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Memorandum

Rec'd 7/14

TO : EG/Deputy Chief, Guidance and Control Division **DATE:** July 7, 1969

In reply refer to:
EG23-69-152

FROM : EG23/Chief, Systems Analysis Branch

SUBJECT: Mission G software FRR (flight readiness review) presentations

As part of the general software FRR reviews for Mission G held at MSC on July 1 and 2, presentations were given on DAP verification.

The DAP presentations associated with the LUMINARY IA and COLOSSUS II testing are enclosed for general information.

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Enclosures 2

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EG23:KJCox:dbb 7-7-69

INDEXING DATA

DATE	OPR	#	T	PGM	SUBJECT	SIGNATOR	LOC
07-07-69	MSC	EG23-69-152	M	LMA	(Above)	Cox	071-51

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SOFTWARE FLIGHT READINESS REVIEW

SUMMARY OF MSC/TRW TESTING AND ANALYSIS OF THE DIGITAL AUTOPILOT FOR THE LUMINARY IA PROGRAM

INTRODUCTION

- SUMMARIZE DAP TESTING AT MSC/TRW
- RESULTS OF DAP TESTING AT MIT/IL TO BE REPORTED SEPARATELY
- LUMINARY IA TESTING IS AN EXTENSION OF LUMINARY I TESTING
- MAJOR DAP RELATED SOFTWARE CHANGES INCORPORATED INTO LUMINARY IA
    - NONORTHOGONAL U'/V' CONTROL AXES UTILIZED FOR DESCENT AND ASCENT CONFIGURATIONS
    - LM/CSM DOCKED BENDING STABILITY INCREASED BY INHIBITING RCS JET FIRING FREQUENCY WHERE THE OFF-DURATION BETWEEN P-, U-, AND V-AXIS ATTITITUDE CONTROL FIRINGS ARE A MINIMUM OF 0.4, 1.0, AND 1.0 SECOND, RESPECTIVELY
    - P-AXIS CONTROL AUTHORITY PREVIOUSLY ASSUMED TO BE A CONSTANT 1.4 DEG/SEC^2 HAS BEEN APPROXIMATED BY A HYPERBOLIC FUNCTION OF MASS TO PREVENT OVER-ESTIMATION OF THE ACTUAL CONTROL AUTHORITY
    - RCS JET SELECT LOGIC MODIFIED TO ALLOW TWO-JET P-AXIS CONTROL RATHER THAN POSSIBLE USE OF FOUR JETS
    - MINIMUM IMPULSE FOR MIC COMMANDS FOR LM/CSM CONFIGURATION INCREASED TO 60 MSEC
    - GTS UNDERFLOW PROBLEM ELIMINATED BY NORMALIZING THE CONTROL LAW BY THE CONTROL AUTHORITY
    - FOR THE ASCENT CONFIGURATION, THE PHASE-PLANE ATTITUDE ERROR INTERCEPT OF THE TURN-ON SWITCH CURVE HAS BEEN CHANGED FROM A FIXED VALUE OF ONE DEGREE TO A PIECEWISE LINEAR FUNCTION OF THE OFFSET ACCELERATION (AOS). THIS WILL DECREASE THE LIMIT CYCLE AMPLITUDE

INTRODUCTION (CONTINUED)

- FOR THE ASCENT CONFIGURATION, THE PHASE-PLANE COAST SWITCH CURVE HAS BEEN STEEPENED BY A FACTOR OF 1.125 TO ELIMINATE EXTRA FIRINGS DUE TO RECROSSING THE SWITCH CURVE

- TO INCREASE STABILITY OF LIGHT ASCENT CONFIGURATION WITH JET FAILED OFF, THE ROUGHLAW TARGET RATE HAS BEEN INCREASED FROM 5.625 TO 6.5 DEGREES/SECOND

- DAP OFFSET ANGULAR ACCELERATION ESTIMATES (AOS) ARE INITIALIZED VIA ERASABLE LOAD FOR ASCENT INITIALIZATION AT LUNAR LIFT-OFF

