# 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 | Aluminum |
| 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)

| | |
|---|---|
| Height | 6 inches |
| Width | 12-1/2 inches |
| Depth | 24 inches |
| Weight | 70 pounds |
| 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 |

Display and keyboard

| | |
|---|---|
| Height | 8 inches |
| Width | 8 inches |
| Depth | 7 inches |
| Weight | 17 pounds |

Signal conditioner assembly

| | |
|---|---|
| Height | 3.3 inches |
| Width | 8.8 inches |
| Depth | 11.2 inches |
| Weight | 5.6 pounds |

## 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<br>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)<br>96.0 watts (operate) |

| | |
|---|---|
| Abort electronics assembly (cont) | |
| Logic levels | Zero: 0 to 0.5 vdc<br>One: +3 to +5 vdc |
| Clock frequency | 1,024 kpps |
| 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° 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° per second |
| Input rate frequency | 20 ± 4 Hz |
| Descent engine control assembly | |
| A-C input power nominal voltage | 115 vrms |
| Operating temperature range | +57° to +97° 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 ±5% |
| Gimbal position | +6° to -6° ±5% |
| Gimbal rate | 0.2°/sec ±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 40,000 feet |
| Velocity capability | From altitude of 24,000 feet |
| Weight (approx) | 43.5 pounds |
| Power consumption | 125 watts dc (nominal)<br>147 watts dc (maximum) |
| Heater power consumption | 63 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)<br>3.5 to 6.5 amperes |
| Temperature range | |
| Electronics assembly | $-20^{\circ}$ 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 | $4.0^{\circ}$ |
| 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 | $0.12^{\circ}$ to $0.24^{\circ}$ |
| 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

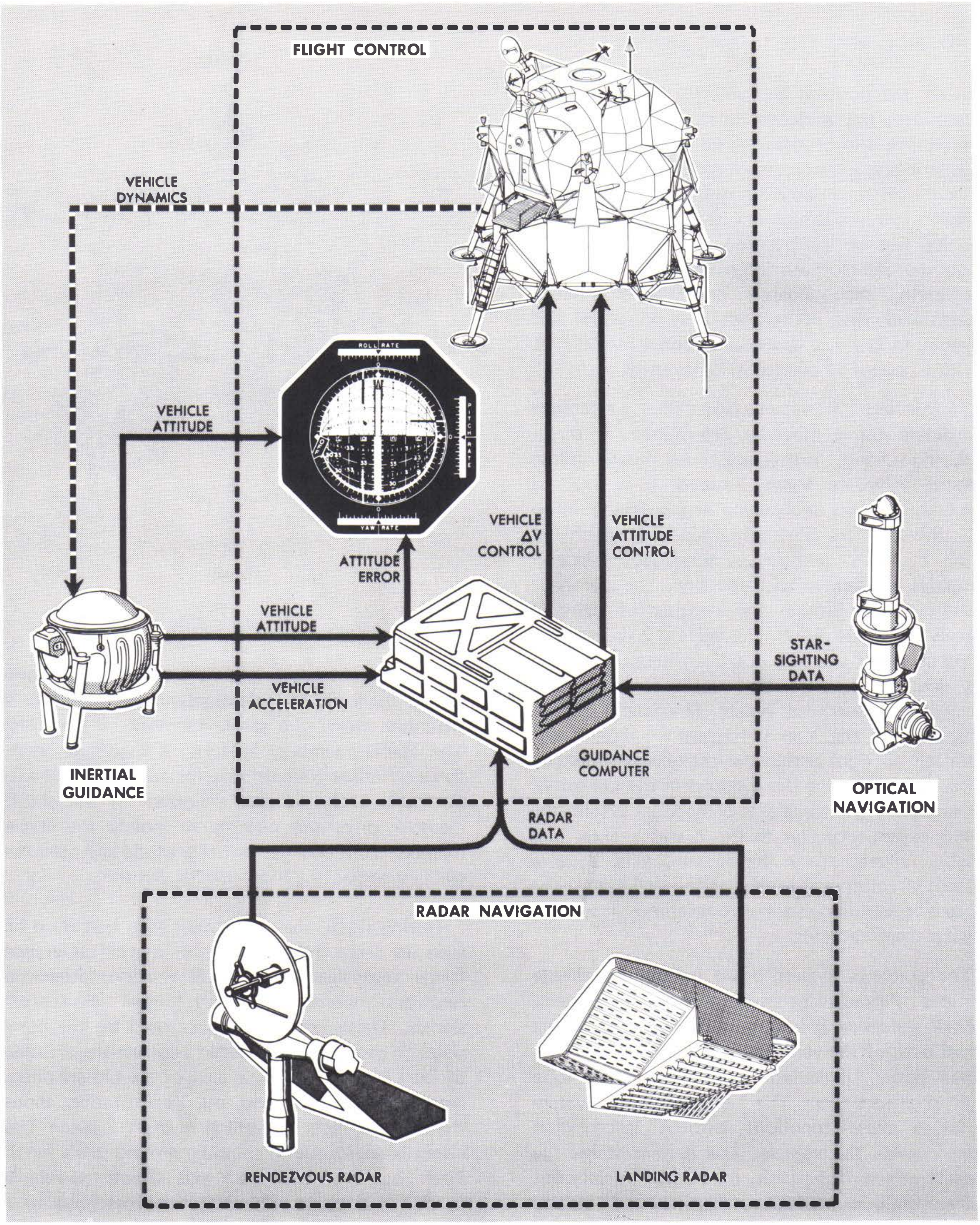
LM navigation involves the determination of the vehicle's present position and velocity so that the guidance function can plot the trajectory that the LM must follow.

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 destination 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 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.




R-44A

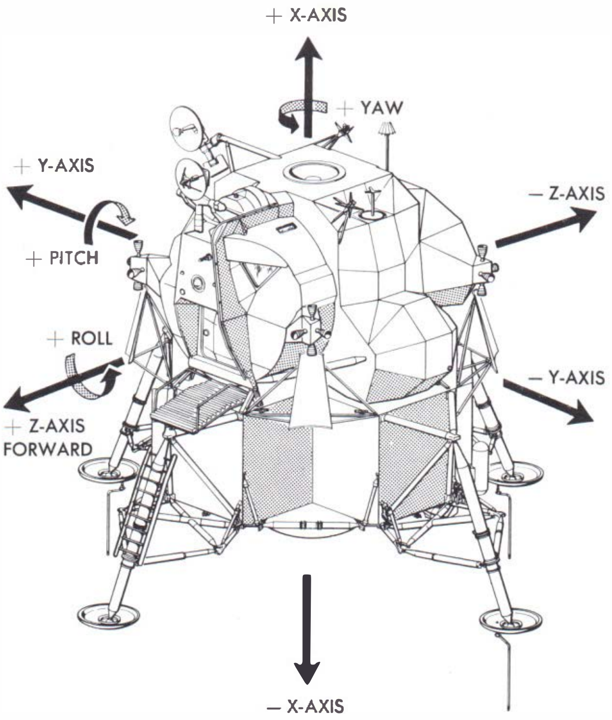
*Guidance, Navigation, and Flight Control Functions*

## 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-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.




R-45A

*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.

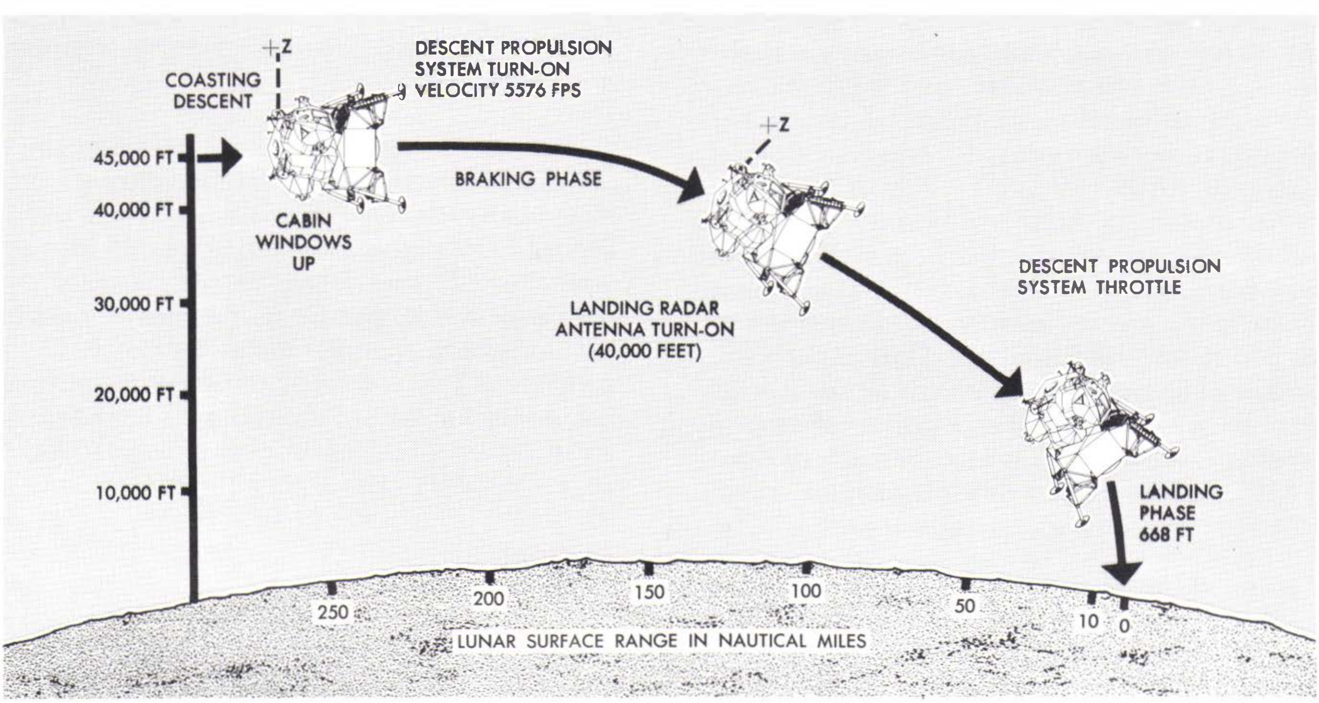
During flight, the stable member's axes must be held in fixed relation to the inertial reference frame regardless of the LM motion; otherwise resolvers mounted on each gimbal issue error signals. These error signals are used by the computer to generate commands to correct the attitude of the LM. The 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.

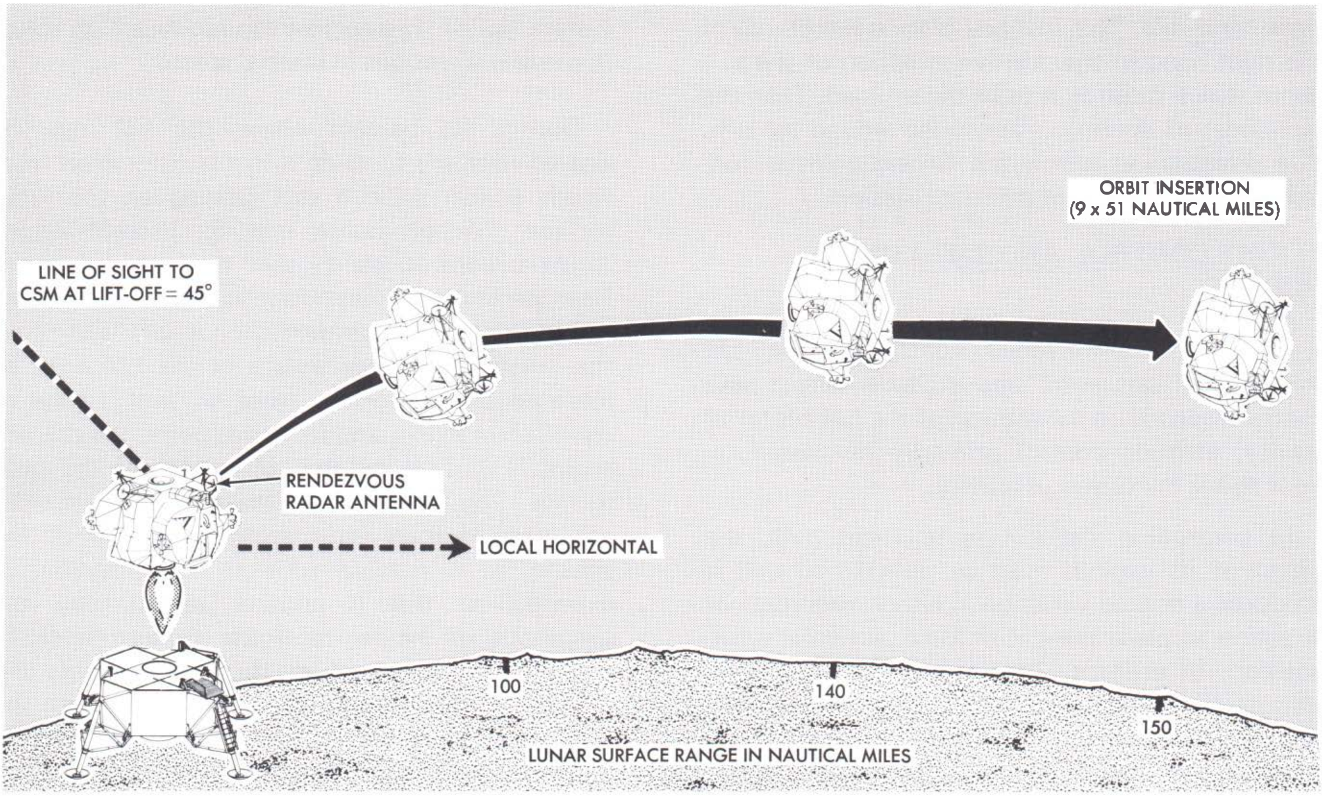
In controlling the LM in its flight path, the thrust of its engines must be directed so that it produces a desired variation in either magnitude or direction to place the LM in some particular orbit, position, or attitude. The major velocity changes associated with the lunar orbit, injection, landing, 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.




R-46A

*LM Powered Descent Profile*




R-47A

*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) thrusters. 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 is directed by attitude control, and thrust magnitude is controlled by controlling the duration of the burn.

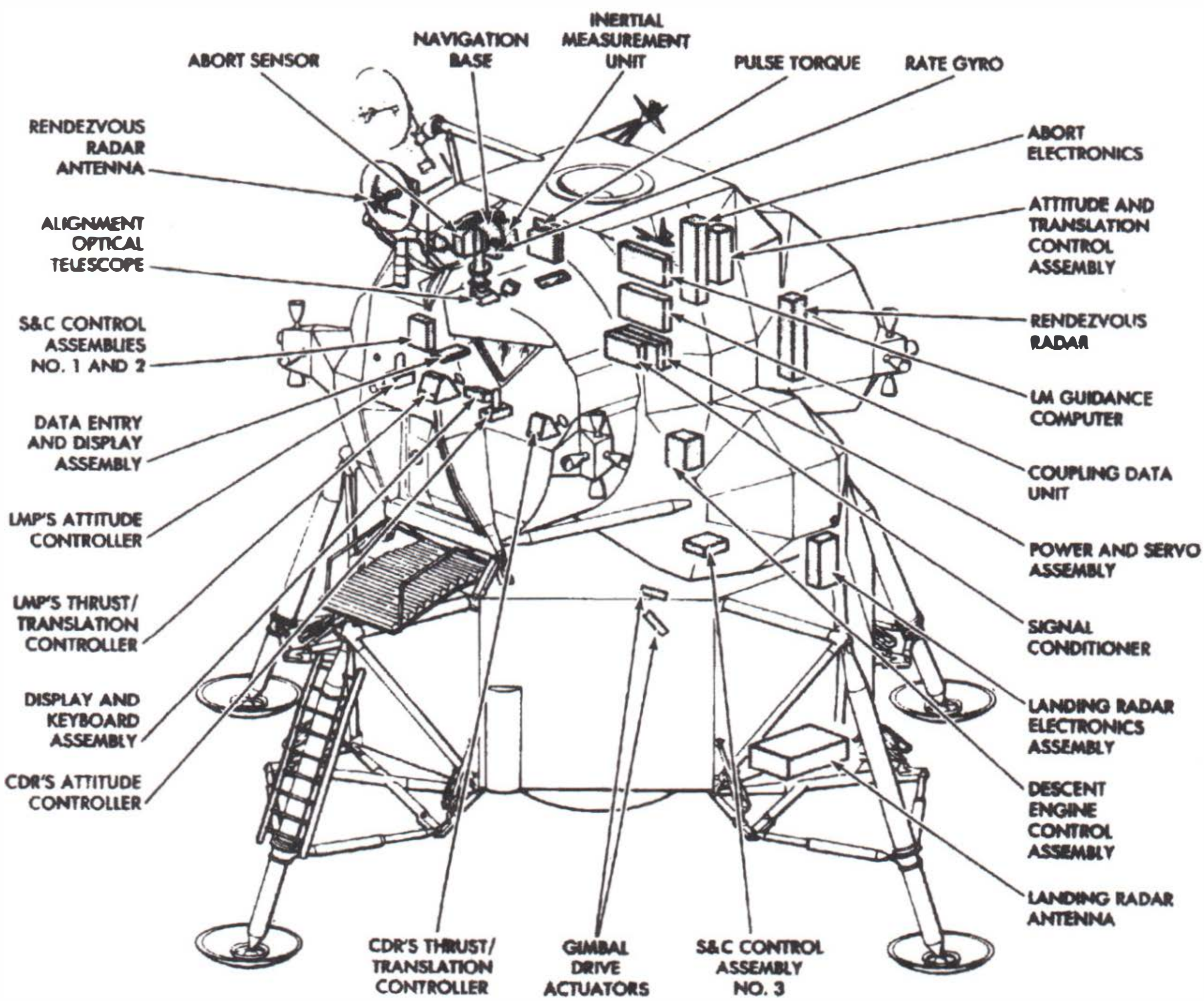
It is apparent then for flight control, that some measure of the LM velocity vector and its position must be determined at all times for purposes of comparison with a desired (predetermined) velocity vector, at any particular instant, to generate an error signal if the two are not equal. The flight control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

