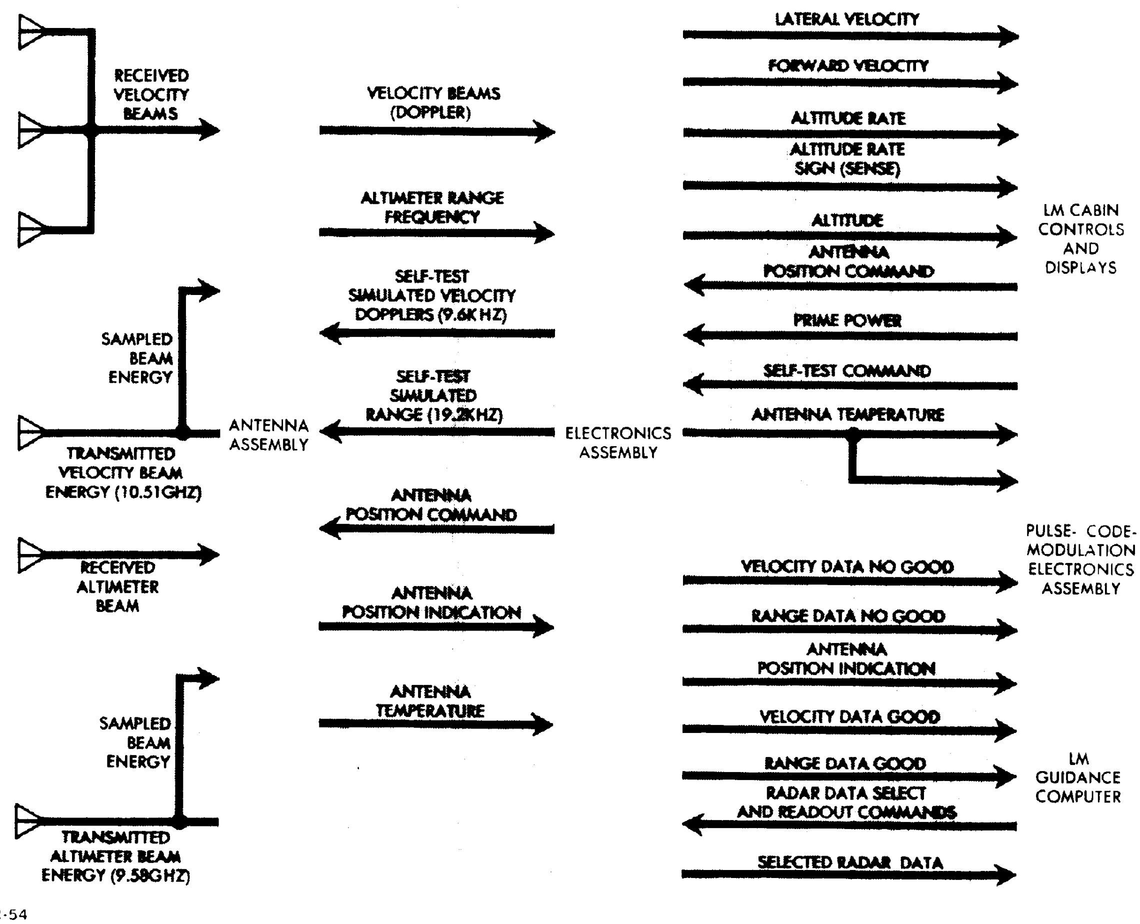
The descent engine control assembly processes engine throttling commands from the astronauts (manual control) and the guidance computer (automatic control), gimbal commands for thrust vector control, preignition (arming) commands, and on and off commands to control descent engine ignition and shutdown.

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

LANDING RADAR

The landing radar senses the velocity and altitude 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.



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.