PURPOSE OF DAP TESTING

- VERIFICATION OF DAP SEQUENCING
  - INITIALIZATION
  - PERIODIC CYCLING
- VERIFICATION OF DAP FUNCTION
  - PHASE PLANE LOGIC
  - JET SELECT LOGIC
  - CG TRACKING
- VERIFICATION OF DAP E-LOAD
- NOMINAL AND DEGRADED PERFORMANCE EVALUATION

MSC/TRW DAP TESTING

- COMPLETED TESTS
  - DESCRIPTION
    1) NOMINAL ASCENT
    2) WORST CASE ASCENT WITH MASS MISMATCH, 3σ ENGINE CANT AND OFFSET
    3) NOMINAL DESCENT WITH THRUST DEFLECTORS
    4) DPS ABORT
    5) DPS/APS ABORT
    6) DPS TEI CONTINGENCY BURN
  - RUN RESULTS
    1) CONTROL OF NOMINAL ASCENT CONFIGURATION SIGNIFICANTLY IMPROVED OVER LUMINARY I. MAXIMUM PEAK-TO-PEAK STEADY-STATE RESPONSE WAS 3.0 DEG IN ATTITUDE ERROR AND 5.5 DEG/SEC IN RATE ERROR. LIMIT CYCLE FREQUENCY WAS 0.35 Hz.
    2) MASS MISMATCH OF 17.5% AND 3σ ENGINE CANT AND OFFSET IN ASCENT CONFIGURATION CAUSE ONLY SLIGHT DEGRADATION IN PERFORMANCE. MAXIMUM PEAK-TO-PEAK RESPONSE WAS 3.2 DEG IN ATTTITUDE ERROR AND 6.6 DEG/SEC IN RATE ERROR. THE LIMIT CYCLE FREQUENCY WAS INCREASED TO 0.375 Hz.
    3) SLOSH OSCILLATIONS AND LOW-FREQUENCY GUIDANCE AND CONTROL INTERACTION EFFECT NOTED IN NOMINAL DESCENT TEST. MAXIMUM PEAK-TO-PEAK RESPONSE WAS 2.0 DEG IN ATTITUDE ERROR, 3.0 DEG/SEC IN RATE ERROR, AND 6.0 DEG/SEC^2 IN ACCELERATION. THE LOW-FREQUENCY LIMIT CYCLE HAD FREQUENCY OF 0.128 Hz.
    4) EARLY DPS ABORT EXHIBITED NO OSCILLATIONS. MAXIMUM TRANSIENT BEHAVIOR WAS IN RESPONSE TO COMMANDED PITCH MANEUVER WITH ATTITUDE ERROR OF 5.0 DEG AND RATE ERROR OF 7.0 DEG/SEC.

MSC/TRW DAP TESTING (CONT)

- RUN RESULTS (CONTINUED)

  5) MAXIMUM TRANSIENT RESPONSE FOR FITH SEQUENCE RESULTED FROM SEPARATION DYNAMICS AND WAS 6.5 DEG IN ATTITUDE ERROR AND 7.0 DEG/SEC IN RATE ERROR. STEADY-STATE RESPONSE WAS ATTITUDE ERROR WITHIN 1 DEG DEADBAND AND RATE ERROR OF 5.0 DEG/SEC. LIMIT CYCLE FREQUENCY WAS 0.39 Hz FOLLOWING INITIAL TRANSIENT.

  6) THE OSCILLATIONS INDUCED BY SLOSH DURING DPS TEI BURN WERE SUBSTANTIALLY REDUCED FROM THOSE NOTED FOR THE APOLLO 10 (APS OFF-LOADED) TEST CASE. MAXIMUM PEAK-TO-PEAK RESPONSE WAS LESS THAN 1.0 DEG IN ATTITUDE ERROR, 1.7 DEG/SEC IN RATE ERROR AND 3.3 DEG/SEC^2 IN ACCELERATION.

