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AGS VERIFICATION TESTING FOR LM-

VOLUME I - TEST PLAN

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Prepared Under Contract NAS 9-5384

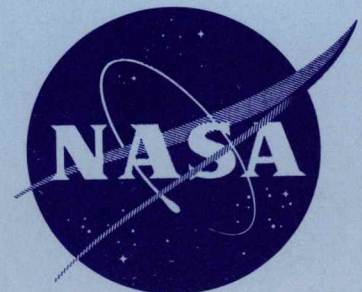
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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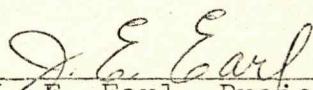
AGS VERIFICATION TESTING FOR LM-4

VOLUME I -- TEST PLAN

August 1968

Prepared Under Contract NAS 9-5384 for  
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION  
MANNED SPACECRAFT CENTER  
HOUSTON, TEXAS 77058

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## 1.0 INTRODUCTION

The test plan contained herein is Volume I of the report on verification testing of the LM-4 flight program for Apollo Mission E. Corresponding test results will be reported as Volume II upon completion of the tests. Included in the test plan are AGS Detailed Test Objectives, nominal and off-nominal tests, abort cases and special tests determined by LEC. Testing priorities will be assigned according to existing mission rules and in accordance with the requirements of the LM G & C Project Office.

Objectives of the AGS Verification Testing for LM-4 described herein are to demonstrate the capability of the AGS software to perform the nominal maneuvers of Mission E and serve as a satisfactory abort system in case of PGNCs failure during the mission.

The scope of the verification testing will be restricted to those functions which are assigned to the AGS software, or may be required in its roll as "back-up" to the PGNCs. The off-nominal and special tests will verify the AGS software capability to handle dispersions, error sources, and system failures. RTCC and PGNCs compatibility will also be verified by test cases to be defined at a later date.

Verification testing described herein will be performed on the TRW ICS/FS digital simulator, LEC/MSc six-degree-of-freedom simulator, and the AGS/CFP simulation. The TRW ICS/FS is described

in Reference 6. Formal documentation on the other two simulations is not currently available.

The flight program to be tested is identical to Flight Program 3 for LM-3 and is described in Reference 4. Constants for the program are also contained in this reference.

Mission E profile information and reference trajectory data are presented in References 1, 2, 3 and 13. The profile is divided into five periods of activity in which LM flight testing is to occur during the third period.

Specification and simulation data necessary for appropriate testing will be (or have been) derived from several sources. Specifically, mass and propulsion data will be extracted from References 1, 2, 3, 9 and 10. Allowable sensor errors will be obtained from Reference 11. Actual sensor errors for LM-4 hardware have been obtained from ASA-011 data, Reference 12.

Trajectory dispersions will be provided by MPAD and/or EG23 generated error analyses. Specifications applicable to instrument calibration were determined from References 6 and 8.

Absolute times used in this test plan are biased by 260,000 sec from the ground elapsed time (g.e.t.) of the reference trajectory.



## 2.0 TEST CRITERIA

These tests are designed to demonstrate the satisfactory implementation of the calibration and flight equations in Flight Program 4 as opposed to determining guidance performance of the AGS due to external errors arising from alignment, initialization, calibration/compensation, sensors, and etc. In addition, the tests will demonstrate program interfaces (PGNCS downlink, DEDA processing, etc.) and program performance under some off-nominal vehicle and abort conditions.

For Inflight Calibration the test criteria are satisfactory performance and compensation during the calibration period as follows: little or no overshoot during the transient response, steady state attainment within five minutes and compensation to within  $\pm 0.50^\circ/\text{hr}$  for each gyro and  $\pm 200 \mu\text{g}'\text{s}$  for each accelerometer.

Criteria for AGS software performance during the various maneuvers and guidance solution phases are favorable comparisons of orbital parameters and state vectors between AGS computations and the reference trajectory and reasonable solutions of the CSI, CDH and TPI guidance modes.

