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GUIDANCE AND NAVIGATION  
PERFORMANCE AND INTERFACE  
SPECIFICATION  
BLOCK I  
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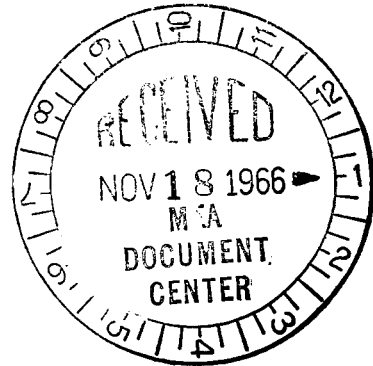
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GFE  
GUIDANCE AND NAVIGATION PERFORMANCE AND  
INTERFACE SPECIFICATION  
BLOCK I

1.0 SCOPE

1.1 Scope

This specification defines performance and interface requirements of the Guidance and Navigation (G&N) subsystem in all areas where the characteristics and capabilities of that subsystem place any design constraints on the Command and Service Module (CSM) System or any of its other subsystems.

Performance characteristics of the Launch Vehicle and other items of Government Furnished Equipment (GFE) with which the design of the G&N subsystem shall be compatible are also specified.

1.2 Objective

The objective of this specification is to provide the base line requirements for the G&N subsystem supporting the CSM - Block I and its associated subsystems.

2.0 APPLICABLE DOCUMENTS

The following documents, of exact issue shown, form a part of this specification to the extent specified herein.

2.1 Project Documents

SPECIFICATIONS

Military

MIL-I-26600 (2)  
5 May 1960

Interference Control Requirements  
Aeronautical Equipment (As amended  
by MSC-ASPO-EMI-IOA)

National Aeronautics and Space Administration (NASA)

MSFC 10M01071  
6 March 1961

Environmental Protection When Using  
Electrical Equipment Within the Areas  
of Saturn Complexes Where Hazardous  
Areas Exist, Procedure for



MSFC-PROC-158A  
12 April 1962

Soldering Electrical Connectors (High Reliability) Procedure for (As amended by MSC-ASPO-S-5B, dated 10 February 1964)

North American Aviation, Inc., Space and Information Systems Division (NAA/S&ID)

SID 63-313  
Revised 22 February 1965

CSM Technical Specification - Block I

SID 64-1237  
Revised 22 February 1965

CSM Master End Item Specification - Block I

Massachusetts Institute of Technology (MIT)

PS1015000  
9 August 1966

Apollo G&N Equipment Master End Item Specification - Block I

PS1000000  
27 July 1966

Contract Technical Specification Airborne G&N Equipment - Block I for Apollo CM and Associated Equipment

STANDARDS

Military

MS-33586A  
16 December 1958

Metals; Definition of Dissimilar

DRAWINGS

Interface Control Documents (ICD's)

MH01-01248-416  
10 August 1965

G&N Environmental Requirements

MH01-01256-416  
17 June 1965

Weights, AGE to Spacecraft



2.2 Precedence.- Should there be a conflict between the requirements of this specification and the requirements of the documents referenced herein, the requirements of this specification shall govern.

Massachusetts Institute of Technology/Instrumentation Laboratory

The below order shall be applicable to the precedence of the documents only, i.e., it shall be applicable only to the extent of any unintentional inconsistencies between the documents and shall not apply to the intentional deviations. Intentional deviations applicable to specific end items or missions shall be defined in the lower end item and/or Mission Contract Specifications. For these end items or missions, these deviations shall govern and shall not be considered inconsistencies.

- a. NAS9-4810 - Contract Basic Statement of Work
- b. NAS9-4810 - Contract Exhibit B, System Characteristics
- c. PS1000000, CSM (Blk I) G and N Systems Technical Specification
- d. This specification
- e. PS1015000 CSM (Blk I) G and N System Master End Item Specification
- f. CSM (Blk I) G and N System Individual End Item Specification
- g. CSM (Blk I) G and N System Mission Specification
- h. Other documents referenced herein.



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3.0 REQUIREMENTS

The basis for design of the G&N subsystem Block I shall be a lunar orbit mission which may be defined as the Lunar Orbit Rendezvous (LOR) mission without the Lunar Excursion Module (LEM) interface and with certain other deviations as specified in this document.

3.1 Functional and Performance Requirements

The G&N subsystem shall be designed to accomplish the LOR mission including a nominal mission time of 10.6 days with 3 days in lunar orbit. The following 10.6-day lunar orbit mission timeline shall serve as a basis for the design and provisioning of the G&N subsystem and CSM system.

<u>Mission Phase</u>	<u>Duration Hours</u>
Prelaunch	10.00
Ascent phase	0.19
Earth parking orbit	4.40
Translunar injection	0.09
Translunar coast	77.00
Lunar orbit injection	0.09
Lunar orbit coast	88.00
Transearth injection	0.04
Transearth coast	84.00
Pre-entry	0.08
Entry	0.50
Recovery	0.17

3.1.1 Functional Requirements

The following are general functional requirements of the G&N subsystem. The requirements in the following sections which are defined by AGC programming will be included in detail in the G&N Systems Operations Plans.

