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(Unclassified Title)
MASTER END ITEM DETAIL SPECIFICATION
(PRIME EQUIPMENT)
PERFORMANCE / DESIGN
AND
PRODUCT CONFIGURATION
REQUIREMENTS
PART I
MEI NO. 2015000
AIRBORNE GUIDANCE AND NAVIGATION EQUIPMENT - BLOCK II
FOR
APOLLO COMMAND MODULE
SPECIFICATION NO. PS2015000

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MASTER END ITEM DETAIL SPECIFICATION
(PRIME EQUIPMENT)

PERFORMANCE/DESIGN
AND
PRODUCT CONFIGURATION
REQUIREMENTS

PART I

MEI NO. 2015000
AIRBORNE GUIDANCE AND NAVIGATION EQUIPMENT - BLOCK II
FOR
APOLLO COMMAND MODULE
(U)

Submitted by Edward G. Schwarm Date 11/22/65
MIT/IL

Approved by Milton B. Trageser Date 11/22/65
MIT/IL

Approved by M. E. Dell per Ltr. EG26-162-65-852 Date 11/22/65
NASA/MSC

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12/20/65	A	24757	Complete revision as negotiated	WK	A. C. METZGER

Table of Contents

1.0 Scope

This part of this specification establishes the requirements for performance, design, test, and qualifications of one type-model-series of equipment identified as MEI 2015000, Airborne Guidance and Navigation Equipment, Block II, for the Apollo Command Module hereinafter referred to as "equipment". This equipment shall be the primary means of accomplishing command module guidance and control and serve as a backup for command module navigation provided by the Manned Space Flight Network. This equipment shall perform these functions for complete lunar operations and the various maneuvers required at any phase thereof. Requirements for developmental missions (e.g. earth orbit, etc.) are not necessarily a part of this specification and will be covered by additional specifications.

2.0 Applicable Documents

The following documents, of the issue in effect on date of invitation for bids, form a part of this specification to the extent specified herein. In the event of conflict between document referred here and other detail content of Section 3 and 4, the detail requirements of Sections 3 and 4 shall be considered the superseding requirement.

2.1 Project Documents

ND-1002019	Specification for General Marking
ND-1002037	Environmental Qualification Specification for A/B Equipment

2.2 Specifications

MIL-A-8421	General Specification for Air Transportability Requirements
MIL-D-70327	Drawings, Engineering, and Associated Lists
MIL-I-8500	Interchangeability and Replaceability of Component Parts for Aircraft and Missiles
MIL-I-26600	Interference Control Requirements, Aeronautical Equipment

2.3 Standards

MIL-STD-12	Abbreviations for Use on Drawings and in Technical-type Publications
MIL-STD-15-1	Graphic Symbols for Electrical and Electronics Diagrams
MIL-STD-16	Electrical and Electronic Reference Designation

MIL-STD-143	Specifications and Standards, Order of Precedence for the Selection of
MIL-STD-447	Definitions of Interchangeable Substitute and Replacement Items
MS 33586	Metals, Definition of Dissimilar

2.4 Publications

2.4.1 NASA

MSC-ASPO-EMI-10A	Addendum to MIL-I-26600, Interference Control Requirements, Aeronautical Equipment
NPC-200-2	Test Methods for Electronic and Electrical Component Parts
NPC-200-3	Inspection System Provision for Suppliers of Space Materials, Parts, Components, and Services
NPC-250-1	Reliability Program Provisions for Space System Contractors
TBD	Performance and Interface Specification for Apollo Guidance and Navigation System, Block II.

2.4.2 MIT Instrumentation Laboratory

E-1167	MIT Apollo Drawing Standards

2.4.3 North American S&ID

TBD	Preparation Manual, Interface Coordination and Documentation

2.4.4 Grumman Aircraft Engineering Corporation

LED 540-12	Design Reference Mission, Apollo Mission Planning Task Force, 30 October 1964

3.0 System Requirements

3.1 Functions and Modes

The principal function of the CSM Block II Guidance and Navigation System is to control the Apollo Spacecraft trajectory throughout a Lunar Landing Mission. This and other required functions are specified in par. 3.1.1.

The G&N equipment shall be entirely contained within the Command Module and require no assistance or data from sources external to the spacecraft in order to perform its assigned functions. The accuracy requirements in this specification apply to this self-contained mode of operation. The system must, however, be designed to accept navigation data from Earth-based facilities when required by the mission plan to improve guidance accuracy, to reduce spacecraft propellant requirements, or to gain some operational advantage. Navigation data from the Earth shall be accepted either by direct crew input or by means of the Up Data Link. The G&N System shall also take maximum design advantage of the unique visual and managerial capabilities of the flight crew. In this respect the system must be operable by a single crew member in or out of his spacesuit.

System functions are specified here in sufficient detail to govern equipment design. A complete definition of functions including guidance equations, control logic, telemetry and display data, etc., is required to govern G&N operations on any specific mission. This complete definition of functions for a specific mission will be documented in a G&N System Operations Plan and implemented by guidance computer programs, operational procedures, and signal conditioning equipment. System design shall take maximum advantage of the assumption that each G&N System Operations Plan will be essentially complete many months in advance of launch.

3.1.1 Primary Functional Characteristics

3.1.1.1 Prelaunch

a) Prior to launch align and hold attitude reference automatically after an initial visual check to ground azimuth reference target.
b) Provide total attitude to the FDAI for gross check on prelaunch alignment

3.1.1.2 S-I Boost

a) Compute position and velocity using accelerometer data
b) Display Boost Monitor parameters on DSKY and total attitude on FDAI
c) Drive CDUs with S-I nominal pitch program so that FDAI attitude error meters indicate boost vehicle attitude error

3.1.1.3 S-II Boost

a) Compute position and velocity using accelerometer data
b) Display Boost monitor parameters on DSKY and total attitude on DSKY
c) Guide S-II toward Earth Orbit on SPACECRAFT CONTROL command from astronaut
d) Initiate program to guide abort on ABORT command from astronaut
e) Display attitude error on FDAI through LES jettison

3.1.1.4 S-IVB Boost Into Earth Orbit

a) Compute position and velocity using accelerometer data
b) Display Boost Monitor parameters on DSKY and total attitude on DSKY
c) Guide S-IVB into Earth Orbit on SPACECRAFT CONTROL command from astronaut
d) Initiate program to guide abort on ABORT command from astronaut

3.1.1.5 Abort From S-I and S-II Boost

3.1.1.5.1 Abort From S-I and S-II Boost with Launch Escape System (LES)

The GN & C system shall provide the capability for a rapid stable platform alignment to the S/C body axes for a LES abort. This shall be used to provide an attitude reference for entry based upon the initial orientation determined by the pilot using visual references through the window.

3.1.1.5.2 Abort From S-II Boost (After LES Jettison)

The following abort modes can be implemented by the G&N system for failures in the S-II booster stage.

a) Guide CSM to Earth Orbit using S-IVB and SPS thrust
b) Guide CSM and LEM to Earth Orbit using S-IVB thrust
c) Guide CSM to Earth Orbit using SPS thrust
d) Guide CM to selected recovery area using SPS thrust and CM lift vector control

The CMC will be programmed to execute a particular abort mode depending on the time it receives the ABORT command. Abort alternatives require input to the CMC via the DSKY.

3.1.1.6 Abort From S-IVB Boost Into Earth Orbit

Two abort modes can be implemented by the G&N system:

a) Guide CSM to Earth Orbit using SPS thrust
b) Guide CM to selected recovery area using SPS thrust and/or CM lift vector control

The CMC will be programmed to execute a particular abort mode depending on the time it receives the ABORT command. Capability for the astronaut to choose either a) or b) would require input to the CMC via the DSKY.

3.1.1.7 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) MSFN tracking via UPLINK
    3) Star-horizon measurements
    4) IMU acceleration data during thrusting phases including S-IVB ullage and venting
d) Determine Initial Conditions for trans-lunar injection
e) Provide an inertial reference for attitude control of the S/C--IVB. This reference will be up-dated from star-sighting data
f) Initiate program to control trans-lunar injection

g) Display appropriate G&N parameters on DSKY
h) Compute abort trajectories
i) Initiate program to guide abort on command from astronaut

3.1.1.8 Earth Orbit Aborts

Guide CM to selected landing site using SPS thrust and CM lift vector control.

An abort from earth orbit can be either minimum time or landing site-programmed. If time is imperative the abort is such as to provide guidance to enter and land. If the abort is not time critical the abort will be programmed to guide to a selected landing site.

3.1.1.9 Trans-Lunar Injections

3.1.1.9.1 Trans-Lunar Injection (S-IVB Guidance Primary Control)

a) Compute position and velocity from accelerometer data
b) Display boost monitor parameters on DSKY and total attitude on FDAI
c) Initiate program to guide abort on command from astronaut
d) Guide S-IVB--S/C to proper trans-lunar trajectory on SPACECRAFT CONTROL command from astronaut

3.1.1.9.2 Trans-Lunar Injection (G&N Guidance Primary Control)

a) Guide S-IVB--S/C to proper trans-lunar trajectory using S-IVB propulsion
b) Compute position and velocity from accelerometer data
c) Display G&N parameters on DSKY and total attitude and attitude errors on FDAI
d) Initiate program to guide abort on command from astronaut

3.1.1.10 Trans-Lunar Injection Aborts

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

Aborts from trans-lunar injection may be either minimum time or to a selected landing site.

3.1.1.11 Trans-Lunar Coast

a) Determine that a suitable trans-lunar trajectory has been attained
b) Maintain best estimate of position and velocity

c) Update best estimate of position and velocity on basis of navigation data from:
   1) Star-landmark measurements
   2) MSFN tracking via UPLINK
   3) Star-horizon measurements

d) Determine initial conditions for mid-course corrections and lunar orbit insertion

e) During times of IMU operation, provide S/C attitude control. The inertial reference will be established and up-dated from star sighting data.

f) Control mid-course corrections to achieve proper initial conditions for lunar orbit insertion.

g) Display appropriate G&N data on DSKY

h) Compute abort trajectories

i) Initiate abort program to guide abort on command from astronaut

j) Initiate program to control lunar orbit insertion

3.1.1.12 Trans-Lunar Coast Aborts

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

Abort from trans-lunar coast may be either minimum time or to a selected landing site.

3.1.1.13 Lunar Orbit Insertion

a) Compute position and velocity using accelerometer data

b) Guide S/C into lunar orbit using SPS thrust

c) Display G&N parameters on DSKY and attitude and attitude errors on FDAI

d) Initiate program to guide abort on ABORT command from astronaut

3.1.1.14 Lunar Orbit Insertion Aborts

a) Guide S/C to lunar parking orbit of reasonable period for subsequent trans-earth injection

b) Guide S/C to direct abort to trans-earth trajectory

The CMC will be programmed to execute a particular abort mode on receipt of the ABORT Command from the astronaut.

Mode a) above would be executed by an immediate or delayed thrust cutoff of the SPS.

Mode b) above would be accomplished by immediate thrust cut-off, reorientation of the S/C and SPS thrust to inject to a trans-earth trajectory.