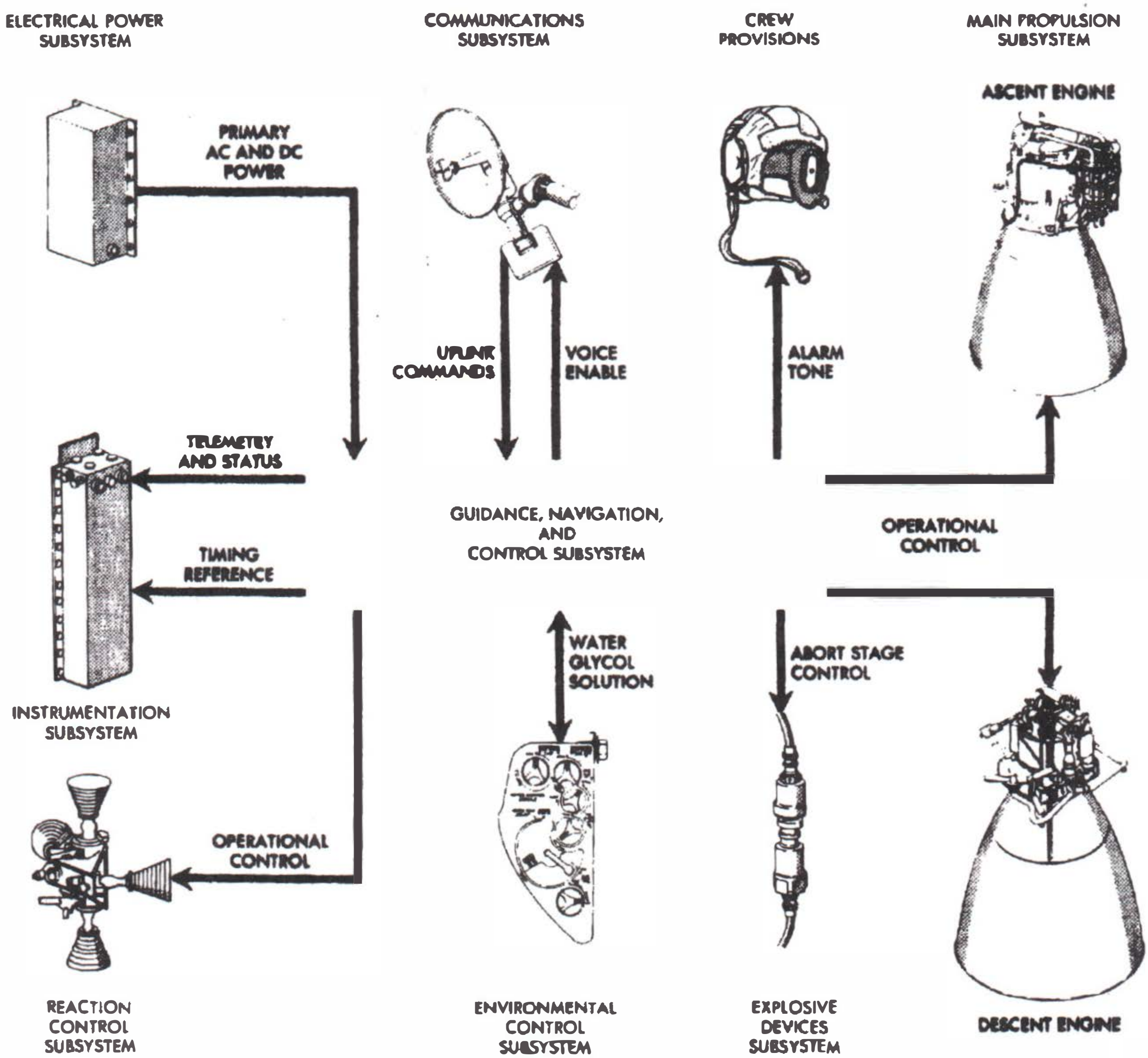



R-48

*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.




R-49

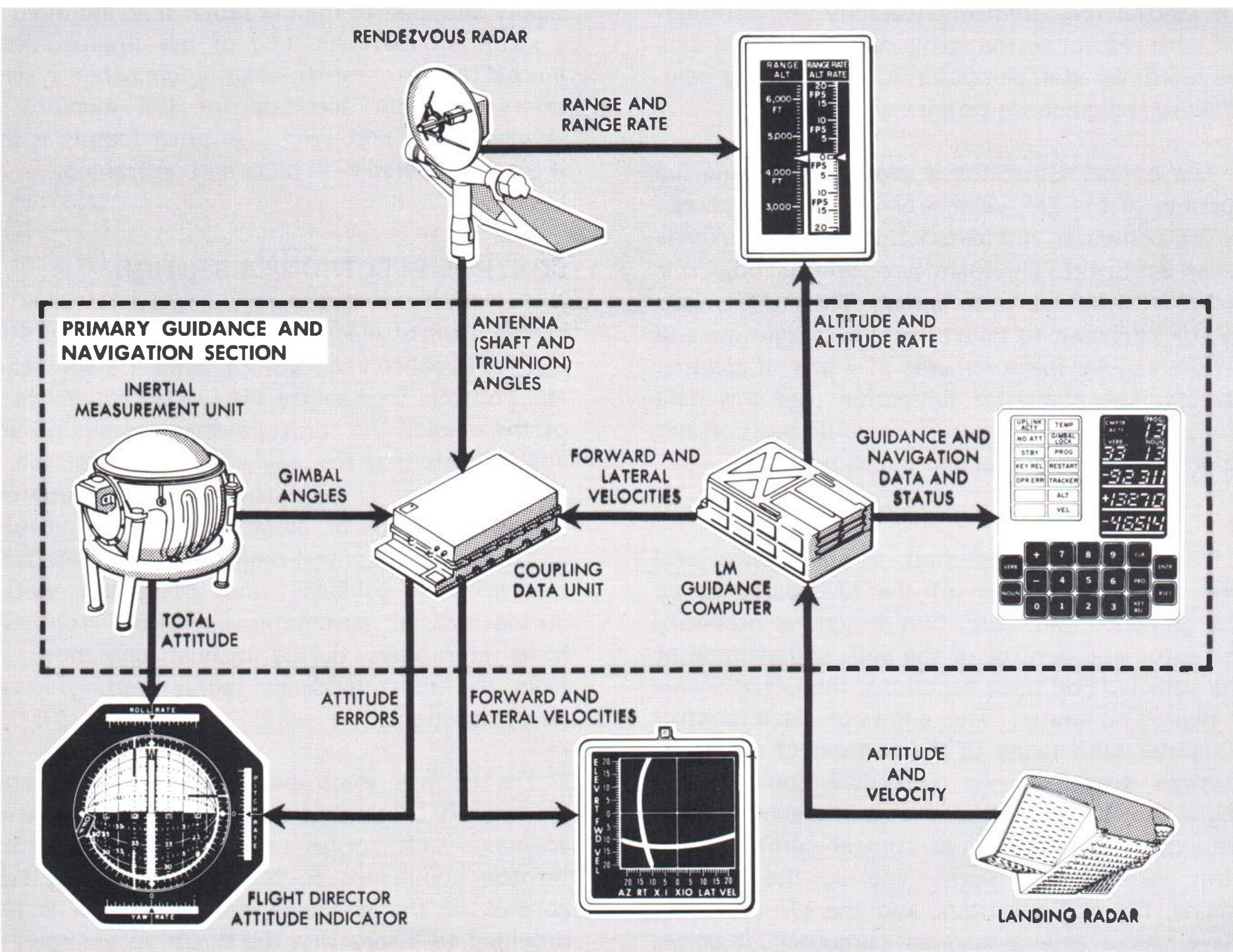
*GN&CS Relationship to Other Subsystems*

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.




R-50A

*Primary Guidance Data Displayed*

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, for 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.

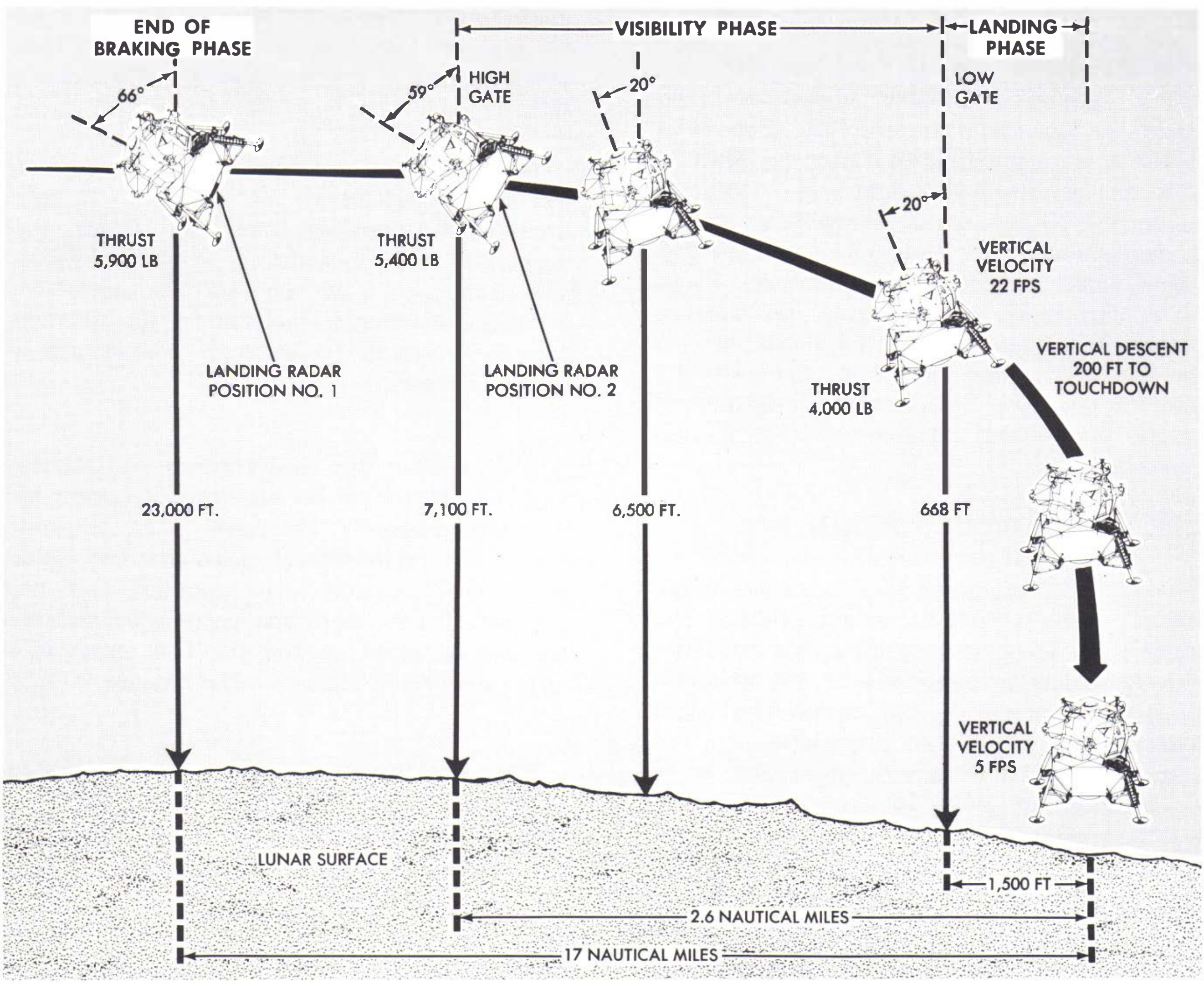
## LANDING RADAR

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. Slant range data begins at approximately 40,000 feet above the lunar surface; velocity data, at approximately 35,000 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




R-51A

*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.

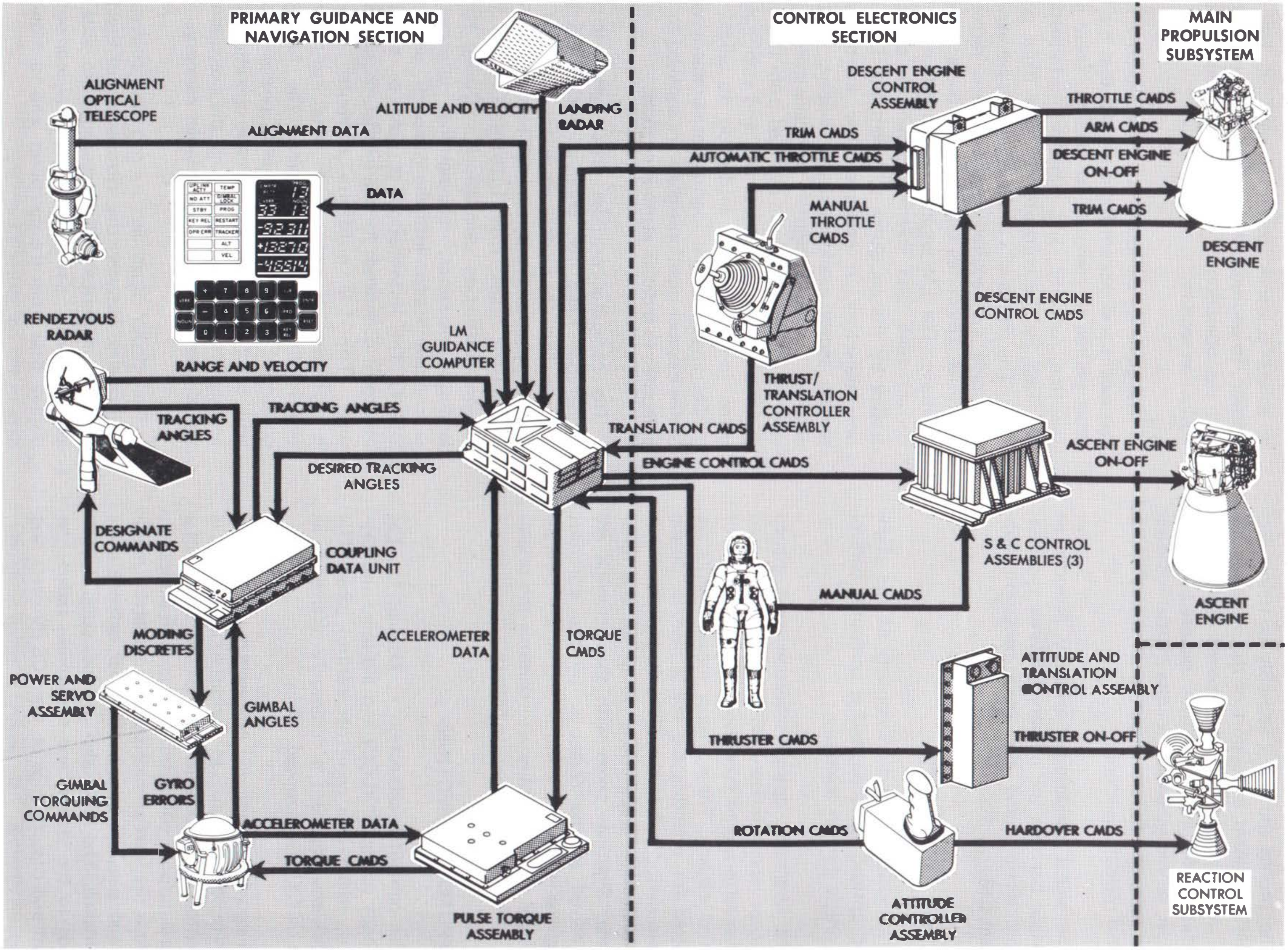
The inertial measurement unit is the primary inertial sensing device of the LM. It is a three-degree-of-freedom, stabilized device that maintains an orthogonal, inertially referenced coordinate system for LM attitude control and maintains three accelerometers in the reference coordinate system for accurate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



GRUMMAN




R-52A

*Diagram of Primary Guidance Path*

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 failure detection 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 data 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

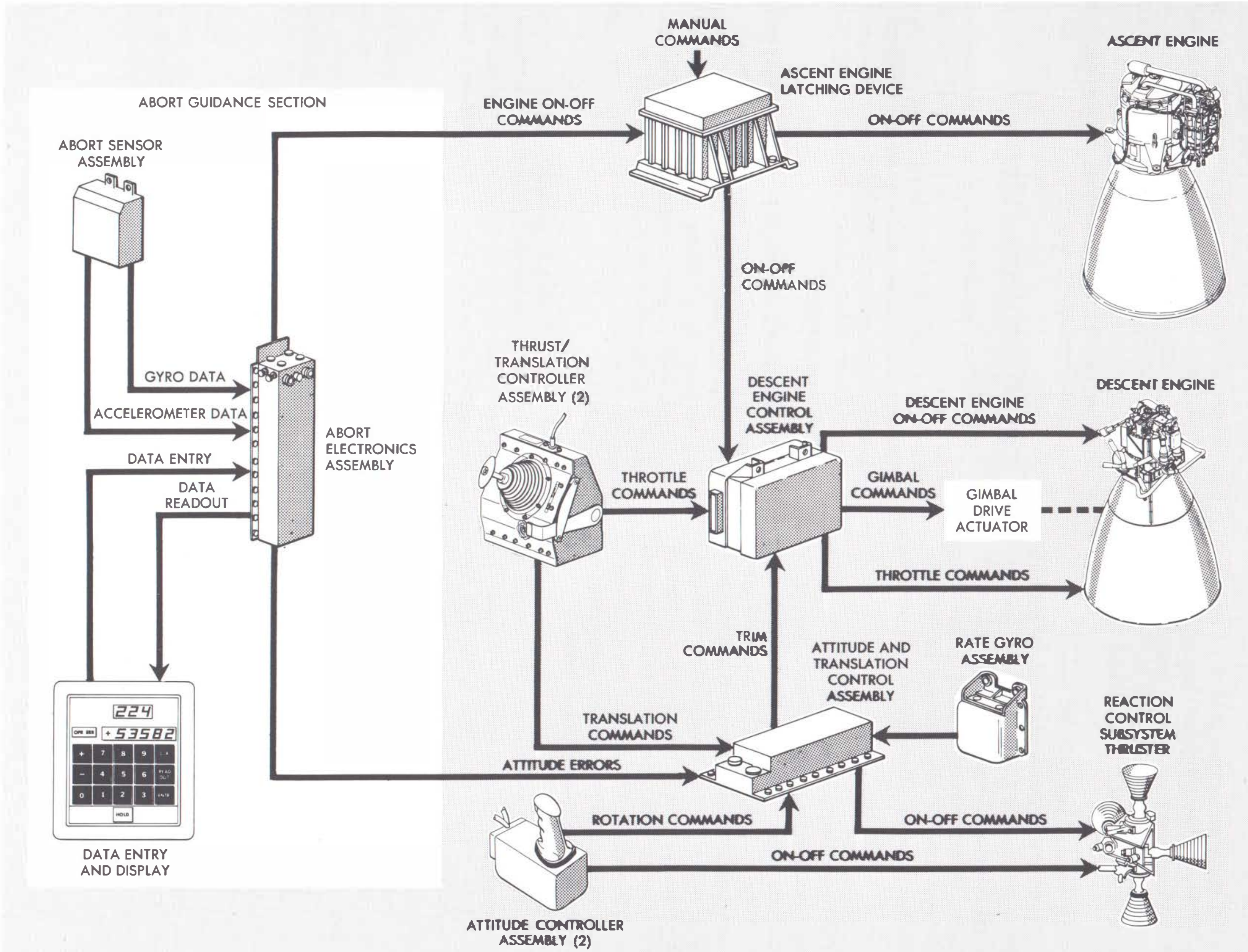
The control electronics section comprises two attitude controller assemblies, two thrust/translation controller assemblies, an attitude and translation control assembly, a rate gyro assembly, descent engine control assembly, three stabilization and control (S&C) control assemblies and two gimbal drive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

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.




