GUIDANCE, NAVIGATION, AND CONTROL

QUICK REFERENCE DATA

PRIMARY GUIDANCE AND NAVIGATION SECTION

Navigation base	
Weight	3 pounds
Diameter	14 inches
Leg length (approx)	10 inches
Material	Beryllium
Inertial measurement unit	
Weight (approx)	42 pounds
Diameter	12.5 inches
Temperature	+126° F
Alignment optical telescope	
Number of detent positions	6
Field of view of each detent	60°
Counter readout	000.00° to 359.98°
Length	36 inches
Computer control and reticle dimmer assembly	
Height	3-3/8 inches
Width	4-3/8 inches
Depth	2-1/2 inches
Weight	3 pounds
Pulse torque assembly	
Height	2-1/2 inches
Width	11 inches
Depth	13 inches
Weight	15 pounds
Power and servo assembly	
Height	2-5/8 inches
Width	8-7/8 inches
Depth	23-1/2 inches
Weight	20 pounds
Coupling data unit	
Number of channels	5
Height	5-1/2 inches
Width	11-1/3 inches
Depth	20 inches
Weight	35 pounds
LM guidance computer	
Computer type	Automatic, electronic, digital, general-purpose and control
Internal transfer	Parallel (all bits simultaneously)
Memory	Random access
Erasable	Coincident-current core; 2,048-word capacity
Fixed	Core rope; 36,864-word capacity

LM guidance computer (cont)

Word length	16 bits
Number system	Binary 1's complement - for manipulation
Circuitry type	Flat pack, NOR micrologic
Memory cycle time	12 microseconds
Add time	24 microseconds
Basic clock oscillator	2.048 MHz
Power Supplies	One +4-volt and one +14-volt switching regulator; operated from 28-volt d-c input power
Logic	Positive (Positive dc = Binary 1; 0 volts = Binary 0)
Parity	Odd

ABORT GUIDANCE SECTION

Data entry and display assembly	
Height	7.3 inches
Width	6.6 inches
Depth	5.6 inches
Weight	8.4 pounds
Logic levels	Zero: 0 to 0.5 vdc One: +3 to +5 vdc
Clock frequency	128 kpps
Abort electronics assembly	
Computer type	Automatic, electronic, digital, general-purpose
Height	23.7 inches
Width	9.0 inches
Depth	5.0 inches
Weight	32.5 pounds
Power	12.5 watts (standby) 96.0 watts (operate)
Logic levels	Zero: 0 to 0.5 vdc One: +3 to +5 vdc
Clock frequency	1,024 pps
Memory capacity	4,096 words
Fixed	2,048 words
Erasable	2,048 words
Word Size	18 bits
Abort sensor assembly	
Height	5.1 inches
Width	9.0 inches
Depth	13.5 inches
Weight	20.7 pounds (with support)
Clock frequency	128 kpps
Operating temperature	+120° F

CONTROL ELECTRONICS SECTION

Attitude and translation controller assembly	
Input signals	Attitude error, command rate, and rate gyro output
Operating frequency	800 Hz
Cooling	Conduction through mounting flanges
Temperature range	0° to $+160^{\circ}$ F
Rate gyro assembly	
Input power	Single- and three-phase, 800 Hz
Starting power	1.8 watts (maximum; three-phase)
Input range	-25° to $+25^{\circ}$ per second
Input rate frequency	20 ± 4 Hz
Descent engine control assembly	
A-C input power nominal voltage	115 vrms
Operating temperature range	$+57^{\circ}$ to $+97^{\circ}$ F
D-C input power nominal voltage	+4, +15, +28, and -15 volts dc
Total power consumption	7.9 watts (maximum)
Gimbal drive actuator	
A-C power	115 ± 2.5 vrms, single phase, 400 Hz
A-C power consumption (steady-state average)	35 watts
Stroke	+2 to -2 inches $\pm 5\%$
Gimbal position	$+6^{\circ}$ to -6° $\pm 5\%$
Gimbal rate	0.2°/sec $\pm 10\%$
Frequency of operation	5.0 Hz (maximum)
Attitude controller assembly	
Operating power	28 volts, 800 Hz
Type of sensor	Proportional transducer
Displacement	0.28 volt/degree
Thrust/translation controller assembly	
Operating power	28 volts, 800 Hz
Type of sensor	Proportional transducer

LANDING RADAR

Velocity sensor	Continuous-wave, three-beam
Radar altimeter	Frequency modulated/continuous wave (FM/CW)
Altitude capability	10 to 25,000 feet
Velocity capability	From altitude of 18,000 feet
Weight (approx)	39 pounds
Power consumption	125 watts dc (nominal)
	147 watts dc (maximum)
Heater power consumption	44 watts dc (maximum)
Altimeter antenna	
Type	Planar array, space-duplexed
RF power	100 mw (minimum)
Velocity sensor antenna	
Type	Planar array, space-duplexed
RF power	200 mw (minimum)
Transmitter frequency	
Velocity sensor	10.51 gHz
Radar altimeter	9.58 gHz
Warmup time	1 minute
FM sweep duration	0.007 second
Acquisition time	12 seconds (maximum)
Primary power	25 to 31.5 volts dc (nominal)
	3.5 to 6.5 amperes
Temperature range	
Electronics assembly	-20° to $+110^{\circ}$ F
Antenna assembly	$+50^{\circ}$ to $+150^{\circ}$ F

RENDEZVOUS RADAR AND TRANSPONDER

Rendezvous radar	
Radar radiation frequency	9832.8 mHz
Radar received frequency	9792.0 mHz ± Doppler
Radiated power	300 mw (nominal)
Antenna design	Cassegrainian
Angle tracking method	Amplitude monopulse
Antenna diameter	24 inches
Antenna beamwidth	4.0°
Gyroscopes	4 (two redundant)
Modulation	Phase modulation by three tones: 200 Hz, 6.4 kHz, and 204.8 kHz
Receiver channels	Reference, shaft (pitch), and trunnion (yaw)
Receiver intermediate frequencies	40.8, 6.8, and 1.7 mHz
Range	80 feet to 400 nm
Range accuracy	1% or 80 feet for ranges between 80 feet and 5 nm; or 300 feet for ranges between 5 and 400 nm
Range data output	15-bit serial format
Range rate	+4,900 to -4,900 fps
Range rate accuracy	±1 fps
Complete acquisition time	15 seconds
Angular accuracy	
5 to 400 nm	0.12° to 0.24°
Transponder	
Weight	16.0 pounds
Antenna	4-inch Y-horn, linearly polarized 12-inch interconnecting waveguide
Transmit frequency	9792 mHz
Receive frequency	9832.8 mHz ± one-way Doppler
Radiated power	300 mw
Acquisition time	1.8 seconds with 98% probability
Intermediate frequencies	
First IF	40.8 mHz
Second IF	6.8 mHz
Modulation	Phase modulation by three tones (200 Hz, 6.4 kHz, 204.8 kHz)
Range	80 feet to 400 nm
Range accuracy	Equal to maximum ranging error
Range rate accuracy	0.25% or 1 fps (whichever is greater)
Input power	75 watts
Heater	20 watts (maximum)

The LM is designed to take two astronauts from the orbiting CSM to the lunar surface and back again. The primary function of the Guidance, Navigation, and Control Subsystem (GN&CS) is accumulation, analysis, and processing of data to ensure the LM follows a predetermined flight plan at all times. To perform these functions, the guidance portion must know present position and velocity with respect to the guidance goal. The GN&CS provides navigation, guidance, and flight control to accomplish the specific guidance goal.

The astronaut is an active and controlling element of the LM. He can monitor information to and from the various LM subsystems and can manually duplicate the various control functions. During completely automatic flight, the astronaut functions as a monitor and decision maker; during semiautomatic flight, he is a controlling influence on the automatic system; and during manually controlled flight he may perform all GN&CS functions himself. The astronaut can also initiate an optical sighting program, utilizing celestial objects to align the guidance equipment.