- TEST DESCRIPTION OF POST-SFRR DAP TESTING

  - WORST CASE DESCENT WITH THRUST DEFLECTORS, STATE VECTOR ERRORS, NOISE IN LR MODEL, UNCOMPENSATED PIPA BIAS AND SCALE FACTOR ERROR

APOLLO 10 MISSION FLIGHT TEST RESULTS

- DESCENT CONFIGURATION
  - AUTOMATIC ATTITUDE HOLD FUNCTION PRIOR TO DOI VERIFIED AS NOMINAL
  - AUTOMATIC MANEUVER AT 2 DEG/SEC TO DOI BURN ATTITUDE APPEARED NOMINAL
  - RESIDUAL VELOCITIES FOLLOWING DOI AND DPS PHASING BURNS WERE ACCEPTABLE

BURN	DESIRED ΔV (FPS)	COMPONENTS OF RESIDUAL VELOCITY (FPS)		
		X	Y	Z
DOI	71.2	-0.1	-0.3	-0.5
PHASING	176.9	0.2	-0.5	-0.9

  - MAXIMUM SPACECRAFT RATE DURING PHASING BURN WAS 1.2 DEG/SEC AND ATTITUDE ERROR DEADBAND WAS MAINTAINED SATISFACTORILY
- ASCENT CONFIGURATION
  - AUTOMATIC ATTITUDE HOLD FUNCTION OF THE ASCENT CONFIGURATION WAS NOMINAL
  - AUTOMATIC MANEUVERS OF THE ASCENT CONFIGURATION WERE PERFORMED NOMINALLY
  - APS INSERTION BURN PERFORMED NOMINALLY WITH RESIDUAL VELOCITY COMPONENTS OF -1.5, 0.3, -1.2 FPS FOR DESIRED ΔV OF 220.9 FPS
  - MAXIMUM RATES DURING APS INSERTION BURN WERE 2.5 DEG/SEC
  - THE TPI BURN APPEARED NOMINAL
  - PGNCS CONTROLLED ULLAGE FOR APS BURN-TO-DEPLETION APPEARED NOMINAL WITH MAXIMUM ATTITUDE ERRORS OF 1.9 DEG

CONCLUSIONS

THE LUMINARY IA DIGITAL AUTOPILOT PROGRAM IS CONSIDERED TO BE FLIGHT

READY FOR APOLLO 11

SOFTWARE FLIGHT READINESS REVIEW

DIGITAL AUTOPILOT PERFORMANCE EVALUATION FROM APOLLO 10

INTRODUCTION

- MAJOR SOFTWARE CHANGES INCORPORATED INTO COMANCHE 55
    - INITIALIZE TVC ATTITUDE ERRORS PERRB AND YERRB WITH RCS DAP ATTITUDE ERRORS FOR CSM-ALONE CONFIGURATION
- RCS DAP UNCHANGED
- ENTRY DAP UNCHANGED
- APOLLO 10 POSTFLIGHT EVALUATION IS APPLICABLE TO CONFIDENCE IN FLIGHT READINESS OF COMANCHE 55 BECAUSE OF CLOSE SIMILARITIES OF THE PROGRAMS

APOLLO 10 MISSION FLIGHT TEST RESULTS

- TVC DAP
  - TVC DAP PERFORMANCE DURING THE FIVE SPS BURNS WAS OUTSTANDING

MANEUVER	ΔV DESIRED (FPS)	ΔV RESIDUALS BEFORE NULLING (FPS)		
		X	Y	Z
EVASIVE	19.7	1.0	0.3	0.7
T/L MCC	48.7	-0.9	-0.1	0.3
LOI-1	2982.4	0.0	-0.2	0.0
LOI-2	138.9	0.5	-0.4	-0.4
TEI	3630.3	0.3	1.6	-0.1