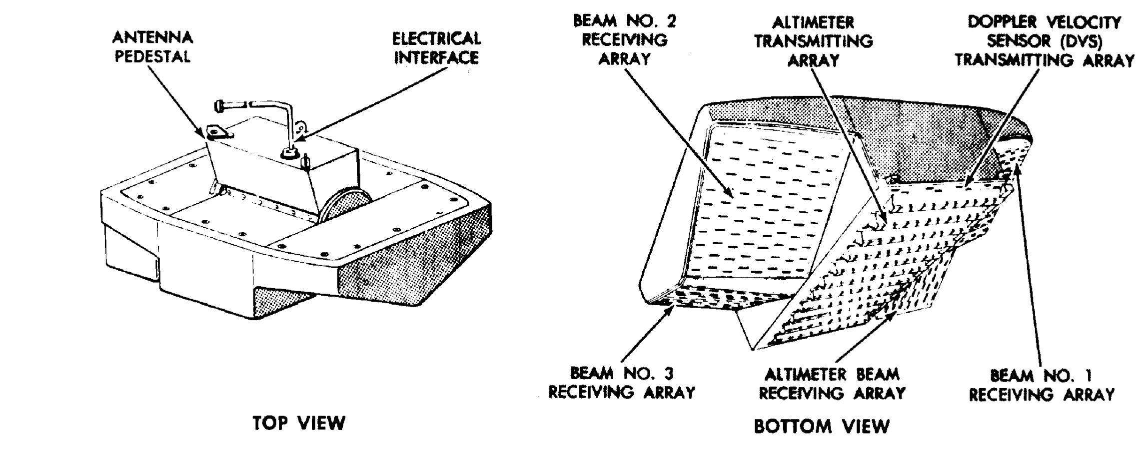
When the electronics assembly is receiving and processing the returned microwave beams, data-good signals are sent to the LGC. When the electronics assembly is not operating properly, data-no-good signals are sent to the pulse code modulation timing electronics assembly of the Instrumentation Subsystem 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 approximately 25,000 feet. Slant range data are continuously updated to provide true altitude above the lunar surface. At approximately 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.



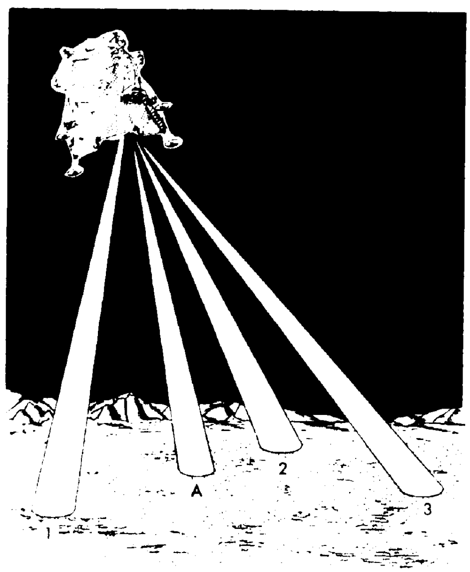
Landing Radar Antenna Assembly

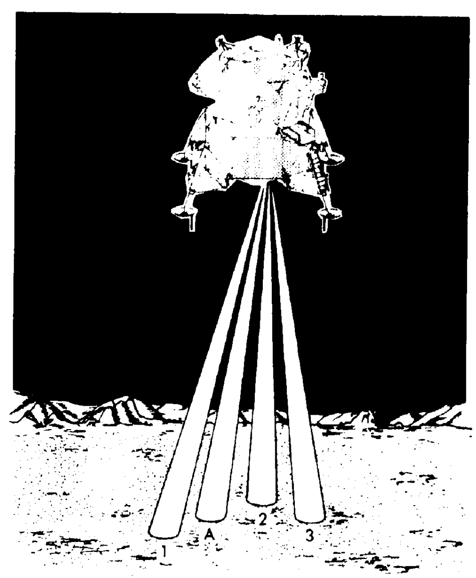
The landing radar antenna has a descent position and a hover position. In the descent position, the antenna boresight angle is 24° from the LM X-axis. In the hover position, the antenna boresight is parallel to the X-axis and perpendicular to the Z-axis. Antenna position is selected by the astronaut 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.