Using cabin displays and controls, the astronaut can select modes of operation necessary to perform a desired function. In some mission phases, sequencing of modes of operation is automatically controlled by a computer. As calculations are performed by the computer, the results are displayed for astronaut evaluation and verification with ground-calculated data.

In the event of failure of automatic control, the astronaut manually controls the LM and performs vehicle flight control normally performed by the computer. He does this with a pair of hand controllers, which control attitude and translation, and with other controls on the cabin panels.

For purposes of the following discussion, a distinction is made between guidance (orbital alteration or redirection of the LM) and navigation (accumulation and processing of data to define the proper guidance to be accomplished).

NAVIGATION AND THE LUNAR MODULE

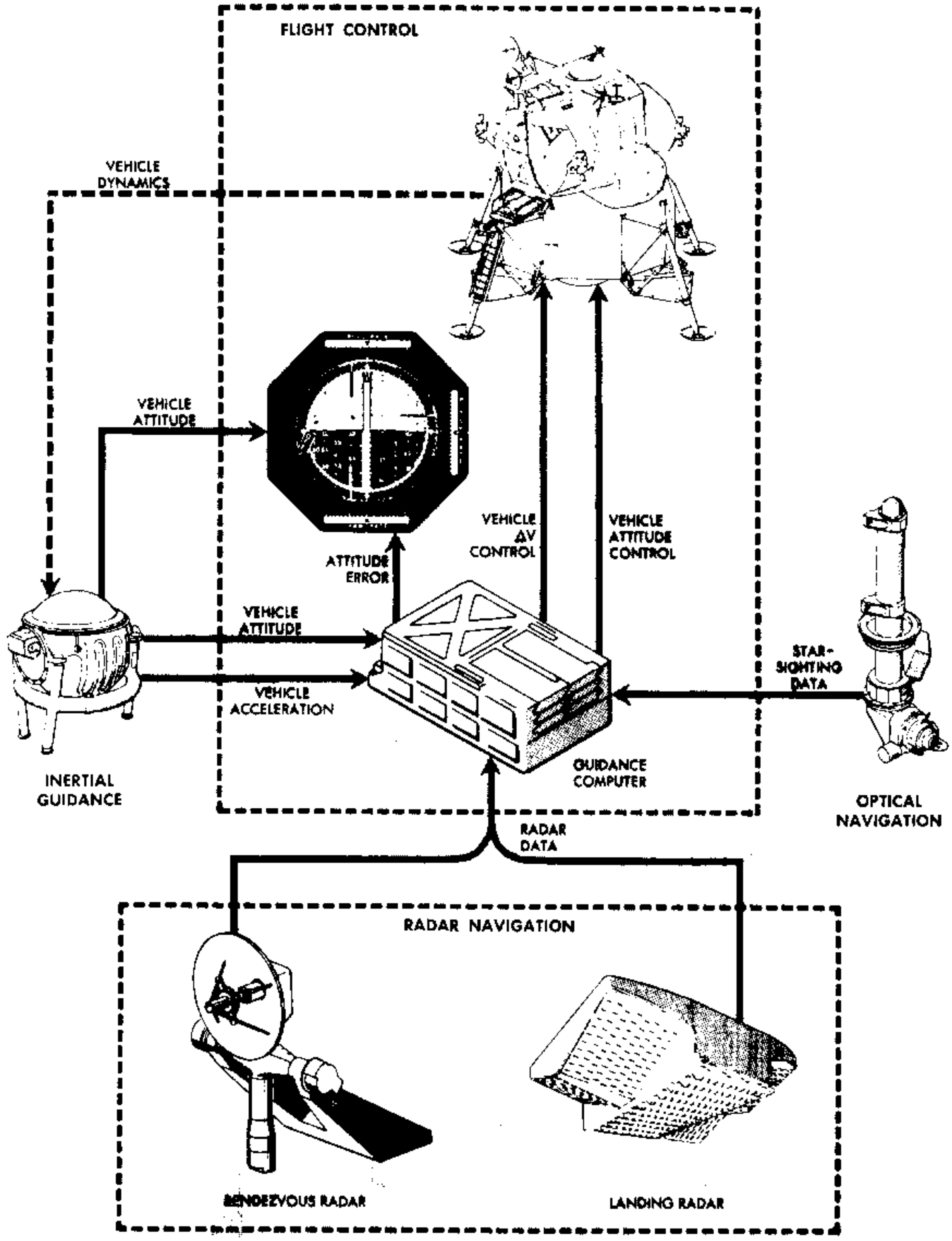
LM navigation involves the determination of the vehicle's present position and velocity so that the guidance function can plot the trajectory that the LM must follow.

When flying an aircraft between two points on earth, both points remain fixed with respect to each other. In spaceflight, however, the origin of the spacecraft's path and its distination or target are moving rapidly with respect to each other.

To determine the present position of the LM, celestial navigation is used to align the guidance system. This is accomplished by determining the vehicle's position in relation to certain fixed stars. Even though the stars may be moving, the distance that they move in relation to the total distance of the stars from the vehicle is so small that the stars can be thought of as being stationary.

The optical device which the astronauts use for navigation is an alignment optical telescope (AOT) protruding through the top of the vehicle and functioning as a sextant. The astronauts use it to take direct visual sightings and precise angular measurements of pairs of celestial objects. These measurements are transferred by the astronaut to the guidance elements to compute the position and velocity of the vehicle and to perform alignment of an inertial guidance system. There is a direct relationship between the angular measurements taken with the telescope and the mounting position of the telescope. The computer program knows the telescope's mounting position which is in alignment with the LM body axes and from this knowledge and astronaut-generated information, the computer is able to calculate the LM position.

During the landing phase and subsequent rendezvous phase, the LM uses radar navigational techniques to determine distance and velocity. Each phase uses a radar designed specifically for that phase (rendezvous radar, landing radar). Both radars inform the astronaut and the computer concerning position and velocity relative to acquired target. During lunar landing, the target is the surface of the moon; during rendezvous, the target is the Command Module.



H-44

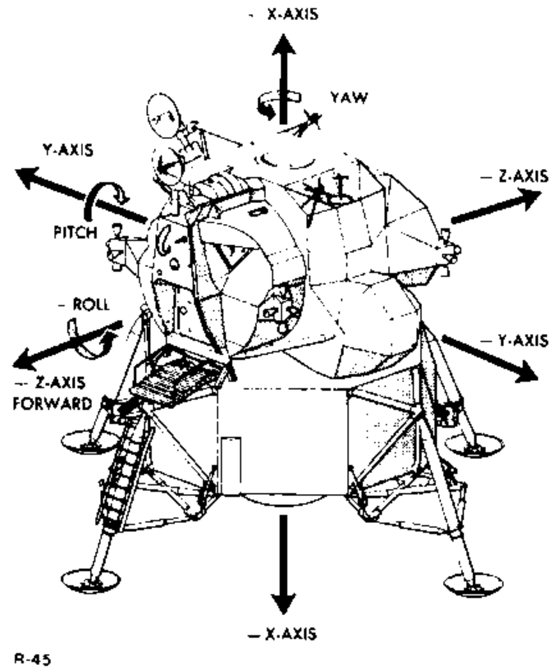
Guidance, Navigation, and Flight Control Functions

GUIDANCE AND THE LUNAR MODULE

After the position and velocity of the LM are determined, the guidance function establishes the steering for the predetermined flight path. Since objects in space are moving targets (as compared to those on earth, which are stationary), the guidance problem involves aiming not at the target's present position but at the position in which it will be when the vehicle path intersects the target path. On earth, the guidance problem is a two-dimensional one; it involves only longitude and latitude. In space, a third dimension is introduced; position cannot be plotted in earth terms.

