

# APOLLO

Approved: R. *Richard H. Battin* Date: Aug 14, 1967  
RICHARD H. BATTIN, TECHNICAL DIRECTOR  
APOLLO GUIDANCE AND NAVIGATION PROGRAM

Approved: *David G. Hoag* Date: 14 Aug 67  
DAVID G. HOAG, DIRECTOR  
APOLLO GUIDANCE AND NAVIGATION PROGRAM

Approved: *Ralph R. Ragan* Date: 14 Aug 67  
RALPH R. RAGAN, DEPUTY DIRECTOR  
INSTRUMENTATION LABORATORY

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## VERIFICATION RESULTS SUMMARY FOR LGC SUNBURST (LM-1 MISSION)

by  
Jay A. Sampson  
(AC Electronics)  
August 1967

# MIT

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VERIFICATION RESULTS SUMMARY  
FOR LGC SUNBURST (LM-1 MISSION)

ABSTRACT

A description and short summary is presented of the all-digital verification runs performed to qualify the LM-1 Guidance Computer Program, BURST116.

Individual runs were made of each mission phase under nominal conditions and with vehicle perturbations, excessive LGC restarts, ignition failures, premature engine shutdowns, and termination commands from the ground. In addition, three end-to-end runs were made from prelaunch through mission phase 13 to verify the protection of the erasable memory load and the integration of the various mission phases, under nominal conditions and with prelaunch stable member misalignments. Finally, some miscellaneous runs were made with both critical and non-critical RCS jet failures, a trim signal failure, an inflight fresh start recovery, excess SIVB tumbling, and sequences of both legal and illegal uplink commands and updates.

Since not all runs were made using the final version of the flight program (SUNBURST Revision 116 or BURST116 Revision 0, which are identical), a revision number is included for each run.

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## Introduction

Unless otherwise noted, in each run the Guidance System Operation Plan (R-527) timeline was adhered to with respect to mission phase timing and sequencing, scheduling of next mission phase and enabling of mission times at end of run, IMP commands, +X translation ON/OFF, DPS/APS engine ON/Off, detection of engine tailoff by  $\Delta V$  monitor after guidance commanded cutoff, RCS pressurization, RCS cold fire purge, tumble monitor verification of tumble rates less than  $3^\circ/\text{sec}$ , LM/SIVB separation sequence, Ascent/Descent staging and Ascent-stage crossfeed valve test.

In most cases, the LGC state vector position and velocity errors at the beginning of the run were zero, IMU errors (PIPA bias, PIPA scale factor, gyro drift) were purposely introduced and exactly compensated for by the flight program, and at least one 100-word down-telemetry list was sampled.

For information concerning the vehicle simulation model, refer to "Digital Simulation for the Verification of Program SUNBURST", MIT Instrumentation Laboratory Report E-2146. (Confidential).

RUN #1

- Description: Mission Phases 1, 2, and 3 (Prelaunch Alignment, Guidance Reference Release and Boost Monitor, and Coast-SIVB Attached) with liftoff detector.
- Revision: 112
- Duration: 60 seconds prior to liftoff through set-up of mission phase 7 (LM/SIVB Separation).
- Objectives:
- 1) Demonstrate proper LGC clock alignment by a VERB 55 prior to initiation of prelaunch alignment.
  - 2) Demonstrate that the prelaunch alignment program can align the IMU stable member to the correct earth-fixed orientation (X PIPA input axis  $30^\circ$  from the local vertical (up), Y PIPA input axis downrange at an azimuth of  $122^\circ$  east of north and elevated  $30^\circ$  above the horizontal plane, and Z PIPA input axis downrange at an azimuth of  $32^\circ$  east of north and in the horizontal plane).
  - 3) Demonstrate proper termination of prelaunch alignment and initiation of MP2 upon detection of 1.1 g's by the prelaunch program.
  - 4) Verify that a redundant GRR (VERB 65) sent at liftoff + 2 seconds is ignored.
  - 5) Verify detection of SIVB shutdown by the boost monitor and proper initiation of MP6.
  - 6) Compare prelaunch alignment, MP2, and MP6 timing against the nominal 206 GSOP timeline.

Results:

1) LGC Clock Alignment Summary

The LGC clock was purposely initialized incorrectly at the start of the run so that it lagged the simulator clock by 7.52 seconds. At 2.5 seconds a VERB 55 was sent followed by a time increment of +752 centiseconds, which perfectly synchronized the LGC clock with the simulator clock.

2) Prelaunch Alignment Summary

- a) The prelaunch alignment program was initiated at liftoff - 55 seconds.
- b) The IMU stable member was open-loop coarse aligned and gyro torqued to the desired earth-fixed orientation by liftoff - 25 seconds.
- c) The prelaunch gyrocompassing loop held the IMU platform to the proper gimbal angles of  $AOG = 122^\circ$ ,  $AIG = 0^\circ$ ,  $AMG = 30^\circ$  such that at GRR the euler set from desired to actual stable member alignment axes were  $X_{mis} = -0.0117^\circ$ ,  $Y_{mis} = -0.0037^\circ$ ,  $Z_{mis} = -0.0084^\circ$ .

3) Guidance Reference Release Summary

- a) At 0.30 seconds after liftoff, 1.1 g's were sensed by the prelaunch alignment program.
- b) Consequently, gyrocompassing was terminated and MP2 initiated at 0.33 seconds.
- c) The LGC clock was zeroed at 0.44 seconds.

4) Redundant GRR Command Summary

A VERB 65 was transmitted at 2 seconds after liftoff, with no resulting action taken by the flight program. In otherwords, MP2 was

not re-initiated by the redundant command.

5) SIVB Shutdown Summary

- a) SIVB shutdown occurred at 587 seconds after liftoff.
- b) The SIVB  $\Delta V$  Monitor detected shutdown at 590 seconds.
- c) MP6 was initiated at 590 seconds.

6) Timeline and Other Summaries

Refer to the appendix.



RUN #2

Description: Mission Phase 3 (Suborbital Abort) with 100 second premature SIVB shutdown and 20 second delay before abort command sent via uplink.

Revision: 116

Duration: 60 seconds of prelaunch alignment through 30 seconds prior to end of MP3.

Objectives: 1) Verify proper initiation of MP3 and termination of MP6 by abort sequencing routine upon receipt of abort command signal.  
2) Compare boost, abort sequencing, and MP3 timing against nominal 206 GSOP timeline.

Results: 1) Abort Sequencing Summary  
a) SIVB ignition occurred at 143 seconds after liftoff.  
b) Abort command and tumble monitors initiated at 145 seconds.  
c) SIVB  $\Delta V$  monitor initiated at 155 seconds.  
d) SIVB shutdown occurred at 500 seconds.  
e) SIVB  $\Delta V$  monitor detected shutdown at 503 seconds.  
f) MP6 initiated at 503 seconds.  
g) Uplink SUBORBITAL ABORT command received at 519 seconds.  
h) Abort command monitor, tumble monitor, and MP6 terminated at 519 seconds.  
i) Tumble monitor re-initiated at 519 seconds.  
j) MP3 initiated at 520 seconds.

- k) Abort RCS pressurization performed at 520 seconds.
- l) Vehicle tumbling rates less than  $3^{\circ}/\text{sec}$  verified at 529 seconds.
- m) LM/SIVB separation sequence initiated at 529 seconds.
- n) Digital autopilot turned on at 530 seconds.

2) Timeline and Other Summaries

- a) The run was terminated because trajectory was too close to the earth. The reading of the PIPA's was not terminated.
- b) One LGC down-telemetry frame was sent twice at liftoff because the computer was too busy to process the telemetry interrupt until the next one came due.
- c) The other summaries are given in the appendix.

RUN #2a

Description: Mission Phase 3 with 100 second premature SIVB shutdown, 5 second delay before abort command sent, and

- 1) DPS/APS fuel slosh.
- 2) DPS/APS engine misalignments.
  - a) DPS/APS X, Y, Z position errors.
  - b) DPS misalignment of thrust axis with engine center line about Y, Z-axes.
  - c) DPS/APS misalignment of engine center line with vehicle X-axis about Y, Z-axes.
- 3) RCS quads 1-4 misalignments.
  - a) X, Y, Z, position errors.
  - b) Misalignment about X, Y, Z-axes.

Revision: 116

Duration: SIVB shutdown through end of MP3.

- Objectives:
- 1) Demonstrate minimal effect of DPS/APS fuel slosh, DPS/APS engine misalignments, and RCS jet misalignments on mission phase performance.
  - 2) Compare summaries with Run #2.

- Results:
- 1) Fuel Slosh and Misalignment Summary
    - a) Mission phase performance was not significantly affected in the areas of navigation or timing.
    - b) There was about 15% more RCS fuel used than in Run #2, even though the two runs were nearly identical.
  - 2) Timeline and Other Summaries

Given in the appendix.

RUN #3

**Description:** Nominal Mission Phase 4 (Contingency Orbit Insertion) with 15 second premature SIVB shutdown and 15 second delay until abort command sent via LGC uplink.

**Revision:** 106

**Duration:** 60 seconds of prelaunch alignment through end of MP4.

**Objectives:**

- 1) Verify proper initiation of MP4 and termination of MP6 by abort sequencing routine upon receipt of CONTINGENCY ORBIT INSERTION uplink signal.
- 2) Verify that proper orbit insertion can be achieved by the DPS commanded by ascent guidance equations.
- 3) Compare boost, abort sequencing, and MP4 timing against nominal timeline.

**Results:**

- 1) Abort Sequencing Summary
  - a) SIVB ignition occurred at liftoff + 143 seconds.
  - b) Abort command and tumble monitors initiated at 145 seconds.
  - c) SIVB  $\Delta V$  monitor initiated at 155 seconds.
  - d) SIVB shutdown occurred at 585 seconds.
  - e) SIVB  $\Delta V$  monitor detected shutdown at 587 seconds.
  - f) MP6 initiated at 587 seconds.
  - g) Uplink CONTINGENCY ORBIT INSERTION abort command received at 601 seconds.
  - h) Abort command monitor, tumble monitor, and

MP6 terminated at 601 seconds.

- i) Tumble monitor re-initiated at 601 seconds.
- j) MP4 initiated at 602 seconds.
- k) Abort RCS pressurization performed at 603 seconds.
- l) Vehicle tumbling rates less than  $3^{\circ}/\text{sec}$  verified at 611 seconds.
- m) LM/SIVB separation sequence initiated at 611 seconds.
- n) Digital autopilot turned on at 612 seconds.
- o) Maneuver to MP4 ignition attitude performed at 628 seconds.

2) Orbital Insertion Guidance Summary

a) Targets

$$R_{\text{injection}} = 21,445,246 \text{ feet}$$
$$V_{\text{injection}} = 25,682.42 \text{ ft/sec}$$

(apogee = 3561.6 n.m.)  
(perigee = 3527.2 n.m.)

b) SIVB Shutdown Conditions at 585 Seconds

$$R = 21,440,078 \text{ feet}$$
$$V = 24,256.65 \text{ ft/sec}$$

(apogee = 3526.5 n.m.)  
(perigee = 2862.6 n.m.)

c) MP4 Ignition Conditions at 664 Seconds

$$R_{\text{ignition}} = 21,422,037 \text{ feet}$$
$$V_{\text{ignition}} = 24,283.63 \text{ ft/sec}$$

(apogee = 3526.4 n.m.)  
(perigee = 2864.5 n.m.)

d) Guidance Cutoff Conditions at 900 Seconds

$$R_{co} = 21,447,710 \text{ feet}$$

$$V_{co} = 25,675.20 \text{ ft/sec}$$

$$(\text{apogee} = 3558.7 \text{ n.m.})$$

$$(\text{perigee} = 3527.4 \text{ n.m.})$$

3) Timeline and Other Summaries

Given in appendix.

RUN #3b

Description: Mission Phase 4 with 40 second premature SIVB shutdown, 20 second delay until abort uplink command, LGC restarts (GOJAM's), and digital autopilot turned off for 4 seconds during burn by a VERB 63.

Revision: 112

Duration: 60 seconds of prelaunch alignment through end of MP4.

Objective:

- 1) Verify that nominal orbit insertion can be achieved with a different premature SIVB shutdown "window" than in Run #3.
- 2) Demonstrate minimal effect of restarts on mission phase performance and verify that MP4 is restart protected.
- 3) Demonstrate effect of turning DAP off for a short time by a VERB 63 in MP4 on body rates.
- 4) Compare timing with Run #3.

Results: 1) Orbit Insertion Guidance Summary

a) Targets

Same as in Run #3.

b) SIVB Shutdown Conditions at 545 Seconds

R = 21,446,073 feet

V = 22,625.60 ft/sec

(apogee = 3528.5 n.m.)

(perigee = 2253.4 n.m.)

c) MP4 Ignition Conditions at 630 Seconds

$$R_{\text{ignition}} = 21,394,696 \text{ feet}$$

$$V_{\text{ignition}} = 22,698.32 \text{ ft/sec}$$

$$(\text{apogee} = 3528.4 \text{ n.m.})$$

$$(\text{perigee} = 2254.5 \text{ n.m.})$$

d) Guidance Cutoff Conditions at 1120 Seconds

$$R_{\text{co}} = 21,447,906 \text{ feet}$$

$$V_{\text{co}} = 25,686.73 \text{ ft/sec}$$

$$(\text{apogee} = 3565.3 \text{ n.m.})$$

$$(\text{perigee} = 3527.4 \text{ n.m.})$$

2) Restarts Summary

Restarts were forced at various critical points in the MP4 program and also every 14 seconds during the burn, for a total of 93 restarts. Mission phase performance was not significantly affected in the areas of guidance, timing, or navigation.

- a) Most everything in the MP4 was repeated (Orbital Integration, Attitude Maneuvers, LMP Commands, etc.) due to restarts, delaying the mission sequencing slightly.
- b) Fuel consumption was noticeably higher than in Run #3, probably due to a combination of restarts and earlier SIVB shutdown.
- c) Program alarm 1412 was displayed, indicating that MP4 attitude maneuver failed to achieve the desired ignition gimbal angles. This was due to the combination of the  $10^{\circ}/\text{sec}$  abort maneuver rate and the restart during the maneuver, which caused the re-maneuver to read its initial gimbal angles before the gimbals stopped.



Consequently it computed the time to read the final gimbal angles too early and alarmed. This will probably always happen under these circumstances, although the DAP will shortly achieve the desired angles.

3) DAP-Off Summary

A VERB 63 was sent at 760 seconds, which resulted in the DAP being turned off between 765 and 769 seconds after liftoff (135 seconds into the burn). The resultant attitude drift of the vehicle while the DAP was off was  $3.25^{\circ}$ .

4) The other summaries are given in the appendix.

RUN #3c

Description: Mission Phase 4 with 20 second premature SIVB shutdown, 5 second delay for abort command, and

- 1) DPS fuel slosh.
- 2) DPS engine misalignments.
  - a) X, Y, Z position errors.
  - b) Misalignment of thrust axis with engine center line about Y, Z-axes.
  - c) Misalignment of engine center line with X-vehicle axis about Y, Z-axes.
  - d) Thrust dependent misalignment (due to bending) about Y, Z-axes.
- 3) RCS quads 1-4 misalignments.
  - a) X, Y, Z position errors.
  - b) Misalignment about X, Y, Z-axes.

