2	4.3 2.5	23.1 13.4	19.3 12.5
TPI ΔV (fps)	Mean σ	75.3 5.3	74.2 4.0	31.0 5.7	28.2 4.5	30.5 8.9	28.0 7.4
MCC1 ΔV (fps)	Mean σ	7.3 4.9	7.2 5.1	9.5 7.0	9.3 7.7	20.0 15.3	18.6 14.7
MCC2 ΔV (fps)	Mean σ	7.9 4.4	7.3 4.4	5.7 3.2	5.2 3.1	17.5 12.5	15.8 11.0
Braking ΔV (fps)	Mean σ	35.3 7.8	34.5 7.3	36.9 7.4	37.6 6.7	46.6 15.2	43.9 12.7