3.1.1.15 Lunar Orbit

a) Determine that a suitable orbit has been attained
b) Maintain best estimate of position and velocity (orbit ephemeris)
c) Up-date 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) Star occultation measurements
   5) IMU accelerometer data during thrusting phases such as translation maneuvers
d) Determine initial conditions for trans-earth injection and LEM guidance
e) During time of IMU operation, provide attitude control of the S/C or CSM. The inertial reference will be updated from star-sighting data.
f) Compute trans-earth trajectories
g) Initiate program to control trans-earth injection
h) Display G&N parameters on DSKY and attitude and attitude errors on FDAI
i) Track intended LEM landing point in order to:
   1) Locate landing site in navigation coordinates
   2) For visual monitor
j) Using MSFN and visual sighting data, maintain best estimate of LEM descent coast orbit, lunar surface position and ascent coast orbit.
k) Compute LEM launch time and azimuth for use by LEM abort guidance system.
l) Compute LEM Rendezvous mid-course corrections for transmission to LEM if required.
m) Compute CSM rendezvous mid-course correction. Guide CSM to accomplish rendezvous mid-course corrections if required.
n) Compute LEM terminal rendezvous maneuver for transmission to LEM, if required.
o) Guide CSM to accomplish terminal rendezvous maneuver if such a maneuver is required of the CSM.

Note: Items j-o are contingent upon the ability to visually sight the LEM with the SXT.

3.1.1.16 Trans-Earth Injection

a) Compute position and velocity using accelerometer data
b) Guide CSM to trans-earth trajectory using SPS thrust
c) Display G&N parameters on DSKY and attitude and attitude errors on FDAI

3.1.1.17 Trans-Earth Coast

a) Determine that a suitable trans-earth trajectory has been attained
b) Maintain best estimate of position and velocity
c) Update best estimate of position and velocity on basis of navigation data from:
    1) Star-landmark measurements
    2) MSFN tracking via UPLINK
    3) Star-horizon measurements
d) Determine initial conditions for mid-course corrections and entry
e) During time of IMU operation provide CSM attitude control. The inertial reference will be established and up-dated from star sighting data.
f) Control mid-course corrections to achieve proper initial conditions for entry
g) Display G&N parameters on DSKY and attitude and attitude errors on FDAI
h) Initiate program for entry guidance
i) Accept manual control inputs

3.1.1.18 Entry

a) Compute position and velocity using accelerometer data and MSFN tracking data via UPLINK
b) Display G&N parameters on DSKY and attitude and attitude errors on FDAI
c) Guide CM to landing site using lift vector control
d) Accept manual control inputs
e) Display attitude error for manual lift vector control
f) Provide rate damping in pitch and yaw
g) Command the lift orientation for initial atmosphere penetration compatible with the EMS corridor verification.
h) Control the entry trajectory to be within critical flight limits defined by the thermal protection subsystem design, structural and crew load tolerance, subsystem lift times, entry range limits, and trajectory monitoring requirements defined by the EMS.

3.1.2 System Operating Modes

Function and Mode Control will be accomplished by means of astronaut control through the display and control panels and the DSKY or by ground control through the MSFN Uplink.

3.1.2.1 Prelaunch Alignment Mode

The purpose of this mode is to align the stable member of the Inertial Measurement Unit in preparation for the Boost Monitor mode. The stable member Z axis will be vertical with the X axis oriented in the direction of the launch azimuth.

The prelaunch alignment mode will be accomplished by two phases: 1) vertical erection and 2) gyrocompassing. Vertical erection is accomplished by first coarse alignment of the IMU by the computer utilizing either coarse align values keyed in by the operator or by values taken from memory. The IMU will then be fine aligned through the computer by using the X and Y PIPA outputs to generate torque signals which will be applied to the IRIG's to level the platform.

The gyrocompassing will be accomplished through the computer pulse torquing the Z IRIG as a function of the resolved X and Y PIPA outputs.

3.1.2.2 Boost Monitor Mode

The Boost Monitor Mode of the G&N System will monitor spacecraft guidance during the S-I, S-II, and S-IVB thrusting phases. Spacecraft attitude and acceleration will be used to compute the boost trajectory. This trajectory data will be compared with a pre-programmed trajectory and the difference shown on visual displays. The computer will also compute and update an abort-re-entry program to be utilized at the command of the astronaut.

Velocity increments and gimbal angles are fed to the CMC from the inertially referenced IMU. These gimbal angles are sent to the SCS and displayed by the FDAI ball. The CMC will compute attitude errors from the difference between the present gimbal angles and the desired gimbal angles which are specified by the pre-programmed pitch program. During S-I thrusting these errors will be sent to the SCS and displayed by the FDAI error needles. During the S-II and S-IVB thrusting these attitude error and also engine cutoff signals will be sent to the S-II and S-IVB computers at the command of the astronaut. Selected parameters (not defined) will be displayed by the CMC on the DSKY.

3.1.2.3 Integrate Equations of Motion

The purpose of this mode is to compute navigational and guidance parameters. During free fall phases the data will be computed in navigational coordinates using inputs from the OSS and MSFN. During applied forces the data will be computed in inertial coordinates using inputs from the ISS. Display of the computed parameters will be on the DSKY.

3.1.2.4 IMU Alignment Mode

The stable member of the IMU must be aligned with the appropriate coordinate frame prior to any control use. This alignment process has two phases: Coarse Alignment and Fine Alignment.

3.1.2.4.1 Coarse Alignment

This mode will be preceded by two star sightings using the SCT to determine the present orientation of the nav base with respect to the inertial frame. During these sightings, the present orientation of the stable member with respect to the nav base is read into the computer. Using this data and the desired orientation of the stable member, the CMC determines the change in IMU gimbal angles that will bring the stable member to the desired position. The CMC then repositions the stable member through the coarse align loop.

The desired change in IMU gimbal angles is applied in the form of pulses to the error angle counters of the ICDU which activate the DAC's to generate error signals that represent the difference between the actual and desired gimbal angles. These error signals will be transformed in the PSA to torque signals and applied to the IMU gimbal torque motors. As the gimbal angles change, this change is fed to the ICDU digitizer loop and thus back to the CMC in the form of pulses representative of increments of angular change. The DAC signals are nulled when the stable member of orientation is the desired orientation.

3.1.2.4.2 Fine Alignment

This section of IMU alignment may be preceded by a spacecraft maneuver through the computer and attitude control loop. The Fine Alignment is based on two star sightings with the SXT. Star acquisition is first made through the use of the SCT or the optics may be prepositioned by the computer. By use of the displays and controls, the astronaut centers the star image in the SXT field. The astronaut may make a manual mark or activate automatic tracking. The star direction angles with respect to the nav base are read into the computer. The stable member orientation with respect to the navigation base is also read into the computer through the IMU gimbal angles. The astronaut next makes a sextant sighting on a second star and these star direction angles are also read into the CMC. The difference between the present gimbal angles and the gimbal angles which would exist if the stable member were in the desired orientation is computed. The computer then positions the stable member through gyro torquing to the desired orientation.

3.1.2.5 Low Orbit Landmark Tracking

The purpose of this mode is to determine the earth or lunar orbit parameters. The scanning telescope will be used as a single-line-of-sight instrument to acquire and track predetermined landmarks.

Prior to this mode, the IMU will be fine aligned to a star frame. The IMU gimbal angles and the optics angles will be read into computer through the ICDU and OCDU digitizer loops. The astronaut, with the use of the optics hand controller, will center the landmark in the optical field of view and press the Mark button. When the Mark button is pressed, the computer records the IMU gimbal angles and optics angles with respect to the common Navigation Base and also the time of "MARK". The astronaut continues to track the landmark and repeats the "MARK". A series of sightings on each of a series of landmarks will be used by the computer to calculate the orbit parameters. The landmarks may be of either known or unknown position. Up to five sightings of known landmarks may be made with the SCT and two sightings of each unknown landmark must be made with the SXT.

3.1.2.6 Star Acquisition Mode

The purpose of this mode is to center the star in the SCT field of view to establish the proper SXT shaft and trunnion values for navigational sightings. This mode has two phases:

a) Shaft Positioning. With the optics in the direct function, the astronaut will direct the SCT shaft with the hand controller until the "R" line intersects the appropriate star image (if the star is not within the 60^{o} field of view, the 25^{o} offset function will be utilized to drive the SCT trunnion to 25^{o} and thus increase the total field of view to 110^{o} as the shaft is rotated through 360^{o}).

b) Trunnion Positioning. After the shaft angle has been established, the hand controller will be used to drive the trunnion until the star image is centered in the SCT field of view.

The optics hand controller signals are processed in the PSA and applied to the SXT integrator loops to drive the SXT shaft or trunnion. The SCT position follow-up loops will position the SCT shaft and trunnion in response to the SXT movement. By generating the proper SCT shaft and trunnion as viewed by the image, the proper shaft and trunnion angles for the SXT will thus have been generated to bring the star image into the SXT field of view.

3.1.2.7 SXT Star-Landmark Angle Measurement

The purpose of this mode is to determine the precision angle between a star and landmark for a navigational sighting. The astronaut will use the optics hand controller and the minimum impulse controller to superimpose the SXT images of the star and landmark. When the images are superimposed, the astronaut presses the Mark button which causes the CMC to record the SXT angles and the time. The CMC uses this data to compute and update the trajectory data so it can provide display of present or extrapolated position and velocity.

3.1.2.8 SXT Star-Horizon Measurement Mode

The purpose of this mode is to determine the precision elevation angle between a star and the closest point to the horizon blue line. After preliminary spacecraft orientation and star acquisition using the SCT, the astronaut initiates star tracking by centering the appropriate star image in the SXT and energizing the tracker. While viewing through the SCT, (0^{o} offset), the astronaut rolls the spacecraft using the 3 axis hand controller to sweep the landmark LOS through the horizon which is directly below the tracked star. When the landmark LOS crosses the "blue line", the photometer generates an automatic Mark signal which causes the CMC to record the SXT angles and the time. The CMC uses this data to compute and update the trajectory data to provide display of present or extrapolated position and velocity. Visual sighting on the moon horizon is also used.

During tracking, the Star tracker will generate SXT error signals which will be processed by the SXT integrator loops to drive the SXT shaft and trunnion and thus the star LOS in such a manner as to cause tracking. When the tracker is locked on a star, a "Star Present" signal will be generated and applied to the computer. The SXT angles are read into the computer through the SXT resolvers and the OCDU digitizer circuits.

3.1.2.9 Attitude Control

3.1.2.9.1 Saturn Launch Vehicle Attitude Control and Backup Guidance

The G&N System shall have the capability to control the attitude of the Saturn Launch Vehicle during both thrusting and free-fall periods by means of analog attitude error signals. Three signals proportional to the computed attitude error resolved into Launch Vehicle axes shall be sent from the G&N System to the Saturn Instrument Unit and to the FDAI error needles upon receipt of a discrete Spacecraft Control Signal from a CM Main Panel Switch.

The G&N System shall also provide two switch closures to the Saturn Instrument Unit, one commanding S-IVB shutdown and the other initiating S-IVB Translunar Injection engine sequence start.

3.1.2.9.2 Command Module Attitude Control

The G&N System shall control the CM attitude about all axes by means of discrete ON/OFF command signals to each of the 12 CM RCS thrusters. These signals shall be generated by computer programs and/or in direct response to discrete inputs from the Rotational Hand Controllers (RHC) in accordance with the following crew-selected mode.

a) AUTO: Thruster command satisfy programmed equations when RHC inputs absent, and provide fixed body rate with axis and sign corresponding to RHC input.
b) HOLD: Thruster commands hold CM attitude when RHC inputs absent, and provide fixed body rate with axis and sign corresponding to RHC input.
c) FREE: Thruster commands are OFF when RHC inputs absent, and provide angular acceleration with axis and sign corresponding to RHC input.