Revision: 116

Duration: SIVB shutdown through 19 seconds beyond end of MP4.

- Objectives:
- 1) Verify that nominal orbit insertion can be achieved with a different premature SIVB shutdown "window" than in Runs #3 and #3b.
  - 2) Demonstrate minimal effect of DPS fuel slosh, DPS engine misalignments, and RCS jet misalignments on mission phase performance.
  - 3) Compare timing with Runs #3 and #3b.

- Results:
- 1) Orbital Insertion Guidance Summary
    - a) Targets  
Same as in Run #3

b) SIVB Shutdown Conditions at 585 Seconds

$R = 21,443,138$  feet

$V = 24,181.50$  ft/sec

(apogee = 3527.0 n.m.)

(perigee = 2831.8 n.m.)

c) MP4 Ignition Conditions at 653 Seconds

$R_{\text{ignition}} = 21,428,866$  feet

$V_{\text{ignition}} = 24,203.59$  ft/sec

(apogee = 3526.9 n.m.)

(perigee = 2834.1 n.m.)

d) Guidance Cutoff Conditions at 881 Seconds

$R_{\text{co}} = 21,445,796$  feet

$V_{\text{co}} = 25,681.08$  ft/sec

(apogee = 3561.0 n.m.)

(perigee = 3527.1 n.m.)

2) Fuel Slosh and Misalignment Summary

- a) Mission phase performance was not significantly affected in the areas of guidance, timing, or navigation.
- b) There was about 15% more RCS fuel used as there was in Run #3, even though they both had approximately the same SIVB shutdown "window" and length of DPS burn.
- c) There was a program alarm 1412 displayed, indicating that the desired ignition attitude was not achieved. As in Run #3b, the high  $10^{\circ}$ /sec maneuver rate probably caused the DAP to overshoot the desired gimbal angles at the time when the final angles should have been achieved. Eventually the desired attitude was attained.

This is the only run in which a 1412 program alarm occurred with a  $10^{\circ}/\text{sec}$  maneuver rate, and with no restarts.

3) Timeline and Other Summaries

Given in the appendix.

RUN #4

Description: Nominal Mission Phases 7 and 8 (SIVB Separation and DPS Cold Soak Maneuver).

Revision: 113

Duration: 60 seconds prior to initiation of MP7 through 15 seconds beyond end of MP8.

Objectives: 1) Verify proper calculation and attainment of desired cold soak attitude.  
2) Compare timing and sequencing against 206 GSOP timeline to demonstrate proper performance.

Results: 1) Cold Soak Attitude Maneuver Summary  
a) The desired cold soak gimbal angles (AOG:  $-112.5^\circ$ , AIG:  $-25.7^\circ$ , AMG:  $-5.4^\circ$ ) were achieved and held within the  $5^\circ$  deadband.  
b) A  $151.88^\circ$ , 30.36 second attitude maneuver was performed to the cold soak attitude.  
c) The amount of RCS fuel used during maneuver was 4.3 pounds.  
2) Timeline and Other Summaries  
a) Due to a programming error in MP7, the RCS cold fire purge lasted only 36.4 seconds, instead of the nominal 40 seconds. The program schedules purge-off in 40 seconds, then performs orbital integration (3.6 seconds in Run #4) before initiating the cold fire purge.  
b) Length of MP7 was 4 minutes, 15 seconds; length of MP8 was 2 minutes, 30 seconds. Time between MP7 and MP8 was nominal 8 seconds.  
c) Other summaries given in the appendix.

RUN #5

Description: Nominal Mission Phase 9 (DPS1).

Revision: 116

Duration: 26 seconds prior to start of MP9 through 19 seconds beyond end of mission phase.

- Objectives:
- 1) Verify that the descent orbit injection guidance equations can:
    - a) control the flight path angle at cutoff to be zero relative to the local horizontal (i.e.: establish perigee at cutoff).
    - b) raise the conic apogee at cutoff to the targeted radial distance  $R_p$ .
  - 2) Compare timing sequences against 206 GSOP timeline to demonstrate nominal performance.

- Results:
- 1) Guidance Summary
    - a) The flight path angle achieved at cutoff was  $0.00^\circ$ .
    - b) The targeted radial distance  $R_p$  of 21,992,000 feet represents an apogee of 3617.0 nautical miles. The apogee achieved at cutoff was 3615.8 nautical miles.
  - 2) Timeline and Other Summaries
    - a) Actual guidance cutoff time occurred one second earlier than the predicted cutoff time.
    - b) The trim gimbal usage during the DPS1 burn was 41%; the remainder of the steering time was accomplished under RCS jet control.
    - c) The other summaries are given in the appendix.

RUN #5a

- Description: Mission Phase 9 with
- 1) DPS fuel slosh.
  - 2) DPS engine misalignments.
    - a) X, Y, Z position errors.
    - b) Misalignment of thrust axis with engine center line about Y, Z-axes.
    - c) Misalignment of engine center line with vehicle X-axis about Y, Z-axes.
    - d) Thrust dependent misalignment (due to bending) about Y, Z-axes.
  - 3) RCS quad 1-4 misalignments.
    - a) X, Y, Z position errors.
    - b) Misalignment about X, Y, Z-axes.
- Revision: 116
- Duration: 26 seconds prior to start of MP9 through 60 seconds beyond end of mission phase.
- Objectives:
- 1) Demonstrate minimal effect of DPS fuel slosh, DPS engine misalignments, and RCS jet misalignments on mission phase performance.
  - 2) Compare Run #5a with Run #5.
- Results:
- 1) Fuel Slosh and Misalignment Summary
    - a) Flight path angle achieved at cutoff was  $0.0005^\circ$ .
    - b) The apogee achieved at cutoff was 3616.1 n.m., compared with the targeted  $R_p$  at 3617.0 n.m.
    - c) Mission phase performance was not significantly affected in the areas of guidance, timing, or navigation.

- d) There was no more RCS fuel used than there was in Run #5 (See appendix).
- e) The trim gimbal usage during the DPS1 burn was 41%; the remainder of the time the steering was accomplished by RCS jet control.
- f) The length of the burn was the same as in Run #5.

2) Timeline and Other Summaries

Given in the appendix.



RUN #5b

Description: Mission Phase 9 with trim gimbal failure and DPS fuel slosh, DPS engine misalignments, and RCS jet misalignments.

Revision: 116

Duration: 26 seconds prior to start of MP9 through 60 seconds beyond end of mission phase.

- Objectives:
- 1) Verify that the trim gimbal monitor can detect a trim gimbal failure (Bit 10 of channel 32) and disable use of the trim gimbal.
  - 2) Demonstrate that the targeted  $R_p$  can be achieved under only RCS jet control after the trim gimbal had failed.
  - 3) Compare Run #5b with Run #5a.

Results: 1) Trim Gimbal Failure Summary

The trim gimbal was made to fail 16 seconds into the DPS1 burn. 0.06 seconds after the fail bit appeared in the LCC channel, the gimbal monitor disabled further use of the trim gimbal. The rather quick response was due to the 2-second gimbal monitor looking for the failure just after it occurred.

2) DPS1 Guidance Summary

- a) The flight path angle achieved at cutoff was  $0.0002^\circ$ .
- b) The apogee achieved at cutoff was 3616.1 n.m., compared with the targeted  $R_p$  of 3617.0 n.m.

3) Timeline and Other Summaries

- a) The trim gimbal was used about 10% of the total burn time.
- b) There was about 10% more RCS fuel used than there was in Run #5a, which did not have a trim gimbal failure.
- c) The length of the burn was the same as in Runs #5 and #5a.
- d) The other summaries are given in the appendix.

RUN #5c

Description: Mission Phase 9 with an inflight fresh start recovery.

Revision: 113

Duration: 60 seconds prior to start of MP9 through 5 seconds beyond end of mission phase.

Objectives:

- 1) Verify that it is possible to recover from an inflight fresh start as outlined in Flight 206 Memo #10.
- 2) Demonstrate that the targeted  $R_p$  can be achieved after a fresh start during MP9 forced the mission phase to be re-scheduled.
- 3) Compare Run #5c with Run #5.

Results:

- 1) Inflight Fresh Start Recovery Summary
  - a) Nominal MP9 was initiated at 14,171 seconds after liftoff.
  - b) A restart was forced with erasable register ERESTORE non-zero, causing the restart to generate a fresh start. This occurred at 14,472 seconds, or when the automatic throttle was increased to maximum.
  - c) FLAGWRD1 and DAPBOOLS were re-initiated at 14,500 seconds via the LGC uplink.
  - d) A VERB 74 was sent at 14,506 seconds to enable the mission timers. This was immediately followed by an ERROR RESET keycode to extinguish the program alarm 1110 caused by a VERB 74 following a fresh start.
  - e) A VERB 76 state vector update was performed at 14,508 seconds to correct the orbital

integration state vector which was invalidated by the fresh start that occurred during powered flight (the Average G state vector navigation is automatically terminated by a fresh start).

f) A VERB 72 mission timer and phase register update was performed at 14,528 seconds to reschedule MP9.

g) MP9 was re-initiated at 14,544 seconds.

2) Re-initiated DPSI Guidance Summary

a) The flight path angle achieved at cutoff was  $0.0019^\circ$ .

b) The apogee achieved at cutoff was 3616.1 n.m., compared with the targeted  $R_p$  of 3617.0 n.m.

3) Timeline and Other Summaries

a) In referring to the appendix, Run #5c is the MP9 terminated by the fresh start and Run #5c' is the MP9 rescheduled after the fresh start.

b) The navigation errors in Run #5c' were higher than in Run #5c because the LGC state vector update between the two MP9's was not perfect.

RUN #6

Description: Mission Phase 11 (DPS2/Fire-In-The Hole/APS1)  
with:

- 1) C.g. offset (when the DPS engine is ignited, the c.g. is shifted away from the nominal c.g. at that loading and decays back to the nominal position with a 30 second time constant).
- 2) DPS engine misalignments.
  - a) X, Y, Z position errors.
  - b) Misalignment of thrust axis with engine center line about Y, Z-axes.
  - c) Misalignment of engine center line with vehicle X-axis about Y, Z-axes.
  - d) Thrust dependent misalignments (due to bending) about Y, Z-axes.
- 3) Fuel slosh.

Revision: 116

Duration: 40 seconds prior to start of MP11 through end of mission phase.

Objectives:

- 1) Verify that the powered landing guidance equations can achieve the desired braking phase and approach phase targets.
- 2) Verify that the throttle control logic can:
  - a) Yield correct thrust commands so that the engine is never required to operate in the critical thrust region.
  - b) Hold the DPS throttle at maximum for most of the braking phase, yet recover throttle control near the end so that the braking and approach conditions can be met.

- 3) Verify proper commanded throttle profile during the random throttle phase.
- 4) Verify proper abort stage sequencing through DPS shutdown, FITH, and APS1 burn.
- 5) Demonstrate effect of turning the DAP off for 4 seconds during DPS2 burn (for the purpose of reverting to the special CDU downlink list and obtaining body bending and fuel slosh data) on body rates.
- 6) Compare timing sequences against GSOP timeline.

Results:

1) Guidance Summary

Tabulated below are the radial and down range position and velocity terminal parameters for the braking and approach phases in spherical, earth-centered, non-rotating coordinates:

Braking Phase

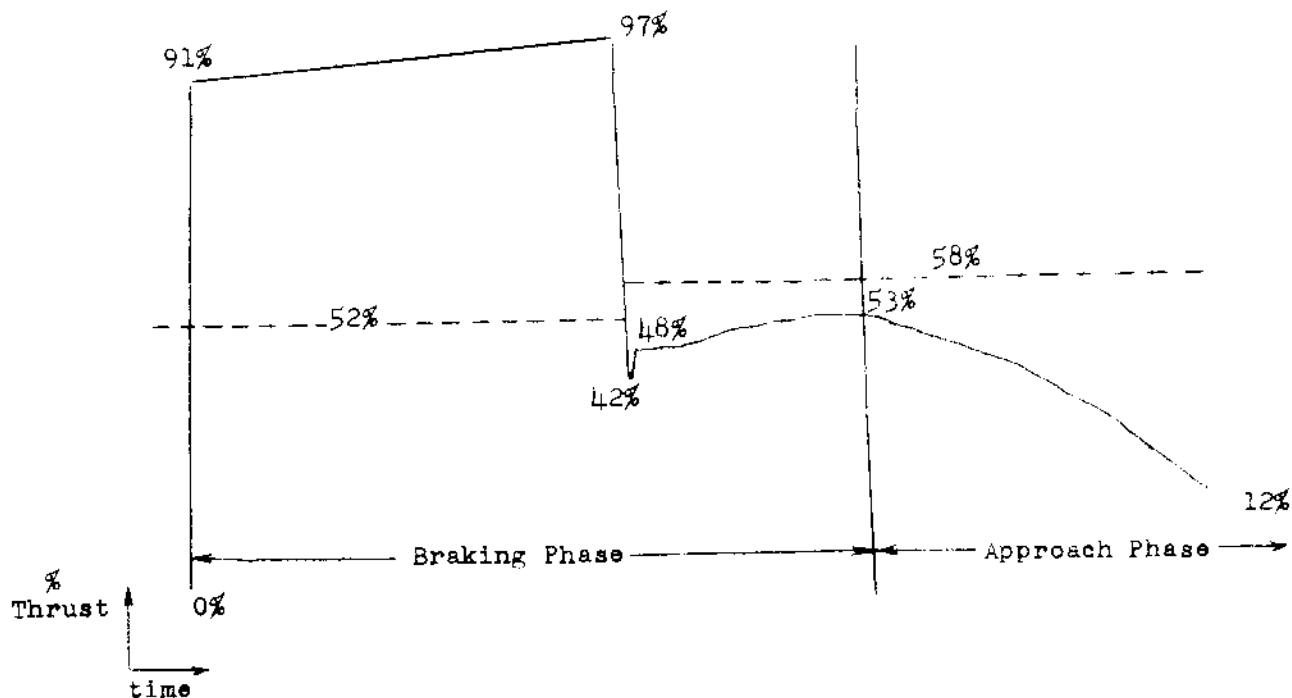
<u>Parameter</u>	<u>Desired</u>	<u>Achieved</u>
RSO(m)	6.686947349E+6	6.686976999E-6
RS2(rad)	5.797001734E-3	5.887299770E-3
VSO(m/sec)	-2.133175242E+1	-2.159881574E+1
VS2(rad/sec)	-6.533226733E-5	-6.593865007E-5

Approach Phase

<u>Parameter</u>	<u>Desired</u>	<u>Achieved</u>
RSO(m)	6.684376002E+6	6.684385936E+6
RS2(rad)	6.577892482E-6	9.365370000E-6
VSO(m/sec)	-7.313936765E+0	-8.094024192E+0
VS2(rad/sec)	-1.469364777E-6	-1.793910064E-6

## 2) Throttle Control Summary

The thrust profile actually achieved during the braking and approach phases is plotted below. During the initial interval the guidance equations commanded a total acceleration which required a thrust magnitude in excess of 52% of the DPS maximum (a DPS throttle restriction is placed on the throttle command until it falls below the specified 52% setting). Prior to the end of the braking phase the thrust required to satisfy the acceleration commanded fell below 52%, so throttle control began so that the desired terminal position and velocity could be achieved without throttle settings above 58% required.