To calculate the guidance parameters, a reference coordinate frame must be determined. A three-axis, right-hand, orthogonal, coordinate frame (inertial reference frame) is used. It is fixed in space and has an unchanging angular relationship with the stars. Its dimensional axes are designated as X, Y, and Z, and all spacecraft positions and velocities are related to this frame. The astronaut establishes this frame by sighting of celestial objects using the AOT. The vertical axis is designated as the X-axis. Its positive direction is from the descent stage to the ascent stage, passing through the overhead hatch. The lateral axis is designated as the Y-axis. Its positive direction is from left to right across the astronauts shoulders when they are facing the windows in the LM cabin. To complete the three three-axis orthogonal system, the Z-axis is perpendicular to the X and Y axes. This axis is referred to as the forward axis, because +Z-axis direction is through the forward hatch. The +Z-axis is also used as the zero reference line for all angular measurements.

The guidance system based on this coordinate frame is referred to as an inertial guidance system. Inertial guidance provides information about the actual path of the vehicle in relation to a predetermined path. All deviations are transmitted to a flight control system. The inertial guidance system performs these functions without information from outside the vehicle. The system stores the predetermined flight plan, then automatically but not continuously, computes distance and velocity for a given mission time (called the state vector) of the vehicle to compensate, through vehicle control, for changes in direction.



LM Vehicle Axes

Inertial guidance systems are based on measurements made by accelerometers mounted on a structure called the stable member or platform. The stable member, in turn, is mounted inside three spherical gimbals, one for each principal axis of motion. Gyroscopes mounted on the stable member drive the gimbals to isolate the stable member from changes in LM attitude and hold the stable member in a fixed inertial position.

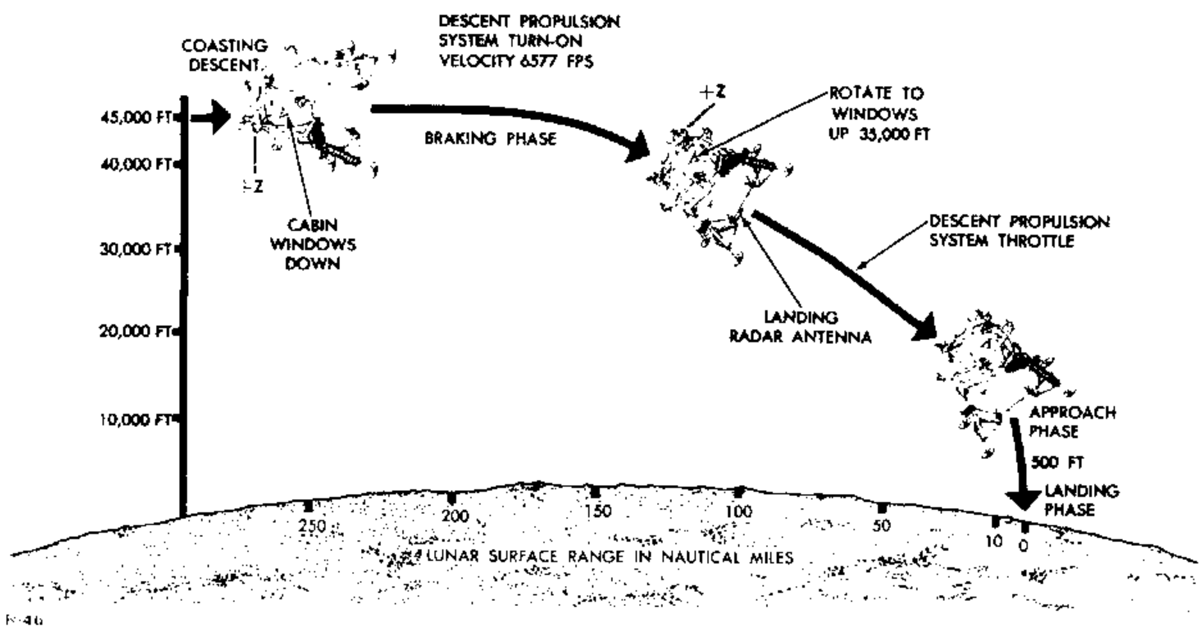
During flight, the stable member's axes must be held in fixed relation to the inertial reference frame regardless of the LM motion; otherwise resolvers mounted on each gimbal issue error signals. These error signals are used by the computer to generate commands to correct the attitude of the LM. The rotational axes of the LM are designated as yaw, pitch, and roll. Yaw rotation, about the X-axis affects the vehicle in the Y-Z plane. The effect is analogous to spinning around one's heels. Pitch rotation, about the Y-axis, affects the vehicle in the X-Z plane. The effect is analogous to a gymnast performing a somersault. Roll rotation, about the Z-axis, affects the vehicle in the X-Y plane. The effect is analogous to a person doing a cartwheel. Positive rotation is determined by the right-hand rule. This involves placing the thumb of the right hand in the positive direction of the axis about which rotation is to be determined. Then the remainder of the fingers are curled around the axis. The direction in which the fingers point is considered the direction of positive rotation.

FLIGHT CONTROL AND THE LUNAR MODULE

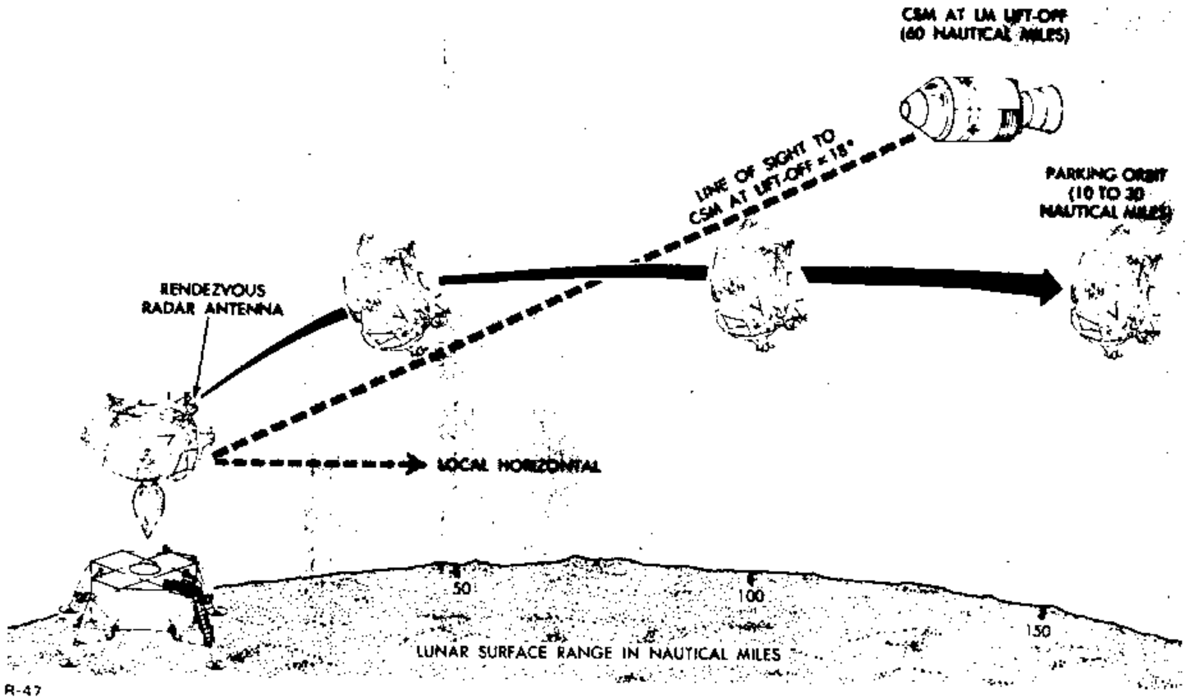
Flight control involves controlling the LM trajectory (flight path) and attitude. Flight path control depends on the motion of the LM center of gravity; attitude control primarily involves rotations about the center of gravity.

In controlling the LM in its flight path, the thrust of its engines must be directed so that it produces a desired variation in either magnitude or direction to place the LM in some particular orbit, position, or attitude. The major velocity changes associated with the lunar orbit, injection, landing, and ascent phases of the mission are accomplished by either the descent propulsion section or ascent propulsion section of the Main Propulsion Subsystem (MPS). The engines can produce high thrust in specific directions in inertial space.