3.1.2.9.3 CSM Attitude Control

The G&N System, when in operation, shall control the attitude of the CSM about all axes during free fall and about the CSM X axis (roll) during SPS thrusting by means of discrete ON/OFF command signals to each of the 16 SM RCS thrusters. These signals shall be generated by computer programs and/or in direct response to discrete inputs from the Rotational Hand Controllers (RHC) in accordance with the following crew-selected modes:

a) AUTO: Thruster commands satisfy programmed equations when RHC inputs absent, and provide fixed body rate with axis and sign corresponding to RHC input.
b) HOLD: Thruster commands hold CSM attitude when RHC inputs absent, and provide fixed body rate with axis and sign corresponding to RHC input.
c) FREE: Thruster commands are OFF when RHC inputs absent, and provide acceleration with axis and sign corresponding to RHC input.

3.1.2.10 Thrust Vector Control Mode

The Thrust Vector Control mode will be used to command and control the spacecraft during velocity change maneuvers (other than midcourse correction). Prior to the initiation of this mode, the magnitude and direction of thrust is determined by the CMC, and the IMU is aligned so that the X PIPA input axis lies along a predetermined direction near the desired velocity change. The computer will provide signals to control engine turnon and cutoff. The IMU will provide velocity increments which are measured by the accelerometers. Velocity perpendicular to the desired direction results in engine gimbal angle commands from the ICDU error angle counters which will cause corrective motion.

The IMU gimbal angles will be displayed by the FDAI ball and the attitude error signals will be displayed by the attitude error meters on the FDAI. Velocity to be gained will be displayed on the DSKY.

3.1.2.11 Midcourse Correction Mode

The purpose of this mode is to control the magnitude of thrust for the midcourse correction and to monitor the thrusting to determine resultant trajectory parameters.

Prior to this mode, the IMU will be aligned to a starframe with the X PIPA input axis nearly along the desired velocity change vector. The computer will issue the engine turnon and cutoff signals. Velocity increments will be generated by the accelerometers and spacecraft attitude changes will be controlled by the CMC using IMU gimbal angles and accelerometer signals.

IMU gimbal angles will be displayed by the FDAI ball and attitude error on the FDAI needles. Velocity to be gained will be displayed on the DSKY.

3.1.2.12 Entry Mode

The purpose of this mode is to control re-entry lift during the re-entry phase which will cause the spacecraft to follow the proper trajectory for entry and landing.

The G&N System shall control the CM flight path in the earth's atmosphere by controlling the lift vector orientation about the relative wind vector. This control will be accomplished by discrete ON/OFF commands to the roll and yaw RCS thrusters in the AUTO mode described above. Attitude stabilization about the relative wind vector and rate stabilization about the stability pitch and yaw axes (normal to the relative wind vector) will be accomplished in both the AUTO and HOLD modes described above.

IMU gimbal angles will be displayed by the ball of the FDAI and roll attitude error will be displayed by the FDAI attitude error needles.

3.1.2.13 Data Readout

Data available in the CMC may be read out on the DSKY through DSKY control, and specific data may be read out on the FDAI.

3.1.2.14 Data Transmission

Data available in the CMC may be transmitted to the ground through the MSFN Downlink. Data transmitted is selected either by CMC program or MSFN Uplink instructions.

3.1.2.15 Data Insertion

Data insertion will be accomplished through the DSKY or MSFN Uplink.

3.1.2.16 Remote Updating

Position and velocity information can be directed to the CMC through the MSFN Uplink from ground tracking data and computation.

3.1.2.17 Alarm Monitor

The purpose of this function is to provide an automatic readout of system operating conditions. These alarms will be displayed to the astronaut. The alarms will also be applied to the S/C Master Caution System.

3.1.2.18 System Monitor

The system operational status will be transmitted to the ground through the MSFN Downlink.

3.1.2.19 In-Flight Inertial Component Null Bias Determination

The GN & C system shall be capable of determining the null bias drift of the gyros and the acceleration bias of the accelerometers while in free fall. It shall be possible to compensate the CMC programs with the information determined by these measurements.

3.1.3 Attitude Error Signals

To provide a backup attitude error indication for manual free-fall attitude control in the event of G&N attitude reference equipment failure, the G&N computer shall accept body axis increment data from the SCS Body Mounted Attitude Gyros (BMAGs).

3.1.4 Alignment of Backup Reference Equipment

The G&N System, when in operation, shall provide direction data needed to align the SCS reference equipment.

3.1.5 Data Link with Entry Monitor System (EMS)

The G&N computer shall have the capability to provide the following signals to the EMS:

a)	G - HI	switch closure
b)	G - LO	switch closure
c)	+ V	increments
d)	- V	increments

3.1.6 Central Timing and Synchronization Signal

The G&N computer shall provide a clock reference signal to the Spacecraft Central Timing System. Frequency instability shall not exceed 2 parts per million.

3.1.7 Telemetry Data

System to permit transmission of analog and digital system data for post-flight analysis and real-time monitor of system performance.

3.1.8 Display of G&N Status

The G&N System shall display a clear indication of status in the performance of guidance and navigation tasks in order to enhance crew participation in and management of system operation.

3.2 Secondary Characteristics

3.2.1 Subsystem Characteristics

3.2.1.1 Computer Characteristics

a) Memory
   1) Erasable: 2048 words of ferrite coincident current
   2) Rope: 36,864 words of wired transformer type tape wound cores. Core rope detail specifications are included in the separate Mission Specification.

b) Word Length: 16 bits (15 bits + parity)

c) Instruction Codes

1) Single precision:	18
2) Double precision:	3
3) In/Out servicing:	7
4) Branching and interrupt control:	7

d) Clock Rate:

Oscillator: Over entire environmental range	2.048 MC ± 2ppm
Memory Cycle Time:	11.7 usec

e) Input, output (see Section 3.2.3)

f) Weight:

Computer:	65.0 pounds nominal*
2 DSKYs	17.5 pounds each nominal*

g) Packaging: Sealed

h) Power as drawn from +28V dc busses
   Standby: 10 watts nominal*
   Operate: 110 watts nominal*

---

*Nominal weight and power requirements status listed in this section is as reported in MIT Report E-1142, System Status Report, Rev. 37.

3.2.1.2 IMU Characteristics

a) General:

The IMU consists of three single-degree-of-freedom gyroscopes (IRIGs) and three single-degree-of-freedom accelerometers (PIPAs) on a stable member isolated from vehicle orientation by a servo-driven three-degree-of-freedom gimbal system.

b) Gimbal arrangement: compatible with Main Panel Flight Director's Attitude Indicators

   1) Outer axis, fixed to vehicle and parallel to and in same direction as vehicle X axis (roll axis).
   2) Middle axis; parallel to and in same direction as vehicle Z axis (yaw axis) when outer Gimbal angle is zero.
   3) Inner axis; parallel to and in same direction as vehicle Y axis (pitch axis) when outer and middle gimbal angles are zero.

c) Components on Inner Gimbal (Stabilized Member) (Beryllium):

   1) Three size 25 single-degree-of-freedom Inertial Reference Integrating Gyros.
   2) Three size 16 single-degree-of-freedom Pulsed Integrating Pendulums.
   3) Gimbal-mounted electronics to service suspensions and output signals of gyros and pendulous accelerometers.
   4) Temperature control heaters and sensors.

d) Components on Inner Axis:

   1) Two assemblies of slip rings, 40 rings each.
   2) Two duplex-pair bearings; one fixed, one floating.
   3) One combination one-speed sixteen-speed resolver transmitter.
   4) One single-speed gyro error signal resolver.
   5) One d-c servo torque generator, 3.8" diameter air gap.
   6) No gimbal stops, unlimited motion.

e) Components on Middle Gimbal (hydroformed aluminum hemispheres):

   1) No components.

f) Components on Middle Axis:

   1) Two assemblies of slip rings, 40 rings each.
   2) Two duplex-pairs of bearings; one fixed, one floating.
   3) One combination one-speed sixteen-speed resolver transmitter.
   4) One d-c servo torque generator, 3.8" diameter air gap.
   5) No gimbal stops, unlimited motion.

g) Components on Outer Gimbal (hydroformed aluminum hemispheres):

   1) Blower motor and fan for heat transport from stable member to case.

h) Components on Outer Axis:
   1) Two assemblies of slip rings, 50 rings each.
   2) Two duplex-pairs of bearings; one fixed, one floating.
   3) One combination one-speed sixteen-speed resolver transmitter.
   4) One d-c servo torque generator, 3.125" diameter air gap.
   5) No gimbal stops, unlimited motion.

i) Components IMU Case (hydroformed aluminum hemisphere):
   1) Roll-bonded coolant passage and quick disconnects.
   2) Electrical sixteen-speed zero adjustment module.
   3) Mounting pads for mounting to Navigation Base.
   4) Two 61-pin electrical connectors.
   5) Blower control relay.
   6) Insulation to control condensation on coolant passages.

j) Size: Case diameter - 12.5 inches
   Along outer axis - 14 inches
   Volume - approx. 1100 cubic inches

k) Weight: 41.3 pounds nominal*

3.2.1.3 Optics Characteristics

The optical subsystem is the primary on-board navigation data measurement equipment. The optical subsystem in conjunction with the rest of the equipment shall provide:

a) Means for making star direction measurements for initial alignment of the IMU visually by the astronaut and automatically.

b) Means for making the navigation angle measurement between navigation stars and landmark features of the earth or moon visually by the astronaut.

c) Means for making the navigation angle measurement between navigation stars and sunlit horizons of the earth or moon visually by the astronaut and automatically.

d) Means for making the navigation direction measurement to landmark features while in low orbit around the earth or moon visually by the astronaut.

e) Means for making navigation measurements by moon-star occultations visually by the astronaut.

f) Means for making manual backup attitude measurements with respect to selected stars for backup alignment of inertial attitude sensors.

g) A pair of articulating telescopes for general viewing by the astronauts, one high-power and one low-power.

3.2.1.3.1 Scanning Telescope (SCT)

The scanning telescope is a single-line-of-sight, unity-power, wide-field, articulating telescope used for:

a) Landmark tracking for low orbit navigation in conjunction with IMU attitude reference.
b) Acquisition instrument for the SXT.
c) Spacecraft attitude measurement for backup alignment of inertial attitude sensors.
d) Low-power, wide-field, general-viewing instrument.

3.2.1.3.1.1 SCT Mechanical Characteristics

a) Articulation of line of sight with respect to spacecraft.
   1) Trunnion motion, $+50^{\circ}$, -5° of line of sight from shaft axis about trunnion axis which is perpendicular to shaft axis.
   2) Shaft motion, continuous rotation carrying trunnion axis about shaft axis located parallel to SXT shaft axis and approximately 33 degrees from the spacecraft Z axis towards spacecraft X axis in the XZ plane.
b) Trunnion axis components:
   1) Servo motor-tachometer at 5952 speed with respect to trunnion prism.
   2) Resolver transmitter at one speed with respect to trunnion prism.
   3) Illuminated mechanical counter readout 000.0 to 359.9 degrees of line-of-sight.
   4) Universal tool manual drive at 696.8 speed with respect to trunnion prism.
   5) Trunnion prism at one-half speed with respect to line of sight.
c) Shaft Axis Components:
   1) Servo motor-tachometer at 2976 speed with respect to the shaft-axis line-of-sight plane.
   2) Resolver receiver at one speed with respect to the shaft-axis line-of-sight plane.
   3) Illuminated mechanical counter readout 000.0 to 359.9 degrees.
   4) Universal tool manual drive at 348.9 speed with respect to the shaft-axis line-of-sight plane.