- a. The primary attitude reference for spacecraft guidance and control, including the means to update this inertial reference manually with star sightings.
- b. The primary guidance and navigation capability for all spacecraft thrusting and attitude maneuvers under control of CSM propulsion units.
- c. A self-contained optics-inertial navigation capability which will be the primary navigation data source during lunar orbit and a





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self-contained optical sextant for measuring angles between celestial bodies to provide backup navigation during cislunar phases.

- d. Displays and controls required to operate the on-board G&N equipment and to indicate status thereof.
- e. Provide spacecraft state vector and G&N status data to the telemetry system.
- f. Launch vehicle G&N monitoring to support the Emergency Detection Subsystem (EDS) function.
- g. Discrete signals as required to support the mission programmers on unmanned flights.
- h. Means of generating Service Propulsion System (SPS) on-off command during the primary CSM G&N mode.
- i. Display on Display and Keyboard Unit (DSKY) selected parameters required by astronauts in various G&N operations.
- j. Provide synchronizing 1024KC pulse to the Central Timing Equipment.
- k. An optical backup means of SCS attitude alignment and manual abort steering reference using visual stars for direction references.

#### 3.1.1.1 Pre-Launch

- a. Align and hold attitude reference automatically using an external target for initial optical azimuth alignment and gyro compass check.
- b. Provide attitude and attitude error signals to Flight Director Attitude Indicator (FDAI) for gross check on alignment.

#### 3.1.1.2 S-1 Boost

- a. Compute position and velocity using accelerometer data.
- b. Display Boost Monitor parameters on DSKY.
- c. Drive CDU's with S-I nominal pitch program so that FDAI attitude error meters indicate boost vehicle attitude error.
- d. Provide total attitude signals for display on the FDAI.



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### 3.1.1.3 S-IVB Boost Into Earth Orbit

- a. Compute position and velocity using accelerometer data.
- b. Display Boost Monitor parameters on DSKY.
- c. Provide total attitude signals for display on the FDAI.
- d. Provide the capability to drive the attitude error needles on the FDAI.

### 3.1.1.4 Abort From S-IVB Boost

Two abort modes shall be implemented by the G&N System:

- a. Guide CSM to earth orbit using Service Propulsion System (SPS) thrust.
- b. Guide the CM to a selected recovery area using SPS thrust and CM lift vector control and provide total attitude signals for display on the FDAI.

The Apollo Guidance Computer (AGC) shall have the capability of being programmed to execute a particular abort mode depending on the time it receives the ABORT command.

### 3.1.1.5 Earth Orbit

- a. Determine that a suitable orbit has been attained.
- b. Maintain best estimate of position and velocity (Orbit Ephemeris).
- c. Update best estimate of position and velocity on basis of navigation data from:
  1. Low orbit landmark tracking
  2. Manned Space Flight Net (MSFN) tracking via UPLINK
  3. Inertial Measurement Unit (IMU) acceleration data during thrusting phases.
- d. Provide an inertial reference for attitude control of the CSM.
- e. Display appropriate G&N parameters on DSKY.



CON [REDACTED]

- f. Provide attitude error signals for display on FDAI when the G&N system is in control or providing commanded maneuvers.
- g. Provide total attitude signals for display on the FDAI.
- h. Compute abort maneuvers.
- i. Initiate program to guide abort on command from astronaut.
- j. Determine initial conditions for trans-lunar injection.
- k. Initiate program to monitor trans-lunar injection.

#### 3.1.1.6 Earth Orbit Abort

Guide and control the CM through safe entry and to selected landing site using SPS thrust and CM lift vector control.

An abort from earth orbit shall be selectable for minimum time or desired landing site.

#### 3.1.1.7 Trans-Lunar Injection

- a. Compute position and velocity from accelerometer data.
- b. Display monitor parameters on DSKY.
- c. Initiate program to guide abort on command from astronaut.
- d. Provide the capability to drive the attitude error needles on the FDAI.
- e. Provide total attitude signals for display on the FDAI.

#### 3.1.1.8 Trans-Lunar Injection Abort

Guide CSM to trans-earth abort trajectory using SPS thrust on astronaut command. Aborts from trans-lunar injection shall be selectable for minimum time or desired landing site.

#### 3.1.1.9 Trans-Lunar Coast

- a. Determine that a suitable trans-lunar trajectory has been attained.
- b. Maintain best estimate of position and velocity. Update best estimate of position and velocity on basis of navigation data from:



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1. Star-landmark measurements
  2. MSFN tracking via UPLINK
  3. Star lunar horizon measurements.
- c. Determine initial conditions for midcourse corrections and lunar orbit insertion.
  - d. During times of IMU operation, provide inertial reference for spacecraft attitude control. The IMU reference will be established and updated from star-sighting data.
  - e. Control mid-course corrections to achieve proper initial conditions for lunar orbit insertion.
  - f. Display appropriate G&N data on DSKY.
  - g. During times of IMU operation, provide attitude and attitude error signals for display on the FDAI.
  - h. Compute abort trajectories.
  - i. Initiate abort program to guide abort on command from astronaut.
  - j. Initiate program to control lunar orbit insertion.

#### 3.1.1.10 Trans-Lunar Coast Abort

Guide the CSM to trans-earth trajectory using SPS thrust on astronaut command.

Abort from trans-lunar coast shall be selectable for minimum time or a desired landing site.