### 3.0 TEST PLAN

#### 3.1 Detailed Test Objectives

Case 1.1: AGS Inflight Calibration and Performance (D.T.O.  
No. S12.6)

Inflight Calibration - AGS gyros and accelerometers will be calibrated in this case following Downlink Initialization and IMU Align. Actual instrument bias errors, as determined from hardware testing, are to be simulated. These errors are 90, 155 and 266  $\mu\text{g}$ 's for the X, Y and Z accelerometers and .02, .03 and  $-.02^\circ/\text{hr}$  for the X, Y and Z gyros respectively. A misalignment error of 1.5 arc minutes about each vehicle axis toward both the other axes will be imposed. In addition, LM will be subjected to attitude motion characteristic of the control system limit cycle. Prior to calibration the AGS computational inertial reference frame will be aligned to PGNCS with  $\theta_p = \psi_p = \phi_p = 45^\circ$ .

The calibration will last 300 seconds and will be performed with the the MODE CONTROL switch in ATT HOLD. Gyro compensation coefficients 1K1, 1K6 and 1K11 and accelerometer coefficients 1K19, 1K21 and 1K23 will be observed for response characteristics. Other appropriate parameters will also be studied.

Inflight Accelerometer Calibration Only - Following AGS Gyro and Accelerometer Calibration, the accelerometers will be calibrated again. The MODE CONTROL switch will be set to ATT HOLD and RCS

jet firing will be inhibited by setting the three Attitude Control switches to DIR (The Attitude Controller must be left in detent).

This calibration will last 30 seconds and the accelerometer coefficients 1K19, 1K21 and 1K23 will be observed throughout the period.

Case 1.2: AGS Control of LM-Active Rendezvous (D.T.O. No. M20.48) -

The objective of this case is to demonstrate the capability of AGS control during the LM-Active Rendezvous period. AGS will control all maneuvers during this, the third, period of activities. The nominal test cases in Section 3.2 of this test plan are designed to satisfy this D.T.O.

### 3.2 Nominal Mission (Mission E)

Case 2.1: APS Insertion Burn - This case starts prior to the burn and begins with a Downlink Initialization and IMU Align. Following a 4 second, four jet RCS burn for ullage, an APS burn will be executed to achieve a  $\Delta V$  of 130 fps. The burn will last 12 sec and will be controlled by AGS External  $\Delta V$  guidance. The test will have the following targeting conditions:

$$28J1 = -37.0 \text{ fps}$$

$$28J2 = 1.0 \text{ fps}$$

$$28J3 = -125.0 \text{ fps}$$

This burn is performed to change the LM orbit from 149 n.mi. altitude circular to 156 x 116 n.mi. altitude elliptical. APS burn time, vehicle velocity, apogee altitude, perigee altitude, and other trajectory parameters will be evaluated to determine if the AGS properly performed the  $\Delta V$  maneuver.

Following the Insertion Burn, the AGS will be switched to the CSI mode to perform a CSI solution (with CDH at 2nd apsis) using the following target parameters:

$$t_{igA} = 85.7 \text{ min.}$$

$$1J = 198.6 \text{ min.}$$

$$2J = \tan 27.3^\circ$$

The solution should result in a  $\Delta V$  ( $V_0$ ) near zero for the CSI maneuver, a CDH  $\Delta V$  ( $V_{p0}$ ) of 74 fps and a differential altitude  $\Delta r$  of about 10 n.mi.

Case 2.2: CDH Maneuver - This case starts prior to the burn and begins with a DEDA Initialization and IMU Align. The burn, which will be preceded by a 4 second, four jet RCS burn for ullage, is performed by the APS with the AGS in CDH guidance. This maneuver is executed to circularize the LM orbit at 159 n.mi. altitude, 10 n.mi. above and 82 n.mi. ahead of the CSM, and requires a  $\Delta V$  of 74 fps (APS burn time of 7 seconds). The targeting parameter for the CDH guidance mode is

$$t_{igB} = 139.6 \text{ min.}$$

In addition to normal trajectory parameters,  $T_\Delta$ ,  $r_f$ ,  $V_G$ , and  $\Delta r$  will be used to evaluate this maneuver.

After completion of the CDH maneuver a TPI Search will be executed to determine  $t_{igC}$  for a  $\theta_{LOS}$  equal to  $27.3^\circ$ . The search will be performed for 30 seconds with the following target constant:

$$T_\Delta = 58.34 \text{ min.}$$

Case 2.3: TPI Maneuver - This case will start prior to the burn with a DEDA Initialization and IMU Align. The TPI maneuver is a 400 lb, + X-axis RCS burn to accomplish a  $\Delta V$  of 22 fps in 18.4 sec.