3.2.1.3.1.2 SCT Optical Characteristics

a) Magnification: unity
b) Field of view: 60 degrees diameter

c) Unobscured field coverage by use of articulation: approx. 50 degrees from shaft axis.

d) Illuminated reticle

e) Eye relief: 0.520 ± .031 inch normal eyepiece
2.7 ± .031 inch one-half power long eye relief eyepiece

3.2.1.3.2 Sextant (SXT)

The sextant is a two-line-of-sight, 28-power telescope having one line of sight identified as the landmark line, fixed parallel to the shaft axis, and the other line of sight identified as the star line, articulated as described below. The sextant is used for:

a) Star-to-landmark or star-to-horizon angle measurement, manual or automatic.
b) Star direction measurement for IMU alignment, manual or automatic.
c) High-power articulating telescope for general viewing.

3.2.1.3.2.1 SXT Mechanical Characteristics

a) Articulating of star line with respect to spacecraft:
   1) Trunnion motion 0 to +90 degrees of line of sight from shaft axis about trunnion axis which is perpendicular to shaft axis.
   2) Shaft motion, ±270 degrees carrying trunnion axis about shaft axis located parallel to SCT shaft axis and approximately 33 degrees from the spacecraft Z axis towards spacecraft X axis in the XZ plane.
b) Trunnion axis components:
   1) Servo motor-tachometer at 11,780 speed with respect to trunnion mirror.
   2) Resolver for optics hand controller cosecant attenuator at two speed with respect to the trunnion mirror.
   3) Resolver transmitter one speed with respect to trunnion mirror.
   4) Resolver transmitter 64 electrical speed, one mechanical speed with respect to trunnion mirror.
   5) Trunnion mirror at one-half speed with respect to star line of sight.
c) Shaft axis components:
   1) Servo motor-tachometer at 3010 speed with respect to the shaft-axis star-line-of-sight plane.
   2) Resolver for hand controller resolution at one speed with respect to the shaft axis star line-of-sight plane.
   3) Resolver transmitter one speed with respect to the shaft-axis star-line-of-sight plane.

4) Resolver transmitter 16 electrical speed, one mechanical speed with respect to the shaft-axis star-line-of-sight plane.
5) Resolver transmitter one-half speed with respect to the shaft-axis star-line-of-sight plane.

d) Star tracker
1) Carried by head of sextant and rotates with shaft motion.
2) Uses portion of trunnion mirror for trunnion motion.
3) Star tracker field one-half by one-half degree.
4) Provides following signals:
trunnion error
shaft error
star present discrete

e) Horizon Photometer
1) Carried by head of sextant and rotated with shaft.
2) Line of sight is parallel to shaft axis.
3) Provides auto-mark signal to computer when horizon brightness reaches measurement state.

3.2.1.3.2.2 SXT Optical Characteristics

a) Magnification: 28 power
b) Field of view: 1.8 degrees diameter
c) Unobscured field coverage of star-line field by use of articulation: approximately 50 degrees from shaft axis.
d) Relative brightness ratio adjustment landmark-line field to star-line field: 1:12
e) Illuminated reticle
f) Eye relief: 0.875 ± .031 inch

3.2.1.4 PSA Characteristics

a) General. The PSA (Power Servo Assembly) is a group of electronics in a common package and supports the operation of the IMU and optics subsystem.
b) Construction. Modular packaging of associated electronic circuitry which plug into a single level header which makes up necessary intermodular interconnection and connections to the rest of the system through a wiring harness. The PSA shall be protected by a sealed container.
c) Weight: 49.4 pounds, nominal.*
d) Module identification for PSA:

Quantity	Name
1	DC Differential Amplifier & PVR
1	Binary Current Switch
1	Pulse Torque Gyro Calibration
1	Pulse Torque Power Supply
1	-28 VDC Power Supply
1	3200 cps 1 percent Amplifier
1	3200 cps Phase & Amplitude Control
2	800 cps 1 percent Amplifier
3	800 cps 5 percent Amplifier
2	800 cps AAC Filter
3	G&N Subsystem Supply Filter
1	IMU Auxilliary
3	Gimbal Servo Amplifier
4	Motor Drive Amplifier
1	800 cps Load Compensation
1	Two-Speed Switch
1	Cosecant Generator
1	Anti-Creep Electronics
1	Modulator & Loop Compensation
1	Tracker Electronics
1	Photometer Electronics
1	Reticle Light Dimmer
1	IMU Load Compensation
4	Relay module
1	Optics Automatic Operate Relay
1	SCT Moding

40 Modules Total

3.2.1.4.1 PIPA Electronics Assembly Characteristics

a) General: The PIPA (Pulsed Integrating Pendulous Accelerometer) electronics listed here to be packaged separately from the rest of the electronics in the PSA. The assembly includes serialized circuitry associated with serialized inertial components in the IMU.

b) Construction: Modular, with sealed covers, plugging into a single-level interconnection header.

c) Weight: 7.9 pounds nominal*

d) Module Identification

Quantity	Name
3	DC Differential Amplifier & PVR
3	Binary Current Switch
3	AC Differential Amplifier & Interrogator
3	PIPA Calibration

12 Modules Total

3.2.1.5 CDU Characteristics

a) General: The CDUs, Coupling Data Units, are the interface units between the digital computer and variables of the rest of the G&N. Each CDU has two sections:

1) An analog-to-digital section (a/d) accepting two-speed resolver data transmission and feeding angle incremental pulses to the appropriate computer counter.

2) A digital-to-analog section (d/a) accepting incremental pulses of the variable of concern and generating an 800-cps suppressed-carrier voltage proportional to the count of the input pulses. Each D/A output also has a synchronous demodulator associated to generate a ground-isolated proportional DC voltage.

b) Construction: All solid-state electronics, no moving parts. Modular packaging plug into wire-wrapped header in sealed container.

c) Weight: 35.7 pounds nominal*

d) Configuration: There are five CDUs for computer interface used as follows:

1a) (A/D), Read IMU inner gimbal angles from 1- and 16-speed resolvers to CMC.

1b) (D/A), Send pitch error from CMC to FDAI pitch attitude error needle and to Saturn instrument unit for spacecraft control of Saturn. During coarse align mode of G&N, send inner gimbal error signal to IMU servo.

2a) (A/D), Read IMU middle gimbal angle from 1- and 16-speed resolvers to CMC.

2b) (D/A), Send yaw error from CMC to FDAI yaw attitude error needle and to Saturn instrument unit for spacecraft control of Saturn. During coarse align mode of G&N, send middle gimbal error signal to IMU servo.

3a) (A/D), Read IMU outer gimbal angle from 1- and 16-speed resolvers to CMC.

3b) (D/A), Send roll error from CMC to FDAI roll attitude error needle and to Saturn instrument unit for spacecraft control of Saturn. During coarse align mode of G&N, send outer gimbal error signal to IMU servo.

4a) (A/D), Read SXT trunnion angle from 64-speed resolver to CMC.

4b) (D/A), Send yaw service module engine command from CMC to engine servo. During optics drive operation, send trunnion error signal to SXT servo.

5a) (A/D), Read SXT shaft angle from 1- & 16-speed resolvers to CMC.

5b) (D/A), Send pitch service module engine command from CMC to engine servo. During optics drive operation, send shaft error signal to SXT servo.

e) Module identification for five CDUs:

Quantity	Name
5	Quadrant Selector
3	Coarse System
5	D/A Converter
5	MSA & Quadrature Rejection
5	Error Angle Counter & Logic
5	Read Counter
1	Mode Module
1	Interrogate
1	Digital Mode
1	Power Supply

32 Modules Total

3.2.2 Performance Characteristics

The following charts list the 1-sigma values of the performance-determining parameters. These are based upon the best information available for estimates applicable to systems suitable for the lunar landing mission.

3.2.2.1 Optical Errors

Table 3.1 shows the error contributions in the navigation sighting of star to plane.

Table 3.1 Optical Errors

SXT Sighting Angle Error Sources	Star-Landmark Line-of-Sight RMS Error in Seconds
Resolver Zeroing Uncertainty	1.7
Resolver Function Error	7.0
Geometric Error	5.0
CDU Linearization Error	2.8
CDU Quantization and Dead Zone Error	5.8
RSS Uncertainty in Navigation Angle	10.85
Astronaut Sighting Uncertainty	
Including Optical Resolution Error	5-7 (Typical)[1]
Star Tracker LOS to Star LOS Nonparallelism	
Measurement Uncertainty in Trunnion Plane	11.5
Measurement Error Perpendicular to Trunnion Plane	102.0[2]
Horizon Photometer LOS to Landmark LOS Nonparallelism	
Measurement Error in Trunnion Plane	102.0[3]
Measurement Error Perpendicular to Trunnion Plane	102.0[2]

3.2.2.2 IMU Errors

Table 3.2 lists the IMU performance errors. For the gyro and accelerometer, certain errors are measured prior to flight and inserted into the computer for in-flight compensation. The acceleration insensitive errors can be measured in flight during free-fall after the IMU is first turned on and before the use of the IMU in a powered maneuver. The Stable Member Alignment Errors listed in Table 3.2 are based upon the in-flight alignment error contributions listed in Table 3.3.

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[1] Refer to Paragraph 6.1.2 for further details.

[2] These errors are compensated to an uncertainty of 40 seconds.

[3] This error is compensated to an uncertainty of 10 seconds.

Table 3.2 Inertial Subsystem Errors

Item		Error Symbol	Error Units	AGC Compensation Range [1] (Quantization)	RMS Value After Compensation (Where Applicable)
Accelerometer Errors					
Bias Error		ACB	cm/sec^2	2.50 (0.01)	0.20
Scale Factor Error		SFE	ppm	976 (1.00)	116
Accel. Square Error		NC	$\mu g/g^2$	--	10 [2]
Input Axis Misalign.		α	arc sec	--	20
Gyro Errors					
Bias Drift		BD	meru	512 (0.1)	2
Input Axis Accel. Sens. Drift		ADIA	meru/g	512 (0.1)	8
Spin Ref. Zxis Accel. Sens. Drift		ADSRA	meru/g	512 (0.1)	5
IA Accel. Squared Sens. Drift		A^2DIA	meru/g	--	0.3 [2]
SRA Accel. Squared Sens. Drift		A^2DSRA	meru/g	--	0.3 [2]
IRIG Scale Factor		SF(G)	ppm	--	500
IA Align about SRA		α SRA	arc sec	--	300
IA Align about OA		α OA	arc sec	--	300
SM Alignment Errors					
Prelaunch	Azimuth		arc sec		500
	Vertical		arc sec		50
Free-Fall	All Axes		arc sec		40

[1] Maximum range is a result of minimum bit size choice and is not to be construed as implying a possible inertial component value

[2] Theoretical values

3.2.2.3 Alignment Errors

Alignment errors are shown in Table 3. 3.