During the descent phase, the LM must be slowed (braked) to place it in a transfer orbit from which it can make a soft landing on the lunar surface. To accomplish braking, descent engine thrust is controllable so that the precise velocity (feet per second) necessary to alter the vehicle's trajectory can be achieved. For a soft landing on the lunar surface, the weight of the LM must be matched by an upward force so that a state of equilibrium exists, and from this point, the descent engine is shut off and the LM free falls to the lunar surface. The thrust of the descent engine provides this upward force, and since the weight of the vehicle is a variable (due to consumption of expendables) this is another reason why the magnitude of the engine thrust is controllable. In addition, the center of gravity is also variable and the thrust must be such that it is in line with the LM center of gravity. This is accomplished by gimbaling (tilting) the descent engine.



LM Powered Descent Profile



LM Powered Ascent Profile

During the lunar ascent phase, the flight control portion of the GN&CS commands the ascent engine. In this phase, control of the thrust direction is not achieved by gimbaling the engine, but by attitude control, using the Reaction Control Subsystem (RCS) thruster. This is necessary during ascent to keep the vehicle stabilized, because the center of gravity changes due to propellant depletion. The ascent engine is not throttleable, since the function of this engine is to lift the ascent stage from the lunar surface and conduct rendezvous. The proper orbit for rendezvous is achieved by means of a midcourse correction (if necessary) in which thrust directed by attitude control, and thrust magnitude is controlled by controlling the duration of the burn.

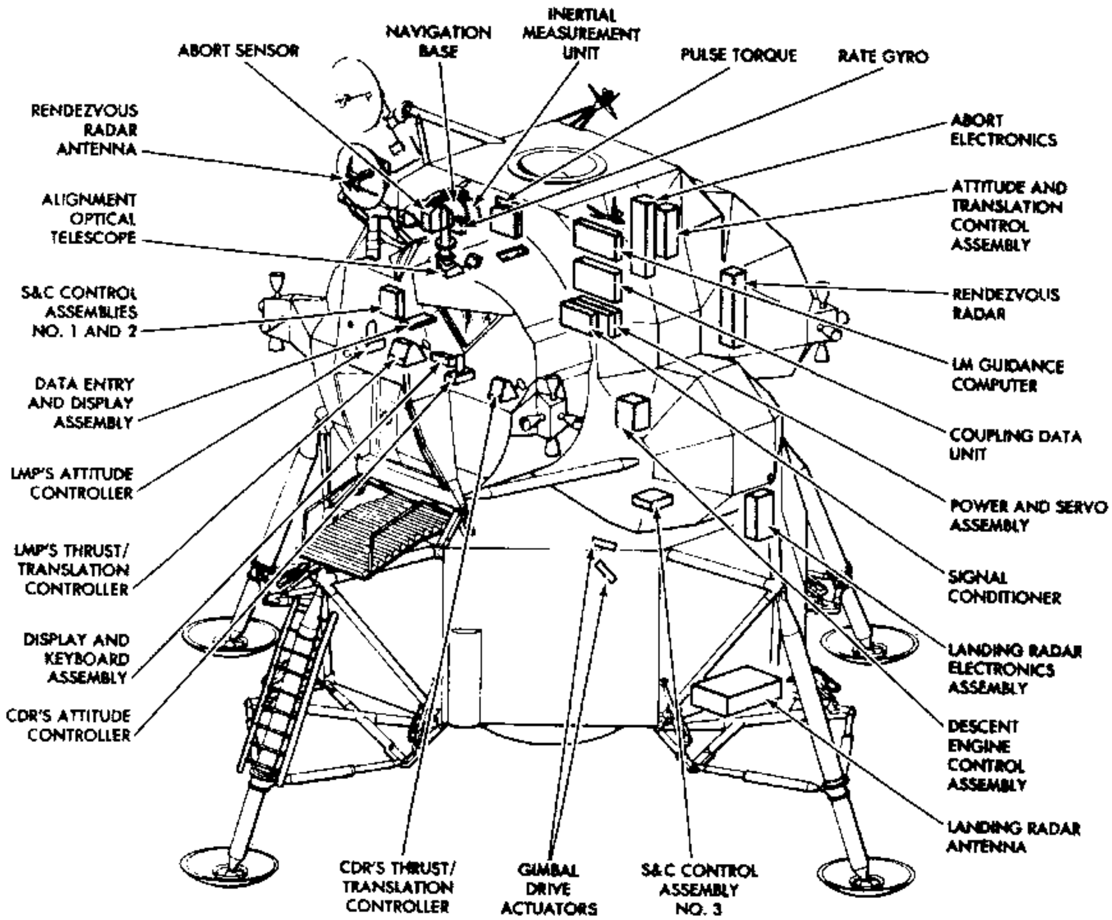
It is apparent then for flight control, that some measure of the LM velocity vector and its position must be determined at all times for purposes of comparison with a desired (predetermined) velocity vector, at any particular instant, to generate an error signal if the two are not equal. The flight control portion of the primary guidance and navigation section then directs the thrust to reduce the error to zero.

Attitude control maintains the LM body axes in a fixed relationship to the inertial reference axes. Any pitch, roll, or yaw rotations of the vehicle produce a misalignment between the LM axes and where the LM axes should be. This is called attitude error and is detected by the inertial guidance system, which, in turn, routes the errors to the computer. The computer generates on and off commands for the RCS to reduce the error to zero. Attitude control is implemented through 16 rocket engine thrusters (100-pounds thrust each) equally distributed in clusters of four around the ascent stage. Each cluster is located so that it will exert sufficient torque to rotate the LM about its center of gravity. The thrusters are capable of repeated starts and very short (fraction of second) firing times. The appropriate thrusters are selected by the computer during automatic operation and manually by the astronaut during manual operation.

GUIDANCE, NAVIGATION, AND CONTROL SUBSYSTEM

To accomplish guidance, navigation, and control, the astronauts use 55 switches, 45 circuit breakers, and 13 indicators which interface with the various GN&CS equipment. This equipment is functionally contained in a primary guidance and navigation section, an abort guidance section, a control electronics section, and in the landing and rendezvous radars.

The primary guidance and navigation section (PGNS) provides, as the name implies, the primary means for implementing inertial guidance and optical navigation for the LM. When aided by either the rendezvous radar or the landing radar, the section provides for radar navigation. The section when used in conjunction with the control electronics section (CES) provides automatic flight control. The astronauts can supplement or override automatic control, with manual inputs.