The burn is along a LOS angle of  $27.3^\circ$  and is controlled by AGS TPI guidance. This maneuver is designed to place the LM on an intercept trajectory with the CSM at  $130^\circ$  central angle of CSM travel from time of ignition. Targeting parameters are

$$6J = 34.47 \text{ min.}$$

$$t_{igC} = 198.6 \text{ min.}$$

The success of this maneuver will be determined by evaluating the TPI solution, state vectors and the projected rendezvous accuracy. After the TPI maneuver a Rendezvous Radar update will be performed and a Mid-Course Correction determined via the TPI mode. Five radar range measurements will be entered into the AGS at 3 minute intervals and a radar range rate measurement will be entered after the last range entry. Radar boresight misalignment errors of 20 m rad about the Y-body axis and 10 m rad about the X-body axis will be simulated. The AGS will remain in the TPI Execute mode and compute the solution for a Mid-Course Correction with the following target parameters:

$$t_{igC} = 218.00 \text{ min.}$$

$$6J = 15.07 \text{ min.}$$

Since the TPI maneuver is to be performed under nominal conditions, the solution for a Mid-Course Correction should indicate a  $\Delta V$  near zero. This assumes, of course, that the Rendezvous Radar provides an update with little error.

### 3.3 Off Nominal Cases

Case 3.1: 3412 lbs APS Insertion Burn - This case starts prior to the burn with Downlink Initialization and IMU Align. Following a 4 sec., four jet RCS burn for ullage, an APS Insertion burn will be executed. The APS will be ignited for a 130 fps  $\Delta V$  burn at (3412 lbs) thrust and will be controlled by the AGS External  $\Delta V$  mode. This case has the following targeting conditions:

$$28J1 = -37.17 \text{ fps}$$

$$28J2 = 0.79 \text{ fps}$$

$$28J3 = -124.87 \text{ fps}$$

The CSI solution will be performed as in Case 2.1 and APS burn time, vehicle velocity, apogee altitude, perigee altitude, and other trajectory parameters will be evaluated. The objective of this case and Case 3.2 is to observe effect of the worst case condition on the nominal APS burn. The thrust tolerance is  $\pm 88$  lbs of full thrust of the APS engine.

Case 3.2: 3588 lbs APS Insertion Burn - This case is identical to Case 3.1 with 3588 lbs APS thrust.

Case 3.3: Canted APS Engine - This test is identical to Case 2.2 (CDH Maneuver) except the guidance equations for a non-canted APS engine will be used with the canted APS engine ( $-2.5^\circ$  in the pitch plane).

Case 3.4: CSI Maneuver ( $\underline{W}_b$  specified by  $\underline{V}_1$ ) - Although this maneuver is nominally zero, a  $0.1^\circ$  wedge angle will be introduced and X-axis RCS thrusting (4 jets) used to remove the resulting out-of-plane velocity. DEDA Initialization and IMU Align will precede the burn which is controlled by the CSI and External  $\Delta V$  guidance routines. The target parameters are

$$t_{igA} = 85.7 \text{ min.}$$

$$1J = 198.6 \text{ min.}$$

$$2J = \tan 27.3^\circ$$

During this burn the Z-axis will be oriented parallel to a plane specified by setting  $\underline{W}_b$  equal to the local horizontal unit vector  $\underline{V}_1$ .

The CSI solution and out-of-plane velocity will be observed during this maneuver. Also,  $\Delta_6$  will be monitored for indication of CSI convergence. If  $\Delta_6$  remains below 2 fps, convergence should exist.

Case 3.5: CSI Maneuver ( $\underline{W}_b$  specified by  $\underline{U}_1$ ) - This case is identical to Case 3.4 except  $\underline{W}_b$  is specified by the radial unit vector  $\underline{U}_1$ .

