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PRELIMINARY

LM/ABORT GUIDANCE SYSTEM

PERFORMANCE AND INTERFACE SPECIFICATIONS

DOCUMENT

PRELIMINARY

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1.0 SCOPE

The purpose of this specification is to define the interface requirements between the AGS hardware and the AGS software. Functional requirements of the hardware are constraints in the design of the software; therefore, specifications for both may be contained within the same chapter. AGS functional and operational performance requirements and verification requirements are described in this document. Product format is also included for use during Earth Prelaunch Calibration (EPC) and testing with Acceptance Checkout Equipment-Spacecraft (ACE -S/C).

The classified portions, which are integral parts of this specification, are contained in a separate cover, Volume II (Confidential).

NOTE: When volume 2 is referenced, the paragraph numbers will correlate to the LSP-500-1 paragraph numbers by the following table.

<u>LSP-500-1</u> <u>Paragraph</u>	<u>Volume 2</u> <u>Paragraph</u>
3.3	2.0
3.3.1	2.1
3.3.2	2.2
3.3.3	2.3
3.3.4	2.4
3.3.5	2.5
3.3.6	2.6
3.3.7	2.7
3.3.8	2.8
3.3.9	2.9
3.3.17	2.10
3.3.18	2.11
10.4	3.0
10.8	3.1
10.9	3.2
Table IV	Table 1
Table VIII	Table 2
Table IX	Table 3

2.0 APPLICABLE DOCUMENTS

2.1 Precedence of Documents. The order of precedence, in case of conflict, shall be as follows:

<u>Grumman</u>	<u>TRW</u>
(a) Contract NAS 9-1100	(a) Contract NAS 9-9810
(b) Top Specification (LSP-470-1A)	(b) P & I Specification 05952-6206-T000
(c) P & I Specification (LSP-500-1)	
(d) MEI Specification (LSP-470-2A)	
(e) Other Documents Referenced herein	

2.2 Reference Documents. The following documents shall be used for reference purposes only:

<u>Number</u>	<u>Title</u>	<u>Date</u>
LSP-300-3A	Abort Guidance Section Guidance Subsystem, Design Control Specification for	11/19/65
LSP-300-33C	Abort Electronics Assembly - Guidance, Navigation and Control Subsystem, Design Control Specification for	11/16/65
LSP-300-37D	Abort Sensor Assembly Guidance, Navigation and Control Subsystem, Design Control Specification for	11/16/65
LSP-300-39B	Data Entry and Display Assembly Guidance, Navigation and Control Subsystem, Design Control Specification for	11/16/65

(Continued)

<u>Number</u>	<u>Title</u>	<u>Date</u>
552.4	Equation Specification Abort Guidance Section Lunar Module (GAEC Retrieval LSP-1090-78)	6/30/65
9322.2-2- 2340	Logic Description AEA - Computer	
9322.2-2- 2350	Logic Description Data Entry and Display Assembly	
9322.10	LM AGS Interpretive Computer Simulation	
GAEC 5.2 & 5.8 (Library Index) Ref. No. 4.24	NASA/MSC GN&C Data Reference Book	

LM Assembly Program by J. J. Kato, TRW Systems

3.0 INTRODUCTION

The LM Abort Guidance Section (AGS) is a strapped-down inertial navigation and guidance system and consists of the following three assemblies:

- a) Abort Electronics Assembly (AEA)
- b) Data Entry and Display Assembly (DEDA)
- c) Abort Sensor Assembly (ASA)

The AGS is a guidance system which provides attitude reference, navigation, monitoring, and abort guidance for the LM. Its primary purpose is to provide the means whereby the LM can be guided to a safe orbit for eventual rendezvous with the CSM from any point in the lunar landing phase of the Apollo mission in the event a malfunction has occurred in the Primary Guidance Navigation and Control Section (PGNCS).

4.0 AGS Functional Requirements. The AGS is required to provide the following functions.

4.1 Navigation and Guidance. The AGS is required to perform all navigation and explicit guidance and steering functions consistent with the requirements of this specification.

4.1.1 NAVIGATION

While the LM is in flight, the flight program shall maintain an estimate of the current position and velocity of the LM in the inertial coordinate system defined by the attitude reference routine specified in Paragraph 4.4. This navigation function shall be accomplished by integrating the differential equations of motion. The force due to gravity may be assumed to be that of a spherical attracting body. The LM navigation equations

shall accept the processed accelerometer readings specified in Paragraph 6.3.2.1 and transform them from body axis coordinates to inertial coordinates. To reduce errors which may result from residual accelerometer bias and non-translational dynamic effects such as limit-cycling and vibration, the accelerometer data shall not be used in the integration unless the indicated thrust is greater than a prescribed threshold.

The LM navigation equations shall be initialized as specified in Paragraph 4.1.3. The equations shall also provide a capability for accepting processed Rendezvous Radar range and range rate data as specified in Paragraph 6.9. The radar data shall be used to modify the current estimate of LM position and velocity relative to the current estimate of CSM position and velocity as provided by the orbit prediction equations specified in Paragraph 4.1.2. It may be presumed that radar data will not be furnished when the range between the LM and CSM exceeds 100 nmi.

4.1.1.1 LM Navigation Equations Accuracy

LM navigation computation errors are defined to be those errors resulting from the limitations of the integration and coordinate transformation techniques used, from the time lag due to data collection, processing, and computation, from round-off and truncation, and from the deviations in the actual gravity field from the central force field assumed. In the lunar landing mission, for the period from the initiation of powered descent to the completion of orbit insertion after an abort from hover, the maximum navigation computation error accumulated in each component of LM inertial position and velocity shall be as follows:

- 1) 2500 ft. in x , y , and z (inertial position)
- 2) 4 fps in \dot{x} , \dot{y} , and \dot{z} (inertial velocity)

No criteria have been established for navigation accuracy in a flight program scaled for earth missions.

4.1.2 ORBIT PREDICTION EQUATIONS

The flight program shall provide a capability for computing estimates of the position and velocity of a vehicle in a free fall orbit about a spherical attracting body using analytical elliptical orbit propagation equations. The position and velocity estimates shall be computed in the inertial reference frame. The equations shall be used to provide estimates of CSM position and velocity at whatever time these may be required by any function of the flight program. The orbit prediction equations shall also be used to initialize the LM navigation equations as specified in Paragraph 4.1.3 and to provide estimates of LM position and velocity at times other than current time.

4.1.3 Navigation Initialization. Provide the necessary processing of the PGNCS downlink data to extract LM and CSM position, velocity and their associate time of computation. This information will be used to initialize or update the AGS navigation computations upon command from the DEDA during non-powered flight phases of the mission. LM and CSM initialization or updating capability is also to be provided by means of inserting the data directly via the DEDA (see Para. 7.2.17, 7.3.1.4.3, & 7.3.2.1.1).

The flight program, upon receipt of an appropriate command via DEDA, shall accept navigation initialization data either from the Downlink Telemetry Register (see Paragraph 6.4.2) or from those DEDA accessible memory locations where the data will have been previously stored for this purpose. For each vehicle, the LM and the CSM, a navigation initialization state vector will consist of three cartesian components of position, three cartesian components of velocity, and the epoch of this data in AGS absolute time (see Paragraph 4.3).

The following assumptions may be made regarding the navigation initialization data furnished:

- 1) The components of position and velocity will be in that inertial reference frame which will be in use during the period for which the data was furnished.
- 2) The epoch of CSM navigation initialization data will be:
 - a) Earlier than current time
 - b) No more than 8191 sec earlier than current time
 - c) Subsequent to the most recent CSM powered maneuver
- 3) When furnished in flight, the epoch of LM navigation initialization data will be:
 - a) Within \pm 8191 sec of current time
 - b) Subsequent to the most recent LM powered maneuver
- 4) When furnished on the lunar surface, the epoch of the LM navigation initialization data will be:
 - a) No more than 8191 sec in advance of current time

- b) Within 10 min of the actual time of lift-off
- c) Presumed to be the minimal lift-off time.

The navigation initialization equations shall decode and scale the input data as required. The GCM state vector furnished shall be stored to serve as the initial point for use by the orbit prediction equations specified in Paragraph 4.1.2. If the navigation initialization is performed in flight, the orbit prediction equations shall be used to propagate the LM initialization data to current time. The existing position and velocity components maintained by the LM navigation equations shall then be replaced by the new ones. A special sub-routine shall be provided for navigation initialization on the lunar surface. This sub-routine shall be provided for navigation equations at lift-off based on the assumption that, prior to lift-off, the LM is traveling in inertial space at a constant velocity equal to that furnished in the input data on a trajectory which passes through the position given in that data at the nominal lift-off time.

4.1.4 SCALING OF NAVIGATION QUANTITIES

The flight program shall be scaled so as to provide the following ranges for the magnitude of navigation quantities:

	<u>Earth Scaled Program</u>	<u>Lunar Scaled Program</u>
Position quantities	2^{25} ft	2^{23} ft
Velocity quantities	2^{15} fps	2^{13} fps

Provision shall be made for the entry of navigation initialization data via the DEDA in decimal. The quantization of the least significant decimal digit entered shall be as follows:

	<u>Earth Scaled Program</u>	<u>Lunar Scaled Program</u>
Position quantities	1000 ft	100 ft
Velocity quantities	1 fps	0.1 fps
Time quantities	0.1 min	0.1 min

4.2 MODING

Provide mode and submode selection by utilizing DEDA inputs, Control Electronics Section inputs and AGS mode switch inputs.

4.3 Time Initialization. Absolute time shall be initialized through the DEDA, and shall be the difference in current mission time and a known time bias constant. Current mission time is denoted by G. E. T. (ground elapsed time from earth liftoff), which is the difference in current Greenwich Mean Time (GMT) and the GMT at lift-off. Thus, the AGS absolute time is GET-K, where K is the time bias constant.

The flight program shall maintain a clock for use by the guidance and navigation computations. The time indicated by the clock is AGS absolute time. The range of AGS absolute time shall be 0 to 4396 minutes.

AGS absolute time shall be initialized by synchronizing the clock to an external reference through the use of the DEDA. The initial time entered shall be an exact multiple of 0.1 minute. The clock will be initialized each time the AGS is put into the OPERATE condition.

4.4 ATTITUDE REFERENCE

The flight program shall maintain an inertial attitude reference in the form of a 3 x 3 orthonormal transformation matrix, $[A]$ of Para. 6.7.3, to define the orientation of the LM body axes (ASA reference axes) with respect to an inertial coordinate frame. The transformation relation is given by:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = [A] \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

The LM body axis coordinate frame, X, Y, Z, is defined in Paragraph 6.3.1.1. The inertial coordinate frame, x, y, z, shall be established by alignment as specified in Paragraph 5.2.1.

The measurements of vehicle rotation, the processed gyro data specified in Paragraph 6.3.2.2, shall be used by the attitude reference routine to update the direction cosines which are the elements of $[A]$. The contribution of the computation alone to the attitude reference drift rate shall not exceed 0.2 deg/hr at any vehicle attitude for vehicle rotation rates up to 5 deg/sec or 0.3 deg/hr for vehicle rotation rates up to 25 deg/sec.

The primary functions of the attitude reference routine

are:

- 1) Provide a means to transform the processed accelerometer data specified in Paragraph 6.3.2.1 into the inertial reference frame in which the navigation and guidance computations will be made
- 2) Provide a means for transforming the results of the guidance computations into steering commands in the form of attitude error signals as specified in Paragraph 6.7.2
- 3) Provide a source of data for the Total Attitude Display Signals specified in Paragraph 6.7.3

4.5 Telemetry Downlink. Provide the capability of outputting digital data via the telemetry data output channel. (see Para. 6.4.2; 6.5 & 7.1.3.5.5)

4.6 Monitoring. Provide the capability of furnishing output analog signals to the instrumentation subsystem to verify AGS performance.

4.7 Acquisition. Provide the capability of orienting the LM Z-axis toward the CSM and of accepting range and angle null data via the DEDA and using this data for midcourse correction computations. The radar data inputs will have accuracies which are consistent with the end point criteria specified in 6.9 and 7.2.9. this Vol. and Par. 1.1 of Vol. 2.

4.8 Sensor Calibration and Compensation.

4.8.1 Calibration. The AGS shall have the capability to calibrate (measure) ASA gyro channel bias (non-acceleration sensitive) drift rate and accelerometer channel bias error under the following mission phase conditions:

- (a) Gyro Channel bias drift rate
 - (1) During pre-launch checkout
 - (2) During coast flight (lunar orbit)
 - (3) On the lunar surface
- (b) Accelerometer channel bias: during coast flight
(see also Para. 6.3.2, 7.1.1, and 7.2.14)

4.8.2 Compensation. The AGS shall have the capability to compensate for the following ASA sensor errors:

- (a) Gyro channel non-acceleration sensitive drift rate
- (b) X-gyro channel spin axis mass unbalance drift rate
- (c) Gyro channel scale factor error
- (d) Accelerometer channel bias error
- (e) Accelerometer channel scale factor error
(see also para. 6.3.2, 7.1.1, and 7.2.14)

4.8.3 Error Values. The AGS shall meet the requirements of this specification if the values of the errors in 4.8.2 (a), (c), (d) and (e) are determined at the times specified below.

- (a) Gyro channel bias drift rate determined during pre-launch checkout is no more than 8 days prior to LM/CSM docking.

- (b) Accelerometer channel scale factor errors and accelerometer channel bias error determined just prior to installation of the ASA in LM, no more than 120 days prior to LM/CSM docking.

4.9 In-Flight Self Test. The requirements for the self test are that it provide a comprehensive in-flight check of the system logic and memory, and that it automatically display information identifying failures and their origin to the maximum extent possible. The self test shall have a minimum of 190 AEA instructions and shall consist of the following automatic continuous tests:

- (a) Instruction test
- (b) Memory Sum Check
- (c) Results display (when requested by astronaut)

The test will stop and the AEA will provide a warning signal if a failure occurs. The astronaut may re-initiate the test by command through the DEDA.

4.10 DMC Program. The requirements of the DMC Program are that it provides the capabilities of:

- (a) Aligning the AGS to a selected inertial coordinate system.
- (b) Calibrating and compensating the gyro and accelerometers
- (c) Initializing the LM and CSM state vectors
- (d) Navigation - Updating of LM and CSM state vectors
- (e) Providing monitoring data to displays and ground channels

- (f) Solving the Abort Guidance Equations according to the Coelliptic Flight Plan defined in paragraph 4.10.1

4.10.1 Coelliptic Flight Plan Requirements. The AGS shall be programmed to perform the following during the LM mission. Provide guidance functions (equations) which will result in a LM-CSM rendezvous from any point in the LM mission in accordance with the Coelliptic Flight Plan (CFP), which imposes the following general conditions:

- (a) For aborts prior to powered descent, a direct intercept transfer or a coelliptic orbit sequence capability shall be provided, as described below.
- (b) For aborts subsequent to the start of powered descent, and prior to the end of powered ascent, the AGS shall have the capability of inserting the LM initially into an elliptical orbit. After insertion into the elliptical orbit, a series of coelliptic rendezvous burns shall be performed as described below resulting in an intercept trajectory passing through the CSM. The AGS will perform midcourse corrections based upon Rendezvous Radar (RR) navigation update as specified in paragraphs 6.9; 7.2.9; and 7.3.2.2.6 and/or CSM/MSFN update as specified in 7.2.17.2.4.
- (c) For aborts after the end of powered ascent, the AGS shall either complete the unfinished coelliptic rendezvous burns or perform a direct transfer intercept burn, as described below.

4.10.1.1 Guidance Routines. The DMC Program shall contain the following routines:

- (a) Orbit Insertion
- (b) External ΔV
- (c) Coelliptic Rendezvous - This routine is divided into steps given in Para. 4.10.1.1.2

- (1) Coelliptic Sequence Initiate Burn (CSI):
Horizontal
- (2) Constant Delta H Burn (CDH)
- (d) Direct Intercept: Used for TPI, MCC and direct intercept elsewhere in the mission at the crew's option.

The flight program shall, at all times, compute a guidance solution using one of the routines specified in this section. The particular guidance routine in use shall be determined by the manual setting of a six-state logic switch, termed the Guidance Routine Selector, located in the DEDA accessible portion of the AEA memory. The six selections shall correspond to the following:

<u>Guidance Routine Selector State</u>	<u>Guidance Routine</u>
0	Orbit Insertion
1	CSI
2	CDH
3	TPI - TPI Search Option
4	TPI - TPI Execute Option
5	External Delta V

On the lunar mission, attitude error signals shall be computed to maintain the thrust axis along the vertical when the LM altitude is less than 25,000 ft and the altitude rate is less than 50 fps when the Orbit Insertion, CSI, or CDH Routines have been selected.

4.10.1.1.1 ORBIT INSERTION ROUTINE

The Orbit Insertion Routine shall be designed to continuously compute attitude error signals and that required incremental velocity which will cause a nominal powered flight maneuver to result in the achievement of certain target conditions at engine cutoff. The orbit insertion conditions to be targeted are as follows:

- 1) Altitude above the radius of the attracting body
- 2) Magnitude of the horizontal component of inertial velocity
- 3) Radial velocity

These target parameters shall be located in the DEDA accessible portion of the AEA memory. Their nominal values shall be determined and incorporated in the program prior to launch.

The Orbit Insertion Routine shall provide a capability for altering the target conditions when it is determined that the predicted insertion altitude falls below a prescribed threshold. The new target conditions shall be computed to ensure that the LM is placed on a rising trajectory at engine cutoff.

The Orbit Insertion Routine shall also provide for steering the LM toward the CSM orbit plane to reduce or eliminate wedge angle between the resulting LM and CSM orbit planes. The extent to which out-of-plane error is removed shall be determined by DEDA accessible constants. A capability for

removing up to 2 degrees of wedge angle shall be provided for the case of abort from the lunar surface.

4.10.1.1.2 COELLIPTIC FLIGHT PLAN RENDEZVOUS GUIDANCE

Two orbits are defined to be coelliptic when their principal foci are coincident and when the product of the length of the semi-major axis and eccentricity of each orbit are equal. The definition also implies that when the two orbits are co-planar, they have coincident centers and vacant foci. For the purpose of designing the guidance routines, deviations from co-planarity may be assumed to be small. Coelliptic orbits will have an essentially constant differential altitude (constant Δh).

The flight program shall contain a set of guidance routines designed to calculate the powered maneuvers required for the LM to execute a coelliptic flight plan for rendezvous with the CSM. This flight plan nominally calls for three powered maneuvers:

- 1) CSI (coelliptic sequence initiate) maneuver
- 2) CDH (constant Δh) maneuver
- 3) TPI (terminal phase initiate) maneuver

The guidance routines specified below are labeled to correspond to the maneuvers they will be designed to compute and control.

In the nominal coelliptic flight plan, the LM shall be placed in an orbit coelliptic with that of the CSM by first executing the CSI maneuver and then the CDH maneuver. In both of these maneuvers, the horizontal component of thrust shall be maintained parallel to the estimated CSM orbit plane. The CSI and CDH Routines discussed below shall be designed to compute and control these maneuvers as described. However, an additional capability shall be provided for removing out-of-plane velocity in the CSI and CDH maneuvers by using the External Delta V Routine for control. To enable this, the required incremental velocities computed by both the CSI and CDH routines shall be automatically furnished to the External Delta V Routine to target, in advance, the in-plane components of the burn.

The final maneuver of the coelliptic flight plan sequence is the TPI maneuver, nominally a burn which shall place the LM on a direct intercept trajectory with the CSM, initiated when the angle of the LM-CSM line-of-sight with respect to the local horizontal is at a preferred value. The TPI Routine, designed to compute and control this maneuver, may also be used for implementing subsequent mid-course correction maneuvers.

4.10.1.1.3 CSI Routine

The CSI routine shall provide a capability for computing that horizontal velocity increment, parallel to the CSM orbit

plane, which will be required to satisfy the following target conditions input via the DEDA.

- 1) Desired AGS absolute time of execution of the CSI maneuver
- 2) Desired AGS absolute time of execution of the TPI maneuver
- 3) Tangent of the desired angle of the LM-CSM line-of-sight with respect to the local horizontal at the desired time of execution of the TPI maneuver
- 4) Codes designating the desired location of the CDH maneuver.

The CDH maneuver will nominally be designated to be performed at the first, second, or third crossing by the LM of the line of apsides of the post-CSI orbit. Alternatively, if the pre-CSI orbit is circular, or nearly so, or if the CSI maneuver is to occur in close proximity to the pericenter or apocenter of the orbit, then the designated location of the CDH maneuver shall be 180, 360, or 540 degrees from the point at which the CSI maneuver is to occur.

The CSI routine shall compute that incremental velocity required from the CSI burn and from the CDH burn and that AGS absolute time of the CDH burn which results in a minimal deviation of the predicted LM-CSM line-of-sight angle from the desired angle at the desired time of the TPI maneuver.

The computed incremental velocities, AGS absolute time of the CDH maneuver, and the predicted differential altitude between the LM and CSM orbits at the completion of the CDH maneuver shall be made available for display via the DEDA along with such other parameters as may be useful in evaluating the result.

The CSI Routine shall continuously compute the attitude error signals necessary to maintain the thrust axis in the horizontal plane parallel to the estimated CSM orbit plane both prior to and during a burn. Prior to the targeted execution time, the computation of the required velocity increment shall be based on the predicted positions and velocities at that time. From the targeted execution time forward, current estimates of position and velocity shall be used.

4.10.1.1.4 CDH Routine

The CDH Routine shall compute the incremental velocity required to make the LM orbit coelliptic with the CSM orbit. The computations shall use the maneuver execution time previously computed by the CSI Routine or a substituted value entered via the DEDA.

Prior to the designated maneuver execution time, the required velocity increment computed shall be based on the predicted positions and velocities of the LM and CSM at that time. The attitude error signals shall orient the thrust axis at that angle with respect to the current horizontal which is equal to the same angle predicted to be required at the designated execution time. Orbital rate torquing shall result.

From the designated execution time forward, current estimates of position and velocity shall be used to compute the required incremental velocity and those attitude error signals which will

orient the thrust axis in the corresponding direction.

4.10.1.1.5 TPI Routine

The TPI Routine shall calculate the velocity increment required to place the LM on a direct intercept transfer trajectory based upon a specified time interval for the transfer, input via the DEDA, and a designated time for the initiation of the transfer. This routine shall be used in two alternative options as determined by appropriate setting of the Guidance Routine Selector, the TPI Search option and the TPI Execute option.

The TPI Search option shall be used for pre-thrusting calculations only. In this option, the routine shall continuously solve for that intercept trajectory which is initiated at a fixed time increment in advance of current time. The time increment will be input via the DEDA.

The TPI Execute option shall be used prior to and during a maneuver. In this option the designated transfer initiation time shall remain fixed. This fixed absolute time shall be either that which corresponded to the transfer initiation time at switchover from the TPI Search option to the TPI Execute option or a new time input subsequently via the DEDA.

A capability shall be provided for modifying the velocity increment computed by the routine so that the transfer orbit produced will intersect the CSM orbit at some selected distance from the CSM. This shall result from a DEDA input which

displaces the estimate of CSM position. The input will be the time, in minutes to the nearest 0.01 minute, required for the CSM to traverse the desired displacement.

An additional capability shall be provided which will produce a maneuver similar to the nominal direct transfer. However, the direction of the burn and the plane of the transfer orbit shall be rotated so that the LM will intersect the CSM orbit plane at a specified time prior to the time at which rendezvous would have otherwise taken place. The specified time shall be entered via the DEDA in minutes to the nearest 0.01 minute. The altitude at which the LM will intersect the CSM orbit plane shall be the same as though the nominal maneuver were computed.

Prior to the designated transfer initiation time, using the TPI Execute option, the required velocity increment computed shall be based on the predicted positions and velocities of the LM and CSM at that time. The attitude error signals shall orient the thrust axis along that vector and maintain that attitude with respect to the inertial reference frame.

From the designated transfer initiation time forward, current estimates of position and velocity shall be used for the computation.

The TPI Routine shall not be required to compute transfer trajectories which result in intercept with the CSM more than 2^{13} seconds in the future. Also, it may be presumed that the specified time interval for the transfer will not be chosen to produce solutions in which the central angle traversed by the LM between the transfer initiation time and the nominal rendezvous time is close to 0 degrees, 180

degrees, or any multiple of 180 degrees. For earth missions, the central angle traversed shall not lie within ± 20 degrees of these singularity regions. For lunar missions, the central angle traversed shall not lie within ± 10 degrees of the singularity regions.

For any period in which the TPI Routine is to be utilized, it may be presumed that the angular displacement of the x-z plane of the inertial reference frame with respect to the CSM orbit plane will not exceed 80 degrees.

4.10.1.1.6 EXTERNAL DELTA V ROUTINE

The External Delta V Routine shall be designed to accept the three components of a desired incremental velocity vector defined in the following way:

- 1) Delta V_1 is in the local horizontal plane, positive in the direction of motion and parallel to the CSM orbit plane
- 2) Delta V_2 is perpendicular to the CSM orbit plane, positive in the direction opposite to the CSM angular momentum vector
- 3) Delta V_3 is along the local vertical, positive downward toward the center of attraction.

All three components may be furnished via the DEDA but a capability shall also exist to accept the components Delta V_1 and Delta V_3 from either the CSI Routine or the CDH Routine where they will be computed for this purpose.

Prior to the time ullage is sensed, the External Delta V Routine shall compute attitude error signals to maintain the

thrust axis along the vector resultant of the components in real time. That is, the thrust axis will be continuously reoriented with respect to the inertial reference frame so that the definition of the incremental velocity vector as given above remains current. At the time ullage is first sensed, the required incremental velocity shall be fixed in the inertial frame. The External Delta V Routine shall then compute attitude error signals and the value of the remaining velocity-to-be-gained during the maneuver so that the fixed required velocity increment is implemented.

4.10.1.2 Residual Trimming Capability. At termination of AGS controlled maneuvers utilizing a main engine, the AGS shall be implemented (upon astronaut request) to null out individual body axis components of velocity to be gained (see procedures).

NOTE: For the programs specified above, all burns resulting in a delta V of less than 60 fps; shall be performed with the RCS. For velocity changes greater than 60 fps and less than 200 fps, either the main engine or the RCS shall be used at the crew option. For velocity changes greater than 200 fps, the main engine shall be used, and also for the CSI and CDH burns (specified above) the steering shall be such that thrusting is parallel to the CSM and the TPI burn steering shall remove all residual out-of-phase conditions.

5.0 AGS Operational Requirements. Selection of AGS operation shall be performed via the AGS mode switch, the DEDA, and descretes from the CES. These AGS operations are described below.

5.1 AGS Operational Conditions. The AGS shall be placed in any one of the following conditions:

5.1.1 Unpowered Condition. The AGS will be in this condition when AGS is unpowered as determined by circuit breakers on the circuit breaker panel. The circuit breaker panel is not part of the AGS. This condition is used in the event of an AGS failure.

5.1.2 OFF Condition. Iniation of the OFF Condition shall occur only upon application of both the following signals:

- (a) 28 volts DC
- (b) External Warm-up signal

During OFF Condition, the ASA shall utilize 28 VDC excitation for the temperature control circuitry.

5.1.3 Standby/Operate Condition. The Standby/Operate Condition shall be initiated when all of the following conditions occur:

- (a) 28 volts DC is present
- (b) The Warm-up signal is absent
- (c) The Clock Signal is present.

5.1.3.1 Standby/Operate Condition Operational Constraints.

During the Standby/Operate Condition, the ASA shall provide the following:

- (a) Excitation and power for all subassemblies within the ASA.
- (b) Degraded operation after a ten minute period. All of the period may be spent in Standby/Operate, or part of it may be spent in OFF and part in Standby/Operate; however, at least the last five minutes of the ten minute period shall be spent in Standby/Operate. During this degraded operation;
 - (1) The ASA drift rate shall not exceed 6.0 degrees per hour per axis.
 - (2) The gyro scale factor error shall not exceed 1.0 percent.
 - (3) The accelerometer bias error shall not exceed $8 \times 10^{-4}g$.
 - (4) The accelerometer scale factor shall not exceed 1.0 percent.
- (c) Complete operational capability after a 40 minute period. All of the period may be spent in Standby/Operate, or part of it may be spent in OFF and part in Standby/Operate; however, at least the last 25 minutes of the 40 minute period shall be spent in Standby/Operate. If 25 minutes or more are spent in OFF, an additional 25 minutes shall be spent in Standby/Operate before complete operational capability is obtained.

5.1.3.2 Standby. The ASA is fully powered. In addition, the capability shall be provided in the AEA to accept PGNCs alignment information twenty (20) seconds after entering the STANDBY condition. This information shall include the $\pm \theta$, $\pm \phi$ and $\pm \psi$ and the "CDU Zero" signals.

5.1.3.3 Operate. In this condition the three assemblies (AEA, ASA, DEDA) must be functioning, inputting, and outputting such information as is needed to properly execute the Flight Programs under one of the submodes defined in 5.2.

5.2 PROGRAM MODES AND SUBMODES

The operating modes of the flight program shall be designated as follows:

- (1) Inertial Reference Mode
- (2) Alignment and Calibration Mode

When the flight program is in the Inertial Reference Mode, it shall be in one of the following submodes:

- (1) Attitude Hold Submode
- (2) Guidance Steering Submode
- (3) Z Body Axis Steering Submode

When the flight program is in the Alignment and Calibration Mode, it shall be in one of the following submodes:

- (1) PGNCs to AGS Alignment Submode
- (2) Lunar Alignment Submode
- (3) Body Axis Alignment Submode
- (4) Gyro and Accelerometer Calibration Submode
- (5) Accelerometer Calibration Only Submode

The Particular submode in which the flight program shall be operating shall be determined by the setting of a single eight-state logic switch, termed the AGS Submode Selector, which shall be located in the DEDA accessible portion of the AEA memory. The program shall execute the selection logic every 40 ms to determine the appropriate submode of operation.

5.2.1 INERTIAL REFERENCE FRAMES

There are many possible inertial reference frames which may be established during a mission. Since the preferred method of alignment is the PGNCS to AGS Alignment specified in Paragraph 5.23.1.1, the inertial reference frames established for given periods may be expected to correspond to the orientations established for the IMU stable member. For all of these frames, the origin is at the center of the attracting body.

5.2.1.1 Preferred Alignment

For certain thrusting maneuvers, the x inertial axis will be established to be parallel to the desired thrusting direction at the instant of ignition as determined by the PGNCS. The y inertial axis will be determined by forming the vector product of the desired thrusting direction and the position vector. The z inertial axis will complete the right-handed orthogonal triad.

5.2.1.2 Nominal Alignment

The nominal alignment for orbital operations will establish the x inertial axis to be along the position vector at a given instant, positive outward from the center of the attracting body. The inertial y axis will lie along the LM orbit angular momentum vector, positive in the direction opposite to the

momentum. The inertial z axis will complete the right-handed orthogonal triad.

5.2.13 Lunar Landing and Launch Alignment

For the lunar landing mission, the x inertial axis will be established to be along the designated landing site position vector at the nominal landing time, positive outward from the lunar center. The vector product of the CSM orbit angular momentum vector and the x inertial axis will define the z inertial axis. The y inertial axis will complete the right-hand orthogonal triad.

After landing and re-alignment, the inertial reference frame will be similar to that given above except that the x inertial axis will be defined to pass through the actual landing site at the nominal time of launch.

5.2.2 Inertial Reference Mode

5.2.2.1 Attitude Hold Submode

When the flight program is in the Attitude Hold Submode, attitude error signals shall be computed which, if used to control the vehicle, shall maintain the attitude constant with respect to the inertial reference frame. The attitude maintained shall be that which existed at the time of entry into this submode.

5.2.2.2 Guidance Steering Submode

When the flight program is in the Guidance Steering Submode, attitude error signals shall be computed which, if used to control the vehicle, shall orient the thrust axis in the direction of the desired incremental velocity computed by the particular guidance routine currently in use. An operator option shall be provided to orient the LM Z body axis either parallel to the CSM orbit plane or parallel to an arbitrary plane specified by the components of a unit vector normal to that plane input via the DEDA.

For the purposes of this submode, the thrust axis is defined to be the X body axis when either the descent engine or the reaction control system is to be used to produce a powered maneuver. When the ascent engine is to be used, the thrust axis assumed for computing attitude error signals shall be offset from the X body axis by a cant angle

determined from program constants. A DEDA accessible logic switch shall be provided to control the use of the cant angle offset. Whether or not the switch is set manually, it shall be set automatically when the Ascent Engine On Discrete is sensed and reset when Engine OFF is commanded at the completion of the maneuver.

5.2.2.3 Z Body Axis Steering Submode

When the flight program is in the Z Body Axis steering Submode, attitude error signals shall be computed in accordance with one of two options which shall be selected by a code entered via the DEDA. The attitude error signals, if used to control the vehicle, shall orient the Z body axis either along the estimated line-of-sight to the CSM or in the direction of the desired incremental velocity computed by the particular guidance routine currently in use.

5.2.3 Alignment and Calibration Mode

When the flight program is in any submode of the Alignment and Calibration Mode, the attitude error signals shall be set to zero and only Engine OFF commands shall be issued.

5.2.3.1 ALIGNMENT Mode. During this mode of operation, the AGS shall be capable of aligning to any inertial reference frame

as determined by the alignment submode scheme selected via the DEDA. Entry into the ALIGNMENT mode shall always be made by inserting one of the following submode instructions.

- (a) PGNCNS to AGS ALIGN Submode
- (b) LUNAR ALIGN Submode
- (c) BODY AXIS ALIGN Submode

The AGS shall have the capability to initialize the navigation computation during the ALIGNMENT mode. The AGS shall cause the attitude error signals to the CES to be reduced to zero during the ALIGNMENT mode. On exit from one of the ALIGNMENT Submodes and entry into the INERTIAL REFERENCE mode, the AGS shall be capable of performing all the abort guidance functions required by this specification within 2 seconds.

The flight program shall provide a capability for attitude reference alignment by initializing the direction cosines of the transformation matrix $[A]$ of Para. 6.7.3 upon command via the DEDA. The preferred and nominal result of alignment will be the setting of the values of the direction cosines so that the inertial reference frame established is the appropriate one of those described in Paragraph 5.2.1.

Misalignment error exists when the inertial reference frame established by an alignment procedure and maintained by the attitude reference equations through the use of processed gyro data differs from the inertial reference frame which was intended to be established.

5.2.3.1.1 PGNCS to AGS Alignment

When a PGNCS to AGS Alignment is commanded, the flight program shall input the data contained in the IMU gimbal angle registers as described in Paragraph 6.4.1. The data shall be used to compute the elements of an attitude reference transformation matrix according to the relations shown for the matrix $[B]$ in that paragraph. The direction cosines thus computed shall then be corrected for the pre-flight measured misalignment between the IMU and ASA reference axes. After such correction, the direction cosines shall be used as the corresponding elements of $[A]$. The time required to complete a PGNCS to AGS Alignment shall not exceed 6 seconds, which includes DEDA delay and the delay due to PGNCS/AGS misalignment correction. Exit from this alignment shall be automatic.

The inertial reference frame established in this manner will be nominally the same as the IMU stable member coordinate frame. It may be presumed that a PGNCS to AGS Alignment will never be commanded within 20 seconds of the time when the PGNCS has transmitted a CDU Zero Signal. See Paragraph 6.4.1.

5.2.3.1.2 Lunar Surface Alignment

The purpose of a Lunar Surface Alignment is to establish the post-landing inertial reference frame of Paragraph 5.2.1.3 without using the IMU gimbal angle data.

The flight program shall provide a capability for storing the direction cosines of the pre-landing z inertial axis shortly after lunar touchdown upon an appropriate command via the DEDA. A capability shall also be provided for storing data, input via the DEDA, which will be furnished for the purpose of modifying the z inertial axis direction cosines to produce the post-landing inertial frame of Paragraph 5.2.1.3 by correcting for the effects of lunar rotation during the dwell period, changes in the CSM orbit plane, and any changes in the LM attitude due to settling and shifting.

When a Lunar Surface Alignment is commanded, the z inertial axis direction cosines shall be corrected by using the data entered for that purpose and the x inertial axis shall be established to be along the local vertical through the use

of processed data from the ASA Y and Z accelerometers. See Paragraph 6.3.2.1. The time required for Lunar Surface Alignment shall not exceed three minutes. The alignment shall be terminated via a DEDA command.

For the purpose of designing and evaluating the Lunar Surface Alignment routine, the following assumptions may be made.

- 1) An in-flight accelerometer calibration was performed prior to landing
- 2) The inclination of the X body axis did not exceed 30 degrees from the local vertical
- 3) The alignment continued for at least three minutes and was terminated within 4 minutes of the nominal lift-off time but prior to the actual lift-off.

5.2.3.1.3 Body Axis Alignment

When a Body Axis Alignment is commanded, the flight program shall set and maintain the transformation matrix $[A]$ to be an identity matrix until the alignment is terminated by another command via the DEDA. The inertial reference thus established will correspond to the orientation of the LM body axes at the instant that Body Axis Alignment is terminated. The use of data external to the AGS and externally controlled maneuvers will be necessary to establish the preferred inertial reference frames of Paragraph 5.2.1. During this submode, the vehicle will be restricted to:

- (a) Vehicle limit cycling as given in Table I, Vol. 2.
- (b) Vehicle slewing rates up to 2 deg/sec.

5.2.3.2 Calibration Mode

5.2.3.2.1 Gyro and Accelerometer Calibration Submode

When the flight program is in the Gyro and Accelerometer Calibration Submode, an in-flight calibration as specified in Paragraph 6.3.2.2.3 and an in-flight accelerometer calibration as specified in Paragraph 6.3.2.1.3 shall be implemented provided the LM is not resting on the lunar surface. On the lunar surface, a lunar surface gyro calibration only shall be implemented as specified in Paragraph 6.3.2.2.4. When the calibration is completed, the program shall be automatically switched to the Attitude Hold Submode.

5.2.3.2.2 Accelerometer Calibration Only Submode

When the flight program is in the Accelerometer Calibration Only Submode, an in-flight accelerometer calibration shall be implemented as specified in Paragraph 6.3.2.1.3. When the calibration is completed, the program shall be automatically switched to the Attitude Hold Submode.

5.2.4 SYSTEM OPERATING STATES

The flight program and the AGS generally shall be considered to have three operating states.

- (1) Follow-Up State
- (2) Attitude Control State
- (3) Complete Control State

The state in which the system is operating shall be determined by the six hardwired control discrettes listed in Paragraph 6.6.

5.2.4.1 Follow-up State

The flight program and the AGS shall be in the Follow-up State when the Follow-up Discrete is present. If the Automatic Discrete is present, the attitude error signals computed in accordance with the particular submode in which the program is operating will be output. If the Automatic Discrete is absent, attitude error signals shall be set to zero.

When the system is in the Follow-Up State, the program shall issue an Engine ON command every 40 ms provided the program is in the Inertial Reference Mode and either the Descent Engine On Discrete or Ascent Engine On Discrete is present. Otherwise, the flight program shall issue an Engine OFF command every 40 ms.

5.2.4.2 Attitude Control State

The flight program and the AGS shall be in the Attitude Control State when the Follow-up Discrete, the Abort Discrete, and the Abort Stage Discrete are all absent. In this state, attitude error signals computed in accordance with the particular submode in which the program is operating will be output. If the Automatic Discrete is absent, the program shall be in the Attitude Hold Submode. If the Automatic Discrete is present any submode is permissible.

When the system is in the Attitude Control State, the program shall issue an Engine ON command every 40 ms provided the program is in the Inertial Reference Mode and either the Descent Engine On Discrete or Ascent Engine ON Discrete is present. Otherwise, the flight program shall issue an Engine OFF command every 40 ms.

5.2.4.3 Complete Control State

The flight program and the AGS shall be in the Complete Control State when the Follow-Up Discrete is absent and either the Abort Discrete or the Abort Stage Discrete is present. In this state, attitude error signals computed in accordance with the particular submode in which the program is operating will be output. If the Automatic Discrete is absent, the program shall be in the Attitude Hold Submode. If the Automatic Discrete is present any submode is permissible with two exceptions.

- (1) The program shall be held in the Attitude Hold Submode when the Abort Stage Discrete is present from the time the Ascent Engine On Discrete is first received until a preselected time thereafter. The preselected time shall have, as a minimum, a range of 0 to 10 seconds.
- (2) At the completion of a maneuver when Engine OFF is commanded because the conditions for issuing Engine On commands, as listed below, are no longer satisfied, the program shall automatically be returned to the Attitude Hold Submode.

When the system is in the Complete Control State, the program shall issue an Engine ON command every 40 ms when all of the following four conditions are simultaneously satisfied.

- (1) The Automatic Discrete is present
- (2) The AGS Submode Selector has been manually set to Guidance Steering via the DEDA
- (3) Either the ullage condition has been satisfied or the Ascent Engine has been ignited while the LM is on the lunar surface

- (4) Either the magnitude of velocity-to-be-gained exceeds a specified threshold or the projection of the velocity-to-be-gained on the X body axis is in the + X body axis direction and exceeds the nominal ascent engine cutoff velocity impulse.

Otherwise, the flight program shall issue an Engine OFF command every 40 ms.

The ullage condition will be satisfied when the accumulated sensed velocity increments along the X body axis have exceeded a specified threshold in each consecutive two-second computation cycle for a prescribed number of cycles. The ullage condition shall be reset and the count restarted if the accumulated sensed velocity increment along the X body axis falls below the specified threshold in any one two-second computation cycle.

5.2.5 AGS Operation in Each Submode. The operations performed by the AGS in each of the submodes are given in Table IV.

The operations performed in a submode can be classified as those which are always performed in the submode and those which are performed on command via the DEDA. The former are identified by a "1" and the latter by a "2" in Table IV. The exceptions to this are that when LM and CSM initialization via the downlink or LM initialization via the DEDA are commanded, CSM Navigation, and the Guidance computation are not performed. In the Calibration mode, commanded via the DEDA, the AGS performs Inflight Gyro Drift Calibration, PGNCS to AGS Align and Inflight Accelerometer Bias Calibration, and the additional operations indicated in Table IV when LM is in coasting flight. When on the lunar surface, as indicated by the lunar surface signal (an internal flag set when Store Lunar Azimuth is commanded at lunar touchdown), the AGS performs Lunar Surface Gyro Drift Calibration and the additional operations indicated in Table IV.

5.2.6 Earth Prelaunch Calibrations

In addition to the calibrations contained in the flight program, an earth prelaunch calibration program is provided which is stored in the AEA softwired memory through ACE prior to the final loading of the flight program (See Chapter 9).

6.0 AGS GENERAL PERFORMANCE REQUIREMENTS. The AGS consists of the following assemblies:

- (a) Abort Electronics Assembly (AEA)
- (b) Data Entry and Display Assembly (DEDA)
- (c) Abort Sensor Assembly (ASA)

6.1 Abort Electronics Assembly (AEA)

6.1.1 AEA General Hardware Requirements. The AEA is a general purpose digital computer used for the data processing function of the AGS. It is a fixed point 18 bit machine, with 17 value bits and a sign bit (no parity), using 2's complement arithmetic. It is a clocked computer deriving its timing from a 1.024 mc signal.

- (a) AEA Memory. The AEA memory shall be of conventional ferrite core construction with a 4096 word capacity. Half of this capacity shall be electrically programmable and shall operate "read-restore". The other half shall be programmed at manufacture and shall be "read" only. These sections shall be referred to as the "software" and "hardware" memory respectively. A flight program shall be placed in the computer using both sections. However, a portion of the software memory shall be reserved for scratchpad use. (See Table for computer word estimates.)
- (b) Operations and Instructions. The AEA has 27 instructions including the common arithmetic operations, transfers, shifts and input/output. There shall be a 3-bit index register for address modification. The AEA is a machine, performing the simpler operations in 10 microseconds including the "fetch". Other operations such as division and shifts are longer.

- (c) Input/Output Capability. An I/O capability is provided in the AEA. It shall be used to process digital inputs from the ASA and the Inertial Measurement Unit (IMU) gimbal angles of the Primary Guidance, Navigation and Control Subsystem (PGNCS), discretes from the vehicle, GSE and telemetry inputs, telemetry outputs, discrete outputs to the vehicle, digital and analog outputs to the vehicle and command and display information to and from the DEDA. The AEA is also used to supply FDAI with display inputs. All of the input and output signals of the AEA related to flight program operation are listed in Table 6-1.

6.1.1.1 Initial Logic Reset. Upon application of power to the AEA, a signal shall be generated which shall reset all flipflops and clear all registers which are required to be initially in the "zero" state. The reset function shall be completed within 20 seconds after the application of power. The PGNCS accumulators (θ , ψ , and ϕ) shall reset only with a "CDU Zero" signal.

Table 6-1. AEA Interfaces

	<u>Input/Output</u>	<u>Source/Destination</u>	<u>Signal</u>	<u>Signal Characteristics</u>	<u>AEA Program Interface</u>	<u>Primary Function</u>
1	Input	ASA-Accelerometer	ΔV_X - Data	Pulse Train, 64 kpps max.	11-bit Ripple Counter	Accumulate Accelerometer Output Data
2	Input	ASA-Accelerometer	ΔV_Y - Data	Pulse Train, 64 kpps max.	11-bit Ripple Counter	Accumulate Accelerometer Output Data
3	Input	ASA-Accelerometer	ΔV_Z - Data	Pulse Train, 64 kpps max.	11-bit Ripple Counter	Accumulate Accelerometer Output Data
4	Input	ASA-Gyro	$\Delta \int P$ - Data	Pulse Train, 64 kpps max.	11-bit Ripple Counter	Accumulate Gyro Output Data
5	Input	ASA-Gyro	$\Delta \int Q$ - Data	Pulse Train, 64 kpps max.	11-bit Ripple Counter	Accumulate Gyro Output Data
6	Input	ASA-Gyro	$\Delta \int R$ - Data	Pulse Train, 64 kpps max.	11-bit Ripple Counter	Accumulate Gyro Output Data
7	Output	ASA	Clock	Pulse Train, 128 kpps	- - -	Timing Reference
8	Input	DEDA	DEDA Enter Discrete	Momentary Switch Closure	Discrete Word 2	Control Data Transfer Between AEA and DEDA
9	Input	DEDA	DEDA Readout Discrete	Momentary Switch Closure	Discrete Word 2	Control Data Transfer Between AEA and DEDA
10	Input	DEDA	DEDA Hold Discrete	Momentary Switch Closure	Discrete Word 2	Control Data Transfer Between AEA and DEDA
11	Input	DEDA	DEDA Clear Discrete	Momentary Switch Closure	Discrete Word 2	Control Data Transfer Between AEA and DEDA
12	Output	DEDA	Data	4-bit Pulse Burst, 64 kpps	4-bit DEDA Shift Register	Data for DEDA Display Data for Program Control or Use
13	Input	DEDA	Data	4-bit Pulse Burst, 64 kpps		
14	Output	DEDA	Clock	Pulse Train, 128 kpps	- - -	Timing Reference
15	Input	DEDA	DEDA Shift Clock	Pulse Burst, 4, 64 kpps	- - -	Implement Data Transfer into or out of 4-bit DEDA Shift Register
16	Output	DEDA	DEDA Shift In Discrete	Single Pulse	Discrete Output Pulse Trigger	Initiate Data Transfer into 4-bit DEDA Shift Register
17	Output	DEDA	DEDA Shift Out Discrete	Single Pulse	Discrete Output Pulse Trigger	Initiate Data Transfer out of 4-bit DEDA Shift Register
18	Input	FGNCS-IMU CDU	$\pm \Delta \theta$ - Data	Pulse Trains on Two Separate Lines, 6.4 kpps max.	15-bit Integrator Register	Accumulate IMU Gimbal Angle Data

Table 6-1. AEA Interfaces (Continued)

	<u>Input/Output</u>	<u>Source/Destination</u>	<u>Signal</u>	<u>Signal Characteristics</u>	<u>AEA Program Interface</u>	<u>Function</u>
19	Input	PGNCS - IMU CDU	$\pm \Delta\alpha$ - Data	Pulse Trains on Two Separate Lines, 6.4 kpps max.	15-bit Integrator Register	Accumulate IMU Gimbal Angle Data
20	Input	PGNCS - IMU CDU	$\pm \Delta\phi$ - Data	Pulse Trains on Two Separate Lines, 6.4 kpps max.	15-bit Integrator Register	Accumulate IMU Gimbal Angle Data
21	Input	PGNCS	CDU Zero	Pulse Burst, 51.2 kpps 300 ms duration	- - -	Clears 15-bit Integrator Registers used to Accumulate IMU Gimbal Angle Data
22	Input	PGNCS Downlink Telemetry	Data	Pulse Burst, 40 bits, 51.2 kpps	18-bit Shift Register (Downlink Telemetry Register)	Store Navigation Initialization Data
23	Input	Ground Service Equipment	Data	Pulse Burst, 18 bits, 51.2 kpps		
24	Input	PGNCS Downlink Telemetry	Shift Clock	Pulse Burst, 40, 51.2 kpps	- - -	Implement Data Transfer into Downlink Telemetry Register
25	Input	PGNCS Downlink Telemetry	Stop Pulse Discrete	Pulse Train, 50 pps	Discrete Word 2	Sets Discrete Flip-Flop to Indicate Completed Transmission of a Downlink Word
26	Output	Instrumentation Subsystem	Data	Pulse Burst, 24 bits, 51.2 kpps	24-bit Shift Register (Output Telemetry Register)	AGS Output Telemetry
27	Output	Ground Service Equipment	Data	Pulse Burst, 24 bits, 51.2 kpps		
28	Input	Instrumentation Subsystem	Shift Clock	Pulse Burst, 24, 51.2 kpps	- - -	Implement Data Transfer out of Output Telemetry Register
29	Input	Instrumentation Subsystem	Stop Pulse Discrete	Pulse Train, 50 pps	Discrete Word 1	Sets Discrete Flip-Flop to Indicate Completed Transmission of an Output Telemetry Word
30	Input	Ground Service Equipment	Shift Clock	Pulse Burst, 18, 51.2 kpps	- - -	Implement Data Transfer into Downlink Telemetry Register or out of Output Telemetry Register
31	Input	Ground Service Equipment	GSE Discrete 1	Switch Closure	Discrete Word 2	Indicates that the GSE has loaded a word into the Downlink Telemetry Register
32	Input	Ground Service Equipment	GSE Discrete 2	Switch Closure	Discrete Word 2	Indicates that the GSE has loaded the last word of the list in the Downlink Telemetry Register

Table 6-1. AEA Interfaces (Continued)

<u>Input/Output</u>	<u>Source/Destination</u>	<u>Signal</u>	<u>Signal Characteristics</u>	<u>AEA Program Interface</u>	<u>Function</u>	
33	Input	Ground Service Equipment	GSE Discrete 3	Switch Closure	Discrete Word ?	Indicates that the GSE has received a complete word from the Output Telemetry Register
34	Input	Ground Service Equipment	GSE In Use Discrete	Switch Closure	- - -	Inhibits receipt of signals from PGNS Downlink Telemetry when GSE is in use.
35	Output	Ground Service Equipment	GSE Discrete 4	Single Pulse	Discrete Output Pulse Trigger	Notifies the GSE that a complete word has been loaded into the Output Telemetry Register
36	Output	Ground Service Equipment	GSE Discrete 5	Single Pulse	Discrete Output Pulse Trigger	Notifies the GSE that a complete word has been transferred from the Downlink Telemetry Register into memory.
37	Output	Ground Service Equipment	GSE Discrete 6	Single Pulse	Discrete Output Pulse Trigger	Notifies the GSE that the last word of the list has been loaded into the Output Telemetry Register
38	Output	Ground Service Equipment	Clock	Pulse Train, 50 pps	- - -	Timing Reference
39	Input	Control Electronics Section	Automatic Discrete	Switch Closure	Discrete Word 1	Indicates that the Attitude Mode Control Switch is in Automatic (AUTO) position
40	Input	Control Electronics	Abort Discrete	Switch Closure	Discrete Word 1	Indicates that the Abort Switch has been depressed.
41	Input	Control Electronics Section	Abort Stage Discrete	Switch Closure	Discrete Word 1	Indicates that the Abort Stage Switch has been depressed.
42	Input	Control Electronics Section	Follow-up Discrete	Switch Closure	Discrete Word 1	Indicates either that the Guidance Control Switch is in the PGNS position or, if the Guidance Control Switch is in the AGS position, that the Attitude Mode Control Switch is in the Attitude Hold position and an Attitude Controller is out of detent.
43	Input	Control Electronics Section	Descent Engine ON Discrete	Switch Closure	Discrete Word 1	Indicates that the Descent Engine is on.
44	Input	Control Electronics Section	Ascent Engine ON Discrete	Switch Closure	Discrete Word 1	Indicates that the Ascent Engine is on.
45	Output	Control Electronics Section	Engine OFF Discrete	Switch Closure	Discrete Output Flip-Flop	Commands Engine Off
46	Output	Control Electronics Section	Engine ON Discrete	Switch Closure	Discrete Output Flip-Flop	Commands Engine On

Table 6-1. AEA Interfaces (Continued)

	<u>Input/Output</u>	<u>Source/Destination</u>	<u>Signal</u>	<u>Signal Characteristics</u>	<u>AEA Program Interface</u>	<u>Function</u>
47	Output	Control Electronics Section and Flight Control Displays	E_X - Control and Data	800 Hz Analog	10-bit Static Register and D/A Converter	Attitude Error Signal Transmitted to the Control Electronics Section for vehicle control and to the FDAI for display on two separate lines.
48	Output	Control Electronics Section and Flight Control Displays	E_Y - Control and Data	800 Hz Analog	10-bit Static Register and D/A Converter	Attitude Error Signal transmitted to the Control Electronics Section for vehicle control and to the FDAI for display on two separate lines.
49	Output	Control Electronics Section and Flight Control Displays	E_Z - Control and Data	800 Hz Analog	10-bit Static Register and D/A Converter	Attitude Error Signal transmitted to the Control Electronics Section for vehicle control and to the FDAI for display on two separate lines.
50	Output	Flight Control Displays	Sin α - Data	400 Hz Analog	10-bit Static Register and D/A Converter	FDAI Total Attitude Display Gimbal Drive Signal
51	Output	Flight Control Displays	Cos α - Data	400 Hz Analog	10-bit Static Register and D/A Converter	FDAI Total Attitude Display Gimbal Drive Signal
52	Output	Flight Control Displays	Sin β - Data	400 Hz Analog	10-bit Static Register and D/A Converter	FDAI Total Attitude Display Gimbal Drive Signal
53	Output	Flight Control Displays	Cos β - Data	400 Hz Analog	10-bit Static Register and D/A Converter	FDAI Total Attitude Display Gimbal Drive Signal
54	Output	Flight Control Displays	Sin γ - Data	400 Hz Analog	10-bit Static Register and D/A Converter	FDAI Total Attitude Display Gimbal Drive Signal
55	Output	Flight Control Displays	Cos γ - Data	400 Hz Analog	10-bit Static Register and D/A Converter	FDAI Total Attitude Display Gimbal Drive Signal
56	Output	Flight Control Displays	Lateral Velocity-Data	DC Analog	9-bit Static Register and D/A Converter	Lateral Velocity Display for X-Pointers
57	Output	Flight Control Displays	Altitude - Data	Pulse Burst, 15 bits, 64 kpps	15-bit Shift Register	Data for display on the Altitude/Range Indicator. Altitude and Altitude Rate are loaded alternately into the same register but are transmitted on separate lines.
58	Output	Flight Control Displays	Altitude Rate-Data	Pulse Burst, 15 bits, 64 kpps		
59	Output	Flight Control Displays	Shift Clock	Pulse Burst, 15, 64 kpps	Altitude Display Discrete	Implement Data Transfer into Altitude Display.
60	Output	Flight Control Displays	Shift Clock	Pulse Burst, 15, 64 kpps	Altitude Rate Display Discrete	Implement Data Transfer into Altitude Rate Display
61	Output	Caution and Warning Displays (AGS Failure Warning Light)	Test Mode Failure Discrete	Switch Closure	Discrete Output Flip-Flop	Indicate AEA Failure

6.1.2 AEA General Software Requirements

The LM AGS flight program contained in the AEA shall provide a capability for accepting and processing data and discrete inputs from the two other components of the AGS, the Abort Sensor Assembly (ASA) and the Data Entry and Display Assembly (DEDA). The program shall also be capable of processing and controlling the transfer of data from a restricted portion of the AEA software memory to the DEDA for display.