R-53

*Diagram of Abort Guidance Path*

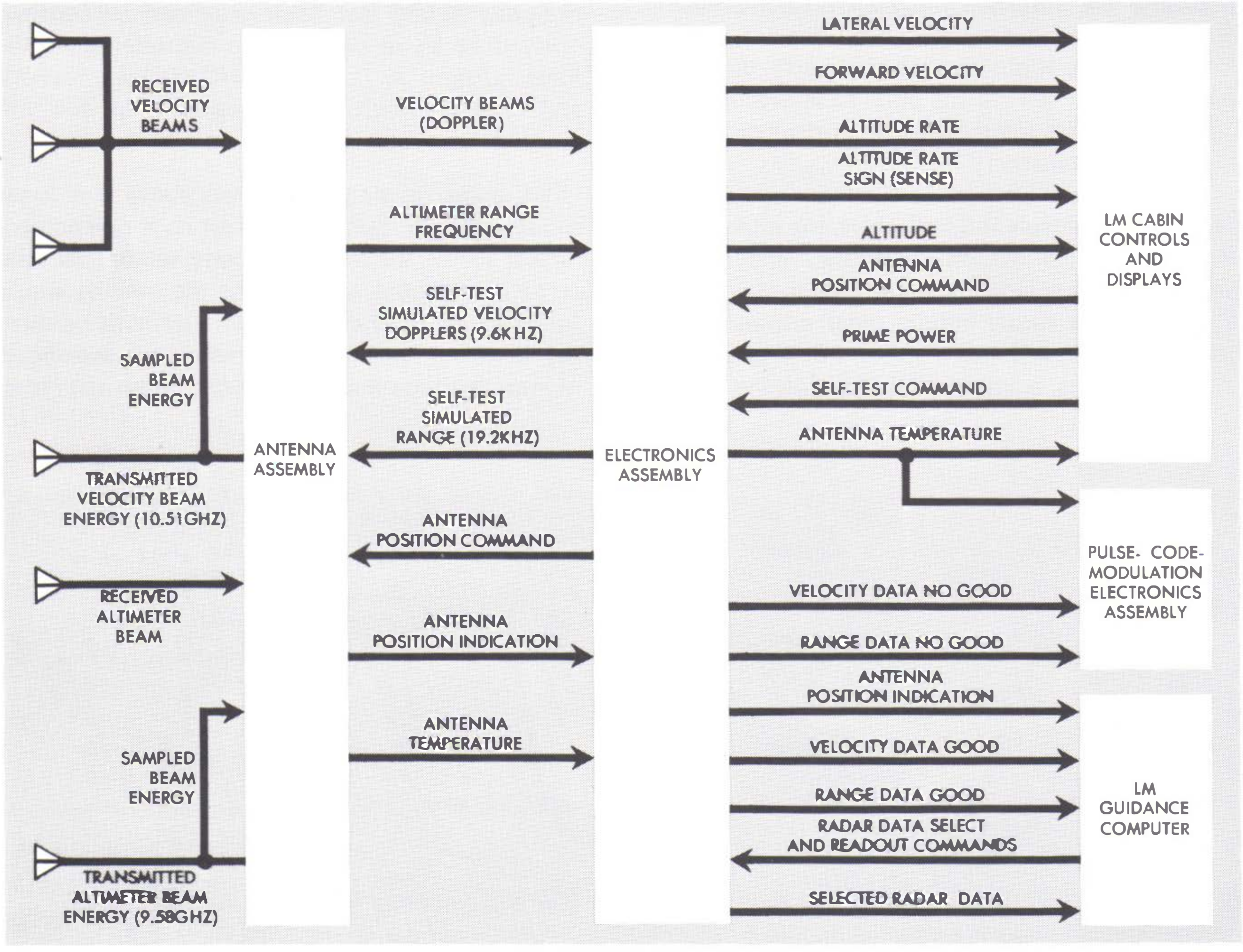
The descent engine control assembly processes engine throttling commands from the astronauts (manual control) and the guidance computer (automatic control), gimbal commands for thrust vector control, preignition (arming) commands, and on and off commands to control descent engine ignition and shutdown.

The S&C control assemblies are three similar assemblies. They process, switch, and/or distribute the various signals associated with the GN&CS.

The gimbal drive actuators position the descent engine in roll and pitch in response to DECA outputs.

## LANDING RADAR

The landing radar senses the velocity and slant range of the LM relative to the lunar surface by means of a three-beam Doppler velocity sensor and a single-beam radar altimeter. Velocity and range data are made available to the LM guidance computer as 15-bit binary words; forward and lateral velocity data, to the LM displays as d-c analog voltages; and range and range rate data, to the LM displays as pulse-repetition frequencies.




R-54

*Landing Radar Signal Flow*

The landing radar consists of an antenna assembly and an electronics assembly. The antenna assembly forms, directs, transmits, and receives the four microwave beams. Two interlaced phased arrays transmit the velocity- and altimeter-beam energy. Four broadside arrays receive the reflected energy of the three velocity beams and the altimeter beam. The electronics assembly processes the Doppler and continuous-wave FM returns, which provide the velocity and slant range data for the LM guidance computer and the LM displays.

The antenna assembly transmits velocity beams (10.51 gHz) and an altimeter-beam (9.58 gHz) to the lunar surface.

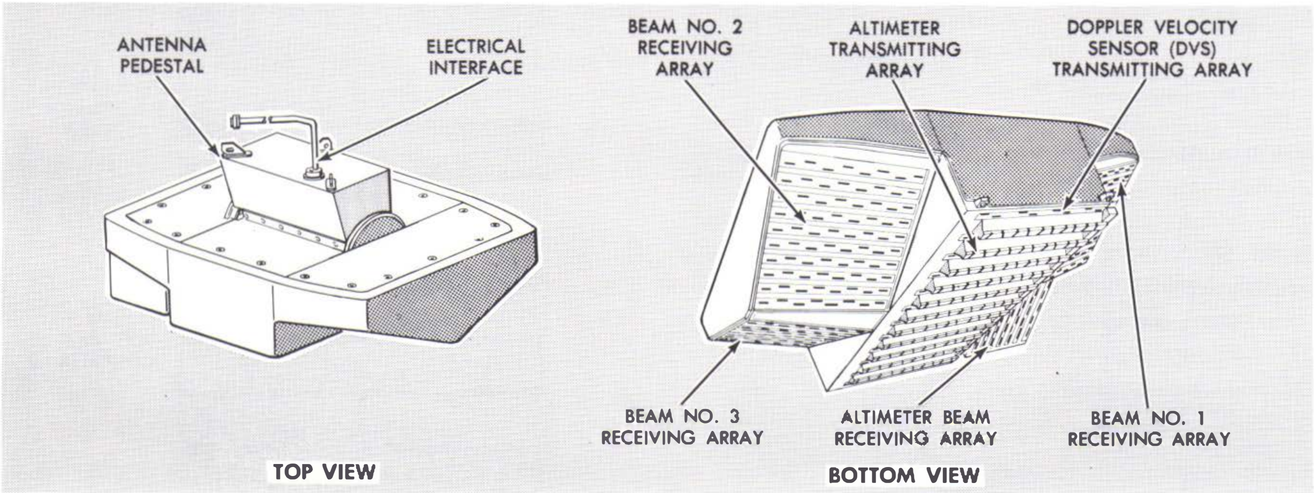
When the electronics assembly is receiving and processing the returned microwave beams, data-good signals are sent to the LGC. When the electronics assembly is not operating properly, data-no-good signals are sent to the pulse code modulation timing electronics assembly of the Instrumentation Subsystem for telemetry.

Using LM controls and indicators, the astronauts can monitor LM velocity, altitude, and radar-transmitter power and temperatures; apply power to energize the radar; initiate radar self-test; and place the antenna in descent or hover position. Self-test permits operational checks of the radar without radar returns from external sources. An antenna temperature control circuit, energized at earth launch, protects antenna components against the low temperatures of space environment while the radar is not operating.

The radar is first turned on and self-tested during LM checkout before separation from the CSM. The self-test circuits apply simulated Doppler signals to radar velocity sensors, and simulated lunar range signals to an altimeter sensor. The radar is self-tested again immediately before LM powered descent, approximately 70,000 feet above the lunar surface. The radar operates from approximately 50,000 feet until lunar touchdown.

Altitude (derived from slant range) is available to the LGC and is displayed on a cabin indicator at or above 25,000 feet. Slant range data are continuously updated to provide true altitude above the lunar surface. At, or above 18,000 feet, forward and lateral velocities are available to the LM guidance computer and cabin indicators.

At approximately 200 feet above the lunar surface, the LM pitches to orient its X-axis perpendicular to the surface; all velocity vectors are near zero. Final visual selection of the landing site is followed by touchdown under automatic or manual control. During this phase, the astronauts monitor altitude and velocity data from the radar.



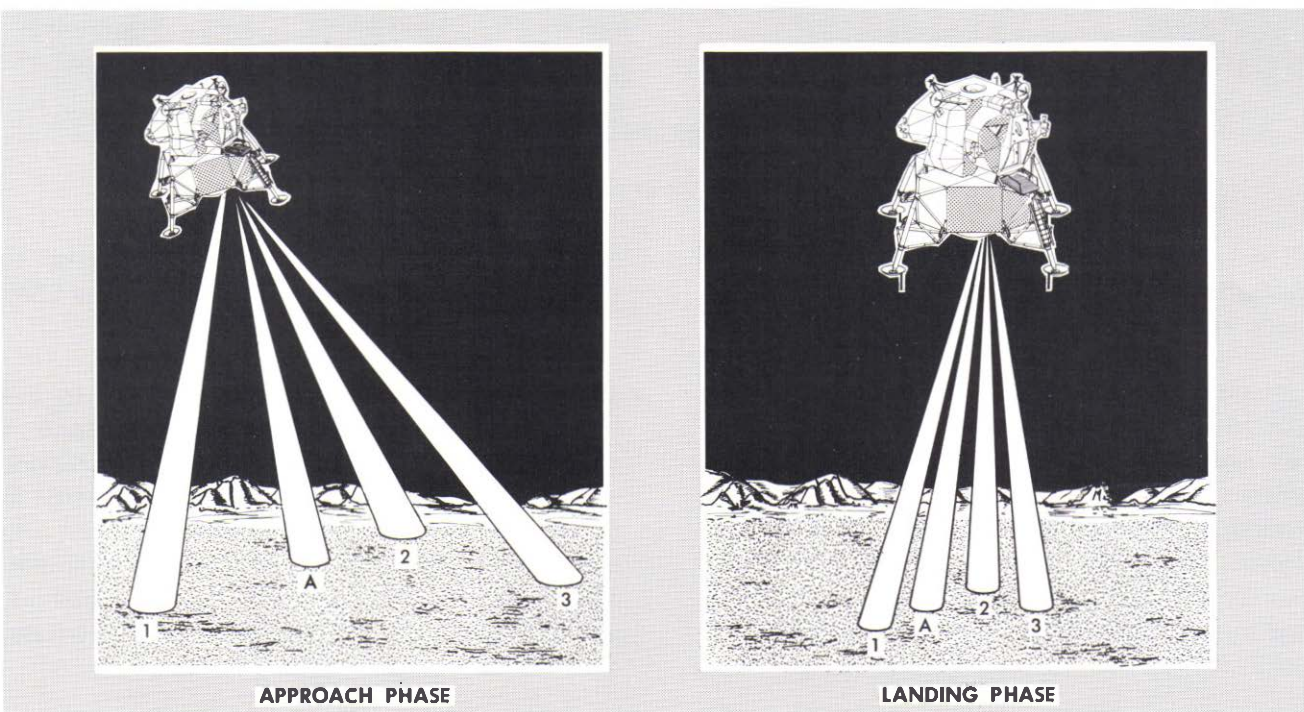

*Landing Radar Antenna Assembly*

The landing radar antenna has a descent position and a hover position. In the descent position, the antenna boresight angle is 24° from the LM X-axis. In the hover position, the antenna boresight is parallel to the X-axis and perpendicular to the Z-axis. Antenna position is selected by the astronaut during manual operation and by the LM guidance computer during automatic operation. During automatic operation, the LM guidance computer commands the antenna to the hover position 8,000 to 9,000 feet above the lunar surface.

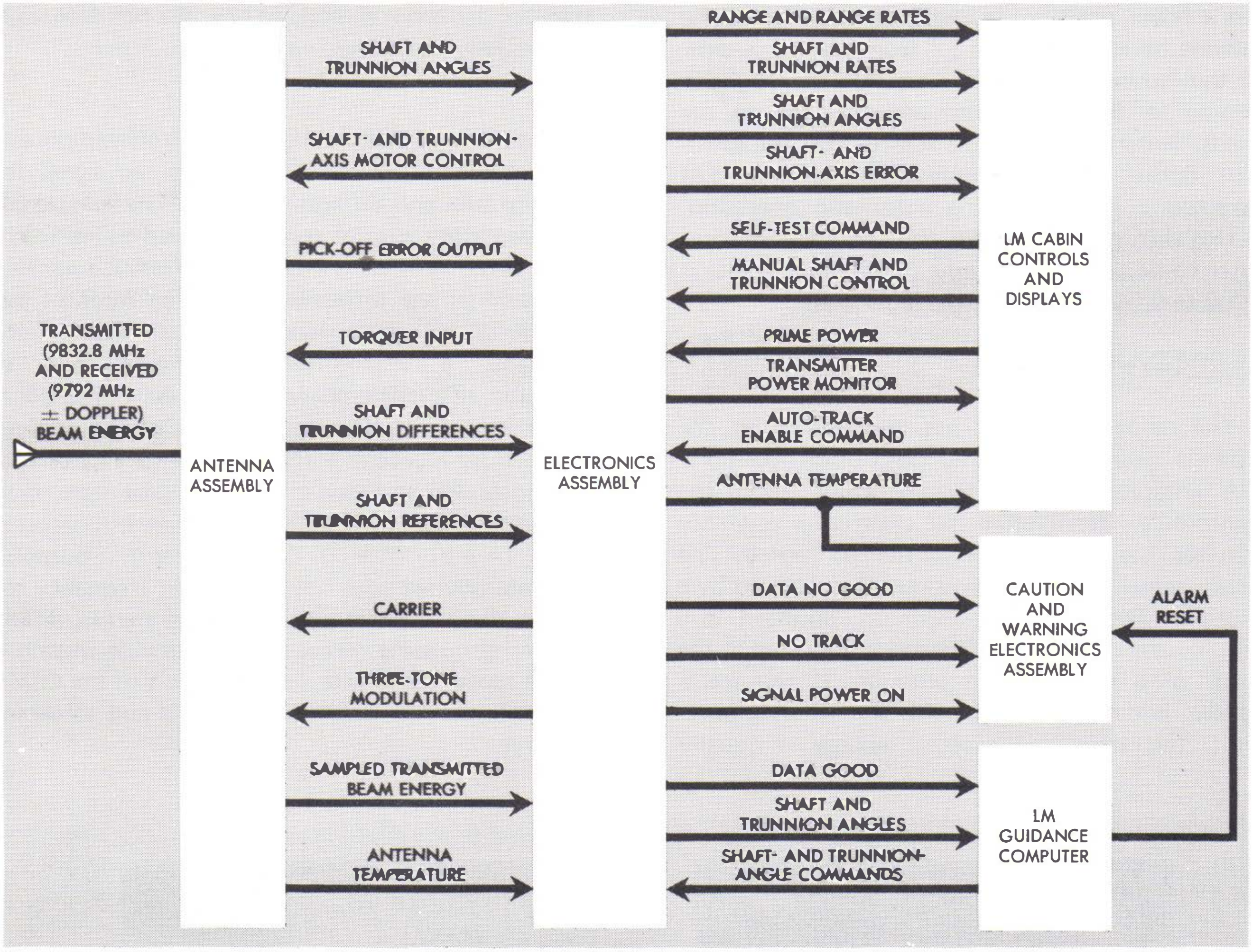
## RENDEZVOUS RADAR

The rendezvous radar has two assemblies, the antenna assembly and the electronics assembly. The antenna assembly automatically tracks the transponder signal after the electronics assembly acquires the transponder carrier frequency. The return signal from the transponder is received by a four-port feedhorn. The feedhorn, arranged in a simultaneous lobing configuration, is located at the focus of a Cassegrainian antenna. If the transponder is directly in line with the antenna boresight, the transponder signal energy is equally distributed to each port of the feedhorn. If the transponder is not directly in line, the signal energy is unequally distributed among the four ports.

The signal passes through a polarization diplexer to a comparator, which processes the signal to develop sum and difference signals. The sum signal represents the sum of energy received by all feedhorn ports (A + B + C + D). The difference signals, representing the difference in energy received by the feedhorn ports, are processed along two channels: a shaft-difference channel and a trunnion-difference channel. The shaft-difference signal represents the vectoral sum of the energy received by adjacent ports (A + D) - (B + C) of the feedhorn. The trunnion-difference signal represents the vectoral sum of the energy received by adjacent ports (A + B) - (C + D). The comparator outputs are heterodyned with the transmitter frequency to obtain three intermediate-frequency signals. After further processing, these signals provide unambiguous range, range rate, and direction of the CSM. This information is fed to the LGC and to cabin displays.