  - PEAK ATTITUDE ERRORS DURING BURNS WERE 0.5 DEGREE OR LESS
  - MAXIMUM INITIAL ENGINE GIMBAL EXCURSIONS WERE LESS THAN 0.5 DEGREE
  - CMC INITIALIZED ENGINE GIMBAL TRIM ESTIMATES WITH FINAL VALUES COMPUTED BY THE TVC DAP CG ESTIMATOR LOOP DURING PREVIOUS BURN EXCEPT WHEN SPACECRAFT CONFIGURATION WAS CHANGED
  - BODY BENDING OSCILLATIONS OF APPROXIMATELY 15.5 RAD/SEC WERE NOTED DURING T/L MCC AND LOI BURNS OF THE DOCKED CONFIGURATION. DURATION OF THE OSCILLATIONS WERE SEVEN CYCLES OR LESS
  - PROPELLANT SLOSH OSCILLATIONS WITH FREQUENCY OF APPORXIMATELY 4.5 RAD/SEC DETECTED DURING THE UNDOCKED TEI BURN IN PITCH AND YAW AXES. PITCH OSCILLATIONS DAMPED AFTER ≈70 SECONDS WHILE YAW OSCILLATIONS WERE EVIDENT FOR THE ENTIRE BURN. THE OSCILLATIONS WERE NOT DIVERGENT AND PRESENTED NO STABILITY PROBLEM.

APOLLO 10 MISSION FLIGHT TEST RESULTS (CONT)

- TVC ROLL DAP PERFORMED IN ACCORDANCE WITH PHASE-PLANE DESIGN. DURING LOI-1, ROLL ATTITUDE ERROR BOUNCED OFF NEGATIVE BEADBAND WHICH ALSO OCCURRED IN PREVIOUS FLIGHTS. ROLL ATTITUDE ERROR TRAVELED BETWEEN BOTH DEADBANDS DURING TEI.

- RCS DAP
  - COASTING FLIGHT ATTITUDE HOLD FUNCTION VERIFIED AS NOMINAL FOR PERIODS OF BOTH NARROW AND WIDE DEADBAND ATTITUDE HOLD.
  - AUTOMATIC MANEUVERS AT 0.2 AND 0.5 DEG PER SECOND SATISFACTORY WITH NO OVERSHOOT
  - ATTITUDE ERRORS DURING ULLAGE WERE LESS THAN 0.6 DEGREE
  - MCC DURING T/E COAST REQUIRED $\approx$ 1.5 FPS ΔV. POSTBURN VG COMPONENTS WERE 0.1, -0.1, -0.1 FPS
  - INITIAL PTC FUNCTION UNDER CMC PTC MODE EXHIBITED "BOUNCING OFF" THE 20 DEGREE PITCH AND YAW ATTITUDE DEADBANDS. SUBSEQUENT CMC PTC FUNCTIONS WERE PERFORMED WITH PITCH AND YAW ATTITUDE HOLD DEADBANDS INCREASED TO 30 DEGREES AND THE ROLL RATE INCREASED FROM 0.1 TO 0.3 DEG/SEC. ALSO, ALL SPACECRAFT RATES WERE THOROUGHLY NULLED PRIOR TO ESTABLISHING THE PTC MODE. THE NEW PROCEDURE WAS QUITE SATISFACTORY WITH NO SUBSEQUENT EXCESSIVE RCS ACTIVITY.

- ENTRY DAP
  - ENTRY DAP EMPLOYED AFTER 0.05 G
  - ROLL DAP PERFORMANCE WAS FOUND NOMINAL ON A FUNCTIONAL BASIS
  - PITCH AND YAW RATE DAMPER FIRINGS WERE VERIFIED

CONCLUSIONS

BASED ON PERFORMANCE OF THE COLOSSUS II (COMANCHE 45) DIGITAL AUTOPILOT PROGRAMS ON THE APOLLO 10 MISSION, THE COMANCHE 55 DIGITAL AUTOPILOT PROGRAMS (TVC, RCS, AND ENTRY) ARE CONSIDERED TO BE FLIGHT READY.