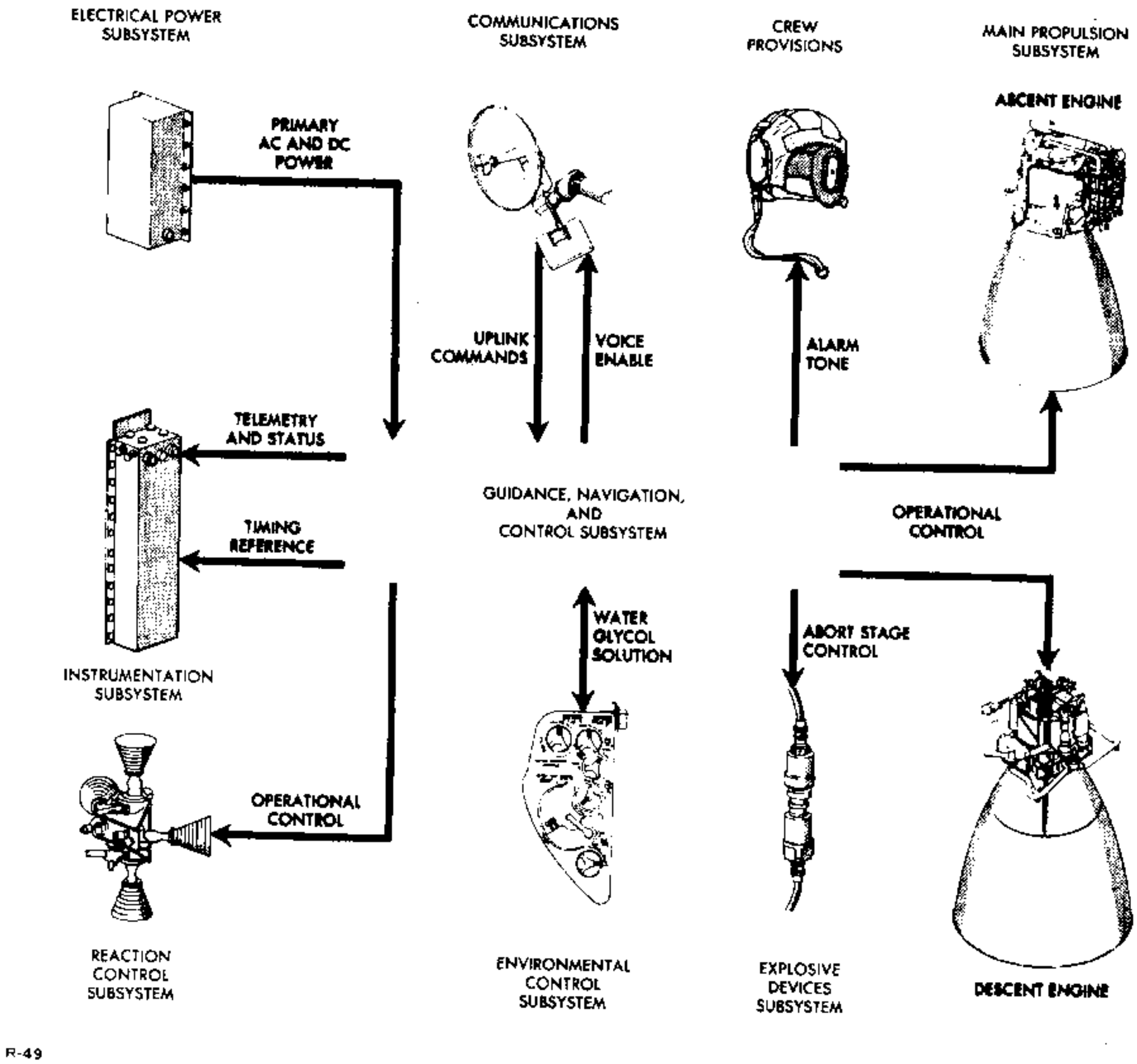


R-48

Guidance, Navigation, and Control Major Equipment Location

The abort guidance section (AGS) is primarily used only if the primary guidance and navigation section malfunctions. If the primary guidance and navigation section is functioning properly when a mission is aborted, it is used to control the LM. Should the primary section fail, the lunar mission would have to be aborted; thus, the term "abort guidance section." Abort guidance provides only guidance to place the LM in a rendezvous trajectory with the CSM or in a parking orbit for CSM-active rendezvous. The navigation function is performed by the primary section, but the navigation information also is supplied to the abort section. In case of a primary guidance malfunction, the abort guidance section uses the last navigation data provided to it. The astronaut can update the navigation data by manually inserting rendezvous radar data into the abort guidance section.

These integrated sections allow the astronauts to operate the LM in fully automatic, several semi-automatic, and manual control modes.



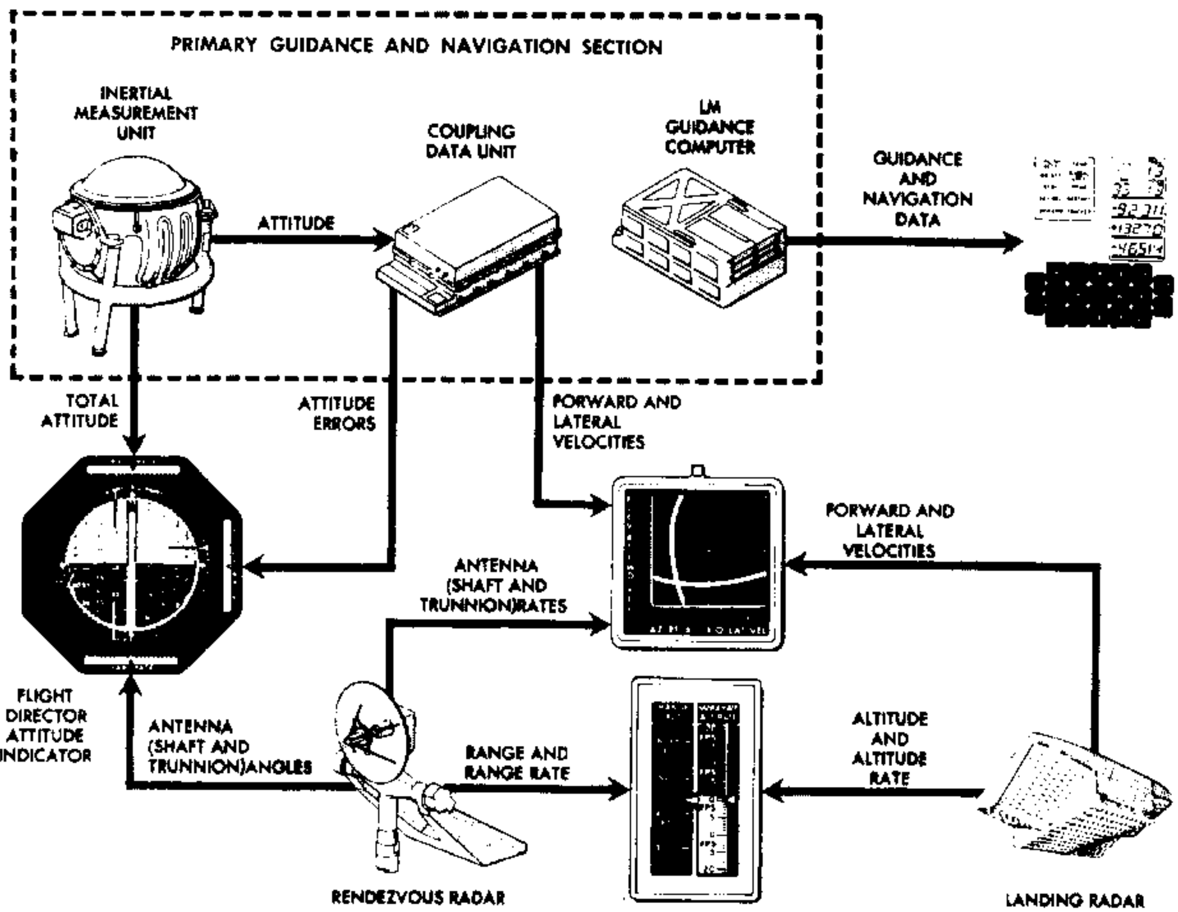
GN&CS Relationship to Other Subsystems

Because the astronauts frequently become part of the control loop in this highly flexible system, a great deal of information must be displayed for their use. These displays include attitude and velocity, radar data, fuel and oxidizer parameters, caution and warning information, total velocity change information, timing and other information to assist them in completing their mission.

PRIMARY GUIDANCE AND NAVIGATION SECTION

The primary guidance and navigation section acts as an autopilot in controlling the LM throughout the mission. Normal guidance requirements include transferring the LM from a lunar orbit to its descent profile, achieving a successful landing at a preselected or crew-selected site, and performing a powered ascent maneuver which results in terminal rendezvous with the CSM. If the mission is to be aborted, the primary guidance and navigation section performs guidance maneuvers that place the LM in a parking orbit or in a trajectory that intercepts the CSM.

The navigational functional requirement of the section is that it provides the navigational data required for LM guidance. These data include line-of-sight (LOS) data from the AOT for inertial reference alignment, signals for initializing and aligning the abort guidance section, and data to the astronauts for determining the location of the computed landing site.



H-50

Primary Guidance Data Displayed

GN-13

The primary guidance and navigation section includes three major subsections: inertial, optical, and computer. Individually or in combination they perform all the functions mentioned previously.