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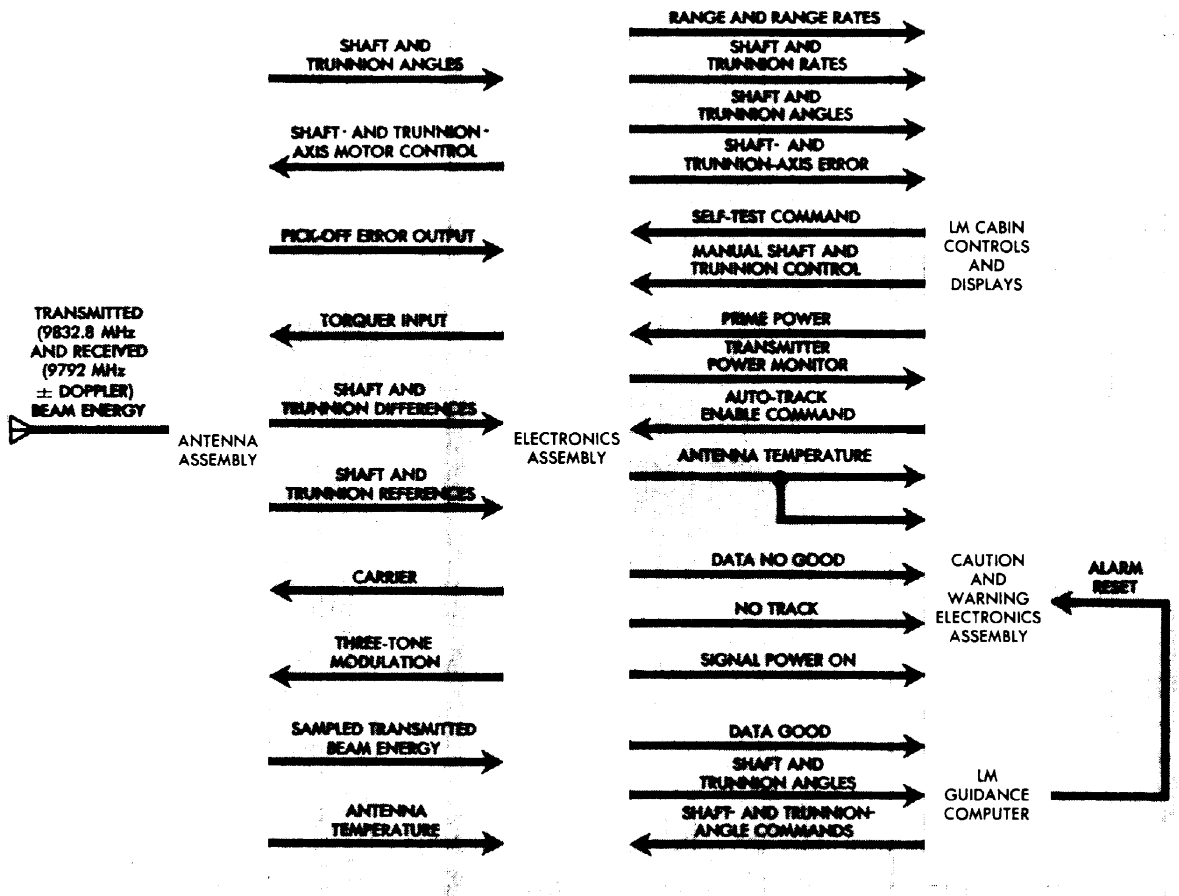
Landing Radar - Antenna Beam Configuration



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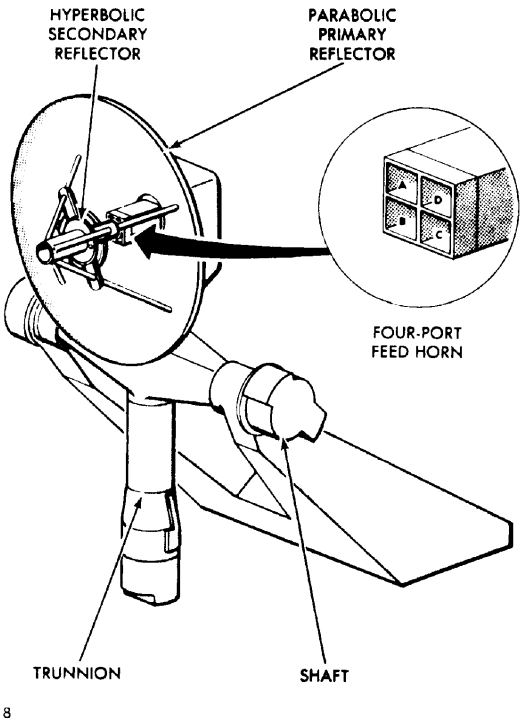
Rendezvous Radar Signal Flow

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.