Case 3.6: TPI Maneuver With Initial LM State Errors - This case will start 156 sec. prior to the burn. Initial LM state errors in the AGS will be 25,000 ft and 20 fps out of plane and in plane. The TPI maneuver is a 400 lb, + X-axis RCS burn to accomplish a  $\Delta V$  of 22 fps in 18.4 sec. The burn is along a LOS



angle of  $27.3^\circ$  and is controlled by AGS TPI guidance. This maneuver is designed to place the LM on an intercept trajectory with the CSM at  $130^\circ$  central angle of CSM travel from time of ignition. Targeting parameters are

$$6J = 34.47 \text{ min.}$$

$$t_{igC} = 198.6 \text{ min.}$$

After the TPI Maneuver a Rendezvous Radar update will be performed and a Mid-Course Correction determined via the TPI mode. Five radar range measurements will be entered into the AGS at 3 minute intervals and a radar range rate measurement will be entered after the last range entry. Radar bore sight misalignment errors of 20 m rad about the Y-body axis and 10 m rad about the X-body axis will be simulated. The AGS will remain in the TPI Execute Mode and compute the solution for a Mid-Course Correction with the following target parameters:

$$t_{igC} = 218.00 \text{ min.}$$

$$6J = 15.07 \text{ min.}$$

Because of the initial errors in the state of the LM prior to the TPI maneuver, the solution for a Mid-Course Correction should indicate that another burn is required to achieve rendezvous. The accuracy of the solution will depend on the Rendezvous Radar update.

### 3.4 Abort Cases

Case 4.1: TPI Preceded by 15 Min. Solution - This case starts 15 min. prior to the maneuver with DEDA initialization and IMU Align. Targeting parameters are

$$\begin{aligned} t_{igC} &= 198.6 \text{ min.} \\ 6J &= 34.47 \text{ min.} \end{aligned}$$

The TPI solution will be performed continuously up to TPI time. The resulting burn will utilize X-axis RCS thrusting (4 jets) to attain the required  $\Delta V$ .

Case 4.2: TPI with 2 jet, X-Axis Thrust - This case is the same as Case 4.1 but the maneuver is a 2 jet (200 lb), X-axis RCS burn.

Case 4.3: TPI with 2 jet, Z-Axis Thrust - This case is identical to Case 4.2 but the LM is reoriented to perform the burn with a 2 jet RCS thrust along the Z-axis.

Case 4.4: Early Abort - This case starts 60 seconds before the maneuver with Downlink Initialization and IMU Align. The target conditions are

$$\begin{aligned} t_{igC} &= 173.6 \text{ min.} \\ 6J &= 34.47 \text{ min.} \end{aligned}$$

The TPI solution is to begin immediately after IMU Align and will determine if an abort can be made at the specified TPI time. If

an adequate solution is obtained, the corresponding burn will be performed with X-axis RCS thrusting (4 jets) controlled by the AGS TPI guidance mode.

### 3.5 Special Cases

Case 5.1: 1st CDH Solution (Extended) - This case starts 5 min. prior to the 1st CDH burn with DEDA Initialization and IMU Align. Following alignment, the AGS will be placed in the CDH mode and will continuously compute the CDH solution up to burn time. The burn will not be performed. Parameters of the CDH solution will be checked to observe the effect of AGS navigation errors.

Case 5.2: Mid-Course Correction (AGS in Z-Axis Steering) - This case will consist of performing a Z-axis RCS jet burn required to make the Mid-Course Correction indicated in Case 3.6 with AGS in the Z-Axis Steering mode. The problem will be initialized using data from Case 3.6. Target conditions are

$$\begin{aligned} t_{igC} &= 218.00 \text{ min.} \\ 6J &= 15.07 \text{ min.} \end{aligned}$$

The rendezvous state vectors and attitude excursions will be observed.

Case 5.3: Mid-Course Correction (AGS in Attitude Hold) - This case is identical to Case 5.2 except AGS will be in Attitude Hold.

Case 5.4: Inflight Accelerometer Calibration Only - Following Downlink Initialization and IMU Align, the accelerometers will be calibrated using bias errors of 2000, -500, and 200  $\mu\text{g}$ 's for the X, Y and Z accelerometers, respectively. The MODE CONTROL switch

will be set to ATT HOLD and RCS jet firing will be inhibited by setting the three Attitude Control switches to DIR (The Attitude Controller must be left in detent). Prior to calibration the AGS computational inertial reference frame will be aligned to PGNCS with  $\theta_p = \psi_p = \phi_p = 45^\circ$ .