*Landing Radar - Antenna Beam Configuration*




R-57

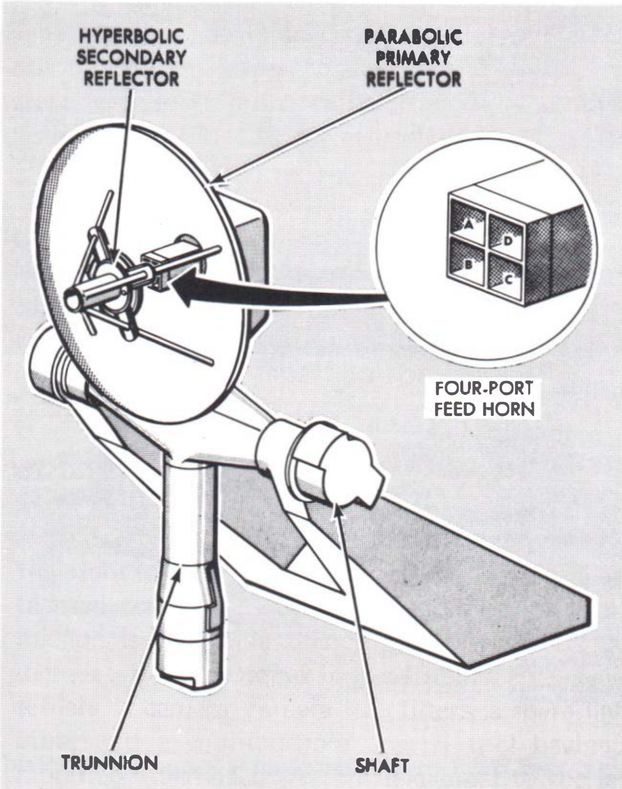
*Rendezvous Radar Signal Flow*

The rendezvous radar operates in three modes: automatic tracking, slew (manual), or LM guidance computer control.

Automatic Tracking Mode. This mode enables the radar to track the CSM automatically after it has been acquired; tracking is independent of LM guidance computer control. When this mode is selected, tracking is maintained by comparing the received signals from the shaft and trunnion channels with the sum channel signal. The resultant error signals drive the antenna, thus maintaining track.

Slew Mode. This mode enables an astronaut to position the antenna manually to acquire the CSM.

LM Guidance Computer Control Mode. In this mode, the computer automatically controls antenna positioning, initiates automatic tracking once the CSM is acquired, and controls change in antenna orientation. The primary guidance and navigation section, which transmits computer-derived commands to position the radar antenna, provides automatic control of radar search and acquisition.




R-58

*Rendezvous Radar Antenna Assembly*

## PRIMARY GUIDANCE PATH

The primary guidance path comprises the primary guidance and navigation section, control electronics section, landing radar, and rendezvous radar and the selected propulsion section required to perform the desired maneuvers. The control electronics section routes flight control commands from the primary guidance and navigation section and applies them to the descent or ascent engine, and the appropriate thrusters.

## INERTIAL ALIGNMENT

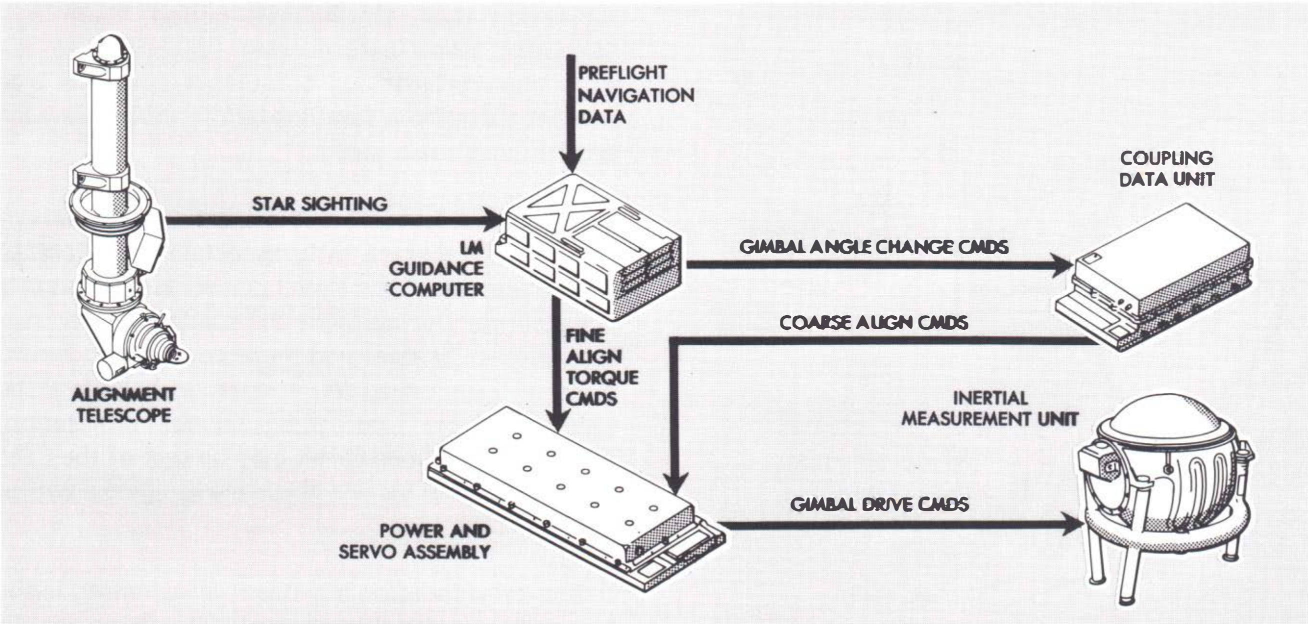
Inertial subsection operation can be initiated automatically by the primary guidance computer or manually by the astronaut, using DSKY entries to command the computer. The inertial subsection status or mode of operation is displayed on the DSKY as determined by a computer program. When the inertial subsection is powered up, the gimbals of the inertial measurement unit are driven to zero by a reference voltage and the coupling data unit is initialized to accept inertial subsection data. During this period, there is a 90-second delay before power is applied to the gyro and accelerometer torquing loops. This is to prevent them from torquing before the gyros reach synchronous rotor speed.

The stable member of the inertial measurement unit must be aligned with respect to the reference coordinate frame each time the inertial subsection is powered up. During flight the stable member may be periodically realigned because it may deviate from its alignment, due to gyro drift. Also, the crew may desire a new stable member orientation. The alignment orientation may be that of the CSM or that defined by the thrusting programs within the computer.

Inertial subsection alignment is accomplished in two steps: coarse alignment and fine alignment. To initiate coarse alignment, the astronaut selects, by a DSKY entry, a program that determines stable member orientation, and a coarse-alignment routine. The computer sends digital pulses, representing the required amount of change in gimbal angle, to the coupling data unit. The coupling data unit converts these digital pulses to analog signals which drive torque motors in the inertial measurement unit. As the gimbal angle changes, a gimbal resolver signal is applied to the coupling data unit, where it is converted to digital pulses. These digital pulses cancel the computer pulses stored in the coupling data unit. When this is accomplished, coarse alignment is completed and the astronaut can now select an in-flight fine-alignment routine.

To perform the fine-alignment routine, the astronaut must use the alignment optical telescope to sight on at least two stars. The gimbals, having been coarse aligned, are relatively close to their preferred angles. The computer issues fine-alignment torquing signals to the inertial measurement unit after it processes star-sighting data that have been combined with known gimbal angles.

Once the inertial subsection is energized and aligned, LM rotation is about the gimbaled stable member, which remains fixed in space. Resolvers mounted on the gimbal axes act as angle-sensing devices and measure attitude with respect to the

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*Functional Diagram of Inertial Alignment*

stable member. These angular measurements are displayed to the astronauts by the flight director attitude indicators, and angular changes of the inertial reference are sent to the computer.

Inertial stability of the stable member in the inertial measurement unit is maintained with a stabilization loop which uses the IMU gyro outputs as inputs to amplifiers in the power and servo assy. The amplifier outputs drive torquers on each of the three IMU gimbals to null out the gyro errors.

## ATTITUDE CONTROL

Desired attitude is calculated in the primary guidance computer and compared with the actual gimbal angles. If there is a difference between the actual and calculated angles, the inertial subsection channels of the coupling data unit generate attitude error signals, which are sent to the attitude indicators for display. These error signals are used by the digital autopilot program in the primary guidance computer to activate RCS thrusters for LM attitude correction. LM acceleration due to thrusting is sensed by three accelerometers, which are mounted on the stable member with their input axes orthogonal. The resultant signals (velocity changes) from the accelerometer loops are supplied to the computer, which calculates the total LM velocity.

Two normal modes of operation achieve attitude control: automatic and attitude hold. In addition to these two modes, there is a minimum impulse mode and a four-jet manual override mode. Either of the two normal modes may be selected on the primary guidance mode control switch.

In automatic mode, all navigation, guidance, and flight control is handled by the primary guidance computer. The computer calculates the desired or preferred attitude, generates the required thruster commands and routes them to the attitude and translation control assembly which fires the selected thruster.

Attitude hold mode is a semiautomatic mode in which either astronaut can command attitude change at an angular rate proportional to the displacement of his attitude controller. The LM holds the new attitude when the controller is brought back to its neutral (detent) position. During primary guidance control, rate commands proportional to controller displacement are sent to



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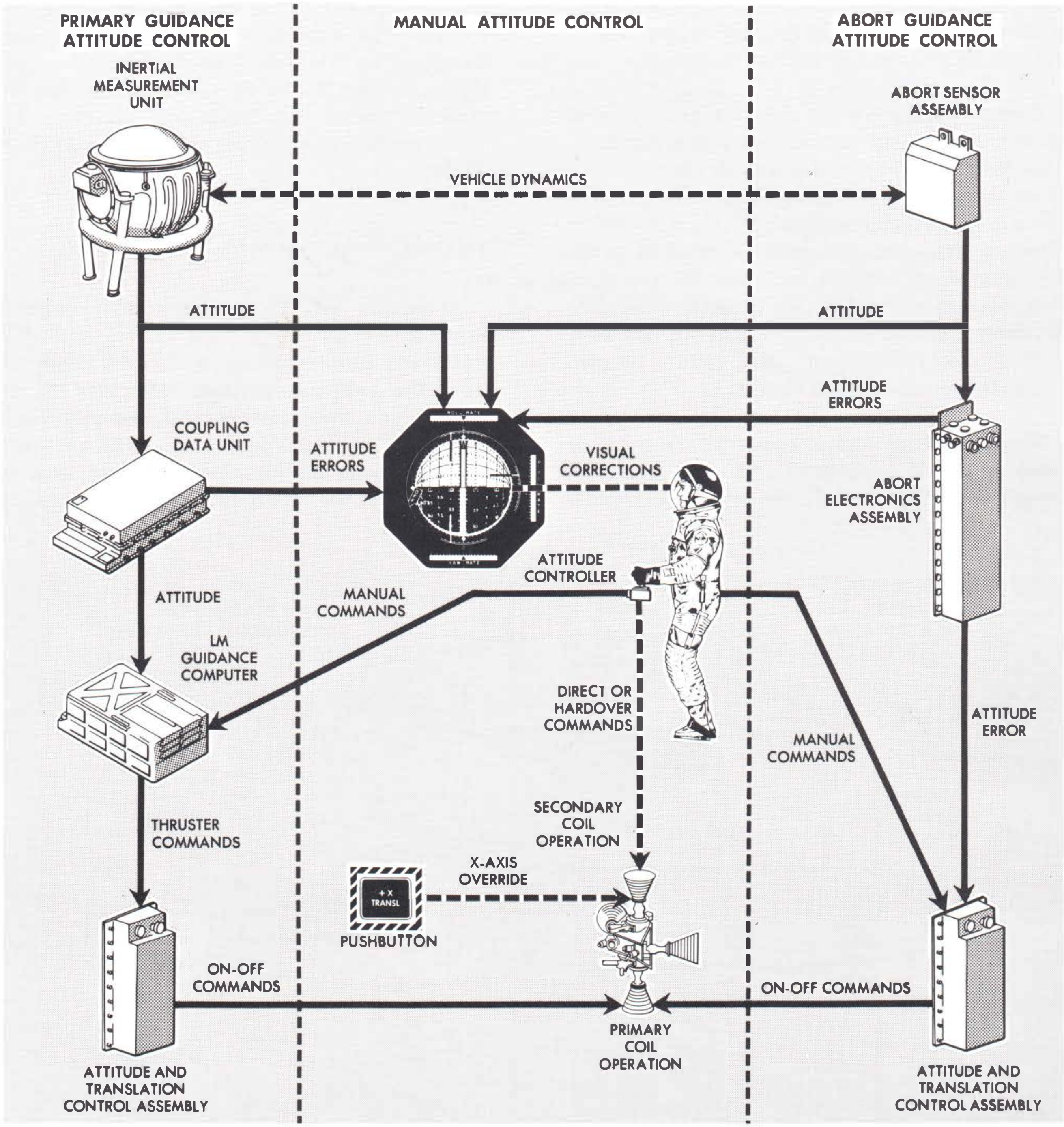



R-60

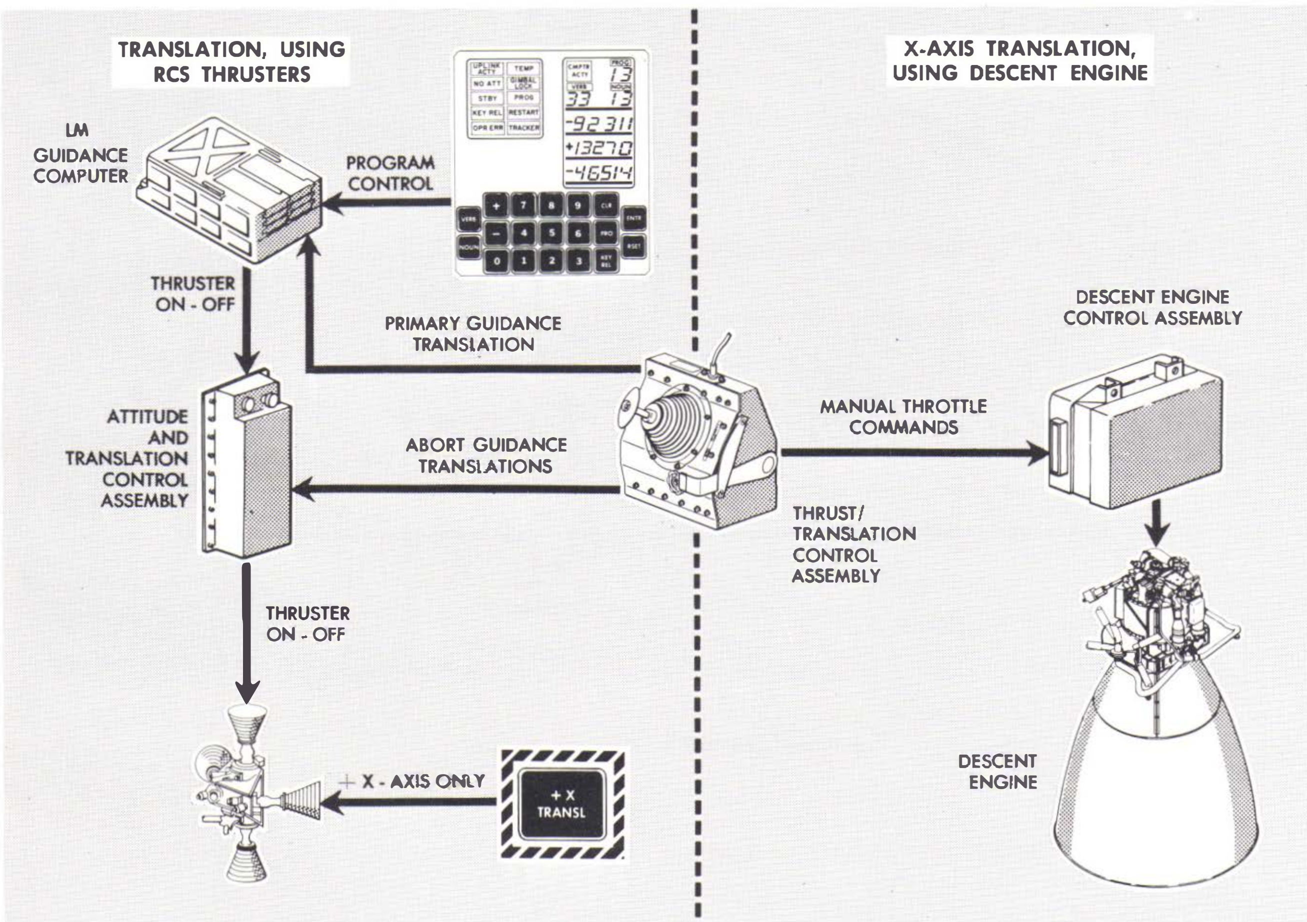
*Functional Diagram of Attitude Control* the computer. The computer processes these commands and generates thruster commands for the attitude and translation control assembly.

Minimum impulse mode enables the astronaut to control the LM with a minimum of fuel consumption. Each movement of the attitude controller out of its detent position causes the primary guidance computer to issue commands to the appropriate thrusters. The controller must be returned to the neutral position between each impulse command. This mode is selected by DSKY entry only while the control electronics section is in attitude hold. In this mode, the astronaut must perform his own rate damping and attitude steering.

Manual override also is known as the hardover mode. In certain contingencies that may require an abrupt attitude maneuver, the attitude controller can be displaced to the maximum limit (hardover position) to command an immediate attitude change about any axis. This displacement applies signals directly to the RCS solenoids to fire four thrusters that provide the desired maneuver. This maneuver can override any other attitude control mode.

## TRANSLATION CONTROL

Automatic and manual translation control is available in all three axes, using the RCS. Automatic control consists of thruster commands from the primary guidance computer to the attitude and translation control assembly. These commands are used for translations of small velocity increments and for ullage maneuvers (to settle propellant in the tanks) before ascent or descent




R-61

*Functional Diagram of Translation Control*



Grumman

engine ignition after coasting phases. Manual control during primary guidance control consists of on and off commands generated by the astronaut using his thrust/translation controller. These commands are routed through the computer to the attitude and translation control assembly to fire the proper thrusters. Translation along the +X-axis can also be initiated by the astronaut using a pushbutton switch that actuates the secondary solenoid coils of the four downward firing thrusters.

## DESCENT ENGINE CONTROL

Descent engine ignition is controlled either automatically by the primary guidance and navigation section, or manually through the control electronics section. Before ignition can occur, the engine arm switch must be set to the descent engine position. This opens the pre-valves to allow fuel and oxidizer to reach the propellant shutoff valves, arming the descent engine.