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

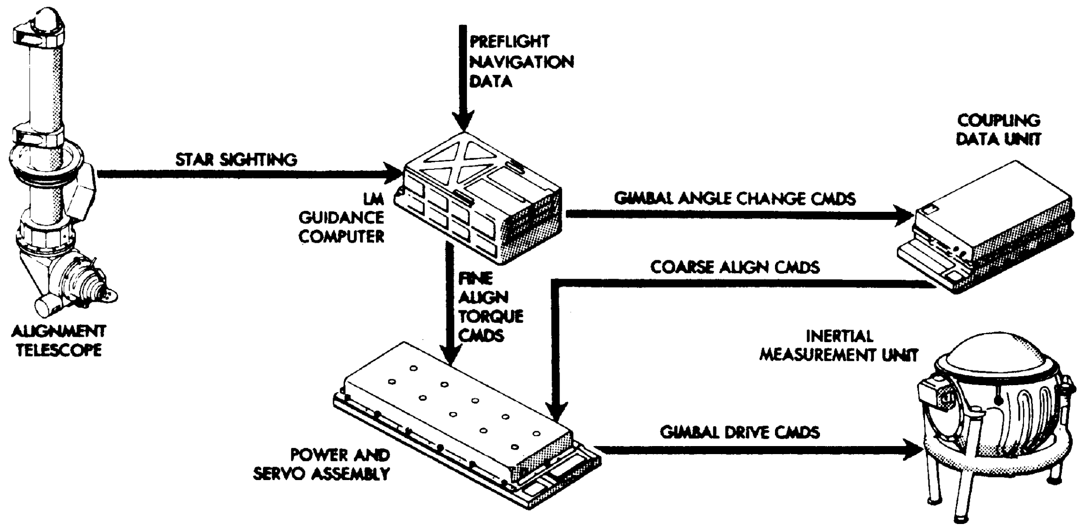
Inertial subsection operation can be initiated automatically by the primary guidance computer or manually by the astronaut, using DSKY entries to command the computer. The inertial subsection status or mode of operation is displayed on the DSKY as determined by a computer program. When the inertial subsection 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 accelerometers. 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 members 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.