3) Random Throttle Summary

The throttle profile commanded and achieved are summarized below:

<u>% Commanded</u>	<u>% Achieved</u>
10	12
50	52
30	31
40	42
20	21

4) Abort Stage Summary

- a) Throttle was set to 92.5% at end of random throttle phase at 17,344 seconds.
- b) ABORT STAGE - ARM LMP command sent at 17,345 seconds.
- c) ABORT STAGE - COMMAND LMP command sent at 17,345.8 seconds.
- d) DPS engine shut off at 17,345.8 seconds.
- e) Abort staging occurred at 17,346.2 seconds.
- f) APS engine ignited at 17,346.4 seconds.
- g) Stage verify discrete detected at 17,346.5 seconds.
- h) APS engine shut off at 17,351.6 seconds.
- i) ABORT STAGE - COMMAND RESET LMP command sent at 17,357.8 seconds.

5) DAP-off Summary

The DAP was turned off 193 seconds into the DPS2 burn for 4 seconds, as part of the mission control sequence when DAPOFFDT contains 162 seconds. The resultant attitude drift of the vehicle due to temporary loss of attitude control was 4.65°.



6) Timeline and Other Summaries

- a) The trim gimbal usage during the DPS2 burn was 60%; the remaining percentage of the burn time was spent under RCS jet control.
- b) The other summaries are listed in the appendix.

RUN #6a

Description: Mission Phase 11 with 10% low thrust.

Revision: 104

Duration: 40 seconds prior to start of MP11 through end of mission phase.

- Objectives:
- 1) Verify that the powered landing guidance equations can achieve the desired braking phase and approach phase targets with 10% low thrust.
  - 2) Demonstrate effect of 10% low thrust on throttle control logic's ability to:
    - a) Yield correct thrust commands so that the engine is never required to operate in the critical thrust region.
    - b) Hold the DPS throttle at maximum for most of the braking phase, yet recover throttle control near the end so that the braking and approach conditions can be met.
  - 3) Demonstrate effect of 10% low thrust on throttle profile during the random throttle phase.
  - 4) Compare timing sequences against 206 GSOP timeline.

Results: 1) Guidance Summary

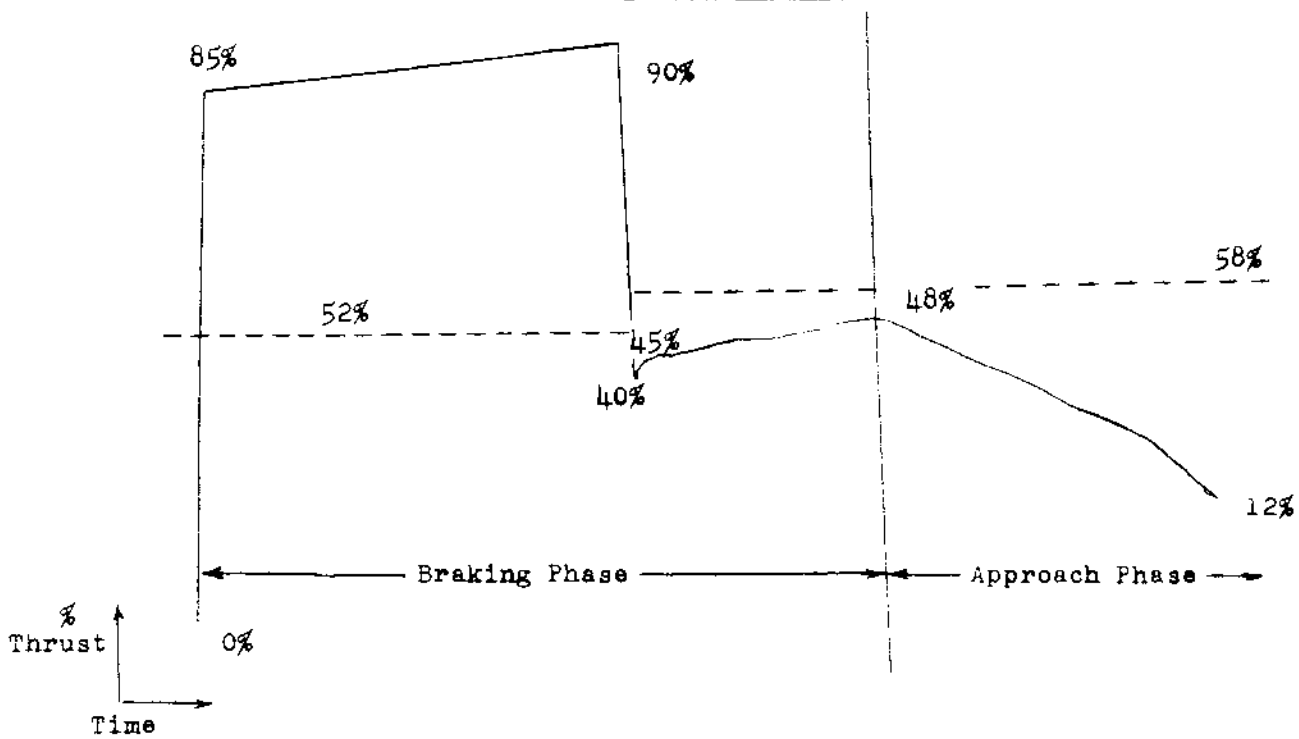
Braking Phase

<u>Parameter</u>	<u>Desired</u>	<u>Achieved</u>
RS0(m)	6.686947352E+6	6.686920687E+6
RS2(rad)	5.797020381E-3	5.814176050E-3
VSO(m/sec)	-2.133262792E-1	-2.019004774E+1
VS2(rad/sec)	-6.533786150E-5	-7.528071815E-5

Approach Phase

<u>Parameter</u>	<u>Desired</u>	<u>Achieved</u>
RS0(m)	6.684376002E+6	6.684384686E+6
RS2(rad)	6.577892482E-6	8.262690000E-6
VS0(m/sec)	-7.313936765E+0	-7.070541312E+0
VS2(rad/sec)	-1.469364771E-6	-1.679256896E-6

2) Throttle Control Summary



3) Random Throttle Summary

<u>% Commanded</u>	<u>% Achieved</u>
10	12
50	46
30	31
40	38
20	21

4) Timeline and Other Summaries

Refer to the appendix.

RUN #7

Description: Nominal Mission Phase 13 (APS2 Burn) with a 456 second burn to fuel completion and  $KT = 0.34$ .

Revision: 106

Duration: 30 seconds prior to start of MP13 through APS2 shutdown.

- Objectives:
- 1) Verify that the powered ascent guidance equations can:
    - a) Achieve the desired intercept target.
    - b) Achieve the desired altitude at cutoff.
  - 2) Demonstrate detection of premature APS shutdown by Delta V monitor.
  - 3) Compare timing sequencing against 206 GSOP timeline.

Results: 1) Guidance Summary

- a) At MP13 ignition, the LGC Time-To-Go and Velocity-To-Be-Gained were 500 seconds and 7280 feet/sec, respectively. At fuel depletion TGO was 33.4 seconds and VG was 614 feet/sec.

Integrating the vehicle state at cutoff ahead in stable member coordinates to the time of intercept along a conic (no oblateness effects), the targeted intercept point ( $\overline{RIVEC}$ ) is compared with the projected vehicle state at 24,719 seconds (TINT):

<u><math>\overline{RIVEC}</math> (meters)</u>	<u><math>\tilde{R}</math> (meters) at TINT</u>
-3,228,194	-3,282,747
-5,765,136	-5,660,905
-813,281	-896,430

- b) The targeted radius magnitude at cutoff was 6,681,480 meters. The RCO achieved was 6,681,996 meters.

2)  $\Delta V$  Monitor Summary

- a) APS fuel was exhausted at 22,775.3 seconds.
- b)  $\Delta V$  Monitor detected premature engine shut-down at 22,782.8 seconds and went to mission idle.

RUN #7a

Description: Nominal Mission Phase 13 with a 30 second burn and  
KT = 0.34.

Revision: 113

Duration: 30 seconds prior to start of MP13 through end of  
mission phase.

- Objectives:
- 1) Verify that the powered ascent guidance equations can:
    - a) Achieve the desired intercept target.
    - b) Achieve the desired altitude at cutoff.
  - 2) Compare timing sequences against GSOP timeline.

- Results:
- 1) Guidance Summary
    - a) At MP13 ignition, the LGC TGO and VG were 26 seconds and 293.6 feet/sec, respectively. Integrating the vehicle state at cutoff ahead in stable member coordinates to the time of intercept along a conic, the targeted intercept point ( $\bar{R}_{VEEC}$ ) is compared with the projected vehicle state at 23,849 seconds (TINT):

<u><math>\bar{R}_{VEEC}</math>(meters)</u>	<u><math>\bar{R}</math>(meters) at TINT</u>
-5,080,390	-5,081,512
-1,619,840	-1,623,904
3,987,755	3,987,696

- b) The targeted radius magnitude at cutoff was 6,688,532.749 meters; the RCO achieved was 6,688,451.0376 meters.

2) Timeline and Other Summaries

Refer to the appendix.

RUN #8, #9

**Description:** Mission Phase 9 (DPS1 Burn) with a non-critical RCS jet failure during the attitude maneuver and another one during the pre-burn ullage, and:

- 1) DPS fuel slosh.
- 2) DPS engine misalignments.
  - a) X, Y, Z position errors.
  - b) Misalignment of thrust axis with engine center line about Y, Z-axes.
  - c) Misalignment of engine center line with vehicle X-axis about Y, Z-axes.
  - d) Thrust dependent misalignment (due to bending) about Y, Z-axes.
- 3) RCS quad 1-4 misalignments.
  - a) X, Y, Z position errors.
  - b) Misalignment about X, Y, Z-axes.

**Revision:** 116

**Duration:** 20 seconds prior to start of MP9 through 60 seconds beyond end of mission phase.

**Objectives:**

- 1) Verify that the RCS failure monitor can:
  - a) Detect an RCS jet failure (low 8 bits of channel 32).
  - b) Isolate the appropriate jet pair by LMP commands.
  - c) Keep a record of the state of the isolation valves.
  - d) Update the DAP's jet-policy selection logic.

- 2) Demonstrate minimal effect of non-critical RCS jet failures, DPS fuel slosh, DPS engine misalignments, and RCS jet misalignments on mission phase performance.
- 3) Verify satisfactory 2-jet ullage as a consequence of a +X translation jet failure during pre-burn ullage.
- 4) Compare run with Run #5a.

Results:

- 1) RCS Failure Monitor Summary
  - a) Jet number 3 was failed on at 14,136 seconds during the attitude maneuver; jet number 2 was failed on at 14,398 seconds during the pre-burn ullage. The down-telemetry list edited at 14,428 seconds showed that bits 1 and 3 of channel 32 were zero (inverse logic).
  - b) LMP command 200 (THRUST ISOLATION VALVES, QUADRANT 4, SYSTEM B - CLOSE) was sent at 14,137.46 seconds, resulting in RCS jet pair 1 and 3 being turned off at 14,137.47 seconds. LMP command 232 (THRUST ISOLATION VALVES, QUADRANT 4, SYSTEM A - CLOSE) was sent at 14,399.55 seconds, resulting in RCS jet pair 2 and 4 being turned off at 14,399.56 seconds. The corresponding valve-closure reset commands (201 and 233) were issued 0.96 seconds following the valve-closure commands. Note that by turning off RCS jets 1-4, an entire quad was deactivated for the remainder of the mission phase.
  - c) The downlink list edited showed that erasable register LMPJPAIL contained 00005<sub>g</sub>, indicating that the isolation valves



associated with failure bits 1 and 3 of channel 32 were closed.

- d) The erasable memory dump at the end of the run showed that CH5MASK (Q,R-Axes) and CH6MASK (P-Axis) contained 00003<sub>8</sub> and 00102<sub>8</sub> respectively, the correct channel 5 and channel 6 bit configuration that correspond to the jets turned off.

2) DPSI Guidance Summary

- a) The flight path angle achieved at cutoff was 0.003<sup>o</sup>.
- b) The apogee achieved at cutoff was 3616.3 n.m., n.m., compared with the targeted R<sub>p</sub> of 3617.0 n.m.

- 3) The magnitude of acceleration during a 4-jet ullage is 0.3 ft/sec<sup>2</sup>; the magnitude of acceleration during the 2-jet ullage in this run was 0.2 feet/sec<sup>2</sup>.

4) Timeline and Other Summaries

- a) The trim gimbal was used 42% of the total burn time.
- b) There was about 30% more RCS fuel used than in Run #5a. Most of the extra fuel was used during the attitude maneuver and the burn.
- c) Refer to the appendix for the other summaries.

RUN #10

- Description: Complete nominal mission from prelaunch alignment through mission phase 13 with liftoff detection, 434 second APS2 burn to completion (KT = 0.34), and no updates.
- Revision: 116
- Duration: 60 seconds prior to liftoff through 267 seconds beyond end mission phase 13.
- Objectives:
- 1) Demonstrate proper LGC clock alignment by a VERB 55 prior to initiation of prelaunch alignment.
  - 2) Demonstrate that the prelaunch alignment program can align the IMU stable member to the correct earth-fixed orientation (X PIPA input axis  $30^{\circ}$  from the local vertical (up), Y PIPA input axis downrange at an azimuth of  $122^{\circ}$  east of north and elevated  $30^{\circ}$  above the horizontal plane, and Z PIPA input axis downrange at an azimuth of  $32^{\circ}$  east of north and in the horizontal plane).
  - 3) Demonstrate proper termination of prelaunch alignment and initiation of MP2 upon detection of 1.1 g's by the prelaunch program.
  - 4) Verify detection of SIVB shutdown by the boost monitor and proper initiation of MP6.
  - 5) Verify rejection of late suborbital abort uplink command after abort command monitor has been terminated.
  - 6) Verify proper calculation and attainment of desired cold soak attitude.

- 7) Verify that the descent orbit injection guidance equations (MP9) can:
  - a) Control the flight path angle at cutoff to be zero relative to the local horizontal (i.e.: establish perigee at cutoff).
  - b) Raise the conic apogee at cutoff to the targeted radial distance  $R_p$ .
- 8) Verify that the powered landing guidance equations (MP11) can achieve the desired braking phase and approach phase targets.
- 9) Verify that the throttle control logic can:
  - a) Yield correct thrust commands so that the engine is never required to operate in the critical thrust region.
  - b) Hold the DPS throttle at maximum for most of the braking phase, yet recover throttle control near the end so that the braking and approach conditions can be met.
- 10) Verify proper commanded throttle profile during the random throttle phase.
- 11) Demonstrate the effect of turning the DAP off for 4 seconds during the DPS2 burn (for the purpose of reverting to the special CDU down-link list and obtaining body bending and fuel slosh data) on body rates.
- 12) Verify that the powered ascent guidance equations (MP13) can achieve the desired intercept target.
- 13) Demonstrate accuracy of the Orbital Integration and Average G navigation programs.
- 14) Verify validity and protection of prelaunch erasable memory load, and initiation, timing, and sequencing of the mission phases.

Results:

1) LGC Clock Alignment Summary

The LGC clock was purposely initialized incorrectly at the start of the run so that it lagged the simulator clock by 7.52 seconds. At 2.5 seconds a VERB 55 was sent followed by a time increment of +752 centiseconds, which perfectly synchronized the LGC clock with the simulator clock.