Engine-on commands from either computer are routed to the descent engine control assembly which commands the descent engine on by opening the propellant shutoff valves. The engine remains on until an engine-off discrete is initiated by the astronauts with either of two engine stop pushbuttons or by the computer. When the LM reaches the hover point where the lunar contact probes touch the lunar surface, a blue lunar contact light is illuminated. This indicates to the astronauts that the engine should be shut down. From this point (approximately 5 feet above the lunar surface), the LM free-falls to the lunar surface.

Descent engine throttling can be controlled by the primary guidance and navigation section and/or the astronauts. Automatic increase or decrease signals from the guidance computer are sent to the descent engine control assembly. An analog output from the control assembly corresponds to the percentage of thrust desired. The engine is controllable from 10% of thrust to a maximum of 92.5%. There are two thrust control modes: automatic and manual. In the automatic mode, the astronaut can use the selected thrust/translation controller to increase descent engine thrust only. During this mode, manual commands by the astronaut are used to override the throttle commands generated by the computer. In the manual mode, the astronauts have complete control over descent engine thrust.

Descent engine trim is automatically controlled during primary control, to compensate for center-of-gravity offsets due to propellant depletion and, in some cases for attitude control. The primary guidance computer routes trim commands for the pitch and roll axes. These signals drive a pair of gimbal drive actuators. These actuators, which are screwjack devices, tilt the descent engine about the Y-axis and Z-axis a maximum of +6° or -6° from the X-axis.

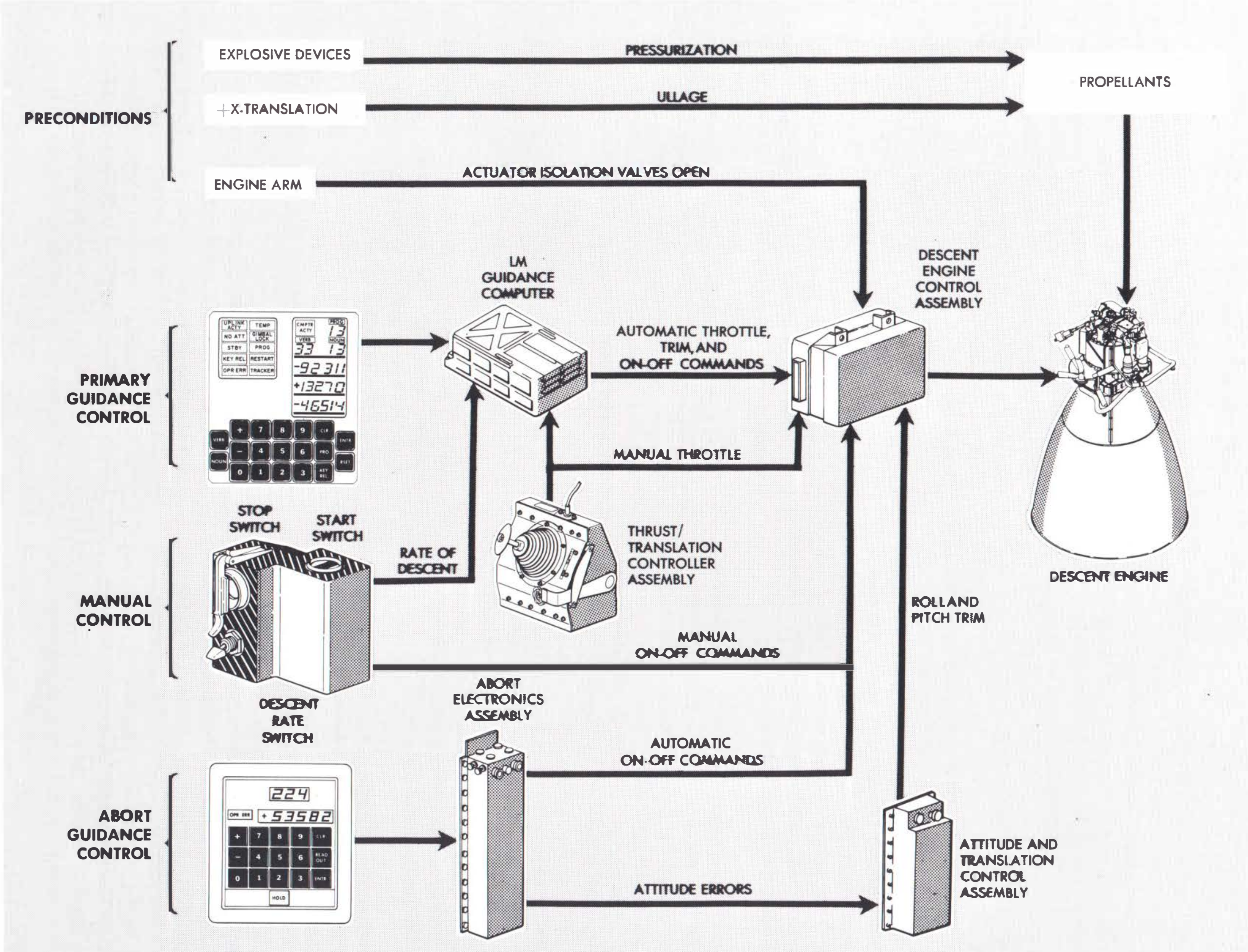
## ASCENT ENGINE CONTROL

Ascent engine ignition and shutdown can be initiated automatically by the primary guidance computer or manually by the astronauts. Automatic and manual commands are routed to the S&C control assemblies. These assemblies provide logically ordered control of LM staging and engine on and off comands. The control assemblies are enabled when the astronauts select the ascent engine position of the engine arm switch.

In an abort stage situation while the descent engine is firing, the control assemblies provide a time delay before commanding staging and ascent engine ignition. The time delay ensures that descent engine thrusting has completely stopped before staging occurs.

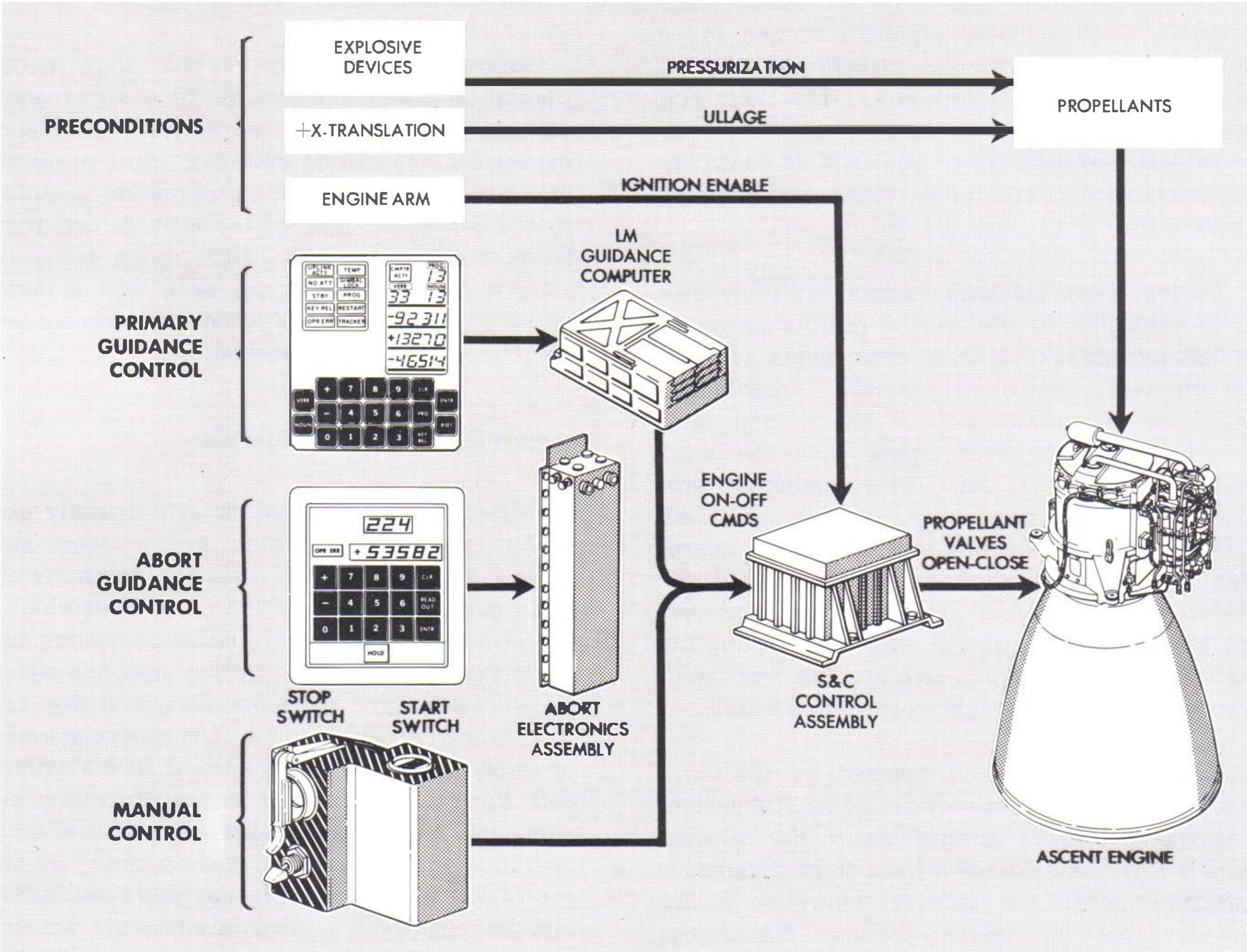
## ABORT GUIDANCE PATH

The abort guidance path comprises the abort guidance section, control electronics section, and the selected propulsion section. The abort guidance path performs all inertial guidance and navigation functions necessary to effect a safe orbit or rendezvous with the CSM. The stabilization and control functions are performed by analog computation techniques, in the control electronics section.






*Functional Diagram of Descent Engine Control*




R-63

*Functional Diagram of Ascent Engine Control*

The control electronics section functions as an autopilot when the abort guidance path is selected. It uses inputs from the abort guidance section and from the astronauts to provide the following: on, off, and manual throttling commands for the descent engine; descent engine gimbal drive actuator commands; ascent engine on and off commands; engine sequencer logic to ensure proper arming and staging before engine startup and shutdown; RCS on and off commands; RCS jet-select logic to select the proper thruster for the various maneuvers; and modes of control, ranging from automatic to manual.

## ATTITUDE CONTROL

The abort guidance path operates in the automatic mode or the attitude hold mode. In automatic, navigation and guidance functions are controlled by the abort guidance section, attitude by the control electronics section. The abort electronics assembly (abort guidance computer) generates roll, pitch, and yaw attitude error signals, which are summed with rate-damping and attitude rate signals in the attitude and translation control assembly. A jet-select logic circuit selects the thruster to be fired and issues the appropriate thruster command.

In attitude hold, the astronaut uses manual control. In this mode, a pulse submode and a two-jet direct submode are available in addition to manual override (hardover). The pulse and two-jet direct submodes are selectable on an individual axis basis only. The attitude controller generates attitude rate, pulse, direct, and hardover commands.

During abort guidance control, with the attitude controller in the neutral position, attitude is held by means of attitude error signals detected by the abort electronics assembly. When either controller is moved out of the neutral position, the attitude error signals from the abort guidance section are zero. Rate commands, proportional to controller displacement, are processed in the attitude and translation control assembly, and the thrusters are fired until the desired vehicle rate is achieved. When the controller is returned to the neutral position, the vehicle rate is reduced to zero and the abort guidance section holds the LM in the new attitude.

The pulse submode is selected by the astronaut, using the appropriate attitude control switch. Automatic attitude control about the selected axis is then disabled and a fixed train of pulses is generated when the attitude controller is displaced from its neutral position. To change vehicle attitude in this submode, the attitude controller must be moved out of neutral. This commands acceleration about the selected axis through low-frequency thruster pulsing. The pulse submode uses the primary solenoid coils of the thrusters; the direct submode, the secondary solenoid coils. To terminate rotation, an opposite acceleration about the selected axis must be commanded.

The direct submode is selected by the astronaut, using the attitude control switches that are used for the pulse submode. When selected, automatic control about the selected axes is disabled and direct commands are routed to the RCS secondary solenoids to two thrusters when the attitude controller is displaced from the neutral position. The thrusters under direct control fire continuously until the controller is returned to the neutral position.

## TRANSLATION CONTROL

During abort guidance control, only manual translation is available because the abort programs do not require lateral or forward translation maneuvers. Translation control consists of on and off commands from a thrust/translation controller to the jet select logic of the attitude and translation control assembly. RCS thrust along the +X-axis is accomplished the same way as during primary guidance control when the astronaut uses the +X-axis translation pushbutton.

## DESCENT ENGINE CONTROL

Descent engine ignition is automatically controlled by programs stored in the abort electronics assembly. This assembly computes the abort guidance trajectory and required steering. If the primary guidance and navigation section fails while the descent engine is being used, the astronaut initiates abort guidance descent engine control through a DEDA entry. The abort electronics assembly can only control descent engine ignition and shutdown. Descent engine throttling and gimbaling are not under computer control when operating with the abort guidance section. As with the primary guidance path, the abort path generates an engine-off command when the required velocity is attained. This velocity depends upon whether the program used will place the LM in a rendezvous trajectory or in a parking orbit. Manual on and off control also is available. In all cases, the S&C control assemblies receive engine on and off commands. As in the primary guidance path, these assemblies route the commands to the descent engine control assembly which routes them to the engine.

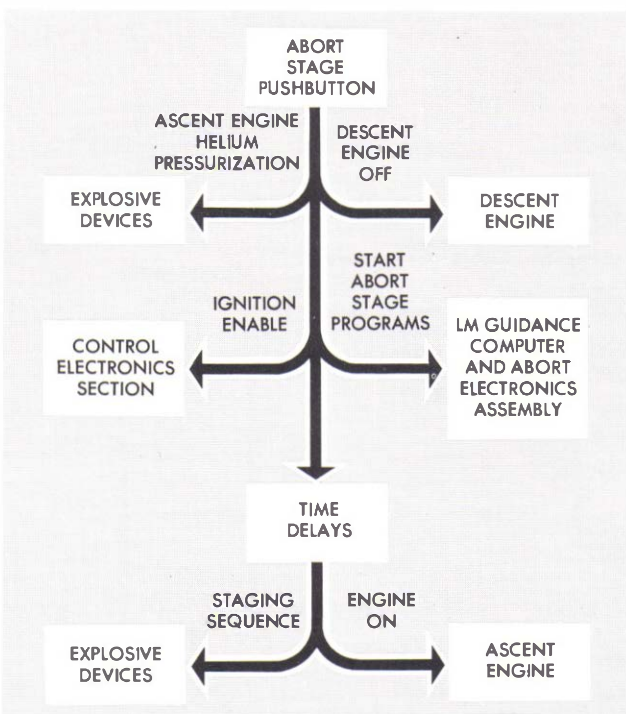
The astronaut uses the thrust/translation controller to control descent engine throttling and translation maneuvers. The manual throttle commands are supplied to the descent engine control assembly, which generates analog signals driving the throttle valve actuator.

Descent engine trim control under abort guidance, is achieved by using attitude errors from the abort electronics assembly. These errors are used by the attitude and translation control assembly for attitude control and steering calculation. The roll and pitch attitude errors are routed to the descent engine control assembly as trim commands.

### ASCENT ENGINE CONTROL

Ascent engine control during abort guidance is similar to that of the primary guidance. During abort guidance control, automatic ascent engine ignition and shutdown are controlled by the abort electronics assembly.

If the descent stage is attached, the LM can be staged manually through use of the appropriate switches on the explosive devices panel. The astronaut has the option of using an abort stage pushbutton to start an automatic ascent engine ignition sequence. If the ascent engine-on command is lost, the ascent engine latching device memory circuit keeps issuing the command.




R-64

*Abort Stage Functions*

# EQUIPMENT

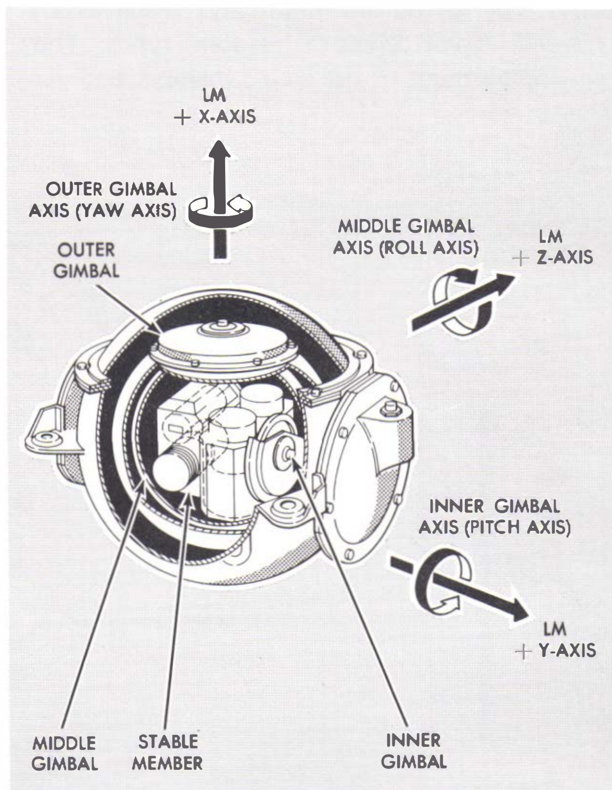
## PRIMARY GUIDANCE AND NAVIGATION SECTION

### NAVIGATION BASE

The navigation base is a lightweight mount (about 3 pounds) bolted to the LM structure above the astronauts heads, with three mounting pads on a center ring. The center ring is approximately 14 inches in diameter and each of the four legs, which are part of the base, is approximately 10 inches long.

### INERTIAL MEASUREMENT UNIT

The inertial measurement unit contains the stable member, gyroscopes, and accelerometers necessary to establish the inertial reference.