#### 3.1.1.11 Lunar Orbit Insertion

- a. Compute position and velocity using accelerometer data.
- b. Guide the Spacecraft into lunar orbit using SPS thrust.
- c. Display appropriate G&N parameters on DSKY.
- d. Provide attitude and attitude error signals for display on the FDAI.
- e. Initiate program to guide abort on ABORT command from astronaut.



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### 3.1.1.12 Lunar Orbit Insertion Abort

- a. Guide the Spacecraft to lunar parking orbit of acceptable elements for transearth injections.
- b. Guide the Spacecraft to direct abort to trans-earth trajectory.

Mode a. above shall be executed by an immediate or delayed thrust cutoff of the SPS. Mode b. above shall be accomplished by immediate thrust cut-off, reorientation of the spacecraft and SPS thrust to inject to a trans-earth trajectory.

### 3.1.1.13 Lunar Orbit

- a. Determine that a suitable orbit has been attained.
- b. Maintain best estimate of position and velocity (Orbit-Ephemeris).

Update best estimate of position and velocity on basis of navigation data from:

1. Low orbit landmark tracking
  2. MSFN tracking via UPLINK
  3. Star Horizon measurements
  4. Period measurements.
  5. IMU accelerometer data during thrusting phases.
  6. Star Occultation measurements.
- c. Determine initial conditions for trans-earth injection.
  - d. During time of IMU operation, provide inertial reference for attitude control of the CSM. The IMU reference will be updated from starsighting data.
  - e. Compute trans-earth trajectories.
  - f. Initiate program to control trans-earth injection.
  - g. Display appropriate G&N parameters on DSKY.



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- h. During time of IMU operation, provide attitude and attitude error signals for display on the FDAI.

#### 3.1.1.14 Trans-Earth Injection

- a. Compute position and velocity using accelerometer data.
- b. Guide CSM to trans-earth trajectory using SPS thrust.
- c. Display appropriate G&N parameters on DSKY.
- d. Provide attitude and attitude error signals for display on the FDAI.

#### 3.1.1.15 Trans-Earth Coast

- a. Determine that a suitable trans-earth trajectory has been attained.
- b. Maintain best estimate of position and velocity. Update best estimate of position and velocity on basis of navigation data from:
  - 1. Star-landmark measurements.
  - 2. MSFN tracking via UPLINK.
  - 3. Star-lunar horizon measurements.
- c. Determine initial conditions for midcourse corrections and entry.
- d. During times of IMU operation provide inertial reference for CSM attitude control. The IMU reference will be established and updated from star-sighting data.
- e. Control midcourse corrections to achieve proper initial conditions for entry.
- f. Display appropriate G&N data on DSKY.
- g. Initiate program for entry guidance.
- h. During times of IMU operation provide attitude and attitude error signals for display on the FDAI.

#### 3.1.1.16 Entry

- a. Compute position and velocity using accelerometer data and when available MSFN tracking data via up-link.



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- b. Display appropriate G&N parameters on DSKY.
- c. Guide CM to landing site using lift vector control.
- d. Provide attitude and attitude error signals for display on the FDAI.
- e. Display attitude error for manual lift vector control.

### 3.1.2 Operability

3.1.2.1 Reliability - The mission success reliability apportionment for the overall G&N Subsystem for a simulated 10.6 day LOR mission as defined in Section 3.1 of this specification shall be .9885 for an equivalent flight time of 105 hrs. This results in a G&N Subsystem operating time of 21 hours except for the Sextant which will operate for only 11 hours.

### 3.1.2.2 Maintainability

#### 3.1.2.2.1 Maintenance

Equipment arrangements, accessibility, and interchangeability features that allow efficient preflight servicing and maintenance shall be given full consideration. Design considerations shall also include efficient mission scrub and recycle procedures. In-flight maintenance shall not be performed on the G&N subsystem.



CON [REDACTED]

### 3.1.2.2.2 Maintenance Concept

Field maintenance of the G&N subsystem shall be performed as follows:

- a. For airframe electrical/electronic equipment (either installed or on the bench), checkout and replacement shall be at the integral package (Black box) level. A "black box" is defined as a combination of factory replaceable units which are contained within a physical package, and which is removable from the CSM as an integral unit.
- b. For non-electrical/electronic equipment (either installed or on the bench), checkout and replacement shall be at the lowest replaceable serialized unit level, which includes only those parts which are removable as integral units from the G&N subsystem.

### 3.1.2.3 Useful Life

#### 3.1.2.3.1 Service Life

The service life of the G&N Subsystem when exposed to the environment and mission specified elsewhere in this specification shall not be less than 336 flight hours plus 1664 hrs under ground checkout and pre-launch conditions.

#### 3.1.2.3.2 Storage Life - Not Applicable

#### 3.1.2.4 Natural Environment

The natural ground and flight environments in which the G&N Subsystem must perform in accordance with regulations specified elsewhere in this specification are defined in ICD MH01-01248-416.

#### 3.1.2.5 Transportability

##### 3.1.2.5.1 Ground Handling and Transportability

Full design recognition shall be given to the durability requirements of G&N equipment during preflight preparation. Wherever possible, the equipment shall be designed to be transported by common carrier with a minimum of protection. Special packaging and transportation methods shall be as required to prevent subsystem penalties.