The flight program shall provide a capability for accepting and processing data transmitted from the LM primary Guidance, Navigation, and Control Section (PGNCS) or from the ground support equipment (GSE) which may be either the Bench Test Maintenance Equipment (BTME) or the Acceptance Checkout Equipment (ACE).

A capability shall be provided for the output of a pre-selected fixed data list by means of an output telemetry link to the Instrumentation Subsystem.

Attitude error signals and Engine ON/OFF commands shall be computed and output to the Control Electronics Section (CES) to provide a means for controlling the LM vehicle attitude through the operation of the Reaction Control System (RCS) and for determining the duration of the burns of the main engines, the Descent Propulsion System (DPS) and the Ascent Propulsion System (APS). Those discrettes furnished by the CES indicating main engine status and certain

astronaut control manipulations shall be recognized and shall produce an appropriate response by means of the program logic.

Certain quantities shall be computed and output for display. Lateral velocity, altitude (lunar mission only), and altitude rate shall be furnished to the Flight Control Displays. Total attitude signals shall be furnished to the Flight Director Attitude Indicators along with the attitude error signals. A discrete signal shall be supplied to the Caution and Warning Displays in the event of the occurrence of certain AEA failures.

6.2 Data Entry and Display Assembly (DEDA)

6.2.1 DEDA General Hardware Requirements

The DEDA is a general-purpose, manually operated, input-output device for use with the AEA. Its major external features are a keyboard and electroluminescent data display devices. The DEDA keyboard consists of ten decimal-digit pushbuttons, two sign pushbuttons, and four control pushbuttons. The Display Registers provide for a three octal digit address, a sign plus five octal- or decimal-digit data word, and an operator error indication (see Figure 6-1). The display devices are activated either by use of the appropriate pushbuttons, by the extraction of data from the AEA, or, in the case of the operator error indicator, by certain improper procedures in the use of the keyboard.

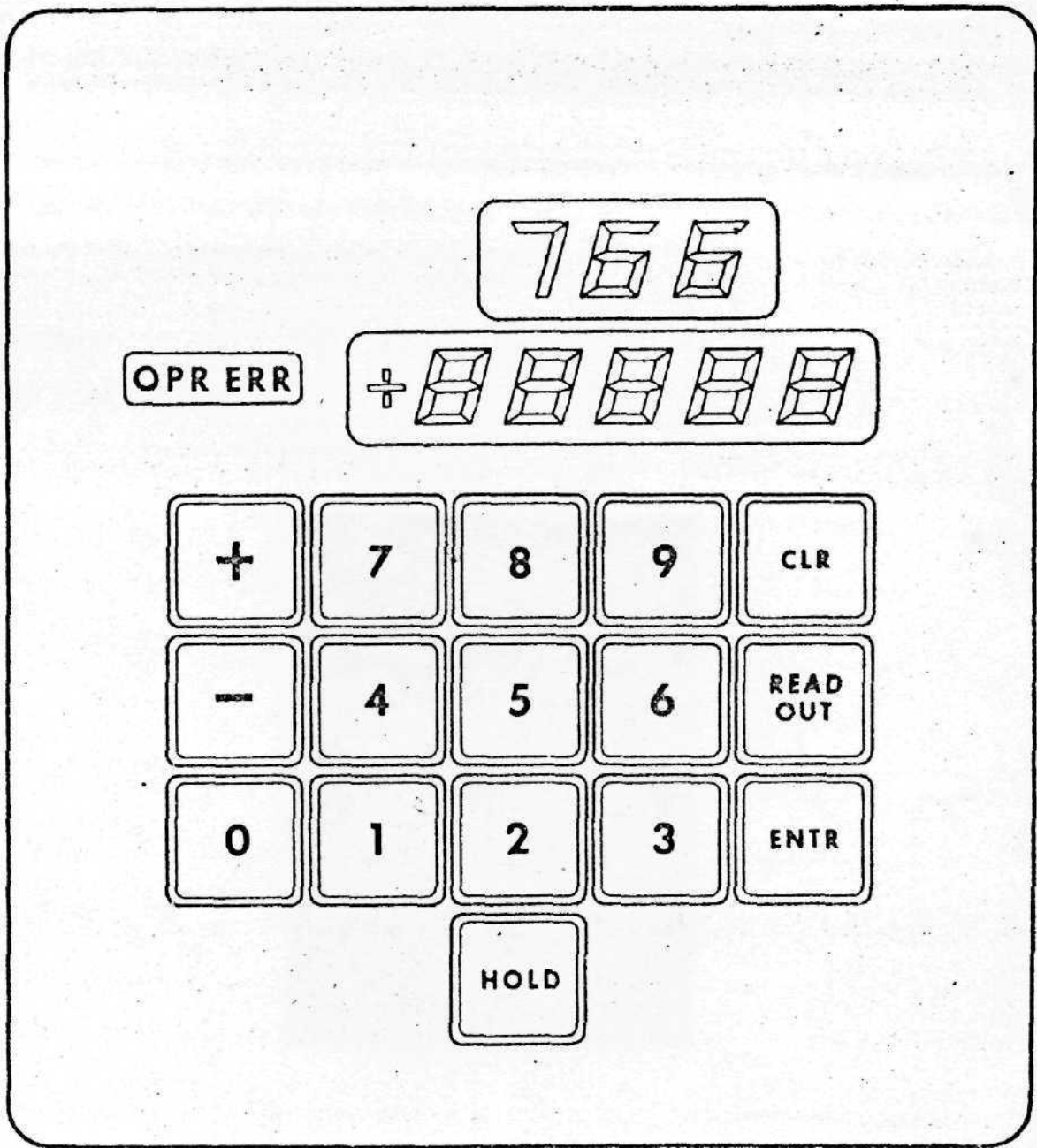


Figure 6-1 DEDA Front Panel

Each of the four control pushbuttons, Clear, Enter, Readout, and Hold, when depressed, cause corresponding DEDA control discrettes to be set in the Discrete Word 2 Register of the AEA. The DEDA control discrettes are buffered switch closures to ground and remain set for only so long as the corresponding DEDA control pushbutton remains depressed.

The DEDA shall be used for manual insertion of data into the AEA and manual initiation of data readout from the AEA. In addition, selection of certain of the operating modes of the flight program and the AGS generally shall be made by appropriate inputs via DEDA.

6.2.2 DEDA General Software Requirements. The DEDA Register, a 4-bit, input-output shift register in the AEA, provides temporary storage for data which is being transferred between the AEA and DEDA under the control of the DEDA Processing Routine in the flight program. The DEDA Processing Routine shall initiate or terminate the data transfer in response to the recognition of the setting of the various DEDA control discrettes.

When data is to be transferred either to or from the DEDA, either the DEDA Shift-Out Discrete or the DEDA Shift-In Discrete, respectively, must be addressed. Upon receipt

of the resulting pulse, the DEDA will transfer a burst of four clock pulses to the DEDA Register. This will cause the shifting of 4 bits of data into or out of the register, as appropriate.

A minimum time interval of 80 μ s must be allowed between subsequent settings of either the DEDA shift-In Discrete or DEDA Shift-Out Discrete to allow sufficient time for the data transfer.

The maximum number of memory location accessible for data input and output via the DEDA shall be 512. These memory locations shall be in a fixed designated section of the software memory.

6.2.2.1 DEDA Word Format

A complete DEDA word contains 36 bits consisting of nine 4-bit groups. Each 4-bit group is associated with one of the DEDA display devices. There are three 4-bit groups for the address, one 4-bit group for the data sign, and five 4-bit groups for the data.

DEDA Word Format

Total Bits = 36

0 X X X	0 X X X	0 X X X	0 0 0 X	* X X X	* X X	{ X X	* X X X
12 bits Address			4 bits Sign	20 bits Data			

Code

0 - Zero

X - Either One or Zero

* Either One or Zero for binary-coded-decimal data
Zero for octal data

In the 4-bit sign group, the three most significant bits are zeros. A zero in the least significant bit will indicate a positive sign, while a one in that location will indicate a negative sign.

6.2.2.2 Data Transmission and Processing

Data transmissions either to or from the DEDA shall be in 4-bit groups beginning at the most significant bit of the 36-bit word. Each 4-bit group is transmitted serially, the most significant bit first.

The DEDA Processing Routine shall provide a capability for decoding address information and data which is transmitted to the AEA via DEDA. In decoding address information, the

most significant bit of each 4-bit group shall be tested to determine if it is zero. If it is non-zero, an operator error shall be assumed. In decoding sign information, the three most significant bits of the 4-bit group shall be deleted. In processing the 20 bits of data, the DEDA Processing Routine shall provide for distinguishing between octal and binary-coded-decimal data based upon the particular address of the data word. For data entered in octal, the most significant bit of each 4-bit group shall be assumed to be zero. For data entered in decimal, the decoding operation shall provide an appropriately rescaled binary word for storage. Reasonableness or ambiguity checks on input data are not required.

The DEDA Processing Routine shall also provide a capability for coding and formatting the 36-bit DEDA word for output. Zeros shall be supplied in those locations requiring them and data from those memory locations designated for display of information in decimal shall be scaled according to specification prior to transmission in binary-coded decimal.

In the event that the operator error display has been activated, the DEDA will transmit all ones to the AEA when the Enter or Readout pushbuttons are depressed. The DEDA Processing Routine shall recognize this error indication by detecting the presence of ones in locations normally constrained to contain zeros. In the event of this error detection, no input data shall be accepted and no data shall be

transmitted until a new sequence is initiated by receipt of the Clear Discrete.

6.2.2.3 DEDA Input/Output Control

The DEDA Control Discretes are set for only so long as the corresponding DEDA pushbuttons are depressed. Therefore, the DEDA Processing Routine is required to sample the discretes at 40 ms intervals to ensure that transmission of a DEDA Control Discrete is recognized.

Each DEDA operation sequence shall be initiated by transmission of the Clear Discrete which shall place the DEDA Processing Routine in a clear mode. While in the clear mode, both the Readout and Enter Discretes shall be interrogated.

On receipt of the Enter Discrete, the DEDA Processing Routine shall cause nine consecutive DEDA Shift-In Discretes to be issued to the DEDA to transfer the 36-bit DEDA word into the AEA. The data word shall be decoded, rescaled if necessary, and stored in the address designated. The Clear Discrete must be received following such an entry before a subsequent entry or readout operation may be performed.

On receipt of a Readout Discrete, the DEDA Processing Routine shall enter the Readout Mode. Three consecutive DEDA Shift-In Discretes shall be issued to bring 12 bits of address information into the AEA. The DEDA Processing Routine shall

extract the data from the address thus requested, code and scale the data as required, and transmit the full 36-bit DEDA word by issuing nine consecutive DEDA Shift-Out Discretes. The extraction of data from the requested address and transmission to the DEDA shall be repeated at half-second intervals until either a Hold or Clear Discrete is sensed.

Upon receipt of the Hold Discrete, the DEDA Processing Routine shall exit from the Readout Mode and suspend extraction and transmission of the data. Upon receipt of a subsequent Readout Discrete, the Readout Mode shall be reentered and data transmission from the same address shall be resumed.

Receipt of a Clear Discrete following either a Readout or Hold Discrete shall return the DEDA Processing Routine to the clear mode.

6.3 ABORT SENSOR ASSEMBLY (ASA)

6.3.1 ASA General Hardware Requirements

The ASA instrument package contains three single-degree-of-freedom pulse-rebalanced rate-integrating gyros, three pendulous pulse-rebalanced accelerometers, and their associated pulse torquing electronic circuitry in a strapdown configuration. The respective instrument input axes are constrained to be collinear, within specified tolerances,

with a set of rectangular coordinates, X, Y, and Z, termed the ASA reference axes. The nominal ASA sensor triad configuration is shown in Figure 6-2. The tolerances on misalignment of the input axes of gyros and accelerometers with respect to the ASA reference axes are given in Paragraphs 7.1.1.2.2 and 7.1.1.3.2, respectively.

For the purposes of this specification, the orientation of the ASA reference axes is defined to be identical with that of the LM body axis coordinates when the ASA is properly mounted on the navigation base. No compensation is required in the flight program for misalignment of the ASA gyros and accelerometers with respect to the ASA reference axes.

6.3.1.1 LM Body Axis Coordinates

The LM body axis coordinate frame is a set of right-handed rectangular coordinate axes, X, Y, and Z, fixed to the vehicle. The X axis lies along the longitudinal axis of the vehicle, positive in the nominal direction of positive main engine thrust acceleration. The Z axis is normal to the X axis, lies in the plane of symmetry of the LM cabin front view, and is positive in the direction of the front view. The Y axis completes the right-handed orthogonal triad. The LM body axis coordinate frame is illustrated in Figure 6-3. See Para. 7.1.1.2.2.1.

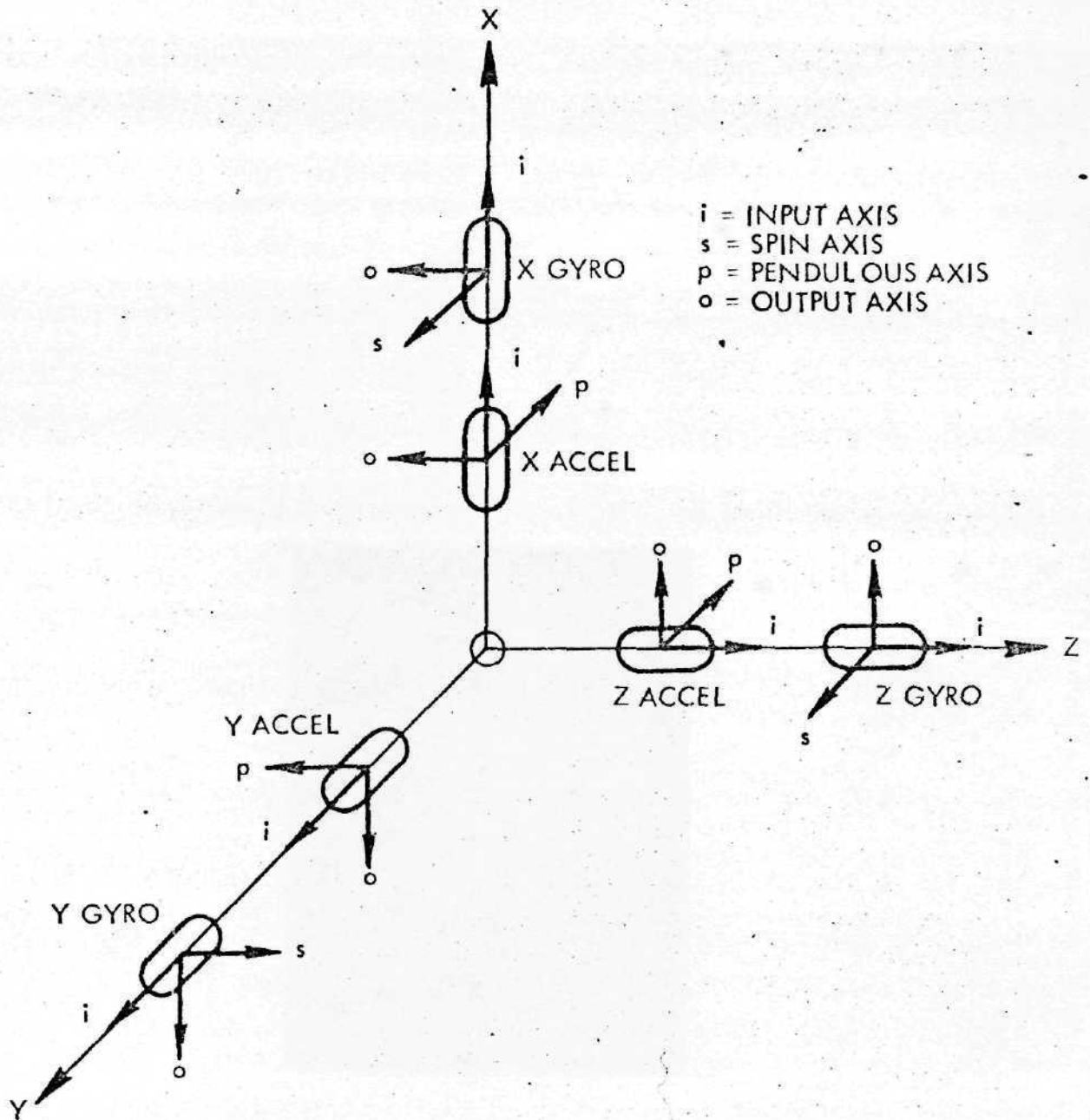


Figure 6-2. ASA Sensor Triad Configuration

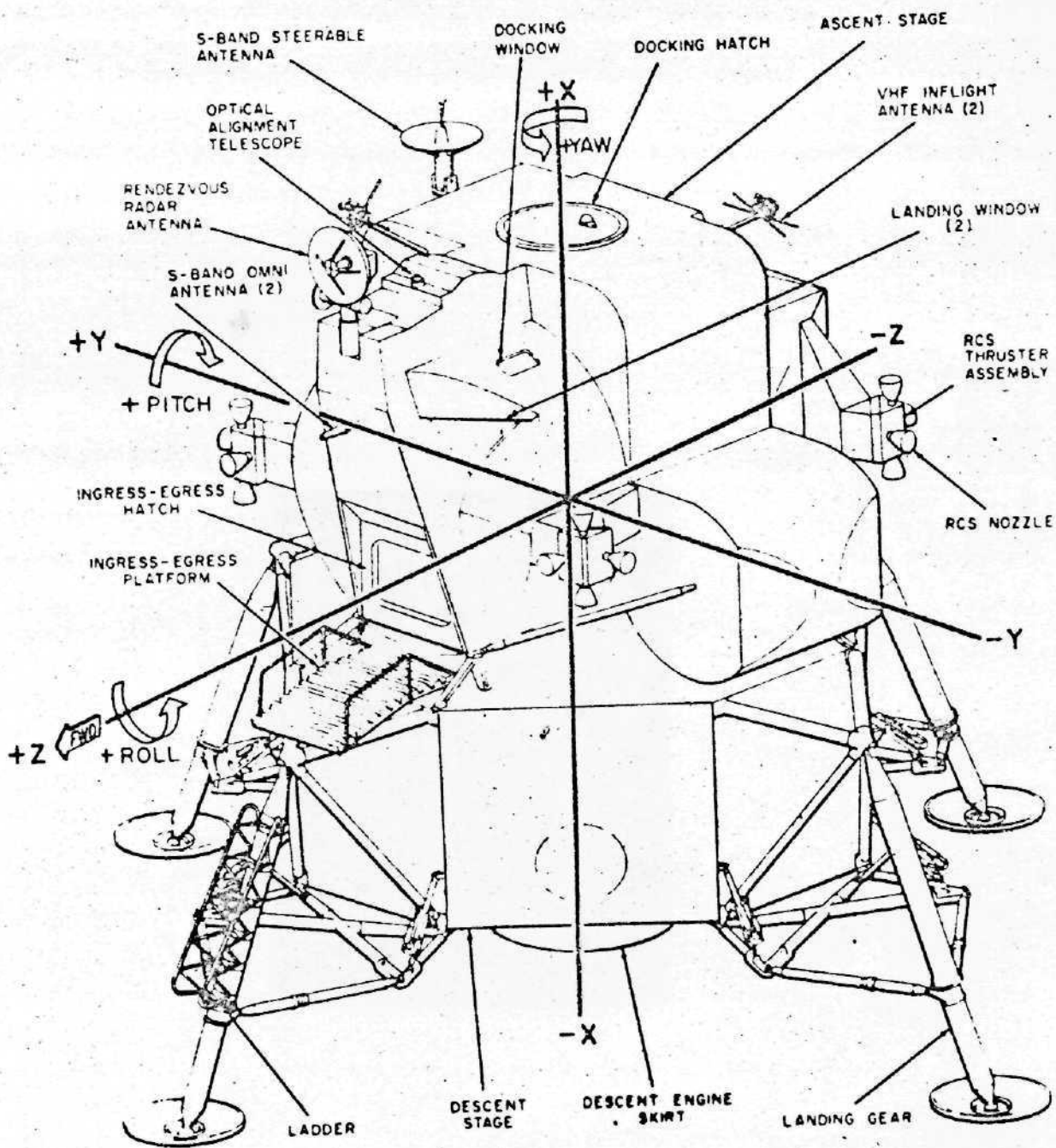


Figure 6-3. LM Body Axis Coordinate System

6.3.1.2 ASA Inputs

The output of each of the six ASA instruments is a train of electrical pulses. These pulse trains are input to the AEA and accumulated in the six ASA input registers, 11-bit input counters. The registers are incremented by one count for each pulse received.

Each gyro pulse represents an incremental angular displacement about the corresponding body axis. Each accelerometer pulse represents an incremental change in velocity along the corresponding body axis.

During any 1 ms period, the accumulation of 32 pulses from a precisely nominal instrument represents a zero signal; the accumulation of 61 pulses represents the maximum positive signal; the accumulation of 3 pulses represents the maximum negative signal.

A positive incremental angular signal from a given gyro represents a positive angular displacement, in the right-handed sense, about the corresponding axis. The nominal weight of the incremental angular information is 2^{-16} rad per pulse.

A positive incremental velocity signal from a given accelerometer represents a positive translational velocity change, due to thrust acceleration, along the corresponding body axis. The nominal weight of the incremental velocity information is 0.1/32 fps/pulse.

Each ASA input register shall be sampled and cleared every 20 ms to prevent overflow. The nominal bias of 640 pulses per 20 ms shall be removed from the data as part of the data processing in the flight program. (Also see para. 7.1.1 and 7.2.14).

6.3.2 ASA General Software Requirements

6.3.2.1 Accelerometer Data Processing

As discussed in Paragraph 6.3.1.2, the flight program is required to read and clear the three accelerometer input registers every 20 ms while the AGS is operating. The accelerometer data obtained in this manner shall be processed as follows:

- 1) The nominal bias of 640 counts per 20 ms interval shall be subtracted from each of the three accelerometer inputs
- 2) Each of the resulting differences shall be multiplied by a corresponding scale factor to convert counts to feet per second
- 3) An accelerometer static bias compensation constant shall be added to each result.

This processed accelerometer data shall be used in the navigation equations (see Paragraph 4.1.1) to provide a measure of the incremental changes in velocity of the LM due to the thrust forces of descent engine, ascent engine, and reaction control system operation and any externally applied forces. (Also see para. 7.1.1 and 7.2.14).

6.3.2.1.1 Accelerometer Scale Factor Compensation

A separate scale factor shall be provided for the data from each accelerometer. The scale factors will be determined by calibration and incorporated in the program prior to launch. A capability shall exist for accomodating deviations up to $\pm 24\%$ of the nominal accelerometer scale factor of 0.1/32 fps/count. The accelerometer scale factors shall be located in the DEDA accessible portion of the AEA memory. A positive residual scale factor error will exist in the sensed incremental velocity data if the true scale factor exceeds the scale factor in use.

6.3.2.1.2 Accelerometer Static Bias Compensation

A positive accelerometer static bias exists when the reading from an accelerometer input register exceeds the nominal 640 counts in free fall. The sensed incremental velocity data shall be compensated for positive static bias by the addition of a negative accelerometer static bias compensation constant.

A separate accelerometer static bias compensation constant shall be provided for correcting the data from each accelerometer. Compensation constants will be determined by calibration and incorporated in the program prior to launch. In addition, The flight program shall provide a capability for updating the compensation constants during free fall periods of the

mission. See Paragraph 6.3.2.1.3. Compensation of the incremental sensed velocity data shall be provided for up to ± 2000 ug of equivalent accelerometer static bias. The compensation constants shall be located in the DEDA accessible portion of the AEA memory.

No compensation is required for changes in the apparent accelerometer bias resulting from the effects of vehicle dynamics on the instruments.

6.3.2.1.3 In-Flight Accelerometer Calibration

The flight program shall provide a capability for measuring the equivalent accelerometer static bias during free fall periods of the mission. Upon entry of an appropriate command via the DEDA, the measurements will be taken and the accelerometer compensation constants will be updated within approximately 30 seconds. The calibration technique employed is not required to account for rotation, attitude limit-cycling, or any other dynamic characteristics of the vehicle in free fall.

6.3.2.2 Gyro Data Processing

As discussed in Paragraph 6.3.1.2, the flight program is required to read and clear the three gyro input registers every 20 ms while the AGS is operating. The gyro data obtained in this manner shall be processed as follows:

- 1) The nominal bias of 640 counts per 20 ms interval shall be subtracted from each of the three gyro inputs
- 2) Each of the resulting differences shall be multiplied by a corresponding scale factor to convert counts to radians
- 3) A fixed gyro drift compensation constant shall be added to each result
- 4) A term shall be added to the incremental attitude change indicated by the X gyro reading to compensate for drift due to the spin axis mass unbalance of the X gyro.
(Also see para. 7.1.1 and 7.2.14).

6.3.2.2.1 Gyro Scale Factor Compensation

Provision shall be made in the flight program to modify the nominal gyro scale factor of 2^{-16} rad/count for each gyro by a correction factor. The deviation from nominal of the scale factor for each gyro shall be determined by calibration and incorporated in the program prior to launch. A capability shall exist for accommodating deviations up to ± 0.78 percent of the nominal gyro scale factor. The measured deviations, termed the gyro scale factor compensation constants shall be located in the DEDA accessible portion of the AEA memory.

A positive gyro scale factor deviation exists when the true scale factor for the gyro is greater than the nominal scale factor. A positive gyro scale factor deviation shall be compensated in the AEA by means of a positive gyro scale factor compensation constant.

6.3.2.2.2 Fixed Gyro Drift Compensation

Positive fixed gyro drift exists if the reading from a gyro input register exceeds the nominal 640 counts when the attitude of the vehicle is fixed in inertial space. The incremental angular displacement data obtained from the gyros shall be compensated for positive fixed gyro drift by the addition of a negative fixed gyro drift compensation constant.

A separate fixed gyro drift compensation constant shall be provided for correcting the data from each gyro. Compensation constants will be determined by calibration and incorporated in the program prior to launch. In addition, the flight program shall provide a capability for updating the compensation constants by means of an in-flight calibration technique during free fall periods of the mission and by means of a surface calibration technique when the LM is resting on the lunar surface. See Paragraphs 6.3.2.2.3 and 6.3.2.2.4. Capability for fixed gyro drift compensation shall be provided over a range of ± 10 deg/hr. The compensation constants shall be located in the DEDA accessible portion of the AEA memory.

6.3.2.2.3 In-Flight Gyro Calibration

The flight program shall provide a capability for updating the fixed gyro drift compensation constants during free fall periods of the mission. The calibration shall be initiated

upon entry of an appropriate command via the DEDA and shall be completed within 5 minutes. Attitude rotation rate should be less than 0.1 deg/sec (See page 17-2 of Operating Manual).

The in-flight gyro calibration technique shall use the PGNCS IMU gimbal angle data as described in Paragraph 6.4.1 as reference information. The program shall initially perform a PGNCS to AGS Alignment as described in Paragraph 5.2.3.1.1 The calibration procedure shall consist of modifying the fixed gyro drift compensation constants so as to approach a null in the apparent angular displacement of the ASA reference axes with respect to the IMU reference axes as defined by the IMU gimbal angle data. In this procedure, compensation shall be applied for the pre-flight measured misalignment between the IMU and ASA reference axes.

6.3.2.2.4 Lunar Surface Gyro Calibration

The flight program shall provide a capability for updating the fixed gyro drift compensation constants while the LM is resting on the lunar surface. The calibration shall be initiated upon entry of an appropriate command via the DEDA and shall be completed within 5 minutes.

The lunar surface calibration technique employed can be based on the following presumptions:

- 1) Either a PGNCS to AGS Alignment as described in Paragraph 5.2.3.1.1 or a lunar alignment as described in Paragraph 5.2.3.1.2 has been implemented

- 2) After alignment, Y-inertial axis must be within 10 degree (Half Cone Angle) of Moon's North Polar Axis.
- 3) The inclination of the LM X body axis with respect to the vertical will not exceed 30 deg.

During lunar surface gyro calibration, the gyro data shall be modified to remove the effects of lunar rotation. The fixed gyro drift compensation constants shall then be modified so as to produce an apparent null in the rotation rate of the vehicle-fixed coordinate frame with respect to the inertial frame as described in Paragraph 4.4.

6.3.2.2.5 X Gyro Spin Axis Mass Unbalance Drift Compensation

For a positive gyro spin axis mass unbalance, a positive thrust acceleration in the direction of the gyro input axis (see Figure 6-2) will produce a negative gyro output unrelated to vehicle rotation, i.e, a negative gyro drift.

The flight program shall compensate for this effect in X gyro data. An X gyro spin axis mass unbalance compensation coefficient will be determined by calibration and incorporated into the program prior to launch. The coefficient shall be located in the DEDA accessible portion of the AEA memory. For a positive gyro spin axis mass unbalance, the compensation coefficient will be positive. Capability shall be provided for accommodating compensation coefficients over a range equivalent to ± 10 deg/hr/g.

The X gyro spin axis mass unbalance compensation coefficient shall be multiplied by the scaled and compensated incremental velocity data from the X axis accelerometer and the result will be added to the X gyro data.

No spin axis mass unbalance compensation is required for the data from the Y and Z axis gyros. No compensation is required for other sources of error in the gyro data.

6.4 PGNCS

6.4.1 IMU Gimbal Angles

The PGNCS provides continuous attitude information to the AGS by means of direct connections between the AEA and the three Coupling Data Units (CDU's) associated with the three gimbal angles of the Inertial Measurement Unit (IMU). The AEA contains three 15-bit integrator registers, each of which accumulates the pulses transmitted on a pair of lines from a corresponding CDU. Each pulse produces a one-count increment or decrement in the register, depending on whether the signal arrives on the plus or minus line.

The receipt of a single pulse nominally represents an angular change of $360/2^{15}$.deg in the corresponding gimbal angle. Thus, the range of the data word in each register is 0 to 360 deg.

All three IMU gimbal angle registers are cleared whenever a CDU Zero signal is received from the PGNCS on another line. The corresponding registers in the PGNCS are cleared simultaneously by a similar signal. The transmission of the CDU Zero signal is controlled by the PGNCS.

After being cleared, the CDU's reload themselves and the IMU gimbal angle registers. This reloading requires no more than 20 seconds to complete. The result is that both guidance systems are initialized at this point to contain the same IMU gimbal angle information with any accumulated errors due to previously occurring transients and drift in the CDU's removed.

Under the control of the flight program, whenever the IMU gimbal data is required in order to perform an alignment of the AGS attitude reference matrix or an in-flight gyro calibration, the IMU gimbal angle registers shall be read and the data stored in memory every 20 ms.

The IMU gimbal angle data provides a measure of that set of Euler angles, θ , Ψ , and ϕ , which define a coordinate transformation, $[B]$, from the rectangular coordinate frame of the IMU stable member, u , v , and w , to the reference axes of the IMU, U , V , and W , as mounted on the navigation base.

$$\begin{bmatrix} U \\ V \\ W \end{bmatrix} = [B] \begin{bmatrix} u \\ v \\ w \end{bmatrix}$$

The IMU reference axes, the ASA reference axes, and the LM body axes all have the same nominal orientation. The misalignment of the IMU reference axes, with respect to the ASA reference axes on navigation base, will not exceed 5.2 arc-min. A capability shall be provided in the flight program to compensate for the preflight measured misalignment between the ASA and IMU reference axes whenever IMU gimbal angle data is being input for use.

The order of rotation from the IMU stable member coordinate axes to the IMU reference axes is illustrated in Figure 6-4. This rotation defines the transformation matrix to be as follows:

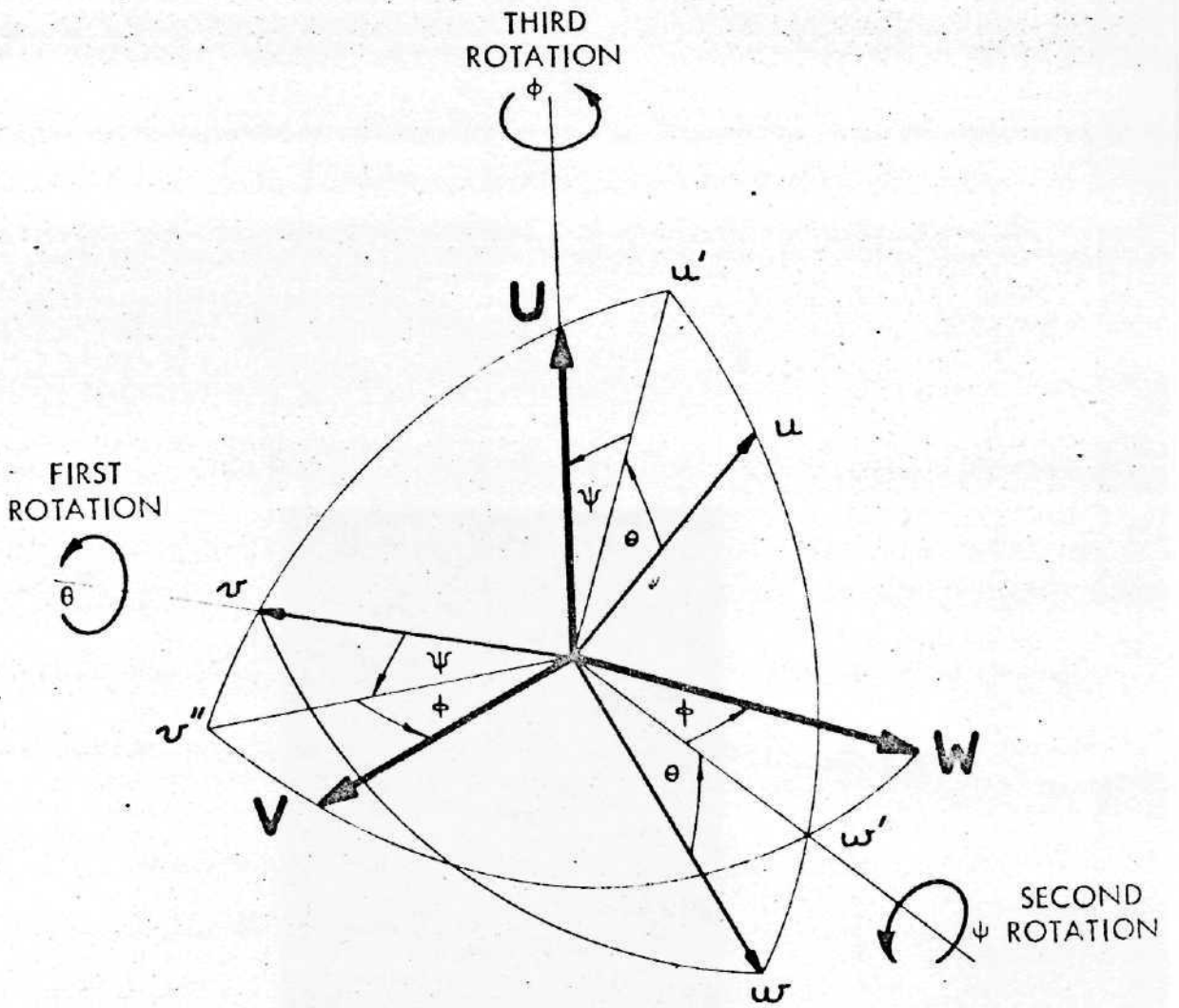
$$[B] = \begin{bmatrix} C\psi C\theta & S\psi & -C\psi S\theta \\ (-C\phi S\psi C\theta & S\phi S\theta) & C\phi C\psi (C\phi S\psi S\theta + S\phi C\theta) \\ (S\phi S\psi C\theta & C\phi S\theta) & -S\phi C\psi (-S\phi S\psi S\theta + C\phi C\theta) \end{bmatrix}$$

The PGNCS limits the range of the middle gimbal angle, ψ , to ± 60 deg. The inner and outer gimbal angles, θ and ϕ , have a range of ± 180 deg.

6.4.2 PGNCS Downlink Telemetry

6.4.2.1 PGNCS Downlink Telemetry Data Transmission

Data is transmitted serially over the PGNCS Downlink Telemetry line at a rate of fifty 40-bit words per sec. The Downlink Telemetry Register in the AEA, an 18-bit shift register, provides a means for accepting the PGNCS Downlink data under appropriate conditions.



FIRST ROTATION, θ , INNER GIMBAL ANGLE
 SECOND ROTATION, ψ , MIDDLE GIMBAL ANGLE
 THIRD ROTATION, ϕ , OUTER GIMBAL ANGLE

Figure 6-4. IMU Euler Angles

The data is loaded into the Downlink Telemetry Register under the control of clock pulses supplied by the Instrumentation Subsystem at a rate of 51.2 kpps. A counter associated with the register permits the loading of only 18 bits of data from the downlink. Once the 18 bits have been loaded into the register, no additional data can be accepted until the register has been read. The counter is reset when the contents of the register have been read, in parallel, into the AEA memory under flight program control.

The Instrumentation Subsystem transmits a single PGNCS Downlink Stop Pulse to the AEA after the transmission of each 40-bit word. The Stop Pulse sets a discrete flip-flop in the Discrete Word 1 Register. The Downlink Stop Pulse Discrete provides a means for synchronizing the loading of data into the AEA memory to the downlink transmission. Each time the Downlink Telemetry Register is read, the Downlink Stop Pulse Discrete flip-flop is reset.

When PGNCS Downlink data is being accepted by the AEA, under flight program control, the Downlink Stop Pulse Discrete must be interrogated at least twice during each 20-ms period with a minimum separation of 1 ms between samplings to ensure synchronous loading of the Downlink data.

6.4.2.2 PGNCS Downlink Telemetry Data Format

Upon appropriate command to the LM guidance computer (LGC) via the Display and Keyboard Assembly (DSKY), a

special data list will be transmitted over the PGNCs Downlink Telemetry line. This list provides navigation initialization data for use by the AGS flight program.

The data list will consist of a block of 17 consecutive words consisting of:

- 1) An identification (ID) word
- 2) Six words defining a position and velocity for the LM in the rectangular coordinates of the IMU stable member
- 3) Two words giving the epoch of the LM position and velocity data in double precision
- 4) Six words defining a position and velocity for the CSM in the rectangular coordinates of the IMU stable member
- 5) Two words giving the epoch of the CSM position and velocity data in double precision

The sequence of words in the list is illustrated in Figure 6-5.

The complete list will be transmitted a total of ten times for each commanded transmission. During the period required for the ten transmissions, no LGC interrupts will occur.

The first, or most significant, bit of a PGNCs downlink word is the word-order-code bit. This bit will be a one if the word is a data word and a zero if the word is an ID word. Following the word order code bit, data words will consist of a sign bit followed by 14 value bits, the most significant bit first. For ID words, a 15-bit binary data index will follow the word order code bit. The binary

- 1) ID word
- 2) LM u position
- 3) LM v position
- 4) LM w position
- 5) LM epoch most significant word
- 6) LM u velocity
- 7) LM v velocity
- 8) LM w velocity
- 9) LM epoch least significant word
- 10) CSM u position
- 11) CSM v position
- 12) CSM w position
- 13) CSM epoch most significant word
- 14) CSM u velocity
- 15) CSM v velocity
- 16) CSM w velocity
- 17) CSM epoch least significant word

Figure 6-5. PGNCS Downlink Word Sequence

data index for navigation initialization data is 111 111 111 111 110. For both ID and data words, the 2 least significant bits of the 18 bits loaded are not applicable and should be discarded in processing the word.

Data will be in two's complement binary form. For earth-scaled flight programs, a one in the most significant bit location for position data will have the value 2^{24} ft and a one in the most significant bit location for velocity data will have the value 2^{14} fps. For lunar-scaled flight programs, a one in the most significant bit location for position data will have the value 2^{22} ft and a one in the most significant bit location for velocity data will have the value 2^{12} fps. The most significant bit of the epoch will have the value 2^{17} sec.

6.4.2.3 PGNCS Downlink Coordinate Frame

The position and velocity initialization data furnished to the AEA on the PGNCS downlink will be in the inertial reference coordinate frame defined by the orientation of the IMU stable member. Therefore, the data will be compatible with the IMU gimbal angle information described in Paragraph 6.4.1.

6.4.2.4 PGNCS Downlink Reference Time

The epoch of the navigation initialization data provided by the PGNCS will be compatible with the current time base

of the AGS clock, i.e., the AGS absolute time base. This compatibility will be achieved by appropriate astronaut procedures.

When the data is furnished on the downlink, the epoch shall be no more than one orbital period earlier than current time and shall be subsequent to the last time of powered flight for the corresponding vehicle.

6.4.2.5 PGNCS Downlink Input Subroutine

PGNCS Downlink Telemetry data shall be accepted and stored in the AEA memory under flight program control only after an appropriate command is given the system via DEDA. When this command is given, the program shall interrogate the PGNCS Downlink Stop Pulse Discrete every 20 ms to determine if a word has been loaded into the downlink telemetry register. When the Stop Pulse Discrete is detected, the contents of the register shall be read into the AEA and the register cleared. Before any data can be stored in memory, a search must be conducted for the ID word which heads the block of navigation initialization data. When the correct ID word is found, the PGNCS Downlink Input Subroutine shall read and store in memory the following 16 words of the data block. The data block shall be read and stored one time only.

6.5 AGS OUTPUT TELEMETRY

6.5.1 AGS Output Telemetry Transmission

The AGS shall supply data for telemetry to the Instrumentation Subsystem by means of the Output Telemetry Register, a 24-bit shift register. AGS Output Telemetry transmission shall be synchronized to a rate of 50 24-bit words per sec by means of control signals supplied by the Instrumentation Subsystem. The Instrumentation Subsystem will supply a burst of 24 AGS telemetry shift pulses, followed by an AGS Output Telemetry Stop Pulse once each 20 ms. The shift pulses will unload the Output Telemetry Register serially at 51.2 kpps, the most significant bit first. The stop pulse sets a discrete flip-flop in Discrete Word, the Output Telemetry Stop Discrete.

6.5.2 AGS Telemetry Subroutines

The flight program shall contain telemetry subroutines to format each telemetry word and load the Output Telemetry Register in synchronism with the control signals supplied by the Instrumentation Subsystem. One output telemetry word shall be loaded every 20 ms, provided that an AGS Output Telemetry Stop Discrete has been sensed. The program shall interrogate this discrete twice per 20 ms cycle, with at least 1-ms separation between interrogations. The Output Telemetry Register will be

loaded only if the discrete is set to ensure that data will not be loaded into the register at the same time data is being shifted out. The AGS Output Telemetry Stop Discrete shall be reset each time a new word has been stored in the Output Telemetry Register.

The telemetry output data shall consist of a 50-word block of computer memory, transmission of which shall be repeated every second. At one second intervals, the program shall be initialized so that transmission of the block of memory is repeated, in sequence, starting with the first word of the block.

6.5.3 AGS Output Telemetry Data Format

The 24-bit telemetry output word assembled in the Output Register shall consist of a 6-bit ID code and 18 bits of information from a particular AEA memory cell. The ID code shall range sequentially from octal 01 to octal 62 with the ID code octal 01 being used to designate the first word of the 50-word block. The ID code shall occupy the first 6 most significant bits of the register. The remaining 18 bits, the computer word, shall represent either codes or numerical data. For numerical data, the 18 bits shall consist of one sign bit followed by 17 value bits, the most significant bit first. The sign bit shall be 0 for positive data and 1 for negative data. The value bits shall be in two's complement binary format.

6.6 CONTROL INPUTS

Six hardwired control discretetes are furnished to the AEA by elements of the Control Electronics Section. These are:

- 1) Automatic Discrete
- 2) Abort Discrete
- 3) Abort Stage Discrete
- 4) Follow-up Discrete
- 5) Descent Engine On Discrete
- 6) Ascent Engine On Discrete

The function of these discretetes is discussed more fully in Section 7, Program Logic. In general terms, they are supplied to control the flight program functions in accordance with the operational decisions and control manipulations of the astronaut and the state of the main engines. The state of these discretetes, all of which are included in Discrete Word 1, shall be examined continuously at a rate of once every 40 ms and the information conveyed by them shall be used to accomplish the objectives of the program.

6.7 CONTROL AND DISPLAY OUTPUTS

6.7.1 Engine Commands

The flight program shall generate either an Engine OFF or an Engine ON command continuously at a rate of once every 40 ms by setting and resetting the appropriate discrete outputs. The rules for determining which command

is to be issued are given in Paragraphs 7.3.1.4.5 and 7.3.1.4.6.

6.7.2 Attitude Errors

The attitude errors are defined to be the errors in angular displacement about the LM body axes as determined by the attitude equations. A positive value of attitude error shall require that a positive right-handed rotation be produced about the corresponding body axis in order to reduce the attitude error to zero.

Attitude error signals shall be computed for both control and display in accordance with the guidance requirements discussed in 4.10.1 and the program logic discussed in paragraph 5.2. The output data shall have the following characteristics:

- 1) Output rate: 25 times per second
- 2) Computation delay: The computation interval between the output of an attitude error signal and the most recent gyro input on which the computation is based shall not exceed 15 ms.
- 3) Word length: Sign plus 9 bits
- 4) Scaling: Least significant bit equals 0.5113269×10^{-3} rad.

The above word length and scaling correspond to a minimal excursion of ± 15 deg. for attitude error.

6.7.3 Total Attitude Display Signals

The flight program shall compute and output six quantities suitable for driving the gimbals of the Flight Director Attitude Indicators (FDAI). These quantities are the sines and cosines of that set of Euler angles, α , β , and γ , which will cause the FDAI to display the total attitude of the vehicle with respect to the inertial frame of the flight program. The relationship of these Euler angles to the elements of the transformation matrix maintained by the attitude reference routine, paragraph 4.4, is as follows:

$$[A] = \begin{bmatrix} (C\alpha C\gamma + S\alpha S\beta S\gamma) & S\alpha C\beta & (-C\alpha S\gamma + S\alpha S\beta C\gamma) \\ (-S\alpha C\gamma + C\alpha S\beta S\gamma) & C\alpha C\beta & (S\alpha S\gamma + C\alpha S\beta C\gamma) \\ C\beta S\gamma & -S\beta & C\beta C\gamma \end{bmatrix}$$

The total attitude display quantities shall be computed and output continuously with the following characteristics:

- 1) Output rate: 25 times per second
- 2) Word length: Sign plus 9 bits
- 3) Scale factor: Most significant value bit equals 0.5.

6.7.4 Lateral Velocity Signals

The projection of the inertial velocity of the LM vehicle onto its Y body axis shall be computed and output continuously to provide a signal for displaying lateral

velocity on the X-Pointers. The output characteristics shall be as follows:

- 1) Output rate: Five times per second
- 2) Word length: Sign plus 8 bits
- 3) Scaling: Most significant value bit equals 100 fps.

6.7.5 Altitude and Altitude Rate Signals

The altitude of the LM vehicle above the attracting body (lunar missions only) and the altitude rate shall be computed and output continuously for display on the Altitude/Range Indicator. Since both quantities are loaded into the same output register, successive loadings of the register must be spaced by a minimum of 270 μ s to allow time for the previously loaded data to be shifted out. Each output of altitude shall follow the corresponding altitude rate output within no more than 1.5 ms. The output rate for both quantities shall be five times per second. Other characteristics shall be as follows:

Altitude

Word length: 15 bits
Scaling: Least significant bit equals 2.34 ft
Format: Magnitude

Altitude rate

Word length: Sign plus 14 bits
Scaling: Least significant bit equals 0.5 fps.
Format: Most significant bit is sign bit, one for positive value and zero for negative value.

6.7.6 Test Mode Failure Discrete

The Test Mode Failure Discrete shall be set to activate the AGS Failure Warning Light and the Master Alarm Light to indicate the occurrence of a failure in the AEA. The discrete shall be set in the event that any one of the following three conditions occur:

- 1) The detection by AEA hardware sensors of out-of-tolerance temperature, power supply voltage, or 400 Hz frequency
- 2) The detection of asynchronous program operation as indicated by the fact that an instruction other than a Delay instruction is being executed when the 20 ms timing pulse is generated
- 3) The detection by the Inflight Self-Test Routine of a failure in the AEA memory of circuitry.

A capability for resetting the Test Mode Failure by means of a DEDA entry shall be provided. This entry shall be made into the inflight self-test status indicator memory location specified in the following paragraph.

6.7.6.1 Inflight Self-Test Routine

The flight program shall contain an Inflight Self-Test Routine which shall be used continuously to indicate that the computer logic circuits and memory are functioning properly. The routine shall provide for two independent tests, a logic test and a memory test. The logic test shall provide for execution of all computer instructions, except those associated with input/output operations. The memory test shall perform a checksum of all of the hardware

memory plus most of that portion of the software memory which contain fixed data.

A DEDA accessible memory location shall be varied to indicate the status of the inflight self test. An indication of successful test completion, logic test failure, memory test failure, and a combination of both logic and memory test failure shall be provided. In the event that a failure is indicated, the operation of the Inflight Self-Test Routine shall be inhibited. The test shall be reinitiated by resetting the inflight self test status indicator memory location via the DEDA.

6.8 GSE SERVICE ROUTINE

The hardware portion of the AEA flight program shall contain a GSE Service Routine to provide the capability for loading the software (erasable) portion of the AEA memory with data supplied from ground support equipment either BTME or ACE, through the Downlink Telemetry Register. The number of 18-bit words to be loaded can be variable and will be controlled by the ground support equipment.

The first word loaded shall not be part of the data to be stored. That word shall have the octal form 77xxxx, where xxxx is the starting address for the sequence of memory locations in which the subsequent data is to be stored.

Initiation of data transfer will be controlled by the ground support equipment. In order to control the transfer

of data into the AEA memory, the GSE Service Routine shall recognize the receipt of two input discrettes, GSE 1 and GSE 2, transmitted from the ground support equipment. In addition, the routine shall generate an output discrete, GSE 5. GSE 1 will be set to notify the AEA that a complete word has been loaded by the ground support equipment into the AEA Downlink Telemetry Register. The GSE Service Routine shall cause the AEA to acknowledge receipt and storage of that word by setting the GSE 5 discrete. Receipt of GSE 5 by the ground support equipment will cause the test equipment to reset GSE 1, and to repeat the input sequence for the next word to be loaded.

Following the transmission of the last data word to be loaded, an additional word will be transmitted, accompanied by the setting of both GSE 1 and GSE 2. This additional word will not be loaded into the AEA memory. Upon sensing GSE 2, the GSE Service Routine shall transfer program control to the starting address given in the first input word.

No provision need be made in the GSE Service Routine for checksum verification of the data transfer or any other indication of successful information transfer.

6.9 RADAR DATA PROCESSING

The flight program shall provide a capability for accepting and processing data obtained from the Rendezvous Radar.

This data shall be used to refine the estimate of the LM position and velocity state vector as maintained by the navigation equations specified in Paragraphs 4.1.1 and 7.3.2.1.

No direct connections exist between the Rendezvous Radar and the AEA. Radar data shall be obtained by appropriate astronaut procedures and entered into the AEA via the DEDA. The radar data will consist of the following:

- 1) Range between the LM and CSM entered in units of nautical miles quantized at 0.1 nmi.
- 2) Range Rate between the LM and CEM entered in units of feet per second quantized at 0.1 fps.
- 3) A code entered at the instant an apparent null is achieved in the angular displacement between the Z body axis and the pointing direction of the Rendezvous Radar when the radar is locked onto the CSM.

It may be presumed that Range will be entered within 30 seconds of the time that the Z body axis null code is entered. Range Rate will be entered independently of the requirement to null the Z body axis/Rendezvous Radar angular displacement.