2) Prelaunch Alignment Summary

- a) The prelaunch alignment program was initiated at liftoff - 55 seconds.
- b) The IMU stable member was open-loop coarse aligned and gyro torqued to the desired earth-fixed orientation by liftoff - 25 seconds.
- c) The prelaunch gyrocompassing loop held the IMU platform to the proper gimbal angles of  $AOG = 122^\circ$ ,  $AG = 0^\circ$ ,  $AMG = 30^\circ$  such that at guidance reference release the euler set from desired to actual stable member alignment was  $X_{mis} = 0.0378^\circ$ ,  $Y_{mis} = 0.0242^\circ$ ,  $Z_{mis} = -0.0104^\circ$ .

3) Guidance Reference Release Summary

- a) At 0.42 seconds after liftoff, 1.1 g's were sensed by the prelaunch alignment program.
- b) Consequently, gyrocompassing was terminated and MP2 initiated at 0.45 seconds.
- c) The LGC clock was zeroed at 0.56 seconds.

4) SIVB Shutdown Summary

- a) SIVB shutdown occurred at 582.3 seconds after liftoff.
- b) The SIVB  $\Delta V$  monitor detected shutdown at 584.5 seconds.

c) MP6 was initiated at 584.5 seconds.

5) Late Suborbital Abort Command Summary

- a) The abort command monitor was initiated at 145.5 seconds after liftoff.
- b) The abort command monitor was terminated at 644.6 seconds.
- c) Uplink keycode 23, SUBORBITAL ABORT, was received at 644.6 seconds.
- d) Program alarm 00300<sub>8</sub> (Abort Command Monitor Not Enabled) was displayed at 644.6 seconds.

6) Cold Soak Attitude Maneuver Summary

- a) The desired cold soak gimbal angles (AOG:  $-112.5^\circ$ , AIG:  $-25.7^\circ$ , AMG:  $-5.3^\circ$ ) were achieved and held within the  $5^\circ$  deadband zone.
- b) A  $147.38^\circ$ , 29.46 second attitude maneuver was performed to the cold soak attitude.
- c) The amount of RCS fuel used during the maneuver was 8.99 pounds.

7) DPS1 Guidance Summary

- a) The flight path angle achieved at cutoff was  $0.006^\circ$ .
- b) The targeted radial distance  $R_p$  of 21,992,000 feet represents an apogee of 3617.0 nautical miles. The apogee achieved at cutoff was 3616.2 nautical miles.
- c) The trim gimbal was used 58% of the burn time.

8) DPS2 Guidance Summary

Tabulated on the following page are the radial and down range position and velocity terminal

parameters for the braking and approach phases in spherical, earth-centered, non-rotating coordinates:

Braking Phase

<u>Parameters</u>	<u>Desired</u>	<u>Achieved</u>
RS0(m)	6.686947349E+6	6.686961811E+6
RS2(rad)	5.797001734E-3	5.839668210E-3
VS0(m/sec)	-2.133175242E+1	-2.113037107E+1
VS2(rad/sec)	-6.533226733E-5	-6.563838039E-5

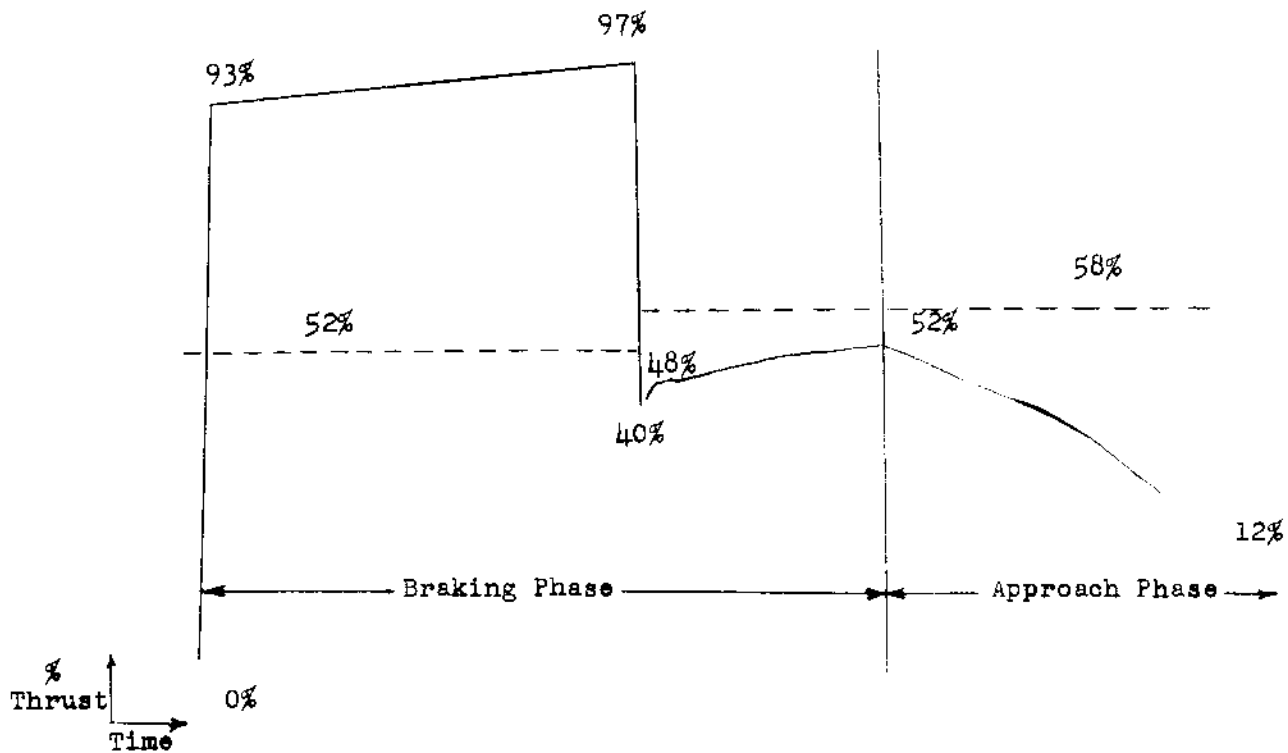
Approach Phase

<u>Parameters</u>	<u>Desired</u>	<u>Achieved</u>
RS0(m)	6.684376002E+6	6.684382999E+6
RS2(rad)	6.577892482E-6	8.240340000E-6
VS0(m/sec)	-7.313936765E+0	-7.523345920E+0
VS2(rad/sec)	-1.469364777E-6	-1.662704101E-6

The trim gimbal usage during the burn was 72%; the remainder of the burn time was spent under RCS jet control.

9) Throttle Control Summary

The thrust profile actually achieved during the braking and approach phases is plotted on the next page. During the initial interval the guidance equations commanded a total acceleration which required a thrust magnitude in excess of 52% of the DPS maximum (a DPS throttle restriction is placed on the throttle command until it falls below the specified 52% setting). Prior to the end of the braking phase the thrust required to satisfy the acceleration commanded fell below 52%, so throttle control began so that the desired terminal position and velocity could be achieved without throttle settings above 58% required.



10) Random Throttle Summary

The throttle profile commanded and achieved are summarized below:

<u>% Commanded</u>	<u>% Achieved</u>
10	12
50	50
30	30
40	39
20	20

11) DAP-Off Summary

The DAP was turned off 193 seconds into the DPS2 burn for 4 seconds, as part of the mission control sequence when DAPOFFDT contains 162 seconds. The resultant attitude drift of the vehicle due to temporary loss of attitude control was 2.24°.

12) APS2 Guidance Summary

- a) At MP13 ignition, the LGC TGO and VG were 467 seconds and 6579 ft/sec., respectively. Integrating the vehicle state at cutoff ahead in stable member coordinates to the time of intercept along a conic (no oblateness effects), the targeted intercept point ( $\bar{R}_{I\bar{V}E\bar{C}}$ ) is compared with the projected vehicle state at 24,794.16 seconds (TINT):

<u><math>\bar{R}_{I\bar{V}E\bar{C}}</math>(meters)</u>	<u><math>\bar{R}</math>(meters) at TINT</u>
-3,057,728	-3,039,744
-5,762,166	-5,759,003
-1,244,790	-1,277,222

- b) The targeted radius magnitude at cutoff was 6,687,649 meters; the RCO achieved was 6,687,020 meters.

13) Orbital Integration/Average G Navigation Summary

The appendix gives the maximum accumulated LGC state vector error from liftoff within each mission phase. What follows is the increase in the state vector error between two mission phases (MPi/MPj - Orbital Integration) and within a mission phase (MPi - Average G):



	<u>Mission Phase</u>	<u><math>\Delta R</math> Error (ft)</u>	<u><math>\Delta V</math> Error (ft/sec)</u>
	MP2	5,279	19.27
	MP6	10,478	-10.68
	MP6/MP7	-7,233	12.14
	MP7	866	-0.30
	MP7/MP9	49,375	46.77
	MP9	2,201	1.11
	MP9/MP11	7,508	11.36
	MP11	-328	4.26
	MP11/MP13	5,262	5.12
	MP13	-282	6.37
Total	MP2-MP13	73,126	95.42

14) Timeline and Other Summaries

The erasable memory load was protected at the end of the run. The run timing matched that of the 206 GSOP. Refer to the appendix for the other summaries.

RUN #11

Description: Complete mission from prelaunch alignment through mission phase 13 with  $\frac{1}{2}^{\circ}$  prelaunch alignment misalignment in azimuth and no updates.

Revision: 116

Duration: 60 seconds prior to liftoff through 298 seconds beyond end of mission phase 13.

Objectives: Same as Run #10.

- Results:
- 1) LGC Clock Alignment Summary  
Same as Run #10.
  - 2) Prelaunch Alignment Summary  
Same as Run #10, except  $X_{mis} = -0.4687^{\circ}$ ,  $Y_{mis} = -0.2678^{\circ}$ , and  $Z_{mis} = -0.0130^{\circ}$ .
  - 3) Guidance Reference Release Summary
    - a) At 0.71 seconds after liftoff, 1.1 g's were sensed by the prelaunch alignment program.
    - b) Consequently, gyrocompassing was terminated and MP2 initiated at 0.75 seconds.
    - c) The LGC clock was zeroed at 0.86 seconds.
  - 4) SIVB Shutdown Detection Summary  
Same as Run #10.
  - 5) Late Suborbital Abort Command Summary  
Same as Run #10.
  - 6) Cold Soak Attitude Maneuver Summary
    - a) Desired cold soak gimbal angles (AOG =  $-112.1^{\circ}$ , AIG =  $-25.4^{\circ}$ , AMG =  $-5.6^{\circ}$ ) were achieved and held within the  $5^{\circ}$  deadband zone.

- b) A  $142.79^\circ$ , 28.54 second attitude maneuver was performed to the cold soak attitude.
- c) The amount of RCS fuel used during the maneuver was 8.77 pounds.

7) DPS1 Guidance Summary

- a) The flight path angle achieved at cutoff was  $-0.010^\circ$ .
- b) The targeted radial distance  $R_p$  of 21,992,000 feet represents an apogee of 3617.0 nautical miles. The apogee achieved at cutoff was 3617.8 nautical miles.
- c) The trim gimbal was used 16% of the burn time.

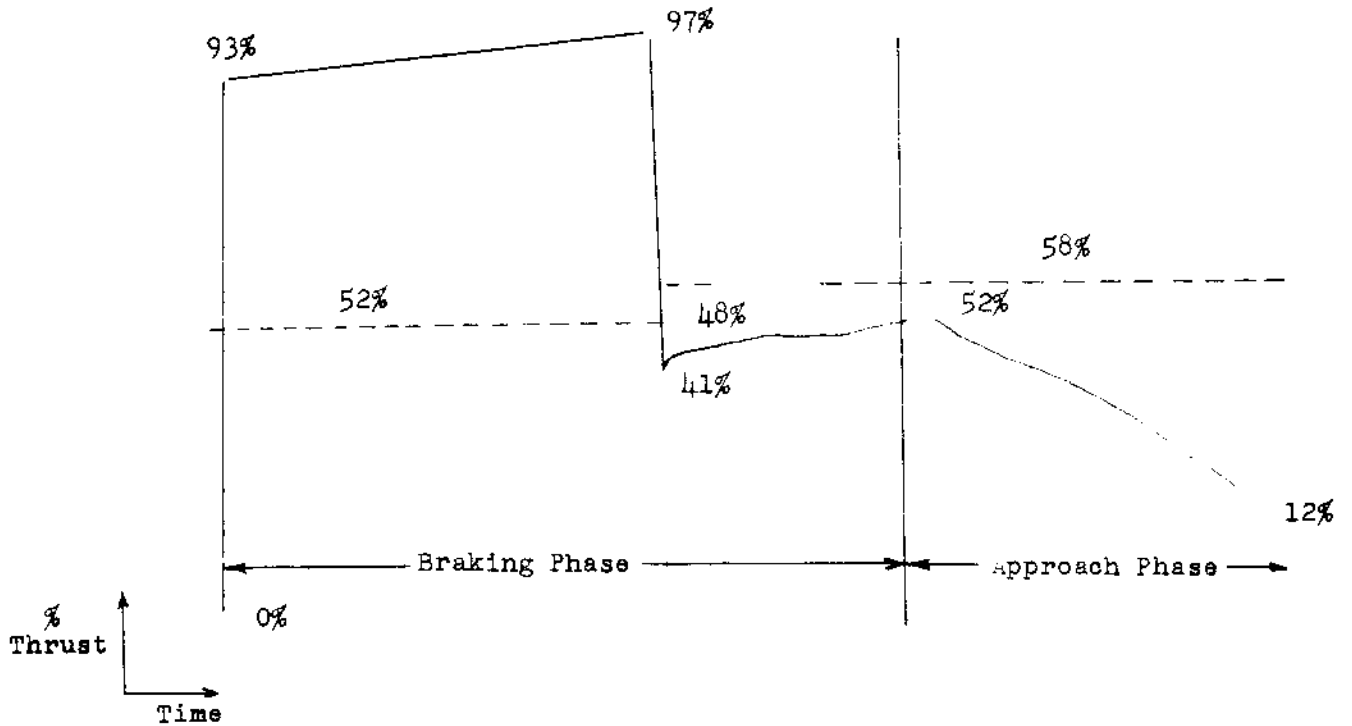
8) DPS2 Guidance Summary

Tabulated below are the radial and down range position and velocity terminal parameters for the approach phase in spherical, earth-centered, non-rotating coordinates:

<u>Parameter</u>	<u>Desired</u>	<u>Achieved</u>
RSO(m)	6.684376002E+6	6.687323E+6
RS2(rad)	6.577892482E-6	-7.32E-3
VSO(m/sec)	-7.313936765E+0	-3.41E-1
VS2(rad/sec)	-1.469364777E-6	-3E-6

The trim gimbal usage during the burn was 88%; the remainder of the burn time was spent under RCS jet control.

9) Throttle Control Summary



10) Random Throttle Summary

The throttle profiles commanded and achieved are summarized below:

<u>% Commanded</u>	<u>% Achieved</u>
10	12
50	50
30	30
40	40
20	20

11) DAP-Off Summary

Same as Run #10, except that the attitude drift was 1.0°.