### 3.1.2.6 Human Performance

#### 3.1.2.6.1 Flight Crew

The CSM flight crew shall consist of three men.

##### 3.1.2.6.1.1 Crew Participation

The flight crew shall have the capability to control the G&N subsystem throughout all flight modes. The flight crew shall participate in navigation, control, monitoring, and observation as required. Status of subsystem shall be displayed for crew monitoring, failure detection and operational mode selection. The G&N subsystem shall be designed so that a single crewman will be able to perform all tasks essential to return the CSM in case of emergency.

##### 3.1.2.6.1.2 Abort Initiation

Provisions shall be made for crew initiation of all abort modes. Initiation of abort modes by automatic subsystems shall be provided only when necessary to insure crew safety.

### 3.1.2.7 Safety

#### 3.1.2.7.1 Hazard Proofing

The design of the G&N subsystem and support equipment shall minimize the hazard of fire, explosion and toxicity to the crew, launch area personnel and facilities. The hazards to be avoided include accumulation of leakage of combustible gases, the hazard of spark on ignition sources including static electricity discharge.

#### 3.1.2.7.2 Equipment

Design of equipment shall be in accordance with MSFC 10M01071, during any part of the mission operation. Where practicable, the various components shall be of explosion-proof construction.

#### 3.1.2.7.3 Fail Safe

Subsystem or component failure shall not propagate sequentially; that is, design shall "fail safe."



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### 3.1.2.8 Induced Environment

The induced ground and flight environments in which the G&N Subsystem must perform in accordance with regulations specified elsewhere in this specification are defined in ICD MH01-01248-416.

### 3.1.3 Performance Requirements

The G&N Subsystem shall accomplish the G&N functions specified herein within the  $\Delta V$  budget limitations given in Table I, when the spacecraft, MSFN, and Launch Vehicle perform within tolerances specified below.

#### 3.1.3.1 Guidance and Navigation Requirements

The G&N Subsystem shall have a self contained capability to perform all Navigation functions beyond Earth Orbit Insertion and all Guidance functions beyond trans-lunar injection. Attitude and SPS maneuver fuel constraints are reflected in the definition of primary G&N responsibilities in the following paragraphs.

##### 3.1.3.1.1 Alignment

During times of IMU operation, the G&N equipment shall provide an inertial reference for attitude control of the S/C. Prior to boost, the IMU will be alined to a  $1\sigma$  accuracy of .25 mr vertical and 2.5 mr in azimuth.

For any time in coasting flight, while the IMU is operating, the uncertainty in the inertial attitude of the navigation base shall be no more than 3.85 mr (0.22 deg) one sigma about each axis up to two hours after the last IMU alignment.

The G&N system shall be capable of SCT manual or servo controlled alignment of the IMU with respect to inertial coordinates with an uncertainty not greater than 0.66 mr (1 Sigma) in each axis. The SCT shall be capable of determining the attitude of the Navigation Base with respect to inertial coordinates utilizing the telescope panel angle counters and the SCT in the manual mode with an accuracy of 0.65 mr. ( $1\sigma$ ) about each axis at the time of "Mach" by the astronaut.

Each IMU alinement requires vehicle orientation to acquire two stars. During earth orbit the maneuver required is a roll of 120 deg. maximum at a rate 0.5 deg/second starting from an attitude with +Z axis down along local vertical. During other flight phases each maneuver is considered to be a new random attitude at maximum rate of .2 deg/sec for translunar and transearth and .5 deg/sec for lunar orbit.

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At least 8 minutes will be available for SCS initialization following the S/C alinement maneuver which aligns the thrust axis to a desired  $\Delta V$  and prior to ullage.

### 3.1.3.1.2 Boost

The boost phase is defined as existing from pad liftoff to the end of the powered phase for earth orbit insertion. During normal Boost, the Space Vehicle shall be guided by the Launch Vehicle Guidance System. The S/C and G&N system shall monitor during Boost and shall function as specified if any of following contingencies occur.

- a. Atmospheric Abort - After Launch Escape System (LES) separation, the G&N shall provide commands to the SPS and SCS such that the CM can be returned safely to earth.
- b. Extra-Atmospheric Abort - The G&N shall provide commands to the SPS and SCS such that the CM can assume a safe trajectory and orientation for reentry.
- c. Abort Into Orbit - The G&N shall provide commands to the SPS and SCS such that an earth orbit with a perigee above 90 nautical miles and an apogee below 450 nautical miles can be achieved.

### 3.1.3.1.3 Earth Orbit

Primary navigation in Earth Orbit is provided by MSFN. Primary guidance and control is provided by the Lunar Vehicle Guidance and Control Systems.

During earth orbit, the G&N Subsystem shall be capable of providing an inertial reference for the S/C. This reference will be updated from star-sighting data once per orbit and a maximum of 3 times. In programming attitude maneuvers, the Launch Vehicle Guidance and Control Systems will take into consideration the middle gimbal limitations of the G&N Subsystem of  $\pm 60^\circ$ .

