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# SOFTWARE FLIGHT READINESS REVIEW

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

# INTRODUCTION

- SUMMARIZE DAP TESTING AT MSC/TRW
- LUMINARY 1B TESTING IS AN EXTENSION OF LUMINARY 1A TESTING
- APOLLO 11 POSTFLIGHT EVALUATION IS APPLICABLE TO CONFIDENCE IN FLIGHT READINESS OF LUMINARY 1B BECAUSE OF CLOSE SIMILARITIES OF PROGRAMS
- MAJOR DAP RELATED SOFTWARE CHANGES INCORPORATED INTO LUMINARY 1B
    - POWERED FLIGHT DEADBAND FOR PROGRAMS P64, P65, P66 AND P67 CHANGED TO 0.3 DEG
    - CHANGED PHASE-PLANE LOGIC TO ENHANCE DAP PERFORMANCE IN PRESENCE OF SMALL DISTURBING ACCELERATION DURING POWERED ASCENT

# 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
# MSC BIT-BY-BIT SIMULATOR

- COMPLETED TESTS
  - DESCRIPTION
    1) NOMINAL AUTOMATIC LANDING INCLUDING TERRAIN AND LANDING RADAR
    2) OFF-NOMINAL LANDING INCLUDING RCS QUAD MISALIGNMENTS AND JET FAILURES
    3) AUTOMATIC LANDING WITH $\triangle$RLS REDESIGNATION PRIOR TO ENTRANCE OF IGNITION ALGORITHM
    4) AUTOMATIC LANDING WITH $\triangle$RLS REDESIGNATION 3 MINUTES AFTER PDI
    5) AUTOMATIC LANDING WITH LATERAL REDESIGNATION OF 6 DEG AT TIME REMAINING IN P64 OF 50 SECONDS
  - RUN RESULTS
    1) SLOSH OSCILLATIONS AND LOW-FREQUENCY GUIDANCE AND CONTROL INTERACTION EFFECT NOTED IN NOMINAL DESCENT CASE. MAXIMUM PEAK-TO-PEAK RESPONSE IN P63 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 A FREQUENCY OF APPROXIMATELY 0.15 HZ. THE MAXIMUM PEAK-TO-PEAK RESPONSE IN P64 AND P65 WAS 0.8 DEG IN ATTITUDE ERROR, 1.25 DEG/SEC IN RATE ERROR AND 1.8 DEG/SEC$^2$ IN ACCELERATION. RCS PROPELLANT CONSUMPTION DURING P64 AND P65 EXCLUSIVE OF THE PITCHOVER MANEUVER, WAS 13.7 POUNDS COMPARED TO 7.3 POUNDS FOR THE LUMINARY IA 1$^\circ$DB.

# MSC/TRW DAP TESTING
# MSC BIT-BY-BIT SIMULATOR (CONT.)

2) INCREASED CONTROL AUTHORITY DUE TO QUAD MISALIGNMENTS CAUSED SLIGHT INCREASE IN RATE AMPLITUDES. FAILED OFF JET UNDETECTED CAUSED SLOWER PITCHOVER MANEUVER AND CREATED CROSSCOUPLING IN ROLL AXIS OF 4.2 DEG/SEC. MAXIMUM PITCH RATE WAS 10.7 DEG/SEC COMPARED TO 11.6 DEG/SEC FOR NOMINAL CASE.

3&4) THE DAP PERFORMANCE WAS UNAFFECTED BY USE OF THE △RLS ROUTINE

5) TRANSIENTS INDUCED BY THE LARGE LATERAL REDESIGNATION WERE DAMPED QUICKLY AND PRODUCED ONLY MINOR OSCILLATIONS.

- PLANNED POST-SFRR DAP TESTING

1) NOMINAL ASCENT
2) ASCENT WITH APS ENGINE ALIGNMENT ERRORS
3) DPS ABORT IN VISIBILITY PHASE
4) APS ABORT IN VISIBILITY PHASE
5) AUTOMATIC LANDING WITH LARGE LATERAL RADAR NOISE SPIKE IN P64