This calibration will last 30 seconds and the accelerometer coefficients 1K19, 1K21 and 1K23 will be observed throughout the period.

Case 5.5: Inflight Accelerometer Calibration Only (RCS not Inhibited) - This case is identical to Case 5.4 with the exception that the RCS jets are not inhibited. It is expected that calibration accuracy will be somewhat degraded as a result.

## LIST OF SYMBOLS &amp; ABBREVIATIONS

<u>Symbol or Abbrev.</u>	<u>Definitions</u>
1J	Desired time of TPI (biased absolute time)
2J	Desired tangent of LOS angle between LM and CSM.
6J	Time duration of transfer from beginning of direct transfer maneuver to rendezvous.
AGS	Abort Guidance System
APS	Ascent Propulsion System
CDH	Constant Delta h
CSI	Coelliptic Sequence Initiate
CSM	Command Service Module
DEDA	Data Entry and Display Assembly
DPS	Descent Propulsion System
h	LM altitude
IMU	Inertial Measuring Unit
LM	Lunar Excursion Module
LOS	Line-of-sight
PGNCS	Primary Guidance, Navigation and Control System
$r_f$	Predicted LM radial velocity after Maneuver
RCS	Reaction Control System
$T_{AO}$	Time from CSI to CDH
$T_c$	Time from CDH to TPI
$t_{igA}$	Time of CSI maneuver (biased absolute time)
$t_{igB}$	Time of CDH maneuver (biased absolute time)

## LIST OF SYMBOLS &amp; ABBREVIATIONS (continued)

<u>Symbol or Abbrev.</u>	<u>Definition</u>
$t_{igC}$	Time of TPI maneuver (biased absolute time)
$T_{\Delta}$	Time increment until TPI
TPI	Terminal Phase Initiate
$\underline{U}_1$	Radial unit vector parallel to CSM orbit plane
$\underline{V}_1$	Horizontal unit vector parallel to CSM orbit plane
$V_G$	Magnitude of LM velocity-to-be-gained
$V_{pO}$	Velocity-to-be-gained in CDH maneuver
$V_O$	Velocity-to-be-gained in CSI maneuver
$V_{yo}$	Present LM out-of-plane velocity
$\underline{W}_b$	Unit vector defining plane used for yaw steering
$\underline{W}_c$	Unit vector normal to CSM orbit plane
$\Delta_6$	Horizontal velocity search increment
$\Delta r$	Differential altitude between coelliptic orbits
$\theta_{LOS}$	Predicted line-of-sight angle at TPI time

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10. Grumman Apollo Operations Handbook (Lunar Module 3), Volume I, dated January 1, 1968.
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12. U. S. Government Memorandum EG26-188-68, "ASA-011 (LM4) Data", dated July 16, 1968.
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APPENDIX

SUMMARY OF AGS VERIFICATION TESTS  
TO BE PERFORMED FOR LM-4/FP4

TEST SUMMARY  
LM-4/FP4

CASE	DESCRIPTION	PROPULSION	$\Delta V$	OBJECTIVE
Detailed Test Objectives				
1.1	AGS Inflight Calibration	---	--	This Case meets the requirements of D.T.O. No. S12.6. (Evaluation of the AGS gyro and accelerometer inflight calibration)
1.2	AGS Control of LM-Active Rendezvous	---	--	This testing meets the requirements of D.T.O. No. M20.48. The objective is to demonstrate AGS control of the LM-Active Rendezvous. The nominal cases listed below satisfy this D.T.O.
Nominal Cases (Mission E)				
2.1	APS Insertion Burn	APS	130 fps	This case will demonstrate AGS' ability to perform the nominal Insertion Burn. Following the maneuver, a CSI solution check will be made.
2.2	CDH Maneuver	APS	74 fps	AGS' control of the CDH maneuver will be exhibited by this case. In addition, the TPI Search Mode will be exercised and the corresponding solution observed.
2.3	TPI Maneuver	RCS (4 jet, X-axis)	22 fps	AGS' control of this maneuver should result in a successful rendezvous. After the TPI maneuver a Rendezvous Radar update will be performed and a solution computed for a Mid-Course Correction. Effects of the TPI burn and Rendezvous Radar update will be evaluated.