The radar data processing equations shall provide a capability for compensating for misalignment between the boresight

of the Rendezvous Radar and the Z body axis when the radar gimbal angles are at zero. If the misalignment is measured and the resulting data is supplied, appropriate compensation constants shall be entered into the program prior to launch. The equations shall be capable of compensating for misalignments up to 1 deg.

The flight program shall accept the radar input data without any editing or reasonableness checks. The data shall be processed to reduce the errors contained therein as defined in Paragraph 6.9.1. This processing shall be consistent with obtaining reasonable reductions in the errors in the estimates of LM position and velocity at ranges not exceeding 100 nmi provided at least one group of five range readings is entered at intervals of approximately three minutes between readings on earth missions and four minutes between reading on lunar missions. There is no requirement to estimate residual misalignment errors, systematic errors, drifts, or bias in the radar data.

6.9.1 Rendezvous Radar Error Model

- 1) Angle bias error: 15 mr (3σ)
This angle bias error includes the total vector sum of the per axis misalignments between the ASA reference axes and the Rendezvous Radar.
- 2) Angle random error:
 - a) 8.1 mr to 6.9 mr (3σ) linear variation from ranges 400 nmi to 200 nmi.

- b) 6.9 mr (3σ) from ranges 200 nmi to 5 nmi.
- 3) Range Rate bias error: 1 fps (3σ)
- 4) Range Rate random error; 1.3% of Range Rate or 1.3 fps (3σ), whichever is larger from 400 nmi to 80 ft. Maximum Range Rate reading is ± 700 fps.
- 5) Range Rate display error: $\pm 1/2$ fps (uniform distribution)
- 6) Range bias error:
 - a) ± 80 ft (uniform distribution) for Range less than 50.8 nmi.
 - b) ± 500 ft (uniform distribution) for Range greater than or equal to 50.8 nmi.
- 7) Range random error:
 - a) 0.083% or 300 ft (1σ) whichever is larger for ranges from 400 nmi to 10 nmi.
 - b) 300 ft (1σ) for ranges from 10 nmi to 5 nmi.
- 8) Range display error:
 - a) ± 1 nmi (uniform distribution) for ranges from 400 nmi to 10 nmi.
 - b) ± 50 ft (uniform distribution) for ranges from 10 nmi to 5 nmi.

No errors are given for ranges less than 5 nmi since it is not anticipated that radar data will be entered in this region.

7.0 AGS DETAILED PERFORMANCE REQUIREMENTS

7.1 Detailed Hardware Requirements

7.1.1 ASA Performance. The ASA will meet the performance requirements specified on an individual ASA basis. If, as a result of the mission environment, the linear accelerations and angular rates exceed the requirements specified herein and the inertial sensors encounter their stops, loss of attitude reference and velocity may result, at which time performance requirements will not be met. Immediately after this shock, the ASA shall meet full performance requirements. (Also see para. 6.3.1)

- (a) Service Environments, Conditions and Life. The AGS shall meet all the requirements of this specification during and after exposure to all service environments, under all service conditions and throughout the operating life as specified under this paragraph.
- (b) Service or Mission Environments. The service or mission environments, operating or non-operating, and the corresponding duration and condition of exposure for the ASA will be as specified in Tables IA and IIA and Table I, Vol. 2. The service environments include all ground handling environments and flight environments.
- (c) Service Conditions. The ASA in the configuration listed below, will satisfy all the performance requirements of this specification while subjected to the environmental condition specified herein.

- (1) Packaged in shipping containers
 - (2) Unpackaged, not operating
 - (3) Unpackaged, operating
 - (4) Installed, not operating
 - (5) Installed, operating
- (d) Operating Life. The ASA shall be designed for a minimum operating life of 5000 hours with scheduled maintenance and a minimum shelf life of five years. During the total operating life, the ASA shall satisfy the requirements of this specification without requiring scheduled maintenance or adjustment for intervals of at least 1000 hours operating time. These 1000 hour intervals of scheduled maintenance free operation are not to be construed as continuous time. Operating time may be accumulated either continuously or intermittently and there shall be no restriction on duty cycle. However, for requirements specified over a 120 day period, it is to be understood that the applicable period is calendar time.

7.1.1.1 ASA Outputs. The ASA provides the AEA with incremental angular information about the vehicle x, y and z axes and incremental velocity changes along the vehicle x, y and z axes. The incremental data in the form of pulses are accumulated in six 11-bit input registers of the AEA. During any one-millisecond period, the presence of 61 pulses represents the maximum positive signal; the presence of 3 pulses represents the maximum negative signal. The bias of 32 pulses per millisecond shall be removed by the program after sampling the input register. The input register shall be sampled at least every 20 msec and shall be cleared under program control upon sampling.

The nominal pulse weight of the velocity increments is (0.1/32)feet/second/pulse. The nominal pulse weight of gyro increments is 2^{-16} radians.

Symbols. -

- (a) Gyro Outputs (ΔA_{xi} , ΔA_{yi} , ΔA_{zi})
- (b) Accelerometer Outputs (ΔV_{xi} , ΔV_{yi} , ΔV_{zi}).

7.1.1.1.1 Following Errors. -

7.1.1.1.1.1 Steady-State Following Error. - The ASA shall be capable of following rotational rates up to and including 25° per second about each axis with a maximum steady-state following error of 30 arc seconds (excluding the time delay due to output signal quantization).

7.1.1.1.1.2 Dynamic Following Error. - The instantaneous dynamic following error (including the time delay due to output signal quantization) shall not exceed 180 arc seconds under the following input conditions:

- (a) All input conditions as specified in Table I of Volume 2.
- (b) An angular acceleration step function of 2 rad/sec^2 driving the input angular rate from an initial value of plus (or minus) 25° per second to a final value of minus (or plus) 25° per second.

7.1.1.2 Gyro Channel Performance.

7.1.1.2.1 Combined Rates. The ASA is capable of following rotational rates up to and including 25.0 degrees per second consecutively or concurrently about all vehicle axes with a maximum lag of 0.05 degrees per axis under all input conditions.

7.1.1.2.2 Gyro Sensitive Axis Alignment. The misalignment of the X gyro input axis with respect to the Y ASA reference axis, the Y gyro input axis with respect to the X ASA reference axis, and the Z gyro input axis with respect to the X ASA reference axis, and the Z gyro input axis with respect to the Y ASA reference axis shall not exceed 130 arc seconds. The misalignment of the X gyro input axis with respect to the Z ASA reference axis and the Y gyro input axis with respect to the Z ASA reference axis shall not exceed 250 arc seconds. These requirements shall apply over the maintenance free periods as defined in 7.1.1, but shall not include changes induced by the flight environment. The alignment changes induced by the flight environments shall not exceed 60 arc seconds (3σ).

7.1.1.2.2.1 ASA Reference Axes Definition - The ASA Reference

Axes are specified as follows:

X Reference Axis: The X reference axis is defined as a line in a perfectly flat plane on which the ASA is mounted. The X reference shall also lie in the plane formed by the centerline of .3128 hole and .3131 slot.

Y Reference Axis: The Y reference axis is defined as a line in a perfectly flat plane on which the ASA is mounted. The Y reference axis shall also lie in the plane perpendicular to the plane formed by the center line of .3128 hole and .3131 slot, and passing through the center line of .3128 hole.

A Reference Axis: The Z reference is defined as a line perpendicular to a perfectly flat plane on which the ASA is mounted coincident with the axis of .3128 hole.

The definition of .3128 hole and .3131 slot is that defined in the ASA Spec Control Drawing, LSC 300-370.

7.1.1.2.3 Gyro Channel Drift Rate. The drift rate of a gyro channel is the deviation of the rotation rate indicated by a gyro channel from the true input rate. It includes the effects of gyro channel bias, vibration induced drift rate, gyro input mass unbalance and gyro spin axis mass unbalance.

The components of drift rate about each ASA axis shall not exceed the values specified below. The time period for averaging drift rate shall be 260 seconds.

7.1.1.2.3.1 Gyro Channel Bias. The absolute value of the non-sensitive drift rate shall not exceed 2.4 deg/hr. This requirement shall apply over scheduled maintenance free periods as defined in 7.1.1.

The bias instability over a three day period shall not exceed 0.67 deg/hr (3σ). The bias instability over an 8 day period shall not exceed 0.85 deg/hr (3σ). The bias instability over a period of 120 days shall not exceed 2.8 deg/hr (3σ).

Residual bias changes due to shock and vibration shall be included but bias discrepancies due to orientation changes and transient changes during vibrations shall not be included.

The difference between the mean bias determined when the input axis is vertical and the mean bias determined when the output axis is vertical shall not exceed 0.2 deg/hr. The difference between the mean bias determined when the spin axis is vertical and the mean bias determined when the output axis is vertical shall not exceed 0.2 deg/hr. The difference between the mean bias determined when the output axis is up and the mean bias determined when the output axis is down shall not exceed 0.33 deg/hr.

(The mean bias determined when the output spin or input axis is vertical is defined to be the average of the mean bias determined when the output spin or input axis is up and the mean bias determined when the output axis is down.)

7.1.1.2.3.2 Gyro Channel Drift Rate (Vibration Environment).

The absolute value of the drift rate attributable to the mission vibration environment, shall not exceed 0.25 deg/hr. This requirement shall apply over scheduled maintenance free periods as defined in 7.1.1.

7.1.1.2.3.3 Gyro Channel Input Mass Unbalance. The absolute value of the input axis mass unbalance shall not exceed 4.0 deg/hr/g. This requirement shall apply over scheduled maintenance free periods as defined in 7.1.1.

The input axis mass unbalance instability over a period of 120 days shall not exceed 1.4 deg/hr/g (3σ).

7.1.1.2.3.4 Gyro Channel Spin Axis Mass Unbalance. The absolute value of the spin axis mass unbalance shall not exceed 4.0 deg/hr/g. This requirement shall apply over scheduled maintenance free periods as defined in 7.1.1.

The Spin axis mass unbalance instability over a period of 120 days shall not exceed 1.4 deg/hr/g (3σ).

7.1.1.2.4 Gyro Channel Scale Factor. The scale factor of each gyro channel shall be 2^{-16} radians/pulse plus or minus 4500ppm. This requirement shall apply over scheduled maintenance free periods as defined in 7.1.1.

The scale factor instability over a period of 120 days shall not exceed 0.000870 deg/deg (3σ).

7.1.1.2.5 Gyro Channel Nonlinearity. For rotation rates from 0.0 deg/sec to 22 deg/sec the loss of attitude reference about each axis due to gyro channel non-linearity shall not exceed 0.00020 deg/deg. For rotation rates from 22 deg/sec to 25 deg/sec, the loss of attitude reference due to gyro channel non-linearity shall not exceed 0.00058 deg/deg. These requirements shall apply over scheduled maintenance free periods as defined in 7.1.1.

7.1.1.2.6 Off-Null Limitation. The gyro loops shall instantaneously maintain the gyro gimbal rotations about their output axes within 40 arc seconds under all input conditions specified in Tables 1A and 2A.

7.1.1.2.7 Gyro Assymetry (See Fig. 7-1)

7.1.1.3 Accelerometer Channel Performance

7.1.1.3.1 Acceleration Range. The ASA shall be capable of sensing acceleration along the vehicle X, Y and Z axes within the range from minus 90 ft/sec² to plus 90 ft/sec². The ASA shall be capable of detecting velocity changes of 0.05 ft/sec. along each vehicle axis.

7.1.1.3.2 Accelerometer Sensitive Axis Alignment. The misalignment of the Y accelerometer input axis with respect to the X ASA reference axis and the Z accelerometer input

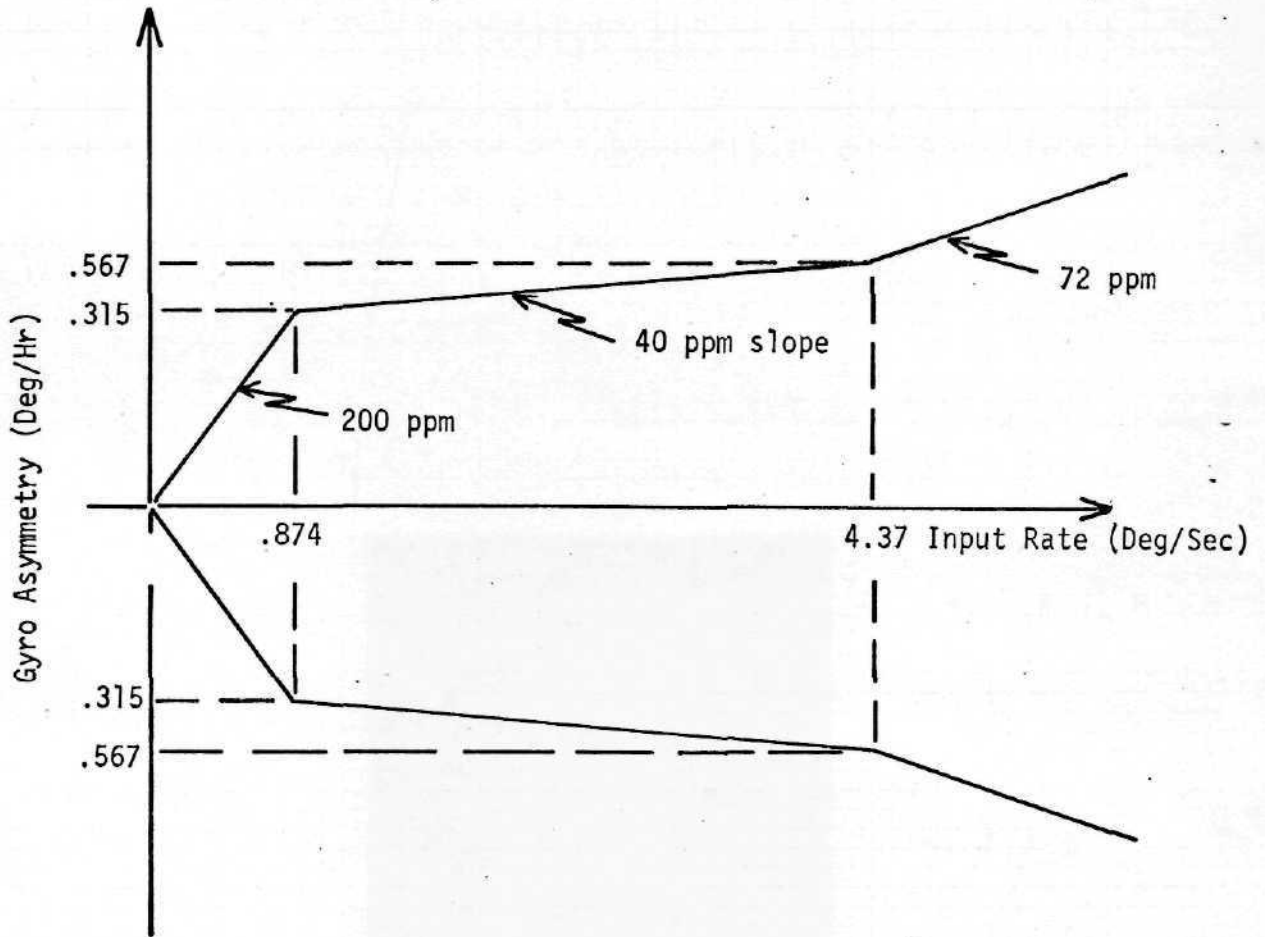


Figure 7-1
Limits on Gyro Asymmetry

TABLE 7-1

LIMITS ON THE MAXIMUM VALUE OF ASA PARAMETERS

PARAMETER		
GYRO BIAS		2.4°/hr
GYRO BIAS DISCREPANCY	OA	.33°/hr
GYRO BIAS DISCREPANCY		.2°/hr
GYRO SCALE FACTOR		4500 ppm
GYRO NONLINEARITY		180 ppm
GYRO ASSYMETRY SPREAD		See Figure 7-1.
GYRO SPIN AXIS UNBALANCE		4°/hr/g
GYRO INPUT AXIS UNBALANCE		4°/hr/g
GYRO MISALIGNMENT, CRITICAL		130 sec
GYRO MISALIGNMENT, NONCRITICAL		250 sec
	BELL VII	KEARFOTT
ACCELEROMETER BIAS	1500 ug	1500 ug
ACCELEROMETER BIAS DISCREPANCY	100 ug	100 ug
ACCELEROMETER SCALE FACTOR	4500 ppm	Open
ACCELEROMETER SCALE FACTOR NONLINEARITY	100 ug	100 ug
ACCELEROMETER MISALIGNMENT, CRITICAL	130 sec	130 sec
ACCELEROMETER MISALIGNMENT, NONCRITICAL	250 sec	250 sec

axis with respect to the X ASA references shall not exceed 130 arc seconds. The misalignment of the X accelerometer input axis with respect to the Y ASA reference axis, the X accelerometer input axis with respect to the Z ASA reference axis, the Y accelerometer input axis with respect to the Z ASA reference axis and the Z accelerometer input axis with respect to the Y ASA reference axis shall not exceed 250 arc seconds. These requirements shall apply over the maintenance-free periods as defined in 7.1.1, but shall not include changes induced by the flight environment. The alignment changes caused by the flight environment shall not exceed 60 arc seconds (3σ).

7.1.1.3.3 Accelerometer Channel Bias. The absolute value of the bias of each accelerometer channel shall not exceed 600 μ g. This requirement shall apply over scheduled maintenance free periods as defined in paragraph 7.1.1 (d).

The bias instability over a period of 3 days shall not exceed 113 μ g (3σ). The bias instability over a period of 120 days shall not exceed 585 μ g (3σ). Residual bias changes due to shock and vibration shall be included. Bias discrepancies due to orientation changes and transient changes during vibration shall not be included.

The difference in the mean bias determined when the pendulous axis is vertical (up and down) and the mean bias determined when the output axis is vertical (up and down) shall not exceed 100 u g.

7.1.1.3.4 Accelerometer Rectification Error. The error in the sensed acceleration of each accelerometer channel attributable to the mission vibration environment shall not exceed 50 u g. This requirement shall apply over scheduled maintenance free periods as defined in 7.1.1 (d).

7.1.1.3.5 Accelerometer Scale Factor. The scale factor of each accelerometer channel shall be 0.003125 ft/sec/pulse plus or minus 0.45 percent. This requirement shall apply over scheduled maintenance free periods as defined in paragraph 7.1.1.(d).

The scale factor instability over a period of 120 days shall not exceed 940×10^{-6} g/g (3).

7.1.1.3.6 Accelerometer Non-linearity. For positive and negative input accelerations to 90 ft/sec^2 , the error in z sensed acceleration shall not exceed 100×10^{-6} g/g. This requirement shall apply over scheduled maintenance free periods as defined in paragraph 7.1.1 (d).

7.1.1.3.7 Limit Cycle Pendulum Motion. The accelerometer pendulum rotations about their output axes due to forced limit cycles under steady-state acceleration shall not exceed 40 arc seconds.

7.1.1.3.8 Dynamic Following Error. The instantaneous dynamic following error in each channel (including the time delay due to output signal quantization) shall not exceed 0.5 feet per second when subjected to an input acceleration ramp function of zero to one g in 50 milliseconds.

7.1.2 DEDA Performance Requirements. The AGS program shall provide for read-in, decoding and storage of mode commands, instructions and data for processing as required. The sequence of operations necessary to insert data is specified in 7.3.3.2.2 through 7.3.3.2.12. The DEDA keyboard, as shown in Figure 1, shall be used to insert the following:

- (a) Control discretetes
- (b) Initialization
- (c) Lunar Align Data
- (d) Rendezvous Radar Data
- (e) Mode and Submode Commands and instructions
- (f) Trajectory Data and Constraints

Logic power is supplied to the DEDA only during the AGS operate mode. Lighting power is supplied to the DEDA

independent of the AGS Status switch position, but the EL numerics shall remain extinguished until the DEDA is supplied logic power. When the AGS is OFF there is no power applied to the DEDA.

7.1.2.1 DEDA Control Discrettes. The control discrettes specified below shall be included in the DEDA Processing Routine (DPR) as described in 7.1.3.5.1 and 7.1.3.5.2.

- (a) Enter Discrete - With the activation of this control, the AGS program shall cause 36 bits of information to be transferred from the DEDA to the AEA serially in groups of four. Depending on the address specified, the entering information may be mode commands, instructions, or input data. The mode commands and instructions shall be stored in the appropriate memory cell. Input data shall be decoded from binary-coded-decimal to two's complement binary and scaled from the input scaling specified herein to that required for subsequent computations using stored scaling information. The information that shall be entered from the DEDA shall be as specified in paragraph 7.3.3.2.1 (c).
- (b) Readout Discrete - Shall be used to instruct the AEA to read-out on the DEDA data display the information specified in paragraphs 7.3.3.2.14 and 7.3.3.4.1. It shall also negate the Hold discrete if it has been activated (see paragraph 7.3.3.2.1 (b)).
- (c) Hold Discrete - When the Hold discrete is activated the DEDA data readout is stopped and updating of the data being outputted to the DEDA display is halted, (see paragraph 7.3.3.2.1 (d)).
- (d) Clear Discrete - Activation of the clear push-button causes all DEDA inputs not already transferred to the AEA to be reset and also causes the Readout, Hold discrettes to be reset (see paragraph 7.3.3.2.1 (a)).

7.1.2.2 DEDA Input Processing. The AEA shall provide input (via the AEA DEDA Data Input Signal Line) of any preselected parameter by the DEDA upon receipt of an Enter Data Signal. The maximum number of parameters that may be preselected for input to the deda shall be 777 (octal notation) equivalent to 512 (decimal notation). Based on other software considerations, fewer quantities than the maximum may be made available.

7.1.2.3 DEDA Output Processing. The same locations available for DEDA inputs shall be made available for DEDA outputs. Upon receipt of the Readout discrete from the DEDA, the AGS program shall transfer to the AEA through the DEDA Data Register, in four-bit serial groups, 9 bits of octal address information held in the DEDA with the format specified in 7.1.3.5.2 by using the DEDA 4 Bits In Discrete. The data held in the addressed memory cell shall be scaled as specified in 7.3.3.4.1 coded into binary-coded decimal and, along with the address information, transferred to the DEDA through the DEDA Data Register in four-bit serial groups with the format specified in 7.1.3.5.2 by using the DEDA 4 Bits In Discrete. This data shall be transmitted to the DEDA at a rate not to exceed twice per second unless the Hold Discrete is received from the DEDA. When the Hold discrete is received, the Program shall stop transmitting the data, but shall resume data transmission from the same address when the Readout discrete is received. Data transmission shall be terminated following receipt of the

Clear discrete (see paragraph 7.1.3.5.1 and 7.1.3.5.2).

7.1.3 AEA Performance Requirements.

7.1.3.1 Modes of Operation. AGS mode selection shall be accomplished with externally applied instructions generated by the DEDA and AEA inputs via the CES. When the AEA is off, it shall be inoperative and shall require no power. The mode instructions shall be present only in the mode selected. The proper initialization for each mode shall be provided during all modes of operation.

7.1.3.2 Conditions of Operation. The off, standby, and operate conditions shall be initiated by the application of an external standby signal and 28 VDC. During Standby and/or operate, the AEA shall accumulate PGNCs, alignment signals and supply a clock signal to the ASA. Twenty seconds following initiation of Standby, the AEA shall be capable of accepting PGNC angles and shall be prepared to start the alignment operation.

7.1.3.3 AEA Memory Allocation. Functions to be incorporated in either the hard-wire or soft-wire portions of the AGS memory shall be allocated as follows: Hard-wired and Soft-wired octal constants are presented in 7.3.1.3.

(a) Hardwired portion (Refer to Table VIII) - The hard-wired portion of the AEA shall:

(1) Have a capacity of 2048 words

- (2) Contain constants, or instructions or both
 - (3) Contain only those functions which can be checked out and tested without using closed loop flight simulation.
 - (4) Contain as many of the 20 ms and 40 ms computations as possible in order to reduce power consumption (see paragraph 7.3.2.6).
- (b) Soft-wired portion - The soft-wired portion of the AEA shall:
- (1) Contain functions directly related to astronaut procedures.
 - (2) Contain those functions or parts of functions which directly interface with other subsystems in the LM and are most subject to change.
 - (3) Contain those constants and scalings which would be affected by earth orbit or surface operations.
 - (4) Contain the guidance option logic and equations.

7.1.3.3.1 Hardwired and Softwired Linkage Requirements.

Provisions shall be made for linking the soft and hard memories through escape points. These escape points shall be programmed in a manner and at locations to permit future alterations to the final program.

7.1.3.4 AEA Inputs. The following equipments shall supply inputs for processing within the AEA: (See Table 6-1 and Table I paragraph 10.1 for input signal characteristics).

- (a) DEDA (See 7.1.3.5.1 and 7.1.3.5.2)

- (b) Control Electronics Section (CES)
- (c) Instrumentation Sybssystem
- (d) ASA
- (e) PGNCS
- (f) GSE

See Table 6-1 for Input-Output signals.

7.1.3.4.1 Time Initialization. The absolute time initialization information will be entered via the DEDA in single precision with the value of the least significant digit of 0.1 min. (see para. 4.3).

7.1.3.4.2 LM & CSM Navigation Initialization. The LM navigation initialization data provided via the DEDA will consist of velocity and position in the AGS inertial coordinate frame existing at the time of initialization, and epoch in the AGS time base (see para. 4.1.3).

The initialization data will be expressed in AGS navigation units: feet, feet per second, minutes.

The word format of the input from DEDA will consist of 5 decimal digits plus sign. The data (position, velocity, and time) will be in single precision. The value of the least significant digit of position will be 100 feet, of velocity 0.1 feet per second. The least significant digit of the epoch will be 0.1 min. See para. 7.2.17.1 and 7.2.17.3 for accuracy and frequency of initialization.

7.1.3.4.3 Lunar Align Data. The lunar align data input via DEDA will consist of the azimuth correction factor $\Delta \delta$ (see 5.2.3.1.2). The input data word format will be octal digits (in radians) plus a sign digit.

7.1.3.4.4 Rendezvous Radar Data. Rendezvous radar data provided via the DEDA will consist of radar range, radar range rate, and a code indicating that the radar pointing error with respect to the vehicle z-axis is nulled (see paragraph 6.9, 7.2.9.1, and 7.2.9.2).

7.1.3.4.5 Input Instructions Provided via the DEDA. (See 7.3.3.2.15).

7.1.3.4.6 Trajectory Data and Constraints. The trajectory data provided via the DEDA is specified in paragraph 7.3.3.4.1.

7.1.3.4.7 CES Inputs. The CES will furnish the AEA with the following input signals:

- (a) Abort
- (b) Abort Stage
- (c) Ascent Engine On
- (d) Descent Engine On
- (e) Automatic

- (f) Followup
- (g) 800 cps reference

7.1.3.4.8 Instrumentation Subsystem (IS). The IS will furnish the AEA with:

- (a) Basic AEA Clock (1.024 mc)
- (b) Telemetry control signals for extracting information from the AEA. (AGS Downlink "Stop" pulse, AGS Downlink bit sync pulses).
- (c) Control Signals for inserting PGNCS Downlink Data into the AEA (PGNCS Downlink "Stop" pulse PGNCS Downlink Bit Sync Pulses)

7.1.3.4.9 PGNCS Inputs. The PGNCS shall furnish the following input signals:

- (a) IMU Gimbal Angles (for IMU Alignment Mode). The PGNCS will furnish the AEA $\pm \Delta \theta$, $\pm \Delta \psi$, $\pm \Delta \phi$, and CDU ZERO signals with the characteristics listed in Table I, para. 10.1. During all modes of operation, the AEA shall sum (in three registers) the Delta angle signals in order to have the IMU θ , ψ , and ϕ gimbal angles available for the IMU Alignment Mode. The CDU ZERO signal is a short duration signal that will clear the AEA registers at the same time similar registers are cleared in the PGNCS. The effect of CDU ZERO is to assure that subsequent to its issuance, the gimbal angle data in the PGNCS and AGS is the same.
- (b) PGNCS Downlink Data for AGS Initialization. Under control of telemetry signals from the Instrumentation Subsystem (see para. 7.1.3.4.8), the AEA shall be capable of reading into a register (the Downlink Telemetry Register), the first 18 bits of each 40-bit transmission of the PGNCS Digital Downlink. During AGS initialization and after command via the DSKY,

the LGC will transmit a special downlist 10 times. This list will be headed by a unique ID word following which there will be 16 words giving the LM and CSM state vectors and epoch times (modified). The general format of the portion of the list of concern to the AEA is shown in Table II. During the 10 transmissions of this list, no LGC interrupts will occur to this format.

The AEA will process under program control the first 16 bits loaded into the 18-bit register. The bit streams from the LGC for the ID and data words for the AGS Initialization list shall be as follows for the 16 bits used by the AEA

ID WORD.

0	00000	0000000001
WORD		(List Identifier)
ORDER		
CODE		

NOTE: Bits appear at the AEA in sequence.

DATA WORD

1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
WORD	S	MSB													LSB
WORD	I	of													of
ORDER	G	LGC													LGC
CODE	N	Word													Word

X = 0 or 1

Note: The sequence in which these bits appear at the AEA is as above reading left to right.

These bit streams are loaded into the AEA register in the following format:

AEA BIT NO.	0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
ID WORD	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1
DATA WORD	1 X X X X X X X X X X X X X X X
	W S L
	O I S
	C G B
	N

The first bit accepted by the AEA is the Word Order Code and is "zero" if the word is an ID word or is "one" if the word is a data word. If the ID word is the unique AGS Initialization ID word, the Word Order Code bit will be followed by 14 "zeros" and then a "one". For data words, the bit following the WOC will be the sign. It will be followed by 14 value bits most significant to least significant. Data will be in 2's complement binary form.

The LM and CSM state vectors transmitted by the LGC in the AGS Initialization list shall have been transformed by the LGC into the LM IMU alignment coordinate system defined in 7.2.20 (a). The corresponding epoch times shall have been modified by the LGC subtracting a time bias, K, from the normal values.

Position and velocity component words will be single precision words (i.e, LGC single precision - sign bit and 14 value bits). The modified epoch time words will be double precision words. The bit weights will be as follows:

- Position: Most significant bit = 2^{22}_{12} feet
- Velocity: Most significant bit = 2 feet/second
- Time: Most significant bit of most significant half of word = 2^{17} seconds.

Most significant bit of least significant half-of-word = 2^3 seconds.
(Lunar-scaled flight programs).

7.1.3.5 AEA Outputs. The detailed characteristics of the output signals shall be in accordance with Table III , paragraph 10.3 (also see Table 6-1). The AEA shall provide signals to:

- (a) DEDA
- (b) CES
- (c) Instrumentation Subsystem
- (d) ASA
- (e) Displays and Controls Subsystem
- (f) GSE

7.1.3.5.1 DEDA Output Discrettes. The following output discrettes shall be used to transfer data to and from the DEDA.

- (a) DEDA 4 Bits Out - This discrete shall be set to cause transfer of 4 bits of information from the DEDA Data Register in the AEA to the DEDA. The maximum frequency of settings of this discrete shall be 12,500 per second.
- (b) DEDA 4 Bits In - This discrete shall be set to cause transfer of 4 bits of information from the DEDA to the DEDA Data Register in the AEA. The maximum frequency of settings of this discrete shall be 12,500 per second.

7.1.3.5.2 DEDA Information Format. Information shall be outputted from the AEA to the DEDA via the 4-bit DEDA Data Register in 4-bit serial groups. The information shall consist of 36 bits of octal address and binary-coded-decimal data for output data or octal address and octal-coded signal for output signals with the following format:

Total bits		36
Address	Sign	Data
12	4	20
Address is	Octal 8421	
Sign	000x where + = 0, - = 1.	
Data Bits	8421 BCD	

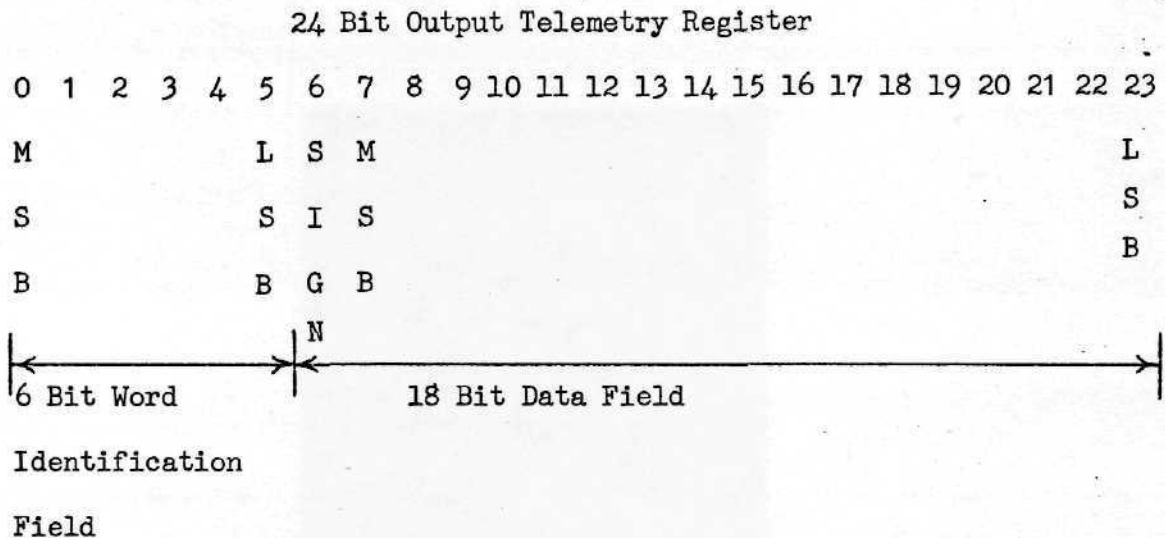
The output rate of the total information shall be every 0.5 ± 0.02 seconds.

7.1.3.5.3 DEDA Data. The data output to the DEDA shall consist of five decimal or octal digits plus sign (see paragraph 7.3.3.4.1).

7.1.3.5.4 CES. The AEA shall provide the CES with steering signals (E_x, E_y, E_z) and engine commands (Engine On Command and Engine Off Command).

7.1.3.5.5 Instrumentation Subsystem. Under control of signals from the Instrumentation Subsystem (see paragraph 7.1.3.4.8 (b)) the AEA shall supply the Downlink with a

24 bit serial digital word at the rate of 50 words/sec. It will transmit a fixed list of 50 words each second (see paragraph 7.3.3.4.2). The 24 bit word shall be assembled in the Output Telemetry Register. The serial bit stream will be from most significant bit of the register (position 0) to least. The format is as follows:



The word identification field contains the ID or serial number of the data in the fixed list of 50. The ID ranges from 1 to 50 (01 to 62 octal). For example the bit configuration in the ID field for the 50th word is

1	1	0	0	1	0
0	1	2	3	4	5

7.1.3.5.6 ASA. The AEA shall provide the ASA with a 128 kpps synchronizing signal.

7.1.3.5.7 Displays and Control Subsystem Output. The

AEA shall continually provide the Display and Control Subsystem with:

- (a) Total attitude (sin α and cosine α , sin β and cos β , sin γ , and cos γ) in the operate mode.
 - (b) Attitude error signals (E_x , E_y , E_z) during the Inertial Reference Mode.
 - (c) * Lateral body velocity (V_y)
 - (d) * Altitude (h)
 - (e) * Altitude rate (\dot{h})
- * V_y , h, and \dot{h} are output 5 times per second

7.2 DETAILED PERFORMANCE ACCURACY

7.2.1 Alignment Accuracy. The AGS shall be aligned to the accuracy specified within a 3 minute period. The single axis alignment error is defined as the average of the angular rotations about an axis of the desired inertial reference required to rotate each of the nominally orthogonal axes of the AGS inertial reference frame to be coincident within the corresponding axes of the AGS inertial coordinate frame.

- (a) PGNCS to AGS Alignment Accuracy - The AGS inertial reference frame shall be aligned to the PGNCS command angles with a maximum error of 4 arc minutes at the completion of the PGNCS to AGS Alignment Submode.

- (b) Lunar Alignment Accuracy - The AGS inertial reference frame shall be aligned to within 10 arc minutes, maximum, per axis of the gravity vector at the completion of the lunar align submode and shall be aligned to within 10 arc minutes of the stored value of azimuth. (See note).
- (c) Body Axis Alignment Accuracy - The AGS inertial reference frame shall be aligned to within 3 arc minutes per axis of the ASA frame at the completion of the Body Axis Align Submode.

NOTE: If, as a result of the mission environment specified in 7.1.1, the linear acceleration and angular rates exceed the requirements specified in 7.1.1.2.1, 7.1.1.3.1, 7.2.8 and the inertial sensors encounter their stops, loss of attitude reference and velocity may result, at which time the performance requirements of this specification will not be met. Immediately after the shock, the AGS shall meet all the requirements of this specification after subsequent alignment and initialization, or after a lunar align provided the loss of azimuth reference due to the shock does not exceed 1.0 degrees.

7.2.2 PGNCS Alignment Data Accuracy. The accuracy of PGNCS alignment data transferred to the AGS is determined by errors associated with the measurements and computations involved in defining the desired orientation, the process of fine IMU alignment, the orientation drift of the IMU since the last fine alignment, the angle readout associated with the CDU's and the errors associated with the mounting misalignment of the ASA with respect to the attachment points of the PGNCS Navigation Base.

A limit on AGS alignment input data from the CDU, referred to the PGNCS Navigation Base attachment points for the

purposes of interface design is 2 milliradians plus 3 milliradians times the time in hours (3σ) since the last IMU fine alignment.

A limit on alignment of the ASA reference axes with respect to the PGNCB Navigation Base is 0.6 milliradians (3σ) (Refer to 7.1.1.2.2).

7.2.3 Navigation Accuracy. The maximum navigation computation error in inertial position and velocity encountered in an abort from hover until burnout shall be as follows:

- (a) Inertial position - 2500 feet for x, y, or z (including effects of lunar triaxiality).
- (b) Inertial velocity - 4 feet/sec for \dot{x} , \dot{y} , or \dot{z}

Navigation computation errors are considered to be those errors resulting from integration, lag, transformation between coordinate frames, round-off, and truncation.

7.2.4 Drift Rate. All errors resulting from the AEA processing limitations shall add up to an attitude reference drift rate which shall not exceed 0.2 deg/hr at any vehicle attitude for vehicle rotation rates up to 5 deg/sec, or 0.3 deg/hr for vehicle rotation rates up to 25 deg/sec.

7.2.5 Total Attitude Signal Accuracy. The total attitude signal shall be accurate to ± 0.5 degrees, maximum, per

axis except when within ± 0.5 degrees of either of the two attitude points of singularity. In this case, the maximum error in the angle " β " shall be less than 0.5 degrees and the maximum error in the sum of the angles $\alpha + \beta$ shall be less than 0.5 degrees.

7.2.6 Attitude Error Signal Accuracy.

7.2.6.1 Attitude Error Signal Range. The deviation of the actual attitude from the commanded attitude shall have a maximum magnitude of 180° . The range of the attitude error signals issued by the AGS shall be ± 15 degrees.

7.2.6.2 Attitude Error Signal Characteristics.

- (a) Attitude Error Signal Resolution - The attitude error signals shall have a resolution of 2 arc minutes or less per axis.
- (b) Attitude Error Signal Cycle Time - Attitude Error signals output to the CES shall be updated every 40 milliseconds.
- (c) Attitude Error Signal Computation Delay - The maximum computation delay between sampling of the rotations detected by the gyros and the subsequent output of attitude error signals shall not exceed 15 milliseconds.

7.2.6.3 CSM Acquisition Accuracy. The AGS shall provide attitude error signals of sufficient accuracy to command the LM Z-body axis to within an angle of 0.5 degrees of the AGS computed direction to the CSM during the CSM acquisition submode.

7.2.7 Time Base. The basis for all AGS navigation will be absolute time introduced into the AGS as an initialization operation. All initialization data introduced into the AGS shall be based on AGS absolute time (See para. 4.3).

7.2.8 Acceleration Range. The AEA shall be capable of processing accelerometer range of ± 90 feet/second² with a velocity increment of $0.1/32$ feet/second per pulse.

7.2.9 Radar Data Accuracy. The AGS shall combine radar data with AGS derived navigation variables to improve navigational accuracy. This data will be processed in a manner to reduce errors associated with statistical variation of radar input data. Radar data will be processed to determine smoothed position and velocity. No effort will be made to solve for radar misalignments, systematic errors, drifts and biases. The AGS shall have the capability to accept rendezvous radar information through the DEDA for purposes of navigation updating during periods of abort in free flight in a manner described above.

7.2.9.1 Radar Range. Radar range will be measured with no range averaging. There will be a bias error of ± 80 ft for ranges < 50.8 nm and ± 500 ft for ranges > 50.8 nm.

The random uncertainty on range will be independent between measurements and has the following characteristics:

<u>Radar Range</u>	<u>Radar Random Error</u>	<u>Display Resolution</u>
400 nm to 10 nm	0.083% (1σ) or 300 ft*	1 nm
10 nm to 5 nm	300 ft	50 ft
5 nm to 1000 ft	0.33 % (1σ) or 80 ft*	50 ft
1000 ft to 80 ft	80 ft	2.5 ft

* whichever is greater

The data will be in units of nautical miles. The least significant digit will be 0.1 n. mi. The maximum limit range data will be 400 n. mi. (See Para. 6.9.1).

7.2.9.2 Radar Pointing Error Nulled.

When the radar pointing error is nulled, a code is entered via the DEDA. The error in nulling has the following characteristics:

The one-sigma bias error on the radar gimbal null angular measurement is 5 mr., vector sum, total.

The random error has the one sigma values given below:

<u>Range</u>	<u>Random Error</u>	<u>Random Error Variation</u>
400 n mi	2.7 mr	Direct Variation with range
300 n mi	2.5 mr	
200 n mi	2.3 mr	
200 n mi	2.3 mr	
5 n mi	2.3 mr	Constant

Display resolution is $1/12^\circ$ (1σ)

- (a) Bias error is the mean value of the error between the true value of the parameter and the indicated value averaged over any 10 min. interval.
- (b) Random error is the variation of the error about the bias error. It is assumed that the astronaut generates error signals for the autopilot to null radar angle based on these measurements.

At least one radar data point will be available to the AGS in every 4 minute interval. Maximum variation in RR angle bias shall not exceed 0.5 mr in any 10 minute time period.

7.2.9.3 Radar Range Rate Accuracy. The range rate measurement accuracy over the operating limits of ± 4900 fps (i.e. closing or opening) and 400 n.mi., is as follows:

Radar Random Error (3σ) = 1.3% or 1.3 fps whichever
is greater

Radar Bias Error (3σ) = 1.0 fps

Display Resolution = 0.5 fps

- Notes: (1) The bias and random error definitions specified in 7.2.9.2 apply.
- (2) The random uncertainty specification includes quantization uncertainties in the RR.

7.2.10 Orbit Insertion. For aborts subsequent to the start of powered descent and prior to the end of powered ascent, the AGS shall have the capability of inserting the LM initially into a standard elliptical orbit having a minimum clear pericyynthion of 30,000 feet above the mean lunar radius. Capability shall be provided to perform a fully automatic orbit insertion maneuver as described above using initialization

data from any one of the following sources: PGNCS, CSM Voice Link and MSFN, whenever they are available. Accuracy and availability of these initialization sources are given in paragraph 7.2.17.

7.2.11 Coelliptic Orbit Sequence. For aborts prior to the start of powered descent or after insertion into the elliptical orbit, the AGS shall have the capability to perform a series of coelliptic rendezvous burns as described in paragraph 4.10.1. For aborts after the end of powered ascent, the AGS shall have the capability to complete the unfinished burns of the coelliptic sequence. For the Design Mission, an orbit with a minimum clear pericyynthion of 30,000 ft. above the mean lunar radius shall result after each of these burns.

The burns for the above cases shall result in an intercept trajectory passing within a sphere having a 5 n. mi. (3 sigma) radius with its center at the CSM. At the point of intersection of the LM and the sphere, the magnitude of the vector difference between the nominal AGS computed relative velocity (i.e., velocity of LM with respect to the CSM) and the actual relative velocity shall be less than 30 fps (3 sigma). This requirement shall be contingent upon the target constraints and the AGS performance of midcourse corrections based upon RR

navigation updates as specified in paragraph 7.2.9 and 7.3.2.2 6 and to cases where the TPI burn is completed is less than one revolution of the CSM after the CSI maneuver.

Capability shall also be provided to perform a coelliptic orbit sequence as described in 4.10.1, using initialization data from the following sources: PGNCS, CSM Voice Link and MSFN, whenever they are available. Accuracy and availability of the initialization sources are given in paragraph 7.2.17.

7.2.12 Direct Intercept. The direct intercept maneuver described in 4.10.1.15 shall only be used for aborts prior to powered descent, and after the end of powered ascent. The direct transfer burn shall result in an intercept trajectory passing within a sphere having a 5 n.mi. radius (3 sigma) with its center at the CSM. At the point intersection of the LM and the sphere, the magnitude of the vector difference between the nominal AGS computed relative velocity (i.e., velocity of LM with respect to the CSM) and the actual relative velocity shall be less than 30 fps (3σ). This requirement shall be contingent upon the AGS performance of midcourse corrections based upon RR navigation updates as specified in paragraph 7.2.9 and 7.3.2.2.6. Capability shall also be provided to perform the Direct Intercept Maneuver

using initialization data from any one of the following sources: PGNCS, CSM Voice Link, and MSFN, whenever they are available. Accuracy and availability of these sources are given in paragraph 7.2.17.

7.2.13 External Delta V. Capability shall be provided to perform a velocity change based on velocity components obtained from an external source and inserted via the DEDA. (See paragraph 4.10.2.4).

7.2.14 Calibration and Compensation Accuracies.

7.2.14.1 Earth Prelaunch Calibration/Compensation. The Earth Prelaunch Calibration/Compensation shall be based on a scheme which uses the known latitude of the launch site, a self alignment to local vertical and an azimuth angle with respect to true north known to 0.1 degree. The calibration scheme shall also use a measurement of the X-gyro channel spin axes mass unbalance made a maximum of 120 days prior to completion of the lunar landing mission.

The implementation of this scheme shall have a calibration capability within a maximum of 20 minutes such that the compensated AGS attitude drift rate during the mission environment, when the AGS is operating, shall be less than the following:

Days After Calibration	Environment	X Channel	Y & Z Channels
0 to 8 days	Coasting	2.49°/hr (3σ)	0.90°/hr (3σ)
0 to 8 days	Boosting	*1	1.03°/hr (3σ)

7.2.14.2 In-Flight Calibration/Compensation. The AGS In-flight Calibration/Compensation shall be initiated via a DEDA command and shall be performed based on a scheme which uses the PGNCs reference against which the AGS Attitude drift rate performance is monitored. For a calibration time of not more than 5 minutes, during coasting phase, compensation shall be performed such that the resulting AGS Attitude drift rate during the mission environment, when the AGS is operating, shall be less than the following:

Days After Calibration	Environment	X Channel	Y & Z Channels
0 to 3 days	Coasting	.73°/hr (3σ)	.73°/hr (3σ)
0 to 3 days	Boosting	*2	.89°/hr (3σ)

The PGNCs total attitude drift rate shall be assumed to be 0.15°/hr (3σ) for the purposes of this requirement.

A filtering technique shall be implemented in order to minimize noise present in the PGNCs and AGS angle data.

*NOTE: 1	Uncorrelated	1.03°/hr (3σ)
	Uncorrelated g sens	0.96°/hr/g (3σ)
	Correlated g sens	2.32°/hr/g (3σ)
*NOTE: 2	Uncorrelated	0.89°/hr (3σ)
	Correlated g sens	2.35°/hr/g (3σ)

7.2.14.3 Accelerometer Channel In-Flight Calibration/Compensation.

The AGS upon DEDA command shall have the capability to calibrate/compensate AGS accelerometer channel bias.

For a calibration time of not more than 4 minutes, during the coasting phase, compensation shall be performed such that the resultant AGS accelerometer channel bias during the mission environment, when the AGS is operating, shall be less than the following:

<u>Days After Calibration</u>	<u>X, Y & Z Channels</u>
0 to 3 days: Coast and Boost	$230 \times 10^{-6} (3\sigma)$

7.2.14.4 Lunar Surface Prelaunch Calibration/Compensation.

The AGS shall have the capability to automatically calibrate/compensate AGS Attitude drift rates while LM is resting on the lunar surface. This operation shall be initiated by a DEDA command after the appropriate constraints are inserted via the DEDA for use in the calibration process.

The implementation of this operation shall have a calibration capability within a maximum of 5 minutes, such that the compensated AGS attitude drift rate during the mission environment, when the AGS is operating, shall be less than the following:

<u>Days After Calibration</u>	<u>X Channel</u>	<u>Y and Z Channels</u>
0 to 1 day (Coast)	.77°/hr (3σ)	.84°/hr (3σ)
0 to 3 days (Boosting)	*	1.00°/hr (3σ)

The above requirements do not include bias drifts due to lunar rotation. The maximum inclination of the LM X axis from the vertical shall be 30°.

7.2.14.5 Gyro Channel Scale Factor Pre-Flight Calibration/Compensation. The AGS shall have the capability to compensate AGS gyro channel scale factor. The compensation coefficients shall be entered into the AEA via the DEDA. The AGS gyro channel scale factor error after compensation and in the mission environment when the AGS is operating, shall be less than the following:

<u>Days After Calibration</u>	<u>X, Y and Z Channels</u>
0 to 120 days	935 x 10 ⁻⁶ deg/deg (3σ)

7.2.14.6 Accelerometer Scale Factor Channel Pre-Flight Calibration/Compensation. The AGS shall have the capability to compensate AGS accelerometer channel scale factor. The compensation coefficient shall be entered into the AEA via the DEDA. The AGS accelerometer channel scale factor

*NOTE: Uncorrelated	0.78°/hr (3σ)
Uncorrelated g sens	0.46°/hr/g (3σ)
Correlated g sens	2.35°/hr/g (3σ)

error after compensation, and in the mission environment when the AGS is operating, shall be less than the following:

<u>Days After Calibration</u>	<u>X, Y & Z Channels</u>
0 to 120 days	$940 \times 10^{-6} \text{ g/g } (3\sigma)$

7.2.14.7 Accelerometer Bias Pre-Flight Calibration/Compensation.

The AGS shall have the capability to compensate AGS accelerometer channel bias. The compensation coefficient shall be entered into the AEA via the DEDA. The AGS accelerometer channel bias after compensation during the mission environment when the AGS is operating, shall be less than the following:

<u>Days After Calibration</u>	<u>X, Y, & Z Channels</u>
0 to 120 days	$615 \times 10^{-6} \text{ g } (3\sigma)$

NOTE: The numerical values specified in the previous paragraphs shall be considered as the absolute value of the 3σ dispersion plus the absolute value of the mean of the performance values obtained during any 300 sec interval during the total time interval associated with each performance number (i.e., 3 day, 7 day, 120 days, as applicable).

7.2.14.8 X-Gyro Spin Axis Mass Unbalance Compensation. The AGS shall have the capability to compensate for X-gyro

spin axis mass unbalance. The compensation coefficient shall be entered into the AEA via the DEDA. The AGS X-gyro spin axis mass unbalance after compensation during the mission environment when the AGS is operating shall be less than the following:

<u>Days After Calibration</u>	<u>X Channel</u>
0 to 120 days	0.7 deg/hr/g (3 σ)

7.2.15 Combined Rates. The AEA shall be capable of following gyro input rates up to and including $25^{\circ}/\text{sec}$. consecutively or concurrently about all vehicle axis with a maximum computational lag error of $\pm .70^{\circ}$ per axis.

7.2.16 Engine On/OFF Commands. In the semi-automatic mode, the AGS shall be required to initially turn on either the ascent or descent engine if a state of ullage has been detected by the AGS. The ullage detection shall be based on a scheme which makes use of the thrust acceleration computed every two seconds. The state of ullage shall exist when the thrust acceleration remains, for six seconds, above a threshold level of 0.1 feet per second squared. The AGS shall continue to maintain an Engine ON signal until the velocity to be gained (V_{GX}) decreases below a pre-selected threshold.

7.2.17 Initialization Uncertainties.

7.2.17.1 Initialization Via PGNC S Downlink.

7.2.17.1.1 Prior to Descent Orbit Insertion. The LM and CSM state vector covariance matrix at the start of insertion shall be the following matrix. (See chart on following page).

Matrix in Landing Site Inertial Coordinates

x		y		z		\dot{x}		\dot{y}		\dot{z}	
2.5810	E 05	6.2126	E 03	7.8080	E 05	-4.6841	E 02	1.0752	E 01	8.4849	E 01
6.2132	E 03	3.4745	E 05	-3.5151	E 04	1.8546	E 01	-9.8968	E 00	-1.7999	E 01
7.8080	E 05	-3.5152	E 04	3.6544	E 06	-2.2177	E 03	3.8407	E 01	8.2620	E 02
-4.6842	E 02	1.8546	E 01	-2.2177	E 03	1.4119	E 00	-2.2902	E-02	-5.1607	E-01
1.0752	E 01	-9.8968	E 00	3.8407	E 01	-2.2902	E-02	2.0520	E-01	6.8779	E-03
8.4849	E 01	-1.8000	E 01	8.2620	E 02	-5.1608	E-01	6.8779	E-03	2.5974	E-01

These numbers represent 1-sigma deviations in landing site inertial coordinates. The epoch of CSM and LM data shall not be more than 10 minutes old. During ascent operations from the lunar surface, the above matrix shall apply for the CSM at its orbital position at the time of initialization. When initialized during ascent coast or in a parking orbit, the initialization uncertainty of LM shall be described by the above matrix.

7.2.17.1.2 Prior to Powered Descent. The following uncertainties shall be used during initialization of the navigation ten minutes prior to the start of powered descent.

(a) LM State Initialization Uncertainty
(10 minutes before powered descent)
expressed in LM/AGS inertial coordinates
in units of ft^2 and $(\text{ft}/\text{sec})^2$.