Each navigation acquisition requires a roll maneuver of the S/C SIVB about the earth oriented attitude (S/C +Z-axis down along local vertical) at a maximum rate of .5 deg/sec. The navigation acquisitions will be landmarks. Each navigation acquisition and sighting shall consume no more than 5 minutes. If yaw maneuvers are required, the SIVB/S/C shall be limited to yaw maneuvers not be exceed  $45^\circ + 15^\circ$  overshoot. During navigation sighting periods, the Launch Vehicle will control a Space Vehicle attitude deadband of not more than 1 degree in pitch, yaw and roll and a deadband rate of less than .05<sup>o</sup>/sec in all those axes.



The APS propellant allotted for G&N maneuvers during the earth orbit phase shall be in accordance with Table II.

#### 3.1.3.1.4 Translunar Coast

MSFN will be the primary source of Navigation data during Translunar Coast. On board Optical Navigation will provide a backup means of Navigation. During translunar coast, the IMU will be aligned not more than 4 times and no more than 3 midcourse corrections will be made with the SPS. The time required for each midcourse correction, including IMU alignment, shall be less than 40 minutes. The initial condition errors, the translunar injection errors, and the Guidance errors will be such that the total of the 3 midcourse corrections shall not exceed the amounts shown in Table I assuming updating by MSFN as defined in Table III. The RCS shall provide no more than 2 corrections whose sum shall not exceed the value shown in Table I. The RCS propellant allotted for G&N attitude maneuvers during the translunar phase are based on executing these maneuvers at an angular rate of 0.2 deg./sec.

#### 3.1.3.1.5 Lunar Orbit Insertion

During lunar orbit insertion, the G&N shall use no more than the value shown in Table I over the ideal velocity increment.

#### 3.1.3.1.6 Lunar Orbit

Primary Navigation in Lunar Orbit will be by the G&N Subsystem with backup capability provided by MSFN. During lunar orbit, the IMU will be aligned no more than 10 times and a maximum of 20 optical sightings will be made. The time required for a sighting shall not exceed 5 minutes. A maximum of 30 spacecraft reorientations will be required. A minimum residual angular rate of the S/C of 5 arc min/sec shall be maintainable by the control system and astronaut in the minimum impulse mode. The RCS propellant allotted for G&N maneuvers during lunar orbit are based on executing these maneuvers at an angular rate of 0.5 deg./sec.

#### 3.1.3.1.7 Transearch Injection

During trans-earth injection, the G&N system shall not use more than the value shown in Table I over the ideal velocity increment. The steering law implemented during transearch injection should provide a constant S/C inertial attitude orientation during this maneuver.



The  $1\sigma$  initial position and velocity uncertainties just prior to TEI shall be equal to or less than the following:

$$E\Delta R = 3000 \text{ ft.}, E\Delta N = 3000 \text{ ft.}, E\Delta T = 3000 \text{ ft.}$$

$$E\Delta R = 1.7 \text{ ft/sec}, E\Delta N = 1.3 \text{ ft/sec}, E\Delta T = 1.3 \text{ ft/sec.}$$

### 3.1.3.1.8 Transearch Coast

Primary Navigation during Transearch Coast will be provided by MSFN with backup capability provided by the G&N Optical Subsystem. During the transearch phase, the IMU will be aligned not more than 4 times and not more than 3 midcourse corrections will be made with the SPS. Each midcourse correction, including IMU alignment shall not take more than 40 minutes.

The initial condition errors, the transearch injection errors and the Guidance errors will be such that the total of 3 midcourse corrections shall not exceed the value shown in Table I. The RCS shall provide for a maximum of 3 vernier corrections not to exceed the value shown in Table I.

The last IMU alignment shall not be made less than 35 minutes from the entry interface.

A maximum of 50 star landmarks navigational measurements will be sufficient to satisfy the entry corridor requirement, if the backup optical navigation is used. No more than 33 S/C attitude changes will be required. Each maneuver is considered to be to a new random attitude. The time required to sight a star and landmark shall not exceed 5 minutes.

The RCS propellant allotted for G&N attitude maneuvers during the transearch phase are based on execution of these maneuvers at an angular rate of 0.2 deg/sec.

### 3.1.3.1.9 Entry

Entry as defined in this specification begins at 400,000 ft. and terminates at parachute deployment. The 3 sigma entry corridor (depth vacuum perigee variation) due to navigation accuracy and midcourse execution errors will be no greater than 20 nautical miles. The  $1\sigma$  inertial condition uncertainties (given with respect to local vertical coordinates at start of entry) shall be less than:

$$E\Delta R = 4000 \text{ ft.}$$

$$E\Delta T = 6000 \text{ ft.}$$

$$E\Delta N = 3000 \text{ ft.}$$



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$$E\dot{\Delta R} = 8 \text{ fps.}$$

$$E\dot{\Delta T} = 3 \text{ fps.}$$

$$E\dot{\Delta N} = 3 \text{ fps.}$$

The G&N Subsystem shall guide the S/C such that a deceleration greater than 10 g's shall not be encountered during normal operation except during boost abort where the maximum deceleration is limited to 15 g's. The entry transit time will be a maximum of 30 min. The required entry termination accuracy for entry ranging requirement of 1500 nautical miles minimum and 2500 nautical miles maximum will be achieved for a lift to drag ratio of not less than 0.3 at velocities greater than 25,000 fps. During the entry phase, the G&N Subsystem shall display range-to-go on the DSKY. The entry termination accuracy shall be 10 nautical miles CEP.