Table 3. 3 Alignment Errors

Stable Member Alignment Error Sources	RMS Error in Seconds of Arc
Stable Member to Navigation Base	
Resolver (16X) Zeroing Uncertainty (OGA, MGA, IGA)	4. 9
Resolver (16X) Functional Errors (OGA, MGA, IGA)	12. 0
CDU Quantization and Dead Zone Errors (OGA, MGA, IGA)	11. 6
CDU Linearization Errors (OGA, MGA, IGA)	5. 6
MGA-OGA Non-orthogonality	15.5
IGA-MGA Non-orthogonality	19. 2
OGA Alignment to Nav. Base Mounting Plane (about Z_{nb})	7. 0
OGA Alignment to Nav. Base Mounting Plane (about Y_{nb})	7. 0
Sextant L. O. S. to Navigation Base	
Sextant Shaft Axis to Nav. Base Alignment (about Z_{nb})	17. 0
Sextant Shaft Axis to Nav. Base Alignment (about Y_{nb})	20. 0
Sextant Shaft Axis to Nav. Base Alignment (about X_{nb})	12. 0
Resolver Zeroing Uncertainty	
SDA (16X)	5. 7
TDA (64X)	1. 7
Resolver Functional Errors	
SDA (16X)	12. 0
TDA (64X)	7. 0
CDU Linearization Errors	
SA	5. 6
TA	2. 8
CDU Quantization and Dead Zone Error	
SA	11. 6
TA	5. 8
Trunnion Axis/Shaft-Axis Non-orthogonality and Star LOS/ Trunnion Axis Non-orthogonality (combined error)	11. 5
Geometric Error	5. 0
Sighting and Optical Resolution Error	2. 5

3.2.3 Interface Lists

The following lists tabulate all electrical and function interfaces between the G&N and the remainder of the spacecraft, booster, or crew. In each list the following code is used:

a) First letter - alphabetically assigned for use of these lists only.

b) Three-digit number, when present, is the appropriate computer interface control code.

c) Interface type:

DE: d-c input to computer "in bit"
SD: Switch closure of dc
DC: DC proportional analog voltage
800-cps: Analog 800-cps suppressed carrier or 800-cps power
400-cps: Analog 400-cps suppressed carrier
CB: Computer dc output under program control
XC: Computer transformer output continuous signal
X-: Computer transformer output special signal.
Y-: Computer transformer input special signal.
YG: Computer transformer input into counter.
XA: Computer transformer output under counter control.
28VDC: 28VDC power
DSKY: Associated with either or both of the Displays and Keyboards.
E.L.: Associated with computer data display through electroluminescent panel.
STATUS: Associated with white status lights.
CAUTION: Associated with yellow caution lights.
LEB Annunciator: Lights of the Lower Equipment Bay condition annunciator.
NAV Panel Light: Status light on navigation control panel. Counter: Degrees and decimal degrees counter.
Eyepiece: Eyepiece

d) Interface name: Listed after interface type.

e) Number in parentheses is that used in minutes of the Integrated Guidance and Control Implementation Meetings at MSC.

f) Description of Interface

3.2.3.1 Mode Control

a) 004 DE Ullage Thrust Present (106), Signal from Saturn indicates S-IVB ullage engine is firing to signal G&N to integrate resulting acceleration.

b) 007 DE Lift Off (108), Signal from Saturn indicates first motion of booster.

c) 068 DE Guidance Reference Release (109), Signal from Saturn indicates to G&N that the Saturn booster guidance has ceased gyro torquing to the local launch vertical and the trajectory plane framework.

d) 066 DE S-IVB Separate/Abort (42), Signal from the master event sequencer indicates that S-IVB is staged and is interpreted as an abort if it occurs early.

e) 060 DE LEM Attached (44), Indicates LEM is attached to CSM.

f) 067 DE SM Separate (43), Signal from SM/CM reaction jet control transfer unit indicates the SM is staged.

g) 065 DE Free Function (59), Indicates astronaut has selected the FREE mode of G&N attitude control wherein the G&N responds only to hand controller acceleration output signals and commands corresponding RCS firings.

h) 040 DE Hold Function (58), Indicates astronaut has selected the HOLD mode of the G&N attitude control wherein the G&N holds present spacecraft attitude except when responding to hand controller velocity commands.

i) Auto Function (-), (Indicated by NOT FREE or NOT HOLD), Indicates that the astronaut has selected the AUTO mode of the G&N attitude control wherein the G&N commands spacecraft position according to computer program or hand controller velocity commands.

j) 082 DE SPS Ready (41), Indicates that the astronaut has completed the engine start checklist and the G&N can proceed with engine RCS-ullage-SPS-firing cycle.

k) 158 DE SC Control of Saturn (105), Indicates that the pilot has chosen to have the Apollo G&N guide Saturn.

l) 159 DE G&N Autopilot Control (26), Indicates the pilot has chosen primary G&N control of RCS and SPS engines for attitude and thrust vector control.

m) - SD IMU Cage, Contact closure on main panel to cause IMU gimbal to be coarse aligned to zero.

n) 083 DE Block Uplink, Signals the astronauts have selected to prevent ground-up telemetry from entering computer, either from main panel switch or from NAV panel switch. Up-telemetry is accepted by the computer only when both switches are closed so that the computer receives "accept" discrete from the series connection of these two switches.

o) - R	Discrete Power, Wires from computer 28VDC through resistors as appropriate to contacts for the above discrete signals.	

3.2.3.2 Analog Signals

a)	DC	Pitch SPS Gimbal (1) drive signal from G&N	
b)	DC	Yaw SPS Gimbal (2) drive signal from G&N	
c)	800 cps	Pitch Error (6)	G&N error signals to attitude error needles of FDAIs for error display
d)	800 cps	Yaw Error (8)	
e)	800 cps	Roll Error (7)	
f)	800 cps	Sin Inner (3)	IMU gimbal signals to FDAIs for indication of vehicle total attitude.
g)	" "	Cos Inner (3)	
h)	" "	Sin Middle (5)	
i)	" "	Cos Middle (5)	
j)	" "	Sin Outer (4)	
k)	" "	Cos Outer (4)	
l)	DC	Pitch Error (101)	G&N error signals from Apollo CM to Saturn instrument unit for spacecraft steering of Saturn.
m)	DC	Yaw Error (103)	
n)	DC	Roll Error (102)	

3.2.3.3 Engine & Jet Control

a)	801 CB	+X, +pitch jet (9)	a-p are the 16 jets of the SM reaction control system or the 12 jets of the CM reaction control system. Switched by the SCS to SM or CM jets depending upon separation status. Jets are turned on by G&N for length of time signal is present.
b)	806 CB	-X, -pitch jet (10)	
c)	805 CB	-X, +pitch jet (11)	
d)	802 CB	+X, -pitch jet (12)	
e)	803 CB	+X, +yaw jet (13)	
f)	808 CB	-X, -yaw jet (14)	
g)	807 CB	-X, +yaw jet (15)	
h)	804 CB	+X, -yaw jet (16)	
i)	813 CB	+Z, +roll jet (17)	
j)	816 CB	-Z, -roll jet (18)	
k)	815 CB	-Z, +roll jet (19)	
l)	814 CB	+Z, -roll jet (20)	
m)	809 CB	+Y, +roll jet (21)	
n)	812 CB	-Y, -roll jet (22)	
o)	811 CB	-Y, +roll jet (23)	
p)	810 CB	+Y, -roll jet (24)	

q) 011 CB SPS Engine On/Off (25), output signal when present indicates SPS firing command; when disappears indicates SPS shutdown.

r) 407 SD Injection Sequence Start (104), output signal from G&N main panel DSKY indicating command which starts S-IVB engine firing sequence.

s) 409 SD S-IVB Cutoff Command, output signal from G&N main panel DSKY indicating command to shutdown S-IVB engine.

t) --- SD SC Control of Saturn. Saturn 28VDC switched during SC control of Saturn at main panel to main panel DSKY to power discretes "Injection Sequence Start" and "S-IVB cutoff command".

3.2.3.4 Maneuver Command Signals

a) 093 DE +pitch manual rotation (27)

b) 094 DE -pitch manual rotation (28)

c) 095 DE +yaw manual rotation (29)

d) 096 DE -yaw manual rotation (30)

e) 097 DE +roll manual rotation (31)

f) 098 DE -roll manual rotation (32)

The above discretes from the hand rotation controller indicate controller is out of detent and is commanding a fixed angular rate and direction about the indicated axis. (During FREE mode, motion is acceleration and not rate.)

g) 018 DE +X translation command (34)

h) 019 DE -X translation command (35)

i) 020 DE +Y translation command (36)

j) 021 DE -Y translation command (37)

k) 022 DE +Z translation command (38)

l) 023 DE -Z translation command (39)

The above discretes from the hand translation controller indicate controller is out of detent and is commanding an acceleration in the direction indicated.

3.2.3.5 Computer Telemetry and Timing

a) 001 XC Spacecraft Central Timing Equipment, signal to synchronize spacecraft clock to the computer oscillator.

b) 017 X- Downlink Data, serial downlink data from computer to telemetry.

c) 014 Y- Downlink Start, signal indicating to computer to start sending serial downlink data on receipt of downlink sync pulses.

d) 015 Y- Downlink End, signal indicating to computer to stop shifting out data and reload downlink register.

e) 016 Y- Downlink Syn., timing for shifting out data into telemetry.

f) 024 YG Uplink Zero, uplink data bit signifying zero.

g) 025 YG Uplink One, uplink data bit signifying one.

3.2.3.6 Backup Attitude Signals

a) 817 YG	+ Pitch BMAG		Angle increment data from the Gyro display coupler of SCS Body Mounted Attitude Gyros used when IMU has failed as an attitude source so as to permit the computer to generate attitude error signals. Computer must be put into this mode via keyboard entry.
b) 818 YG	- Pitch	"	
c) 819 YG	+ Roll	"	
d) 820 YG	- Roll	"	
e) 821 YG	+ Yaw	"	
f) 822 YG	- Yaw	"	

3.2.3.7 Status Light Control

a) 441 SD Computer Warning: from main panel DSKY to Master Caution and Warning system indicating occurrence of computer power failure or circuit alarm.

b) 429 SD Inertial System Warning: from main panel DSKY to Master Caution and Warning system from CGC indicating detection of IMU accelerometer, gyro, or CDU error.

c) 444 SD G&N Caution: from main panel DSKY to Master Caution and Warning system from CGC indicating detection of IMU temperature out of limits, gimbal lock caution, tracker caution, computer restart, or program caution.

d) --- SD Master Alarm Reset: from switch on Nav. Panel to Master Alarm system; circuit closure to reset Master Alarm at LEB.