X	Y	Z	\dot{X}	\dot{Y}	\dot{Z}
$2.319(10)^6$					
$-2.849(10)^4$	$3.232(10)^5$				
$3.039(10)^6$	$-1.041(10)^4$	$5.932(10)^6$			
$-1.932(10)^3$	$2.961(10)^1$	$-2.751(10)^3$	$1.827(10)^0$		
$-1.409(10)^1$	$-2.531(10)^1$	$-1.496(10)^1$	$6.479(10)^{-3}$	$2.929(10)^{-1}$	
$2.662(10)^3$	$-1.373(10)^1$	$5.268(10)^3$	$-2.566(10)^0$	$-7.754(10)^{-3}$	$4.799(10)^0$

(b) CSM State Vector Uncertainty 10 minutes
prior to the start of powered descent
based on 98.4 min. of tracking), expressed
in LM/AGS inertial coordinates in units
of ft^2 and $(\text{ft}/\text{sec})^2$.

R	T	N	V_R	V_T	V_N
$.6414(10)^4$					
$-.8742(10)^4$	$.5892(10)^5$				
$.2407(10)^4$	$.2628(10)^6$	$.1396(10)^7$			
$.5867(10)^1$	$-.4561(10)^2$	$-.2019(10)^3$	$.3535(10)^{-1}$		
$.4804(10)^1$	$.1408(10)^1$	$.3824(10)^2$	$-.8401(10)^{-3}$	$.4630(10)^{-2}$	
$.6148(10)^2$	$-.3049(10)^3$	$-.1209(10)^4$	$.2371(10)^0$	$.1438(10)^{-1}$	$.1680(10)^1$

NOTE: The above two matrices should be modified by the time synchronization errors specified in the following paragraph.*

* Absolute Time Uncertainty. The absolute time uncertainty is dependent on the procedures used and MSFN uncertainties.

The Absolute time uncertainty is 400 milliseconds or less.

7.2.17.1.3 On Lunar Surface. The LM Initialization Uncertainty while on the lunar surface is 500 ft (1σ) in X and 1500 ft (1σ) in Y and Z with zero velocity errors.

7.2.17.1.4 Prior to GSI burn . -TBD

7.2.17.1.5 Prior to CDH burn . -TBD

7.2.17.1.6 LM State Vector Update Uncertainty at TPI based on MSFN tracking and applicable 600 seconds before TPI expressed in AGS inertial coordinates in units of (ft)² and (ft/sec)².

X	Y	Z	\dot{X}	\dot{Y} (symmetric)	\dot{Z}
.6163(10) ⁴					
-.1645(10) ⁶	.1495(10) ⁸				
.1640(10) ⁵	.7127(10) ⁶	.2259(10) ⁶			
-.1714(10) ¹	-.1985(10) ³	-.4408(10) ²	.1053(10) ⁻¹		
-.6686(10) ²	.5464(10) ⁴	.1354(10) ³	-.8663(10) ⁻¹	.4732(10) ¹	
.1231(10) ²	.1264(10) ⁴	.2895(10) ³	-.5780(10) ⁻¹	.2423(10) ⁰	.3901(10) ^C

CSM State Vector Update Uncertainty at TPI based on MSFN tracking for 1.1 orbits expressed in AGS inertial coordinates in units of (ft)² and (ft/sec)².

X	Y	Z	\dot{X}	\dot{Y} (symmetric)	\dot{Z}
4614.21					
-278134	28.7(10) ⁶				
1682.7	-87835.9	1137.22			
-1.11245	77.3994	.042208	7.007(10) ⁻⁴		
75.2939	-8079.94	-8.80315	-5.002(10) ⁻²	8.12995	
3.68192	-228.869	1.50806	-8.716(10) ⁻⁴	4.563(10) ⁻²	.003348

7.2.17.1.7 Prior to Mid-Course Correction - TBD.

7.2.17.2 Initialization Via MSFN.

7.2.17.2.1 Lunar Surface.

- (a) The LM Initialization Uncertainty while on the lunar surface is 500 ft (1 σ) in X and 1500ft (1 σ) in Y and Z with zero velocity errors.
- (b) CSM State Vector Uncertainty 10 minutes prior to the start of powered descent (based on 98.4 min of tracking), expressed in LM/AGS inertial coordinates in units of ft² and (ft/sec)²

R	T	N	V_R	V_T (symmetric)	V_N
.6414(10) ⁴					
-.8742(10) ⁴	.5892(10) ⁵				
.2407(10) ⁴	.2628(10) ⁶	.1396(10) ⁷			
.5867(10) ¹	-.4561(10) ²	-.2019(10) ³	.3535(10) ⁻¹		
.4804(10) ¹	.1408(10) ¹	.3824(10) ²	-.8401(10) ⁻³	.4630(10) ⁻²	
.6148(10) ²	-.3049(10) ³	-.1209(10) ⁴	.2371(10) ⁰	.1438(10) ⁻¹	.1680(10) ¹

7.2.17.2.2 The LM State Vector Update Uncertainty at CSI Update Time, based on MSFN tracking for .15 orbits, and applied 10 minutes prior to CSI expressed in AGS inertial coordinates in units of ft^2 and $(\text{ft}/\text{sec})^2$.

X	Y	Z	V_X	V_Y (symmetric)	V_Z
33590.4					
701456.	$77.5(10)^6$				
21056.7	-393729	-27409.6			
52.3361	386.58	47.3894	.105536		
-105.089	-735.	-49.0514	.142017	69.8	
39.5894	232.181	35.5639	.072665	-.671018	.061064

The CSM State Vector Update Uncertainty at CSI update time, based on 1.1 orbits of MSFN tracking expressed in AGS inertial coordinates in units of ft^2 and $(\text{ft}/\text{sec})^2$.

X	Y	Z	V_X	V_Y (symmetric)	V_Z
4918.72					
270366	$28.7(10)^6$				
-255.357	-37849.6	465.28			
.869445	35.5013	.341045	$4.925(10)^{-4}$		
-58.7576	-8080	39.5028	$1.9904(10)^{-2}$	8.13	
3.83934	238.373	-.410445	$5.447(10)^{-4}$	$-6.1577(10)^{-2}$	$3.5075(10)^{-3}$

7.2.17.2.3 Prior to GSI burn . - TBD

7.2.17.2.4 Prior to TPI burn . - The LM State Vector
covariance matrix, 10 minutes prior to TPI burn:

.198490E06	-.749092E05	.730386E06	.273973E + 03	-.392589E 02	.149117E + 03
	.336705E05	-.575542E05	-.963142E + 02	.139232E + 02	.215871E + 02
		.149486E08	.126712E + 04	-.178509E + 03	.546861E + 04
(symmetrical)			.390414E + 00	-.570762E -01	.257122E + 00
				.102501E -01	.100499E -01
					.473182E + 01

7.2.17.2.5 Prior to Mid-Course Corrections. - TBD

7.2.17.3 Frequency of Initialization.

- (a) Automatic (LM and CSM). During non-abort conditions, or an abort in which the PGNCSS is operating properly, the AGS shall be initialized using signals from the PGNCSS down-link at the following items:
- (1) 30 minutes or less prior to insertion into descent coast
 - (2) 20 minutes or less prior to start of powered descent
 - (3) 20 minutes or less prior to lunar lift off
 - (4) 10 minutes or less prior to coelliptic sequence initiation (CSI)
 - (5) 10 minutes or less prior to CDH burn
 - (6) 10 minutes or less prior to terminal phase initiation (TPI)
 - (7) 10 minutes or less prior to mid-course corrections
- (b) Manual (LM and CSM). During an abort situation in which the PGNCSS is not operating properly, no automatic initialization data shall be

available from the PGNCS. In this case initialization data will be available from MSFN or from the CSM and shall be inserted manually into the AGS using the DEDA. Manual initialization shall take place at the following times:

- (1) 20 minutes or less prior to lunar lift off
 - (2) 10 minutes or less prior to coelliptic sequence initiation
 - (3) 10 minutes or less prior to CDH burn
 - (4) 10 minutes or less prior to terminal phase initiation
 - (5) 10 minutes or less prior to mid-course corrections
- (c) Manual (Absolute Time). Initialization of AGS absolute time will take place twice during the LM mission in orbit (prior to insertion) and on the lunar surface. (See paragraph 7.2.17.1.2 Note).

7.2.18 Time Range. The range of absolute time to be employed by the AGS shall be from 0 to 4396 min. After absolute time initialization (specified in 4.3), there will be a known one-to-one correspondence between the AGS absolute time and the current mission time base.

7.2.18.1 Compatibility with Epoch Times Obtained Via PGNCS Downlink. The LM/CSM state vector epoch times will be referenced to GET, the PGNCS absolute time base. When initializing the AEA via the PGNCS downlink, the epoch

times will be converted by the LGC to the AGS absolute time base, GET-K (as specified in 4.3), prior to placing it on the downlink.

7.2.19 Time to Rendezvous. The maximum time allowed for any rendezvous conducted by the AGS shall be 10.5 hours including time spent on lunar surface waiting for proper CSM phasing.

7.2.20 Coordinate Systems. The AGS shall utilize the following coordinate systems:

- (a) Stable Member Axis System (Inertial Frame):
The Stable Member Axis System is inertially fixed in space with its origin at the moon's center. Its orientation is different for the descent and ascent phases. For the descent phase, the x_{SM} - axis passes through the intended landing-site at the nominal time of landing, positive outward from the lunar center. The z_{SM} - axis is normal to x_{SM} and parallel to the CSM plane. The y_{SM} - axis is normal to the x_{SM} - plane in a right hand sense. For the ascent phase, the x_{SM} - axis passes through the intended launch-site at the nominal time of launch, positive outward from the lunar center. The z_{SM} - axis is normal to x_{SM} and parallel to the CSM orbit plane. The y_{SM} - axis is normal to the x_{SM} z_{SM} plane in a right hand sense.
(See Figure 7-2).

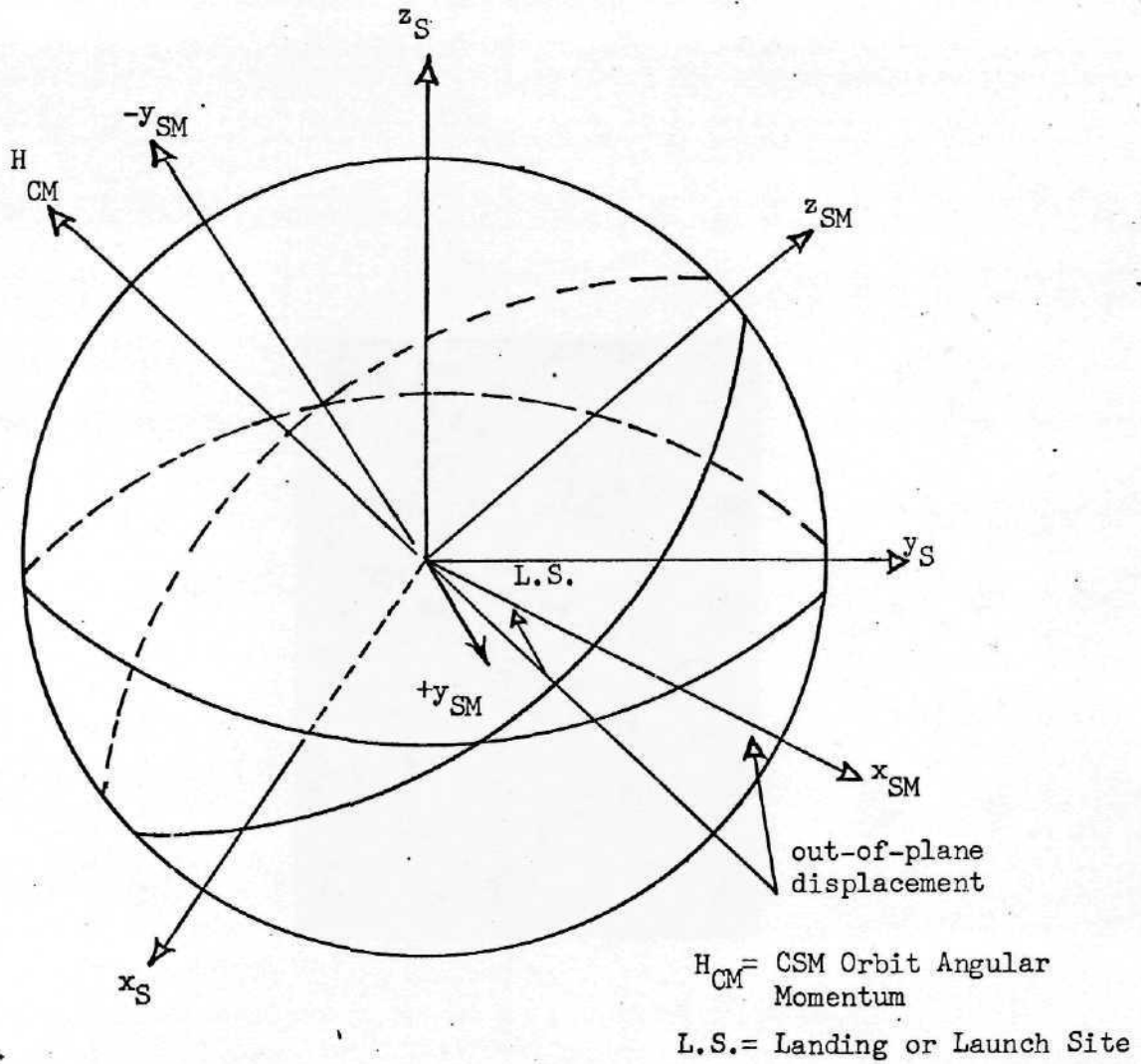


FIGURE 7-2
 Stable Member Axis System

(b) Body Axis System - The figure below defines the reference LM body axis system. (x_B, y_B, z_B) . The origin of this frame is fixed at LM vehicle station $X = 200, Y = 0$, and $Z = 0$). The z axis (z'_B) is normal to x'_B and passes through the intersection of the vehicle separation station ($X = 200$) and the plane of symmetry of the LM cabin front view. The y -axis (y'_B) is normal to the $x'_B z'_B$ plane in a right handed sense. Another body axis system (x_B, y_B, z_B) whose coordinates are parallel to reference body axis system but centered at the instantaneous vehicle center of gravity is necessary when discussing vehicle motion.

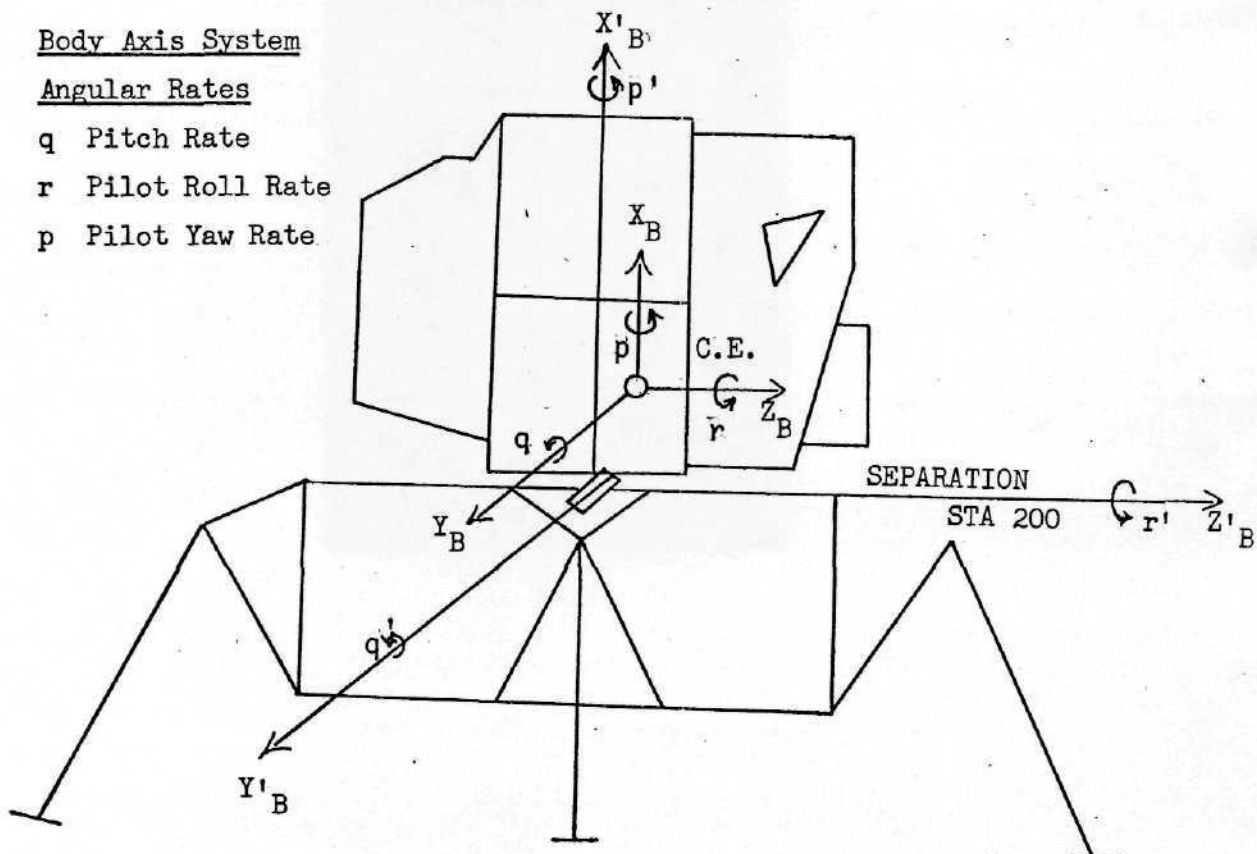


FIGURE 7-3

Body Axis Systems

7.2.21 Out-of-Plane Requirement for Lunar Launch Phase.

Prior to LM ascent, a plane change will be made by the CSM to permit a nominal co-planar LM ascent. This plane change shall result in a maximum out-of-plane angle of 0.5° at LM launch time. This residual out-of-plane angle shall be removed by LM roll steering during orbit insertion. The AGS shall have the guidance capability of removing a residual out-of-plane angle of 2.0 degrees, (assuming sufficient ΔV is available).

7.2.22 Initial Attitude Constraint. For analysis purposes, it shall be assumed that, at the initiation of abort during powered phases, the vehicle attitude shall be within $\pm 45^\circ$ of the nominal attitude which is specified in Table VI . Angular rate at abort initiation about each axis shall be less than $25^\circ/\text{sec}$.

7.2.23 Prelaunch Booster Sway Data.

(a) Dynamic: Elliptical Motion

Frequency: 0.6 cps empty vehicle
0.3 cps full vehicle

Amplitude: () indicates fueled vehicle

	<u>Design Goal</u>	<u>Requirement</u>
Perpendicular to wind:	11.8 in. (5.1 in)	5.9 in. (2.5 ins)
Parallel to wind:	1.7 in. (0.8 in.)	0.8 in. (0.4 in.)

(b) Static: Design Goal Requirement

Wind Velocity (3σ): 63 knots 38 knots

Lateral Displacement: 16.8 inches 8.4 inches

It shall be assumed that the sway data defines the total lateral and rotational motion (except in azimuth) and that the rotation in azimuth is negligible. The motion given in (a) and (b) above applies at the ASA location (Vehicle Station 3463).

7.3 Detailed AGS Software Requirements.

7.3.1 Detailed Functional Requirements of AGS Software.

An AGS software Design Mission Computer Program (DMCP) shall be designed such that, with the constraints imposed, all requirements and accuracies of this specification shall be met for aborts from points in the Design Mission. The method by which the AGS system performance shall be demonstrated by TRW Systems shall be as specified in Section 8. In addition, the functional requirements given in this section shall be met to insure design compatibility with overall LM System functional requirements. Figure 2 is a block diagram depicting the interfacing of the various subroutines to form the overall AGS Functional Block Diagram. Figure 2 is based upon functional requirements imposed upon the AGS software.

7.3.1.1 Frequency of Alignment.

- (a) PGNCS to AGS Alignment - PGNCS fine alignment shall be considered to occur 25 minutes before

the initiation of powered descent and powered ascent. During non-abort conditions or an abort in which the PGNCs is operating properly, the AGS shall be aligned using signals from the PGNCs at the following times:

- (1) 15 minutes or less prior to insertion into coasting orbit
- (2) 5 minutes or less prior to start of powered descent
- (3) Immediately after touchdown on the lunar surface (and again 25 to 30 minutes later after PGNCs, fine align)
- (4) 4 minutes or less prior to lunar lift off
- (5) 5 minutes or less prior to coelliptic sequence initiation
- (6) 5 minutes or less prior to CDH burn
- (7) 5 minutes or less prior to terminal phase initiation

7.3.1.2 Frequency of Calibrations. The AGS will be calibrated at the following times prior to, and during the lunar landing mission:

- (a) Preflight Calibration - The AGS will be calibrated immediately prior to installation in LM. This calibration will be performed a maximum of 120 days prior to completion of the lunar landing mission, i.e. docking. The following parameters will be measured and compensation will be inserted into the AEA:
 - (1) Gyro Channel Scale Factor
 - (2) Accelerometer Channel Scale Factor
 - (3) Accelerometer Bias
 - (4) Gyro Channel Bias Drift Rate

- (5) Gyro Channel Acceleration sensitive drift
(X gyro only)
- (b) Earth Prelaunch Calibration - The AGS automatic earth prelaunch calibration of gyro channel bias will be performed no more than 8 days prior to completion of the mission while the LM is in a stacked configuration.
- (c) Inflight Calibration - The AGS automatic inflight calibration of gyro channel non-g sensitive bias and accelerometer channel static bias will be performed during the period from LM/CSM separation to deboost into coasting descent.
- (d) Lunar Prelaunch Calibration - The AGS automatic lunar prelaunch calibration of gyro channel bias will be performed prior to lift off from the lunar surface.

7.3.1.3 Hardwired and Softwired Constants. Values of constants which affect interface are listed below.

<u>Definition of Constant</u>	<u>Value</u>	<u>Scaling</u>	<u>Quantization</u>
Gyro Scale Factor (rad/pulse)	2^{-16}	--	---
Gyro and Accelerometer Null Bias (pulse)	640	--	---
FDAI Computation Singularity Region	0.00087	B1	
PGNCS Euler Angle Scale Factor (rad/pulse)	6.2831853×2^{-15}	--	---
Ascent Engine Cut-Off Constant	2.1	--	---
<u>Calibration Constants</u>			
Gyro Drift (rad/20 millisecc)	0	± 10	.01
Gyro Scale Factor Error X Gyro Y and Z Gyro		B-7 B-7	---
X Gyro Spin Axis Mass Unbalance (rad/ft/sec)	---	B-14	---
Accelerometer Scale Factor	---	B-8	---
Accelerometer Bias X, Y and Z Accel. (ft/sec/20msec)	---	B1*	---

<u>Definition of Constant</u>	<u>Value</u>	<u>Scaling</u>	<u>Quantization</u>
Attitude Hold V_g Threshold (prior (ft/sec) to cut-off)	---	B 13	---
Limits of Desired Yaw Jerk (orbit (ft/sec ³) insertion)	---	B-2	---
Staging times (1 count/40 msec) to maintain attitude hold momentarily after staging	25 counts	0 to 250	1
Ullage acceleration threshold (fps ²)	0.1	B 7	
Engine Cant Angle-pitch (Rad.)	0.0873	B0	---
Engine Cant Angle-roll (Rad.)	0.034	B0	---

Note: The binary scaling (e.g., B1, B7) which determines the placement of the binary point, specifies the range of the constant. The binary point is moved the specified number of places to the right for a positive designation and to the left for a negative designation.

* 2000 ug range is available

7.3.1.4 Design Mission. The design mission shall consist of a restrictive set of initial conditions, operating modes and operating sequences as described below.

7.3.1.4.1 Initial conditions. Abort maneuvers shall start from anywhere in the nominal trajectory given in Tables V + VI.

7.3.1.4.2 Initialization Prior to Abort.

Initialization to the PGNCs shall take place at the time points given in 7.3.1.1 and 7.2.17.3, except for abort from Lunar Surface. For launch from the lunar surface a lunar align and MSFN initialization is assumed.

7.3.1.4.3 Navigation Initialization. The sequence of initialization after abort shall be any of the following:

Sequence #1

20 min Prior to Launch MSFN update
Prior to CSI burn - MSFN update
Prior to CDH burn - no update
10 min. Prior to Launch MSFN update
Prior to MC Correction RR update

Sequence #2

20 min Prior to Launch MSFN update
Prior to CSI burn RR update
Prior to CDH burn RR update
10 min Prior to TPI burn RR update
Prior to MC Correction RR update

Sequence #3

20 min Prior to Launch MSFN update
Prior to CSI burn RR update
Prior to CSH burn RR update
10 min Prior to TPI burn MSFN update
Prior to MC Correction RR update

Sequence #4

20 min Prior to launch-MSFN update
Prior to CSI burn-no update
Prior to CDH burn-no update
10 min Prior to TPI burn-no update
Prior to MC Correction RR update
(Also See Para. 4.1.3)

7.3.1.4.4 Targeting Parameters. For the DM the nominal trajectory parameters to be used shall be as follows:

h = 30,000 ft. above the mean lunar radius

\dot{h} = 0 fps

V_{ho} = 5510 fps

J^2 = 26.6°

t_{igA} = 34.1 minutes

t_{igC} = 105 minutes

7.3.2 Computational Requirements.

7.3.2.1 Navigation. The AEA must be capable of computing the current value of LM position and velocity in the AGS selenocentric inertial coordinate frame. Navigation of LM, when located on the lunar surface, shall also be provided and need not utilize the same equation as in flight navigation. On the lunar surface, navigation shall begin at the time that the AEA is transferred from the IMU or Lunar Align submode to the Inertial Reference mode. This time shall be designated to the GO INERTIAL TIME. On the lunar surface, this time shall nominally occur no

earlier than 4 minutes prior to nominal lift off time. The nominal lift off time is defined as the time at which LM passes through the X axis of the inertial coordinate frame in which the lunar surface navigation initialization data is provided. The navigation equations shall accept the velocity increment inputs from the ASA accelerometers and shall transform them from body coordinates to inertial coordinates. These inputs shall be employed to sense LM velocity changes due to thrust from ascent or descent engine, reaction control, or due to external forces. The capability for analytically computing the position and velocity of the CSM is also to be provided. An ellipse prediction routine is to be utilized for this purpose. The navigational computations shall be performed at a rate consistent with the performance requirements of this specification. See Para. 4.1.

7.3.2.1.1 Navigation Initialization Computations. The navigation and initialization requirements for the AGS are specified in 4.1.3, 7.2.1.7 and 7.3.1.4.3. The initialization computations shall consist of a rescaling of the input information, propagation of the initialization data from the epoch time to current time, and replacing the existing data by the newly computed data.

7.3.2.1.2 Time Initialization. Absolute time initialization consists of synchronizing the AGS time base to the external reference (either PGNCs, or CSM, or MSFN) which provides the navigation initialization information for the AGS.

Absolute time is initialized via the DEDA. The AEA input logic must provide this capability. (See paragraph 4.3 and 7.2.17.1.2).

7.3.2.1.3 Flight Director Attitude Indicator (FDAI)

Computations. The sines and cosines of the Euler angles α , β , and γ shall be computed from the transformation matrix to provide outputs for total attitude display. The relations of the Euler angles to the nine elements of the transformation matrix, and the order of rotation of these Euler angles which relate the vehicle axes to the inertial axes with the gimbal sequence of the attitude display indicator, are presented in 7.3.3.4.4.

7.3.2.1.4 Navigation Quantities Computed. Based upon the requirements specified, the following quantities shall be computed from the navigation computations:

Altitude - The difference between the magnitude of the position vector of the LM vehicle in the AGS selenocentric coordinate system and the value of the mean lunar radius.

Altitude Rate - The altitude rate of the LM vehicle.

Lateral Velocity - The y-body axis component of the LM vehicle total inertial velocity in the AGS selenocentric coordinate system.

Total Velocity - The LM vehicle total velocity in the AGS selenocentric coordinate system.

7.3.2.1.5 Navigation Output Displays. From the navigation computations, the following variables shall be displayed:

(a) Altitude and Altitude Rate -

	<u>Altitude</u>	<u>Altitude Rate</u>
(1) scale factor	2.34 feet/bit	.5 feet/second/bit
(2) range	15 bits	14 bits plus sign
(3) output rate requirements	5 times/second	5 times/second

(b) Y-axis Velocity -

- (1) Range: \pm 200 feet/second.
- (2) Output rate requirements: five times per second.

7.3.2.2 Guidance, General. The equations shall implement the Coelliptic Rendezvous Technique and shall be capable of computing two impulse transfer trajectories on a continuous basis (e.g., every 2 seconds with velocity-to-be-gained decremented), assuming a lunar spherical gravity force field. Guidance steering shall provide direction control of thrust.

7.3.2.2.1 Orbit Insertion and Guidance Computations. The explicit guidance equations shall be capable of guiding the LM into a safe orbit.

7.3.2.2.2 Midcourse Corrections. The explicit guidance equations shall be capable of performing midcourse corrections complying with the AGS functional requirements in 4.10.1.

7.3.2.2.3 Steering. The equations shall compute body axes attitude error signals E_x , E_y , and E_z at all times in which the AGS is in the Operate Mode. These errors are to be computed from the indicated, and commanded vehicle attitude. (The commanded attitude is a function of the submode in which the equations are operating, and is defined in 5.2).

7.3.2.2.4 Equations for Acquisition Steering. The guidance equations are required to compute the desired attitude of the vehicle, such that if the AGS is in the Acquisition Submode, the AGS generated attitude error signal would orient the vehicle such that the Z body axis lies along the AGS estimated line of sight between the LM and CSM, with the +Z axis toward the CSM.

7.3.2.2.5 Attitude Reference. The attitude reference equations shall maintain an inertial attitude reference in the form of a transformation matrix which relates the vehicle coordinate axes to corresponding inertial coordinates. The equations shall update the transformation matrix, using angular increments about the vehicle axes received from vehicle strapped down gyros. The equations shall provide for alignment of the transformation matrix to reference attitude information. The AEA equations shall be capable of IMU align, lunar align and body axis align as required in 5.2 (See also para. 4.4).

7.3.2.2.6 Radar Updating. The guidance equations shall be capable of accepting rendezvous radar data and updating the LM navigation routine. The radar data will consist of range and range rate data and a time "mark" at which radar pointing error (line of sight to CSM) with respect to the vehicle z-axis is nulled.

The equations shall use the input radar data without any editing or ambiguity checks. This data shall be processed in a manner to reduce errors associated with statistical variation, and shall be combined with the inertial data to estimate position and velocity of LM.

7.3.2.3 Logic Requirements.

7.3.2.3.1 Mode Logic. Mode selection is governed by instructions via the DEDA and discrete signals from the Control Electronics Section. For any particular set of AEA inputs the corresponding mode for the AGS is defined in 4.10.1.1 and 5.2. The AEA mode logic must provide this moding and must insure that the correct set of functions are performed during each mode of operation. (See Figure 3)

7.3.2.3.2 Engine Logic. The computer logic shall be capable of issuing either an Engine On, or Engine Off discrete at all times when the AGS is in the Operate Mode. The logic required must be consistent with the requirements specified in 5.2.

7.3.2.3.2.1 Ullage Detection Logic Equations. The logic equations shall detect ullage when the accumulated velocity increments along the X axis exceeds 0.2 ft/sec in each 2 second computer cycle, for three consecutive cycles. The equations shall detect loss of ullage when, in any 2 second computer cycle, the accumulated velocity increments along the vehicle X axis is less than 0.2 ft/sec.

7.3.2.3.3 Sensor Calibration Logic and Equations. The equations shall be capable of providing in flight calibration of the gyro drift, lunar surface gyro drift calibration, and in flight accelerometer bias calibration that are consistent with the requirements of section 6.3.2, 7.1.1 and 7.2. Range of gyro drift compensation capability to be provided in the Software shall be $\pm 9.8^{\circ}/\text{hr}$. The range of accelerometer bias compensation capability to be provided in the software shall be $\pm 2000 \mu\text{g}$.

7.3.2.3.4 Selection Logic. Figure 4 indicates the logic which recognize the DEDA, CES, and AGS mode switch discretes and accordingly decides on the condition of AGS operation.

7.3.2.4 Required Routines.

7.3.2.4.1 PGNCS Downlink Data Processing Routine (See Figure 5). A routine shall be designed for the computer logic required for decoding of PGNCS. Downlink data to extract position, velocity, and epoch information for navigation updating based on the word and bit information contained in 7.1.3.4.9. (Also see paragraph 7.3.3.3.2).

7.3.2.4.2 Telemetry Routine (See Figure 6). A routine shall be designed for the computer logic required for sending AGS information on the Telemetry Downlink based on the requirements specified in 7.1.3.5.5. (Also see paragraph 7.3.3.4.2).

7.3.2.4.3 In Flight Self Test Routine. The AGS computer program must be capable of performing an in flight test of computer memory and logic according to the minimum requirements as specified in 4.9 of this specification. The self test routine as shown in Figure 7, shall check, on a continuous basis, that the computer's logic and memory are functioning properly. It shall run asynchronously with the guidance and navigation computations. As a minimum, the following tests shall be included:

- (a) Logic Test - This test shall check the computer's ability to execute its instructions and verify its computational capability.
- (b) Memory Test - This test shall perform a sum check of the AEA's memory. All hardwired cells and all fixed cells of the softwired memory above location 1004 shall be summed.

Upon detection of a failure in either test, the astronaut shall have the capability of resetting error

indicators and reinitiating the self test.

7.3.2.4.4 DEDA Processing Routine. The AGS computer program shall provide for read-in, decoding and storage of mode commands, instructions, and input data, and for processing and read-out of data stored in memory through the DEDA Data Register. Reasonableness or ambiguity checks on input data shall not be provided. Detailed software requirements for this routine are specified in 7.3.3.2.1 of this specification. (See Figure 8).

7.3.2.4.5 GSE Service Routine. The AGS computer program shall contain a routine which transfers a block of computer words from the ground support equipment to the erasable portion of the AEA's memory. The GSE Service Routine, as shown in Figure 9, will provide this function. The number of 18-bit words in the block shall be determined by the GSE. Initiation and termination of the information transfer shall also be controlled by the GSE.

The starting address, from which the block of words is to be stored, shall be determined by the first word transmitted to the computer. This word shall contain the starting address and a special code which identifies the word. The format of this word, expressed in octal, shall be as follows:

Bits 0 through 5 (bits are numbered from left to right) constitute the start code, and bits 6 through 17 contain the starting address. When the loading operation is finished, a transfer to the starting location shall be executed.

7.3.2.4.6 Processing Routine. The Interface for the various processing routines for the AEA shall be as follows:

- (a) DEDA to DEDA
- (b) Instrumentation to Telemetry
- (c) Instrumentation to PGNC S Downlink Input Routine
- (d) PGNC S to PGNC S Downlink Input Routine
- (e) PGNC S to PGNC S Euler Angle Input Routine
- (f) ASA to Accelerometer Input Processing Routine
- (g) CES to Attitude Control Engine Logic (Moding)
- (h) GSE Input Discret es

7.3.2.5 Input Processing. The equations must be capable of processing the gyro and accelerometer incremental information specified in para. 7.1.1, must be capable of compensating the gyro drift and scale factor, and accelerometer bias and scale factor terms according to the requirements of para. 7.2.

7.3.2.6 AEA Timing Requirements. In order that the computer performs all of the AGS functions (cited previously)

within the "real-time" bound of the machine, the following timing requirements are to be met:

The major computation cycle duration shall be 2 seconds and within the 2 second cycle shall be subcycles of 20 to 40 msec. The different timed loops shall contain as a minimum the following functions.

20 msec.

- (a) gyro data processing and compensation
- (b) Accelerometer data processing and compensation
- (c) attitude direction cosine updating
- (d) PGNCs downlink data input routine
- (e) telemetry output
- (f) PGNCs euler angle processing

40 msec.

- (a) output AGS attitude error signals
- (b) output AGS main engine commands
- (c) FDAI computations
- (d) DEDA discrete sampling
- (e) decrementing of velocity components to be gained to engine shutdown

2 second cycle.

- (a) Navigation
- (b) Ullage
- (c) Radar Data Processing
- (d) Coelliptic Rendezvous Guidance Option Logic

- (e) Coelliptic Rendezvous Guidance Equation Altitude, altitude rate, and body axis velocity will be read out to the instrument panel every 200 msec.
- (f) Thrust Velocity Vector Incrementing

7.3.3 Software Interface Requirements.

7.3.3.1 Block Diagram. Figure 10 shows a functional representation of the AGS Software Interface requirements. Note that hardware type discrettes (e.g, shift pulses and CDU zero, etc.) are not shown. The inputs that are shown are operated upon by the AGS Software, as specified in the previous sections.

7.3.3.2 DEDA Interface. (see paragraphs 7.1.3.5.1 and 7.1.3.5.2)

7.3.3.2.1 DEDA to DEDA Processing Routine. (see paragraph 7.3.2.4.4).

(a) Clear discrete - The clear discrete shall be the first discrete interrogated by the DEDA Processing Routine (DPR). If the clear discrete is present, the DPR shall enter a clear mode in which the readout and enter discrettes can be interrogated. Operations performed via the

DEDA (mode and submode selection, data entry and data readout) shall be initiated upon depression of the "CLEAR" pushbutton. This action shall cause the EL digital readouts and the status indicator (operator error light) to extinguish and reset all applicable registers and counters in the DEDA and AEA. Digits subsequently depressed shall cause the appropriate display window to become illuminated in agreement with the digit depressed. The first digit depressed shall cause the most significant address window to illuminate.

(b) Readout discrete - Upon receipt of the readout discrete, the DPR shall enter a "Readout mode". While in this mode, the data and the address of the memory location specified by the astronaut shall be outputted to the display. (The data shall be updated by the computer while in this mode). When the readout discrete is received while in the Hold mode, the routine shall return to the Readout mode.

(c) Enter discrete - Upon receipt of the Enter discrete, the DPR shall input the data specified by the astronaut, into the memory location specified by him.

(d) Hold discrete - The hold discrete shall be interrogated only when the DPR is in the readout mode. When it is received, the DPR will enter the Hold mode, which shall cause the computer to stop updating the data being displayed.

7.3.3.2.2 Manual Data Insertion and Display. The sequence of operations necessary to insert data into the AEA shall be as follows:

- (a) Depression of the "CLEAR" pushbutton.
- (b) Depression of three consecutive digits to identify the address of the AEA memory core location into which the data is to be inserted. The address shall be in octal form.
- (c) Depression of the pushbutton corresponding to the sign (plus (+) or minus (-)) of the data to be inserted.
- (d) Depression of five consecutive digits corresponding to the numerical value of the data to be inserted.
- (e) Verification and depression of the "ENTER" pushbutton.

7.3.3.2.3 Data Readout. The sequence of operations necessary to read the contents of a memory location within the AEA shall be as follows:

- (a) Depression of the "CLEAR" pushbutton.
- (b) Depression of three consecutive digits to identify the address of the core from which data is to be extracted. The address shall be in octal form.
- (c) Verification and depression of the "READOUT" pushbutton.

7.3.3.2.4 Hold Pushbutton. After depression of the "READOUT" pushbutton, parameters which are continually updated within the AEA will be sent to the DEDA and displayed at a rate not to exceed twice per second. The operator shall be capable of fixing the last value displayed by depressing the "HOLD" pushbutton. The hold function shall be reset following depression of the "CLEAR" or "READOUT" pushbutton.

7.3.3.2.5 Readout Termination. Information transfer to the DEDA is terminated following depression of the CLEAR pushbutton.

7.3.3.2.6 Information Transfer. Following depression of the "READOUT" pushbutton, the address that is displayed on the DEDA shall be serially shifted to the AEA at a rate of 64 pps as controlled by the AEA shift control, and the address display shall extinguish, then relight along with the data display. When ENTER is depressed, the address and data are shifted to the AEA and the displays extinguished.

7.3.3.2.7 Operator Error. The DEDA shall be capable of detecting operator errors and cause the operator error status indicator to illuminate following an operator error. As a minimum, the DEDA shall be capable of detecting all of the errors listed:

- (a) ENTER pushbutton depressed before nine keys have been depressed, following last depression of CLEAR pushbutton.
- (b) READOUT pushbutton depressed before three keys have been depressed or after four or more keys have been depressed following the last depression of the CLEAR pushbutton.
- (c) More than nine keys depressed.
- (d) A decimal eight or nine depressed when keyboarding the address portion of the display.
- (e) Depressing the PLUS or MINUS key in other than the fourth position.
- (f) Not depressing the PLUS or MINUS in the fourth position.

Once illuminated, the operator error light shall remain in that state until the CLEAR pushbutton is depressed.

7.3.3.2.8 Inhibit. Following activation of the operator error light, the DEDA shall transmit all ones to the AEA when the ENTER or READOUT pushbutton is depressed, and the AEA program will recognize the error by detecting one's in positions normally constrained to contain zeroes.

7.3.3.2.9 Display Blanking. The electroluminescent address, and data displays shall extinguish under the following conditions:

- (a) Prior to the application of DC voltage, regardless of the presence of AC lighting power.

- (b) Following depression of the CLEAR pushbutton.
- (c) Following depression of the ENTER pushbutton.

7.3.3.2.10 DEDA Input Signals. The characteristics of the input signals will be as specified in Table 6-1.

7.3.3.2.11 DEDA Output Signals. The characteristics of the output signals shall be as specified in Table 6-1.

7.3.3.2.12 Manual AGS Mode Control. AGS modes and submodes of operation, with the exception of the inertial reference submodes, shall be selected via the DEDA. The sequence of operations necessary to select a mode shall be as follows:

- (a) Depression of the CLEAR pushbutton
- (b) Depression of three consecutive digits to identify the address of the AEA memory core location into which the new mode will be inserted. The address shall be in octal form.
- (c) Depression of the plus (+) pushbutton.
- (d) Depression of five consecutive digits corresponding to the Code chosen for the particular mode or submode to be selected.
- (e) Verification and depression of the ENTER pushbutton.

7.3.3.2.13 Decimal DEDA Constants and Variables. See paragraphs 7.3.3.2.14 and 7.3.3.4.1 for listed Constants and Variables which shall be entered and/or read out in octal or decimal via the DEDA.

(a) Data - Selection of codes and addresses for the DEDA inputs shall be predicated upon the following:

- (1) Assign codes and addresses in logical groups which will facilitate astronaut utilization.
- (2) Minimize computer memory space required for the DEDA processing routine.

7.3.3.2.14 DEDA Input Data and Instruction. A list of required DEDA inputs and their quantization appears below. Capability shall exist for entering the following parameters via the DEDA.

<u>Symbol</u>	<u>Quantization</u> **	<u>Function</u>	<u>Range</u>
S ₁₀	0	Guidance Selector	
S ₁₆	0	CDH at First or Second Crossing of LM Orbit Line of Apsides.	
S ₀₀	0	Function Selector	
S ₁₁	0	Engine Select	
S ₁₂	0	Self Test Control	

** 0 indicates non-decimal input or output

(Continued)

<u>Symbol</u>	<u>Quantization</u> **	<u>Function</u>	<u>Range</u>
S ₁₃	0	Store Azimuth	
S ₁₇	0	Select CDH at (S ₂ + 1) radians after CSI for Near Circular Orbits	
S ₁₄	0	Navigation Initialize	
S ₀₇	0	Freezes the External V Reference into an Inertial Reference Frame	
S ₁₅	0	Store z-axis Direction Cosines	
J ₁ ¹	0		
J ₂ ¹	100 ft	LM Initial Position Vector	2 ²³
J ₃ ¹			
J ₄ ¹			
J ₅ ¹	.1 fps	LM Initial Velocity Vector	2 ¹³
J ₆ ¹			
J ₇ ¹	0.1 min	LM Epoch Time	4369 min.
J ₁ ²			
J ₂ ²	100 ft	CSM Initial Position Vector	2 ²³
J ₃ ²			

** 0 indicates non-decimal input or output

(Continued)

<u>Symbol</u>	<u>Quantization</u> **	<u>Function</u>	<u>Range</u>
J ₄ ²	.1 fps	CSM Initial Velocity	2 ¹³
J ₅ ²			
J ₆ ²			
J ₇ ²	0.1 min.	CSM Epoch Time	4369 min.
t	0.1 min.	Absolute Time	4369 min.
J ₁ ²⁸	.1 fps	Component of External ΔV Input in X Direction	2 ¹³
J ₂ ²⁸	.1 fps	Component of External ΔV Input in Y Direction	2 ¹³
J ₃ ²⁸	.1 fps	Component of External ΔV Input in Z Direction	2 ¹³
J ¹	0.1 min.	Desired TPI Time for CSI Computation	4369 min.
J ²	.01 deg.	Desired LOS angle at TPI Time for CSI Computation	360°
ΔS	0	Lunar Align Azimuth Correction Delta Delta (input is in octal, radians) N.A.	
J ⁶	0.01 min.	Desired LM Transfer Time for Direct Intercept	136.5 min.
J ¹⁶	1000ft.	Orbit Insertion Targeted Injection Altitude	2 ²³
J ¹⁸	0.1 n. mi.	Radar Range	1380

** 0 indicates non-decimal input or output

(Continued)

<u>Symbol</u>	<u>Quantization</u> **	<u>Function</u>	<u>Range</u>
J ²¹	100 ft	Vertical Pitch Steering Altitude Threshold	2 ²³
J ²²	.1 fps	Vertical Pitch Steering Altitude Rate Threshold	2 ¹³
J ²³	.1 fps	Orbit Insertion Targeted Injection Radius Rate	2 ¹³
J ²⁴	.1 fps	Orbit Insertion Targeted Injection Horizontal Velocity	2 ¹³
T _Δ	0.01 min.	Fixed Time Increment for Direct Intercept	136.5 min.
t _{igA}	0.1 min.	Desired Absolute Time of CSI Maneuver	4369 min.
t _{ig C}	0.1 min.	Desired Fixed Absolute Time of Transfer Phase Initiate (TPI) or Midcourse Maneuvers	4369 min.

** 0 indicates non-decimal input or output

7.3.3.2.15 DEDA Program Control Switches. -

- (a) Function Selector Switch S_{00} - Switch Functional Selector is an eight state switch which shall be used to control the operation of the program. The states shall be as follows:
- 0 Attitude Hold
 - 1 Rendezvous
 - 2 Acquisition
 - 3 PGNS to AGS Align
 - 4 Lunar Align
 - 5 Body Axis Align
 - 6 Inflight Calibrate
 - 7 Accelerometer Calibration
- (b) Switches S_{13} , S_{15} , S_{16} and S_{17} shall be two-state switches.
- (c) Switch S_{12} is a five state switch used for initiating the self test and indicating its results. The states shall be as follows:
- 0 Reset error indicators and reinitiate testing
 - 1 Test successfully completed
 - 3 Logic test failure
 - 4 Memory test failure
 - 7 Logic and memory test failures
- (d) Switch S_{14} is a four state switch which shall be as follows:
- 0 No initialization
 - 1 Initialize LM and CSM via downlink
 - 2 Initialize LM via DEDA
 - 3 Initialize CSM via DEDA
- (e) Switch S_{10} is a six state switch which shall be as follows:
- 0 Orbit Insertion
 - 1 Coelliptic Sequence Initiate
 - 2 Constant delta h (CDH)

- 3 Direct Transfer - (time incremented)
- 4 Direct Transfer - (absolute time)
- 5 External Delta V

All the S switches shall be automatically set to zero upon computer power turn on (except for S₅₅).

7.3.3.3 Program Inputs (See paragraph 7.1.3.4). -

7.3.3.1 AGS Downlink Stop Pulse. Every 20 milliseconds, a word shall be loaded into the output telemetry register, provided a telemetry stop pulse has been sensed. Receipt of the telemetry stop pulse indicates that the last output word has been shifted out of the register by the telemetry system. Proper synchronization shall be assured by monitoring the telemetry stop pulse discrete twice per computer 20 millisecond cycle.

7.3.3.3.2 PGNCS Downlink Input Routine. When initialize is commanded via the DEDA, a program flag shall be set that will cause the program to inspect the Downlink Telemetry Register every 20 ms if a Downlink Stop Pulse has previously been received by the AEA. The inspection shall first consist of a check to determine the presence of an LGC ID word. When one is found, it is checked to determine if it is the ID word of the AGS Initialization list. If this ID

word is found, the AEA will store the next 16 words (data words) loaded into the Downlink Telemetry Register. In particular, it shall store the first 15 bits after the Word Order Code (WOC) bit of each of these words. After storing the last of the 16 data words, the routine will set a program flag calling for the navigation initialize routines.

7.3.3.3 PGNCS Euler Angle Input Routine. This routine shall store the contents of the Euler Angle Input registers in locations in scratch pad memory every 20 msec. This data shall be accessed for further processing if the PGNCS to AGS ALIGN or In Flight Calibration modes are commanded.

7.3.3.4 Gyro Input Processing Routine. Every 20 ms, the gyro input processing routine shall sample the input registers containing the x, y and z gyro raw output pulses, and compute the compensated incremental components of vehicle rotation about the x, y and z body axes in radians.

7.3.3.5 Accelerometer Input Processing Routine. Every 20 ms, the accelerometer input processing routine shall sample the input registers containing the x, y and z accelerometer raw output pulses, and compute the compensated incremental velocity components accumulated along the x, y and z body axes in fps.

7.3.3.3.6 CES Attitude Control Engine Logic (Moding).

- (a) Abort - The abort discrete shall be interrogated every 40 ms by the mode select logic. The mode select logic shall be a function of this discrete, and other discrettes as specified in 5.0.
- (b) Abort Stage Discrete - Same as above (7.3.3.3.6 (a)).
- (c) Ascent Engine On - The Ascent Engine On verification discrete shall be interrogated every 40 ms in the engine logic as specified in 5.0. In addition, this discrete shall be utilized by the program to indicate staging, and to remove the "lunar surface" indication. It shall also be used for the attitude hold logic, required during the staging sequence.
- (d) Descent Engine On - The Descent Engine On verification discrete shall be interrogated every 40 ms in the engine logic as specified in 5.0.
- (e) Automatic - The automatic discrete shall be interrogated every 40 ms, provided the DEDA function selector S_{00} is in an Inertial Reference state. The Automatic discrete shall be utilized in the mode select logic for which the requirements are specified in 5.0.
- (f) Followup - The Followup discrete shall be interrogated in the 40 ms loop provided the DEDA function selector S_{00} is in an Inertial Reference state. The Followup discrete shall be utilized in the mode select logic, for which the requirements are specified in 5.0.

7.3.3.3.7 GSE Input Discretes.

7.3.3.3.7.1 GSE Discretes 1 and 2. The GSE Service Routine (described in paragraph 7.3.2.4.5) shall utilize 2 input discretes (GSE 1 and GSE 2) to control the transfer of information. GSE 1 is set by the test equipment to notify the computer that a word has been transmitted. GSE 2 is used in conjunction with GSE 1 to denote that the present word being transmitted constitutes the end of the block.

7.3.3.4 Program Outputs. (See paragraph 7.1.3.5)

7.3.3.4.1 Outputs to DEDA - (Data for Readout). A capability shall exist for readout of the following parameters via the DEDA: (See following page).

<u>Symbol</u>	<u>Quantization</u> **	<u>Function</u>	<u>Range</u>
r_x	100 ft	LM Position Vector	2^{23}
r_y			
r_z			
v_x	.1 fps	LM Velocity Vector	2^{13}
v_y			
v_z			
v	.1 fps	LM Velocity	2^{13}
r_{cx}	100 ft	CSM Position Vector	2^{23}
r_{cy}			
r_{cz}			
v_{cx}	.1 fps	CSM Velocity Vector	2^{13}
v_{cy}			
v_{cz}			
t	0.1 min	Absolute Time	0 to 4369 min
q	0.1 n.m.	Pericyynthion of Present LM Trajectory	± 1379.7 n.m.
q_1	0.1 n.m.	Pericyynthion of Predicted LM Transfer Trajectory	± 1379.7 n.m.

** 0 indicates non-decimal input or output

(Continued)

<u>Symbol</u>	<u>Quantization</u> **	<u>Function</u>	<u>Range</u>
θ_{LOS}	.01 deg	Predicted LOS Angle at t_{igC}	360°
ΔV_{gx}	0.1 fps	Body Axis Components of Velocity-to-be-gained to Engine Shutdown	2^{13}
ΔV_{gy}			
ΔV_{gz}			
V_{dx}	0.1 fps	Accumulated Sensed Velocity Along x Body Axis	2^{13}
V_o	0.1 fps	ΔV for CSI Maneuver	2^{13}
V_{po}	0.1 fps	ΔV for CDH Maneuver	2^{13}
Δr_o	100 ft	Differential Altitude	$\pm 8,388,500$ ft
T_{AO}		Coast Time from CSI to CDH	0 to 136.5 min
R	0.1 nmi	Range from LM to CSM	1380
\dot{R}	0.1 fps	Range Rate	2^{13}
\dot{r}	0.1 fps	LM Radius Rate	2^{13}
h	100 ft	LM Altitude	2^{23}
V_G	0.1 fps	Magnitude of LM Velocity-to-be-Gained	2^{13}
t_{igC}		Absolute Time of TPI Maneuver	0 to 4369 min

** 0 indicates non-decimal input or output

(Continued)

<u>Symbol</u>	<u>Quantization</u> **	<u>Function</u>	<u>Range</u>			
T_{Δ}	0.01 min	Time Increment to TPI Time	136.5 min			
δ_{21}	0	Lunar Surface Flag				
r_f	100 ft	Predicted Burnout Altitude in Orbit Insertion	2^{23}			
y	100 ft	Out-of-CSM-Orbit-Plane Displacement in Orbit Insertion	2^{23}			
V_y	.1 fps	LM Velocity Normal to CSM Orbit Plane	2^{13}			
K_1^1 K_6^1 K_{11}^1	.01°/hr	Gyro Drift Compensation Coefficients	$9.8^{\circ}/hr$			
S_{00} to S_{16}				0	Selector Switches (See DEDA Inputs)	
V_T				.1 fps	Direct Transfer plus Terminal V's	2^{13}
C'_0	0.01°	CSI Convergence Error				

** 0 indicates non-decimal input or output

Capability shall be provided such that additional quantities can be added to the list at some future time. Memory assignments shall be made in such a way so as to minimize the impact of adding data to the list.