R-65

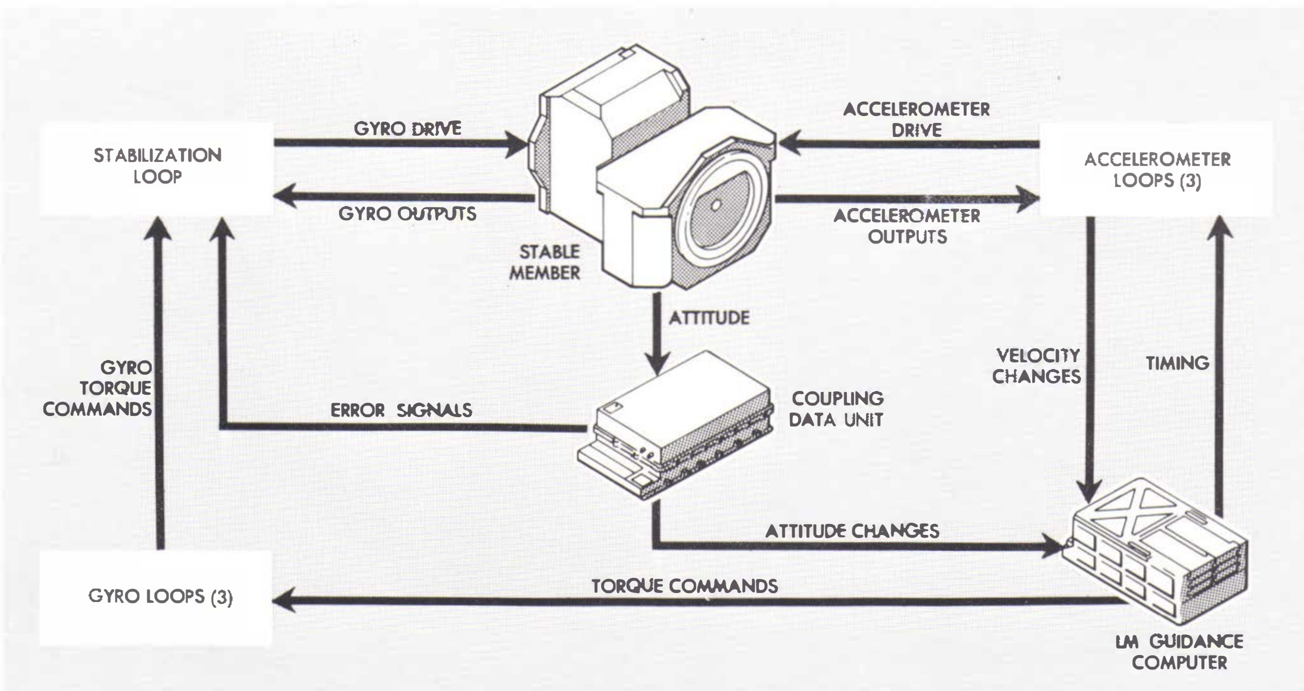
*Inertial Measurement Unit*

The stable member serves as the space-fixed reference for the inertial subsection. It is supported by three gimbal rings (outer, middle, and inner) for complete freedom of motion.

The outer gimbal is mounted to the case of the unit; its axis is parallel to the LM X-axis. The middle gimbal is mounted to and perpendicular with the outer; its axis is parallel to the LM Z-axis. The inner gimbal supports the stable member; its axis is parallel to the LM Y-axis. The inner gimbal is mounted to the middle one. All three gimbals are spherical with 360 degrees of freedom. To overcome the small amount of friction inherent in the support system, small torque motors are mounted on each axis.

The three Apollo inertial reference integrating gyroscopes, used to sense attitude changes, are mounted on the stable member, mutually perpendicular. The gyros are fluid- and magnetically-suspended, single-degree-of-freedom types. They sense displacement of the stable member and generate error signals proportional to displacement. The three pulse integrating pendulous accelerometers are fluid- and magnetically-suspended devices.

Thermostats maintain gyro and accelerometer temperature within their required limits during inertial measurement unit standby and operating modes. Heat is applied to end-mount heaters on the inertial components, by stable member heaters, and by a temperature control anticipatory heater. Heat is removed by convection, conduction, and radiation. The natural convection used during inertial measurement unit standby mode is changed to blower-controlled, forced convection during the operating mode. Inertial measurement unit internal pressure is normally between 3.5 and 15 psia, enabling the required forced convection. To aid in removing heat, water-glycol passes through the case. Therefore, heat flow is from the stable member to the case and coolant. The temperature control system consists of the temperature control circuit, the blower control circuits, and temperature alarm circuit.




*Inertial Subsection Functional Loops*



Grumman

## COUPLING DATA UNIT

The coupling data unit performs analog-to-digital conversion, digital-to-analog conversion, inertial subsection moding and failure detection. It consists of a sealed container which encloses 34 modules of 10 different types that make up five almost identical channels: one each for the inner, middle, and outer gimbals of the inertial measurement unit and one each for the rendezvous radar shaft and trunnion gimbals. Several of the modules are shared by all five channels.

The two channels used with the rendezvous radar interface between the antenna and the guidance computer. The computer calculates digital antenna position commands before acquisition of the CSM. These signals are converted to analog form by the coupling data unit and applied to the antenna drive mechanism to aim the antenna. Tracking-angle information in analog form is converted to digital by the unit and applied to the guidance computer.

The three channels used with the inertial measurement unit provide interfaces between it and the guidance computer and between the computer and the abort guidance section. Each of the three IMU gimbal-angle resolvers provide its channel with analog gimbal-angle signals that represent LM attitude. The coupling data unit converts these signals to digital form and applies them to the guidance computer. The computer calculates attitude or translation commands and routes them through the control electronics section to the proper thruster. The coupling data unit converts attitude error signals to 800-cps analog signals and applies them to the attitude indicator. Coarse- and fine-alignment commands generated by the guidance computer are coupled to the inertial measurement unit through the coupling data unit.

The digital-to-analog converters of the coupling data unit are a-c ladder networks. When the unit is used to position a gimbal, the guidance computer calculates the difference between the desired gimbal angle and the actual gimbal angle. This difference results in a servo error signal that drives the gimbal to the desired angle.

The analog-to-digital converter operates on an incremental basis. Using a digital-analog feedback technique which utilizes the resolvers as a reference, the coupling data unit accumulates the proper angular value by accepting increments of the angle to close the feedback loop. These data are applied to counters in the guidance computer for rendezvous radar tracking information, and to counters in the primary and abort guidance computers for the inertial reference gimbal angles. In this manner, the abort guidance section attitude reference is fine-aligned simultaneously with that of the primary guidance and navigation section.

## PULSE TORQUE ASSEMBLY

The pulse torque assembly consists of 17 electronic modular subassemblies mounted on a common base. There are four binary current switches: one furnishes torquing current to the three gyros; the other three furnish torquing current to the three accelerometers. Four d-c differential amplifier and precision voltage reference subassemblies regulate torquing current supplied through the binary current switches.

Three a-c differential amplifier and interrogator subassemblies amplify accelerometer signal generator signals and convert them to positive and negative torque pulses. The gyro calibration module applies torquing current to the gyros when commanded by the guidance computer. Three accelerometer calibration modules compensate for the difference in inductive loading of accelerometer torque generator windings and regulate the balance of positive and negative torque. A pulse torque isolation transformer couples torque commands, data pulses, interrogate pulses, switching pulses, and synchronizing pulses between the guidance computer and the pulse torque assembly. The pulse torque power supply supplies power for the other 16 subassemblies.

## POWER AND SERVO ASSEMBLY

The power and servo assembly provides a central mounting point for the primary guidance and navigation section amplifiers, modular electronic components, and power supplies. The assembly is on the cabin bulkhead behind the astronauts. It consists of 14 subassemblies mounted to a header assembly.

## SIGNAL CONDITIONER ASSEMBLY

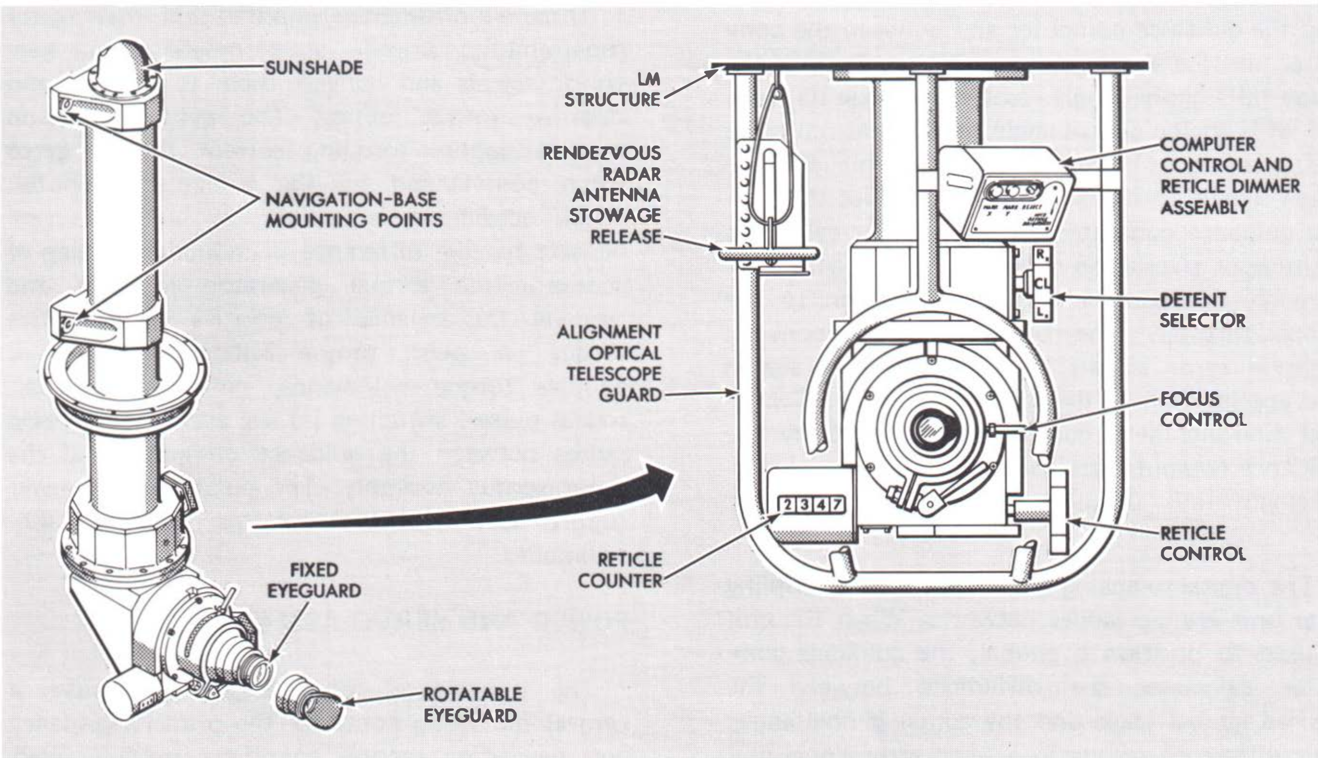
The signal conditioner assembly preconditions primary guidance and navigation section measurements to a 0- to 5-volt d-c format before the signals are routed to the Instrumentation Subsystem.

## ALIGNMENT OPTICAL TELESCOPE

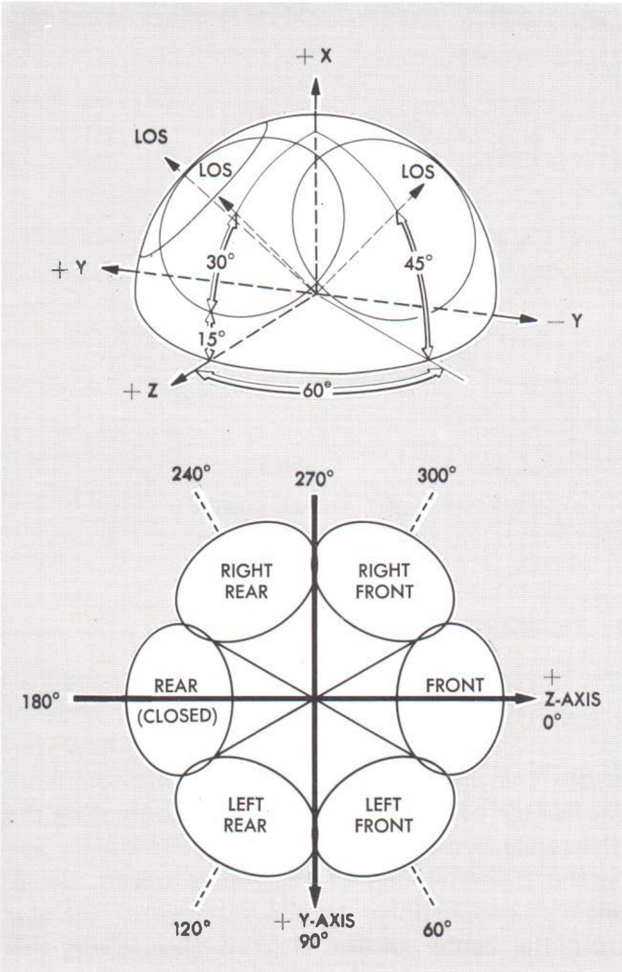
The alignment optical telescope, mounted on the navigation base to provide mechanical alignment and a common reference between the telescope and the inertial measurement unit, is a unity-power, periscope-type device with a 60° conical field of view. It is operated manually by the astronauts. The telescope has a movable shaft axis (parallel to the LM X-axis) and a line of sight approximately 45° from the X-axis in the Y-Z plane.

The telescope line of sight is fixed in elevation and movable in azimuth to six detent positions. These detent positions are selected by turning a detent selector knob on the telescope; they are located at 60° intervals. The forward (F), zero detent position, places the line of sight in the X-Z plane. looking forward and up as one would look from inside the LM. The right (R) position places the line of sight 60° to the right of the X-Z plane; the left (L) position, 60° to the left of the X-Z plane. Each of these positions maintains the line of sight at 45° from the LM +X-axis. The remaining three detent positions reverse the prism on top of the telescope. These positions are right-rear, closed (CL), and left-rear. The CL position (180° from the F position) is the stowed position. The right-rear and left-rear positions have minimal use.

The optics consist of two sections: shaft optics and eyepiece optics. The shaft optics section is a -5 power complex that provides a 60° field of view. The eyepiece optics section is a +5 power complex that provides shaft and trunnion angle




*Alignment Optical Telescope*

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*Alignment Optical Telescope – Detents and Field of View*

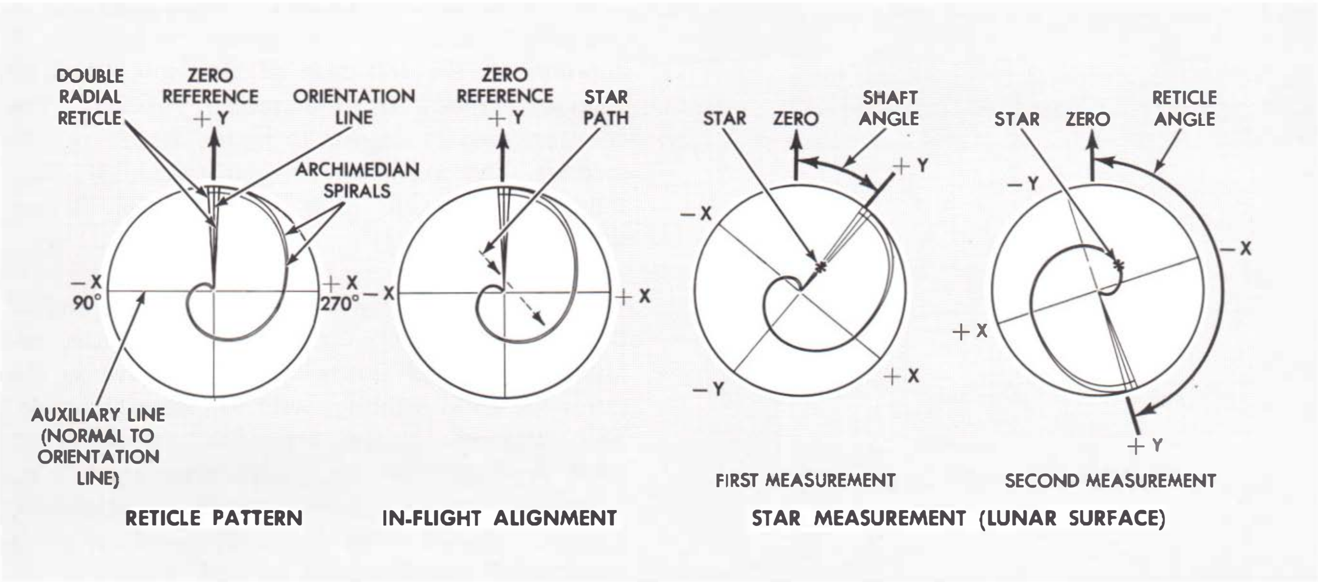
measurements. The reticle pattern within the eyepiece optics consists of crosshairs and a pair of Archimedes spirals. The vertical crosshair, an orientation line designated the Y-line, is parallel to the LM X-axis when the reticle is at the 0° reference position. The horizontal crosshair, an auxiliary line designated the X-line, is perpendicular to the orientation line. The one-turn spirals are superimposed from the center of the field of view to the top of the vertical crosshair. Ten miniature red lamps mounted around the reticle prevent false star indications caused by imperfections in the reticle and illuminate the reticle pattern. Stars will appear white; reticle imperfections, red. Heaters prevent fogging of the mirror due to moisture and low temperatures during the mission.

A reticle control enables manual rotation of the reticle for use in lunar surface alignments. A counter on the left side of the unit, provides angular readout of the reticle rotation. The counter reads in degrees to within ±0.02° or ±72 seconds. The maximum reading is 359.88°, then the counter returns to 0°. Interpolation is possible to within ±0.01°.

A rotatable eyeguard is fastened to the end of the eyepiece section. The eyeguard is axially adjustable for head position. It is used when the astronaut takes sightings with his faceplate open. This eyeguard is removed when the astronaut takes sightings with his faceplate closed; a fixed eyeguard, permanently cemented to the telescope, is used instead. The fixed eyeguard prevents marring of the faceplate by the eyepiece. A high-density filter lens, supplied as auxiliary equipment, prevents damage to the astronaut's eyes due to accidental direct viewing of the sun or if the astronaut chooses to use the sun as a reference.

The alignment optical telescope is used for in-flight and lunar surface sightings.