The inertial subsection establishes the inertial reference frame that is used as the central coordinate system from which all measurements and computations are made. The inertial subsection measures attitude and incremental velocity changes, and assists in converting data for computer use, onboard display, or telemetry. Operation is started automatically by the guidance computer or by an astronaut using the computer keyboard. Once the subsection is energized and aligned to the inertial reference, any LM rotation (attitude change) is sensed by the stable member. All inertial measurements (velocity and attitude) are with respect to the stable member. These data are used by the computer in determining solutions to the guidance problems.

The optical subsection is used to determine the position of the LM, using a catalog of stars stored in the computer and celestial measurements made by an astronaut. The identity of celestial objects is determined before earth launch. The AOT is used by the astronaut to take direct visual sightings and precise angular measurements of a pair of celestial objects. The computer subsection uses this data along with prestored data to compute position and velocity and to align the inertial components.

The computer subsection, as the control and data processing center of the LM, performs all the guidance and navigation functions necessary for automatic control of the path and attitude of the vehicle. For these functions, the GN&CS uses a digital computer. The computer is a control computer with many of the features of a general-purpose computer. As a control computer, it aligns the stable member and positions both radar antennas. It also provides control commands to both radars, the ascent engine, the descent engine, the RCS thrusters, and the LM cabin displays. As a general-purpose computer, it solves guidance problems required for the mission.

ABORT GUIDANCE SECTION

The abort guidance section is used as backup for the primary guidance and navigation section during a LM mission abort. It determines the LM trajectory or trajectories required for rendezvous with the CSM and can guide the LM from any point in the mission, from LM-CSM separation to LM-CSM rendezvous and docking, including ascending from the lunar surface. It can provide data for altitude displays, and making explicit guidance computations and also issue commands for firing and shutting down engines. Guidance can be accomplished automatically or manually by the astronauts, based on data from the abort guidance section.

The abort guidance section is an inertial system rigidly strapped to the LM rather than mounted on a stabilized platform. Use of the strapped-down inertial system, rather than a gimbaled system, offers sufficient accuracy for LM missions, at savings in size and weight. Another feature is that it can be updated with radar and optical aids.

CONTROL ELECTRONICS SECTION

The control electronics section processes RCS and MPS control signals for vehicle stabilization and control. To stabilize the LM during all phases of the mission the control electronics section provides signals that fire any combination of the 16 RCS thrusters. These signals control attitude and translation about or along all axes. The attitude and translation control data inputs originate from the primary guidance and navigation section during normal automatic operation from two hand controllers during manual operations, or from the abort guidance section during certain abort situations.

The control electronics section also processes on and off commands for the ascent and descent engines, and routes automatic and manual throttle commands to the descent engine. Trim control of the gimbaled descent engine is also provided to assure that the thrust vector operates through the LM center of gravity.

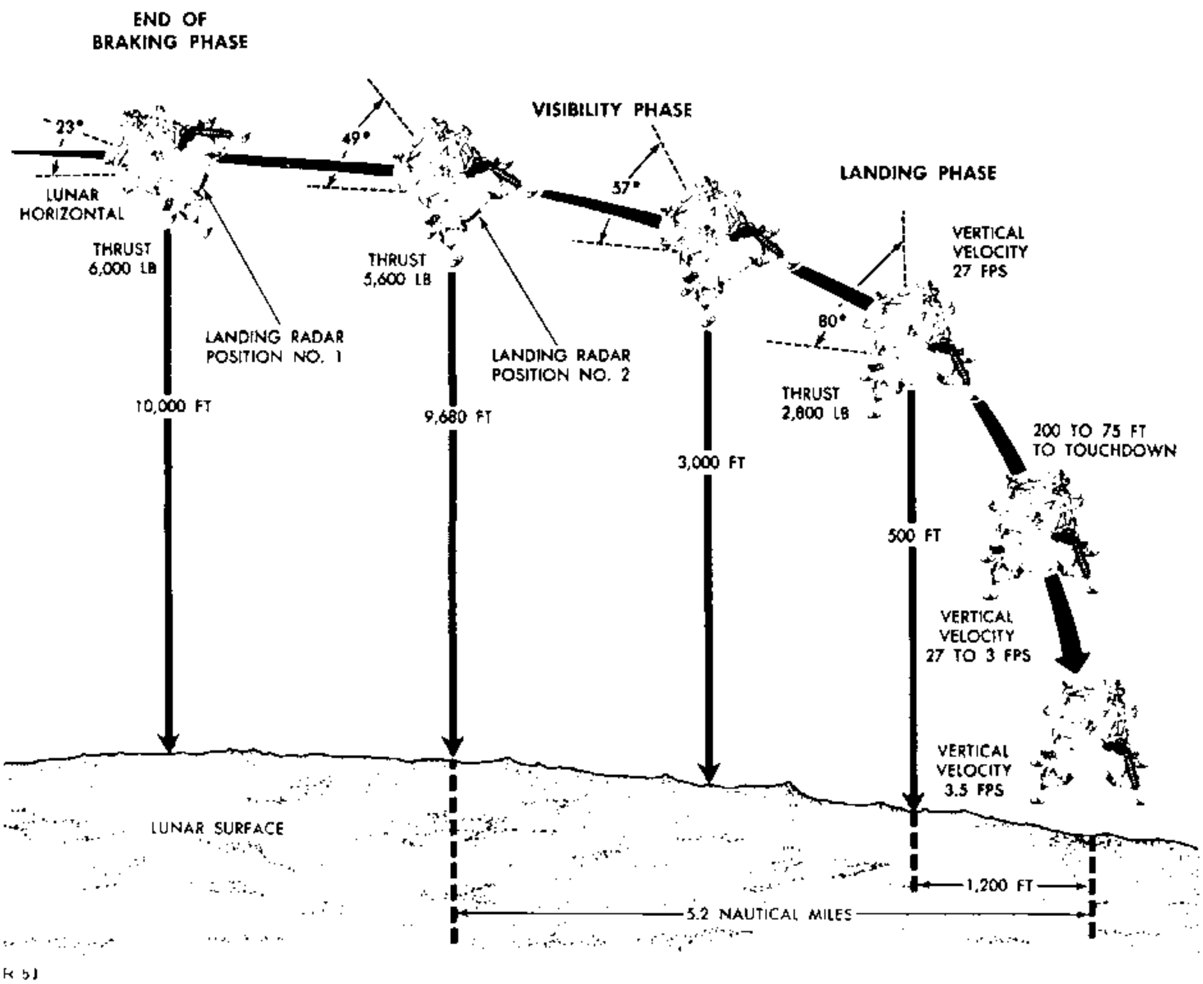
LANDING RADAR

The landing radar, located in the descent stage, provides altitude and velocity data during lunar descent. The primary guidance and navigation section calculates control signals for descent rate, hovering, and soft landing. Altitude data begins at approximately 25,000 feet above the lunar surface; velocity data, at approximately 18,000 feet.

The landing radar uses four microwave beams; three to measure velocity by Doppler shift continuous wave, one to measure altitude by continuous-wave frequency modulation.

RENDEZVOUS RADAR

The rendezvous radar, operated in conjunction with a CSM transponder, acquires and tracks the CSM before and during rendezvous and docking. The radar, located in the ascent stage, tracks the CSM during the descent phase of the mission to supply tracking data for any required abort maneuver and during the ascent phase to supply data for rendezvous and docking. When the radar tracks the CSM, continuous measurements of range, range rate, angle, and angle rate (with respect to the LM) are provided simultaneously to the primary guidance and navigation section



Nominal Descent Trajectory from High Gate to Touchdown and to LM cabin displays. This allows rendezvous to be performed automatically under computer control, or manually by the astronauts. During the rendezvous phase, rendezvous radar performance is evaluated by comparing radar range and range rate tracking values with MSFN tracking values.