7.3.3.4.2 Output to Instrumentation Subsystem, AGS

Downlink Data.

The output data shall comprise a 50-word block of computer softwired memory, ;the output of which is normally repeated every second. At the end of each second, the program shall be initialized such that the next word output shall be the first word of the block. The data loaded into their locations is controlled by hardwired or softwired program. The AGS Telemetry Downlink data shall consist of the following: (See following pages).

7.3.3.4.2

AEA Telemetry Word List

Word No.	Equation Symbol	Least Significant Bit Weight	Units	Hardwired	Description
1	δ 41	---	--	Yes	DEDA readout mode flag; a 1 in the sign bit indicates DEDA processing is in the readout mode
2	DD	---	---	Yes	Most recent DEDA data word in the computer unit
3	δ 38	---	---	Yes	DEDA clear mode flag; a 1 in the sign bit indicates DEDA processing is in the clear mode
4	$\left. \begin{matrix} a_{11} \\ a_{12} \\ a_{13} \end{matrix} \right\}$	---	---	---	Row 1 of direction cosine matrix
5		2^{-16}	---	Yes	
6		---	---	---	
7	ADST	---	---	Yes	Octal address associated with most recent DEDA communication
8	$\left. \begin{matrix} a_{31} \\ a_{32} \\ a_{33} \end{matrix} \right\}$	---	---	---	Row 3 of direction cosine matrix
9		2^{-16}	---	Yes	
10		---	---	---	
11	h	2^6	ft	Yes	LM altitude above mean lunar surface
12	\underline{r}	2^6	ft	Yes	Components of LM inertial position
13					
14					
15	q	2^6	ft	Yes	Pericyynthion of present LM orbit
16	\underline{r}_c	2^6	ft	Yes	Components of CSM inertial position
17					
18					
19	r_f	2^6	ft	Yes	Predicted value of LM radius at time of orbit insertion or TPI maneuver

AEA Telemetry Word List

Word No.	Equation Symbol	Least Significant Bit Weight	Units	Hardwired	Description	
20	ΔV_x	2^{-16}	fps	Yes	Compensated incremental velocity components accumulated per 20 msec along the X, Y, or Z body axis by the corresponding X, Y, or Z accelerometer	
21						ΔV_y
22						ΔV_z
23	t	2^{-16}	sec	Yes	Least significant half of AGS absolute time	
24	Δa_x	2^{-23}	rad	Yes	Compensated incremental components per 20 msec of vehicle rotation about the X, Y, or Z body axis as measured by the X, Y, or Z gyro	
25						Δa_y
26						Δa_z
27	T _B	2^{-8}	sec	Yes	Time to LM engine burnout	
28	\underline{V}	2^{-4}	fps	Yes	Components of present LM inertial velocity vector	
29						
30						
31	V _{y_b}	2^{-4}	fps	No	Component of LM velocity along Y-body axis	
32	\underline{V}_c	2^{-4}	fps	Yes	Components of CSM inertial velocity vector	
33						
34						
35	\dot{h}	2^{-4}	fps	Yes	LM altitude rate	
36	V _G	2^{-4}	fps	Yes	Magnitude of the velocity-to-be-gained	

AEA Telemetry Word List

Word No.	Equation Symbol	Least Significant Bit Weight	Units	Hardwired	Description
37	V_{p0}	2^{-4}	fps	No	Predicted velocity-to-be-gained in CDH burn
38	V_{dx}	2^{-4}	fps	No	Accumulated total of sensed velocity increments along X body axis, updated every 40 ms
39	T_{A0}	2^{-4}	sec	No	Time from nominal CSI burn to CDH burn corresponding to best (least) cost function for this computing cycle
40	X_{bD}	2^{-16}	---	Yes	Components along the X, Y, and Z inertial axes of unit vector commanding desired pointing direction for LM X-body axis
41					
42					
43	t	2^1	sec	Yes	Most Significant half of AGS absolute time
44	S_{00}	--	---	Yes	Function Selector by which submode logic is selected via DEDA
45	$B's$	--	---	Yes	Discretes which make up "Discrete Word One"
46	S_{12}	--	---	Yes	Selector which reads out the results of the in-flight self test and resets the error indications
47	Engine/ON	--	---	No	A "1" in the sign bit indicates the AEA is commanding Engine/ON
48	U_8	2^0	counts	Yes	Ullage Counter
49	Δr_0	2^6	ft	No	Value of differential altitude of the LM and the CSM, measure along the line of apsides corresponding to the best(least) value or the cost function
50	Y_f	2^6	ft	No	Predicted component of final LM inertial position vector at burnout perpendicular to the CSM orbit plane

7.3.3.4.3 Outputs to CES.

7.3.3.4.3.1 Attitude. Every 40 ms, the attitude control equations shall produce, and output, attitude steering signals E_x , E_y , E_z , which shall be simultaneous, limited angular errors about the three vehicle body axes. The commanded attitudes for AGS steering shall be computed every 2 seconds.

7.3.3.4.3.2 Engine On. The computer engine logic shall generate an Engine On signal every 40 ms under the following conditions:

- (a) Function selector S_{00} in an Inertial Reference state (Attitude Hold, Rendezvous, or Acquisition), Followup signal present, and either Ascent Engine On, or Descent Engine On signal present.
- (b) Function selector S_{00} in an Inertial Reference state (Attitude Hold, Rendezvous or Acquisition), Followup signal absent, Auto discrete absent, and either Ascent Engine On, or Descent Engine On signal present.
- (c) Function selector S_{00} in Inertial Reference state (Rendezvous only), Followup signal absent, Auto discrete present, Abort or Abort Stage signals present, state of Ullage present, and V_G greater than 100 fps or V_{gx} greater than 2.1 fps.

7.3.3.4.3.3 Engine Off. The computer engine logic shall generate an Engine Off signal every 40 ms under the following conditions.

- (a) Function Selector S_{00} in an align state
- (b) Function Selector S_{00} in an Inertial Reference State, Followup signal present, and both Ascent Engine On and Descent Engine On signals absent.
- (c) Function Selection S_{00} in an Inertial Reference state, Followup signal absent, Auto signal absent, and both Ascent Engine On and Descent Engine On signals absent.
- (d) Function Selector S_{00} in an Inertial Reference state, Followup signal absent, Auto signal present, Abort or Abort Stage Signals present, and Ullage condition absent.
- (e) Function Selector S_{00} in an Inertial Reference state, Followup signal absent, Auto signal present, Abort or Abort Stage signals present, Ullage condition present, and V_G less than 100 fps or V_{gx} less than 2.1 fps.

7.3.3.4.4 Outputs to Displays.

- (a) $\sin \alpha$, $\cos \alpha$, $\sin \beta$, $\cos \beta$, $\sin \gamma$, $\cos \gamma$ - The FDAI routine shall compute, and output these quantities every 40 ms based upon the following transformation:

$\cos \alpha \cos \gamma$	$-\sin \alpha \cos \gamma$	
$+\sin \alpha \sin \beta \sin \gamma$	$+\cos \alpha \sin \beta \sin \gamma$	$\cos \beta \sin \gamma$
<hr/>		
$\sin \alpha \cos \beta$	$\cos \alpha \cos \beta$	$-\sin \beta$
<hr/>		
$-\cos \alpha \sin \gamma$	$\sin \alpha \sin \gamma$	
$+\sin \alpha \sin \beta \cos \gamma$	$+\cos \alpha \sin \beta \cos \gamma$	$\cos \beta \cos \gamma$

- (b) E_x, E_y, E_z - (see 3.2.3.2.2.1 (b)).
- (c) The navigation equations shall compute, and output the Y body axis velocity, altitude, and altitude rate V_y, h, \dot{h} every 200 msec., in accordance with the requirements of this specification. Altitude output shall follow Altitude Rate output by a maximum of 1.5 milliseconds.

7.3.3.4.5 Output Discretes to GSE.

- (a) GSE 5 - The GSE shall utilize one output discrete (GSE 5) to control the transfer of information. The routine shall acknowledge that a word has been accepted and stored by setting GSE 5. The setting of GSE 5 is used by the test equipment to initiate the transfer of the next word. (See paragraph 7.3.2.4.5).

7.3.3.5 Astronaut Interface Requirements. Refer to LM AGS Operating Manual, TRW Document 05952-6141-T000, Rev. B, April 1967.

NOTE: The referenced document applies to the DMCP only and becomes an integral part of this specification. Future operating manuals will carry the vehicle and/or flight program designation in its title and will not be a part of this specification.

8.0 QUALITY ASSURANCE

8.1 AGS Simulation Requirements. Simulations demonstrating AGS performance using the AGS Guidance Programs described in 4.10 are required for AGS aborts occurring during the following mission phases:

- (a) Coasting Descent
- (b) Powered Descent
- (c) Lunar Surface Operations
- (d) Powered Ascent
- (e) Coasting Ascent

8.2 Nominal Mission Phases. Simulations will be performed to demonstrate that the AGS operation during aborts from nominal trajectory points, as defined by the Design Mission (DM) and outlined in Tables V and VI, satisfy the guidance and ΔV requirements established in this document. All simulations are required to demonstrate AGS performance using the coelliptic flight plan. Additional simulations distinct from the DM are included to determine overall AGS capabilities. These simulations are identified by an asterisk (*). Additionally, the termination of an abort simulation is defined as the point where the CSM/LM relative range is not greater than 5 n. mi. and the conditions specified in section 7.2.11 and 7.2.12 are satisfied.

8.2.1 Coasting Descent. Aborts during coasting descent are to be performed using both the direct intercept and coelliptic rendezvous routines.

- (a) 1500 seconds after descent orbit insertion
- (b) At the scheduled AGS alignment time, 5 minutes before the initiation of powered descent (assume the alignment was not completed).

8.2.2 Powered Descent.

8.2.2.1 Descent/Ascent Engine Aborts.

- (a) 28 seconds-end of low thrust maneuver
- (b) 270 seconds
- (c) 350 seconds
- (d) 400 seconds-start of final approach
- (e) 515 seconds-low gate

8.2.2.2 Ascent Engine Aborts.

- (a) 400 seconds-start of final approach
- (b) 635 seconds-touchdown

The guidance requirements as specified apply but the ΔV requirements do not apply.

8.2.3 Lunar Surface.

- (a) "Nominal" launches in-plane
 - (b) "Nominal" Launches $\frac{1}{2}^\circ$ ou-of-plane
 - * (c) "Early" launches in-plane
- $\Delta\phi$ -CSM Lead Angle at lift-off = 9.3°
- $\Delta\phi$ -CSM Lead Angle at lift-off = -34°

- * (d) "Early" launches $\frac{1}{2}^\circ$ out-of plane
 $\Delta\phi$ -CSM Lead Angle at lift-off = -34°
- * (e) "Late" launches in-plane
 $\Delta\phi$ -CSM Lead Angle at lift-off = $+34.0^\circ$
- (f) "Nominal Launch" - use initial conditions defined
in Table V .
- * (g) "Late" launch 2.0° out-of-plane
 $\Delta\phi$ -CSM Lead Angle at lift-off = $+34.0^\circ$

8.2.4 Powered Ascent.

- (a) 100 seconds
- (b) 200 seconds
- (c) 300 seconds
- (d) 30 seconds prior to burn-out
- (e) 10 seconds prior to burn-out

8.2.5 Coasting Ascent.

- (a) 25 seconds prior to ascent engine burn-out
- (b) 5 minutes prior to CSI
- (c) 5 minutes prior to CDH
- (d) 5 minutes prior to TPI
- (e) After TPI burn

The AGS performance of a direct intercept maneuver is to be evaluated for each of the points (a) thru (e) above, provided the CSM/LM phasing is such that the ΔV and pericynthion constraints specified in 7.2.12 and paragraph 2.10 of Volume II are not violated.

8.2.6 Demonstrate Completion of Ascent Burn with RCS -

- (a) Fuel depletion 25 seconds prior to burn-out.

8.3 Nominal Mission Phase. Guidance and Trajectory Errors:

Simulations required to demonstrate that the AGS operation in the presence of the combined guidance and navigation errors presented below satisfy the guidance performance and ΔV requirements for the mission phases presented in section 8.2.2.2 (b) and 8.2.3 (f). The ΔV expenditures are to be determined for all mission bases subsequent to abort initiations.

8.3.1 AGS Errors. The AGS errors to be incorporated in the simulation are to be determined from the ASA errors specified in section 6.3 and 6.4, the computational errors specified in section 7.2.3 and 7.2.4, the alignment accuracies specified in sections 7.2.1 and 7.2.2 and the AGS Earth Prelaunch and Preflight Calibration and Compensation errors specified in section 7.2.14.

8.3.2 Vehicle Characteristic Variations. The variations in the vehicle characteristics (i.e. Thrust, I_{sp} , etc.) are listed in Table 3 of Vol. 2. The simulations required in section 8.3 are to be repeated with the variations listed in the Table on the following page.

TABLE

One Sigma (1σ) Vehicle Characteristics Variations

<u>Quantity</u>	<u>Descent State</u>	<u>Ascent Stage</u>
I_{sp}		
Thrust		Refer to Table 3, Vol. 2
Mass		Refer to Table 2, Vol. 2
Pitch c.g. offset	.06667	1.0 in.

8.3.3 AGS Navigation Initialization Errors. The AGS navigational estimate will be initialized at various times and from various sources during the mission. The sources of navigation initialization are:

- (a) PGNCN/LGC (Downlink)
- (b) Rendezvous Radar(RR)
- (c) MSFN (Voice Link)
- (d) CSM (Voice Link)

The AGS navigation initialization errors for (a), (c), and (d) are listed in section 7.2.17 in the form of one sigma (1σ) covariance matrices. A schedule of navigation initialization sources and times for the various mission phases appears in the table below. Each AGS navigation initialization sequence is to be combined with the errors listed in section 8.3.1. The guidance and ΔV performance

requirements and constraints specified in sections 4.0, 5.0, 6.0, and 7.0 apply only to sequence 1 or 2 or 3 or 4.

TABLE
Navigation Initialization Sequences

<u>Sequence</u>	<u>CSI</u>	<u>CDH</u>	<u>TPI</u>	<u>M.C.</u>
1	MSFN	---	MSFN	RR
2	RR	RR	RR	RR
3	RR	RR	MSFN	RR
4	---	---	MSFN	RR

8.3.4 Rendezvous Radar Navigational Initialization. The evaluation of the AGS/RR navigational estimation technique is required. The characteristics of the RR are presented in section 7.2.9. The simulation of the sequences described in section 8.3.3, which included navigation initialization by the RR, are to be repeated with and without the RR errors listed in section 7.2.9.

8.3.5 * Repeat the simulation of section 8.2.3 (f) utilizing the manual ΔV_{gx} , ΔV_{gy} , ΔV_{gz} mode for performance of the CSI burn.

8.3.6 External Delta V Mode. Simulations are required to verify the operation of the external ΔV mode.

- (a) The V computed for the CDH maneuver in 8.2.3 (b) is to be used to verify the AGS performance when operating in the External Delta V Mode.

8.4 Off-Nominal Mission Phases. Simulations are required to demonstrate that the AGS performance in the presence of off-nominal trajectory conditions satisfies the system requirements specified in this document.

The simulations required in section 8.2.2.1 and 8.2.4 are to be repeated with the positive and negative off-nominal trajectory conditions listed in section 2 of Vol. II . The positive dispersion for all coordinates shall be combined with the same sign of the velocity dispersions for those coordinates. Also the position and velocity dispersions in all coordinates shall be considered to occur simultaneously. The simulations required in section 8.2.2 and 8.2.4 are to be repeated with the negative off-nominal conditions combined in the above manner.

8.5 Simulation Output Data. The output data required for the evaluation of AGS performance is outlined below:

Simulation output data

E_x, E_y, E_z	- Attitude errors
DT (sec)	- Time increment used in the direct intercept routine for calculation of the LOS angle
h_o (ft)	- Altitude
v_o (fps)	- Inertial cut-off velocity (orbit insertion routine)
\dot{r} (fps)	- Radius rate (orbit insertion routine)
T_1 (sec)	- Time to start CSI burn
T_2 (sec)	- Desired TPI time
ϵ (deg)	- LM elev. angle at TPI time
ΔV_g (fps)	- Thrust velocity to be gained
Δh (ft)	- Differential altitude
TXFER (sec)	- Time of initiation of TPI
TCDH (sec)	- Time of apocynthion or pericyynthion
ΔV_{CSI} (fps)	- Required CSI ΔV magnitude
ΔV_{CDH} (fps)	- Required CDH ΔV magnitude
ΔV_{gx}	- Component of ΔV_g along LM body Y axis
ΔV_{gy}	- Component of ΔV_g along LM body Z axis
\dot{p}	- LM/CSM relative range rate
ΔO_2 (deg)	- Elevation of LM/CSM LOS above the LM local horizontal

(Continued)

Simulation output data

X_L, Y_L, Z_L	-	LM true position in inertial coordinates
X_A, Y_A, Z_A	-	AGS computed LM position in inertial coordinates
$\dot{X}_L, \dot{Y}_L, \dot{Z}_L$	-	LM velocity in inertial coordinates
$\dot{X}_A, \dot{Y}_A, \dot{Z}_A$	-	AGS computed LM velocity in inertial coordinates
X_C, Y_C, Z_C	-	CSM position in LM inertial coordinates
$\dot{X}_C, \dot{Y}_C, \dot{Z}_C$	-	CSM velocity in LM inertial coordinates
H_a (n. mi)	-	CSM apocynthion altitude
H_p (n. mi)	-	CSM pericynthion altitude
e_c	-	CSM eccentricity
θ_c (deg)	-	Angle to CSM line of apsides relative to LM launch site
ϕ_c (deg)	-	Angle of CSM from LM launch site
e_L	-	LM eccentricity
h_p (n. mi)	-	LM pericynthion altitude of present orbit
h_a (n. mi)	-	LM apocynthion altitude of present orbit
O_L (deg)	-	Angle to LM line of apside of present orbit
ϕ_L (deg)	-	Angle of LM from launch site
h_{ca} (n. mi)	-	AGS computed CSM altitude
\dot{h}_{ca} (fps)	-	AGS computed CSM altitude rate
h_c (n. mi)	-	True CSM altitude
\dot{h}_c (n. mi)	-	True CSM altitude rate

(continued)

Simulation output data

r_m (ft)	-	Triaxial moon radius
TH (Lbs)	-	Thrust
\underline{a}_c (fps ²)	-	AGS Commanded thrust acceleration (\dot{x} , \dot{y} , \dot{z}) in LM inertial coord.
\underline{a}_A (fps ²)	-	AGS measured thrust acceleration (\ddot{x} , \ddot{y} , \ddot{z}) in LM inertial coord.
\underline{a} (fps ²)	-	Total acceleration (includes gravity)
g_A (fps ²)	-	AGS gravitational estimate
g (fps ²)	-	True gravitational components
m (slug)	-	LM mass
$\sqrt{V_L}$ (fps)	-	Total LM velocity
V_c (fps)	-	Total CSM velocity
$\Delta \phi$ (deg)	-	Relative CSM/LM central angle
E_L	-	LM eccentric anomaly
E_c	-	CSM eccentric anomaly
λ_c	-	Out-of-plane angle of LM with respect to CSM orbit plane
\underline{r}_{RR} (ft)	-	Rendezvous radar filter estimate of position
\underline{V}_{RR} (fps)	-	Rendezvous radar filter estimate of velocity
C	-	Cost function

8.6 PROGRAM VERIFICATION

When the flight program has been designed and coded for the AEA, both the design and the coded program shall be verified in detail by formal studies and tests implemented on general purpose computers using simulation techniques. The various modes of testing to be employed are described generally below as guidelines. However, prior to the implementation of testing, a detailed Program Verification Test Plan document shall be prepared and submitted to NASA/MSC for approval and concurrence. The test plan shall describe the tests which will be conducted and their individual objectives. The tests shall be devised to demonstrate that the flight program functions have been designed to fulfill the requirements of the AGS in its mission aboard the LM vehicle.

At the completion of the testing specified in the approved test plan, test results shall be documented in a Verification Test Results Summary which shall be submitted to indicate successful completion of the test plan. All computer outputs produced by the tests, whether included in the documentation or not, shall be retained and made available for examination on request.

Upon acceptance of the Verification Test Results Summary by NASA/MSC, the verification of the flight program will be considered to be complete.

8.6.1 VERIFICATION TESTING

Three classes of tests shall be performed to verify that the flight program will fulfill its mission and that its design and coding are as free from inadequacies and errors as may reasonably be determined by the use of software simulation techniques only. The three classes of tests are characterized by the type of simulation used to implement them.

- 1) Scientific Flight Simulation Tests
- 2) Interpretive Computer Simulation Tests
- 3) Interpretive Computer Simulation/ Flight Simulation Tests

8.6.1.1 Scientific Flight Simulation Tests

The scientific flight simulation (SFS) is a general purpose computer program in which the flight program equations and logic are programmed in a convenient compiler language suitable for scientific studies. The representation of the flight program is coupled to a flight simulation (FS) containing models of the vehicle and the environment along with the capability for integrating trajectories in a closed-loop configuration. See Reference 8-1. The FS is a 3 degree-of-freedom simulation.

The SFS shall be used to demonstrate equation performance and to generate trajectories and results for comparison with those generated by the ICS described in Paragraph 8.6.1.2 and the ICS/FS described in Paragraph 8.6.1.3.

8.6.1.2 Interpretive Computer Simulation Tests

The interpretive computer simulation (ICS) is a general purpose computer program which simulates the operation of the AEA precisely, bit-for-bit, including the operation of the interfaces. The program should include an evaluation of computation errors such as round-off, truncation, and non-commutation.

The flight program, as coded for the AEA, shall be loaded into the ICS and exercised, using suitable driver routines, in an open-loop configuration. Sufficient testing shall be conducted to check out the program, that is, to demonstrate that the various flight program functions have been correctly coded in accordance with both the program and computer design.

8.6.1.3 Interpretive Computer Simulation/Flight Simulation Tests

The Interpretive Computer Simulation/Flight Simulation (ICS/FS) is a general purpose computer program which combines the ICS described in Paragraph 8.6.1.2 with the FS previously mentioned in Paragraph 8.6.1.1. See Reference 8-2.

The ICS/FS shall be used to demonstrate that the flight program, as coded for the AEA, functions correctly in a closed-loop configuration on all phases of the missions which have been defined by means of reference trajectories and mission profiles.

8.6.1.3.1 ICS/FS Requirements. The following ICS/FS closed loop runs are required to verify the DMCP coelliptic flight plan software.

8.6.1.3.2 Hover abort to rendezvous (nominal). - 5 minutes prior to P.D. - align, calibrate, initialize, follow-up, abort, orbit insertion, CSI, CDH, TPI, midcourse, closest approach.

8.6.1.3.3 Three descent aborts cases, large initial condition and vehicle dispersions thru orbit insertion.

8.6.1.3.4 Three ascent abort cases, large initial condition and vehicle dispersions. Once case will be abort at lift-off plus 1 second thru orbit insertion.

8.6.1.3.5 Lift off from lunar surface, large initial condition and vehicle dispersions (2° out of CSM plane) thru orbit insertion.

8.6.1.3.6 Four CSI (horizontal burn) cases; $-100 \text{ NM} \leq h \leq 150 \text{ NM}$.

8.6.1.3.7 Lunar surface: touchdown, shutdown, turn-on, initialize, align, calibrate, lift off, (thru orbit insertion).

8.6.1.3.8 External ΔV mode, 2 cases (1) auto steering
(2) body ΔV resolution.

8.6.1.3.9 Demonstrate body ΔV resolution trim capability,
4 cases: orbit insertion, CSI, CDH, TPI.

8.6.1.3.10 Four direct transfer burns with different
phasing with respect to CSM.

8.6.1.3.11 High eccentric orbit - $e > .125$, initialize, do
TPI burn with good phasing.

8.6.1.3.12 3 runs with sensor errors for aborts late in
powered descent, abort from lunar surface, and aborts early
in powered ascent.

8.6.1.3.13 CDH burn run with 10 sigma DPS thrust, -10 sigma
DPS thrust, and -10 sigma weight vehicle dispersions.

8.6.1.3.14 Direct Transfer - noisy radar data, non-nominal
sequence of radar data.

8.6.1.3.15 Reference Data For Simulation

The verification tests for flight programs shall include
simulations using the program with both earth mission scaling

and lunar mission scaling.

For the earth mission tests, the mission profile is that of the D Mission, fifth period of activities, as defined in Reference 8-3. The reference trajectory is given in Reference 8-4 and targeting parameters are provided in Reference 8-5.

Tests of the program with lunar scaling shall be based both on the 60 n. mi. lunar mission and the Design Mission, an 80-n. mi. lunar mission. For the 60-n. mi. lunar mission, the profile and target parameters for an abort from hover are given in Reference 8-6 and a powered descent reference trajectory is given in Reference 8-7. For the Design Mission, the reference trajectory is given in Paragraphs 10.6 and 10.7 of this document.

The modeling for the environment shall be in accordance with the definitions of Section 4.0 of Reference 8-10.

8.7 NOTES

8.7.1 Definitions. -

8.7.1.1 Instability. - The change in a sensor channel parameter due to the combined action of time, non-repeatability, cross-coupling, environmental disturbances and changes in electrical

power and timing signal inputs. Parameter instability includes changes due to time instability and repeatability as defined in paragraphs 8.7.1.2 and 8.7.1.3.

8.7.1.2 Time Instability. - The change in a parameter over a specified period of time. Time instability is determined from a series of measurements at the beginning and a series of measurements at the end of the specified period.

The number of measurements in each series should be sufficiently large that the error in the mean (due to repeatability) is small relative to the time instability. Time instability is computed by differencing the mean of the initial series of measurements and the means of the final series of measurements.

8.7.1.3 Repeatability. The standard deviation of a series of measurements of a single parameter taken under similar conditions over a short period of time.

8.8 References.

- 8-1 TRW Report 05952-6176-T000, "User's Guide, Scientific Simulation, LM AGS Coelliptic Rendezvous Equations," September 1967.
- 8-2 TRW Report 05952-6157-T000, "DMCP LM AGS Interpretive Computer Simulation/Flight Simulation (ICS/FS) Description," March 1968.
- 8-3 MSC Internal Note 67-FM-184, "AS-504/CSM-103/LM-3 Mission Profile," 28 November 1967.

- 8-4 MSC Trajectory Printout H99-G-FM6-005591 (D Mission Fifth Period of Activities), 8 February 1968.
- 8-5 MSC Memo 68-FM71-74, "AGS Data Package for LM-3 Flight Program Verification," 13 February 1968.
- 8-6 MSC Letter EG43-122-68-248, "Contract NAS 9-4810, Reduction in Delta-V Budget and New Lunar Mission Profile for AGS Performance Analysis and Flight Program Verification," 1 March 1968.
- 8-7 Informal 60 nmi lunar mission powered descent reference trajectory (using Apollo Reference Mission Program, Version ARM 05), 2 February 1968.
- 8-8 GAEC Specification No. LSP-500-1, "Abort Guidance Section Software, GFE Performance and Interface Specification (U)," 14 August 1966 (Confidential) as interpreted by Reference 8-9.
- 8-9 TRW Letter 7001.16-1192, "Review of Proposed Changes to the LM/AGS P and I Spec," 13 December 1967.
- 8-10 NASA, Apollo Navigation Working Group, Technical Report No. AN-1. 1, "Apollo Missions and Navigation Systems Characteristics," 4 April 1966.

9.0 PRODUCT FORMAT

This chapter defines the interface requirements of deliverable items for use during Earth Prelaunch Calibrations (EPC) and testing with Acceptance Checkout Equipment - Spacecraft (ACE-S/C).

9.1 EARTH PRE-LAUNCH CALIBRATION

This section establishes the requirements for the Earth Pre-launch Calibration Program (EPC) for the Abort Electronic Assembly (AEA) of the Abort Guidance Section (AGS). The EPC will be use to determine the gyro calibration compensation coefficients for the AGS gyro drift rate during earth prelaunch operations including laboratory testing and launch pad operations.

Deliverable software covered by this specification consists of symbolic program listings, symbolic deck of cards, binary deck of cards, and punched paper tape for Bench Test Maintenance Equipment (BTME) utilization. The specification covers the following major items:

1. Program requirements
2. Functional requirements
3. EPC Program description (Routine)
4. Usage and Input/Output Requirements
5. Software Identification and Delivery

The EPC specified herein shall be applicable for use with all AEA memory configurations, i.e., Interim, HO-2, and HO-3.

The entire program for the EPC shall be softwired. The program shall be designed to operate with the ACE and the BTME, although different tapes are necessary for the different test equipment.

The ACE will load and verify the program and insert necessary data into the AEA. The program shall be self-contained and use only a portion of the softwired memory and hence will be compatible with all of the hardwired memories.

9.1.1 PROGRAM REQUIREMENTS

This paragraph specifies the quantitative performance requirements that must be met by the AGS for the EPC.

a. AGS Performance Requirements

The EPC shall utilize a program based on a scheme which uses the known latitude of the launch site, a self alignment to local vertical and a known azimuth angle with respect to true North known to 0.1 degree. The calibration scheme shall also use a measurement of the X-gyro channel spin axis mass unbalance made a maximum of 120 days prior to completion of the lunar landing mission. The X gyro input axis and the Y and Z gyro spin and input axis mass unbalance measurements may also be used. The range of gyro drift compensation capability to be provided shall be $\pm 10.0^\circ/\text{hr}$.

b. AGS Software Performance Requirement

The performance requirement for the EPC equations is to obtain a calibration (and compensation) value of the gyro drift about each axis to an accuracy of $0.1^\circ/\text{hr}$ for computational errors only.

c. Frequency of Calibration

The AGS automatic earth prelaunch calibration of gyro channel static bias will be performed no more than 44 hours prior to liftoff.

d. Prelaunch Booster Sway Data

The EPC performance requirements shall be met with the prelaunch booster sway environment given in paragraph 7.2.2 3. The EPC Program is required to calibrate within $0.1^\circ/\text{hr}$ of the true value in the presence of the sway model denoted requirement. The design goal sway model is designed

to demonstrate EPC performance under extreme conditions, but specification accuracy requirements do not apply. It shall be assumed that the sway data defines the total lateral and rotational motion (except in azimuth) and it shall also be assumed that the rotation in azimuth is negligible.

e. Pulse Moding Section Comments

The prelaunch calibration shall be required to operate in the presence of pulse moding of the ASA gyros and accelerometers. The model of the accelerometer and gyro pulse moding to be assumed in the EPC software testing shall be a cosine function with a frequency of 120 cps and an amplitude of 15 pulses. However, since the frequency characteristic of the pulse moding is not well determined, the EPC software testing shall include performance samples in which the frequency is between 80 and 140 cps for the gyro, and between 85 and 985 cps for the accelerometer. Peak amplitude for pulse moding rate shall be 10 pulses per millisecond.

9.1.2 FUNCTIONAL REQUIREMENTS

9.1.2.1 ASA Gyro Drift Calibration

This routine shall be composed of integral ASA alignment and gyro drift determination schemes (i.e., the ASA accelerometer axes alignment to the local vertical are determined while the gyro drift compensation coefficient is being determined). The reference axes for alignment and gyro drift determination shall be the earth fixed North-Vertical-East (NVE) axes. These axes and the azimuth measurement relationship to the axes shall be as shown in Figure 9-1. The azimuth measurement shall be available from an optical measurement that gives the azimuth angle of the projection of the Z-body axis on the horizontal plane with respect to true North. The azimuth measurement for the prelaunch operations on the pad shall be available such that a prelaunch calibration can be accomplished at approximately 44 hours prior to launch.

As stated above the ASA accelerometer and gyro inputs to the AEA are compensated within the AEA. In the case of the gyro, the AEA equations shall compensate the gyro inputs for fixed gyro drift, gyro spin and input axis mass unbalance drift and gyro scale factor error. For the accelerometer, the AEA equations shall compensate the accelerometer inputs for accelerometer static bias and accelerometer scale factor errors. The compensations are performed by a correction to the inputs. The corrections are as follows:

a. Fixed Gyro Drift

The fixed gyro drift compensation constants from pre-installation calibration will be inserted into the AEA prior to the prelaunch calibration. The values will be updated following each prelaunch calibration. A positive gyro

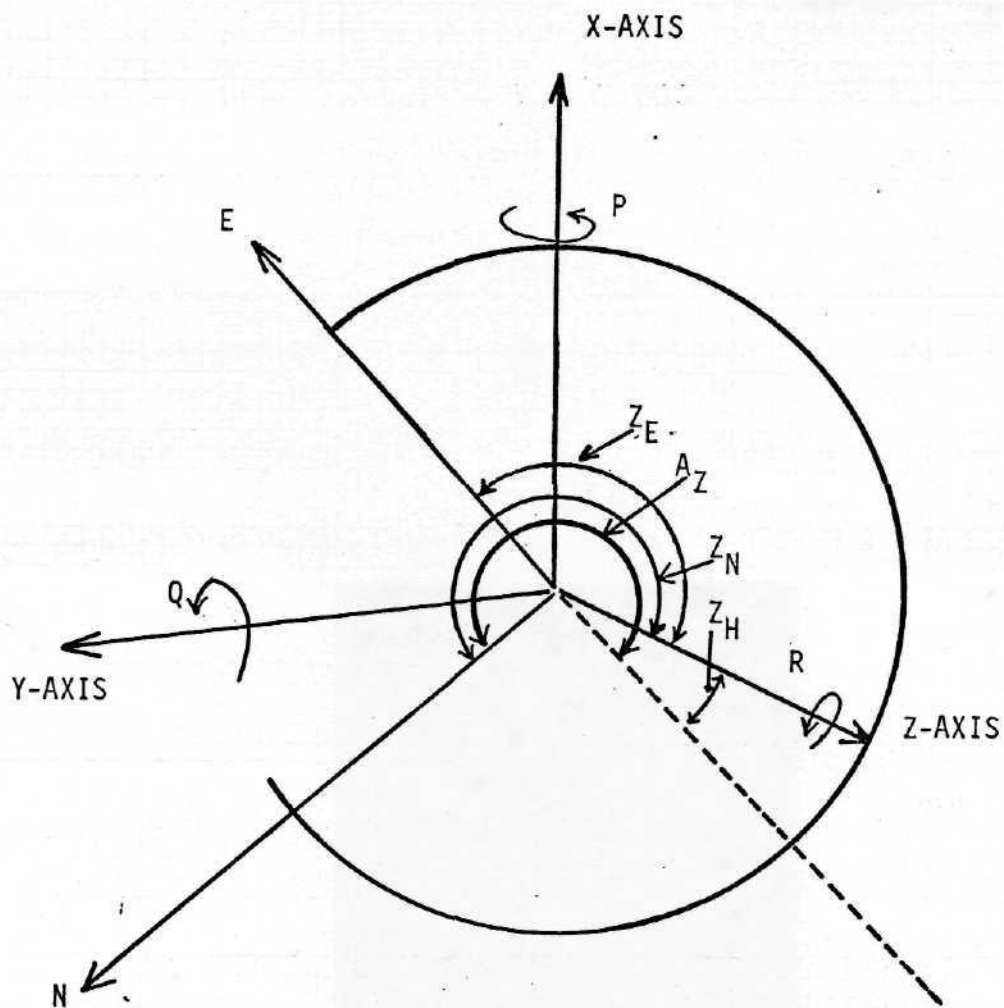


FIGURE 9-1
EPC COMPUTATIONAL REFERENCE AXES

This figure illustrates the projection of the azimuth angle A_Z up from the horizontal plane established by the N, Z, and E axes.

drift results from a gyro output of more than 32 pulses per millisecond during no ASA rotation. A positive gyro drift error is compensated in the AEA by a negative gyro fixed drift compensation constant. Fixed gyro drift compensation shall be provided over a range of ± 10.0 degrees an hour.

b. Gyro Spin Axis and Input Axis Mass Unbalance Drift

The gyro spin axis and input axis mass unbalance compensation constants (two individual constants for each of the X, Y, Z axes) will be inserted into the AEA during the prelaunch operations.

For the spin axis constant a positive ASA acceleration in the direction of the gyro input axis results in a negative gyro output (less than 32 pulses per millisecond with no ASA rotation). The negative gyro output resulting from the positive acceleration is compensated in the AEA by a positive gyro spin axis mass unbalance compensation constant.

For the input axis constant a positive ASA acceleration in the direction of the gyro spin axis results in a negative gyro output (less than 32 pulses per millisecond with no ASA rotation). The negative gyro output resulting from the positive acceleration is compensated in the AEA by a positive gyro input axis mass unbalance compensation constant.

These compensations shall be provided over a range of ± 10.0 degrees per hour per "g" of acceleration.

c. Gyro Scale Factor Errors

The scale factor error compensation constants will be inserted into the AEA during the prelaunch operations. A positive scale factor error exists when the scale factor of a gyro is greater than 2^{-16} radians/pulse. A positive gyro scale factor error is compensated in the AEA by a positive gyro scale factor compensation constant. Scale factor error compensation shall be provided over a range of ± 0.78 per cent of the nominal gyro scale factor.

d. Accelerometer Static Bias

The accelerometer static bias compensation constants will be inserted into the AEA during the prelaunch operations. A positive accelerometer bias error results from an accelerometer output of more than 32 pulses per millisecond with no ASA acceleration. A positive accelerometer bias error is compensated in the AEA by a negative accelerometer bias compensation constant. Accelerometer static bias compensation shall be provided over a range of ± 2000 micro "g" of acceleration.

e. Accelerometer Scale Factor Errors

The accelerometer scale factor compensation constants will be inserted into the AEA during the prelaunch operations. A positive accelerometer scale factor error exists when the scale factor of an accelerometer is greater than 0.003125 feet per second per pulse (0.1/32). A positive scale factor error is compensated in the AEA by increasing the value of the accelerometer scale

factor constant above the nominal value of 0.003125 fps/pulse. Scale factor error compensation shall be provided over a range of $\pm 24\%$ of the nominal value of 0.1/32 fps/pulse.

Figure 6-2 illustrates the ASA sensor orientation and axis coordinates.

9.1.2.2 Limits on the Maximum Value of ASA Parameters

Bounds are set on the absolute value of all ASA parameters to assure that they remain within the operating, calibration, or compensation range of the AGS, and to detect ramping functions which would pass 120-day stability requirements. See Table 7-1 for limits.

In most cases these maximum values are of little consequence because the trim limits during ASA acceptance testing are much tighter, but misalignment, nonlinearity, and bias discrepancy limits reflect mission performance considerations.

Gyro assymetry limits are given in Figure 7-1.

9.1.2.3 TEST LIMITS FOR TIME STABILITY OF ASA PARAMETERS

a. PURPOSE

The AGS incorporates compensation for all critical ASA parameters using the last measurement available before or during flight. The time stabilities of these parameters over the interval from last measurement to use are therefore the most critical performance characteristics of the AGS. The design is such that there is no great margin between the ensemble characteristics and the stability required for mission success, so tracking parameter stability against carefully selected bounds is necessary.

b. DEFINITION

Bounds have been selected (for each ASA parameter) for eight time periods, which in effect specify the maximum allowable change in mean between any two sets* of ASA calibrations performed at KSC.

To accommodate the effects of shipment and equipment differences (tolerances) at the various sites, additional margin is allowed due to misalignments for the mean shift during the interval including the shipment of the ASA to KSC (see Table 9-2).

c. USE

The mean value of each parameter from a calibration set shall be compared to the last measured mean. If the shift in mean exceeds the criteria recommended for the appropriate time interval, then the test conditions,

* A "set" consists of 3 calibrations performed without shutdown.

storage conditions and all contributing factors should be examined. If a probable cause is found a retest is indicated.

If the data is determined to be valid, the system should be considered flightworthy. Assuming of course, that all nonperformance criteria, such as operating hours are satisfied and that the Monte Carlo Mission Analyses performed on the ASA were successful.

TABLE 9-1

TEST LIMITS FOR REPEATIBILITY WITHIN A SET
OF 3 CALIBRATION TESTS PERFORMED ON THE
BTME AT KSC, WITHOUT POWER SHUTDOWN

<u>PARAMETER</u>	<u>MAXIMUM ALLOWABLE STANDARD DEVIATION</u>
GYRO BIAS	.1°/hr
GYRO SCALE FACTOR	35 ppm
GYRO INPUT AXIS UNBALANCE	.1°/hr/g
GYRO SPIN AXIS UNBALANCE	.12°/hr/g
GYRO MISALIGNMENT	18 ^{arc} sec
ACCELEROMETER BIAS	Bell and Kearfott 20 μg
ACCELEROMETER SCALE FACTOR	10 ppm
ACCELEROMETER MISALIGNMENT	12 ^{arc} sec

TABLE 9-2

TIME STABILITY TEST LIMITS

(MAXIMUM SHIFT IN MEAN VALUE OVER THE TIME INTERVAL SPECIFIED)

PARAMETER	TIME INTERVAL - DAYS								SHIPMENT●
	0-2	3-6	7-10	11-20	21-40	41-60	61-90	90-120	
GYRO BIAS	.35	.40	.50	.60	.75	.9	1.0	1.2	
GYRO SCALE FACTOR	140	180	240	290	+290 -390	+290 -500	+290 -560	+290 -620	
GYRO SPIN AXIS UNBALANCE	.35	.4	.5	.6	.75	.9	1.0	1.2	
GYRO INPUT AXIS UNBALANCE, Y & Z*	.25	.3	.35	.4	.6	.7	.8	.9	
GYRO MISALIGNMENT	45	45	45	45	45	45	45	60	30
GYRO INPUT AXIS UNBALANCE, X*	+.25 -.4	+.3 -.7	+.35 -.9	+.4 -1.1	+.4 -1.6	+.4 -2.0	+.4 -2.3	+.4 -2.3	
BELL ACCELEROMETER BIAS**	80	100	150	250	570	570	570	570	
	80	300	300	400	570	570	570	570	
SCALE FACTOR	30	40	60	+60 -100	+60 -200	+60 -350	+60 -450	+60 -550	
MISALIGNMENT	45	45	45	45	45	45	45	45	30
KEARFOTT ACCELEROMETER BIAS	100	150	200	250	325	400	475	570	
SCALE FACTOR	100	130	+150 -180	+150 -240	+150 -350	+150 -450	+150 -550	+150 -650	
MISALIGNMENT	45	45	45	45	45	45	45	45	

● THESE VALUES ARE TO BE ADDED TO TIME STABILITY

* STORAGE WITH X UP

** WITH REDUCED STORAGE TEMPERATURE

9.1.3 Description of EPC Program

The basic unit of time in the Earth Pre-Launch Calibration Program (EPC) shall be 20 milliseconds. At this frequency the accelerometer and gyro registers are input, the attitude reference is updated, and the telemetry stop pulse discrete is twice sampled and when set the output telemetry register is loaded. At 40 millisecond intervals the orthogonality-normality corrections are computed, the GSE and DEDA discrettes are sampled, and if necessary, the GSE service routine is executed. Each 80 milliseconds one complete pass through the calibration equations shall be executed.

The EPC program shall be compatible with the Load and Verify Program and the TCP's at KSC. Locations 0000 to 0205 of the AEA shall be blank when using the EPC during load and execute.

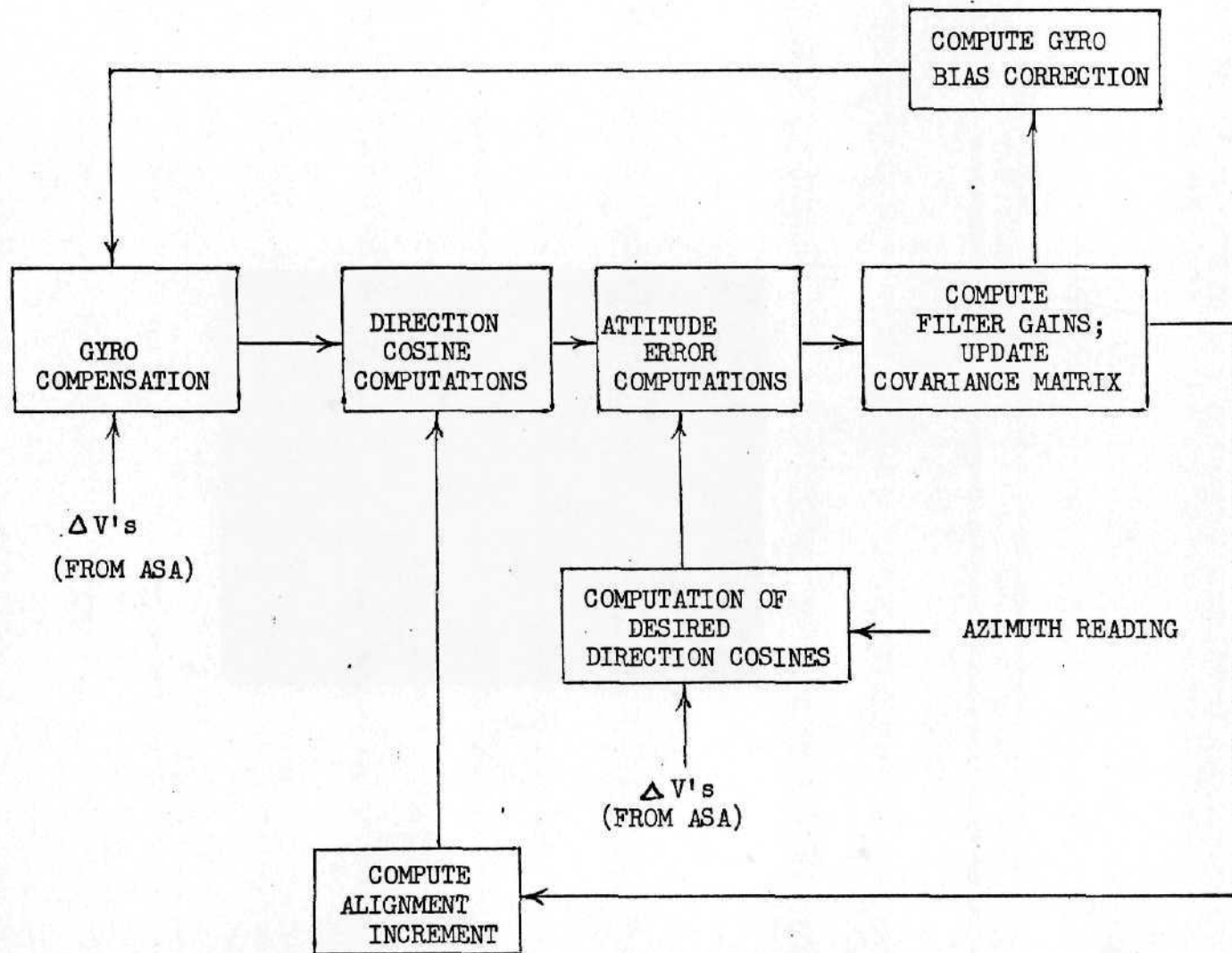


Figure 9-2. Functional Block Diagram of Gyro Calibration

9.1.3.1 GSE Service Routine

The purpose of the GSE Service Routine is to load data received from ACE or BTME into the softwired memory. The initiation and termination of all loads are controlled by discrettes set by the ACE or BTME.

When the program senses discrete GSE1 set true ($= 0$), the GSE Service Routine is entered and the first word is input and must have the format:

$$X_1 X_2 Y_1 Y_2 Y_3 Y_4$$

If $X_1 X_2 = 77$ or 74 , then data is to be input and stored into location $Y_1 Y_2 Y_3 Y_4$ and consecutively higher locations.

After the first word and each successive word is loaded, discrete GSE5 is set denoting receipt and processing of the word. Then the routine waits for GSE1 to be reset ($= 1$) and then resets GSE5 and the test mode failure indicator and awaits the setting of GSE1 to true, signifying that another word is ready for loading. Input terminates when the setting of discrete GSE2 accompanies the setting of GSE1. After each input word has been processed, discrete GSE2 is sensed and if received control is transferred to the checksum routine ($X_1 X_2 = 77$) or to the beginning of the 20 ms cycle ($X_1 X_2 = 74$).

Execution of the checksum routine is an option of the 77 type load. If the second to the last word input is non-zero, then

the sum of all the data words, excluding the last one, must be zero or the test mode failure indicator is set and the program returns to the beginning of the 20 ms cycle. If the sum is zero, the sign of the last input word is sensed and if positive control is transferred to location $Y_1 Y_2 Y_3 Y_4$, the location of the first data word loaded; otherwise, control is transferred to the beginning of the 20 ms cycle.

After each word is input, it is output with the I. D. code 77 via the telemetry register.

If $X_1 X_2 \neq 77, 76, \text{ or } 74$, the test mode failure indicator is set and control is transferred to the start of the 20 ms cycle.

Figures 9-3 and 9-4 are detailed flow diagrams of the GSE Service Routine.

GSE SERVICE ROUTINE

RESET
GSE 1
SUBROUTINE

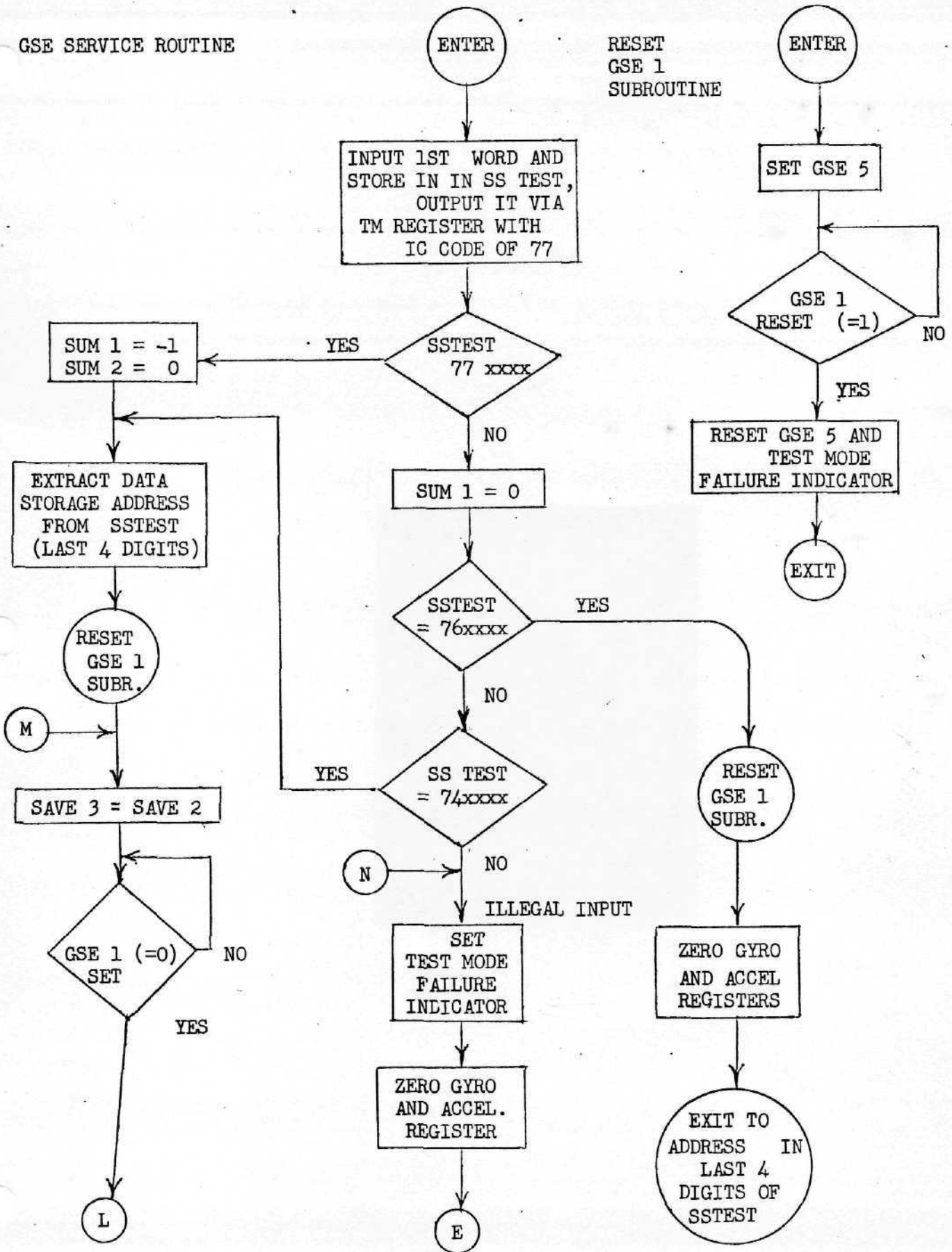


Figure 9-3.