12) APS2 Guidance Summary

a) At MP13 ignition, the LGC TGO and VG were

459 seconds and 6419 ft/sec, respectively. Integrating the vehicle state at cutoff ahead in stable member coordinates to the time of intercept along a conic, the targeted intercept point ( $\bar{R}_{VEEC}$ ) is compared with the projected vehicle state at 24,794.16 seconds (TINT):

<u><math>\bar{R}_{VEEC}</math>(meters)</u>	<u><math>\bar{R}</math>(meters) at TINT</u>
-3,057,728	-3,105,875
-5,762,166	-5,768,294
-1,244,790	-1,144,465

b) The targeted radius magnitude at cutoff was 6,687,649 meters; the RCO achieved was 6,692,266 meters.

13) Orbital Integration/Average G Navigation Summary

<u>Mission Phase</u>	<u><math>\Delta R</math> Error (feet)</u>	<u><math>\Delta V</math> Error(ft/sec)</u>
MP2	56,406	219.71
MP6	119,722	-125.77
MP6/MP7	-108,893	129.06
MP7	8,719	-3.67
MP7/MP9	113,645	-52.14
MP9	15,104	-26.25
MP9/MP11	-78,942	90.22
MP11	88,335	-51.48
MP11/MP13	5,487	91.88
<u>MP13</u>	<u>36,152</u>	<u>24.04</u>
Total MP2-MP6	255,735	295.60

14) Timeline and Other Summaries

Refer to the Appendix.

RUN 11a

Description: Complete mission from prelaunch alignment through mission phase 13 with 1° prelaunch alignment misalignment in azimuth and no updates.

Revision: 116

Duration: 60 seconds prior to liftoff through 267 seconds beyond end of mission phase 13.

Objectives: Same as Run #10

- Results:
- 1) LGC Clock Alignment Summary  
Same as Run #10.
  - 2) Prelaunch Alignment Summary  
Same as Run #10, except  $X_{mis} = -0.9121^\circ$ ,  
 $Y_{mis} = -0.5237^\circ$ ,  $Z_{mis} = -0.0128^\circ$ .
  - 3) Guidance Reference Release Summary
    - a) At 0.64 seconds after liftoff, 1.1 g's were sensed by the prelaunch alignment program.
    - b) Consequently, gyrocompassing was terminated and MP2 initiated at 0.67 seconds.
    - c) The LGC clock was zeroed at 0.77 seconds.
  - 4) SIVB Shutdown Detection Summary  
Same as Run #10.
  - 5) Late Suborbital Abort Command Summary  
Same as Run #10.
  - 6) Cold Soak Attitude Maneuver Summary
    - a) Desired cold soak gimbal angles ( $AOG = -111.7^\circ$ ,  $AIG = -25.1^\circ$ ,  $AMG = -5.8^\circ$ ) were achieved and held within the  $5^\circ$  deadband zone.

- b) A  $149.00^\circ$ , 29.79 second attitude maneuver was performed to the cold soak attitude.
- c) The amount of RCS fuel used during the maneuver was  $8.91^\circ$

7) DPS1 Guidance Summary

- a) The flight path angle achieved at cutoff was  $-0.039^\circ$ .
- b) The targeted radial distance  $R_p$  of 21,992,000 feet represents an apogee of 3617.0 nautical miles. The apogee achieved at cutoff was 3618.2 nautical miles.
- c) The trim gimbal was used 39% of the burn time.

8) DPS2 Guidance Summary

Tabulated below are the radial and down range position and velocity terminal parameters for the braking and approach phases in spherical, earth-centered, non-rotating coordinates:

Braking Phase

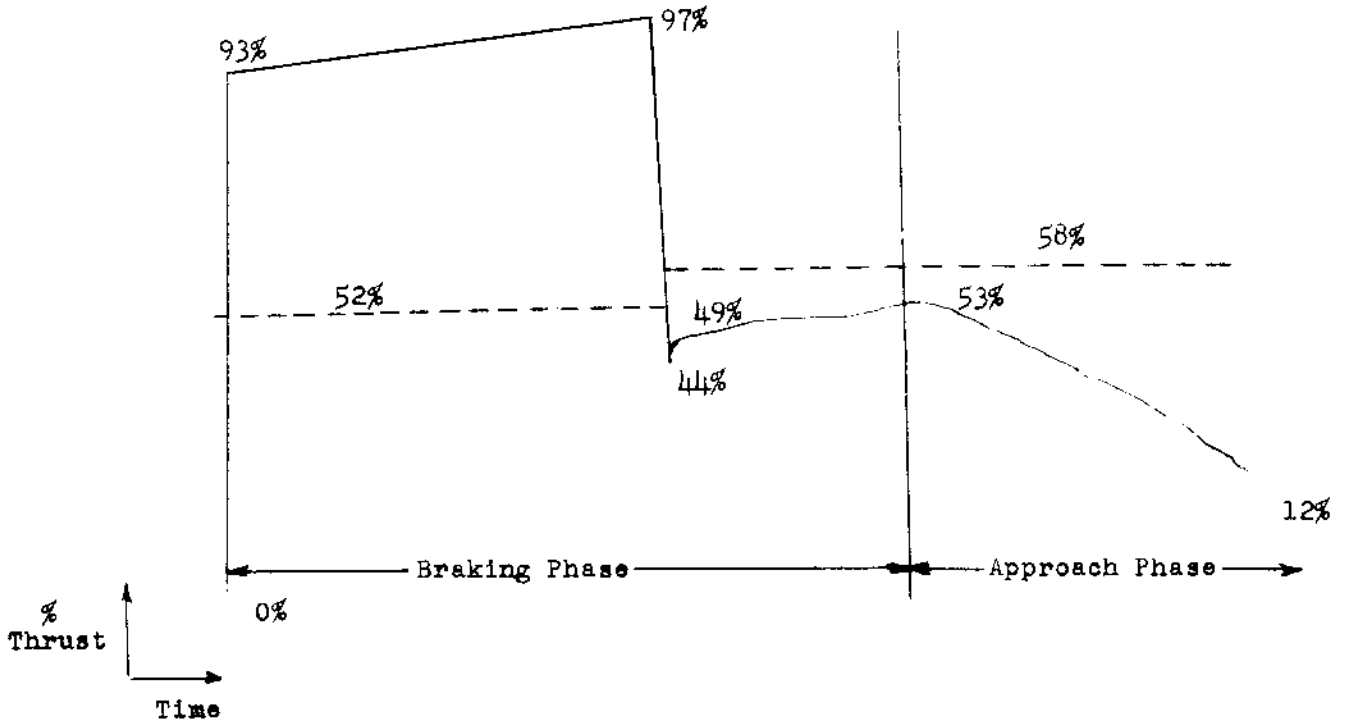
<u>Parameters</u>	<u>Desired</u>	<u>Achieved</u>
RS0(m)	6.686947349E+6	6.687167248E+6
RS2(rad)	5.797001734E-3	6.461263780E-3
VS0(m/sec)	-2.133175242E+1	-2.207412684E+1
VS2(rad/sec)	-6.533226733E-5	-6.976296159E-5

Approach Phase

<u>Parameters</u>	<u>Desired</u>	<u>Achieved</u>
RS0(m)	6.684376002E+6	6.684454998E+6
RS2(rad)	6.577892482E-6	3.300607000E-5
VS0(m/sec)	-7.313936765E+0	-7.715987968E+0
VS2(rad/sec)	-1.469364777E-6	-3.568311492E-6

The trim gimbal usage during the burn was 91%; the remainder of the burn time was spent under RCS jet control.

9) Throttle Control Summary



10) Random Throttle Summary

The throttle profiles commanded and achieved are summarized below:

<u>% Commanded</u>	<u>% Achieved</u>
10	12
50	50
30	30
40	40
20	20

11) DAP-Off Summary

Same as Run #10, except that the attitude drift was 1.06°.



12) APS2 Guidance Summary

- a) At MP13 ignition, the LGC TGO and VG were 456 seconds and 6362 ft/sec, respectively. Integrating the vehicle state at cutoff ahead in stable member coordinates to the time of intercept along a conic, the targeted intercept point ( $\bar{R}_{VEEC}$ ) is compared with the projected vehicle state at 24,794.16 seconds (TINT):

<u><math>\bar{R}_{VEEC}</math>(meters)</u>	<u><math>\bar{R}</math>(meters) at TINT</u>
-3,057,728	-3,165,563
-5,762,166	-5,768,000
-1,244,790	-1,039,018

- b) The targeted radius magnitude at cutoff was 6,687,649 meters; the RCO achieved was 6,695,317 meters.

13) Orbital Integration/Average G Navigation Summary

<u>Mission Phase</u>	<u><math>\Delta R</math> Error (feet)</u>	<u><math>\Delta V</math> Error(ft/sec)</u>
MP2	110,442	428.88
MP6	233,317	-247.52
MP6/MP7	-218,267	252.80
MP7	18,019	- 7.29
MP7/MP9	268,021	- 46.48
MP9	28,745	- 40.49
MP9/MP11	-137,924	148.87
MP11	142,966	- 69.61
MP11/MP13	17,128	162.89
<u>MP13</u>	<u>60,349</u>	<u>52.52</u>
Total	522,796	634.57

14) Timeline and Other Summaries

Refer to the appendix.

RUN #12

Description: Mission phases 7 and 8 with mission phase and timer updates, state vector updates, burn target updates, uplink guidance reference release command, uplink DFI T/M calibrate, uplink mission idle command, uplink LMP command, and function inhibit/enable updates. Includes a sequence of illegal updates.

Revision: 106

Duration: 60 seconds prior to initiation of MP7 through scheduling of MP9.

Objective: Demonstrate proper uplink activity for VERB's 64 through 76 during both active and inactive portions of the mission.

Results:

- 1) In the interval between MP7 and MP8 (mission timers enabled and MP8 scheduled via mission timer #4) a VERB 65 ENTER was sent. As a result bit 2 of FLAGWRD1 (GRR flag) was changed from a zero to a one. Since the prelaunch alignment program was not running, the major mode was not changed to 04.
- 2) A VERB 66 ENTER was sent to initiate the LGC DFI T/M CALIBRATE sequence. As a result LMP command 236 was issued, followed in 12 seconds by LMP commands 237 and 198, and followed in 2 seconds by LMP command 199.
- 3) A VERB 67 ENTER was sent, followed by a legal (1-255) but unused LMP command 26. The LMP command was transmitted and bit 6 of FLAGWRD2 (VERI flag) was inverted.
- 4) A VERB 70 ENTER was sent to set unused mission timer #2 to 16383 seconds. As a result MTIMER2 was changed from 77777<sub>8</sub> to 37777<sub>8</sub>.

and VERI flag was inverted.

- 5) A VERB 71 ENTER was sent to set unused mission phase register #2 to MP8. As a result MPHASE2 was changed from 7777<sub>5</sub> to 10<sub>5</sub> and VERI flag was inverted.
- 6) A VERB 76 ENTER was sent followed by the first of 14 state vector update components. Next a VERB 75 ENTER was sent to try changing a burn parameter before completing the state vector load. As a result the Operator Error light was lit and an ERROR RESET was sent to extinguish it. The next two components of the state vector were loaded and then the sequence was terminated by a VERB 34 ENTER. The major mode was changed from 27<sub>8</sub> and VERI flag was left unchanged.
- 7) At 3321 seconds a VERB 64 ENTER was sent followed by an index of one and a GET of 5248 seconds. As a result mission timer 1 was changed from 7777<sub>8</sub> to 3607<sub>8</sub> (1927 seconds) and VERI flag was inverted.
- 8) A VERB 75 ENTER was sent followed by 3 illegal target parameter indices of 7, -1, and 0. The illegal indices were ignored. Next a legal index of 1 was sent followed by the major and minor parts of  $R_p$ . Then a third DPSI target parameter was sent which was treated as an index and ignored because it was not in the legal range of 1-4. Similarly two more illegal indices of -2 and 0 were sent and ignored. Finally a legal index of 3 was sent followed by more parameter numbers, all of which were ignored. As a result of all this, the original  $R_p$  parameters loaded were not altered and VERI flag was inverted.

- 9) A VERB 67 ENTER was sent followed by an illegal LMP command 256. As a result the LMP command was not issued, the Operator Error light was lit, and VERI flag was inverted. An ERROR Reset was sent to extinguish the alarm light.
- 10) A VERB 72 ENTER was sent to schedule illegal mission phase 23 in 123458 seconds via mission timer #1. As a result the mission timer pair was left alone (MPHASE1 = 777778, MTIMER1 = 35628), the Operator Error light was lit, and VERI flag was inverted. An ERROR RESET was sent to extinguish the alarm light.
- 11) A VERB 71 ENTER was sent to schedule mission phase 6 via mission timer #2. Since MP6 is not suppose to be started via the mission scheduling routine(it is initiated upon detection of SIVB shutdown), MPHASE2 was left at 777778, the Operator Error light was lit, and VERI flag was inverted. An ERROR RESET was sent to extinguish the alarm light.
- 12) At 3350 seconds a VERB 64 ENTER was sent followed by an index of three and a GET of 0 seconds. Since the GET represents a time gone past, MTIMER3 was left at 777778, the Operator Error light was lit, and VERI flag was inverted. An ERROR RESET was sent to extinguish the alarm light.
- 13) A VERB 73 ENTER was sent to perform a function inhibit/enable update, followed by an illegal index of 4. As a result none of the function inhibit/enable switches were changed, the Operator Error light was lit, and VERI flag was inverted. An ERROR RESET was sent to extinguish the alarm light.
- 14) A series of four VERB 75 ENTER's were sent followed by normal burn target updates for DPS1, DPS2, APS2 and a time update. For index 4

TIME2,1 and TE,+1 were incremented by 12 centiseconds. Each burn and time parameter was correctly modified and VERI flag was inverted correctly after each of the four updates.

- 15) A series of six VERB 73 ENTER's was sent to individually invert and reinvert each of the function inhibit/enable switch states. The state of bits 1, 2, 3 of FLAGWRD2 were flipped properly and VERI flag was inverted correctly after each of the six updates.
- 16) A VERB 76 ENTER was sent to perform a normal state vector update. All 14 components were loaded correctly into  $\overline{REFRCV}$ ,  $\overline{REFVCV}$ , TE, +1 correctly and VERI flag was inverted.
- 17) A VERB 34 ENTER was sent after the VERB XX ENTER, for XX = 64, 67, 70, 71, 72, 73, 75, 76. As a result each uplink sequence was terminated properly and VERI flag was never inverted.
- 18) The Orbital Integration flag (bit 7 of FLAGWRD2) was set and then a VERB 76 ENTER state vector update was attempted. As a result the Major Mode remained at 27<sub>g</sub>, the incorporation of the state vector into  $\overline{REFRVC}$ ,  $\overline{REFVCV}$ , and TE, +1 was delayed, and VERI flag was inverted. Next the Orbital Integration flag was reset and the Major Mode changed to 00, the state vector was incorporated and VERI flag was not inverted.
- 19) The Orbital Integration flag was set and then a VERB 75 ENTER state vector time update was attempted. As a result the Major Mode remained at 27<sub>g</sub>, TIME2,1 and TE, +1 were not incremented by 24 centiseconds, and VERI flag was inverted. Next the Orbital Integration flag was reset and the Major Mode was changed to 00, TIME2,1 and TE, +1 were incremented by 24 centiseconds,

and VERI flag was not inverted.