3.2.3.8 Unused Capability
(Not connected to spacecraft systems but retained by NASA direction)

a) 338 SD	G high light	To signal lights intended on the entry monitor to indicate high or low entry, from LEB DSKY. These relays operate functionally with the "injection seq. start" and "S-IVB cutoff" from the main panel DSKY.
b) 340 SD	G low light	

c) 029 XA	Entry velocity plus	Intended for entry monitor to up-down counter and comparator with SCS accelerometer integration. These are incremental data.
d) 030 XA	Entry velocity minus	

3.2.3.9 Power

a) 28VDC	CMC power bus A
b) 28VDC	CMC power bus B
c) 28VDC	IMU operate power bus A
d) 28VDC	IMU operate power bus B
e) 28VDC	IMU standby power bus A
f) 28VDC	IMU standby power bus B
g) 28VDC	Optics power bus A
h) 28VDC	Optics power bus B
i) 400 cps	DSKY electroluminescent keyboard power - from master dimmer 115V nominal for both main panel and LEB DSKYs.
j) DC or 400 cps	MP & LEB DSKY status light power, from master dimmer, 5V nominal.
k) DC or 400 cps	DSKY caution light power, from master dimmer, 5V nominal for both MP and LEB DSKYs.
l) resistance	DSKY numeric dimmer control, from master dimmer for both MP & LEB DSKYs.
m) 400 cps	Optics reticules, power from S/C for optics reticules.
n) 800 cps	800-cps power, to SCS as 800-cps reference for FDAI and autopilot reference.
o) --DC	Power returns for above on a one-for-one basis.

3.2.3.10 Astronaut Interface Displays

(Note: All DSKY displays are duplicated at main panel and LEB.)

a) DSKY E L (green)	CMPTR ACTY, signified computer activity in processing data.
b) " "	PROG, two digit (octal) 00 to 77 signifies major program mode of computer activity.
c) " "	VERB, two digit (octal) 00 to 77 signifies verb chosen by astronaut or signaled to astronaut.
d) " "	NOUN, two digit (octal) 00 to 77 signifies noun chosen by astronaut or signaled to astronaut.

e) " "	X DATA, five digits (decimal) and sign ±00000 to ±99999 displaying X variable data.
f) " "	Y DATA, five digits (decimal) and sign ±00000 to ±99999 displaying Y variable data.
g) " "	Z DATA, five digits (decimal) and sign ±00000 to ±99999 displaying Z variable data.
h) DSKY STATUS (white)	UPLINK ACTY: indicates the computer is receiving data from up-telemetry.
i) " "	AUTO; AUTO attitude control mode, will execute existing attitude control program.
j) " "	HOLD; HOLD attitude control mode, program will respond to hand controller to hold spacecraft at present attitude.
k) " "	FREE; FREE attitude control mode, program will turn on jets for acceleration response to hand controller only, otherwise spacecraft in free drift.
l) " "	NO ATT; signifies that attitude data are not available from the IMU.
m) " "	STBY; indicates that the computer is in the power-saving standby mode.
n) " "	KEY REL; keyboard release indicates that the internal program has attempted to display information on DSKY but found display system program busy (Flashing.)
o) " "	OPP ERR; operator error, keyboard and display program has detected improper use of keyboard by astronaut (Flashing).
p) DSKY CAUTION (yellow)	TEMP; indicates IMU temperature in excess of $\pm 5^{o}$F from set point.
q) " "	GIMBAL LOCK; indicates an IMU middle gimbal angle in excess of $\pm 60^{o}$ and there is, consequently, a possibility of reaching gimbal lock.
r) " "	PROG; indicates a program internal check has failed.
s) " "	RESTART; internal detection in computer signifies abnormal operation.
t) " "	TRACKER; indicates star tracker is in acquisition status but star not acquired.
u) LEB ANNUNCIATOR	CMC red light; indicates computer power supply failure or circuit alarm from LEB DSKY relay.
v) " "	ISS red light; indicates IMU gyro error (tumbling IMU), accelerometer error, or CDU failure has been detected (under computer program control) from LEB DSKY relay.

w)	" "	PGNS yellow light; indicates detection from accelerometer error, IMU temperature, gimbal lock caution, tracker caution, program, restart, or optics CDUs. Under computer program control from LEB DSKY relay.
x)	" "	MASTER ALARM red light; lit from spacecraft Master Alarm detection.

3.2.3.11 Astronaut Interface Controls

1) Stick	Minimum impulse controller, navigator's right hand control for spacecraft minimum impulse control through AGC when in FREE mode.
2) Button	Mark, signals computer instant of time as appropriate.
3) Button	Reject Mark, signals computer to reject last mark.
4) Stick	Optics controller, navigator's left hand control for aim of optics.
5) 3-pos switch	CMC, optics under computer program control; MANUAL, optics under astronaut control; ZERO, optics driven to zero shaft and trunnion.
6) 3-pos switch	Controller speed; HI, MED, and LO selects gain of optics controller to line of sight motion.
7) 2-pos switch	Controller coupling; DIRECT, optics controller signals X and Y drive shaft and trunnion controlled directly; RESOLVED, optics controller signals X and Y are resolved into X and Y motions in field of view.
8) 3-pos switch	Tracker; TRACK, optics are under direction control of the star tracker; ACQUIRE, optics are under direction control of the hand controller for acquisition of a star; OFF, photometer-tracker electronics power is off.
9) 3-pos switch	Telescope Trunnion; SLAVE TO SXT, sets SCT to follow SXT star line trunnion angle; 25^o sets SCT trunnion to 25^o for simultaneous star and landmark acquisition; 0^o sets SCT to zero trunnion to look along SXT landmark line.
10) Potentiometer	Reticle brightness, adjust brightness of SXT and SCT reticles and telescope angle counters.
11) 3-pos switch	Condition lamps; ON supplies power to LEB annunciator lamps: CMC Warning, ISS Warning; & PGNS Caution at Nav. Station; OFF turns off power; TEST lights all Nav. Station annunciator lamps including Master Alarm.

12) Button	Reset; closes circuit to Master Caution and Warning system to reset Master Alarm.
13) on SXT	Eyepiece focus for Sextant.
14) on SCT	Eyepiece focus for Scanning Telescope.
15) on SXT	Landmark dimmer; polaroid dimmer for landmark line.
16) Universal tool	Optics Door; for use of opening and shutting optics door.
17) Universal tool	SCT shaft; to rotate SCT shaft directly.
18) Universal tool	SCT trunnion; to rotate SCT trunnion directly.
19) 2-pos switch	UP-TELEMETRY; BLOCK, computer does not accept up-telemetry data; ACCEPT, computer accepts up-telemetry data. This switch is in series with a similar switch on main panel.
20) DSKY button	VERB, signifies next two digits are verb code.
21) " "	NOUN, signifies next two digits are noun code.
22) " "	+ , signifies next five digits are positive decimal numbers.
23) " "	- , signifies next five digits are negative decimal numbers.
24)-33) "	Digits; 0 thru 9.
34) DSKY button	CLR; Clear data in numeric display.
35) " "	STBY; puts computer in power-saving standby mode, and takes it out of standby.
36) " "	KEY REL; Releases keyboard from manual operation for display of program data or requests.
37) " "	ENTR; enters keyboard data into program.
38) " "	RSET; Resets appropriate lights under program control.

3.2.3.12 Signals Available for Telemetry

The following signals could be buffered and conditioned for transmission to telemetry. This is not a telemetry signal list but rather a list of typical signals from which a signal list can be made.

1. IMU 800 cps 1 percent Supply
2. 3.2 KC 28V 1 percent Supply
3. PIPA +120 VDC Supply
4. X PIPA +28 VDC PVR
5. Y PIPA +28 VDC PVR
6. Z PIPA +28 VDC PVR
7. 2.5 VDC Telemetry Bias
8. CMC Temperature
9. PIPA Calibration Module Temperature
10. PSA Temperature
11. PIPA Temperature
12. X PIPA SG OUT, QUAD
13. Y PIPA SG OUT, QUAD
14. Z PIPA SG OUT, QUAD
15. CMC Warning
16. IRIG Temperature
17. IMU Standby Discrete
18. CMC Operate Discrete
19. OPTX Operate Discrete
20. IG 1X RES Out Sine
21. IG 1X RES Out Cosine
22. MG 1X RES Out Sine
23. MG 1X RES Out Cosine
24. OG 1X RES Out Sine
25. OG 1X RES Out Cosine
26. SXT SH Tach. Output
27. SXT TR Tach. Output
28. X PIPA SG Out, In Phase
29. Y PIPA SG Out, In Phase
30. X PIPA SG Out, In Phase
31. IG IMU Servo Error, In Phase
32. MG IMU Servo Error, In Phase
33. OG IMU Servo Error, In Phase
34. IMU Blower Current
35. PITCH CDU Attitude Error
36. ROLL CDU Attitude Error
37. YAW CDU Attitude Error
38. Shaft CDU DAC Out
39. Trunnion CDU DAC Out
40. (3) Axis Nav. Base Vib. record
41. (3) Axis PIP record
42. IMU Heater Current
43. Tracker X Fork Drive
44. Tracker Y Fork Drive
45. Tracker P/A Out
46. Photometer P/A Out
47. SCT SH Tach. Out
48. SCT TR Tach. Out
49. Pitch CDU Fine Error
50. Roll CDU Fine Error
51. Yaw CDU Fine Error
52. SXT SH Motor Control Winding
53. SXT TR Motor Control Winding
54. SXT SH MDA Input
55. SXT TR MDA Input
56. Shaft CDU Fine Error
57. TR CDU Fine Error
58. IG Torque Motor Current
59. MG Torque Motor Current
60. OG Torque Motor Current
61. CMC Down Telemetry

3.3 Operability

This section specifies the performance requirements which are general measures of efficiency of the command module Guidance and Navigation Equipment. Requirements included herein are allocated from or in recognition of requirements established for the Apollo Program.

3.3.1 Reliability

Guidance and Navigation subsystem failure rates shall be demonstrated by an analytical model of each subsystem for approval by NASA. These failure rates shall be reported quarterly along with an overall mission success probability analysis using an approved mission operating timeline. The existing status of G&N subsystem failure rates (February 1965) derived from the current analytical model follows. Variations in reported rates can be expected as experience with the equipment and analytical techniques indicate.

a) IMU:	125 failures per 10^6 hours
b) IMU electronics (PSA):	116 failures per 10^6 hours
c) IMU/CDU:	181 failures per 10^6 hours
d) OPTICS:	85 failures per 10^6 hours
e) OPTICS electronics (PSA)	80 failures per 10^6 hours
f) OPTICS/CDU	104 failures per 10^6 hours
g) CMC:	382 failures per 10^6 hours
h) DSKY:	20 failures per 10^6 hours
i) Displays and Controls	22 failures per 10^6 hours

This list does not include failures arising from wearout of switches and buttons of the controls where failure modes are more accurately a function of number of operations.

3.3.2 Maintainability

Basic maintainability principles shall be considered in the design of the G&N equipment. The equipment shall be capable of rapid and positive recognition of failure and the identification of the failed replaceable element. The complexity of pre-launch maintenance tasks shall be minimized by the use of simple designs which include optimum interchangeability and the use of standardized equipment. There is no requirement for inflight maintenance. The design shall provide for accessibility of all components requiring maintenance, inspection, calibration, adjustment, servicing, removal, or replacement. Limited-life items shall be identified and appropriate means provided for easy replacement and/or maintenance.

3.3.2.1 Maintenance Requirements

In addition to the general maintainability requirements stated above, the G&N equipment shall include on-board self test and failure warning circuits for use during and prior to flight.

3.3.2.2 Maintenance Repair Cycle

The CM G&N equipment shall be designed such that a minimum of scheduled maintenance (e.g., inspection, calibration, adjustment, servicing) shall be required during the time period from erection of the spacecraft onto the assembled launch vehicle through mission accomplishment, a maximum of 30 days. This is exclusive of calibrations and adjustments required during system preparation and countdown periods for a specific flight. No inflight scheduled or unscheduled maintenance shall be performed. The requirements for scheduled component replacement from the time of delivery of the G&N equipment to the procuring agency shall be kept to a minimum and in no cases shall require such replacement more often than one in any 12-month interval (exclusive of unscheduled maintenance).