GSE SERVICE
ROUTINE (CONT)

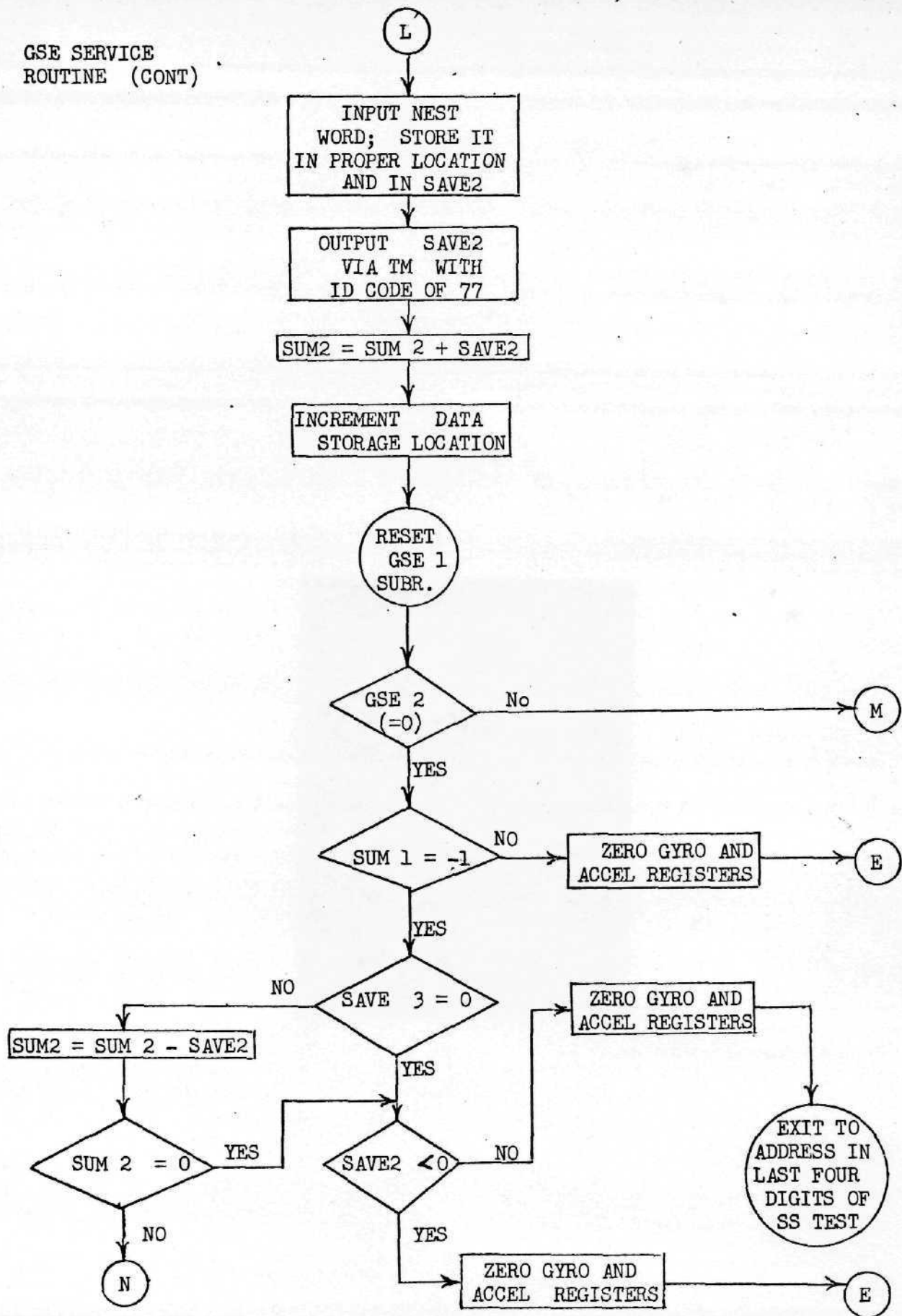


Figure 9-4

9.1.3.2 AEA Load and Verify Routine

The GSE load and verify routine incorporated into the EPC program (EPC L/V) shall be compatible with the flight load and verify (Flt L/V) routine. The Flt L/V shall provide the following capabilities:

- a. Program load with checksum and execution (program transfer) options.
- b. Single word or block word load of data.
- c. Word by word verify via the output telemetry register.
- d. Memory dump.

The EPC L/V shall provide the capability for (a), (b), and (c) of the above list. Item (a) is the normal load capability which uses the last two words loaded to control the checksum and execution options. Item (b) allows the loading of individual cells or block of computer (AEA) memory.

Item (c), the verify capability, will always be available at the option of the test (BTME, or ACE) equipment. As each word is input, it will be output to the least significant 18 bits of the output telemetry register. If it is desired to verify the load, the output telemetry register must be read out prior to loading the next word.

9.1.3.3 DEDA Routine

The DEDA routine shall provide for read-in, decoding and storage of instructions and data, and processing and read-out of stored flags and data through the DEDA Data Register. All transfer of information between DEDA and the AEA shall be initiated under control of the DEDA discretes.

Data shall be processed in two forms, octal or decimal. Octal words consist of a sign and 5 octal characters. Decimal data consists of a sign and 5 BCD (binary coded decimal) characters. Decimal parameters shall have an associated scale factor stored in the AEA memory.

All data transfer shall be initiated by the Clear discrete. Upon sensing the Clear, the routine shall set up the Clear mode during which it awaits either an Enter or a Read-out discrete. Upon sensing an Enter discrete, the routine shall input and process the data contained in the DEDA Shift Register. Upon sensing a Read-out discrete, the routine shall read-in the address of the requested data from the DEDA Shift Register. Thereafter, the requested data shall be output twice per second until either a Hold or a Clear discrete shall be sensed. This will reinitiate output twice per second.

Figures 9-5 and 9-6 are flow diagrams of the DEDA routine.

Table 9-3 lists the variables which must be entered in decimal and which are read out in decimal when addressed by DEDA.

All remaining variables which are located in words 0000 through 0777 must be entered in octal and are read out in octal when addressed by DEDA. These variables are listed in Table 9-4.

The program shall accept data without any reasonableness checks except that the three character octal address shall be tested to determine if each character is less than eight. If it is not, it is an indication of bad input data and all DEDA mode flags shall be reset and the routine exited.

The DEDA shall be accessible during all pre-installation tests and up to launch minus 16 hours during all prelaunch operations with ACE.

9.1.3.4 AGS Telemetry Downlink Routine

The AGS shall supply one digital output telemetry word every 20 milliseconds, provided a telemetry stop pulse from the instrumentation section has been sensed. This is indicated by the telemetry control discrete which will be set upon receipt of a telemetry STOP pulse by the AEA after data from

DEDA ROUTINE

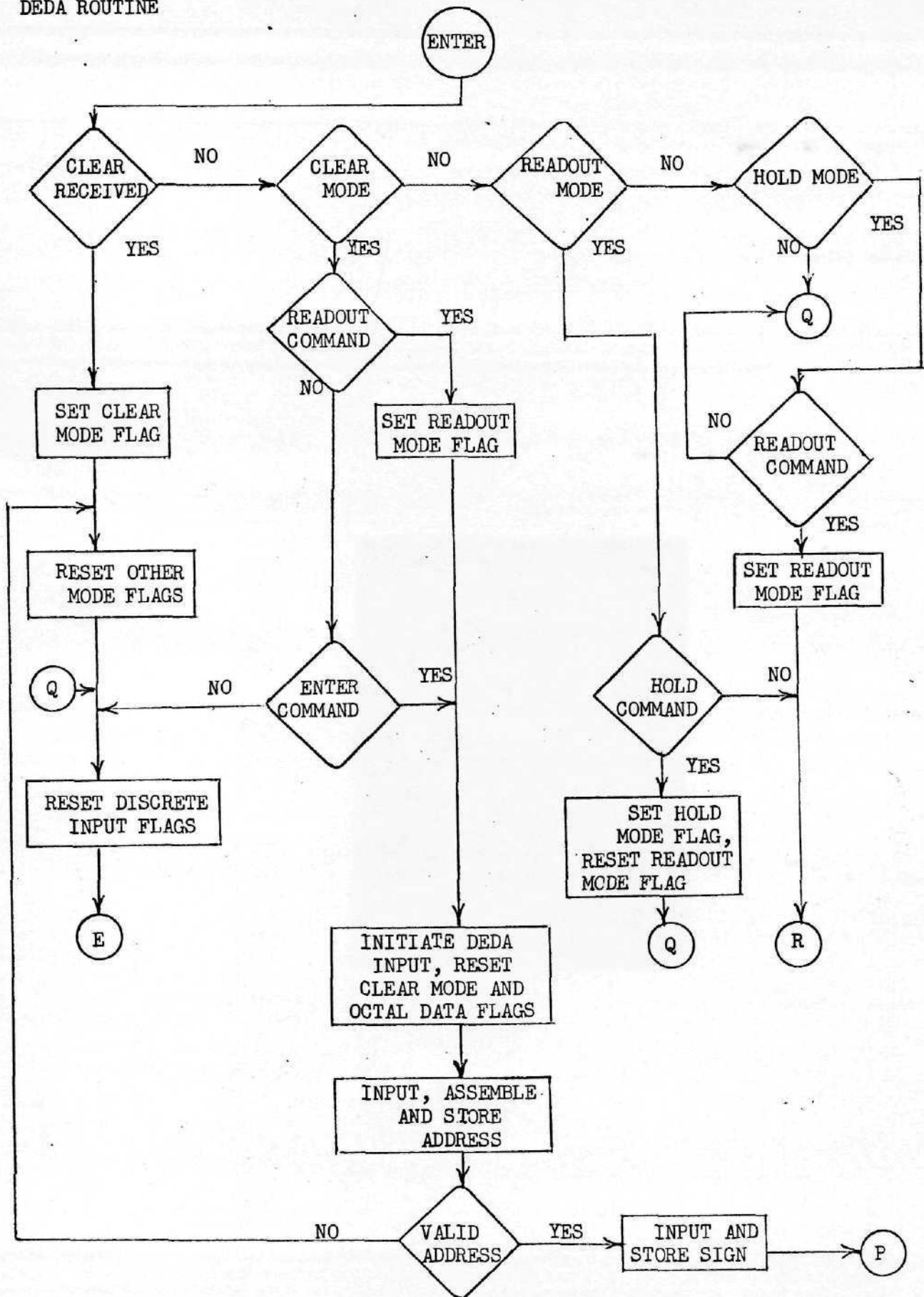


Figure 9-5

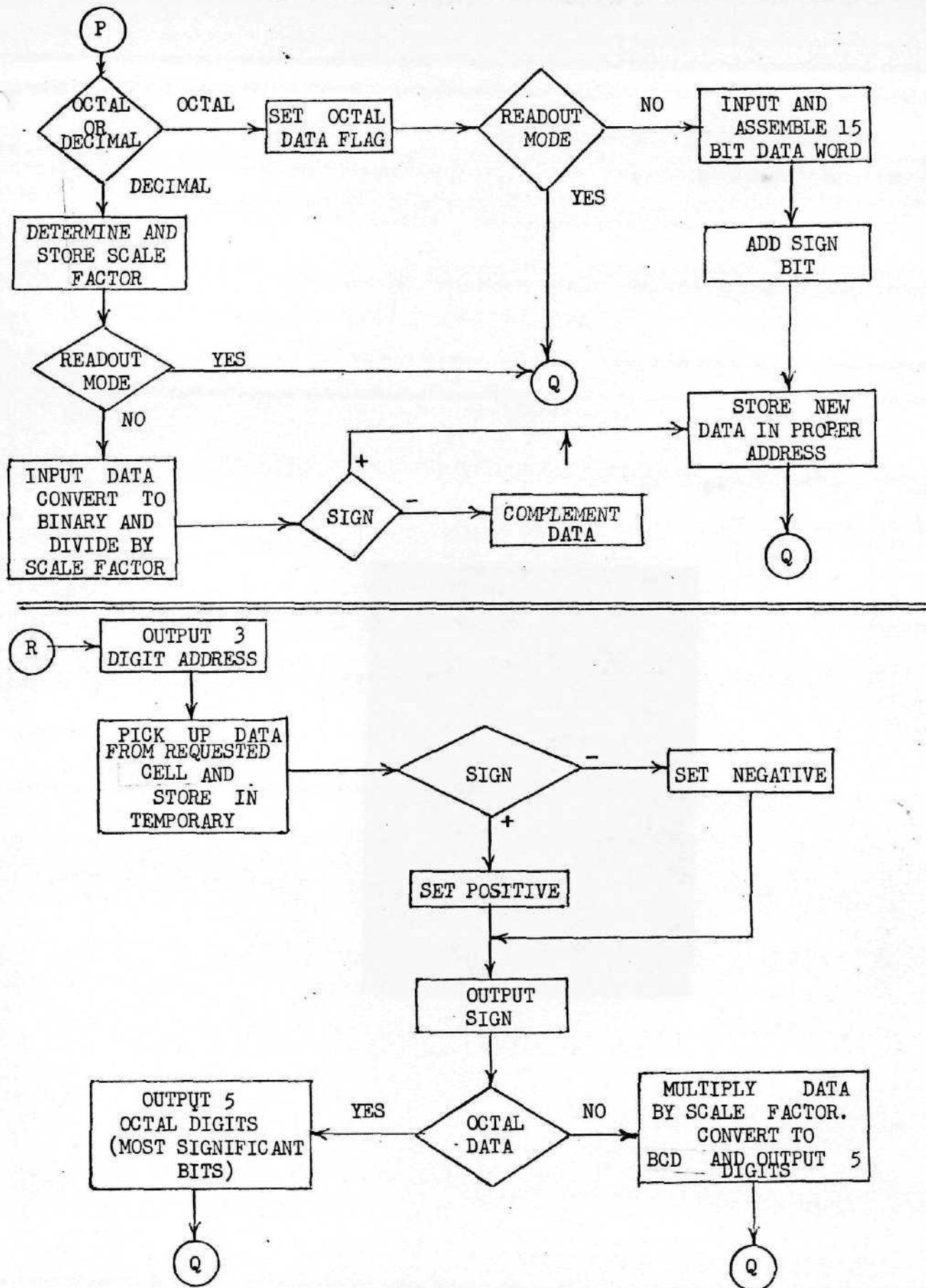


Figure 9-6.

Table 9-3 DECIMAL DEDA VARIABLES

<u>Name</u>	<u>Program Symbol</u>	<u>DEDA Address</u>	<u>Quantization and Units</u>	<u>Comment</u>
K ₁₈ ¹	1K18	610	10 ⁻⁷ ft/sec/pulse	Accelerometer Scale Factor including compensation for errors
K ₂₀ ¹	1K20	611	10 ⁻⁷ ft/sec/pulse	
K ₂₂ ¹	1K22	612	10 ⁻⁷ ft/sec/pulse	
K ₁₉ ¹	1K19	614	10 ⁻⁴ ft/sec/pulse	Accelerometer Bias Compensation
K ₂₁ ¹	1K21	615	10 ⁻⁴ ft/sec/pulse	
K ₂₃ ¹	1K23	616	10 ⁻⁴ ft/sec/pulse	
K ₁ ¹	1K1	620	.01 °/hr	Gyro Bias Compensation Constants
K ₆ ¹	1K6	621	.01 °/hr	
K ₁₁ ¹	1K11	622	.01 °/hr	
K ₃ ¹	1K3	624	10 ⁻⁷ rad	Gyro Scale Factor Compensation Constant
K ₈ ¹	1K8	625	10 ⁻⁷ rad	
K ₁₃ ¹	1K13	626	10 ⁻⁷ rad	
AK1	AK1	660	.01 °/hr	Averaged Gyro Bias Compensation Constants
AK6	AK6	661	.01 °/hr	
AK11	AK11	662	.01 °/hr	
Az	AZ	712	10 ⁻⁴ rad	Local Azimuth from True North
λ	LAMDA	713	10 ⁻⁴ rad	Local Astronomical Latitude
K ₄₆	K46	726	10 ⁻⁴ rad	Azimuth Angle Correction

Table 9-3 (Continued)

<u>Name</u>	<u>Program Symbol</u>	<u>DEDA Address</u>	<u>Quantization and Units</u>	<u>Comment</u>
K ₄₀	K40	714	10 ⁻¹⁰ rad/ft/sec	Gyro Mass Unbalance Compensation Coefficients
K ₄₁	K41	720	10 ⁻¹⁰ rad/ft/sec	
K ₄₂	K42	715	10 ⁻¹⁰ rad/ft/sec	
K ₄₃	K43	721	10 ⁻¹⁰ rad/ft/sec	
K ₄₄	K44	716	10 ⁻¹⁰ rad/ft/sec	
K ₄₅	K45	722	10 ⁻¹⁰ rad/ft/sec	
K ₄₇	K47	717	10 ⁻⁸ rad ²	Initial Value for filter-parameter K ₁
K ₄₈	K48	723	10 ⁻¹³ (rad ² /sec ²)	Initial Value for filter-parameter K ₂
K ₅₀	MUF	724	10 ⁰	Desired number of passes through calibration loop
K ₅₁	MUS	725	10 ⁰	Number of calibration cycles when averaging of K _j ¹ values starts
μ ₄₀	MU40	747	10 ⁰	Counter for calibration loop
K ₄₉	K49	735	10 ⁻⁹ rad/sec	Earth Rate

Table 9-4 PROGRAM VARIABLES

<u>Equation Symbol</u>	<u>Program Symbol</u>	<u>Computer Location</u>	<u>Definition</u>	<u>Scaling</u>
Δa_{xi}	--	--	Raw gyro data (pulses) pulse = 2^{16} radians	
Δa_{yi}	--	--		
Δa_{zi}	--	--		
ΔV_{xi}	--	--	Raw accelerometer data (pulses)	
ΔV_{yi}	--	--		
ΔV_{zi}	--	--		
ΔV_x	DVX	0564	Processed accelerometer inputs	1
ΔV_y	DVY	0565		
ΔV_z	DVZ	0566		
Δa_x	DAX	0570	Processed gyro inputs	-6
Δa_y	DAY	0571		
Δa_z	DAZ	0572		
$\Delta a_{x \text{ rem}}$	SKXD	0600	Remainders from processing of gyro inputs	-13
$\Delta a_{y \text{ rem}}$	SKYD	0601		
$\Delta a_{z \text{ rem}}$	SKZD	0602		
Δa_{xA}	DAXA	0604	Misalignment Correction	-6
Δa_{yA}	DAYA	0605		
Δa_{zA}	DAZA	0606		
V_x	VX	0574	Sum of processed acceler- ometer inputs	2
V_y	VY	0575		
V_z	VZ	0576		

Table 9-4 (Continued)

<u>Equation Symbol</u>	<u>Program Symbol</u>	<u>Computer Location</u>	<u>Definition</u>	<u>Scaling</u>
a_{11}	A11	0510	Direction cosine matrix	1
a_{12}	A12	0511		
a_{13}	A13	0512		
a_{21}	A21	0520		
a_{22}	A22	0521		
a_{23}	A23	0522		
a_{31}	A31	0514		
a_{32}	A32	0515		
a_{33}	A33	0516		
Δa_{11}	DA11	0530	Direction cosine increments	-5 or -8
Δa_{12}	DA12	0531		
Δa_{13}	DA13	0532		
Δa_{31}	DA31	0534		
Δa_{32}	DA32	0535		
Δa_{33}	DA33	0536		
E_1	E1	0524	Normality and orthogonality errors	-6 or -9
E_3	E3	0525		
E_{13}	E13	0526		
ω_n	WN	0710	North and vertical components of earth rate (rad/sec)	-13
ω_v	WV	0711		

Table 9-4 (Continued)

<u>Equation Symbol</u>	<u>Program Symbol</u>	<u>Computer Location</u>	<u>Definition</u>	<u>Scaling</u>
AZP	--	--	Corrected Azimuth	
CAZ	CAZ	0645	Cos AZP	1
SAZ	SAZ	0646	Sin AZP	
a_{11D}	A11D	0540	Desired Direction cosine matrix	1
a_{12D}	A12D	0541		
a_{13D}	A13D	0542		
a_{21D}	A21D	0550		
a_{22D}	A22D	0551		
a_{23D}	A23D	0552		
a_{31D}	A31D	0544		
a_{32D}	A3wD	0545		
a_{33D}	A33D	0546		
HRF	HRF	0627	Control flag for scaling of Δa_{ij} and E_1, E_3, E_{13}	Octal
DD	DD2	0706	$\left[1 - (a_{32D})^2 \right]$	2
CZH	CZH	0517	\sqrt{DD}	1
SK1	SK1	0740	Most significant part of sum of K_j^1 after	4
SK6	SK6	0741		
SK11	SK11	0742		
--	SK1L	0744	$\mu_{40} \geq K_{51}$	-13
--	SK6L	0745		
--	SK11L	0746		
			Least significant part of SK1, SK6, SK11, resp.	

Table 9-4 (Continued)

<u>Equation Symbol</u>	<u>Program Symbol</u>	<u>Computer Location</u>	<u>Definition</u>	<u>Scaling</u>
μ_{40}	MU40	0747	Calibration cycle counter	17
μ_{50}	MU50	0647	K_j^1 averaging loop counter	
K_2^1	--	--	Gyro Scale factor (rad/pulse)	
DECNT	DECNT	0743	DEDA counter	17
δ_{30}	D30	0663	Initial pass through calibration loop flag	Octal
FLAG	FLAG	0664	FLAG 0 then calibration in process, minus when not in process	
E_x	EX	0500	Misalignment or a attitude errors	2
E_y	EY	0501		
E_z	EZ	0502		
K_1	K1	0727	Attitude variance (rad ²)	-10
K_2	K2	0730	Initial gyro drift variance (rad ² /sec ²)	-27
K_{12}	K12	0731	Attitude gyro drift co- variance (rad ² /sec ²)	-22
--	K1L	0702	Least significant part of K1, K2, K12, resp.	-27
--	K2L	0703		-44
--	K12L	0704		-39
K_1^*	KA1	0636	Forward prediction of K_1, K_2, K_{12} , resp.	-10
K_2^*	KA2	0643		-27
K_{12}^*	KA12	0640		-22
--	K1L	0637	Least significant part of KA1, KA2, KA12, resp.	-27
--	KA2L	0644		-44
--	KA12L	0641		-39
DEL	DEL	0705	Sum of measurement variance and extrapolated state variance for align- ment (rad ²)	-6

Table 9-4 (Continued)

<u>Equation Symbol</u>	<u>Program Symbol</u>	<u>Computer Location</u>	<u>Definition</u>	<u>Scaling</u>
Q_1	WQ1	0633	Filter Weighting quantities	-2
Q_2	WQ2	0634		-16
AK1	AK1	0660	Running average of K_j^1 values after $u_{40} \geq K_{51}$	-13
AK6	AK6	0661		
AK11	AK11	0662		
--	A11A	0630	Snapshot values of (a_{ij}) and E_x, E_y, E_z for telemetry output	1
	A12A	0631		
	A13A	0632		
	A31A	0650		
	A32A	0651		
	A33A	0652		
	EXT	0654		
	EYT	0655		
	EZT	0656	2	

the telemetry output register has been shifted out. (This discrete will be reset upon storing a new output word in the telemetry output register). The program will interrogate the telemetry control discrete twice per 20 millisecond computer cycle, with at least a 1 millisecond separation. It will then load the output register only if the control discrete is set to ensure that the output register is not loaded while data is being shifted from the output register.

Each output word shall contain 24 binary bits, the most significant 6 bits being an identification (ID) word and the least significant 18 bits comprising an AEA word. The ID code ranges sequentially from Octal 01 to Octal 31 with Octal 01 being downlink word 1 (See Figure 9-7).

The output data shall be comprised of a twenty-five word block of computer memory, the output of which shall be repeated every $1/2$ second and shall be as defined in Table 9-5. The program is initialized at each occurrence of word 31_g (the twenty-fifth word of the list) such that the next word output will be the first word of the telemetry block. During the cycle in which the first word is output, 6 current direction cosines, and 3 current attitude error signals shall be stored in the block for later output, i.e., for output in the current telemetry block.

TELEMETRY

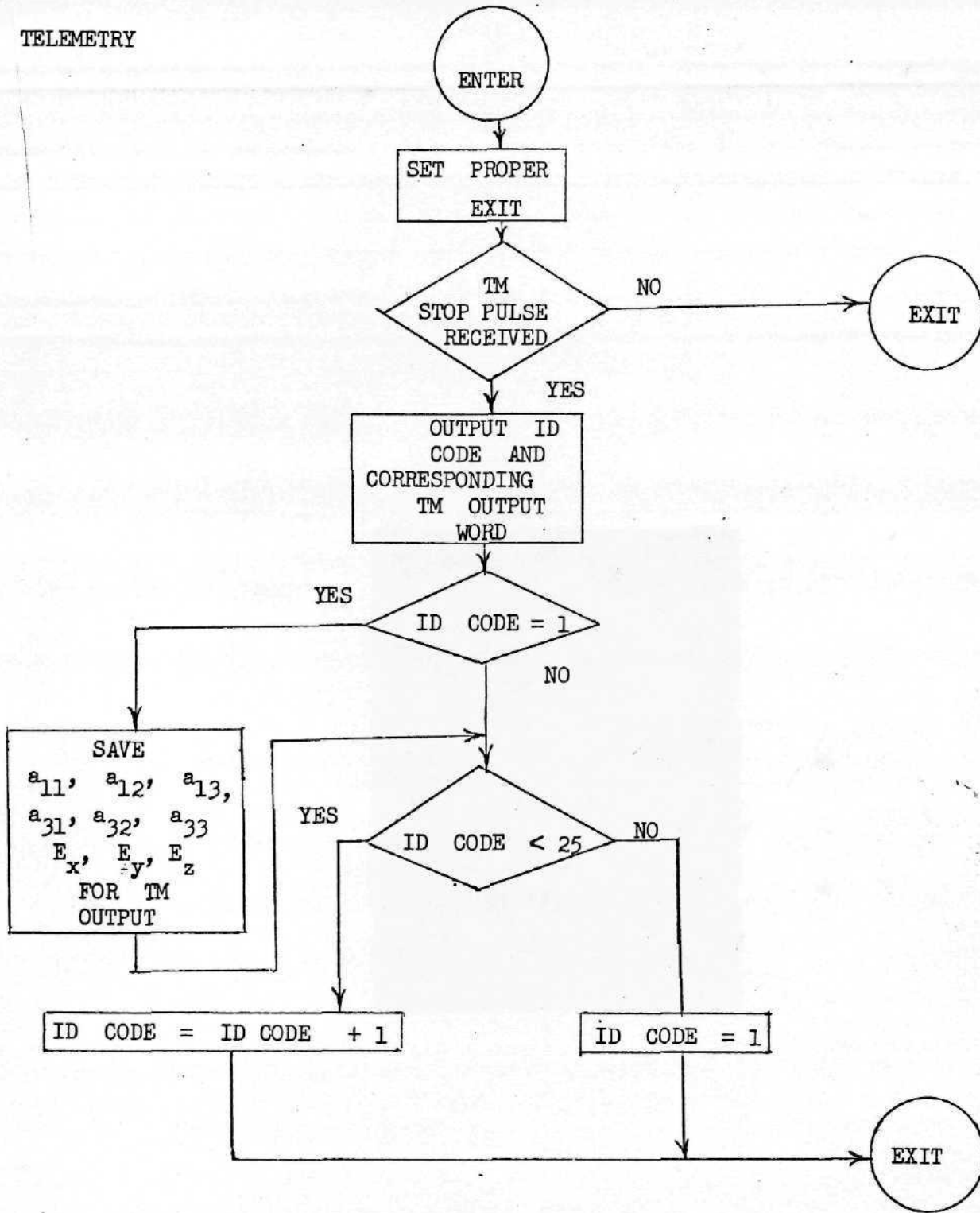


Figure 9-7

Table 9-5

AGS DOWNLINK (TELEMETRY) PARAMETERS

Word Number	ID Code (Octal)	Program Symbol	Equation Symbol	MSB Weight	LSB Weight	Units	Function	Comments
1	01	Mu40	u40			counts	Stop program counter	(B17)* counts 40ms loop passes - approximately 30,000
2	02	D30	δ ³⁰				Initial pass flag	Uses sign bit (-) means in progress
3	03	S ₀₀	S ₀₀				Mode indicator	
4	04	AZ	AZ	2 ²	2 ⁻¹⁴	radians	Azimuth angle	(B3)
5	05	AK1	AK ₁	2 ⁻¹⁴	2 ⁻³⁰	rad/20 ms		(B-13)
6	06	AK6	AK ₆	2 ⁻¹⁴	2 ⁻³⁰	rad/20 ms	Gyro drift constant estimates	(B-13)
7	07	AK11	AK ₁₁	2 ⁻¹⁴	2 ⁻³⁰	rad/20 ms		(B-13)
8	10	EX	E _X	2 ¹	2 ⁻¹⁵	radians	X-axis attitude error signal	(B2)
9	11	EY	E _Y	2 ¹	2 ⁻¹⁵	radians	Y-axis attitude error signal	(B2)
10	12	EZ	E _Z	2 ¹	2 ⁻¹⁵	radians	Z-axis attitude error signal	(B2)
} from snapshot buffer loaded at first word								
11	13	Q ₁	Q ₁	2 ⁻³	2 ⁻¹⁹	-	Filter weighting constant	(B-2)
12	14	Q ₂	Q ₂	2 ⁻¹⁷	2 ⁻²³	-	Filter weighting constant	(B-16)
13	15	LAMDA	λ	2 ²	2 ⁻¹⁴	radians	Astronomical latitude	(B3)

* (B17) and all (BXX) data in this column indicate value of full word in binary, i.e., B17 = 2¹⁷ = 131072, B-6 = 2⁻⁶ = .015625.

Table 9-5 (Continued)

Word Number	ID Code (Octal)	Program Symbol	Equation Symbol	MSB Weight	LSB Weight	Units	Function	Comments
14	16	DAX	$\Delta \alpha_{xi}$	2^{-7}	2^{-23}	radians	X-axis gyro output angular increment	(B-6)
15	17	DAY	$\Delta \alpha_{yi}$	2^{-7}	2^{-23}	radians	Y-axis gyro output angular increment	(B-6)
16	20	DAZ	$\Delta \alpha_{zi}$	2^{-7}	2^{-23}	radians	Z-axis gyro output angular increment	(B-6)
17	21	DVX	ΔV_x	2^0	2^{-16}	ft/sec	X-axis accelerometer velocity increment	(B1)
18	22	DVY	ΔV_y	2^0	2^{-16}	ft/sec	Y-axis accelerometer velocity increment	(B1)
19	23	DVZ	ΔV_z	2^0	2^{-16}	ft/sec	Z-axis accelerometer velocity increment	(B1)
20	24	A11	a_{11}	2^0	2^{-16}	-	Direction cosine values	(B1)
21	25	A12	a_{12}	2^0	2^{-16}	-		(B1)
22	26	A13	a_{13}	2^0	2^{-16}	-		(B1)
23	27	A31	a_{31}	2^0	2^{-16}	-		(B1)
24	30	A32	a_{32}	2^0	2^{-16}	-		(B1)
25	31	A33	a_{33}	2^0	2^{-16}	-		(B1)

from snapshot
buffer loaded
at first word

9.1.4 USAGE AND INPUT/OUTPUT REQUIREMENTS

9.1.4.1 Program Data Usage

The computer program specified herein shall be used to determine the ASA gyro drift rate compensation coefficient for the X, Y, and Z axis gyros during the prelaunch operations for the Apollo-Saturn missions. The EPC program shall be used at the GAEC in-plant test facility, the TRW Systems compatibility test facility, and the KSC laboratory and pad testing areas. The program will be usable with the BTME or the ACE. Program read-in, constants input, and data output shall be accomplished with the BTME and the ACE.

9.1.4.2 Input and Output

A list of required DEDA inputs and outputs including data characteristics are given in Tables 9-6 and 9-7. Decimal inputs and outputs have a range of plus or minus 10^5 times their quantization. The addresses assigned to instructions and data, and the values of the states of the selector switches and output flags will be specified in the "Utilization of the Earth Prelaunch Calibration (EPC) Program" document.

9.1.4.2.1 Input Data Prior to EPC

In addition to the computer (AEA) program, the following data shall be inserted into the AEA prior to EPC usage (see Table 9-8).

- a. ASA compensation coefficients from Pre-installation Calibration i.e., from the last successful calibration of the gyros and accelerometers prior to installation of the ASA into LM).

- (1) Gyro non-acceleration sensitive drift compensation constants for the X, Y, and Z gyro axes.
 - (2) Gyro attitude rate scale factor compensation constants for the X, Y, and Z gyro axes.
 - (3) Gyro mass unbalance compensation constants for the X, Y, and Z gyro input and spin axes.
 - (4) Accelerometer scale factor constants including compensation for errors for the X, Y, and Z accelerometer axes.
 - (5) Accelerometer bias compensation constants for the X, Y, and Z accelerometer axes.
- b. Azimuth alignment constants as available from the independent optical azimuth alignment measurement. For the prelaunch pad operations this data will be obtained from a measurement completed by GAEC and shall be transferred via the ACE or the DEDA to the AEA in AEA compatible format. The constants include the following:
- (1) The azimuth angle of the projection of the positive Z LM body axis on the horizontal plane measured CW with respect to true North with an accuracy of 0.1 degrees.
 - (2) The azimuth angle correction constant is available for secondary changes to the azimuth angle. Such changes might arise from mechanical shifts of test equipment or flight equipment and new azimuth data.
- c. The latitude for the particular test site. (At present only constant to be loaded is the astronomical latitude of the particular test site.)
- d. The mode control flag S_{00} will be used to start the calibration process. When this flag is Q, the AEA is in program idle. For initiation of the calibration process the flag is set to 6.

9.1.4.2.2 ASA Inputs

The ASA shall provide the equations in the AEA with incremental angular information about the vehicle X, Y, and Z axes and incremental velocity changes along the vehicle X, Y, and Z axes. The orientations of the ASA gyros and accelerometers with respect to the vehicle axes are as shown in Figure 6-2.

The incremental data in the form of pulses are accumulated in six 11 bit input registers of the AEA. During any one millisecond period, the presence of 32 pulses represents a zero signal; the presence of 61 pulses represents the maximum positive signal; the presence of 3 pulses represents the maximum negative signal.

A positive incremental angular signal represents a positive angular displacement in the direction of the arrows about the body axes shown in Figure 6-2. A positive incremental velocity represents a positive translational velocity change in the direction of the arrows along the body axes shown in Figure 6-2.

The bias of 32,000 pulses per second shall be removed by the program after sampling the input register. The input register shall be sampled every 20 milliseconds and shall be cleared under program control upon sampling.

The nominal pulse weight of the incremental angular information is 2^{-16} radians.

The nominal pulse weight of the velocity increments is 0.003125 fps.

9.1.4.2.3 Output Requirements

The output of the EPC program shall be available in three forms. The DEDA readout, the AGS downlink telemetry and the outputs provided to the BTME. These are described as follows:

- a. DEDA Output - In those tests in which the DEDA is accessible, the output of the EPC program shall be as defined in Paragraph 9.1.4.2. In addition to these outputs, any of the contents of the AEA memory accessible to the DEDA will be available for trouble shooting or EPC problem isolation.
- b. Downlink telemetry - The downlink telemetry outputs will be available during those tests in which the AGS telemetry can be received and decoded. These outputs are defined in Paragraph 9.1.3.4, Table 9-5. The downlink is the output from the AGS when used with ACE.
- c. BTME outputs - In addition to the downlink, a test plug shall be connected for use by the BTME in test monitoring.

9.1.5 Software Identification and Delivery

The EPC deliverable items of software shall conform to the specification of Paragraph 9.3.

TABLE 9-6

DEDA INPUT PARAMETERS

<u>Symbol</u>	<u>Quantization</u>	<u>Function</u>
S ₀₀	0	Function Selector
1K1	.01°/hour	Gyro Bias Compensation Constant
1K6	.01°/hour	Gyro Bias Compensation Constant
1K11	.01°/hour	Gyro Bias Compensation Constant
1K3	10 ⁻⁷	Gyro Scale Factor Compensation Constant
1K8	10 ⁻⁷	Gyro Scale Factor Compensation Constant
1K13	10 ⁻⁷	Gyro Scale Factor Compensation Constant
1K18	10 ⁻⁷	Accelerometer Scale Factor Including Compensation for Errors
1K20	10 ⁻⁷	Accelerometer Scale Factor Including Compensation for Errors
1K22	10 ⁻⁷	Accelerometer Scale Factor Including Compensation for Errors
1K19	10 ⁻⁴	Accelerometer Bias Compensation
1K21	10 ⁻⁴	Accelerometer Bias Compensation
1K23	10 ⁻⁴	Accelerometer Bias Compensation
K ₄₀ - K ₄₅	10 ⁻¹⁰ radians	Local Astronomical Latitude
AZ	10 ⁻² radians	Local Azimuth from True North
K ₄₆	10 ⁻² radians	Azimuth Angle Correction
K ₄₇	radians ²	Initial value for filter parameter K ₁
K ₄₈	(rad/sec) ²	Initial value for filter parameter K ₂
K ₄₉	10 ⁻⁹ radians/sec	Earth rate
K ₅₀	1	Desired number of passes through calibration loop
K ₅₁	1	Number of calibration cycles when averaging of K _j ¹ values start

TABLE 9-7

DEDA READOUT PARAMETERS*

<u>Equation Symbol</u>	<u>Quantization</u>	<u>Functions</u>
S_3	0	Function Selector
$\dot{\mu}_{40}$	0	Stop Program Counter
S_{30}	0	Initial Pass Flag
AZ	10^{-2} radians	Azimuth Angle
λ	10^{-2} radians	Astronomical Latitude
AK_1, AK_6, AK_{11}	.01°/hour	Gyro Drift Calibration Constants
$1K1, 1K6, 1K11$.01°/hour	Gyro Drift Calibration Constants

* Other quantities are available via DEDA but they are available in octal scaling only.

TABLE 9-8

GSE INPUTS FOR LAUNCH OPERATIONS

<u>Equation Symbol</u>	<u>Quantization</u>	<u>Function</u>
K_1^1, K_6^1, K_{11}^1	2^{-30}	Gyro non-acceleration drift compensations (radians)
K_3^1, K_8^1, K_{13}^1	2^{-24}	Gyro attitude rate scale factor compensations (radians)
$K_{18}^1, K_{20}^1, K_{22}^1$	2^{-25}	Accelerometer Scale Factor Including Compensation (ft/sec/pulse)
λ	2^{-14}	Astronomical latitude (radians)
AZ	2^{-14}	Azimuth angle (radians)
$K_{19}^1, K_{21}^1, K_{23}^1$	2^{-16}	Accelerometer bias compensation (feet/second)
$K_{40}, K_{41}, K_{42},$ K_{43}, K_{44}, K_{45}	2^{-36}	Gyro mass unbalance drift compensations (radians/foot/second)
K_{46}	2^{-14}	Azimuth angle correction (radians)

9.2 ACCEPTANCE CHECKOUT EQUIPMENT--SPACECRAFT (ACE- S/C)

The ACE is an integrated checkout and display system which provides for centralized programmed control of spacecraft checkout operations. The ground station can accommodate independent subsystem and/or integrated system testing. Large quantities of test data can be processed and displayed in real time, as well as recorded for post-test analysis. Figure 9-10 is a block diagram of the ACE-S/C.

Tapes generated for loading/checkout of the AGS using the ACE system shall have a format as specified in Paragraph 9.2.1.

9.2.1 ORGANIZATION OF AEA DATA ON ACE MAGNETIC TAPE

Each program or data block will appear on tape as a separate file. All records within the files will be 36 bytes long. The first record will be used by the 160G computer to identify the file and to store the number of AEA words in the file.

All records after the first will contain AEA information. There will be one AEA word stored in every four bytes. Nine AEA words will comprise one record. If the last transcription of the file runs out of AEA words before the record is complete (36 bytes), filler zero words are used to fill the record to capacity.

The 18 bit word occupies four bytes on 160G tape. Figure 9-8 demonstrates the tape layout for a typical AEA word.

An illustration of the actual appearance on tape of a hypothetical AEA program is shown in Figure 9-9. It should be noted that the bytes of 160G words have their most significant bit at the right hand side of the tape, and that tape travel is such that the highest order digits are read first. The AEA words, on the other hand, are configured backwards. That is, the least significant bit is at the right hand side, and the low order digits are read first. In both cases, the parity bit is at the right hand side of the tape (shown as an X).

At the top of the tape in Figure 9-9 is shown the last word of the preceding transcription. It is obviously a filler zero word.

An end-of-file gap precedes the 160G record which introduces the program. The first two bytes form the first 12-bit 160G word. The word contains the program number, octal 0734 in this case. This number serves as the identifier by which the ACE operator calls the program in whenever he desires to run it. No two files on tape will bear the same number.

Following the first two bytes of the ACE word will be 32 bytes of zeros. The binary value of these 12 bits indicates the exact number of AEA words contained in the remainder of the file. This value does not include filler zero words at the end of the program.

An inter-record gap follows the 160G word, after which the AEA words begin. The actual text of the AEA program or data block is sandwiched between four control words. There are two control words at the beginning and two at the end of the AEA word block.

The first AEA word indicates whether or not a word-by-word verification is required. If the sign bit (most significant bit) is a zero, an echo check will be performed. If it is one, no check will be done.

When an echo check is performed, each transmission from the ACE to the AEA is followed by a retransmission of the same word from the AEA to the ACE for verification. If the word received by ACE is identical to the word sent, transmission continues. If it is not validated, an error indication is stored in 160G memory for subsequent printout.

The second AEA word is also a control word. It must contain a 77 in the high order six bits, followed by the address at which the program test load is to start. For the case shown in Figure 9-9 (a), the load will begin at AEA memory location 0466 (octal).

The actual program text follows the second control word. Thus, the first AEA record will contain the two control words plus seven words of the program. The second record through the ninth will contain the next 72 AEA program words.

The tenth record will start with AEA program words until the 85th program word (the 87th actual AEA word) is reached.

The 88th word is a control word which indicates whether or not a checksum is required. If it contains all zeros, no checksum is performed. If it contains any non-zero bits, the word is construed as the correct checksum of the program, and as a command to perform a checksum operation. The AEA will perform a summation of the bits of the words in the program, and compare the result with the control word.

The last AEA word (89th word) specifies whether the program just loaded is to be executed. A zero in the sign bit will cause instant execution of the program. A one will inhibit execution.

To complete the last record, a filler zero word is added to the transcription. This is followed by an end-of-file gap, after which the next program, program number 0735 (octal) is stored.

AEA WORD

2^{17}	F	E	D	C	B	A	2^0
1	1	1	0	0	1	0	1
0	1	0	1	1	0	1	0
1	0	0	1	0	0	1	0
1	0	1	0	1	1	0	1

SAME WORD ON ACE TAPE

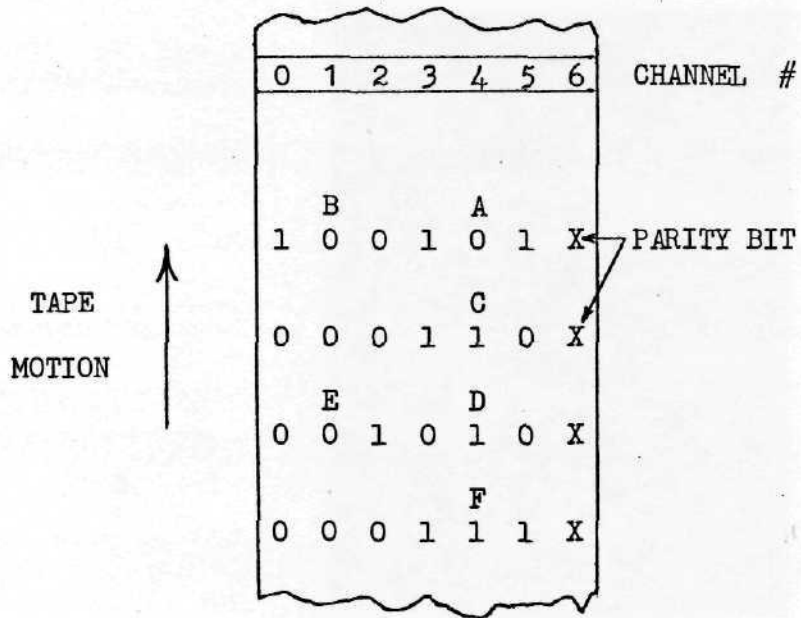


FIGURE 9-8

TAPE MOTION



0	1	2	3	4	5	6
0	0	0	0	0	0	X
0	0	0	0	0	0	X
0	0	0	0	0	0	X
0	0	0	0	0	0	X
0	0	0	0	0	0	X
END OF FILE GAP						
1	1	1	0	0	0	X
0	0	1	1	1	0	X
32 BYTES OF ZEROS						
1	0	0	0	0	0	X
1	0	0	1	1	0	X
END OF RECORD GAP						
0	0	0	0	0	0	X
0	0	0	0	0	0	X
0	0	0	0	0	0	X
0	0	0	1	0	0	X
1	1	0	1	1	0	X
0	0	0	1	0	0	X
1	1	1	0	0	0	X
0	0	0	1	1	1	X
85 WORDS OF PROGRAM TEXT BROKEN INTO 9 WORD RECORDS						

(a)

Channel #
Parity Bit
Filler Zero Word-Last
Word of preceding file

First ACE word
Program number 0734.

Last ACE word
Word count (0131)

First AEA word
400000 indicates no
verification required

Second AEA word
770466 indicates
load starts at 0466

0	0	0	1	1	1	X
0	0	0	1	0	1	X
1	0	0	1	1	0	X
0	0	0	0	0	1	X
0	0	0	0	0	0	X
0	0	0	0	0	0	X
0	0	0	0	0	0	X
0	0	0	0	0	0	X
0	0	0	0	0	0	X
0	0	0	0	0	0	X
0	0	0	0	0	0	X
0	0	0	0	0	0	X
0	0	0	0	0	0	X
END OF FILE GAP						
1	1	1	0	0	0	X
1	0	1	1	1	0	X
0	0	0	0	0	0	X
0	0	0	0	0	0	X
ETC.						

88th AEA word
Checksum word
146507

89th AEA word
Execute program
000000

90th Word
Filler Zeros

First ACE Word
Program Number 0735

Figure 9-9

(b)

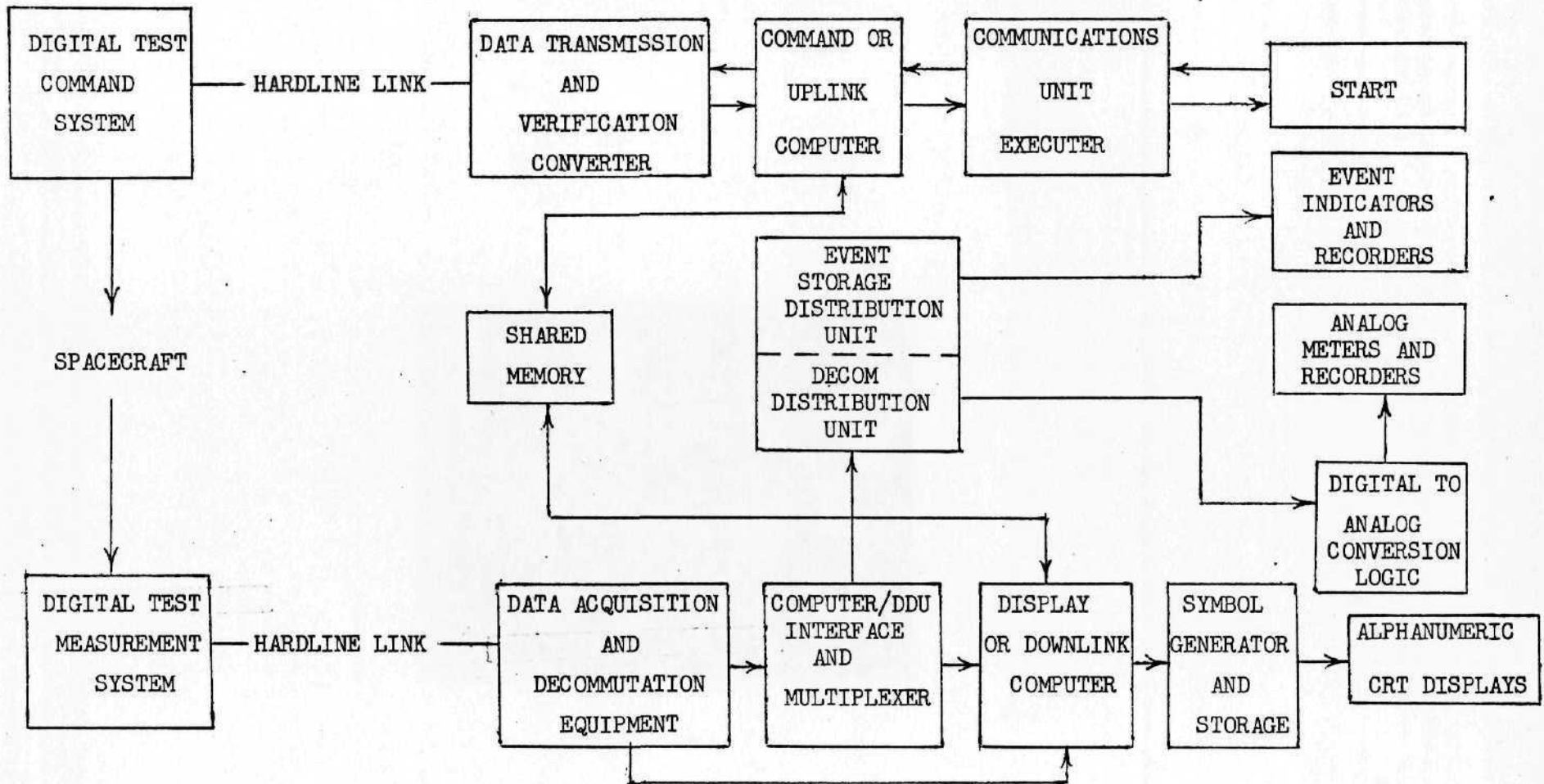


Figure 9-10.
ACE-S/C Block Diagram

9.2.2 ACE Program descriptions.

The following pages describe the format and interface requirements of ACE programs. The Uplink Program (U003-2) contains diagrams and symbol definitions while the AEA Transmission Program (C004-0) details the system response.

U003-2

Title: Abort Electronics Assembly (AEA) program

Part Of: Uplink Program

Purpose: To load the AEA computer with 18-bit data or instruction words.

Calling Sequence:Entry:

Entry to this program occurs whenever data is to be sent to the AEA computer. The entry is manually controlled by C-START's.

Data:Input -

Input consists of a C-START insert (five types), only two of which will be used during transmission.

2 4 1 0 0 0 X_1 X_2 X_3 X_4

2 4 2 0 Z_1 Z_2 Z_3 Z_4 Z_5 Z_6

2 4 3 M Z_1 Z_2 Z_3 Z_4 Z_5 Z_6

2 4 5 0 0 0 0 0 0 E

2 4 4 0 0 0 L_1 L_2 L_3 L_4

Where: 241, 242, 243, 245 and 244 are all C-START Routine identification numbers.

$(X_1 X_2 X_3 X_4)_8$ - four octal digits which represent the AEA address to which data will be sent.

Data: (Continued)

$(Z_1 Z_2 Z_3 Z_4 Z_5 Z_6)_8$ - six octal digits which represent the AEA data (18 bits).

$(L_1 L_2 L_3 L_4)_8$ - the AEA program number which the 160G will use to search the magnetic tape.

E - identifies the program in the AEA that will enable the AEA to be loaded via ACE-S/C. Each of the three programs are different and require subprogram alterations with respect to number of words transmitted, order of relay setting, verification procedures and options.

"E" can have three (3) values:

- (a) 0 - software GSE - will be used to load all test programs and flight programs.
- (b) 1 - flight hard - will be used only to load the software GSE.
- (c) 2 - interim hard - will be used only to load the software GSE.

When M=3, a transfer to the U004 subprogram is made as soon as the AEA is initiated by the program initiate.

Routines of the Subprogram:

1. Mag Tape Routine - searches for program ID and reads data records and other information from mag tape.
2. DTCS Transmission Routine - Sends data words and relay settings.
3. Comparison Routine - compares transmitted uplink data to downlink data.
4. C-START Entry Routine - allows entry into the program and receives data from the C-START inserts.
5. Main Routine - consists of main logic of the subprogram.

Data: (Continued)

Other inputs to this subprogram consists of records from magnetic tape read into the Uplink computer prior to ACE-S/C transmission to the AEA. Each record will consist of 72 bits, 3 AEA words, and will be loaded into six 160G locations. Each of the six locations will contain 9 bits of data that will be sent to the AEA. After transmitting the data from these locations to the AEA, the magnetic tape will be moved to read in another record, and so on.

Measurement GSE5, and 16-bit word, will also be received by the downlink program. GSE5 is sent from the AEA to ACE-S/C and is used by the transmission program to ascertain whether the AEA has loaded the word just transmitted.

Measurement G10001 is entering the ACE-S/C Downlink 160G and may represent the 18 bits of AEA data transmitted Uplink

Output:

1. Relay (DTCS) Settings generated from this program:
 - GSE1 (For further information concerning these
 - GSE2 relay settings, see the Symbol Table)
 - GSE7
2. AEA words (DTCS) - 18 bits of data to be transmitted to the AEA from the 160G Uplink.

Normal Exit: To Uplink Control

Error Exit: None

Computation Sequence:Manual Mode of Transmission

1. If it is desired to initiate a program or change a single location within the AEA, then the magnetic tape is not

used. Instead, two C-START inserts are necessary. The first entry (241) would specify the AEA location which is to be accessed. The second entry (242 or 243) would contain the AEA data word which is to be sent to the AEA. From 242 the subprogram would determine whether it is necessary to change a single location within the AEA. While from 243, the subprogram would determine whether a program initialization is required. After this step, the subprogram would begin data formatting and data transmission. Every data word that is transmitted will be verified by a word-by-word comparison with the GLOOL measurement, which is the same word transmitted.

2. Automatic Mode of Transmission

If it is desired to transmit a block of data (or a program) to the AEA, the magnetic tape will be used. On the magnetic tape (the AEA program tape) there will be the AEA program. Associated with the AEA program, there will be $(L_1L_2L_3L_4)_8$, the AEA program ID number, and a Sum which is the total number of words to be transmitted from the 160G uplink.

To send a block of data to the AEA, the control room operator will first access the magnetic tape by use of C-START (244). After the AEA program has been found and is ready for transmission, (a printer indication will be available for the console operator by voice communication from the computer operator), another C-START (245) will be used. This second C-START insert will initiate transmission of the block of data to the AEA. A word-by-word check is always performed at the completion of the loading process if E=1 or 2. If E=0, a word-by-word check may be performed (an option) after each data word is transmitted from ACE-S/C.

Operator Action:

The control room console operator will control and initiate this program by the use of C-START inserts.