- 20) A VERB 72 ENTER was sent to schedule MP8 in 7 seconds via mission timer #3. As a result MTIMER3 was changed from 77777<sub>8</sub> to 7<sub>8</sub>, MPHASE3 was changed from 77777<sub>8</sub> to 10<sub>8</sub>, and VERI flag was inverted.
- 21) A VERB 76 ENTER state vector update sequence was initiated to overlap the start of a mission phase. When MP8 became due prior to the completion of the load sequence, an interval VERB 34 ENTER was generated to kill the state vector update. VERI flag was not inverted.
- 22) A series of VERB XX ENTER was sent, for XX = 64, 67, 70, 71, 72, 73, 75, and 76. Since MP8 was active and the mission timers were not enabled, the operator error light was lit and VERI flag was not inverted. An ERROR RESET was sent after each update.
- 23) A VERB 74 ENTER was sent to terminate MP8.
- 24) A VERB 72 ENTER was sent to schedule MP9 in 8 seconds via mission timer #3. As a result MTIMER3 was changed from 77777<sub>8</sub> to 10<sub>8</sub>, MPHASE3 was changed from 77777<sub>8</sub> to 10<sub>8</sub>, and VERI flag was inverted.

RUN #13

Description: Mission Phases 1 and 2 (Prelaunch Alignment and Guidance Reference Release) with GRR via VERB 65 at 3 seconds before liftoff, followed by three redundant VERB 65's.

Revision: 112

Duration: 60 seconds prior to liftoff through 20 seconds beyond liftoff.

Objectives: 1) Demonstrate proper termination of prelaunch alignment and initiation of MP2 upon receipt of a VERB 65.  
2) Verify that redundant VERB 65's sent after guidance reference release are ignored.

Results: 1) Prelaunch Alignment and GRR Summary  
a) The prelaunch alignment program was initiated at liftoff - 55 seconds.  
b) The prelaunch gyrocompassing loop held the IMU platform to the proper gimbal angles of  $AOG = 122^\circ$ ,  $AIG = 0^\circ$ ,  $AMG = 30^\circ$  such that at GRR the euler set from desired to actual stable member alignment axes were  $X_{mis} = -0.0072^\circ$ ,  $Y_{mis} = -0.0003^\circ$ ,  $Z_{mis} = -0.0091^\circ$ .  
c) A VERB 65 was received and the internal GRR flag set at 2.99 seconds before liftoff.  
d) Consequently, gyrocompassing was terminated and MP2 initiated at 2.70 seconds before liftoff.  
e) The LGC clock was zeroed at 0.30 seconds after liftoff.

2) Redundant VERB 65 Summary

Three more VERB 65's were received at 1.69, 1.29, and 0.89 seconds before liftoff. No resultant action was taken because the prelaunch alignment program had already been terminated and only it can initiate MP2.



RUN #14, #15, #17

Description: Mission phases 9, 11, and 13 with an engine ignition failure.

Revision: See below.

Duration: Start of mission phase through premature termination of mission phase.

Objectives: Verify that the PGNCs Delta V monitor can:

- a) Detect a DPS engine ignition failure in MP9, MP11 and an APS engine ignition failure in MP13.
- b) Initiate the mission idling sequence and enable the mission timers.
- c) Protect the Average G state vector until it is transferred to the Orbital Integration program.

Results: Ignition Failure Detection Summary

- 1) The time that the DPS/APS engine was commanded on is given below with the time that the  $\Delta V$  monitor detected that the engine thrust level had not built up to 22.5 cm/sec<sup>2</sup> (DPS) or 200 cm/sec<sup>2</sup> (APS) during the first few seconds of the burn (Program Alarm 01405g).

<u>Run #</u>	<u>Rev.</u>	<u>Mission Phase</u>	<u>Engine Commanded On</u>	<u><math>\Delta V</math> Monitor Detection</u>
14	106	MP9	14,446.43 sec.	14,450.59 sec.
15	113	MP11	16,615.02	16,620.82
17	106	MP13	22,318.89	22,324.85

2) To terminate mission phase activity (Program Alarm 00315g), the LGC system programs were initialized, the engine was commanded off, the vehicle attitude was held, +X translation was terminated, the DAP deadband was set to 5.0°, and the mission timers were enabled.

3) The Average G position and velocity state vector errors just before the engine was commanded on are listed below along with those transferred to the Orbital Integration program when the reading of the PIPA's was terminated.

<u>RUN #</u>	<u>Engine Commanded On</u>		<u>Orbital Integration</u>	
	<u>R-Error</u>	<u>V-Error</u>	<u>R-Error</u>	<u>V-Error</u>
14	566 ft.	0.47 ft/sec	570 ft.	0.58 ft/sec.
17	406 ft.	0.86 ft/sec	389 ft.	3.00 ft/sec.

RUN #18 through #21

Description: Mission phases 9 and 11 with premature engine shutdown(s).

Revision: See below.

Duration: Start of mission phase through early termination of mission phase.

Objectives: Verify that the PGNC Delta V monitor can:

- a) Detect a premature DPS engine shutdown.
- b) Initiate the mission idling sequence and enable the mission timers.
- c) Protect the Average G state vector until it is transferred to the Orbital Integration program.

Results: Premature Engine Shutdown Detection Summary

- 1) The time that the DPS engine shutdown prematurely is given below, with the time that the  $\Delta V$  monitor detected that the engine thrust level fell below  $22.5 \text{ cm/sec}^2$  for a few seconds during the burn (Program Alarm 01405). (A), (B), and (R) below represent the approach, braking, and random throttle phases of MP11.

<u>Run #</u>	<u>Rev.</u>	<u>Mission Phase</u>	<u>Premature Shutdown</u>	<u>V Monitor Detection</u>
18	106	MP9	14,474.08 sec.	14,480.59 sec.
19	113	MP11A	17,140.08 sec.	17,146.81 sec.
20	113	MP11B	16,794.08 sec.	16,800.81 sec.
21	113	MP11R	17,297.08 sec.	17,302.81 sec.

2) To terminate mission phase activity (Program Alarm 003158), the LGC system programs were initialized, the DPS engine was commanded off, the vehicle attitude was held, +X translation was terminated, the DAP deadband was set to  $5.0^{\circ}$ , and the mission timers were enabled.

3) The Average G position and velocity state vector errors just before the engine shut down prematurely are listed below along with those transferred to the Orbital Integration program when the reading of the PIPA's was terminated.

<u>Run #</u>	<u>Premature Shutdown</u>		<u>Orbital Integration</u>	
	<u>R-Error</u>	<u>V-Error</u>	<u>R-Error</u>	<u>V-Error</u>
18	613 ft.	0.54 ft/sec.	626 ft.	8.42 ft/sec.

RUN #23

Description: Mission Phase 13 (APS2 Burn) with a 192 second burn to completion and  $KT = 0.34$ .

Revision: 116

Duration: 30 seconds prior to start of MP13 through end of mission phase.

- Objective:
- 1) Verify that the powered ascent guidance equations can:
    - a) Achieve the desired intercept target.
    - b) Achieve the desired altitude at cutoff.
  - 2) Compare timing sequences against the GSOP timeline.

- Results:
- 1) Guidance Summary
    - a) At MP13 ignition, the LSC TGO and VG were 194 seconds and 2296 ft/sec, respectively. Integrating the vehicle state at cutoff ahead in stable member coordinates to the time of intercept along a conic, the targeted intercept point ( $\overline{RIVEC}$ ) is compared with the projected vehicle state at 24,419 seconds (TINT):

<u><math>\overline{RIVEC}</math>(meters)</u>	<u><math>\overline{R}</math>(meters) at TINT</u>
-4,748,158	-4,746,589
-4,585,276	-4,586,742
849,360	845,816

- b) The targeted radius magnitude at cutoff was 6,686,035 meters; the RCO achieved was 6,686,009 meters.
- 2) Timeline and Other Summaries

Refer to the appendix.

RUN #24 through #33

Description: Mission phases 3 through 13 with a VERB 74 termination.

Revision: See below.

Duration: Start of mission phase through premature termination of mission phase.

Objectives: Verify that a VERB 74 transmitted via the uplink can:

- a) Terminate mission phase activity, initiate the mission idling sequence, and enable the mission timers.
- b) Protect the Average G state vector until the reading of the PIPA's is terminated and the state vector is transferred to the Orbital Integration program.

Results: VERB 74 Termination Summary

a)	<u>Run #</u>	<u>Rev.</u>	<u>Mission Phase</u>	<u>Occurrence</u>
	24	108	MP7	After SIVB/LM separation failure.
	25	106	MP8	Cold soak maneuver
	26	106	MP9	Burn
	27	108	MP11	Random throttle phase
	28	108	MP11	Braking phase
	29	108	MP11	Approach phase
	30	106	MP13	Burn
	31	108	MP11	Pre-burn attitude maneuver
	32	112	MP3	2nd DPS burn
	33	106	MP4	Burn

In each case, immediately after the VERB 74 was received, the LGC system programs were

initialized, the engine was commanded off, the vehicle attitude was held, +X translation was terminated, the DAP deadband was set to  $5.0^\circ$ , and the mission timers were enabled.

- b) The Average G position and velocity state vector errors just before the VERB 74 was received are listed along with those transferred to Orbital Integration when the reading of the PIPA's was terminated.

<u>Run #</u>	<u>VERB 74</u>		<u>Orbital Integration</u>	
	<u>R-Error</u>	<u>V-Error</u>	<u>d-Error</u>	<u>V-Error</u>
24	343 ft.	0.77 ft/sec	346 ft.	0.69 ft/sec.
26	613 ft.	0.54 ft/sec	571 ft.	0.46 ft/sec.
30	410 ft.	3.68 ft/sec	412 ft.	4.09 ft/sec.
32	35 ft.	0.32 ft/sec	35 ft.	0.30 ft/sec.
33	242 ft.	2.41 ft/sec	276 ft.	2.37 ft/sec.

RUN #34

Description: Mission Phase 9 (DPS1 Burn) with critical RCS jet failures during the pre-burn attitude maneuver.

Revision: 113

Duration: 60 seconds prior to start of MP9 through 30 seconds beyond premature termination of mission phase.

- Objectives:
- 1) Verify that the RCS failure monitor can:
    - a) Detect an RCS jet failure (low 8 bits of channel 32).
    - b) Isolate the appropriate jet pair by LMP commands.
    - c) Keep a record of the state of the isolation valves.
    - d) Update the DAP's jet-policy selection logic.
  - 2) Verify that when the DAP fails to find a jet-policy selection to perform the attitude maneuver with the failed RCS jets, the jet-abort sequence is initiated which will terminate mission phase activity, initiate the mission idling sequence, and enable the mission timers.

- Results:
- 1) RCS Failure Monitor Summary
    - a) Jet numbers 2 and 14 were failed on at 14,180.80 seconds during the attitude maneuver and jet number 5 was failed on 2 seconds later. The LGC erasable memory dump at the end of the run showed that bits 1, 2, and 5 of channel 32 were zero (inverse logic).



- b) LMP command 108 (THRUST ISOLATION VALVES, QUADRANT 1, SYSTEM B - CLOSE) was sent at 14,182.78 seconds, resulting in RCS jet pair 14 and 16 being turned off at 14,182.78 seconds. LMP command 232 (THRUST ISOLATION VALVES, QUADRANT 4, SYSTEM A - CLOSE) was sent at 14,183.74 seconds, resulting in RCS jet pair 2 and 4 being turned off at 14,183.86 seconds. LMP command 94 (THRUST ISOLATION VALVES, QUADRANT 3, SYSTEM A - CLOSE) was sent at 14,184.82 seconds, resulting in RCS jet pair 5 and 8 being turned off at 14,184.82 seconds. The corresponding valve closure reset commands (109, 233, and 94) were issued 0.96 seconds following the valve-closure commands.
- c) The LGC erasable memory dump at the end of the run showed that LMPJFAIL contained 00023<sub>8</sub>, indicating that the isolation valves associated with failure bits 1, 2, and 5 were closed.
- d) The dump also showed that CH5MASK (Q, R-axes) and CH6MASK (P-axis) contained 00206<sub>8</sub> and 00340<sub>8</sub> respectively, the correct channel 5 and channel 6 bit configurations that correspond to the jets disabled.

2) Jet Abort Summary

The jet abort routine (Program Alarm 00312<sub>8</sub>) terminated mission phase activity (Program Alarm 00315<sub>8</sub>) by initializing the LGC system programs, commanding the DPS engine off, terminating X translation, commanding vehicle altitude hold, setting the DAP deadband to 5.0°, and enabling the mission timers.

RUN #35

Description: Mission Phase 9 (DPS1 Burn) with critical jet failures during the pre-burn ullage.

Revision: 106

Duration: 60 seconds prior to start of MP9 through 50 seconds beyond premature termination of mission phase.

- Objectives:
- 1) Verify that the RCS failure monitor can:
    - a) Detect an RCS jet failure (low 8 bits of channel 32).
    - b) Isolate the appropriate jet pair by LMP commands.
    - c) Keep a record of the state of the isolation valves.
    - d) Update the DAP's jet-policy selection logic.
  - 2) Verify that when the DAP fails to find a jet-policy selection to perform the ullage with the failed RCS jets, the jet-abort sequence is initiated which will:
    - a) Terminate mission phase activity, initiate the mission idling sequence, and enable the mission timers.
    - b) Protect the average G state vector until it is transferred to the Orbital Integration program.

- Results:
- 1) RCS Failure Monitor Summary
    - a) Jet numbers 2 and 7 were failed on at 14,442.40 seconds during the pre-burn ullage.

The LGC erasable memory dump at the end of the run showed that bits 1 and 4 of channel 32 were zero (inverse logic).

- b) LMP command 110 (THRUST ISOLATION VALVES, QUADRANT 3, SYSTEM B - CLOSE) was sent at 14,443.90 seconds, resulting in RCS jet pair 6 and 7 being turned off at 14,443.90 seconds. LMP command 232 (THRUST ISOLATION VALVES, QUADRANT 4, SYSTEM A - CLOSE) was sent at 14,444.98 seconds, resulting in RCS jet pair 2 and 4 being turned off at 14,444.98 seconds. The corresponding valve-closure reset commands (111 and 233) were issued 0.96 seconds following the valve-closure commands.
- c) The LGC erasable memory dump at the end of the run showed that LMPJPAIL contained 00011<sub>8</sub>, indicating that the isolation valves associated with failure bits 1 and 4 were closed.
- d) The dump also showed that CH5MASK (Q, R-axes) and CH6MASK (P-axis) contained 00012<sub>8</sub> and 00101<sub>8</sub> respectively, the correct channel 5 and channel 6 bit configurations that correspond to the jets disabled.

2) Jet Abort Summary

- a) The jet-abort routine (Program Alarm 00312<sub>8</sub>) terminated mission phase activity (Program Alarm 00315<sub>8</sub>) by initializing the LGC system programs, commanding the DPS engine off, terminating +X translation, commanding vehicle attitude hold, setting the DAP deadband to 5.0°, and enabling the mission timers.
- b) The Average G position and velocity state vector errors just before the RCS jet failures were 564 feet and 0.49 ft/sec, respectively. When the reading of the PIPA's was terminated

and the state vector was transferred to the  
Orbital Integration program, the R-Error was  
567 feet and the V-Error was 0.47 ft/sec.