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TEST SUMMARY (continued)  
LM-4/FP4

CASE	DESCRIPTION	PROPULSION	$\Delta V$	OBJECTIVE
Off Nominal Cases				
3.1	Insertion Burn	3412 lb APS thrust	130 fps	Case 3.1 and 3.2 represent worst case tolerance conditions ( $\pm 88$ lbs of full thrust) on the APS burn. The resulting effects on orbit parameters and state vectors will be evaluated.
3.2	Insertion Burn	3588 lb APS thrust	130 fps	See Objectives under Case 3.1 above.
3.3	Canted APS Engine	APS	74 fps	This case is identical to Case 2.2 with a $-2.5^\circ$ pitch cant angle. The objective is to determine the effect of using a canted APS with guidance selected for an uncanted engine.
3.4	CSI Maneuver ( $\underline{W}_b$ specified by $\underline{V}_1$ )	RCS (4 jet, X-axis)	--	AGS' ability to remove a $0.1^\circ$ wedge angle with the RCS during a CSI maneuver will be evaluated in this case. In addition, the Yaw Steering option will be exercised by orienting the LM Z-axis parallel to a plane perpendicular to the horizontal unit vector $\underline{V}_1$ .
3.5	CSI Maneuver ( $\underline{W}_b$ specified by $\underline{U}_1$ )	RCS (4 jet, X-axis)	--	This case is identical to Case 3.4 except the Z-axis will be oriented parallel to a plane perpendicular to the radial unit vector $\underline{U}_1$ .

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TEST SUMMARY (continued)  
LM-4/FP4

CASE	DESCRIPTION	PROPULSION	$\Delta V$	OBJECTIVE
Off Nominal Cases (continued)				
3.6	TPI Maneuver with Initial State Errors	RCS (4 jet, X-axis)	22 fps	This case will indicate the effects of initial LM state errors on the Terminal Phase (TPI) maneuver. The subsequent solution for a Mid-Course Correction should reveal that a correction is necessary to achieve rendezvous. A Rendezvous Radar update will be performed during the solution and its effectiveness will be evaluated.
Abort Cases				
4.1	TPI (15 min solution)	RCS (4 jet, X-axis)	--	An abort will be attempted by performing the TPI maneuver at nominal time. The TPI solution will begin 15 minutes prior to the burn and the effects of the resulting navigation errors on rendezvous will be observed.
4.2	TPI (2 jet, X-axis Burn)	RCS (2 jet, X-axis)	--	This case is designed to study the effect of a two jet, X-axis burn on rendezvous accuracy.
4.3	TPI (2 jet, Z-axis Burn)	RCS (2 jet, Z-axis)	--	This case is identical to Case 4.2 except Z-axis RCS thrusting is utilized.
4.4	Early Abort	RCS (4 jet, X-axis)	--	An early abort will be attempted 25 minutes prior to nominal TPI time if the performed solution indicates a rendezvous can be made.

TEST SUMMARY (continued)  
LM-4/FP4

CASE	DESCRIPTION	PROPULSION	$\Delta V$	OBJECTIVE
Special Cases				
5.1	CDH Solution (Extended)	---	--	The parameters of the CDH Solution will be checked to observe the effect of AGS navigation errors.
5.2	Mid-Course Correction (Z-axis Steering)	RCS (2 jet, Z-axis)	--	This case will demonstrate the Mid-Course Correction capability of the AGS. Attitude excursions will be of interest since, during Z-axis steering, AGS guidance does not automatically revert to Attitude Hold as $V_G$ becomes small.
5.3	Mid-Course Correction (Attitude Hold)	RCS (2 jet, Z-axis)	--	During this test AGS will be in Attitude Hold as the correction is made. Results of this case will be compared with those of Case 5.2.
5.4	Inflight Accelerometer Calibration Only	---	--	The accelerometer will be calibrated using 2000, -500 and 200 $\mu g$ 's for X, Y and Z accelerometers. RCS jets will be inhibited.
5.5	Inflight Accelerometer Calibration Only (RCS not inhibited)	---	--	This case is identical to Case 5.4 with the exception that the RCS jets will not be inhibited.