Uplink Requirements:

DTCS Transmission - as required by the subprogram.

DTCS Stimuli -

1. GSE1 J17027 a relay setting
2. GSE2 J17028 a relay setting
3. GSE7 J17043 a relay setting
4. AEA word transmission via DTCS, see Diagrams D and E.

Downlink Requirements:

G10001 - 24-bit word - represents AEA data transmitted

Downlink

GSE5 - 16-bit word - represents counts

These measurements are both being sampled at 50 samples per second.

CTR Display: None

Remarks: See Symbol Table and Diagrams A through E.

SYMBOL TABLE

Symbol	Definition
241	A C-START identification number used with either an AEA initiation or a single word location change.
242	A C-START insert ID for the single word location change.
243	A C-START ID for AEA program initiation.
244	C-START identification number for magnetic tape search.
245	A C-START ID for AEA block transmission.
AEA	Abort Electronics Assembly. The 4096 18-bit word computer in the Abort Guidance Section of the Stabilization and Control Subsystem.
ABU	The Abort Guidance Section (AGS) Buffer Unit, which is capable of receiving DTCS transmissions and sending the resultant 18-bit AEA data word to the AEA. The ABU is GSE equipment.
E	Specifies whether loading is done by means of: 0 = GSE soft 1 = flight hard 2 = interim hard
EBM	Execute Buffer Memory
GSE1	1 = DTCS relay setting from ACE-S/C to the AEA that tells the AEA that an 18-bit word is ready to be loaded and is in the downlink telemetry register of the AEA. "0" shuts off GSE5.
GSE5	A measurement emanating from the AEA telling ACE-S/C whether or not the AEA has accepted (loaded) the word just sent.
GSE7	1 - A DTCS relay setting inhibiting the use of the AEA loading register for purposes other than ACE-S/C loading.
GSE2	1 - A DTCS relay setting that tells the AEA that no more AEA words will be sent from ACE-S/C.

SYMBOL TABLE (Continued)

<u>Symbol</u>	<u>Definition</u>
ID	Contains the 6 MSB of G10001, the telemetry word from the AEA.
LBM	Load Buffer Memory
LLLL	AEA program identification number. This program identified as LLLL will be loaded from magnetic tape (by C-START call-up) and sent to the AEA.

C-START

TYPES OF INSERTS

1	2	3	4	5	6	7	8	9	10
2	4	1	0	0	0	X ₁	X ₂	X ₃	X ₄
2	4	2	0	Z ₁	Z ₂	Z ₃	Z ₄	Z ₅	Z ₆
2	4	1	0	0	0	X ₁	X ₂	X ₃	X ₄
2	4	3	0	Z ₁	Z ₂	Z ₃	Z ₄	Z ₅	Z ₆
2	4	5	0	0	0	0	0	0	E
2	4	4	0	0	0	L	L	L	L

DESCRIPTION AND DEFINITION

Single Word Location Change

AAA = first insert ID

X₁X₂X₃X₄ = four octal digits describing AEA address

BBB = second insert ID

Z₁Z₂Z₃Z₄Z₅Z₆ - six octal digits - (000000₈ - 777777₈) 18-bit data word

AEA Program Initiation

AAA = first insert ID

CCC = second insert ID

X₁X₂X₃X₄ = four octal digits describing AEA address

Z Z Z Z Z Z = six octal digits - (000000₈ - 777777₈) 18-bit data word

AEA Block Transmission

AAA = first insert ID

E = 0 - GSE soft

1 - flight hard

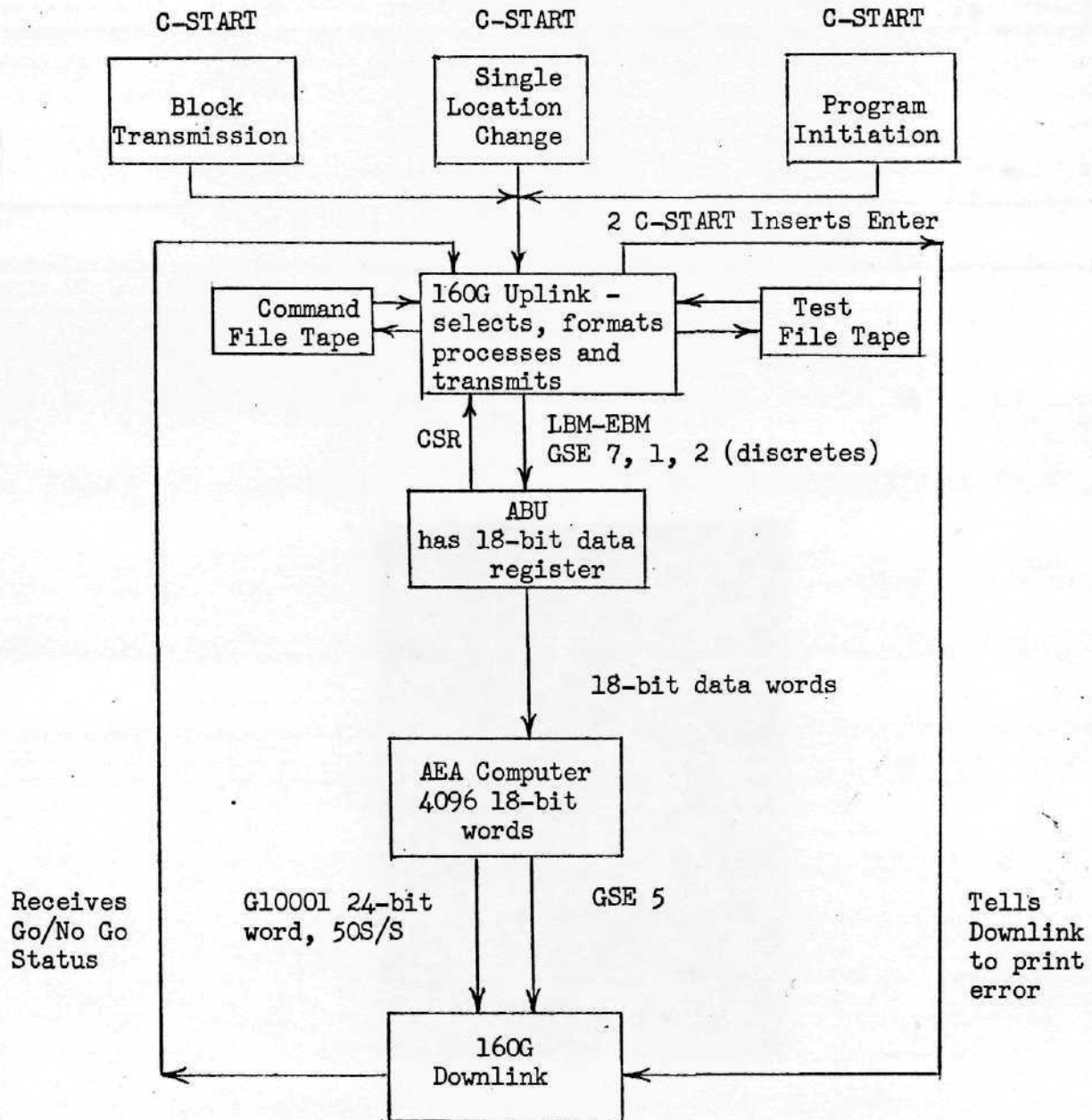
2 - interim hard

Mag Tape Call-up

EEE = insert ID

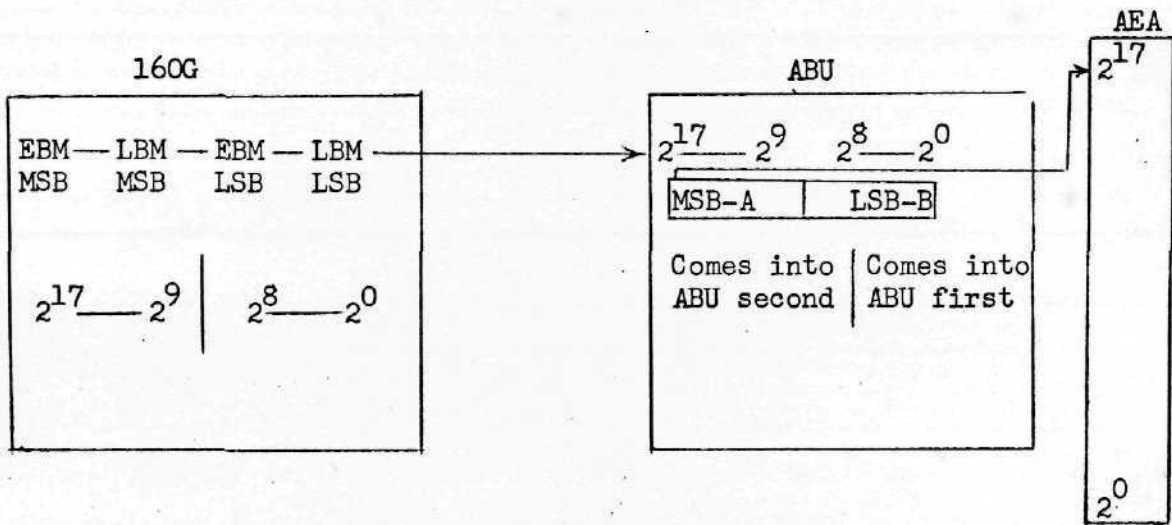
LLLL = Program (ID) on Mag Tape

Diagram A



Equipment Block Diagram

DIAGRAM B



2^{17} serially shifted first

$2^8 - 2^0$ - 9 LSB of AEA Word

$2^{17} - 2^9$ - 9 MSB of AEA Word

Downlink
Telemetry
Register

DIAGRAM C

DIAGRAM D GAEC-U003-2

160G Uplink and ABU Interface

A = 9 MSB of 18-bit data word

b = 9 LSB of 18-bit data word

12 Lines

160G
UPLINK

2^{23} - 2^{12}
 2^{11} - 2^0
 2^{23} - 2^{12}
 2^{11} - 2^0
 2^{23} - 2^{12}
 2^{11} - 2^0
 2^{23} - 2^{12}
 2^{11} - 2^0

EBM A

LBM A

EBM B

LBM B

DTVC
Converts all input
to redundant serial

RELAYS
GSE 7, 1, 2

2^{23}
 2^{12}
 2^{23}
 2^{12}

EBM A

2^{11}
 2^0
 2^{11}
 2^0

2^{23}
 2^{12}
 2^{23}
 2^{12}

LBM A

11
0
11
0

One
Line

23
12
23
12

EBM B

11
0
11
0

23
12
23
12

LBM B

CSR 2 per 18-bits
loaded in ABU

ABU
18-bit Register
A B

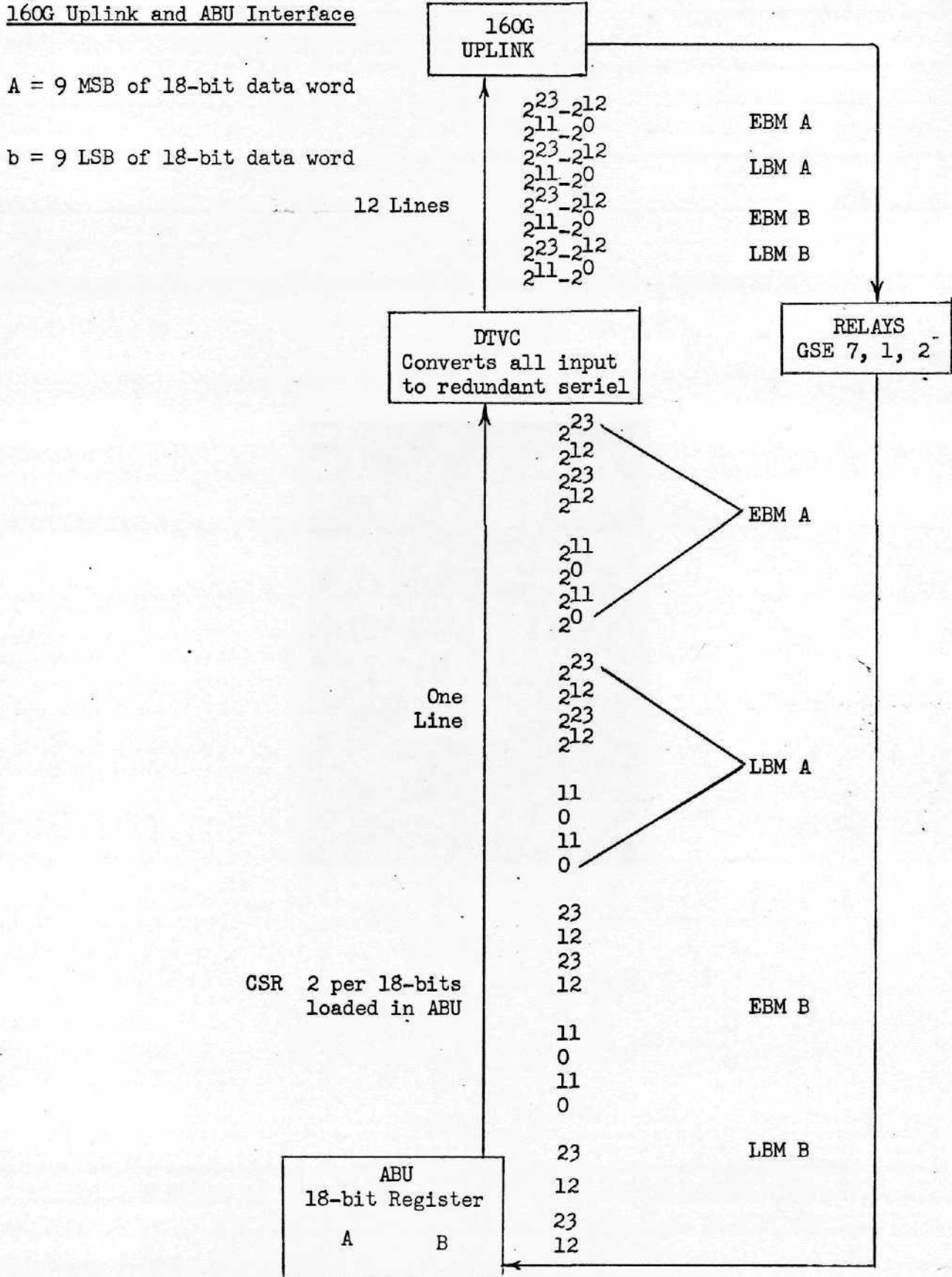


DIAGRAM E

	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LBM A	1	G	G	G	G	B	B	B	B	0	0	0	0	1	2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0	0
EBM A	1	G	G	G	G	B	B	B	B	0	0	0	1	0	"	"	"	"	"	"	"	"	"	0
LBM B	1	G	G	G	G	B	B	B	B	0	0	1	0	0	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0	2^9	0
EBM B	1	G	G	G	G	B	B	B	B	0	0	1	1	1	"	"	"	"	"	"	"	"	"	0
R e s e r v e d		Group				Baseplate Select				Not Used		Mode Bits		9 Bits of Data									Not Used	

COO4-0

Title: AEA Transmission Program

Part Of: Uplink and Downlink Programs

Purpose: To load the AEA computer with 18-bit data or instruction words.

Calling Sequence:

Entry: Entry of this subprogram occurs whenever data is to be sent to the AEA computer. The entry is manually controlled by C-START's.

Data: Input consists of C-START inserts as shown below -

1. AA1BC₁C₂X₁X₂X₃X₄ Where, X₁X₂X₃X₄ is the octal address.
2. AA20C₁C₂X₁X₂X₃X₄ Where, X₁X₂X₃X₄ is the octal address.
3. AA30Z₁Z₂Z₃Z₄Z₅Z₆ Where, Z₁Z₂Z₃Z₄Z₅Z₆ is the octal data.
4. AA40000000
5. AA50C₁C₂X₁X₂X₃X₄ Where, X₁X₂X₃X₄ is the octal start address of dump.
6. AA60C₁C₂X₁X₂X₃X₄ Where, X₁X₂X₃X₄ is the octal end address of dump.
7. AA7000L₁L₂L₃L₄ Where, L₁L₂L₃L₄ is the magnetic tape ID in octal.
8. AA80000FGE Where, "G" specifies whether the Load and Verify program itself is being loaded; "E" specifies the AEA program which interfaces with COO4-0 during this loading procedure.
9. AA90000000 This is a general C-START insert which is used for initialization purposes.

COO4-0

All inserts will contain only octal digits and all non-octal digits should produce a non-confirm on the C-START.

Inputs: 1. C-START Inputs

(a) AA1	(h) AA8
(b) AA2	(i) AA9
(c) AA3	(j) $C_1 C_2$
(d) AA4	(k) $S_1 X_2 X_3 X_4$
(e) AA5	(l) $Z_1 Z_2 Z_3 Z_4 Z_5 Z_6$
(f) AA6	(m) $L_1 L_2 L_3 L_4$
(g) AA7	(n) G
	(o) E, B
	(p) F

Where:

- (a) AA1 specifies a program initiate or a transfer control.
- (b, c, d) AA2, AA3 and AA4 specify a multiple-location change or operator load.
- (e, f) AA5 and AA6 specify a memory dump.
- (g, h) AA7 and AA8 specify a block transmission load from tape.
- (i) AA9 specifies a general purpose initialization insert.
- (j) $C_1 C_2$ consists of two octal digits that interface with the Load and Verify Program in the AEA.
- (k) $X_1 X_2 X_3 X_4$ consists of four octal digits that specify the AEA address.
- (l) $Z_1 Z_2 Z_3 Z_4 Z_5 Z_6$ consists of six octal digits that represent AEA data.

COO4-0

1. C-START Inputs (continued)

- (m) $L_1L_2L_3L_4$ refers to the four octal digit tape ID which specifies a file on the test file tape.
- (n) "G" can take on two values: "0" or "1", where "0" specifies that the Load and Verify program is not to be loaded, and "1" specifies that the Load and Verify Program is to be loaded.
- (o) "E" can take on three values: "0", "1" or "2", where, "0" specifies that the Load and Verify program is in the AEA computer; "1" specifies that the flight program is in the AEA computer; and "2" specifies that the interim program is in the AEA computer.

If "B" is equal to one (1), COO4-0 will immediately initiate U004 after the COO4-0 initiation is completed.

- (p) $F=1$, first word sent more than once; $F=0$, only once.

2. Two PCM Inputs enter this Subprogram -(a) G17031

Called GSE5. Represents the output of a 16-bit counter which is in two 8-bit time slots. The sampling rate of this measurement is ten (10), $GSE5=0$; otherwise, $GSE5=1$. This measurement is used for communicating between the AEA and COO4-0 and the presence or absence of a count in GSE5 is used for interpreting the status of the AEA.

(b) G10001

Represents AEA telemetry data. It is used to dump the AEA memory or to send downlink the same data that is sent uplink. This measurement is sampled 50 times a second and consists of a 24-bit word represented by three 8-bit time slots.

COO4-0

3. Data Stored on Tape

The data stored on tape is divided into files, where each file consists of data to be loaded by COO4. One file will be loaded at any one time and this file is treated as an entity. Contained in each file will be three items:

1. The magnetic tape ID

The ID is unique for a particular file and is searched by COO4-0 until the ID on tape matches the ID that is specified in C-START insert AA7. The ID consists of four octal digits.

2. Sumword

Consists of four octal digits, the count of which represents the total number of data words that are within the file.

3. Data Words -

Consist of 18 bits of data to be stored in the AEA.

COO4-0

Output: Three (3) Types of Output

1. DTCS Output
2. Command File Tape Output
3. CRT Output

1. DTCS Output

- (a) J17027 - GSE1
- (b) J17028 - GSE2
- (c) J17035 - AEA data to the AGS buffer unit.

2. Command File Tape output

The output to the Command File tape will consist of a binary output. The binary output is needed because BCD filing requires too much tape when COO4 is loading.

The Command File tape will store the following BCD messages in binary:

- (a) GSE1 = 1 relay filing
GSE1 = 0 relay filing
- (b) GSE2 = 1 relay filing
GSE2 = 0 relay filing
- (c) DATA SENT XXXXXX_g NO.XXXX_g
- (d) C-START entries
- (e) Time of filed message
- (f) AEA END
- (g) AEA EXIT - when a tape ID is not found and an exiting is required.
- (h) AEA CSR - when a bad CSR causes an exiting from COO4-0.
- (i) Tape ID XXXX_g CALLED - XXXX_g is the tape ID that was found.
- (j) AEA GSE5 = 1 - when a GSE5 = 1 was not found and COO4-0 exited.

COO4-0

- (k) AEA GSE5 = 0 - When a GSE5 = 0 was not found and COO4-0 exited.
- (l) ADDR XXXX₈ DATA XXXXXX₈ - When dumping memory via insert AA5 and AA6.
- (m) NO COMPARE - SENT XXXXXX₈ REC XXXXXX₈ NO.XXXX₈
A comparison was made, but the compare was not correct.
- (n) AEA SYNC - A PCM synchronization error occurred when the program wanted G10001 or G17031. The program exited.
- (o) RECD NO 77 REC XXXXXX₈ NO.XXXX₈
- (p) TAPE ID NOT FOUND
- (q) G10001 NEVER ZERO - G10001 was never zero and COO4 exited.
- (r) Parity Error - Tape parity is incorrect.
- (s) Illegal Entry Code - C-START insert is incorrect.

NOTE: In all cases, NO.XXXX₈ refers to the octal count of the word that was transmitted in the block.

3. CRT Output

There are five (5) types of output to be displayed:

- (a) COMPARE - Counts the number of words which did not compare correctly.
- (b) TRANSMISSION TTTT - Where TTTT represents one of the following:
 1. SYNC
 2. CSR
 3. EXIT
 4. END
 5. G50, G51
 6. G10
 7. NO77

COO4-0

3. CRT Output (continued)
 - (c) GSE5 - Display an "ON" if GSE5 is a non-zero; display an "OFF" if GSE5 is a zero (all 16 bits).
 - (d) G10001 - Once per second the program will display the eight octal digits that are translated from the three 8-bit words.
 - (e) Tape ID - Displays the Tape ID that is currently accessed by COO4-0.

Normal Exit: Downlink Control

Error Exit: None

Computation Sequence:

COO4-0 Functional Divisions

1. Program Initiate (or Transfer Control)
2. Multiple Location Change (or Operator Load)
3. Memory Dump
4. Block Transmission
 - (a) Using LAV II (Software)
 - (b) Using Flight Program
 1. Loading LAV II
 2. Not Loading LAV II
 - (c) Using Interim Program
 1. Loading LAV II
 2. Not loading LAV II
5. Initialization
6. CRT Display

A description of each of the six COO4-0 Functional Divisions follows.

COO4-0

1. Program Initiate or Transfer Control

This function will enable the Control Room operator to initiate a program in the AEA.

FLOW

C-START insert AA1BC₁C₂X₁X₂X₃X₄

- (1) Blank CRT and initialize
- (2) Set GSE1, 2, 7=0
- (3) Delay 10 milliseconds (should be able to change time delay if required; i.e. delay variable.)
- (4) Delay 10 milliseconds
- (5) Send data C₁C₂X₁X₂X₃X₄
- (6) Set GSE1=1
- (7) Delay 10 milliseconds
- (8) COMPARE 2A
- (9) GSE1=0
- (10) VERIFY 0
- (11) CRT: condition END
DMF: AEA END
- (12) If "B" is equal to one (1), transfer to U004; otherwise exit to downlink control.

NOTE: All subroutines will be shown in capital letters. For details, see subroutine section at the end of the Computation Sequence.

2. Multiple Location Change or Operator Load

This function will enable the control room operator to change either one or more memory locations in the AEA computer. The maximum number of locations that can be changed is fifty (50) (fifty-one words will be sent to the AEA). Three C-START inserts, AA2, AA3, and AA4 will be used.

C004-0

2. Multiple Location Change or Operator Load (continued)

AA2 will contain the data word that specifies the start address to which the remainder of the data, as defined by inserts AA3 and AA4, will be sent.

AA3 will contain the six octal-digit data word.

If fifty (50) data locations are to be changed, AA3 will be used fifty times, AA2 will be used once, and AA4 will be used once.

AA4 signifies that the data just loaded via the AA3 inserts should be sent to the AEA and that there will not be any additional data words.

FLOW

C-START inserts AA2, multiple or single AA3 and AA4

- | | |
|---------------------------|----------------------------|
| (1) Blank CRT | (15) GSE2 = 1 |
| (2) Set GSE1, 2 = 0 | (16) 10 millisec. delay |
| (3) Delay 10 milliseconds | (17) GSE1 - 1 |
| (4) 10 millisecond delay | (18) GSE5 = 1 (subroutine) |
| (5) Data 1 | (19) GSE1, 2 = 0 |
| (6) GSE1 = 1 | (20) END - Display on CRT |
| (7) COMPARE 2B | |
| (8) GSE1 = 0 | |
| (9) VERIFY 0 | |
| (10) Data 2 | |
| . | |
| . | |
| . | |
| Data (Last) | |
| (11) GSE1 = 1 | |
| (12) COMPARE 2B | |
| (13) GSE1 = 0 | |
| (14) VERIFY 0 | |

NOTE:

Number of location changes is limited to 50. The console operator will not send any words to the AEA until AA4 has been sent. The data and address will be stored in the 160G and sent up as if a Block Transmission with LAV II was being done.

COO4-0

3. Memory Dump

The memory dump does the following:

1. C-START inserts AA5 and AA6, define the first address and the last address of the memory area in the AEA to be dumped, inclusively.
2. Starts the memory dump in the AEA.
3. Receives the AEA dump and outputs the dump data and the AEA address to the Command File Tape.

FLOW

AA5 and AA6 are received. The address specified by AA6 must be greater than the AA5 address; otherwise, there is an error and an illegal entry should be noted on the CMF. Calculate SUMWORD, which is the difference between addresses AA5 and AA6 plus one (1).

- (1) Blank CRT
- (2) Set GSE1, 2 = 0
- (3) Delay 10 milliseconds
- (4) Set counter to zero
- (5) 10 millisecond delay
- (6) Send first word (AA5 data C₁C₂X₁X₂X₃X₄)
- (7) Set GSE1 = 1
- (8) Delay 10 milliseconds
- (9) COMPARE 2A
- (10) GSE1 = 0
- (11) VERIFY 0
- (12) Send Second Word (AA6 data C₁C₂X₁X₂X₃X₄)
- (13) Set GSE1 = 1
- (14) Delay 10 milliseconds
- (15) COMPARE 2A

- (16) GSEL = 0
- (17) VERIFY 0
- (18) Set GSEL = 1
- (19) Dumpword 1
- (20) Increment count (by 1)
- (21) COMPARE 1
- (22) GSEL = 0
- (23) VERIFY 0
- (24) CHECKSUM
- (25) GSEL = 1
- (26) Dumpword 2
- .
- .
- .
- (27) Dumpword (LAST)
- (28) Increment count (by 1)
- (29) COMPARE 1
- (30) GSEL = 0
- (31) VERIFY 0
- (32) CHECKSUM

NOTE: The program will write the address, which it will calculate from the AA5 insert, and the dumpword on the Command File Tape.

4. Block Transmission

The Block Transmission is the transfer of AEA data that is contained in one file on the Test File Tape to the AEA computer. The tape format of the data is contained in Addendum A of this specification.

The AA7 insert initiates a search of the Test File Tape to find the desired AEA data file to be loaded.

The AA8 insert tells this program what interface program is contained in the AEA and transmits the data in the data file to the AEA according to a definite sequence of operations which is defined in the flow.

In the first record of each data file, there is a Tape ID which defines the file and a sumword which defines the number of data words to be sent to the AEA.

By the Sumword, the program knows how many words are to be sent to the AEA and therefore, when to end transmission.

When GE = 12 or 11, a block of 600_{10} 1600 memory locations must be reserved for storing the data sent to the AEA (maximum, 300 18-bit data words). If more than 300 words are to be loaded in this manner, the 301st words would eradicate word 1, etc. Due to the nature of the AEA LAV program, the first word dumped when GE=12 or 11, will be the third word sent to the AEA.

A. Block Transmission via LAV 11 (Or Tape Load)

The logic in the flow shown below is identical to the operator load.

FLOW

- (1) Receive AA7
- (2) Search tape for ID
- (3) If ID is not found, file on the CMF: "Tape ID not found" and put "EXIT" on the CRT; exit to the Uplink executive routine.

- (4) If ID is found, file on the CMF tape: TAPE ID XXXX, blank the CRT, and set GSEL, 2 = 0; exit to the Uplink.
- (5) Receive AAS where G and E are zero (0)
- (6) Delay 10 milliseconds
- (7) Send first data word
- (8) Send GSEL = 1
- (9) COMPARE 2B
- (10) GSEL = 0
- (11) VERIFY 0
- (12) Send DATA 2

·
·
·
Data (Last)

GSEL = 1

COMPARE 2A

GSEL = 0

VERIFY = 0

GSEL = 1

Delay 10 milliseconds

GSEL = 1

GSEL = 1 (Subroutine)

GSEL, 2, 7 = 0

Display END on CRT and CMF

B. Block Transmission via Flight Program, when E=1.

This portion will be divided into two sections; when G=0 and when G=1.

1. When G=0 - the LAV II is not being loaded

FLOW

- (1) Received AA7
- (2) Search tape for ID
- (3) If ID is not found, file on the CMF: "Tape ID not found" and put "EXIT" on the CRT; exit to the Uplink.
- (4) If ID is found, file on the CMF tape: TAPE ID XXXX, blank the CRT and set GSEL, 2 = 0; exit to the Uplink.
- (5) Receive AA8 where E=1 and G=0
- (6) Set Count = 2
- (7) Delay 10 milliseconds
- (8) WORD-IN
- (9) GSEL = 0
- (10) GSE5 = 0 (See Subroutines)
- (11) Word 2
- (12) GSEL = 1
- (13) GSE5 = 1 (See Subroutines)
- (14) GSEL = 0
- (15) GSE5 = 0
- (16) Word 3
- .
- .
- .
- Word (last)
- (113) GSEL = 1
- (114) GSE5 = 1
- (115) GSEL = 0
- (116) GSE5 = 0
- (117) GSE2 = 1

- (118) Delay 10 milliseconds
- (119) GSEL = 1
- (120) Delay 10 milliseconds
- (121) GSEL, 2 = 0
- (122) END - Display on CRT and CMF

II. When G=1, the words sent to the AEA will be stored in the 160G. After loading is completed, the AEA will dump the words and comparison with the stored words will be made. This sequence is the same as G=0, except after step 120.

FLOW

- (120) 10 milliseconds delay
- (121) GSE2 = 0
- (122) Dumpword 1
 - COMPARE 2B
 - GSEL = 0
 - VERIFY 0
 - Increment count (by 1)

- GSE5END
- GSEL = 1
- Dump word 2
 - .
 - .
 - .
 - .
- Dump word (LAST)
- COMPARE 2B
- GSEL = 0
- VERIFY 0
- Increment count (by 1)

- GSE5END

C. Block Transmission via Interim Program when E=2

This portion will be divided into two sections, when G=0 and when G=1.

1. When G=0 - the LAV II is not being loaded.

FLOW

- (1) Receive AA7 (do the same as in 4.A, steps 1-4)
- (2) Receive AA8 where E=2 and G=0
- (3) Set Count = 2
- (4) Delay 10 milliseconds
- (5) WORD-IN
- (6) Set GSEL = 0
- (7) GSE5 = 0
- (8) Word 2
- (9) GSEL = 1
- (10) GSE5 = 1
- (11) GSEL = 0
- (12) GSE5 = 0
- (13) Word 3
- .
- .
- (114) Word (LAST)
- (115) GSE2 = 1
- (116) Delay 10 milliseconds
- (117) GSEL = 1
- (118) Delay 10 milliseconds
- (119) GSE5 = 1
- (120) GSEL = 0
- (121) GSE5 = 0
- (122) GSE2 = 0
- (123) END, display on CRT, CMF

II. When G=1 (The same as 4.B II)

This sequence is the same as G=0 except after step (121).

(122) GSE1 = 1
GSE2 = 0
Dump Word 1
COMPARE 2B
GSE1 = 0
VERIFY 0
Increment count (by 1)

GSE5END
GSE1 = 1
Dump Word 2
.
.
.
Dump word (LAST)
COMPARE 2B
GSE1 = 0
VERIFY 0
Increment count (by 1)

GSE5END

5. Initialization

Combine all the following functions into the insert AA9.

- (a) Blank CRT
- (b) Set GSE1, 2 = 0

6. CRT Display of G10001 and GSE5

G10001 Always display one of 50 samples every second
as an eight octal-digit display.

GSE5 Always display one of ten samples every second
as an "On" of "Off" event.

When GSE5 = 1, GSE5 is "On"

When GSE5 = 0, GSE5 is "Off"

SUBROUTINES

COMPARE 1 - The G10001 will be tested to see if the first two octal digits are 77_8 .

Make up to 100 comparisons. Is at least one comparison correct?

COMPARE 1A

YES - Continue

NO - On CMF: RECD NO 77 REC XXXXXX₈ NO. XXXX₈

Set: GSE1, 2 = 0

Display: (condition) NO 77 on CRT

Exit: Display on CMF

COMPARE 2 - The G10001 will be tested to determine if all bits are identical to that which was sent.

Make five comparisons.* Is at least one comparison correct?

YES --Continue immediately after receiving correct comparison.

**NO - On CMF: NO COMPARE SENT XXXXXX REC XXXXXX NO. XXXX

CRT Display: COMP ERR - increment by one (1)

2A (Program Initiate and Memory Dump)

SET GSE 1, 2 = 0

EXIT: Display on CRT, CMF

2B (Block Transmission) and Miltiple Location Change)

Continue

VERIFY 0 - The G10001 will be tested to see if all bits are zero. Make up to 100 tests. Is at least one correct?

* For each comparison do a COMPARE 1 and then a COMPARE 2.

** Continue, do not exit, when G=1 and are comparing 10th or 23rd word sent up.

YES - Continue immediately after correct verify.
NO - CMF: G10001 NEVER ZERO
CRT: Condition G10
SET: GSEL, 2 = 0
EXIT: Display on CMF

CHECKSUM

Is counter = SUMWORD

YES -

SET: GSEL, 2 = 0

END: Display on CRT and CMF

NO - Continue receiving dumpwords

CSR

Send up word. Is CSR good?

YES - Continue

NO - Send same word again. Repeat this cycle for a maximum of three (3) times. Sif still getting bad CSR, then:

Display: SCR on CRT, CMF

Exit: To Uplink Executive Routine

WORD-IN

F = 1

Send up word 1 followed by GSEL=1, every 100 milli-seconds. Immediately test to determine if a GSE5=1 is received (will accept spurious).

NO - Repeat

YES - Immediately send word 1 and GSE=1 again. Wait three seconds. Is good GSE5=1 (non-spurious) received?

NO - Exit on CRT, CMF, exit program.

YES - Continue

F = 0

Send up word 1 and GSEL = 1 and test for GSE5 = 1, as shown below; return.

GSE5=1

Is GSE5=1 being received from the AEA?

Make 10 tests.

NO - Display G51 on CRT, CMF

Set GSEL, 2 = 0, EXIT

YES - Continue

GSE5=0

Is GSE5=0 being received from the AEA?

Make 10 tests.

NO - Display: G50 on CRT, CMF

Set: GSEL, 2 = 0, EXIT

YES - Continue

GSE5END

211 milliseconds* after VERIFY 0 is the duration of GSE5 END.

Is GSE5=1 being received from AEA during 211 milliseconds?

NO - Continue program

YES - Set: GSEL, 2 = 0

END: Display on CRT, and CMF

* Make 211 milliseconds a program variable

Operator Action:

Control Room Console Operator will control and initiate this program by the use of C-START inserts.

Uplink Requirements:

DTCS transmission as required.

DTCS Stimuli

1. GSE1
2. GSE2
3. AEA Word

Downlink Requirements:

1. G10001
2. GSE5

CRT Display: To be defined

Tolerance: None

9.3 SOFTWARE DELIVERABLES

For the purposes of what will be termed program delivery, preliminary or final, TRW shall generate and furnish tangible items:

- 1) A program listing
- 2) An absolute deck
- 3) A compressed deck
- 4) A BTME tape
- 5) An ACE tape

Final program delivery will ordinarily take place several months prior to launch to allow time for the various responsible organizations to familiarize themselves with the program and to conduct such additional verification as may be directed by MSC. Early delivery does not allow time to use instrument scale factors and compensation constants based on calibration data collected on the flight hardware in the field. Neither can there be assurance, that far in advance of launch, that the values of other hardware, vehicle, and mission dependent constants generally are firmly established. Therefore, as the term has been used here and elsewhere throughout this specification, flight program delivery implies the use either nominal values for certain constants or values based on such other data as may have been furnished in a timely fashion.

For loading the AEA software memory just prior to launch, TRW shall prepare and deliver an AGS Mission Constants Tape as described in Paragraph 9.3.5.

9.3.1 Compressed Deck

An AEA compressed deck is a deck of IBM cards on which the symbolic form of the program has been punched in binary. This deck contains the complete program including both the hardware and software memory coding. In the course of developing a program for the AEA, modifications and corrections are initiated by punching new cards individually for a compressed deck. This modifying deck is then processed by the LM Assembly Program (LEMAP) which produces an updated compressed deck, absolute deck, and program listing. For a description of LEMAP, see Reference 9-1 which also contains the basic information needed to code a program for the AEA.

9.3.2 Absolute Deck

The AEA absolute deck produced by LEMAP is a deck of IBM cards on which the AEA program, including both the hardware and software memory coding, is punched in column binary format as described below. The absolute deck shall be the standard source of program information. It shall be used to load the ICS for all program verification testing and as the input source for those programs which generate the BTME tapes and AEA file tapes.

9.3.2.1 Absolute Deck Format

The AEA absolute deck is in column binary format. There are twelve bits in each column. Each successive group of three columns comprises a word. Each card contains up to twenty-four 36-bit IBM 7094 words. The card format is as follows:

- 1) The first word on each card is a control word. Labeling the bits 0-36, Bit 0 is always 0; Bits 6-8 and 12-23 are the IBM 7094 octal address of the first word on the card (the first AEA word is always loaded into 7094 address 54000). Bits 9-11 are always 101; Bits 24-35 are a card checksum generated by adding the 12-bit columns with an end around carry of any overflow.
- 2) The first card always begins with the first AEA word (AEA address 0000, 7094 address 54000). All other cards neither start nor end with a word which is all zeroes. All zero words are omitted unless they fall between non-zero words on a card.
- 3) The AEA word is contained in the most significant 18 bits of the 7094 word.
- 4) After the last AEA word in the absolute deck is a word in 7094 address 64000 which is a checksum of all previous AEA words loaded. This word can have bits in the low order 18 bits, as the checksum is generated with an end around carry.
- 5) The checksum is followed by 80 blank words after which a deck identifier and date appears (starting at 7094 address 64121).

- 6) Each card of the deck contains a unique program identification number in card columns 73-76 and a sequence number in card columns 77-80.

9.3.3 Program Listing

AEA program listings are described in some detail in Reference 9-1. A listing is a printed record of the program which defines the binary contents (printed in octal) of each AEA memory location, both hardware and software. The corresponding symbolic label for each AEA operation is also given.

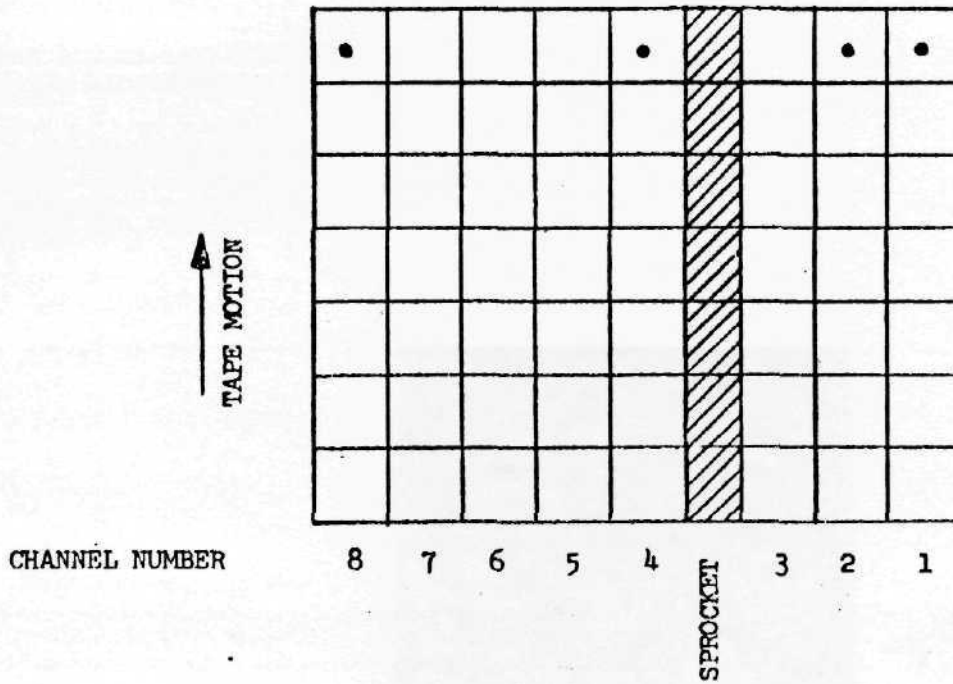
9.3.4 BTME Tape

A BTME tape is a punched mylar tape prepared for loading the software memory by way of the AGS Bench Test Maintenance Equipment. The format of the tape is defined in Reference 9-2 and is illustrated in figures 9-11 and 9-12.

A BTME tape is prepared by using a tape generator program to produce an intermediate magnetic tape. The absolute deck shall be used as the input to this program. The magnetic tape is then loaded onto a punch/reader which punches the software memory portion of the AEA program onto a mylar tape. The punched tape is then run back through the punch/reader equipment to generate a second magnetic tape. This second magnetic tape shall then be compared, bit-by-bit, with the absolute deck using the Tape Comparator Program.

COMMAND NUMBER 013 CLEAR

TAPE FORMAT



							MNEMONIC								VARIABLE FIELD																
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	...	72			
							C	L	R																						

KEY PUNCH FORMAT

FUNCTION:

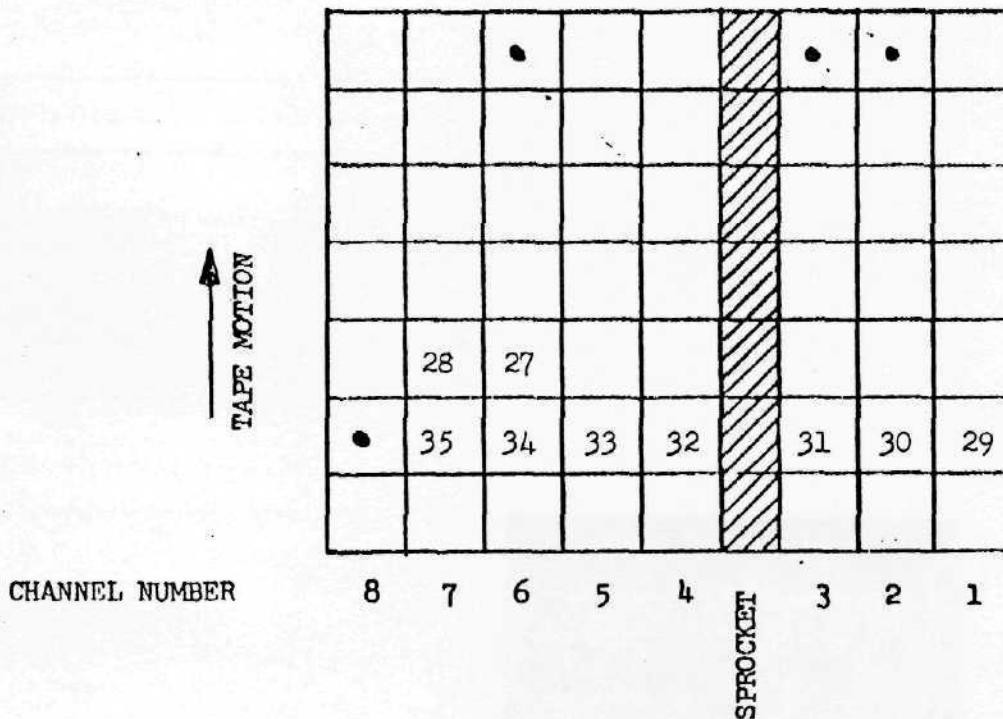
This command causes an INITIAL RESET to occur in the AEA Input/Output Control unit.

CODING:

Only the mnemonic is required.

FIGURE 9-11

TAPE FORMAT



MNEMONIC															VARIABLE FIELD													
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	...	72
							S	M	R						D ₁	D ₂	D ₃											

KEY PUNCH FORMAT

FUNCTION:

This command causes the three counters to begin counting SMRD pulses and to continue to count these pulses for the number of seconds specified in bit positions 27 through 35. The maximum duration is 511 seconds and a duration of at least 1 second must be specified. NOTE: This command operates only in the BTME Test Set.

CODING:

In addition to the mnemonic, the time duration must be specified in decimal as shown.

FIGURE 9-12

9.3.5 AGS Mission Constants Tape (ACE Tape)

At such time as sufficient ASA instrument calibration data has been collected and all other aspects of the mission affecting the values of prelaunch loaded constants have been adequately defined and stabilized, TRW shall prepare and deliver an AGS Mission Constants Tape containing the final values of those constants.

The AGS Mission Constants Tape shall be an AEA file tape, that is, a magnetic tape in a format suitable for use with ACE for loading the software memory of the AEA. The ACE Tape shall contain the entire software memory portion of the flight program in the format specified in Paragraph 9.2.1.

The AGS Mission Constants Tape is generated by use of the LM Dictionary Analysis Program. The inputs to this program shall be the absolute deck corresponding to the previously released flight program, a deck of cards on which the new values for those constants which are to be changed are punched, and third deck of analysis cards defining the characteristics of all software flight program constants. The output of the program is a new absolute deck and a complete listing of all program constants showing both the values in the previously released flight program and the values in the AGS Mission Constants Tape. The constants listing shall be delivered along with the tape.

The AGS Mission Constants Tape shall be verified by comparing it, bit-by-bit, with the new absolute deck using the Tape Comparator Program. The new absolute deck shall also be compared with the original deck to verify that only the designated constants have been changed.

9.3.6 Software Identification and Shipment

All versions of flight programs shall be given unique identification codes. The identifier for each revised version for a particular flight program which is released shall be given a revision letter to distinguish it from previously released versions of the same flight program. All software items, decks, tapes, and listings, shall be marked with the identification code.

The standard identification code shall be of the form LM AGS XXXXX S03Y. LM AGS is the system identifier. XXXXX is a variable length program identifier, e. g., FP3. S03 indicates the software memory program is compatible with the H03 hardware memory. The Y indicates the location for the revision letter. This space shall be left blank in the first release of a program. For subsequent releases, it shall contain A, B, etc.

9.3.7 Requirements for AGS Tape Packages Received at KSC from TRW

1. Tape package shall consist of:
 - a. ACE Tape
 - b. BTME Tape
 - c. Card Deck (AEA Language)
 - d. LEMAP Listing
 - e. TTG Listing
 - f. ACE Tape Listing
2. EPC program shall be compatible with load and verify program and the KSC TCP's. Locations 0000 to 0205 of the EPC shall be blank during load, and remain so during execute.
3. The magnetic ACE tape shall be sent in a metal container.
4. The tapes and cards shall have a QC seal on their containers. This seal shall be placed in such a manner that the seal will be broken if the container is opened.
5. Tapes and cards shall have a distinct numbering system which specifies usage location (Bethpage, KSC, or Houston), ASA to be used with and spacecraft affected.

9.3.8 References

- 9-1. TRW Report 7322.3-17, "Abort Electronic Assembly Programming Reference," April 1966.
- 9-2. TRW Report LM-MI, Revision D, "AGS/BTME Test Set Programming Manual," 5 May 1966.

10.00 APPENDIX

10.1

TABLE I

AEA Input Signals

Engine On	
1024 KC clock	
Accelerometer Input Pulses (Vx, Vy, Vz)	0.1/32 fps/pulse
DEDA Enter	{ "1" State Switch Closed "0" State Switch Open
DEDA Readout Data	
DEDA Clear	
DEDA Hold	
DEDA Address/Data	64 kpps, 36 bit BCD words
DEDA Shift Pulses	64 kpps
PGNCS Downlink Stop Pulse	50 pps
PGNCS Downlink Bit Sync. Pulses	51.2KC, 40 pulses per burst
PGNCS Downlink Data	
800 cps Reference Signal	
Gyro Inputs (a_{xi} , a_{yi} , a_{zi})	3 to 64 pulses/msec. 2^{-16} radians/pulse 32 pulses/msec.
	Sampling Period
400 cps Power (For total attitude Signals)	

TABLE I (Continued)

AEA Input Signals

CDU Zero		"ON": 51.2 kpps.
PGNCS: θ , \emptyset and		6.4 kpps max 360 x 2 ⁻¹⁵ deg/pulse
Standby	}	{ "1" = ground { "0" = open circuit
Followup		
Automatic		
Abort		
Abort Stage		
AGS Downlink Stop Pulse		50 pps.
AGS Bit Sync. Pulses		51.2 KC
GSE Discrete No. 1	}	{ "1" = ground { "0" = open circuit
GSE Discrete No. 2		

TABLE I (A)
(MISSION LEVELS)
ENVIRONMENTAL AND LOAD CONDITIONS

(a) Prelaunch - Packaged

Acceleration: (ns) 2.67g vertical with 1.0g lateral applied to package.

Shock: (ns) Shock as in MIL-STD-810, Method 516, Procedure III.

Vibration: (ns) The following vibration levels are specified during transportation, handling and storage. Vibration to be applied, along three mutually perpendicular axes, x, y and z to the package. (Time: 1/2 octave per minute, 3 times per axis, from 5 cps. to max. cps and back to 5 cps.)

CPS	g or D.A.
5-7.2	.5 inch D.A.
7.2-26	±1.3g
26-52	.036 inch D.A.
52-500	± 5.0g

*Pressures: (c) Atmospheric Pressure from sea level to 50,000 feet.

Temperature: (c) -65°F to 160°F ambient

TABLE I (A) (Continued)

(a) Prelaunch - Packaged (Continued)

*Electromagnetic Interference: (c) In accordance with LSP-530-001

(b) Prelaunch Unpackaged

Acceleration: (ns) 2.67g vertical (+x), with 1.0g lateral.

Shock: (ns) Shock as in MIL-STD-810, Method 516, Procedure 1, Modified. Modify shock pulse to sawtooth 15g peak 10-12 ms rise, 0-2 ms decay.

Vibration: (ns) Same as prelaunch packaged but applied to item.

Pressure: (c) Ambient ground level pressure. (Hermetically sealed units installed in the cabin will be subjected to a limit pressure of 20.5 psi absolute during preflight checkout.)

Temperature: (c) -20°F to 110°F Ambient Air Temperature plus 360 BTU/ft² hr. up to 6 hr/day.

Electromagnetic Interference: (c) Same as prelaunch packaged.

Cold plate not necessarily installed.

TABLE I (A) (Continued)

(c) Launch and Boost

Acceleration:	X		Y		Z	
	g	rad/sec ²	g	rad/sec ²	g	rad/sec ²
Boost Cond.	+4.7		+0.10		+0.10	
Max q Cond.	+2.1		+ .5		+ .5	
Cut Off Cond. (S-1C)	-2.6		+0.10		+0.10	
Engine Hardover (S-11)	+2.3		+ .63			
Engine Hardover (S-11)	+2.3				+ .63	
Earth Orbit	0	0	0	0	0	0

Vibration:

The mission environment consists of the following random spectrum, applied for 17 minutes along each of the three mutually perpendicular axes, x, y, and z. Input to equipment supports from exterior primary structure.

cps

5-13	0.18g ² /cps constant
13-15	12 db/octave rise to
15-32	0.30g ² /cps constant
32-49	12 db/octave rolloff to
49-950	0.044g ² /cps constant
950-1200	12 db/octave rolloff to
1200-2000	0.015 ² /cps constant

Pressure:

Atmospheric pressure at sea level to 1×10^{-18} mm Hg (N₂)

Temperature:

0°F to +130°F ambient

Electromagnetic Interference:

Same as prelaunch packaged.

Radiation:

Charged particles and electromagnetic radiation present in cislunar space, originating in the Van Allen belts, solar flares and space background, shall be considered in the design.

Cold plate coolant not flowing.

TABLE I (A) (Continued)

(d) Space Flight - Translunar

Acceleration:

	X		Y		Z	
	g	rad/sec ²	g	rad/sec ²	g	rad/sec ²
Serv. Mod. Propulsion System Operating	-0.45	0	+0.11	+0.26	+0.11	+0.26
Serv. Mod. Propulsion System No + Operating	0	0	0	0	0	0
Shock: Condition Transposition	-0.84	0	+0.085	+12.0	+0.085	+12.0

Vibration:

The mission environment consists of the following random spectrum applied for 6 minutes along each of the three mutually perpendicular axes, x, y and z.

Input to equipment supports from primary structure:

5-47 cps	0.089g ² /cps constant
47-65 cps	12 db/octave rolloff to
65-1000 cps	0.024g ² /cps
1000-2000 cps	12 db/octave rolloff to

The above vibration levels apply to the ASA only from the standpoint of survivability. The vibration environment during which ASA performance within specified limits as required shall be as follows:

Linear - sinusoidal

14 cps: 0.036 inch double amplitude, decreasing logarithmically to
 60 cps: 0.0034 inch double amplitude

Angular - sinusoidal

14 cps: 1.0 milliradians double amplitude, decreasing logarithmically to
 60 cps: 0.21 milliradians double amplitude

TABLE I (A) (Continued)

(d) (Continued)

Pressure: 1×10^{-10} mm Hg
 Temperature: 0°F to 130°F
 Electromagnetic Interference: Same as prelaunch packaged.
 Cold plate coolant not flowing during ASA non-operating time.