RUN #36

- Description: Mission Phase 3 (Suborbital Abort) with SIVB tumble rate in excess of  $2.99^{\circ}$ /second.
- Revision: 112
- Duration: SIVB shutdown through 15 seconds beyond detection of tumbling.
- Objectives:
- 1) Demonstrate that the tumble monitor program can detect spin in excess of  $3^{\circ}$ /second about the NAV BASE axes and will keep the TUMBLE flag (bit 13 of FLAGWRD1) set only as long as the tumbling criteria is exceeded.
  - 2) Verify that after the abort RCS pressurization sequence has been performed, the MP3 program will wait indefinitely until the TUMBLE flag is reset before proceeding.
- Results: Tumble Monitor Summary
- 1) SIVB shutdown occurred at 500 seconds.
  - 2) The vehicle was tumbling about X, Y, and Z NAV BASE axes at the rates of  $3.8^{\circ}$ /sec,  $3.5^{\circ}$ /sec, and  $3.2^{\circ}$ /sec respectively.
  - 3) MP3 was initiated via the suborbital abort uplink command at 506 seconds.
  - 4) The tumble monitor was started at 506 seconds.
  - 5) The abort RCS pressurization sequence was initiated at 507 seconds.
  - 6) MP3 began "holding" while the TUMBLE flag was set at 516 seconds.
  - 7) The LGC erasable memory dump at the end of the run showed that the TUMBLE flag was set and that the tumble monitor program was active (TUMBLMON flag set - Bit 14 of FLAGWRD1).

RUN #37

Description: Mission Phase 4 (Contingency Orbit Insertion)  
with SIVB tumble rate in excess of  $2.99^{\circ}$ /second.

Revision: 106

Duration: SIVB shutdown through 20 seconds beyond detection  
of tumbling.

- Objectives:
- 1) Demonstrate that the tumble monitor program can detect spin in excess of  $3^{\circ}$ /second about the NAV BASE axes and will keep the TUMBLE flag (bit 13 of FLAGWRD1) set only as long as the tumbling criteria is exceeded.
  - 2) Verify that after the abort RCS pressurization sequence has been performed, the MP4 program will wait indefinitely until the TUMBLE flag is reset before proceeding.

Results: Tumble Monitor Summary

- 1) SIVB shutdown occurred at 585 seconds.
- 2) The vehicle was tumbling about X, Y, and Z NAV BASE axes at the rates of  $3.8^{\circ}$ /sec,  $3.5^{\circ}$ /sec, and  $3.2^{\circ}$ /sec respectively.
- 3) MP4 was initiated via the contingency orbit insertion uplink command at 590 seconds.
- 4) The tumble monitor was started at 590 seconds.
- 5) The abort RCS pressurization sequence was initiated at 591 seconds.
- 6) MP4 began "holding" while the TUMBLE flag was set at 600 seconds.
- 7) The LGC erasable memory dump at the end of the run showed that the TUMBLE flag was set and that the tumble monitor program was active (TUMBLMON flag set - bit 14 of FLAGWRD1).

RUN #38 through #41

Description: Mission Phases 1, 2, 6, 7, and 8 with LGC restarts (GOJAM's), liftoff detector, and subsequent redundant GRR via VERB 65.

Revision: 113

Duration: 60 seconds of prelaunch alignment through end of MP8.

- Objectives:
- 1) Verify that mission phases 1, 2, 6, 7, and 8 are restart protected.
  - 2) Demonstrate minimal effects of restarts on the following mission phase performance:
    - a) Prelaunch stable member alignment.
    - b) Proper termination of prelaunch alignment and initiation of MP2 upon detection of 1.1 g's by the prelaunch program.
    - c) A redundant GRR (VERB 65) sent 2 seconds after liftoff is ignored.
    - d) Detection of SIVB shutdown by the boost monitor and proper initiation of MP6.
    - e) Proper calculation and attainment of desired cold soak attitude.

Results: 1) Restart Summary

Restarts were forced at various critical points within each mission phase and also every 8.2 seconds, for a total of 404 restarts. The performance of the mission phases was not significantly affected in the area of timing, although some events were repeated (cold fire purge initiation, attitude maneuver) due to restarts, delaying mission sequencing slightly. In addition,

one LGC down-telemetry frame was sent twice, once at liftoff and again at initiation of the boost monitor, because the computer was too busy to process the telemetry interrupt until the next one came due. The LGC state vector navigation errors were noticeably high, due to the restarts that occurred at liftoff and during the navigation program.

## 2) Mission Phase Performance

### a) Prelaunch Alignment Summary

The prelaunch gyrocompassing loop held the IMU platform to the proper gimbal angles of  $AOG = 122^\circ$ ,  $AIG = 0^\circ$ ,  $AMG = 30^\circ$  such that at GRR the euler set from desired to actual stable member alignment axes were  $K_{mis} = -0.0519^\circ$ ,  $Y_{mis} = -0.0256^\circ$ ,  $Z_{mis} = -0.0048^\circ$ .

### b) Guidance Reference Release Summary

- i) At 0.68 seconds after liftoff, 1.1 g's were sensed by the prelaunch alignment program.
- ii) Consequently, gyrocompassing was terminated and MP2 initiated at 0.71 seconds.
- iii) The LGC clock was zeroed at 0.87 seconds.

### c) Redundant GRR Command Summary

A VERB 65 was transmitted at 2 seconds after liftoff, with no resulting action taken by the flight program.

### d) SIVB Shutdown Summary

- i) SIVB shutdown occurred at 587 seconds after liftoff.
- ii) The SIVB Delta V monitor detected shutdown at 590 seconds.
- iii) MP6 was initiated at 590 seconds.



e) Cold Soak Attitude Maneuver Summary

- i) The desired cold soak gimbal angles (AOG:  $-112.5^{\circ}$ , AIG:  $-25.7^{\circ}$ , AMG:  $-5.4^{\circ}$ ) were achieved and held within the  $5^{\circ}$  deadband.
- ii) A  $149.11^{\circ}$ , 29.81 second attitude maneuver was performed to the cold soak attitude.
- iii) The amount of RCS fuel used during the cold soak maneuver was 24.7 pounds, compared with the nominal 5-10 pounds.
- iv) See appendix for other details.

RUN #42

Description: Mission Phase 9 (DPS1 Burn) with LGC restarts (GOJAM's).

Revision: 109

Duration: 60 seconds prior to start of MP9 through 10 seconds beyond end of mission phase.

Objectives. 1) Verify that MP9 is restart protected.  
2) Demonstrate minimal effect of restarts on mission phase performance.

Results: 1) Restart Summary

Restarts were forced at various critical points within the mission phase and also every 10 seconds, for a total of 101 restarts. The performance of MP9 was not significantly affected in the areas of guidance, timing, or navigation, although some events were repeated (Orbital integration, attitude maneuver) due to restarts, delaying mission sequencing slightly. The state vector errors were about double those in Run #5.

2) Guidance Summary

- a) The flight path angle achieved at cutoff was  $0.001^{\circ}$ .
- b) The targeted radial distance  $R_p$  of 21,992,000 feet represents an apogee of 3617.0 nautical miles. The apogee achieved at cutoff was 3619.9 n.m.
- c) See appendix for other details.

RUN #43, #44

Description: Mission Phase 11 (DPS2/Fire-In-The-Hold/APS1)  
with LGC restarts.

Revision: 113

Duration: 40 seconds prior to start of MP11 through end of  
mission phase.

Objectives: 1) Verify that MP11 is restart protected.  
2) Demonstrate minimal effect of restarts on mission  
phase performance.

Results: 1) Restart Summary

Restarts were forced at various critical points within the mission phase and also every 20 seconds, for a total of 303 restarts. The performance of MP11 was not significantly affected in the areas of guidance, timing, or navigation, although some events were repeated (Orbital Integration, attitude maneuver) due to restarts, delaying mission sequencing slightly.

One LGC down-telemetry frame was sent twice at DPS ignition because the computer was too busy to process the telemetry interrupt until the next one came due. Also, due to the way that the LM vehicle was modeled in the simulation, the abort staging sequence was successfully completed following restarts during the DPS burn, in spite of the discrepancy in the flight program (refer to 206 Flight Memo #12); in the real LM vehicle, the staging could not have occurred because a restart sets LGC channel 11 bits 13 (engine on) and 14 (engine off) both to zero. Finally, the LGC mass estimation and state vector errors were about twice as high as expected.

2) Guidance Summary

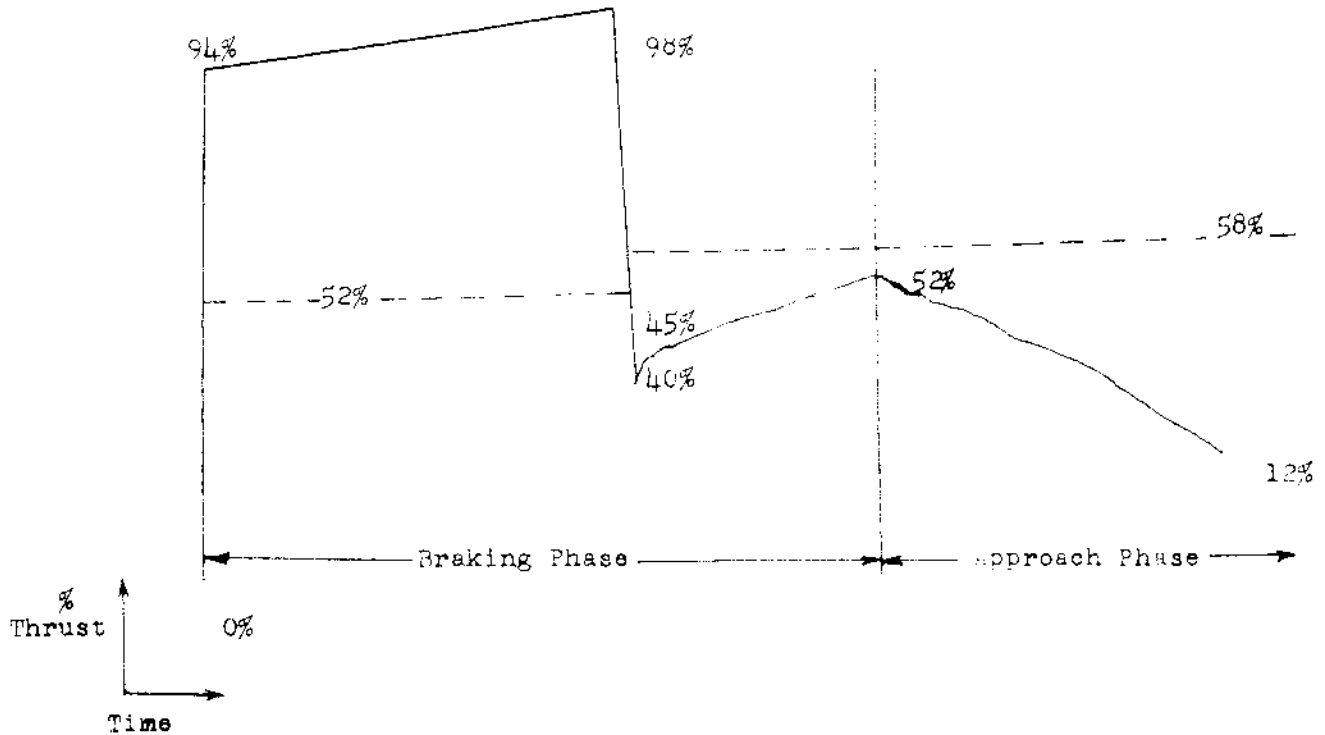
a) Braking Phase

<u>Parameter</u>	<u>Desired</u>	<u>Achieved</u>
RS0(m)	6.686947192E+6	6.687175123E+6
RS2(rad)	5.797020381E-3	6.506681440E-3
VS0(m/sec)	-2.133262798E+1	-2.200431820E+1
VS2(rad/sec)	-6.533766150E-5	-6.991933784E-5

Approach Phase

<u>Parameter</u>	<u>Desired</u>	<u>Achieved</u>
RS0(m)	6.684376002E+6	6.684457436E+6
RS2(rad)	6.577692132E-6	3.433972000E-5
VS0(m/sec)	-7.313938765E+0	-7.717513728E+6
VS2(rad/sec)	-2.46936171E-6	-3.647630797E-6

b) Throttle Control Summary



c) Random Throttle Summary

<u>% Commanded</u>	<u>% Achieved</u>
10	12
50	49
30	28
40	39
20	18

d) Timeline and Other Summaries

Refer to the appendix.

RUN #45

Description: Mission Phase 13 (APS2 Burn) with a LGC restart 82 seconds into the burn.

Revision: 106

Duration: 30 seconds prior to start of MP11 through end of mission phase.

Objectives: 1) Verify that a restart after ignition in MP13 will detach the guidance so that the burn will continue at a fixed attitude until fuel depletion.  
2) Verify that the continuation burn is restart protected.

Results: a) MP13 ignition occurred at 22,319 seconds.  
b) The ascent crossfeed valve test set sequence initiated at 22,320 seconds.  
c) A restart was forced at 22,391 seconds.  
d) The major mode was changed to 47 at 22,391 seconds, indicating that the dummy MP13 program had been initiated to hold a constant burn attitude.  
e) More restarts were forced every 3.15 seconds beginning at 22,770 seconds.  
f) Fuel depletion occurred at 22,775 seconds.  
g) The Delta V monitor detected thrust tailoff at 22,783 seconds.  
h) The ascent crossfeed valve test reset sequence was initiated at 22,800 seconds.  
i) The reading of the RIPDs was terminated at 22,823 seconds.  
j) Refer to the appendix for other details.

RUN #46

Description: Mission Phase 3 (Suborbital Abort) with LGC restarts.

Revision: 110

Duration: SIVB shutdown through end of MP13.

Objectives: 1) Verify that MP3 is restart protected.  
2) Demonstrate minimal effect of restarts on mission phase performance.

Results: 1) Restart Summary  
29 restarts were forced at various critical points within the mission phase. The performance of MP3 was not significantly affected in the areas of guidance, timing, or navigation.  
2) Mission Phase Performance  
Refer to the appendix.

RUN #47

Description: Mission Phase 4 (Contingency Orbit Insertion) with a 20 second premature SIVB shutdown, 7 second delay until abort uplink command, and LGC restarts.

Revision: 108

Duration: SIVB shutdown through 19 seconds beyond end of mission phase.

Objectives: 1) Verify that nominal orbit insertion can be achieved.  
2) Demonstrate minimal effect of restarts on mission phase performance and verify that MP4 is restart protected.  
3) Compare with Run #3c, which is almost identical without restarts.

Results: 1) Orbit Insertion Guidance Summary  
a) Targets  
Same as Run #3.  
b) SIVB Shutdown Conditions at 585 Seconds  
Same as Run #3c.  
c) MP4 Ignition Conditions at 653 Seconds  
 $R_{\text{ignition}} = 21,426,735$  feet  
 $V_{\text{ignition}} = 24,205.86$  ft/sec  
(apogee = 3526.4 n.m.)  
(perigee = 2833.4 n.m.)  
d) Guidance Cutoff Conditions at 888 Seconds  
 $R_{\text{co}} = 21,445,758$  feet  
 $V_{\text{co}} = 25,683.52$  ft/sec  
(apogee = 3562.2 n.m.)  
(perigee = 3527.1 n.m.)