### 3.1.3.2 Spacecraft Control Requirements

#### 3.1.3.2.1 Attitude Maneuver

The G&N equipment shall provide an attitude reference used for vehicle attitude control. Attitude error signals are provided by the G&N to the SCS for vehicle control. The G&N Subsystem shall have the capability of limiting by computer program the attitude error commands it transmits to the SCS in different phases.

#### 3.1.3.2.2 SPS Control

ON-OFF SPS commands will be provided for all SPS thrusting periods. Steering error signals are provided to the SCS. Capability shall be provided within the G&N system for executing timed  $\Delta V$  maneuvers in order to make optimum use of the inherent SPS minimum impulse. The G&N equipment shall have the capability of commanding the pre  $\Delta V$  spacecraft attitude and taking into account the SPS gimbal trim corrections automatically for all CSM burning periods. The G&N equipment shall accept manual SPS engine gimbal trim angles through the DSKY prior to ignition.

#### 3.1.3.2.3 Minimum Impulse

The G&N shall provide discrete inputs from the G&N minimum impulse controller to the SCS for generating discrete pulses by the SM RCS engines. The residual S/C rates resulting from these minimum impulses will not exceed 3 min/sec. for midcourse and 5 min/sec for lunar orbit about any axis.



#### 3.1.3.2.4 Display

The G&N equipment will supply output signals for the purpose of driving attitude and attitude error displays. It will also provide a decimal attitude display on the DSKY as commanded.

The IMU gimbal angles will be available as analog signals for purposes of display. During free fall, the accuracy of these signals will be  $\pm 0.25$  deg.  $1\sigma$  plus the inertial reference error as specified in paragraph 3.1.3.1.1.

#### 3.1.3.2.5 Entry

In entry, after .05 g switching, the maximum roll rate achieved by the Spacecraft about the stability roll axis shall be from  $\pm(16.5$  to  $25.7)$  deg/sec. Prior to .05 G the maximum rate achieved by the S/C about the body axes shall be  $\pm(15.0$  to  $20.8)$  deg/sec for roll and  $\pm(5\pm 1)$  deg/sec for pitch and yaw.

Automatic G&N entry capability shall be provided using either single or dual CM-RCS mode.

### 3.2 Interface Requirements

The CSM-GFE G&N subsystem interface will be as delineated in applicable ICD's referenced in 6.1 and in accordance with the terms described therein.

### 3.3 Design and Construction

#### 3.3.1 General Design Features

The design features and physical characteristics of the major assembling of the equipment shall conform with the requirements of the following subparagraphs.

##### 3.3.1.1 Navigation Base (NVB)

The navigation base shall be a rigid structure capable of supporting and maintaining the alignment of the IMU, the optical assembly and associated hardware. The navigation base is mounted to the spacecraft structure via three strain isolators.

##### 3.3.1.2 Inertial Measurement Unit (IMU)

The IMU shall sense vehicle attitude and acceleration. The IMU shall consist of three single-degree-of-freedom gyroscopes (IRIG's) and three single-degree-of-freedom accelerometers (PIPA's) on a stable member



is isolated from vehicle orientation by a servo-driven three-degree-of-freedom gimbal system. The IMU shall be mounted in the spacecraft with the outer axis approximately parallel to the CM entry stability axis.

#### 3.3.1.3 Optical Assembly

The optical assembly shall consist of a Sextant (SXT), a Scanning Telescope (SCT), eyepieces, and a bellows assembly.

##### a. Sextant (SXT)

The sextant shall be a two line-of-sight superimposed image, 1.8 degree-of-field, 28X magnifying power measuring instrument to provide measurements of the angle between identified stars and navigation reference features of the earth or moon.

##### b. Scanning Telescope (SCT)

The scanning telescope shall be a single line-of-sight, 60 degree field-of-view, unity power, articulated telescope used for general viewing, earth or lunar orbital landmark navigation sighting, as an acquisition aid for the sextant, and to provide backup alignment of the SCS.

##### c. Bellow Assembly

The bellows assembly allows movement of the portion of the optics external to the S/C while maintaining capsule seal.

#### 3.3.1.4 Power and Servo Assembly (PSA)

The PSA shall consist of the support electronics, power supplies, IMU and Optical Assembly servo amplifier, IMU temperature control, and gyro and accelerometer pulse torquing modules. The PSA shall be made up of modules which plug into the PSA header assembly.

#### 3.3.1.5 Apollo Guidance Computer (AGC)

The AGC shall be a general purpose computer with special capability for organizing simultaneous real time operations and control data processing for guidance and navigation. Flexibility shall be obtained by the use of fast basic instructions and slower but memory conserving, interpretive routines. The basic fixed memory shall be 24,576 16-bit words (including parity). The erasable memory shall be 1024 words. The AGC has input and output interfaces with the IMU, Optical Subsystem, PCM Telemetry,





Digital Up-Link, spacecraft, ACE, and the astronaut. Two parallel operating display and keyboard (DSKY) units shall be provided with the computer.

### 3.3.1.6 Display and Keyboard Unit (DSKY)

The DSKY shall provide the operating controls and display for the AGC. The DSKY shall consist of a keyboard for entering instructions and data into the computer and a multidigital numerical display of program mode and data. It shall also display alarm indications based upon detected malfunctions in the computer itself or in the rest of the guidance and navigation equipment. One DSKY will be located in the lower equipment bay of the command module at the navigation station, operating in parallel with a similar unit located on the main panel between the left and center couches.