3.3.2.3 Service and Access

All attachments, fittings, wiring and tubing, supports, and accessory fastenings shall be easily accessible during the normal sequence of assembly of the G&N equipment into the spacecraft. Such attachments, test points, fittings, and adjustment devices as shall require manipulation during prelaunch scheduled maintenance shall be so arranged as to require a minimum of dissambly for service, adjustment, checkout and/or calibration.

3.3.3 Useful Life

The Guidance and Navigation equipment shall be capable of meeting the requirements of this specification for a minimum of 2000 system operating hours including the test time logged during all subsystem operations. Elapsed time indicators shall be provided for such accounting where applicable. Nonoperating shelf-life of the G&N equipment shall be a minimum of 36 months. Total useful life of the G&N equipment from the time of delivery to the procuring agency shall be a minimum of 5 years with routine maintenance and servicing.

3.3.4 Natural Environment

Components of the G&N equipment, when contained in appropriate containers, will not be degraded during storage, transportation, or handling when subjected to the applicable natural environmental conditions stated in ND1002037, Environmental Qualification Specification for A/B Equipment and the Performance and Interface Specification.

Those components exposed to space environment expected to exist during all mission flight phases shall be so designed and constructed that they will operate within the performance requirements specified within Section 3.1.1 of this specification when subjected to applicable space environmental conditions stated in ND1002037 and the Performance and Interface Specification.

3.3.5 Transportability

The G&N equipment shall be air transportable in general accordance with the provisions of MIL-A-8421, Air Transportability Requirements. Units of the G&N equipment shall have appropriate shipping containers where necessary to meet these requirements and not exceed the natural and induced environmental requirements for these units as specified in Paragraph 3.1.2.4.

3.3.6 Human Performance

Design of the G&N equipment and arrangement of components shall be in conformance with established human engineering design criteria. Displays and controls shall be provided as necessary for acceptable and accurate operation of the G&N equipment by the crew. Such controls and displays shall be allocated an area within the Lower Equipment Bay and on the Main Display Panel. Airborne controls and displays shall be subject to NASA approval.

3.3.7 Safety

The design of the G&N equipment shall provide maximum safety to personnel during storage, installation, maintenance, and operation. Precautionary safety markings shall be provided as necessary to warn personnel of conditions to be observed to insure safety of equipment.

3.3.8 Induced Environment

The G&N equipment shall be so designed and constructed that it will meet the performance requirements specified in Paragraph 3.1.1 of this specification when subjected to the environmental conditions induced during mission performance as specified in ND1002037 and the Performance and Interface Specification.

3.4 MEI Definition

3.4.1 Interface Requirements

The G&N equipment shall interface with other Apollo spacecraft equipment, the launch vehicle, and the Manned Spacecraft Flight Network as defined in the following sub-paragraphs and described in Paragraph 3.2.3 of this specification. G&N equipment interface with other equipment/systems shall be as defined in Interface Control Documents (ICDs) and by the general schematic arrangement of components discussed in Paragraph 3.4.1.1.

3.4.1.1 Schematic Arrangement

The relationship of components of this MEI to other equipment is shown in Figure 3.1, G&N - Block II/CSM Functional Interface Diagram.

3.4.1.2 Detailed Interface Definition

Any mechanical, electrical, or functional interface between the G&N equipment and subsystems and/or the spacecraft shall require the preparation of ICDs in accordance with NAA/S&ID Report, "Preparation Manual, Interface Coordination and Documentation", as negotiated with NAA/S&ID.

3.5 Design and Construction

The Airborne Guidance and Navigation Equipment shall consist of the following major assemblies:

Navigation Base (NVB)
Inertial Measurement Unit (IMU)
Optical Assembly
Power and Servo Assembly (PSA)
Apollo Guidance Computer (CMC)
Display and Controls (D&C)
Coupling Display Units (CDUs)
Interconnecting Harness
PIPA Electronics Assembly (PEA)
Signal Conditioner Assembly (SCA)

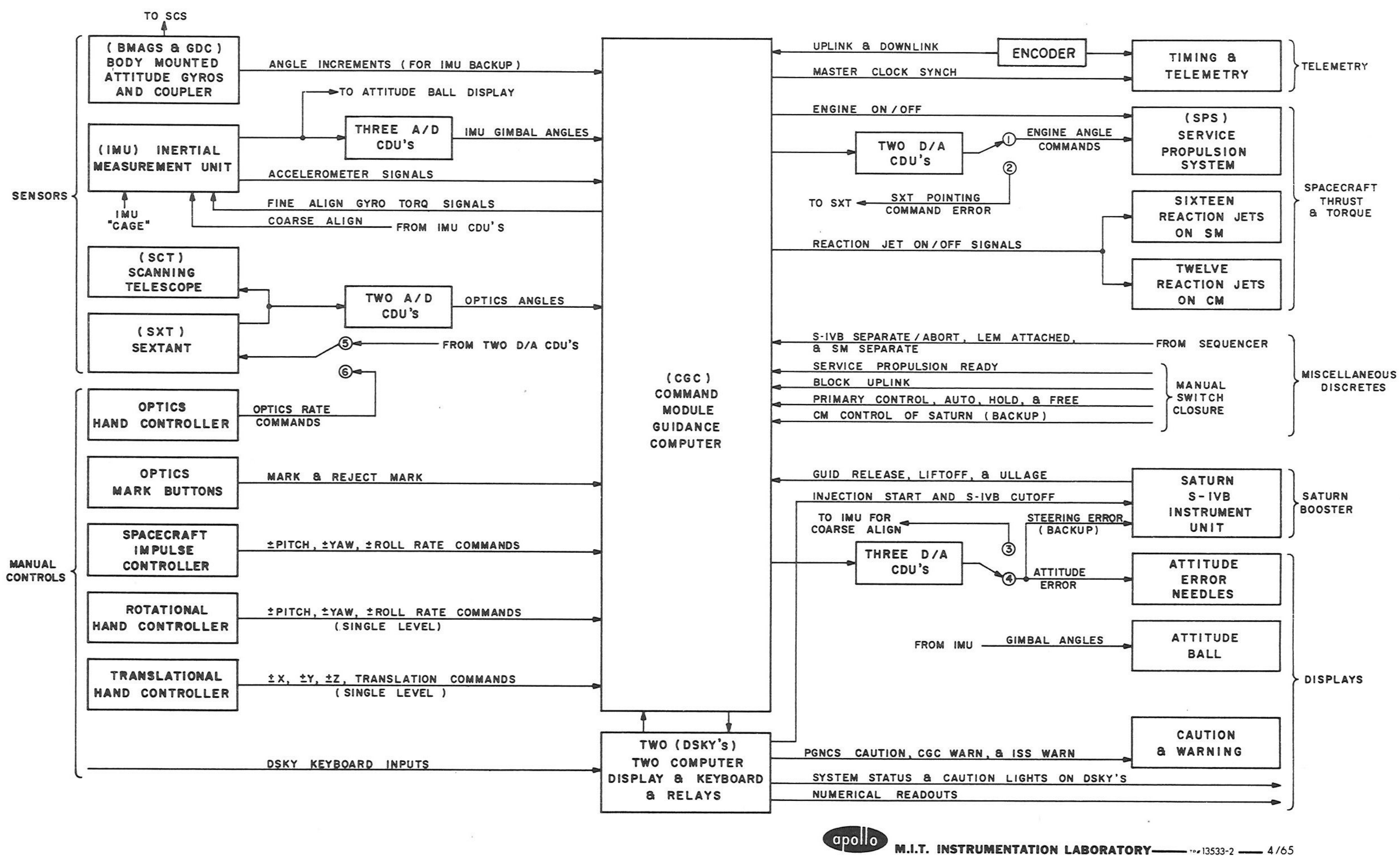

Fig. 3.1 Block II G&N and Block II CSM Functional Interface Diagram

3.5.1 General Design Features

The Guidance and Navigation System shall be designed to operate as an integrated item of equipment in the Apollo Command Module. These relationships shall be established in cooperation with the Spacecraft Contractor and mutually agreed upon, and documented by Interface Control Documents. The control weight for the G&N System shall not exceed 400.0 pounds. Electrical loads shall be coordinated with the Spacecraft Contractor.

3.5.2 Selection of Specifications and Standards

All standards or specifications, other than those established and approved for use by NASA, must be approved by the procuring agency prior to incorporation into this specification.

The selection and application of standards and specifications shall be such to insure that:

a) NASA and then military standards are being utilized to the maximum extent.
b) Prior to application, all standards and specifications have been evaluated and demonstrated directly or indirectly to be suitable for the purpose intended.
c) There are rigorous design reviews to realistically evaluate and approve the selection and application of standards and specifications.
d) Established government specifications or standards shall be selected in accordance with the order of precedence specified in MIL-STD-143.
e) Drawings shall comply with MIT Apollo Drawing Standards Publication E-1167 and be interpreted in accordance with MIL-D-70327.

3.5.3 Materials, Parts, and Processes

Materials, parts, and processes utilized in the fabrication of the equipment shall conform with the applicable requirements of the following subparagraphs.

3.5.3.1 Materials

During the early stages of design the selection of materials shall be based on vendor's qualification for best performance under definable environments. However, as the space environmental conditions become better defined, material selection shall be based on the requirements posed by these environments (i.e. high vacuum, 100 percent oxygen, thermal, high humidity, organic contaminants, electromagnetic and particle radiation, etc.) The suitability of selected materials shall be regularly reviewed as additional requirements become known and are defined.

3.5.3.2 Parts

Suitable specifications will be referenced in the appropriate component procurement specifications, SCDs, or drawings.

3.5.3.3 Processes

Suitable specifications will be referenced in the appropriate component procurement specifications, SCDs, or drawings.

3.5.4 Standard and Commercial Parts

NASA approved standard parts for the Apollo Space Program shall be used wherever practicable.

3.5.5 Moisture and Fungus Resistance

All G&N equipment shall be either moisture-proof or hermetically sealed.

Materials that are nutrients for fungi should not be used when their use can be avoided. When used and not hermetically sealed, they shall be treated with a fungicidal agent which will render the resulting exposed surface fungus-resistant. If they are used in a hermetically sealed enclosure or if they are used and stored in a continuously controlled environment, fungicidal treatment will not be necessary.

3.5.6 Corrosion of Metal Parts

3.5.6.1 Corrosive Metals

Metals shall be the corrosion-resistant type or suitably treated to resist corrosive conditions likely to be met in storage or normal service.

3.5.6.2 Dissimilar Metals

Unless suitably protected against electrolytic corrosion, dissimilar metals, as defined in Standard MS 33586, shall not be used in contact with each other.

3.5.7 Interchangeability and Replaceability

Interchangeability and replaceability items shall be categorized within the definition established by MIL-STD-447. All assemblies, components, and parts to the lowest level of spare parts programmed shall be designed to be interchangeable in accordance with the definition established by MIL-STD-447. Where interchangeability is not practicable, such equipment, assemblies, and components shall be designed to be replaceable in accordance with MIL-I-8500. Drawings shall be marked to show interchangeability or replaceability status. As an objective, no "In Position" electrical adjustments shall be required when a part of the equipment categorized as interchangeable is replaced with an identical part.