The CSM transponder receives an X-band three-tone phase-modulated, continuous-wave signal from the rendezvous radar, offsets the signal by a specified amount, and then transmits a phase-coherent carrier frequency for acquisition by the radar. This return signal makes the CSM appear as the only object in the radar field of view. The transponder provides the long range (400 nm) required for the mission.

The transponder and the radar use solid-state varactor frequency-multiplier chains as transmitters, to provide high reliability. The radar antenna is space stabilized to negate the effect of LM motion on the line-of-sight angle. The gyros used for this purpose are rate-integrating types; in the manual mode they also supply accurate line-of-sight, angle-rate data for the astronauts. Range rate is determined by measuring the two-way Doppler frequency shift on the signal received from the transponder. Range is determined by measuring the time delay between the received and the transmitted three-tone phase-modulated waveform.

FUNCTIONAL DESCRIPTION

The GN&CS comprises two functional loops, each of which is an independant guidance and control path. The primary guidance path contains elements necessary to perform all the functions required to complete the LM mission. If a failure occurs in this path the abort guidance path can be substituted. To understand these two loops, the function of each major component of GN&CS equipment must be known.

PRIMARY GUIDANCE AND NAVIGATION SECTION

INERTIAL SUBSECTION

The inertial subsection consists of a navigation base, an inertial measurement unit, a coupling data unit, pulse torque assembly, power and servo assembly, and signal conditioner assembly.

The navigation base is a lightweight mount that supports in accurate alignment, the inertial measurement unit (IMU), the AOT, and an abort sensor assembly (part of the abort guidance section). Structurally, it consists of a center ring with four legs that extend from either side of the ring. The inertial measurement unit is mounted to the legs on one end and the telescope and the abort sensor assembly are mounted on the opposite side.

The inertial measurement is the primary inertial sensing device of the LM. It is a three-degree-of-freedom, stabilized device that maintains an orthogonal, inertially referenced coordinate system for LM attitude control and maintains three accelerometers in the reference coordinate system for accurate measurement of velocity changes.

The coupling data unit converts and transfers angular information between the navigation and guidance hardware. The unit is an electronic device that performs analog-to-digital and digital-to-analog conversions. The coupling data unit processes the three attitude angles associated with the inertial reference and the two angles associated with the rendezvous radar antenna.

The pulse torque assembly supplies inputs to, and processes outputs from, the inertial components in the inertial subsection.

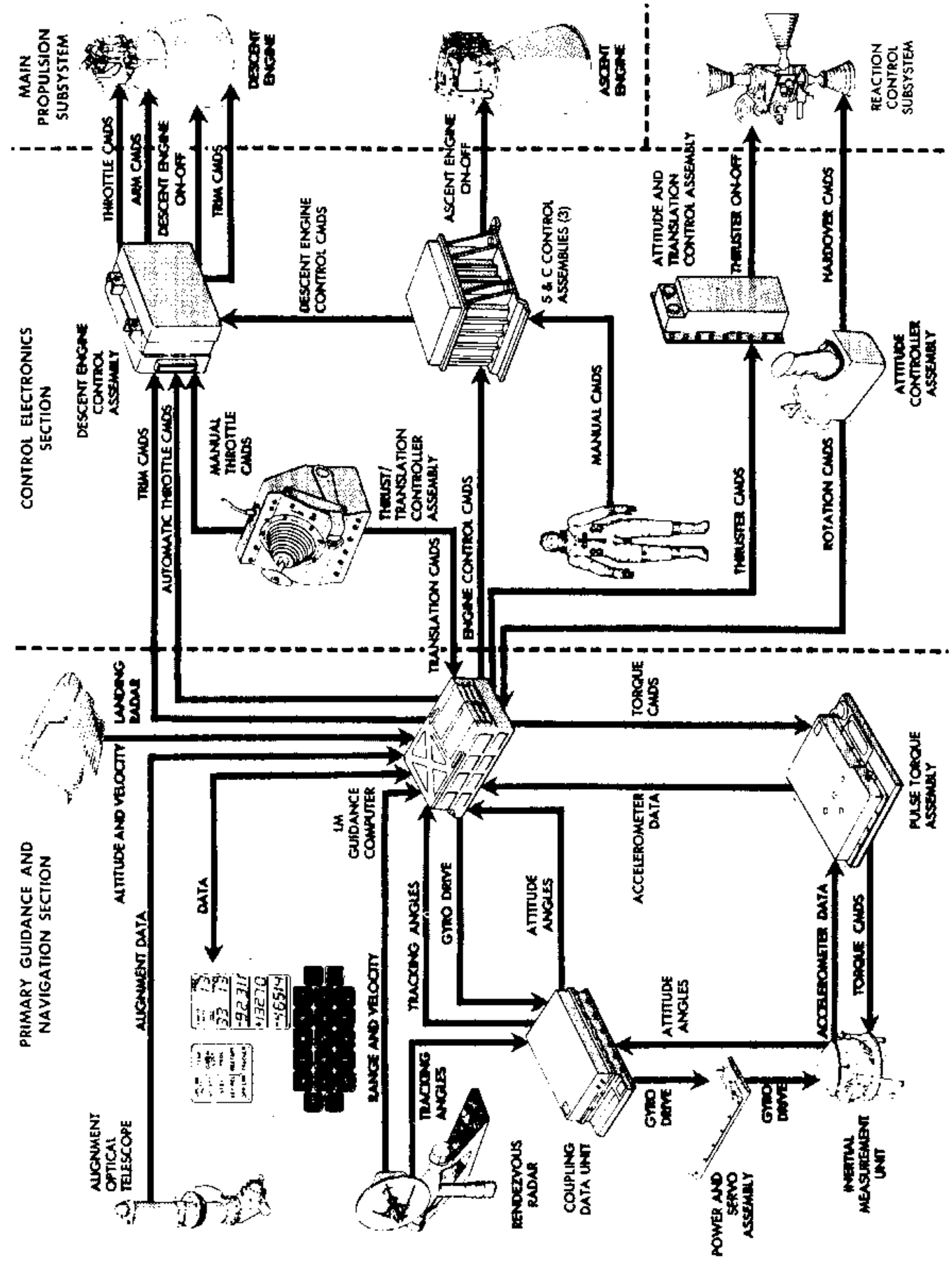


Diagram of Primary Guidance Path

Grumman

GN-17

The power and servo assembly contains electronic equipment in support of the primary guidance and navigation section: power supplies for generation of internal power required by the section, servomechanisms for the inertial measurement unit, and temperature control circuitry for the inertial measurement unit.

The signal conditioner assembly provides an interface between the primary guidance and navigation section, and the Instrumentation Subsystem (IS).

OPTICAL SUBSECTION

The optical subsection consists of the alignment optical telescope and a computer control and reticle dimmer assembly.

The alignment optical telescope, an L-shaped periscope approximately 36 inches long, is used by the astronaut to take angular measurements of celestial objects. These angular measurements are required for orienting the stable member during certain periods while the LM is in flight and during prelaunch preparations while on the lunar surface. Sightings taken with the telescope are transferred to the computer by the astronaut using the computer control and reticle dimmer assembly. This assembly also controls the brightness of the telescope reticle pattern.

COMPUTER SUBSECTION

The computer subsection consists of the LM guidance computer (LGC) and a display and keyboard, which is a computer control panel. The display and keyboard is commonly referred to as "the DSKY" (pronounced "disky").

The guidance computer processes data and issues discrete control signals for various subsystems. It is a control computer with many of the features of a general-purpose computer. As a control computer, it aligns the inertial measurement unit stable member and provides rendezvous radar antenna drive commands. The LGC also provides control commands to the landing and rendezvous radars, the ascent and descent engines, the RCS thrusters, and the cabin displays. As a general purpose computer, it solves guidance problems required for the mission. In addition, the guidance computer monitors the operation of the primary guidance and navigation section.