### 3.3.1.7 Display and Controls (D&C)

The D&C shall consist of operating controls and status lights in the Navigator lower equipment bay, associated with the IMU and Optical Assembly.

### 3.3.1.8 Coupling Display Units (CDU's)

The CDU is a conversion device for digitizing resolver outputs, and for converting pulse train AGC outputs to analog voltages.

- a. There are five CDU's. They are used to digitize the following shaft angle resolver outputs:

- (1) IMU gimbal angles (3)
- (2) Optics shaft angles (2)

- b. The output sections of the CDU's are used to convert the following AGC outputs to analog form:

- (1) IMU a line (3)
- (2) Attitude errors (3)
- (3) Optics drive (2)

### 3.3.2 Design Criteria

#### 3.3.2.1. General Design Analysis Criteria

The G&N Subsystem shall be designed capable of functioning at limit load conditions when exposed to the environments delineated in ICD MH01-01248-416.



### 3.3.2.2 Performance Margins

#### 3.3.2.2.1 Multiple Failure

The decision to design for single or multiple failures shall be based on the expected frequency of occurrence as it affects subsystem reliability and safety.

#### 3.3.2.2.2 Design Margins

The G&N subsystem shall be designed to zero or positive margins of safety.

#### 3.3.2.2.3 Attitude Constraints

Attitude Control is permissible to eliminate subsystem constraints which would impose excessive subsystem requirements subject to attitude maneuver fuel and other spacecraft attitude requirements.

#### 3.3.2.2.2.4 Thermal Control

Thermal design of the G&N subsystem shall normally use passive means of thermal control, such as insulation, coatings, and control of thermal resistances. Full cognizance shall be taken of thermodynamic considerations in establishing conceptual design and selection of working fluids and materials for the subsystem such that the maximum allowable temperature range consistent with other design considerations shall be provided. Thermal design may incorporate the application of cold plates subject to further negotiation between contractor(s).

### 3.3.3 Weights

The weights of the major assemblies of the G&N equipment shall not exceed those specified in ICD MH01-01256-416. The total weight of the G&N equipment, including all assemblies, components and parts shall not exceed 430 pounds.

### 3.3.4 Selection of Specifications and Processes

Not applicable.

### 3.3.5 Materials, Parts and Processes

#### 3.3.5.1 Flammable Materials

Materials that may support combustion or are capable of producing flammable gases (which in addition to other additives to the environment, may



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reach a flammable concentration) will not be used in areas where the environment or conditions are such that combustion would take place.

### 3.3.5.2 Toxic Materials

Unless specific written approval is obtained from the NASA, materials that produce toxic effects or noxious substances when exposed to CM interior conditions shall not be used.

### 3.3.5.3 Unstable Materials

Materials that emit or deposit corrosive substances, induce corrosion, or produce electrical leakage paths within an assembly shall be avoided or protective measures incorporated.

### 3.3.6 Standard Materials, Parts, and Processes

#### 3.3.6.1 Soldering Requirements

The soldering of electrical connectors shall be in accordance with specification MSFC-PROC-158, as amended by MSC-ASPO-S-5.

#### 3.3.7 Moisture and Fungus Resistance

Fungus-inert materials shall be used to the greatest extent practicable. Fungus-nutrient materials may be used if properly treated to prevent fungus growth for a period of time, dependent upon their use within the CSM. When used, fungus-nutrient materials shall be hermetically sealed or treated for fungus and shall not adversely effect equipment performance or service life.

#### 3.3.8 Corrosion of Metal Parts

All metals shall be of corrosive-resistant type or shall be suitably protected to resist corrosion during normal service life. Gold, silver, platinum, nickel, chromium, rhodium, palladium, titanium cobalt, corrosion-resistant steel, tin, lead-tin alloys, tin alloys, Alclad aluminum, or sufficiently thick platings of these metals may be used without additional protection or treatment.

##### 3.3.8.1 Dissimilar Metals

Unless suitably protected or coated to prevent electrolytic corrosion, dissimilar metals, as defined in Standard MS33586, shall not be used in intimate contact.



### 3.3.8.2 Electrical Conductivity

Materials used in electronics or electrical connections shall have such characteristics that, during specified environmental conditions, there shall be no adverse effect upon the conductivity of the connections.

### 3.3.9 Interchangeability and Replaceability

Not applicable.

### 3.3.10 Workmanship

Not applicable.

### 3.3.11 Electromagnetic Interference

The equipment shall not generate electromagnetic interference in excess of, or be susceptible to electromagnetic interference within, the allowable limits of MIL-I-26600/MSFC-EMI-10.

Bonding requirements, wire treatment, and signal classification shall be provided in accordance with Specification MIL-I-26600/MSFC-EMI-10 and supplemented as required by applicable ICD's.