# APOLLO 11 MISSION FLIGHT TEST RESULTS

- DESCENT CONFIGURATION
  - NO TELEMETRY DATA AVAILABLE FOR DOI BURN, BUT VOICED DOWN RESIDUALS OF -0.1, -0.4, AND 0.1 FT/SEC INDICATE NOMINAL DAP PERFORMANCE
  - MAXIMUM TRANSIENTS DUE TO ULLAGE AND DPS IGNITION FOR POWERED DESCENT WERE:

    | | | | |
    |---|---|---|---|
    | YAW: | -0.49 DEG/SEC | YAW: | 1.08 DEG |
    | PITCH: | +0.67 DEG/SEC | U': | -1.02 DEG |
    | ROLL: | -0.69 DEG/SEC | V': | -1.02 DEG |

    THE TRANSIENTS WERE QUICKLY DAMPED
  - SLOSH OSCILLATIONS WERE FIRST APPARENT 233 SEC INTO THE BURN. THE FREQUENCY OF THE SLOSH OSCILLATION WAS 0.5 - 0.6 HZ AND CAUSED MAXIMUM PEAK-TO-PEAK RATE AMPLITUDES OF 3.0 DEG/SEC. THE OSCILLATIONS WERE BOUNDED WITHIN ACCEPTABLE LIMITS.
  - POWERED DESCENT REQUIRED 88 POUNDS OF RCS PROPELLANT COMPARED TO A BUDGET OF 40 POUNDS. THE MAJORITY OF THE PROPELLANT USED, 66 POUNDS, WAS EXPENDED DURING PERIODS OF MANUAL CONTROL. THE BUDGET DID NOT ACCOUNT FOR THE FULL EXTENT OF RCS ACTIVITY REQUIRED DURING THE P66 PHASE.

# APOLLO 11 MISSION FLIGHT TEST RESULTS (CONT.)

- THE GDA/RCS ACTIVITY DURING POWERED DESCENT WAS IN ACCORDANCE WITH SOFTWARE SPECIFICATIONS

- ASCENT CONFIGURATION
  - MAXIMUM VALUES OF RATES AND ACCELERATIONS AT TIME OF DATA DROPOUT DURING LIFTOFF WERE:

| | | |
|---|---|---|
| YAW: | -1.48 DEG/SEC | -12. DEG/SEC$^2$ |
| PITCH: | 4.45 DEG/SEC | 25. DEG/SEC |
| ROLL: | 1.68 DEG/SEC | 12. DEG/SEC |

  COMPLETE FITH EFFECTS COULD NOT BE DETERMINED DUE TO DATA DROPOUT

  - THE OFFSET ACCELERATIONS IMMEDIATELY AFTER APS IGNITION AGREED WELL WITH PAD LOADED VALUES
  - THE TOTAL GUIDANCE COMMANDS OF -16.0 - 52.5, AND 1.5 DEG ABOUT THE YAW, PITCH, AND ROLL AXES RESPECTIVELY, WERE EXECUTED NOMINALLY. THE CORRESPONDING RATES AT TIME OF MANEUVER WERE -16.0, 2.0 DEG/SEC ABOUT PITCH AND ROLL AXES. (YAW RATE NOT AVAILABLE)
  - NOMINAL LIMIT CYCLE FREQUENCIES OF 0.3 TO 0.36 HZ AND PEAK-TO-PEAK RATE AMPLITUDES OF 12.6 AND 4.6 DEG/SEC ABOUT THE PITCH AND ROLL AXES WERE OBSERVED DURING POWERED ASCENT. THE MAXIMUM ATTITUDE ERRORS WERE -1.1, -2.2 AND 2.3 DEG ABOUT THE P, U', AND V' AXES RESPECTIVELY.

# APOLLO 11 MISSION FLIGHT TEST RESULTS (CONT.)

- THE RESIDUAL VELOCITIES AFTER APS CUTOFF WERE:

  X: -2.1 FT/SEC
  Y: -0.1 FT/SEC
  Z: 1.8 FT/SEC

  THE OVERBURN OF APPROXIMATELY 2 FT/SEC WAS A RESULT OF HIGHER TAILOFF EFFECTS THAN WERE ESTIMATED

- THE FOUR RCS TRANSLATION BURNS IN THE RENDEZVOUS SEQUENCE WERE PERFORMED NOMINALLY WITH SATISFACTORY RESIDUAL VELOCITIES

# CONCLUSIONS

**THE LUMINARY IB DIGITAL AUTOPILOT PROGRAM IS CONSIDERED TO BE FLIGHT READY FOR APOLLO 12**