The guidance computer stores data pertinent to the ascent and descent flight profiles that the LM must assume to complete its mission. These data (position, velocity, and trajectory information) are used by the computer to solve flight equations. The results of various equations are used to determine the required magnitude and direction of thrust. The computer establishes corrections to be made. The LM engines are turned on at the correct time, and steering commands are controlled by the computer to orient the LM to a new trajectory, if required. The inertial subsection senses acceleration and supplies velocity changes to the computer for calculating total velocity. Drive signals are supplied from the computer to the coupling data unit and stabilization gyros in the inertial subsection to align the gimbal angles in the inertial measurement unit. Stable-member position signals are supplied to the computer to indicate attitude changes.

The computer provides drive signals to the rendezvous radar for antenna positioning and receives, from the rendezvous radar channels of the coupling unit, antenna angle information. The computer uses this information in the antenna-positioning calculations. During lunar-landing operations, star-sighting information is manually loaded into the computer, using the DSKY. This information is used to calculate alignment commands for the inertial measurement unit. The LM guidance computer and its programming help meet the functional requirements of the mission. The functions performed in the various mission phases include both automatic and semiautomatic operations that are implemented mostly through the execution of the programs stored in the computer memory.

The DSKY provides a two-way communications link between the astronauts and the LM guidance computer. The astronauts are able to insert various parameters into the computer, display data from the computer, and to monitor data in the computer's memory.

ABORT GUIDANCE SECTION

The abort guidance section consists of an abort sensor assembly, a data entry and display assembly (DEDA), and an abort electronics assembly. The data entry and display assembly is commonly referred to as "the DEDA" (pronounced "deeda").

The abort sensor assembly, by means of gyros and accelerometers, provides incremental attitude information around the LM X, Y, and Z axes and incremental velocity changes along the LM X, Y, and Z axes. Data pulses are routed to the abort electronic assembly, which uses the LM attitude and velocity data for computation of steering errors.

The DEDA is used by the astronauts to select the desired mode of operation, insert the desired targeting parameters, and monitor related data throughout the mission. To select a mode of operation or insert data, three digits (word address) then a plus (+) or minus (-), and finally, a five digit code must be entered. If this sequence is not followed, an operator error light goes on when the enter pushbutton is pressed. To read out any parameter, three digits (address of the desired word) must be entered and a readout pushbutton pressed.

The abort electronics assembly, by means of special input-output subassemblies, interfaces the abort guidance secton with the other LM subsystems and displays. This assembly is basically a general-purpose digital computer, which solves guidance and navigation problems. Mode and submode entries coupled from the data entry and display assembly determine the operation of the computer. The computer uses incremental velocity and attitude inputs from the abort sensor assembly to calculate LM position, attitude, and velocity in the inertial reference frame. It routes altitude and altitude rate data to altitude and altitude rate indicators; out of plane velocity data, to X-pointer indicators. Also, roll, pitch and yaw steering error signals are routed to flight director altitude indicators.

Engine-on commands are routed to the appropriate engine via the control electronics section when the following occur: an abort or abort stage pushbutton is pressed, appropriate switches are set, necessary data are entered into the DEDA, and velocity-to-be-gained exceeds a predetermined threshold (currently 2.1 fps). At the appropriate time, as determined by velocity-to-be-gained, an engine-off command is sent.

CONTROL ELECTRONICS SECTION

The control electronics section comprises two attitude controller assemblies, two thrust/translation controller assemblies, an attitude and translation control assembly, a rate gyro assembly, descent engine control assembly, and three stabilization and control (S&C) control assemblies.

The attitude controller assemblies are right-hand pistol grip controllers, which the astronauts use to command changes in LM attitude. These controllers function in a manner similar to an aircraft's "control stick". Each is installed with its longitudinal axis approximately parallel to LM X-axis; vehicle rotations correspond to astronaut hand movements.

The thrust/translation controller assemblies are left hand controllers used by the astronauts to control LM translation in any axis. Vehicle translations correspond approximately to the astronauts hand movements.

The attitude and translation control assembly routes the RCS thruster on and off commands from the guidance computer to the thrusters, in the primary control mode. During abort guidance control, the assembly acts as a computer in determining which RCS thrusters are to be fired.

The rate gyro assembly is used during abort guidance control to supply the attitude and translation control assembly with damping signals to limit vehicle rotation rates and to facilitate manual rate control.

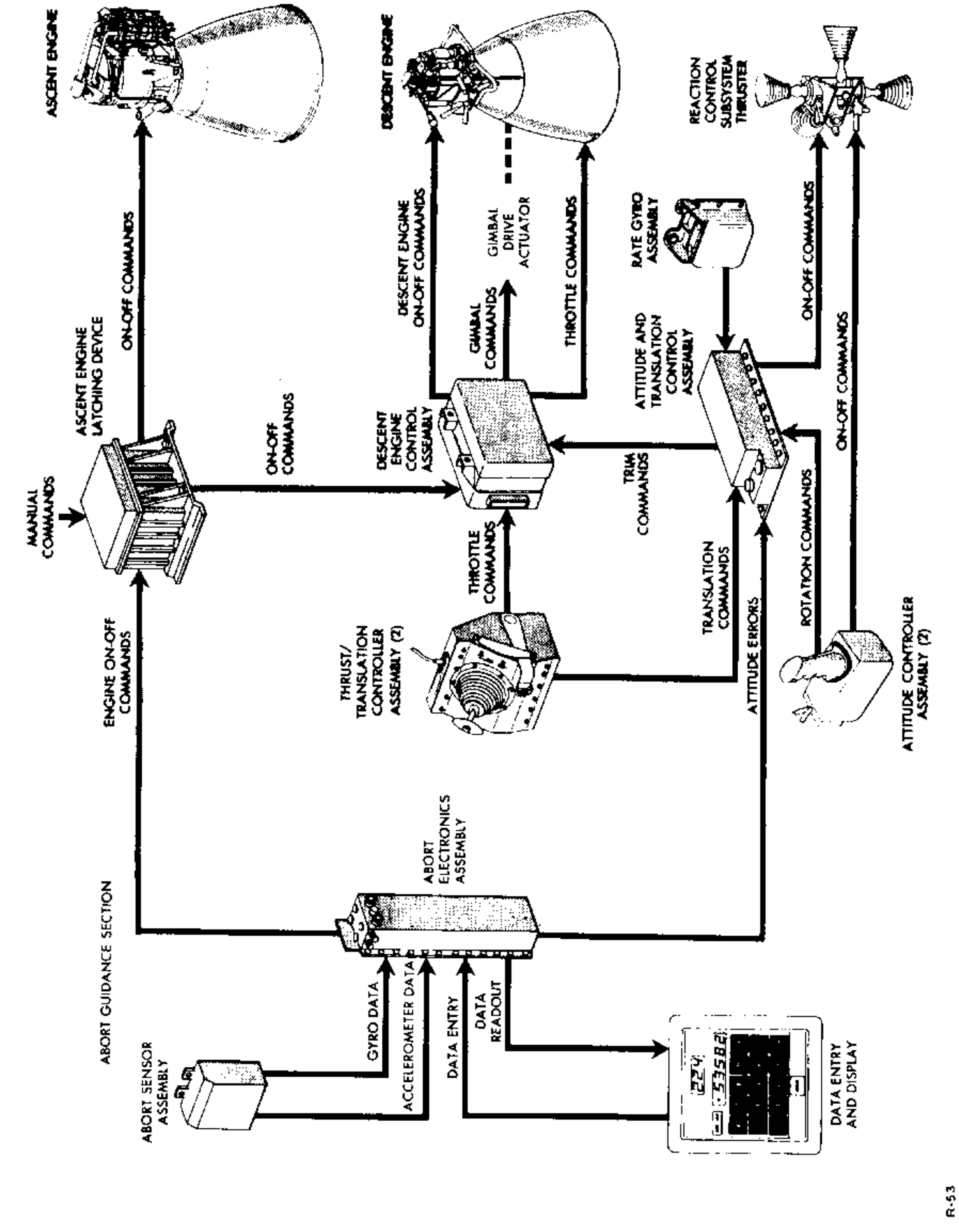


Diagram of Abort Guidance Path

Grumman