2) Restart Summary

Restarts were forced at various critical points in the MP4 program and also every 20 seconds during the burn for a total of 44 restarts. Mission phase performance was not significantly affected in the areas of guidance, timing or navigation.

- a) Some events (Orbital Integration, attitude maneuver) had to be repeated, delaying the mission sequencing slightly.
- b) Fuel consumption was noticeably higher than in Run #3c.
- c) Program alarm 1412g was displayed, indicating that the MP4 attitude maneuver failed to achieve the desired ignition gimbal angles. This was due to the combination of the 10°/sec abort maneuver rate and the restarts during the maneuver, which caused the re-maneuver to read its initial gimbal angles before the gimbals stopped. Consequently it computed the time to read the final gimbal angles too early and alarmed. This will usually happen under these circumstances, although the DAP will shortly achieve the desired angles.
- d) A LGC down-telemetry frame was sent twice 16 seconds before DPS ignition because the computer was too busy to process a telemetry interrupt until the next one came due.

3) Timeline and Other Summaries

Refer to the appendix.

RUN #48

Description: Nominal Mission Phases L and 13, with LM abort staging commanded via the LGC uplink.

Revision: 113

Duration: 60 seconds of prelaunch alignment through 60 seconds beyond end of MP13.

- Objectives:
- 1) Verify that nominal orbit insertion can be achieved with a 40 second premature SIVB shutdown by the DPS commanded by the ascent guidance equations.
  - 2) Demonstrate that following MP4, a LGC state vector update, a burn target update, the abort staging LMP sequence, and a mission phase/timer update can be incorporated via uplink to initiate MP13 properly.
  - 3) Verify that the powered ascent guidance equations can:
    - a) Achieve the desired intercept target.
    - b) Achieve the desired altitude at cutoff.

- Results:
- 1) Orbit Insertion Guidance Summary
    - a) Targets

Same as Run #3.
    - b) SIVB Shutdown Conditions at 545 Seconds.

$R = 21,446,391$  feet  
 $V = 22,625.16$  ft/sec  
(apogee = 3528.5 n.m.)  
(perigee = 2253.4 n.m.)
    - c) MP4 Ignition Conditions at 627 Seconds.

$R_{\text{ignition}} = 21,400,144$  feet  
 $V_{\text{ignition}} = 22,692.56$  ft/sec  
(apogee = 3528.5 n.m.)  
(perigee = 2290.5 n.m.)

d) Guidance Cutoff Conditions at 1106 seconds

$R_{co} = 21,447,865$  feet

$V_{co} = 25,677.86$  ft/sec

(apogee = 3560.3 n.m.)

(perigee = 3527.4 n.m.)

2) Uplink Activity Summary

- a) At 1160 seconds a VERB 76 state vector update was performed. Unfortunately the update made the state vector errors even worse.
- b) At 1186 seconds a VERB 75 burn target update was performed to change RIVEC, TINT, and RCO for MP13.
- c) At 1220 seconds, LMP command 38 (ABORT STAGE - ARM) was sent via VERB 67.
- d) At 1224 seconds, LMP command 22 (ABORT STAGE - COMMAND) was sent via VERB 67.
- e) At 1229 seconds, LMP command 39 (ABORT STAGE - COMMAND RESET) was sent via VERB 67.
- f) At 1340 seconds a VERB 72 mission phase/timer update was performed to schedule MP13 in 429 seconds via mission timer #2.
- g) Something that was overlooked was that LGC MASS should have been updated after staging via a VERB 21, etc. Because it wasn't, the LGC estimation of the mass of the LM during MP13 was some 5700 pounds high or in error by 46%. The effect on mission phase performance was not noticeable because of MP13's anticipated thrust magnitude filter the mass error showed up as an off-nominal thrust and the guidance compensated for it.

NOTE: The above sequence of LMP commands that did not actually occur started to occur. In the future, an alternate method of commanding staging would have to be used.

3) Ascent Guidance Summary

- a) At MP13 ignition, the LBO FBO and VI were 393 seconds and 5224 feet/second, respectively. Integrating the vehicle state at cutoff ahead in stable member coordinates to the time of intercept along a conic, the targeted intercept point ( $\overline{RIVEC}$ ) is compared with the projected vehicle state at 3839.79 seconds (TINT):

<u><math>\overline{RIVEC}</math>(meters)</u>	<u>R(meters) at TINT</u>
-647,735	-657,469
-5,786,642	-5,790,129
-3,101,623	-3,096,505

- b) The targeted radius magnitude at cutoff was 6,559,362 meters; the ROC achieved was 6,559,800 meters.
- c) Refer to the appendix for other summaries.

APPENDIX

A. Length of Mission Phase(s)

<u>Run No(s).</u>	<u>Mission Phase(s)</u>	<u>Hour</u>	<u>Min</u>	<u>Sec</u>
1	2,6		21	49
2	3		3	10
2a	3		3	11
3	4		5	37
3b	4		9	56
3c	4		5	29
4	7,8		0	53
5	9		6	54
5a	9		6	54
5b	9		0	54
5c	9		5	01
5c'	9		6	54
6	11		16	05
6a	11		15	21
7	13		11	20
7a	13		4	10
8,9	9		6	54
10	2,6,7,8,9,11,13	6	21	14
11	2,6,7,8,9,11,13	6	21	16
11a	2,6,7,8,9,11,13	6	21	18
23	13		6	52
38-41	2,6,7,8		56	38
42	9		6	54
43,44	11		16	05
45	13		11	14
46	3		3	12
47	4		5	42
48	4		9	42
48	13		9	50

B. Attitude Maneuver

<u>Run No(s).</u>	<u>Mission Phase</u>	<u>Magnitude (degrees)</u>	<u>Time (seconds)</u>
3	4	68.61	6.85
3b	4	62.73	6.26
3c	4	65.86	6.57
4	8	151.88	30.36
5	9	63.00	12.50
5a	9	63.00	12.50
5b	9	63.00	12.50
5c	9	44.75	8.94
5c'	9	52.10	10.41
6	11	95.76	19.00
6a	11	91.90	18.83
7	13	97.73	19.53
7a	13	89.85	17.92
8,9	9	63.02	12.60
10	8	147.38	29.46
10	9	56.91	11.37
10	11	85.30	17.05
10	13	18.00	3.59
11	8	142.79	28.54
11	9	53.68	10.71
11	11	64.50	16.89
11	13	4.93	0.97
11a	8	149.00	29.79
11a	9	57.18	11.42
11a	11	88.53	17.70
11a	13	13.37	2.66
23	13	93.69	18.73
38-41	8	149.11	29.81
42	9	44.75	8.94
43,44	11	38.26	7.74
45	13	97.73	19.53
47	4	61.55	6.14
48	4	61.55	6.62
L8	13	97.73	19.52

C. Length of Burn(s) in Seconds

<u>Run No(s).</u>	<u>Mission Phase</u>	<u>DPS</u>	<u>SS</u>
2	3	34	54
2a	3	34	54
3	4	236	
3b	4	557	
3c	4	228	
5	9	36.4	
5a	9	36.4	
5b	9	36.4	
5c	9	24.2	
5c'	9	32.4	
6	11	729.0	5.2
6a	11	683.5	5.2
7	13		456.0
7a	13		29.85
8,9	9	36.4	
10	9	36.4	
10	11	737.7	5.0
10	13		439.8
11	9	36.4	
11	11	716.8	5.4
11	13		434.3
11a	9	36.4	
11a	11	700.5	5.2
11a	13		431.5
23	13		192.5
42	9	36.8	
43,44	11	703.3	5.2
45	13		456.0
46	3	33	65
47	4	235	
48	4	479	
48	13		380

D. Fuel Usage in Pounds

<u>Run No(s).</u>	<u>Mission Phase(s)</u>	<u>RCS</u>	<u>DPS</u>	<u>APS</u>	<u>Run No(s).</u>	<u>Mission Phase(s)</u>	<u>RCS</u>	<u>DPS</u>	<u>APS</u>
2	3	49.1	222	733	11	7,8	30.3		
2a	3	57.7	224	733	11	9	23.3	480	
3	4	59.5	7,147		11	11	39.4	15,748	61
3b	4	224.6	15,962		11	13	78.9		4,919
3c	4	68.8	6,769		11a	7,8,9,11,13	179.8	15,970	4,947
4	7,8	30.2			11a	7,8	38.5		
5	9	21.2	487		11a	9	24.9	481	
5a	9	21.9	481		11a	11	37.2	15,489	59
5b	9	24.1	481		11a	13	79.2		4,888
5c	9	19.8	108		23	13	43.1		2,180
5c'	9	21.1	357		38-41	7,8	41.7		
6	11	72.0	15,941	57	42	9	24.1	499	
6a	11	62.4	16,023	53	43,44	11	37.7	16,049	57
7	13	83.7		5,168	45	13	85.0		5,168
7a	13	28.5		338	46	3	57.7	265	721
8, 9	9	31.4	481		47	4	100.0	7,064	
10	7,8,9,11,13	177.9	16,533	5,015	48	4	59.9	15,412	
10	7,8	34.3			48	13	128.4		4,309
10	9	24.5	481						
10	11	38.5	16,052	57					
10	13	80.5		4,958					
11	7,8,9,11,13	171.9	16,228	4,980					



S. Maximum Average G Navigation Errors Accumulated  
since Beginning of Run

<u>Run No(s).</u>	<u>Mission Phase(s)</u>	<u>Position (feet)</u>	<u>Velocity (ft/sec)</u>	<u>Run No(s).</u>	<u>Mission Phase(s)</u>	<u>Position (feet)</u>	<u>Velocity (ft/sec)</u>
1	2,6	5,936	6.75	11	6	176,128	219.56
2	2,3	4,206	9.58	11	7	75,954	223.00
2a	3	70	0.41	11	4	204,703	167.19
3	2,4	3,851	8.57	11	11	214,096	231.35
3b	2,4	3,377	5.22	11	13	255,735	296.10
3c	4	729	2.44	11a	2	110,442	429.22
4	7	441	1.09	11e	6	343,759	428.59
5	9	503	0.36	11a	7	143,511	434.16
5a	9	565	0.50	11a	9	440,277	380.39
5b	9	565	0.50	11a	13	445,319	488.77
5c	9	503	0.36	11a	17	522,796	635.59
5c'	9	1,619	1.62	23	14	507	0.56
6	11	195	0.58	38-41	5	7,334	23.31
7	13	553	0.54	38-41	6	22,866	25.01
7a	13	444	0.54	38-41	7	75,092	78.43
8,9	9	605	0.38	42	9	982	1.06
10	2	5,279	19.28	43,44	11	3,148	3.25
10	6	15,741	19.29	45	13	568	0.56
10	7	4,390	20.74	46	3	130	0.40
10	9	60,966	68.31	47	4	4,494	3.14
10	11	68,604	84.00	48	4	4,077	7.76
10	13	73,408	95.42	48	13	24,855	32.47
11	2	56,406	219.87				

F. Maximum LGC Mass Estimator Error

<u>Run No(s).</u>	<u>Mission Phase</u>	<u>Lbs.</u>	<u>%</u>	<u>Run No(s).</u>	<u>Mission Phase</u>	<u>Lbs.</u>	<u>%</u>
2	3	73	0.6	11	9	100	0.3
2a	3	76	0.8	11	11	120	0.6
3	4	169	0.7	11	13	87	1.3
3b	4	400	2.6	11a	7	13	0.04
3c	4	100	0.4	11a	9	105	0.3
4	7	50	0.1	11a	11	135	0.6
5	9	100	0.3	11a	13	80	1.3
5a	9	100	0.3	23	13	30	0.3
5b	9	80	0.2	38-41	7	6	0.002
5c	9	84	0.2	42	9	93	0.25
5c'	9	85	0.2	43,44	11	682	4.2
6	11	254	2.54	45	13	30	0.6
7	13	30	0.6	46	3	59	0.8
7a	13	30	0.6	47	4	210	0.8
8,9	9	80	0.25	48	4	100	0.4
10	7	13	0.04	49	13	5,875	45.0
10	9	76	0.2				
10	11	130	0.6				
10	13	100	1.1				
11	7	13	0.04				

G. Largest PGNOS IMU Middle Gimbal Angle in Degrees

<u>Run No(s).</u>	<u>Mission Phase(s)</u>	<u>Largest MGA</u>	<u>Run No(s).</u>	<u>Mission Phase(s)</u>	<u>Largest MGA</u>
1	2,6	50.34	11	2	49.82
2	2,3	52.6	11	6	-49.26
2a	3	36.9	11	7,8	-36.33
3	2,4	53.6	11	9	-8.8
3b	2,4	58.0	11	11	-45.79
3c	4	53.3	11	13	-47.63
4	7,8	-41.41	11a	2	49.38
5	9	-13.8	11a	6	-51.31
5a	9	-13.9	11a	7,8	-35.49
5b	9	-13.9	11a	9	-8.21
5c	9	-13.9	11a	11	-47.58
5c'	9	-45.0	11a	13	-40.85
6	11	-44.52	23	13	-42.17
6a	11	-45.33	38-41	2,6,7,8	-52.32
7	13	-38.88	42	9	-17.98
7a	13	-70.84	43,44	11	-44.09
8,9	9	-16.99	45	13	-41.78
10	2	50.53	46	3	42.25
10	6	-49.32	47	4	57.65
10	7,8	-38.18	48	4	53.54
10	9	-11.63	48	13	-58.27
10	11	-48.22			
10	13	-43.18			

H. Date Run was Made, MIT Log Number, and Code

CODE: 1 - MSC has run and edits.  
 2 - MSC does not have run nor edits.  
 3 - MSC has run and edits, but on an older revision.

<u>Run No(s).</u>	<u>Run Date</u>	<u>Log No.</u>	<u>Code</u>	<u>Run No(s).</u>	<u>Run Date</u>	<u>Log No.</u>	<u>Code</u>
1	2/27/67	523995	1	19,20,21	3/2	525120	1
2	4/27	549595	1	23	3/25	535065	1
2a	3/28	536446	1				
3	2/14	518133	1	24	2/21	521427	1
3b	3/1	524772	1	25	2/21	521648	1
3c	3/25	535154	1	26	2/21	521776	1
4	3/4	526410	1	27,28,29	2/24	522792	1
5	3/2	525209	3	30	2/17	519876	1
5a	3/27	535976	1	31	2/24	522792	1
5b	4/6	539793	2	32	2/27	524213	1
5c	3/17	531778	2	33	2/17	519841	1
6	3/3	539137	1	34	3/3	525913	1
6a	2/14	517764	2	35	2/18	519919	1
7	2/17	519930	1	36	2/27	524317	1
7a	3/3	526166	1	37	2/17	519802	1
8,9	4/3	539034	3	38,41	3/1	524872	1
10	3/24	535022	1	42	2/23	522563	1
11	4/5	539810	1	43,44	3/2	525585	2
11a	4/15	544970	1	45	2/15	519229	1
12	2/18	520072	1	46	2/25	523165	1
13	2/27	524240	1	47	2/20	521044	1
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