(e) Lunar Descent - Including separation, descent, hover and touchdown

Acceleration:		X-Peak		Y-Peak		Z-Peak	
		g	rad/sec ²	g	rad/sec ²	g	rad/sec ²
Landing (300 ms max. duration)	<u>Cond</u> #1	+3.3	0	-3.1	+11.8	-3.1	-11.8
	#2	-3.7	0	0	-16.6	+4.9	0
Descent engine operating		+1.0	± 0.31	± 0.11	± 0.47	± 0.11	± 0.47
Transfer Orbit		0	0	0	0	0	0
Shock:	#1	8.0			± 14.0		
(Landing, 10-20 ms rise time, ramp step shock.)	#2			± 8.0			± 14.0
	#3				± 14.0	± 8.0	
	#4	8.0					± 14.0

TABLE I (A) (Continued)

(e) (Continued)

Vibration:

The mission environment consists of the following random spectrum applied for 11.5 minutes along each of the three mutually perpendicular axes, x, y and z.

Input to equipment supports from primary structure.

10-28 cps	0.18g ² /cps constant
28-37 cps	12 db/octave rolloff to
37-1000cps	0.059g ² /cps constant
1000-1200 cps	12 db/ octave rolloff to
1200-2000 cps	0.031g ² /cps constant

The above vibration levels apply to the ASA only from the standpoint of survivability. The vibration environment during which ASA performance within specified limits is required shall be as follows:

Linear - sinusoidal

14 cps: 0.036 inch double amplitude, decreasing logarithmically to
60 cps: 0.0034 inch double amplitude

Angular - sinusoidal

14 cps: 1.0 milliradians double amplitude, decreasing logarithmically to
60 cps: 0.21 milliradians double amplitude

Temperature: 0°F to 160°F

Pressure: 1 x 10⁻¹⁰ mm Hg

Electromagnetic

Interference: Same as prelaunch packaged.

TABLE I (A) (Continued)

(f) Lunar Stay

Acceleration:	<u>X</u>	<u>Lateral</u>	<u>Pitch</u>
cond. - at rest	1/6g	0g	0 rad/sec ²
Shock:	Not critical		
Vibration:	(a) To be supplied (b) Ascent and descent engines not operating.		
Pressure:	1 x 10 ⁻¹⁰ mm Hg		
Temperature:	0°F to 160°F		
Electromagnetic Interference:	In accordance with LSP-530-001		

(g) Lunar Ascent - Including ascent, rendezvous and docking

Acceleration	X		Y		Z	
	g	rad/sec ²	g	rad/sec ²	g	rad/sec ²
Engine operating	+1.0	+0.88	+0.05	+0.88	+0.05	+2.00
Docking Condition	0	0	0	0	-4.0	0
Transfer Orbit	0	0	0	0	0	0

Shock: To be supplied by Grumman.

Vibration: The mission environment consists of the following random spectrum applied for 8.5 minutes along each of the three mutually perpendicular axes, x, y, and z.

TABLE I (A) (Continued)

Vibration:	Input to equipment supports from primary structure.	
	10-28 cps	0.18g ² / cps constant
	28-37 cps	12 db/octave rolloff to
	37-1000 cps	0.059g ² /cps constant
	1000-1200 cps	12 db/octave rolloff to
	1200-2000 cps	0.031g ² /cps constant

The above vibration levels apply to the ASA only from the standpoint of survivability. The vibration environment during which ASA performance within specified limits is require shall be as follows:

Linear - sinusoidal

14 cps: 0.036 inch double amplitude, decreasing logarithmically to

60 cps: 0.0034 inch double amplitude
Angular - sinusoidal

14 cps: 1.0 milliradians double amplitude, decreasing logarithmically to

60 cps: 0.21 milliradians double amplitude

Pressure: 1×10^{-10} mm Hg

Temperature: 160°F to 160°F

Electromagnetic

Interference: In accordance with LSP-530-001.

LGC FORMAT FOR AGS INITIALIZATION

- a) ID Word
- b) X component of LM Position Vector
- c) Y component of LM Position Vector
- d) Z component of LM Position Vector
- e) Most Significant Word Half of Modified LM Epoch Time Double Precision Word
- f) X component of LM Velocity Vector
- g) Y component of LM Velocity Vector
- h) Z component of LM Velocity Vector
- i) Least Significant Word Half of Modified LM Epoch Time Double Precision Word
- j) X component of CSM Position Vector
- k) Y component of CSM Position Vector
- l) Z component of CSM Position Vector
- m) Most Significant Word Half of Modified CSM Epoch Time Double Precision Word
- n) X component of CSM Velocity Vector
- o) Y component of CSM Velocity Vector
- p) Z component of CSM Velocity Vector
- q) Least Significant Word Half of Modified CSM Epoch Time Double Precision Word

10.2.1

TABLE IIAMISSION PROFILE

Phase	Time (Minutes)		Environment Table IA
	Boost Total	Non- Boost Total	
Prelaunch*		120.0 days	a & b
Earth launch & ascent	11.8		c
Earth orbit through transposition	5.2	210.9	d
Continue translunar trip through insertion into lunar orbit	6.4	3627.4	d
Coast in lunar orbit (LM Checkout)		223.3	d
Total preseparation	23.4	4661.6	
LM separation to insertion		20.0	e
Insertion and Hohmann Transfer orbit	0.6	57.9	e
Powered descent from pericyynthion to hover	8.4		e
Hover to touchdown	1.14		e

TABLE IIA (Continued)

Phase	Time (Minutes)		Environment (Table IA)
	Boost Total	Non- Boost Total	
Post landing checkout		75.0	f
Exploration		65.0	f
Prelaunch preparation		100.0	f
Total lunar stay for mission success estimate		2153.5	f
Additional lunar stay for crew safety estimate		1200.0	f
Powered ascent	7.2		g
Coast (approximately) 30 mins		28.	g (no vibration)
Coelliptic sequence initiation, 0.5 RCS horizontal burn			g
Coast to apocynthion		49.	g (no vibration)
Circularization burn at 65 mi., 0.5 RCS burn			g
Coast in 65 mi. parking orbit		45.	g (no vibration)

TABLE IIA (Continued)

Phase	Time (Minutes)		Environment (Table IA)
	Boost Total	Non- Boost Total	
Terminal Phase Initiation, RCS burn	0.5		g
Coast 140° central angle, includes 2 midcourse corrections with RCS burns of 24 and 4 sec. (V=30 and 5 fps)		48.	g (no vibration)
Rendezvous, includes 3 RCS burns of approximately 4, 8, and 4 sec (V=5, 10 and 5 fps)		10.	g (no vibration)
Docking		15.	g

*This phase consists of pad time after calibration on site and does no include 4.5 years of storage or 850 hours of operating test time.

AEA OUTPUT SIGNALS

Engine Cut Off Command	}	Transistor switch closure
Engine On Command		
Test Mode Fail		
Shift 4 Bits In	}	Single Pulses
Shift 4 Bits Out		
DEDA Clock		128 kpps
DEDA Data		64 kpps, 36 bit BCD word
Lateral Velocity		range: 0 to 5vdc; ± 200 fps; 25mv/fps
Altitude		15 bit word (MSB first), 5 per sec.
Altitude Rate		Sign plus 14 bit word, 5 per sec.
Shift Pulses for Altitude		64 kpps
Shift Pulses for Altitude Rate		64 kpps
AGS Downlink		{ 51.2 KC max 50 words/sec 24 bits/word
GSE Discrete No. 5		128 kpps; on = "1", off = "0"
GSE Data Output		51.2 kpps; on = "1"; off = "0"
50 pps (reference)		
Attitude Error Signals (E_x , E_y , E_z)		0 to 4.5 V, 800 cps 300 mv/deg $\pm 5\%$ ± 15 degrees range

TABLE III (Continued)

TOTAL ATTITUDE SIGNALS ($\sin \alpha \sin \beta \sin \gamma$)	$E_0 \sin \theta_A \sin (2\pi ft + \zeta)$ (See Note 1) 0-15V rms, 400 cps 30 mv/step, 25 times/sec rate
ASA clock	128 kpps

Note 1: $\zeta = 5^\circ$ max

$$\theta_A - \tan^{-1} \frac{\sin \theta}{(\cos \theta)} = \pm 0.5^\circ$$

TABLE IV (Continued)

Operation	IMU Align	Lunar Align	Body Axes Align	Followup	Attitude Hold	Semi Automatic	Automatic	Acquisition	Calibration	Notes
LM Navigation	1 ⁽⁵⁾	1 ⁽⁵⁾	1 ⁽⁵⁾	1 ⁽⁵⁾	1 ⁽⁵⁾	1	1	1	1 ⁽⁵⁾	
CSM Navigation	1 ⁽⁵⁾	1 ⁽⁵⁾	1 ⁽⁵⁾	1 ⁽⁵⁾	1 ⁽⁵⁾	1	1	1	1	Legend:
Inflight Self-Test	1	1	1	1	1	1	1	1	1	1 - These operations are always performed in the submodes indicated
Inflight Gyro Drift Calibration									1 ⁽³⁾	
Lunar Surface Gyro Drift Calibration*									1 ⁽²⁾	2 - These operations are performed on command via DEDA in the submodes indicated
Inflight Accelerometer Bias Calibration									1 ⁽³⁾	0 - These operations should not be commanded in the submodes indicated
Navigation Display	1	1	1	1	1	1	1	1	1	
Engine ON/OFF Commands	1 ⁽⁴⁾	1 ⁽⁴⁾	1 ⁽⁴⁾	1	1	1	1	1	1 ⁽⁴⁾	* - These operations are not described in the Flight Equations document (Ref. 5)
Store Lunar Azimuth	2	0	0	2	2	0	0	0	0	

10.7

TABLE VII

The program shall be constrained to utilize the hardwired memory containing program LM AGS H03. Memory usage shall be as follows:

<u>FUNCTION</u>	<u>HARDWIRED MEMORY USAGE</u>
Input PGNS, gyros, accelerometers	18
Downlink input and format conversion	43
Telemetry output	25
DEDA	118
FDAI	61
Tape Load	26
Accelerometer and gyro processing	33
Direction cosine update	172
Alignment	84
Direction cosines from Euler Angles	52
Calibrate	--
LM and CSM epoch initialize	59
Navigation	121
Navigation displays	51
LM orbit parameters	50
CSM present and predicted vel. and position	58

TABLE VII (Continued)

<u>FUNCTION</u>	<u>HARDWIRED MEMORY USAGE</u>
Orbit parameters from epoch and ellipse predictor subroutines	135
Radar filter, range rate, and acquisition steering commands	--
Rendezvous Guidance Computation (Coelliptic Rendezvous)	263
Guidance Steering Commands	12
Guidance Steering attitude errors	59
General Purpose subroutines	250
Executive and miscellaneous	65
Diagnostic	195
Hard/soft integration	40
Startup initialization	13
Constants	45
Variables	--

(Note: These estimates include the latest hardwired memory (HO-3) and implement the Coelliptic Rendezvous Technique).

10.8

TABLE VIII

DEDA INPUT SIGNALS

DEDA Clock	128 kpps
Shift 4 Bits In } Shift 4 Bits Out }	Single Pulse
DEDA Data	64 kpps, 36 bit BCD word

10.9

TABLE IX
DEDA OUTPUT SIGNALS

DEDA Enter	
DEDA Readout	"1" = ground
DEDA Clear	"0" = open
DEDA Hold	
DEDA Address/Data	64 kpps, 36 bit BCD word
DEDA Shift Pulses	64 kpps

COELLIPTIC
FLIGHT PLAN

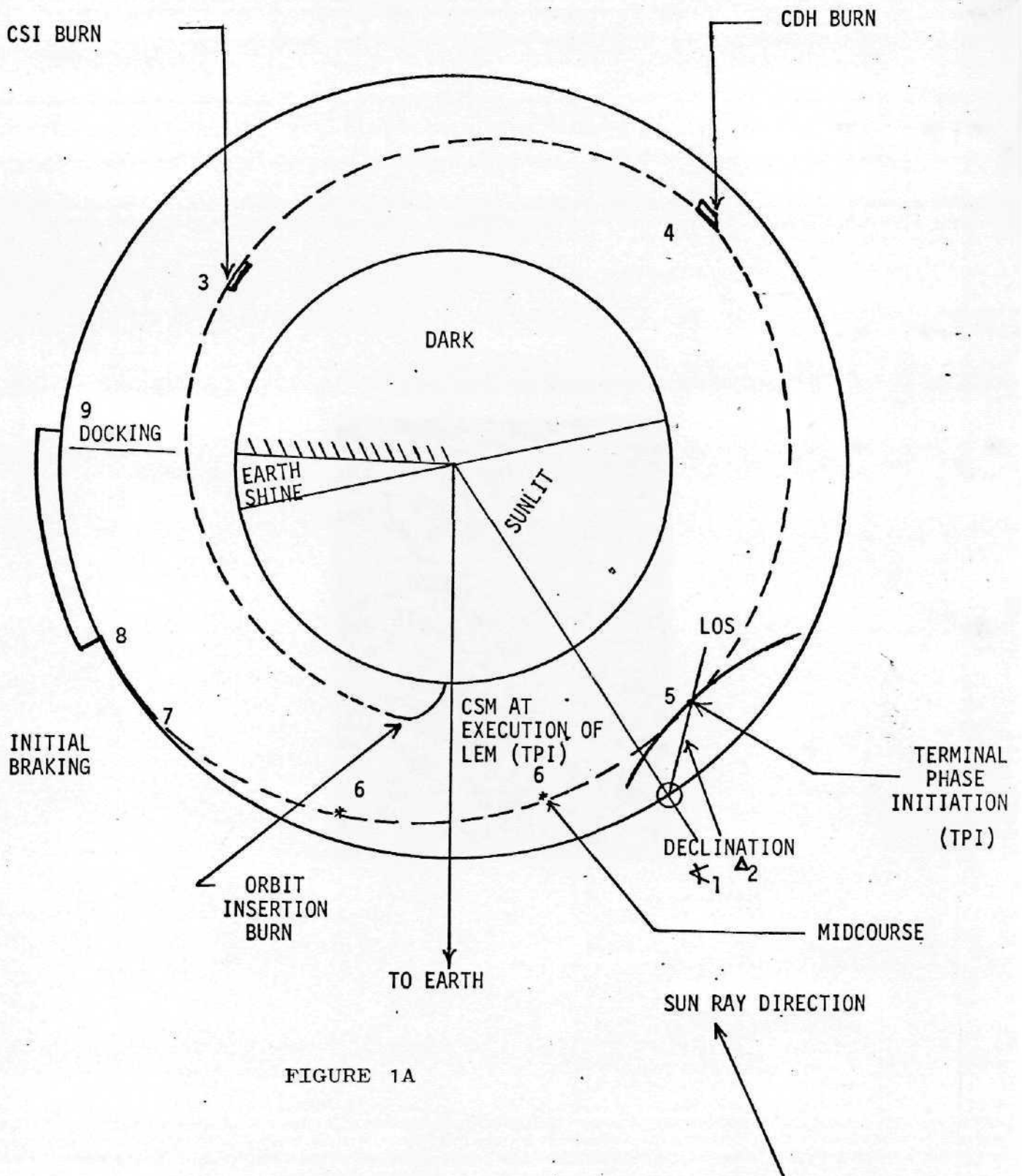


FIGURE 1A

NOTE: NOT TO SCALE

FIGURE 1B
AGS ALTITUDE & ALTITUDE RATE INITIAL
CONDITIONS AT ABORT INITIATION DURING
HOVER-TO-TOUCHDOWN (DESCENT ENGINE)

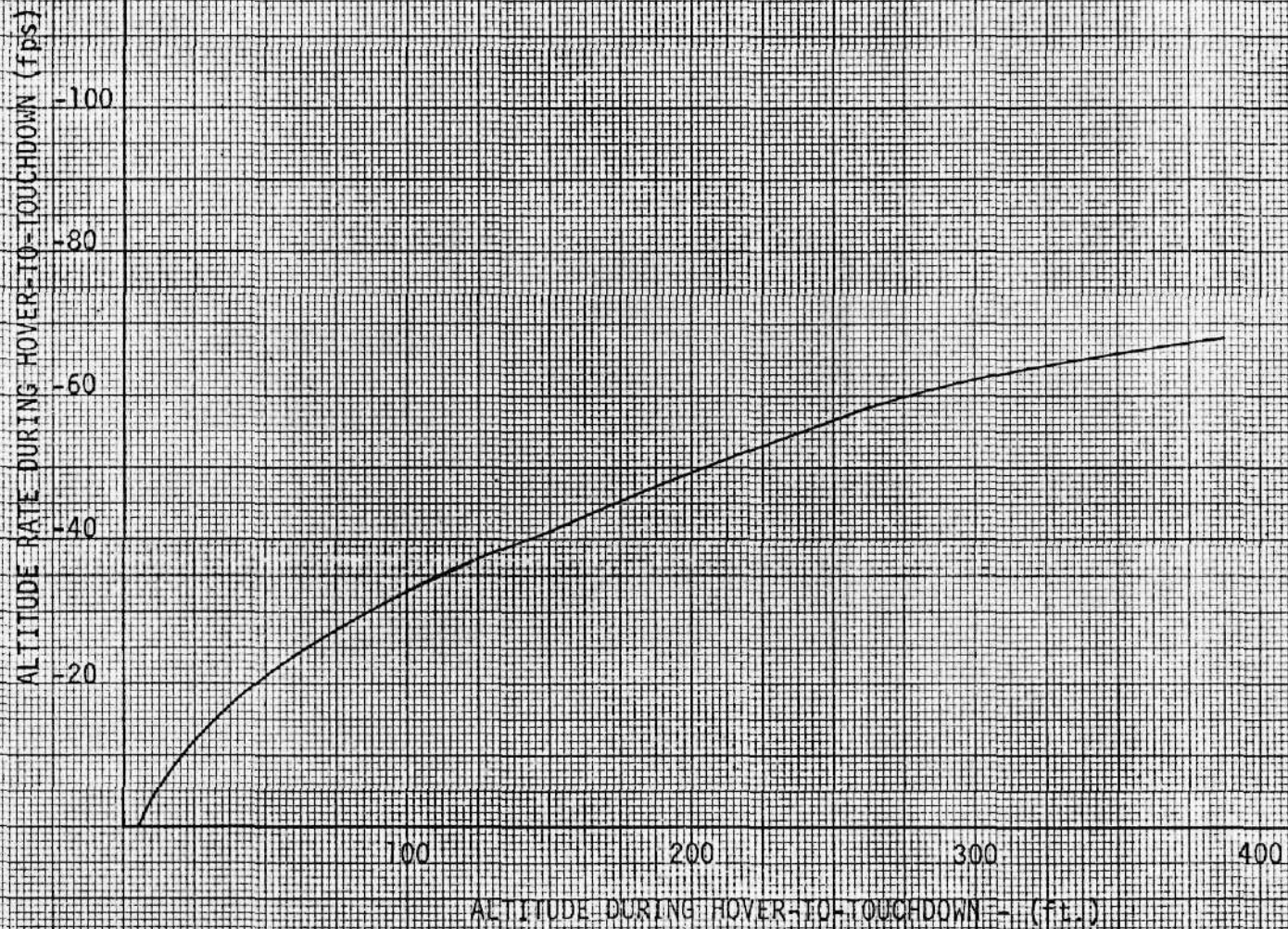


FIGURE 1C

AGS ALTITUDE & ALTITUDE RATE INITIAL
CONDITIONS AT ABORT INITIATION DURING
HOVER-TO-TOUCHDOWN (ASCENT ENGINE)

ALTITUDE RATE DURING HOVER-TO-TOUCHDOWN

-50

-40

-30

-20

-10

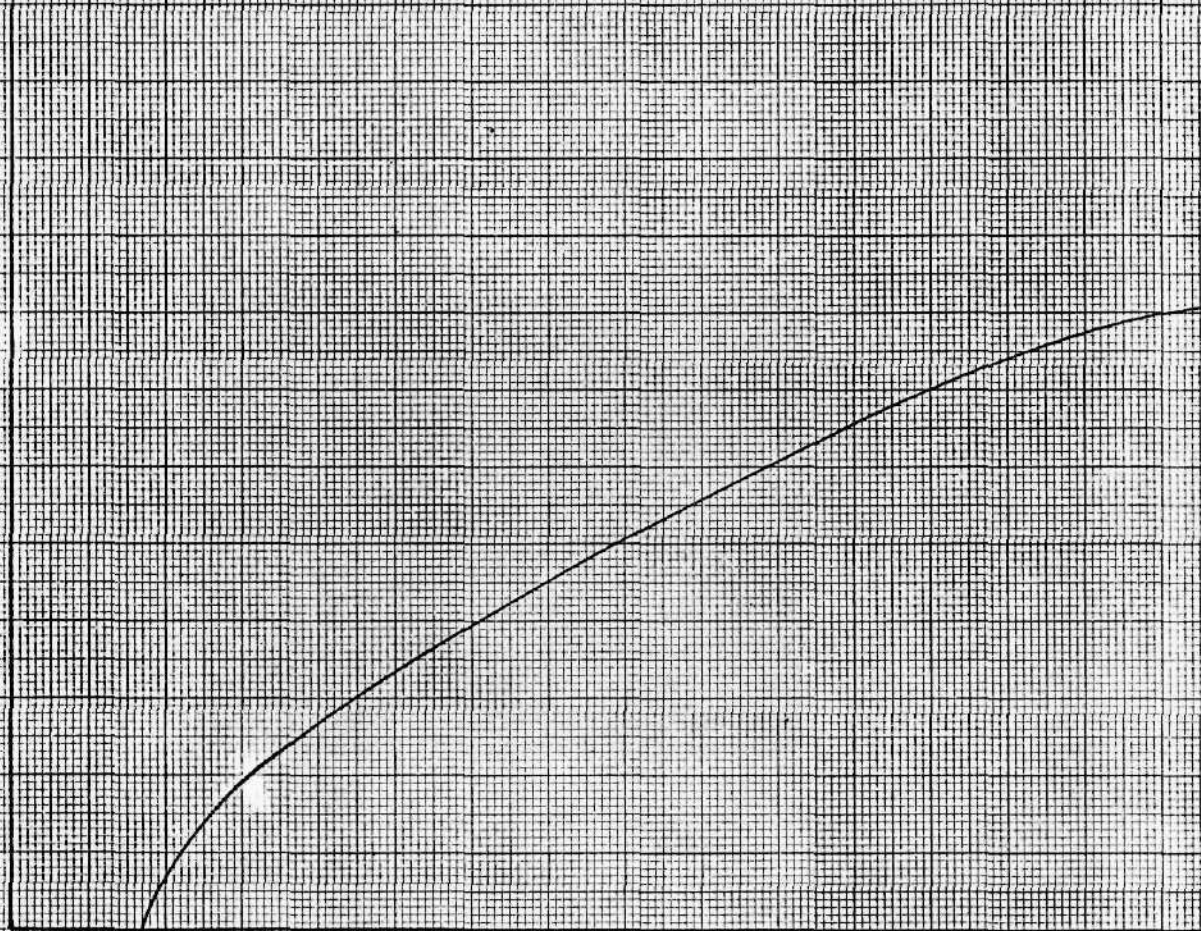
0

100

200

300

ALTITUDE DURING HOVER-TO-TOUCHDOWN - (ft.)



AGS FUNCTIONAL BLOCK DIAGRAM

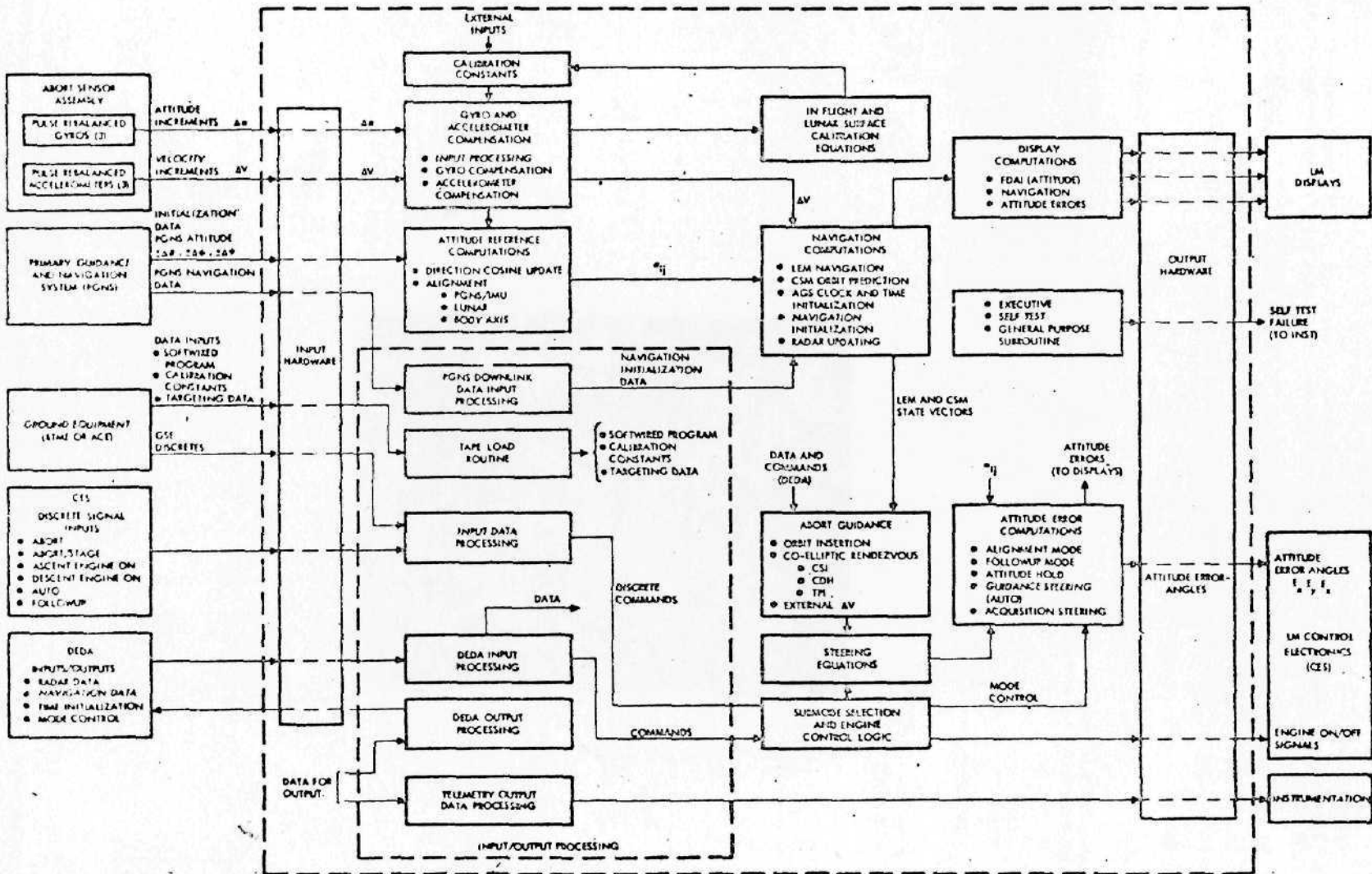


Figure 2 - ACS Functional Block Diagram

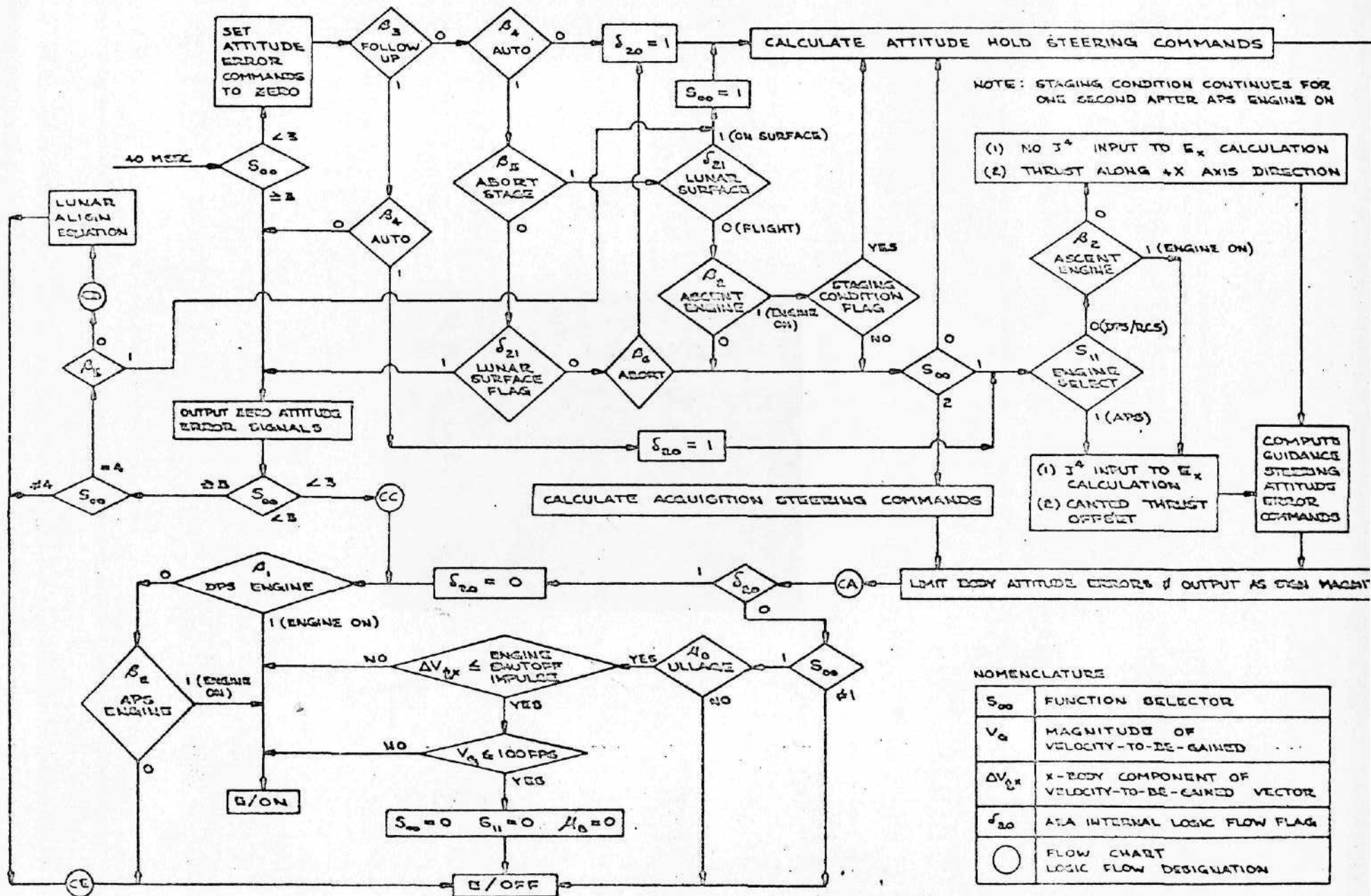


Figure 3 - 40 ms computations

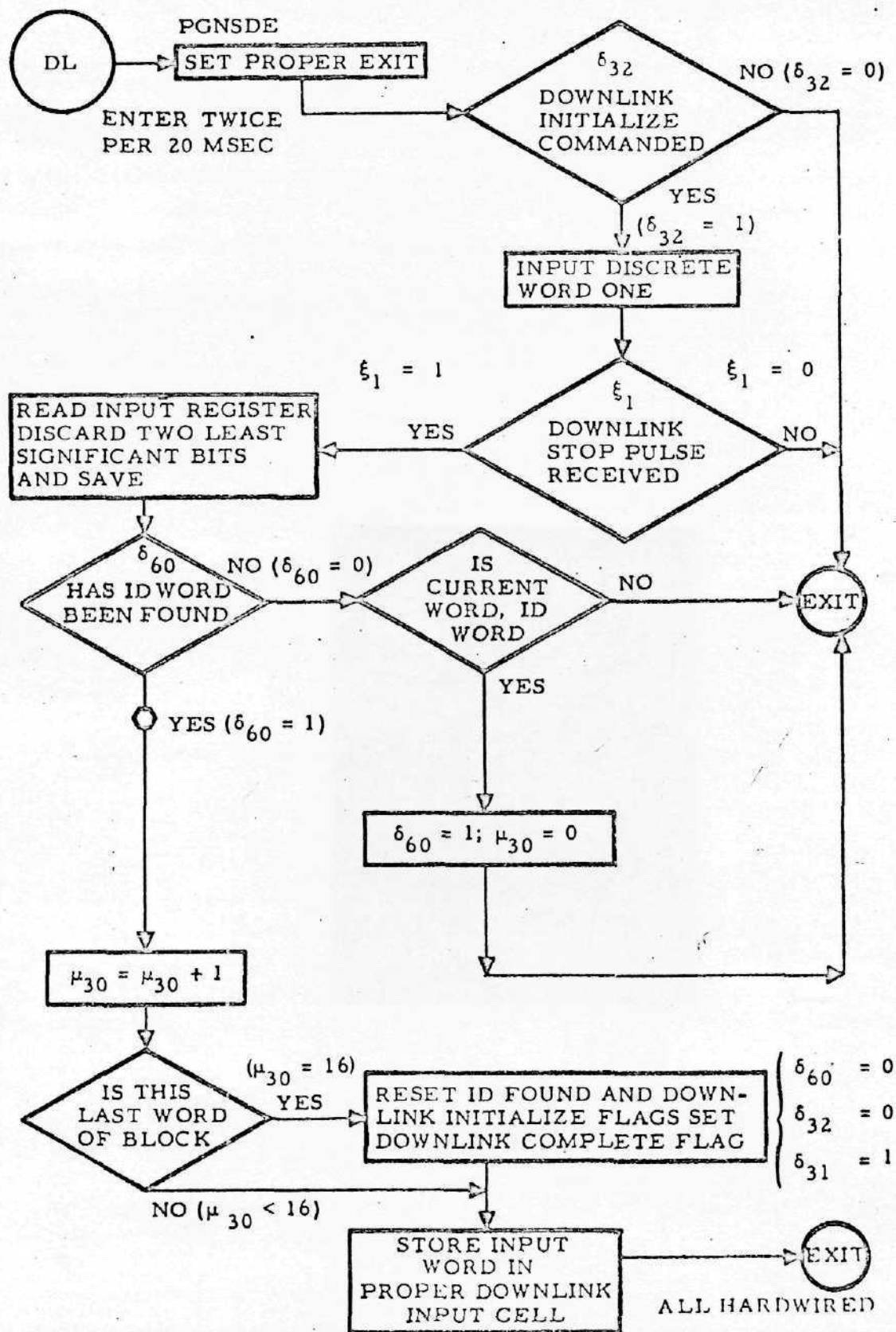


Figure 4 PGNSC Downlink Input Subroutine

ENTER TWICE PER 20 MSEC

ENTER
ONCE PER
SECOND

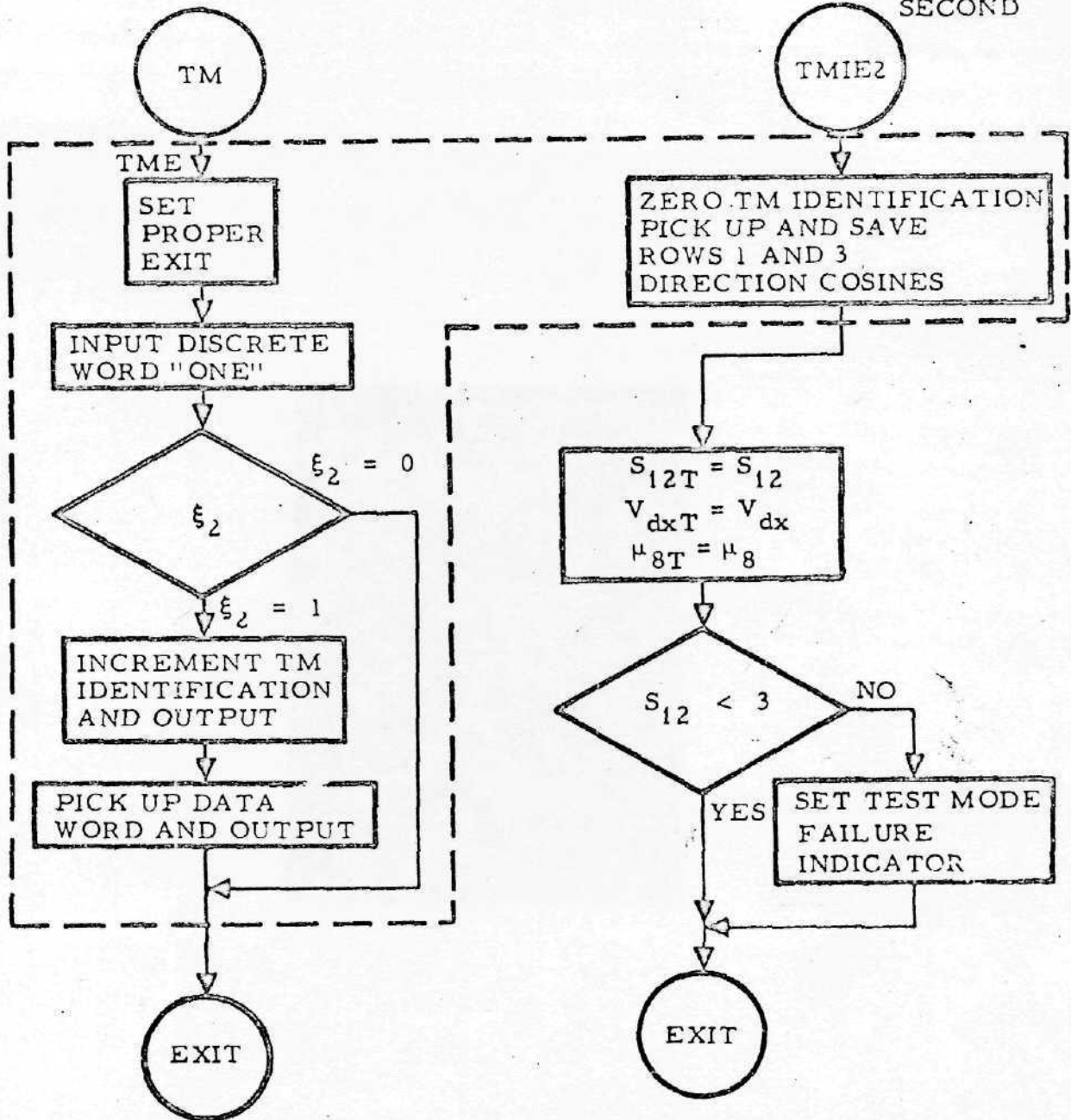


Figure 5 AGS Telemetry Subroutines

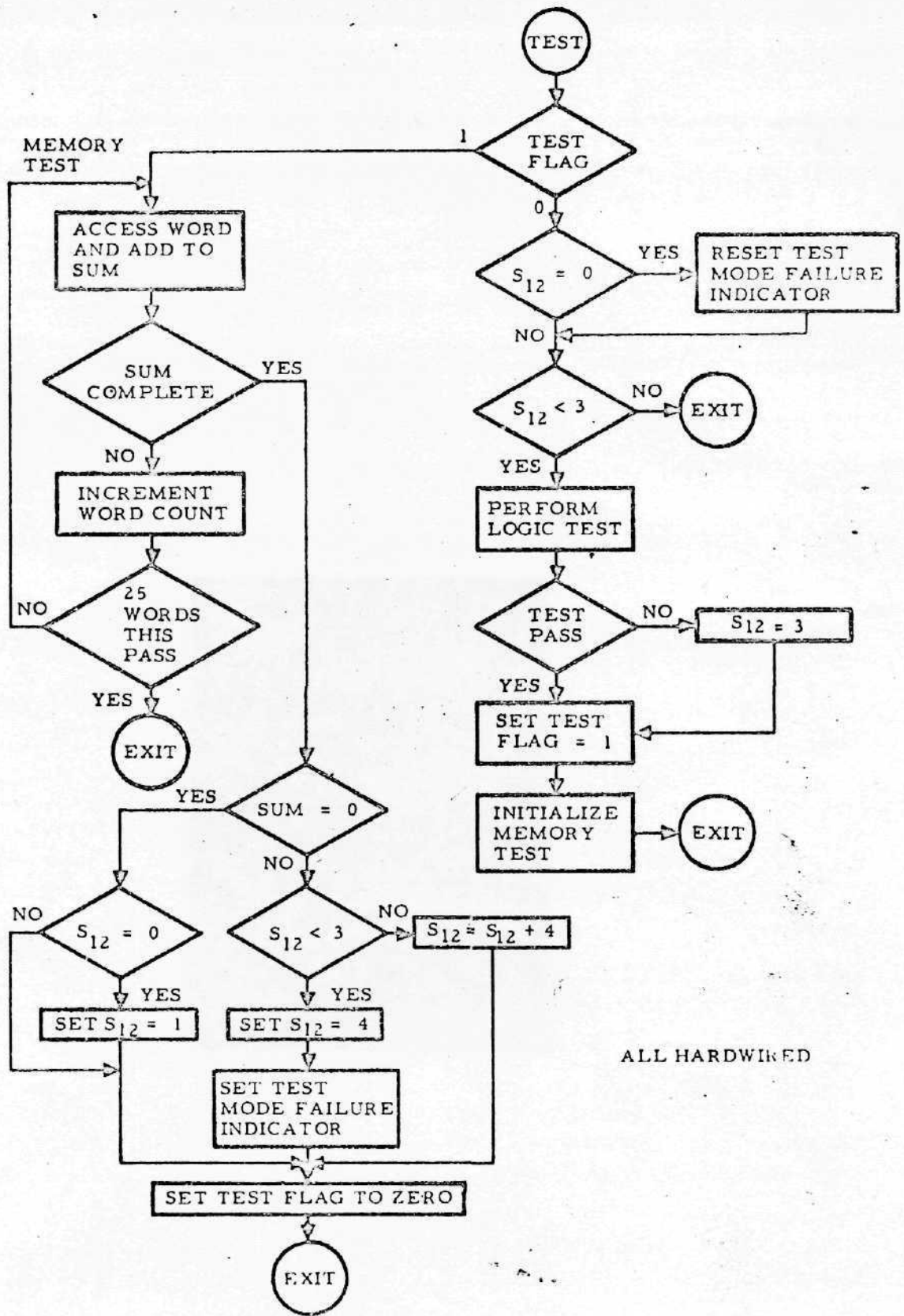
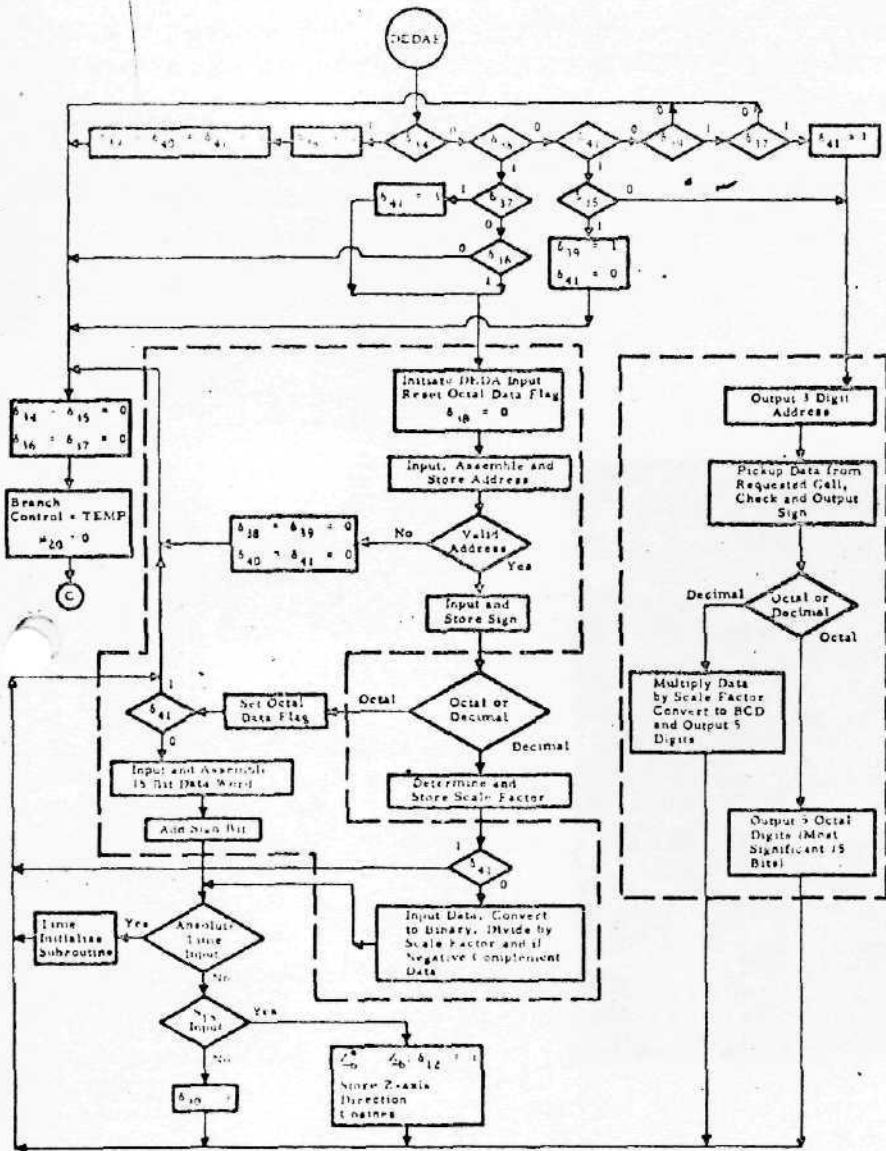


Figure 6 Inflight Self-Test Routine



Flag	Function
634 =	1 DEDA clear discrete input received
	0 Not received
635 =	1 DEDA hold discrete input received
	0 Not received
636 =	1 DEDA enter discrete input received
	0 Not received
637 =	1 DEDA readout discrete input received
	0 Not received
638 =	1 DEDA clear mode
	0 Not DEDA clear mode
639 =	1 DEDA hold mode
	0 Not DEDA hold mode
640 =	1 DEDA enter mode
	0 Not DEDA enter mode
641 =	1 DEDA readout mode
	0 Not DEDA readout mode

Figure 7 DEDA Processing Routine

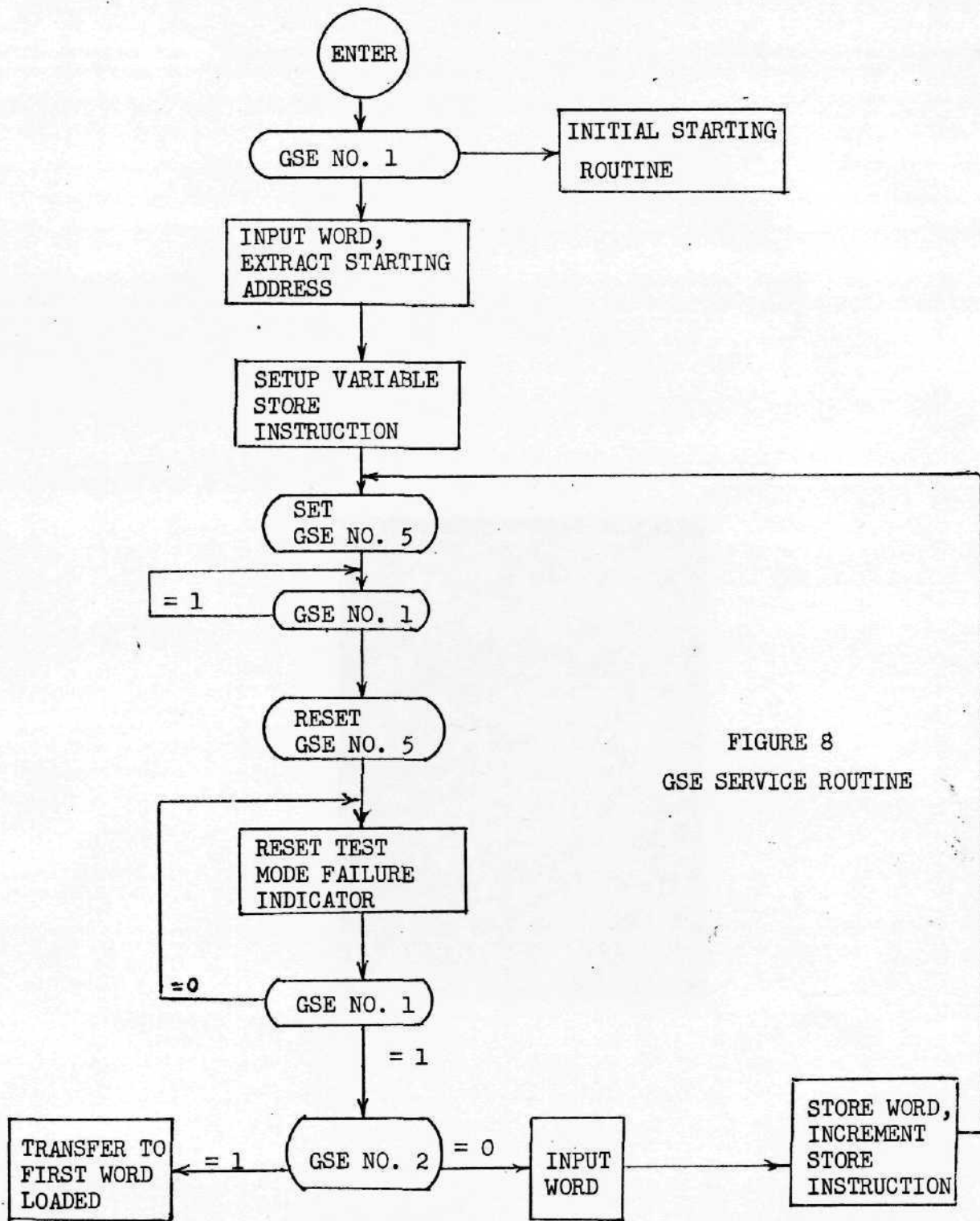


FIGURE 8
GSE SERVICE ROUTINE

AGS SOFTWARE INTERFACE REQUIREMENTS FUNCTIONAL BLOCK DIAGRAM

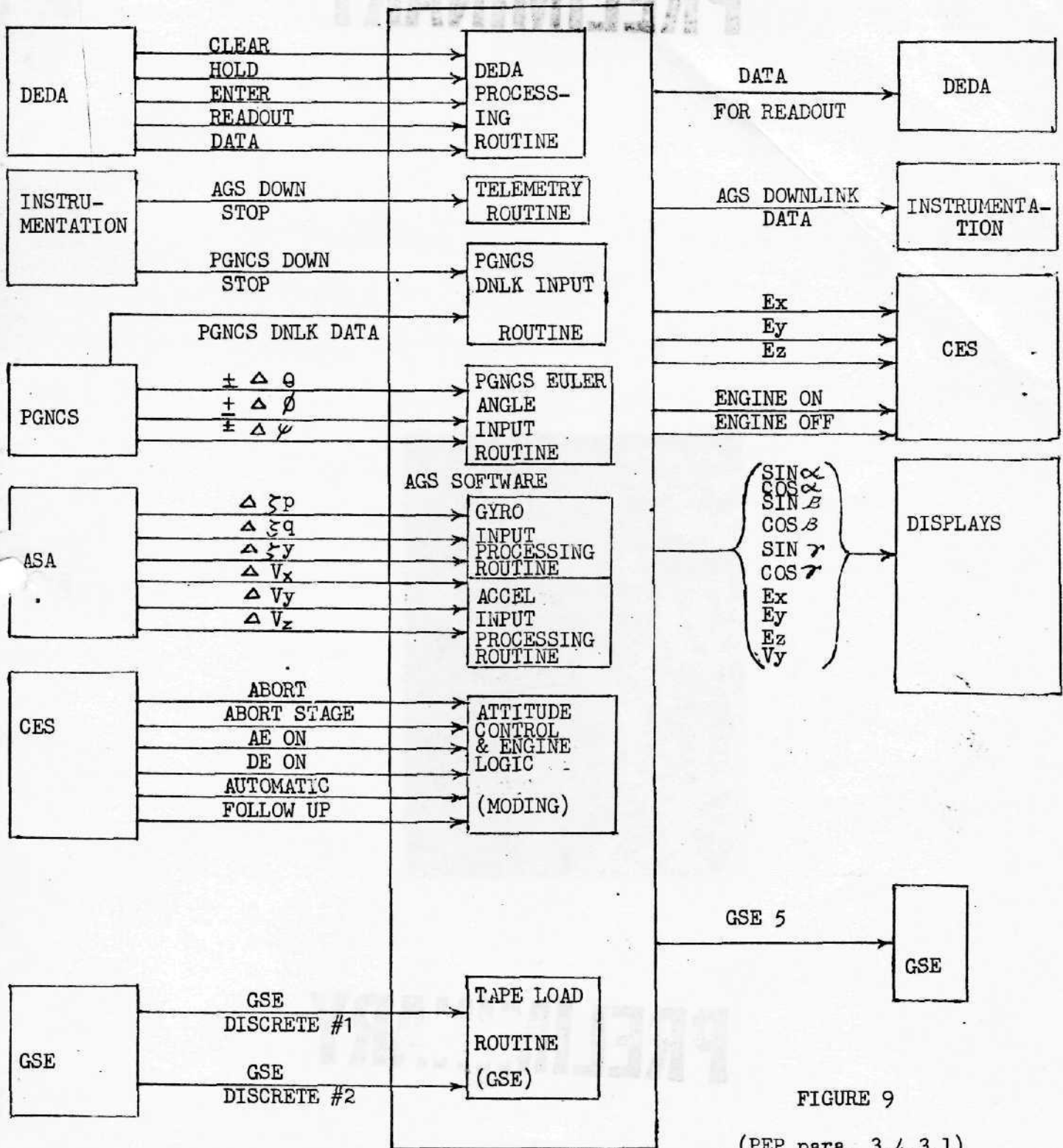


FIGURE 9

(PEP para. 3.4.3.1)