3.5.8 Workmanship

The equipment, including all parts and assemblies, shall be constructed and finished in accordance with best practices for high-reliability airborne equipment. Thoroughness of soldering, wiring, impregnation of coils, plating, painting, riveting, machine screw assemblages, welding, and brazing shall comply with best applicable standards.

3.5.9 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, as amended by MSC-ASPO-EMI-10A, to the degree negotiated with the procuring activity.

3.5.10 Identification and Marking

The equipment shall be marked for identification in accordance with the applicable drawings and shall conform to the requirements of ND1002019.

3.5.10.1 Safety Markings

Precautionary markings shall be provided as necessary to warn personnel of hazardous conditions and precautions to be observed to insure the safety of personnel and equipment.

3.5.10.2 Electrical/Electronic Symbols

Electrical and electronic symbols shall be in accordance with the requirements of MIL-STD-15-1.

3.5.10.3 Electrical/Electronic Reference Designations

Electrical and electronic reference designations shall be in accordance with the applicable requirements of MIL-STD-16.

3.5.10.4 Panel Markings

The visible surface adjacent to panel-mounted devices, such as connectors, controls, indicators, switches, and the like, shall be clearly and legibly marked with an appropriate word, phrase, or abbreviation indicating the functional purpose of the part. Abbreviations shall conform to MIL-STD-12.

3.5.11 Storage

Equipment shall meet the storage requirements specified in Paragraph 3.1.2.4 for 36 months without equipment or performance degradation when MEI is in specified containers and IMU temperature is maintained.

4.0 Quality Assurance

The Command Module Airborne G&N Equipment shall be subjected to verification of performance, design, and construction as specified in NPC 250-1, NCP 200-2, and NPC 200-3 and herein as a condition of acceptance of design and development engineering performed under the terms and conditions of the contract. The required verification tests (including inspections, analyses, and demonstrations) fall under two classifications:

a) Phase I Test/Verification. Those tests and analyses required to demonstrate the performance characteristics and design features specified in Section 3 of this specification, exclusive of Phase II Integrated Test Requirements defined below.

b) Phase II Integrated Test Requirement. Those tests required to demonstrate system performance and design characteristics specified in Section 3 of this specification which cannot be verified until the G&N equipment is assembled into the Command Module.

Each requirement in this section is directly correlated to performance, design, and construction requirements of Section 3 by reference and similarity of paragraph titles.

4.1 Phase I Test/Verification

4.1.1 Engineering Test and Evaluation

4.1.1.1 Primary Performance Characteristics Tests

Primary performance characteristics specified in the Performance and Interface Specification shall be verified by means of analyses correlated to the results of functional tests of hardware items (specified in Paragraph 4.1.3.4.1).

4.1.1.2 General Design Features

General design features required by Paragraph 3.3.1 which cannot be verified by inspection (Paragraph 4.1.2.1.) shall be verified by analysis.

4.1.1.3 Electromagnetic Interference Tests

Electromagnetic interference tests required by Paragraph 3.3.9 which cannot be verified by test (Paragraphs 4.1.3.4.4 and 4.2.2.4) shall be verified by analysis.

4.1.1.4 Detailed Interface Tests

Functional interfaces between elements of the G&N equipment and between the G&N equipment and the Spacecraft/Apollo Booster system which cannot be verified by test shall be verified by analysis.

4.1.2 Preliminary Qualification Tests

Preliminary qualification of elements of the G&N equipment, in accordance with NASA approved test plans and procedures, shall be conducted. Preliminary qualification tests shall be identified as prerequisites to specific spacecraft development tests including unmanned flight tests.

4.1.3 Formal Qualification Test

The following subparagraphs specify the requirements for, and the methods of formally verifying that each requirement in Section 3 has been satisfied.

4.1.3.1 Inspection

The following requirements of Section 3 shall be verified by an inspection of the G&N equipment and/or documentation at the time and place of qualification testing:

Paragraph 3.3.2.3: "Service and Access"
Paragraph 3.4.1.1: "Schematic Arrangement"
Paragraph 3.5.1: "General Design Features"
Paragraph 3.5.3: "Materials, Parts, and Processes"
Paragraph 3.5.4: "Standard and Commercial Parts"
Paragraph 3.5.7: "Interchangeability and Replaceability"
Paragraph 3.5.8: "Workmanship"
Paragraph 3.5.10: "Identification and Marking"

4.1.3.2 Analysis

The following requirements of Section 3 shall be verified by review of analytical data:

Paragraph 3.3.2, "Maintainability" - To include a review of the maintenance portion of the "system engineering" documentation and contractor internal documentation analyzing the anticipated modes of failure of the G&N equipment.

Paragraph 3.3.3, "Useful Life" - To include analysis of contractor experience data to date of review and vendor historical and analytical summaries, as well as stress analyses and accomplished on critical assemblies, etc.

4.1.3.3 Demonstrations

The following requirements of Section 3 shall be verified by demonstrations:

Paragraph 3.3.2.1, "Maintenance Requirements"
Paragraph 3.3.2.3, "Service and Access"
Paragraph 3.3.5, "Transportability" - The demonstration shall include a complete preparation for movement, and movement of the G&N equipment.

4.1.3.4 Tests

The following requirements in Section 3 shall be verified during the formal qualificaton test program:

Paragraph 3.1.1, "Functional Characteristics"
Paragraph 3.3.4, "Natural Environment"
Paragraph 3.3.8, "Induced Environmental"
Paragraph 3.5.9, "Electromagnetic Interference"

4.1.3.4.1 Functional Characteristics Tests

The G&N Equipment shall be subjected to tests specified in the appropriate G&N System Final Performance Test Requirements to verify compliance with the requirements of Paragraph 3.1.1.

The results of these tests shall be correlated to the analyses required by Paragraph 4.1.1.1.

4.1.3.4.2 Natural Environment Tests

Satisfactory completion of the tests specified in Paragraph 4.1.3.4.3 will constitute compliance with the Natural Environment requirements of Paragraph 3.3.4.

4.1.3.4.3 Induced Environmental Tests

The G&N Equipment shall be subjected to the following tests in accordance with NASA Apollo Specification ND-1002037:

Temperature - altitude (operating)
Temperature - (nonoperating)
Humidity (operating)
Explosion (operating)
Acceleration - Launch (operating)
Acceleration - Launch (nonoperating)
Acceleration - Entry (operating)
Vibration - Launch (operating)
Vibration - Launch (nonoperating)
Vibration - Flight (operating)
Shock-Flight (operating)
Shock-Earthlanding (nonoperating)

4.1.3.4.4 Electromagnetic Interference

The G&N Equipment when totally assembled shall be tested for susceptibility to EMI and for levels of EMI generation as specified in Specification MIL-I;26600, as amended by MSC-ASPO-EMI-10A, to the degree negotiated with the procuring activity. Flight harnesses shall be used and S/C wiring simulated where required.

4.1.4 Reliability Test and Analyses

Reliability of the G&N Equipment shall be verified by analysis of test data and use data generated in accordance with the requirements of NASA Document NPC-250-1.

4.2 Phase II Integrated Test Requirements

The G&N Equipment shall be subjected to the following system level tests as an integral part of the spacecraft:

Prerequisite Tests
Design Integration Tests
Development Flight Tests
Performance Analyses
Reliability Analyses

4.2.1 Prerequisite Tests

Each set of G&N Equipment shall have successfully met the appropriate System Final Performance Test Requirements prior to being subjected to the system tests specified herein.

4.2.2 Design Integration Tests

The following design integration tests shall be performed utilizing the G&N Equipment and the NAA house or prototype spacecraft and associated G&N Equipment and spacecraft ground checkout equipment.

4.2.2.1 Interface Verification Tests

Compliance with G&N equipment to spacecraft interfaces specified in Paragraph 3.2.1 shall be verified by inspection, installation, and functional tests as specified in the ICDs and associated test requirements.

4.2.2.2 System Performance Tests

System performance tests shall be conducted in accordance with the System Final Performance Test Requirements to determine compliance with the system performance requirements specified in Section 3 of this specification.

4.2.2.3 Environmental Tests

Integrated system environmental tests shall be conducted to determine compliance with the requirements of Paragraphs 3.1.2.4, "Natural Environment" and 3.1.2.8, "Induced Environment".

4.2.2.4 Electromagnetic Interference Tests

Electromagnetic interference tests specified in MIL-I-26600 as amended by MSC-ASPO-EMI-1OA shall be conducted to determine compliance with the requirements of Paragraph 3.3.9, "Electromagnetic Interference".

4.2.2.5 Maintainability Tests

Maintainability tests shall be conducted to determine compliance with the requirements of Paragraph 3.1.2.2, "Maintainability" with respect to access, removal, and replace concepts, service and calibration requirements, etc.

4.2.2.6 Human Performance

The human engineering and performance tests shall be conducted to determine compliance with Paragraph 3.1.2.6, "Human Performance".

4.2.3 Development Flight Tests

Development flight tests, including earth orbit and lunar orbit missions, shall be conducted to verify compliance with the requirements of Paragraph 3.1.1, "Operational Requirements" to the extent specified in the NASA approved Test Plan for each flight.

4.2.4 Performance Analyses

Compliance with the requirements of Paragraph 3.1 "Performance" shall be verified by analysis of equipment performance test data generated during the development program.

4.2.5 Reliability Analyses

Compliance with the requirements of Paragraph 3.1.2.1, "Reliability" shall be verified based upon analysis of reliability data generated during the development program in accordance with NASA Publication NPC 250-1.

5.0 Preparation for Delivery

Not applicable to Part I of this specification.

6.0 Notes

6.1 Supplemental Information

6.1.1 Abbreviations

AGS	Abort Guidance System
CDU	Coupling Data Units
CM	Command Module
CMC	Command Module Computer
CSM	Command and Service Module
D&C	Display and Controls
DSKY	Display and Keyboard
EMI	Electromagnetic Interference
FDAI	Flight Director and Attitude Indicator
G&N	Guidance and Navigation System
IMU	Inertial Measuring Unit
LEM	Lunar Excursion Module
LGC	LEM Guidance Computer
LGE	LEM Guidance Equipment
LES	Launch Escape System
LOI	Lunar Orbit Injection
MEI	Master End Item
MIT	Massachusetts Institute of Technology
MSC	Manned Spacecraft Center (Houston, Texas)
MSFN	Manned Space Flight Network
NAA/S&ID	North American Avaition, Inc. /Space & Information Systems Division
NASA	National Aeronautics and Space Administration
NVB	Navigation Base
PIPA	Pulse Integrating Pendulum Accelerometer
PSA	Power and Servo Assembly

RHC	Rotational Hand Controller
S-IVB	Saturn V, Third Stage
S/C	Spacecraft
SCS	Stabilization and Control System
SCT	Scanning Telescope
SM	Service Module
SPS	Service Module Propulsion System
SXT	Sextant
TLI	Translunar Injection

6.1.2 Astronaut Sighting Uncertainty

Further details on this subject are available in MIT Thesis Report T-385, Human Performance During a Simulated Apollo Midcourse Navigation Sighting, June 1964, by C. Duke and M. Jones.

Appendix A

NOTICE

When Apollo G&N drawings, specifications, or other data are used for any purpose other than in connection with a definitely related NASA procurement operation, NASA hereby incurs no responsibility nor any obligation whatsoever, and the fact that NASA may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other persons or corporation or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.