4.0 QUALITY ASSURANCE PROVISIONS - Not Applicable.

5.0 PREPARATION FOR DELIVERY - Not Applicable.



## 6.0 NOTES

6.1 Interface Control Documents (ICD's)

<u>TITLE</u>	<u>NUMBER</u>
Outputs-AGC to S/C Control Programmer	MH01-01200-216
G&N Nav. Base & Optica Assy. to CM Structure	MH01-01201-216
Apollo Guidance Computer to S/C LEB Structure	MH01-01202-116
End Connector and PSA to CM LEB Structure	MH01-01203-116
G&N Controls and Displays to CM LEB Structure	MH01-01204-116
AGC DSKY TO CM Main Display Console	MH01-01205-116
G&N Wire Routing to LEB	MH01-01206-116
Coolant Lines, and Connections to G&N	MH01-01208-116
G&N Exterior and Interior Leakage	MH01-01211-416
G&N Installation Handling Equipment Attach Points	MH01-01213-100
S/C to Optical Range in 290	MH01-01214-100
Optical Field of View Installed	MH01-01215-116
G&N Loose Equipment Stowage & Eyepiece Stowage Unit	MH01-01216-116
Intercom. AGC to MDP AGC DSKY	MH01-01220-216
Attitude Error Signals	MH01-01224-216
Total Attitude Signals	MH01-01225-216
Central Time Equipment Sync. Pulse	MH01-01226-216
Electrical Input Power	MH01-01227-216
Data Transmission to Operational PCM Telemetry Equipment	MH01-01228-216
ICTC and PSA Adapter Module to SID Cable Set	MH01-01235-200
ACE Uplink/Spacecraft Digital Up-Data Link to AGC	MH01-01236-200
G&N Attitude Hold	MH01-01237-216
Engine On-Off Signal to SCS	MH01-01238-216
S/C Polarity Test Fixture	MH01-01241-100
G&N Condition and Display Lights	MH01-01242-216
Color Coding G&N C&D's	MH01-01246-416
G&N Thermal Requirements	MH01-01249-416
G&N Installation Procedure	MH01-01250-416
Materials Compatibility List G&N Equipment	MH01-01251-416



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<u>TITLE</u>	<u>NUMBER</u>
Minimum Impulse Controller	MH01-01257-416
MIT Optical GSE to SID Optical Alignment Support	MH01-01264-100
Electrical Power to MIT Optical GSE	MH01-01276-200
PSA Adapter Module to LEB Structure	MH01-01277-116
Launch Vehicle to G&N Interface	MH01-01278-216
SCS Mode Signal to AGC	MH01-01279-216
Vehicle Separation Signals to AGC	MH01-01280-216
Lifting Temp. Controller to GSE Hatch	MH01-01281-100
Electrical Power to LTC	MH01-01282-200
PSA Adapter Module Hardline Downlink	MH01-01283-200
G&N Signal Conditioner to S/C Flight	MH01-01287-216
Qualification Tape Recorder	
G&N/ACE Signal Conditioners	MH01-01290-200



TABLE I. SERVICE PROPULSION AND REACTION CONTROL SUBSYSTEMS  $\Delta V$  BUDGET

TRANSLUNAR

Mission Phase	Minimum Possible	Flexi- bility	Patch Conic Calibration Bias		Guidance		Weight Reporting
			Mean	$3\sigma$	Mean	$3\sigma$	
Midcourse*	—	—	—	—	68	(91)	68
Lunar Orbit Inertion	2600	800	35	(15)	10	(20)	3445
RSS of $3\sigma$ Values							(94)
Total							3607

TRANSEARTH

Mission Phase	Minimum Possible	Flexi- bility	Patch Conic Calibration Bias		Guidance		Weight Reporting
			Mean	$3\sigma$	Mean	$3\sigma$	
Transearth Injection	2600	400	85	(15)	3	--	3088
Midcourse**	--	--	--	--	40	(60)	40
RSS of $3\sigma$ Values							(62)
Total							3190

\*Midcourse allowance based on 2 ft/sec  $\Delta V$  available in RCS budget for Vernier correction.

\*\*Midcourse allowance based on 6 fps  $\Delta V$  available in the RCS for vernier corrections.

Table I. Service Module Service Propulsion Subsystem  $\Delta V$  Budget (ft./sec.)



TABLE II. LAUNCH VEHICLE APS FUEL BUDGET

<u>FUNCTION</u>	<u>APS FUEL (Lbs.)</u>
Attitude Stabilization for $4\frac{1}{2}$ hrs. in Earth Orbit with $\leq 1^\circ$ deadband, $\perp$ to local vertical.	30.7
21 roll maneuvers at $0.5^\circ$ sec.	<u>27.3</u>
Total	58.0





TABLE III. MSFN PERFORMANCE CAPABILITIES

Measurement	Noise	Bias	Sample Rate	Station	Location	Bias
Range Rate	.1 ft./sec. (2)	.07 ft./sec. <sup>2</sup>	1/min.	X (up)	Y (east)	Z (north)
Range (1)	60 ft.	120 ft.	1/hr.	145 ft.	274 ft.	252 ft.

Assumptions

$$\sigma_u \text{ (earth)} = 106 \times 10^9 \text{ ft.}^3/\text{sec.}^2 \quad \sigma_u \text{ (moon)} = .6 \times 10^9 \text{ ft.}^3/\text{sec.}^2$$

(1) Range measurements were taken from CNB, GST, MAD, and CRO.

(2) The  $\hat{h}$  noise value is for 1 sec. sampling rate.

(3) Averaged for all stations used.