For in-flight sightings, the telescope may be placed in any of the usable detent positions. However, when the LM is attached to the CSM, only the forward position is used. The astronaut selects a detent and the particular star he wishes to use. He then maneuvers the LM so that the selected star falls within the telescope field of view. The specific detent position and a code associated with the selected star are entered into the guidance computer by the astronaut using the DSKY. The LM is then maneuvered so that the star image crosses the reticle crosshairs. When the star image is coincident with the Y-line, the astronaut presses the mark Y pushbutton; when it is coincident with the X-line, he presses the mark X pushbutton. The astronaut may do this in either order and, if desired, he may erase the latest mark by pressing the reject pushbutton. When a mark pushbutton is pressed, a discrete is sent to the guidance computer. The guidance computer then records the time of mark and the inertial measurement unit gimbal angles at the instant of the mark.

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*Alignment Optical Telescope - Reticle Pattern*

Crossing of a reticle line by the star image defines a plane containing the star. Crossing of the other reticle line defines another plane containing the same star. The intersection of these planes forms a line that defines the direction of the star. To define the inertial orientation of the stable member, sightings on at least two stars are required. Each star sighting requires the same procedure. Multiple reticle crossings and their corresponding marks can be made on either or both stars to improve the accuracy of the sightings. Upon completion of the second star sightings, the guidance computer calculates the orientation of the stable member with respect to a predefined reference coordinate system.

On the lunar surface, the LM cannot be maneuvered to obtain a star-image that crosses the reticle crosshairs. The astronaut using the reticle control knob, adjusts the reticle to superimpose the orientation (Y) line on the target star. The reticle angle display on the reticle counter, is then inserted into the computer by the astronaut. This provides the computer with the star orientation angle (shaft angle). The astronaut then continues rotating the reticle until a point on the spirals is superimposed on the target star. This second angular readout (reticle angle) is then entered into the computer along with the detent position and the code of the observed star. The computer can now calculate the angular displacement of the star from the center of the field of view by computing the difference between the two counter readings. Due to the characteristics of the reticle spirals, the Δ angle is proportional to the distance of the star from the center of the field of view. Using this angle and a proportionality equation, the computer can calculate the trunnion angle. At least two star sightings are required for determination of the inertial orientation of the stable member.

## COMPUTER CONTROL AND RETICLE DIMMER ASSEMBLY

The computer control and reticle dimmer assembly is mounted on the alignment optical telescope guard. The mark X and mark Y pushbuttons are used by the astronauts to send discrete signals to the primary guidance computer when star sightings are made. The reject pushbutton is used if an invalid mark has been sent to the computer. A thumbwheel on the assembly is used to adjust the brightness of the telescope's reticle lamps.

## LM GUIDANCE COMPUTER

The LM guidance computer is the central data-processing device of the GN&CS. It is a parallel fixed-point, one's-complement, general-purpose digital computer with a fixed rope core memory and an erasable ferrite-core memory. It has a limited self-check capability. Inputs to the computer are received from the landing radar and rendezvous radar, from the inertial measurement unit through the inertial channels of the coupling data unit and from an astronaut through the DSKY. The computer performs four major functions: (1) calculates steering signals and generates engine and RCS thruster commands to keep the LM on a required trajectory (2) aligns the stable member (inner gimbal) of the inertial measurement unit to a coordinate system defined by precise optical measurements, (3) conducts limited malfunction isolation for the GN&CS, and (4) computes pertinent navigation information for display to the astronauts. Using information from navigation fixes, the computer determines the amount of deviation from the required trajectory and calculates the necessary attitude and thrust corrective commands. Velocity corrections are measured by the inertial measurement unit and controlled by the computer. During coasting phases of the mission, velocity corrections are not made continuously, but are initiated at predetermined checkpoints.

The computer's memory consists of an erasable and a fixed magnetic core memory with a combined capacity of 38,916 16-bit words. The erasable memory is a coincident-current, ferrite core array with a total capacity of 2,048 words; it is characterized by destructive readout. The fixed memory consists of three magnetic-core rope modules. Each module contains two sections; each section contains 512 magnetic cores. The capacity of each core is 12 words, making a total of 36,864 words in the fixed memory. Readout from the fixed memory is non-destructive.

The logic operations of the computer are mechanized using micrologic elements, in which the necessary resistors are diffuzed into single silicon wafers. One complete NOR gate, which is the basic building block for all the circuitry, is in a package the size of an aspirin tablet. Flip-flops, registers, counters, etc. are made from these standard NOR elements in different wiring configurations. The computer performs all necessary arithmetic operations by addition, adding two complete words and preparing for the next operation in approximately 24 microseconds. To subtract, the computer adds the complement of the subtrahend. Multiplication is performed by successive additions and shifting; division, by successive addition of complements and shifting.

Functionally, the computer contains a timer, sequence generator, central processor, priority control, an input-output section, and a memory unit.

The timer generates all necessary synchronization pulses to ensure a logical data flow with the LM subsystems. The sequence generator directs the execution of the programs. The central processor performs all arithmetic operations and checks information to and from the computer. Memory stores the computer data and instructions. Priority control establishes a processing priority for operations that must be performed by the computer. The input output section routes and conditions signals between the computer and the other subsystems.

The main functions of the computer are implemented through execution of programs stored in memory. Programs are written in machine language called basic instructions. A basic instruction can be an instruction word or a data word. Instruction words contain a 12-bit address code and a three-bit order code.

The computer operates in an environment in which many parameters and conditions change in a continuous manner. The computer, however, operates in an incremental manner, one item at a time. Therefore, for it to process the parameters, its hardware is time shared. The time sharing is accomplished by assigning priorities to the processing functions. These priorities are used by the computer so that it processes the highest priority processing function first.

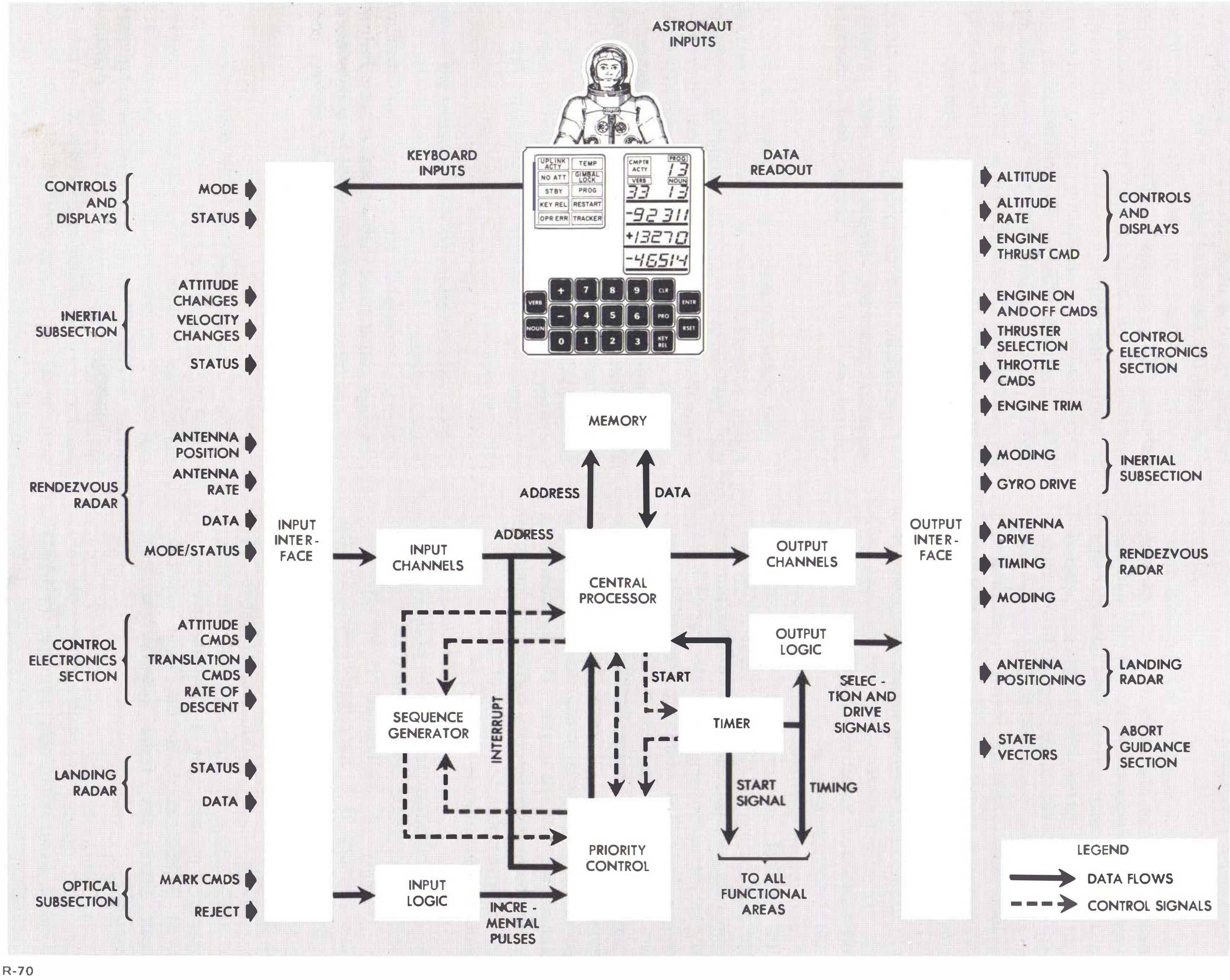



*Diagram of LM Guidance Computer*

In addition, each of the functions has a relative priority with respect to the others; also within each there are a number of processing functions, each having a priority level relative to the other in the group. Most of the processing performed by the computer is in the program controlled processing category. During this processing the computer is controlled by the program stored in its memory.

Real time, which is used in solving guidance and navigation problems, is maintained within the computer's memory. A 745.65-hour (approximately 31 days) clock is provided. The clock is synchronized with ground elapsed time (GET) which is "time zero" at launch. This time is transmitted once every second by downlink operation for comparison with MSFN elapsed time.

Incremental transmissions occur in the form of pulse bursts from the output channels to the coupling data unit, the gyro fine-alignment electronics, the RCS, and the radars. The number of pulses and the time at which they occur are controlled by the program. Discrete outputs, originating in the output channels under program control, are sent to the DSKY and other subsystems. A continuous pulse train at 1.024 mHz originates in the timing output logic and is sent as a synchronization signal to the timing electronics assembly in the Instrumentation Subsystem (IS).

The uplink word from MSFN via the digital uplink assembly is supplied as an incremental pulse to the priority control. As this word is received, priority produces the address of the uplink counter in memory and requests the sequence generator to execute the instructions that perform the serial-to-parallel conversion of the input word. When the conversion is completed, the parallel word is transferred to a storage location in memory by the uplink priority program. The uplink priority program also retains the parallel word for subsequent downlink transmission. Another program converts the parallel word to a coded display format and transfers the display information to the DSKY.

The downlink operation is asynchronous with respect to the IS. The IS supplies all the timing signals necessary for the downlink operation.

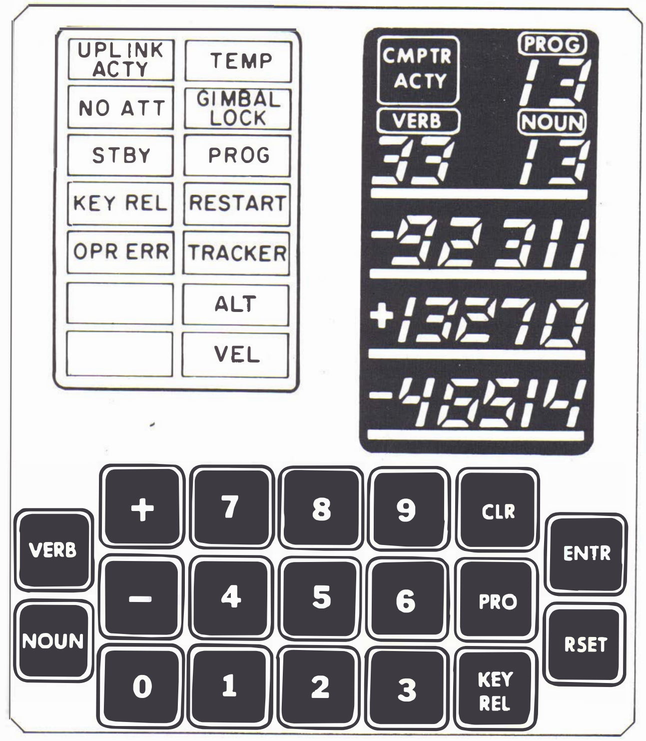
Through the DSKY, the astronaut can load information into the computer, retrieve and display information contained in the computer, and initiate any program stored in memory. A key code is assigned to each keyboard pushbutton. When a DSKY pushbutton is pressed, the key code is sent to an input channel of the computer. A number of key codes are required to specify an address or a data word. The initiated program also converts the keyboard information to a coded display format, which is transferred by another program to an output channel and to the DSKY for display. The display is a visual indication that the key code was received, decoded, and processed properly.

## DISPLAY AND KEYBOARD

The DSKY is located on panel 4 between the Commander and LM Pilot and above the forward hatch. The upper half is the display portion; the lower half comprises the keyboard. The display portion contains seven caution indicators, seven status indicators, seven operation display indicators, and three data display indicators. These displays provide visual indications of data being loaded in the computer, the computer's condition and the program being used. The displays also provide the computer with a means of displaying or requesting data.

The caution indicators when on, are yellow; the status indicators, white. The operation and data displays are illuminated green when energized. The words "PROG," "VERB," and "NOUN" and the lines separating the three groups of display indicators, and the 19 pushbuttons of the keyboard are illuminated when the guidance computer is powered-up.

| Pushbutton | Function |
| --- | --- |
| 0 through 9 | Enters numerical data, noun codes, and verb codes into computer |
| + and – | Informs computer that following numerical data are decimal and indicates sign of data |
| VERB | Indicates to computer that it is going to take some action and conditions computer to interpret the next two numerical characters as a verb code |
| NOUN | Conditions computer to interpret next two numerical characters (noun code) as to what type of action is applied to verb code |
| CLEAR | Clears data contained in data display; pressing this pushbutton clears data display currently being used. Successive pressing clears other two data displays |
| PRO | Commands computer to proceed to standby mode; if in standby mode, commands computer to resume regular operation |
| KEY REL | Releases keyboard displays initiated by keyboard action so that information supplied by computer program may be displayed |
| ENTR | Informs computer that data to be inserted is complete and that requested function is to be executed |
| RSET | Turns off condition indicator lamps after condition has been corrected |

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*Display and Keyboard*

The DSKY enables the astronauts to insert data into the guidance computer and to initiate computer operations. The astronauts can also use the keyboard to control the moding of the inertial subsection. The exchange of data between the astronauts and the computer is usually initiated by an astronaut; however, it can also be initiated by internal computer programs.

The operator of the DSKY can communicate with the computer by pressing a sequence of pushbuttons on the DSKY keyboard. The computer can also initiate a display of information or request the operator for some action, through the processing of its program.

The basic language between the astronaut and the DSKY consists of verb and noun codes. The verb code indicates what action is to be taken (operation). The noun code indicates to what this action is applied (operand). Verb and noun codes may be originated manually or by internal computer sequence. Each verb or noun code contains two numerals. The standard procedure for manual operation involves pressing a sequence of seven pushbuttons:

VERB $V_1$ $V_2$ NOUN $N_1$ $N_2$ ENTR

Pressing the verb pushbutton blanks the verb code display on the display panel and clears the verb code register within the computer. The next two pushbuttons (0 to 9) pressed provide the verb code ($V_1$ and $V_2$). Each numeral of the code is displayed by the verb display as the pushbutton is pressed. The noun pushbutton operates the same as the verb pushbutton, for the noun display and noun code register. The enter pushbutton starts the operation called for. It is not necessary to follow any order in punching in the verb or noun code. It can be done in reverse order, and a previously entered verb or noun may be used without repunching it.

An error noticed in the verb code or the noun code before pressing the enter pushbutton is corrected by pressing the verb or noun pushbutton and repunching the erroneous code, without changing the other one. Only when the operator has verified that the desired verb and noun codes are displayed does he press the enter pushbutton.

Decimal data are identified by a plus or minus sign preceding the five digits. If a decimal format is used for loading data, it must be used for all components of the verb. Mixing of decimal and octal data for different components of the same load verb is not permissible. If data are mixed, the OPR ERR condition light goes on.

After any use of the DSKY, the numerals (verb, noun, and data words) remain visible until the next use of the DSKY. If a particular use of the DSKY involves fewer than three data words, the unused data display registers remain unchanged unless blanked by deliberate program action. Some verb-noun codes require additional data to be loaded. If additional data are required after the enter pushbutton is pressed, following the keying of the verb-noun codes, the verb and noun displays flash on and off at a 1.5-Hz rate. These displays continue to flash until all information associated with the verb-noun code is loaded.

### OPERATION UNDER COMPUTER CONTROL

Keyboard operations by the internal computer sequences are the same as those described for manual operation. Computer-initiated verb-noun combinations are displayed as static or flashing displays. A static display identifies data displayed only for astronaut information; no crew response is required. A flashing display calls for appropriate astronaut response as dictated by the verb-noun combination. In this case, the internal sequence is interrupted until the operator responds appropriately, then the flashing stops and the internal sequence resumes. A flashing verb-noun display must receive only one of the proper responses, otherwise, the internal sequence that instructed the display may not resume.

## ABORT GUIDANCE SECTION

### ABORT SENSOR ASSEMBLY

This assembly contains three floated, pulse-rebalanced, single-degree-of-freedom, rate-integrating gyros and three pendulous reference accelerometers. These six sensors are aligned with the three LM reference axes and housed in a beryllium block mounted on the navigation base. The assembly is controlled to maintain its internal temperature at +120° F, with external temperatures between -65° and +185° F. This is accomplished by two temperature control circuits, one each for fast warmup and fine temperature control. During fast warmup, temperature can be raised from 0° to +116° F in 40 minutes. The fine temperature control circuit controls the temperature after +116° F is reached and raises the temperature 4°. This operating temperature (+120° F) is maintained within 0.20° F.

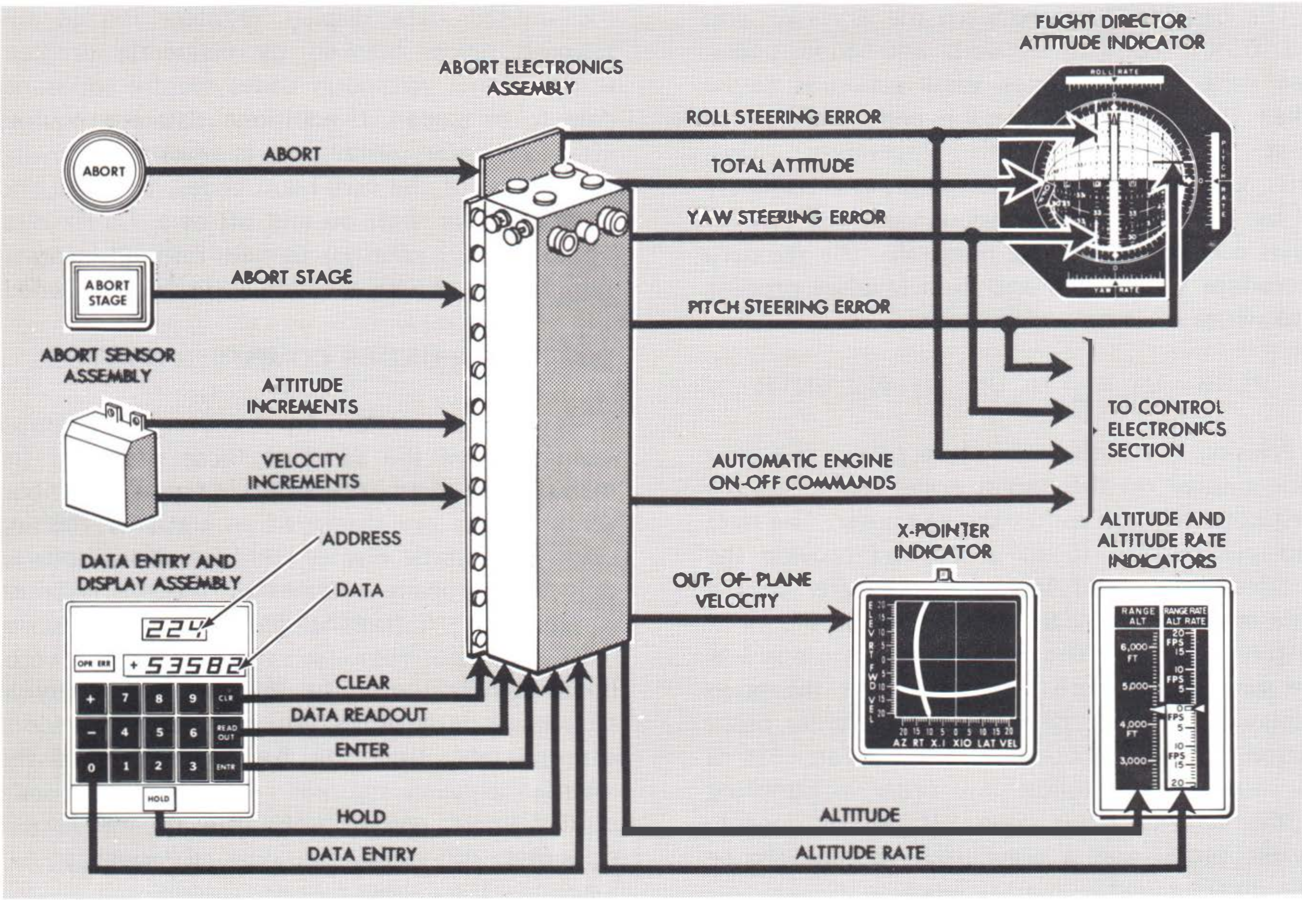


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*Diagram of Abort Guidance Section*

## DATA ENTRY AND DISPLAY ASSEMBLY

Essentially, the DEDA consists of a control panel to which electroluminescent displays and data entry pushbuttons are mounted and a logic enclosure that houses logic and input/output circuits.

As each numerical pushbutton is pressed, its code is displayed. When the appropriate number of pushbuttons are pressed, the enter or readout pushbutton can be pressed to complete the operation. The logic circuits process octal and decimal data. Octal data consists of a sign and five octal characters. Decimal data consists of a sign and five binary-coded decimal characters. The input/output circuits transfer data to and from the abort electronics assembly (computer). Data transfer occurs when the computer detects the depression of the enter or readout pushbutton.

## ABORT ELECTRONICS ASSEMBLY

This assembly is a high-speed, general-purpose computer with special-purpose input/output electronics. It uses a fractional two's complement, parallel arithmetic section and parallel data transfer. Instruction words are 18 bits long; they consist of a five-bit order code, an index bit, and a 12-bit operand address. For purposes of explanation, the assembly may be separated into a memory, central computer, and input/output subassembly.

The memory is a coincident-current, parallel, random-access, ferrite-core stack with a capacity of 4,096 instruction words. It is divided into two sections: temporary storage and permanent storage. Each section has a capacity of 2,048 instruction words. The temporary memory stores replaceable instructions and data. Temporary results may be stored in this memory and may be updated as necessary. The permanent memory stores instructions and constants that are not modified during a mission. The cycle time of the memory is 5 microseconds.

Basically, the central computer consists of eight data and control registers, two timing registers, and associated logic. The data and control registers are interconnected by a parallel data bus. Central computer operations are executed by appropriately timed transfer, controlled by the timing registers, of information between the registers, memory, and input/output subassembly.

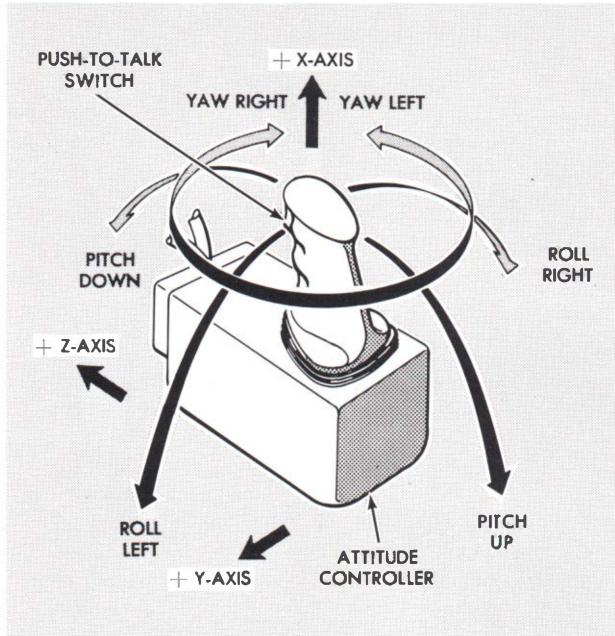
The input/output subassembly consists of four basic types of registers: integrator, ripple counter, shift, and static. These registers operate independently of the central computer, except when they are accessed during execution of an input or output instruction. All transfers of data between the central computer and the input-output registers are in parallel.

## CONTROL ELECTRONICS SECTION

### ATTITUDE CONTROLLER ASSEMBLIES

Each attitude controller assembly supplies attitude rate commands proportional to the displacement of its handle, to the computer and the attitude and translation control assembly; supplies an out-of-detent discrete each time the handle is out of its neutral position; and supplies a followup discrete to the abort guidance section each time the controller is out of detent. A trigger-type push-to-talk switch on the pistol grip handle of the controller assembly is used for communication with the CSM and ground facilities.

As the astronaut uses his attitude controller, his hand movements are analogous to vehicle rotations. Clockwise or counterclockwise rotation of the controller commands yaw right or yaw left, respectively. Forward or aft movement of the controller commands vehicle pitch down or up, respectively. Left or right movement of the controller commands roll left or right, respectively.

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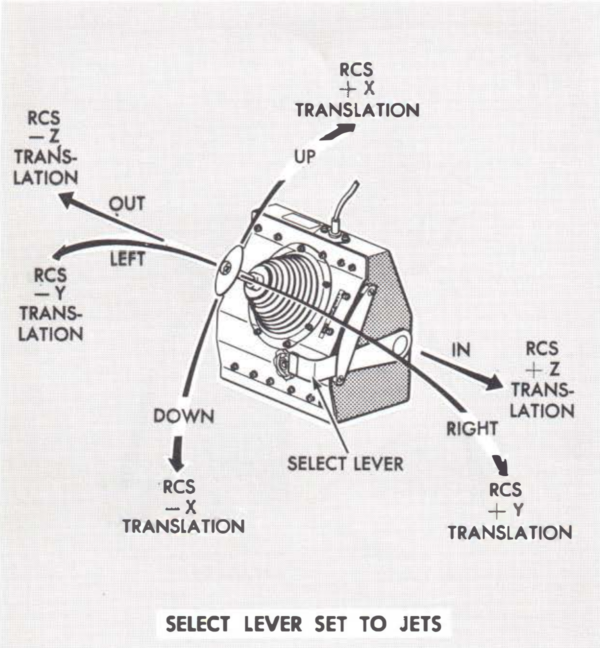
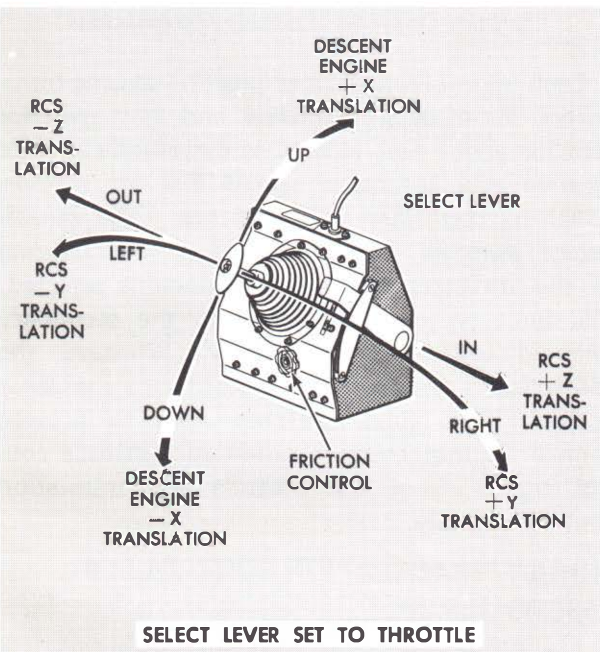
*Attitude Controller Assembly Manipulations*

Each assembly consists of position-sensing transducers, out-of-detent switches, and limit switches installed about each axis. The transducers provide attitude rate command signals that are proportional to controller displacements. The out-of-detent switches provide pulsed or direct firing of the thrusters when either mode is selected. The limit switches are wired to the secondary solenoid coils of the thrusters. Whenever the controller is displaced to its hardstops (hardover position), the limit switches close to provide commands that override automatic attitude control signals from the attitude and translation control assembly.

### THRUST/TRANSLATION CONTROLLER ASSEMBLIES

The thrust/translation controller assemblies are functionally integrated translation and thrust controllers. The astronauts use these assemblies to command vehicle translations by firing RCS thruster and to throttle the descent engine between 10% and 92.5% thrust magnitude. The controllers are three axis, T-handle, left-hand controllers; they are mounted with their longitudinal axis approximately 45° from a line parallel to the LM Z-axis (forward axis).




R-74

*Thrust/Translation Controller Assembly Manipulations*

Setting a switch in the LM cabin determines whether the Commander's or LM Pilot's assembly is in command. A lever on the right side of the controller enables the astronaut to select either of two control functions: (1) to control translation in the Y-axis and Z-axis using the RCS thrusters and throttling of the descent engine to control X-axis translation; and (2) to control translation in all three axes using the RCS thrusters.

Due to the assembly mounting position, LM translations correspond to astronaut hand movements when operating the controller. Moving the T-handle to the left or right commands translation along the Y-axis. Moving the tee-handle inward or outward commands translation along the Z-axis. Moving the tee-handle upward or downward commands translation along the X-axis, using the RCS thrusters when the select lever is in the down position. When the lever is in the up position, upward or downward movement of the controller increases or decreases, respectively, the magnitude of descent engine thrust.

The controller is spring loaded to its neutral position in all axes when the lever is in jets position. When the lever is in the throttle position the Y and Z axes movements are spring loaded to the neutral position but the X-axis throttle commands will remain at the position set by the astronauts.

## ATTITUDE AND TRANSLATION CONTROL ASSEMBLY

The attitude and translation control assembly controls LM attitude and translation. In the primary guidance path, attitude and translation commands are generated by the primary guidance computer and applied directly to jet drivers within the assembly. In the abort guidance path, the attitude and translation control assembly receives translation commands from the thrust/translation controller assembly, rate-damping signals from the rate gyro assembly, and attitude rate commands and pulse commands from the attitude controller assembly.

The assembly combines attitude and translation commands in its logic network to select the proper thruster to be fired for the desired combination of translation and rotation.

## RATE GYRO ASSEMBLY

The rate gyro assembly consists of three single-degree-of-freedom rate gyros mounted so that they sense vehicle roll, pitch, and yaw rates. Each rate gyro senses a rate of turn about its input axis, which is perpendicular to the spin and output axes. The rate of turn is dependent on the gimbal position of the gyro. In abort guidance control, pickoff voltages are routed to the attitude and translation control assembly for rate damping.

## DESCENT ENGINE CONTROL ASSEMBLY

The descent engine control assembly accepts engine-on and engine-off commands from the S&C control assemblies, throttle commands from the primary guidance computer and the thrust/translation controller assembly, and trim commands from the primary guidance computer or the attitude and translation control assembly. Demodulators, comparators, and relay logic circuits convert these inputs to the required descent engine commands. The assembly applies throttle and engine control commands to the descent engine and routes trim commands to the gimbal drive actuators.

Under normal operating conditions with primary guidance in control, the descent engine is manually selected and armed by an astronaut action. The descent engine control assembly responds by routing, through relay logic, 28 volts dc to the actuator isolation solenoids of the descent engine. Once the engine is armed, the assembly receives an automatic descent engine-on command from the primary guidance computer or a descent engine-on command initiated by the Commander pressing the start pushbutton. When the engine is fired, the descent engine control switching and logic latch the engine in the on position until an automatic or manual off command is received by the assembly. When the measured change in velocity reaches a predetermined value, the primary guidance computer generates a descent engine-off command. Manual engine commands are generated by the astronauts and will override the automatic function.

The control assembly accepts manual and automatic throttle commands from the thrust/translation controller assembly and the primary guidance computer, respectively. Manual or automatic thrust control is selected by the astronaut. During manual throttle control, computer throttle commands are interrupted and only manual commands are accepted by the assembly. The astronauts can monitor the response to their manual commands on the thrust indicator. Manual throttle commands consist of 800-Hz a-c voltages which are proportional to X-axis displacement of the thrust/translation control assembly. The active controller always provides at least a 10% command. These commands drive a nonlinear circuit to provide the desired thrust level. At an approximately 60% thrust the nonlinear region of the thrust/translation controller assembly is reached; it is displaced to its hard stop (92.5% thrust) to prevent erratic descent engine operation.

Automatic throttle increase or decrease commands are generated by the primary guidance computer under program control. These are predetermined levels of thrust and can be overridden by the astronaut using his thrust controller. No provision is made for automatically throttling the engine, using the abort guidance computer. The automatic commands appear on two separate lines (throttle increase and throttle decrease) as 3,200-Hz pulse inputs to an integrating d-c counter (up-down counter). Each pulse corresponds to a 2.7-pound thrust increment.

During automatic throttle operation, computer-commanded thrust is summed with the output of the thrust/translation controller. When the thrust/translation controller is in its minimum position, the computer-commanded thrust is summed with the fixed 10% output of the controller. When an active controller is displaced from its minimum position, the amount of manual thrust commanded is summed with the computer-commanded thrust to produce the desired resultant. In this case, the controller overrides the computer's control of descent engine thrust. The total thrust commanded (automatic and/or manual) cannot exceed 92.5%. Automatic thrust commands derived by the computer are always 10% lower than required thrust to compensate for the fixed output of the thrust controller.

Two channels of electronics are provided to control the roll and pitch position of the descent engine thrust vector with respect to the vehicle's center of gravity. When the descent engine is firing, this trim control acts as a low-frequency stabilization system in parallel with the higher frequency RCS. Each channel is driven by either the primary guidance computer when the primary guidance mode is used; by the attitude and translation control assembly when the abort guidance mode is used.

In the primary guidance mode, the computer provides automatic trim control. When the computer determines the required descent engine trim, it provides a trim command to the descent engine control assembly, on a positive or negative trim line for the pitch or roll axis. The trim command is routed to a malfunction logic circuit and to a power-switching circuit, which applies 115-volt, 400-Hz power to the proper gimbal drive actuator. In the abort guidance mode, trim commands are provided by the descent engine control assembly, by using the analog trim signals generated in the pitch and roll error channels of the attitude and translation control assembly.

## LANDING RADAR

### ELECTRONICS ASSEMBLY

The electronics assembly comprises frequency trackers (one for each velocity beam), a range frequency tracker, velocity converter and computer, range computer, signal data converter, and data-good/no-good logic circuit.

### ANTENNA ASSEMBLY

The assembly comprises four microwave mixers, four dual audio-frequency preamplifiers, two microwave transmitters, a frequency modulator, and an antenna pedestal tilt mechanism. The antenna consists of six planar arrays: two for transmission and four for reception. They are mounted on the tilt mechanism, beneath the descent stage, and may be placed in one of two fixed positions.

## RENDEZVOUS RADAR

### ELECTRONICS ASSEMBLY

The electronics assembly comprises a receiver, frequency synthesizer, frequency tracker, range tracker, servo electronics, a signal data converter, self-test circuitry, and a power supply. The assembly furnishes crystal-controlled signals, which drive the antenna assembly transmitter; provides a reference for receiving and processing the return signal; and supplies signals for antenna positioning.

### ANTENNA ASSEMBLY

The main portion of the rendezvous radar antenna is a 24-inch parabolic reflector. A 4.65-inch hyperbolic subreflector is supported by four converging struts. Before the radar is used, the antenna is manually released from its stowed position. The antenna pedestal and the base of the antenna assembly are mounted on the external structural members of the LM. The antenna pedestal includes rotating assemblies that contain radar components. The rotating assemblies are balanced about a shaft axis and a trunnion axis. The trunnion axis is perpendicular to, and intersects, the shaft axis. The antenna reflectors and the microwave and RF electronics components are assembled at the top of the trunnion axis. This assembly is counterbalanced by the trunnion-axis rotating components (gyroscopes, resolvers, and drive motors) mounted below the shaft axis. Both groups of components, mounted opposite each other on the trunnion axis, revolve about the shaft axis. This balanced arrangement requires less driving torque and reduces the overall antenna weight. The microwave, radiating, and gimbaling components, and other internally mounted components, have low-frequency flexible cables that connect the outboard antenna components to the inboard electronics assembly.