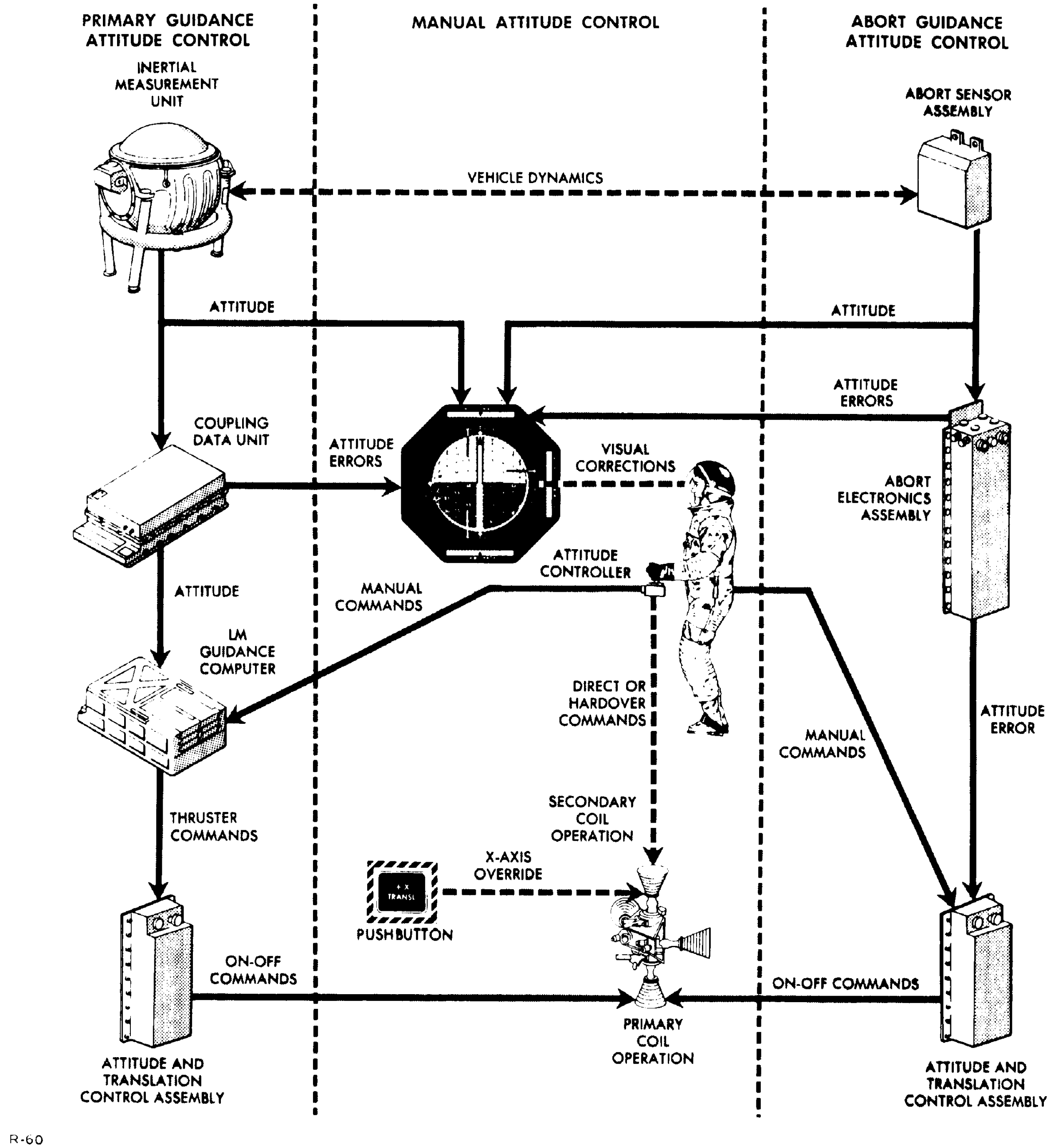
ATTITUDE CONTROL

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



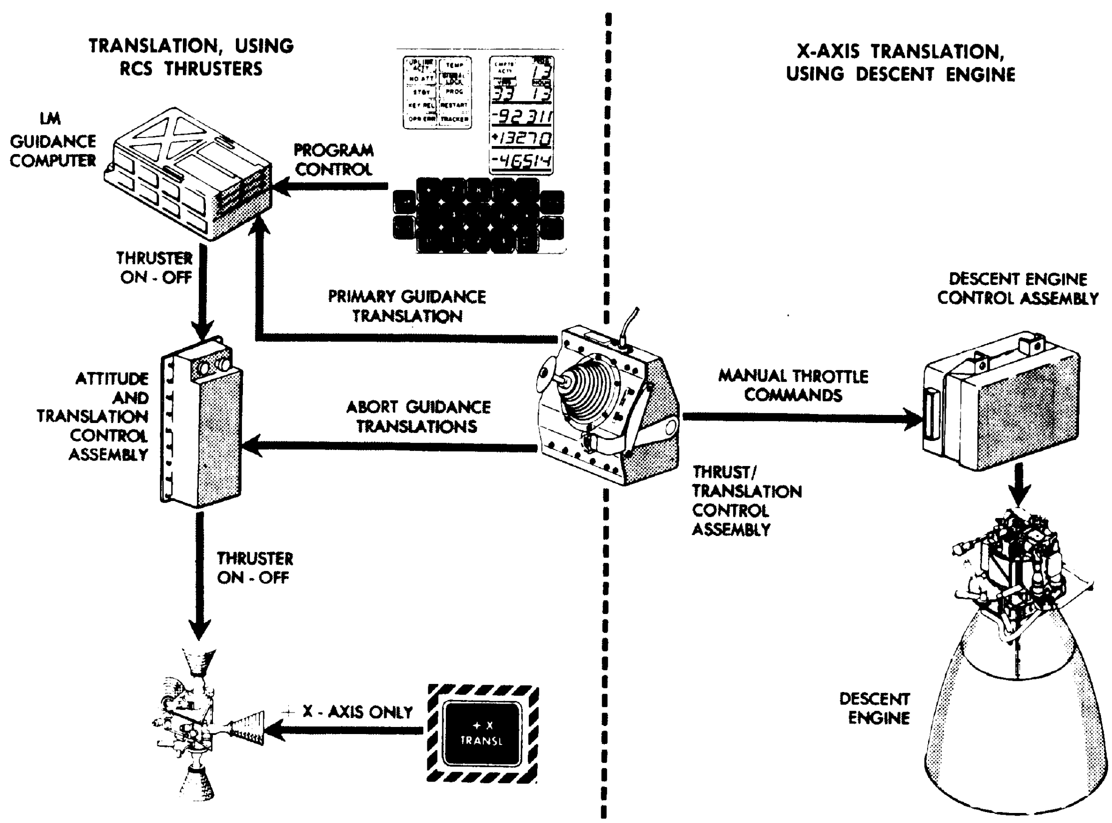
Functional Diagram of Attitude Control the computer. The computer processes these commands and generates thruster commands for the attitude and translation control assembly.

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



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Functional Diagram of Translation Control 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 push-button 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 push-buttons 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 along the Y-axis and Z-axis a maximum of +6° or -6° from the X-axis.

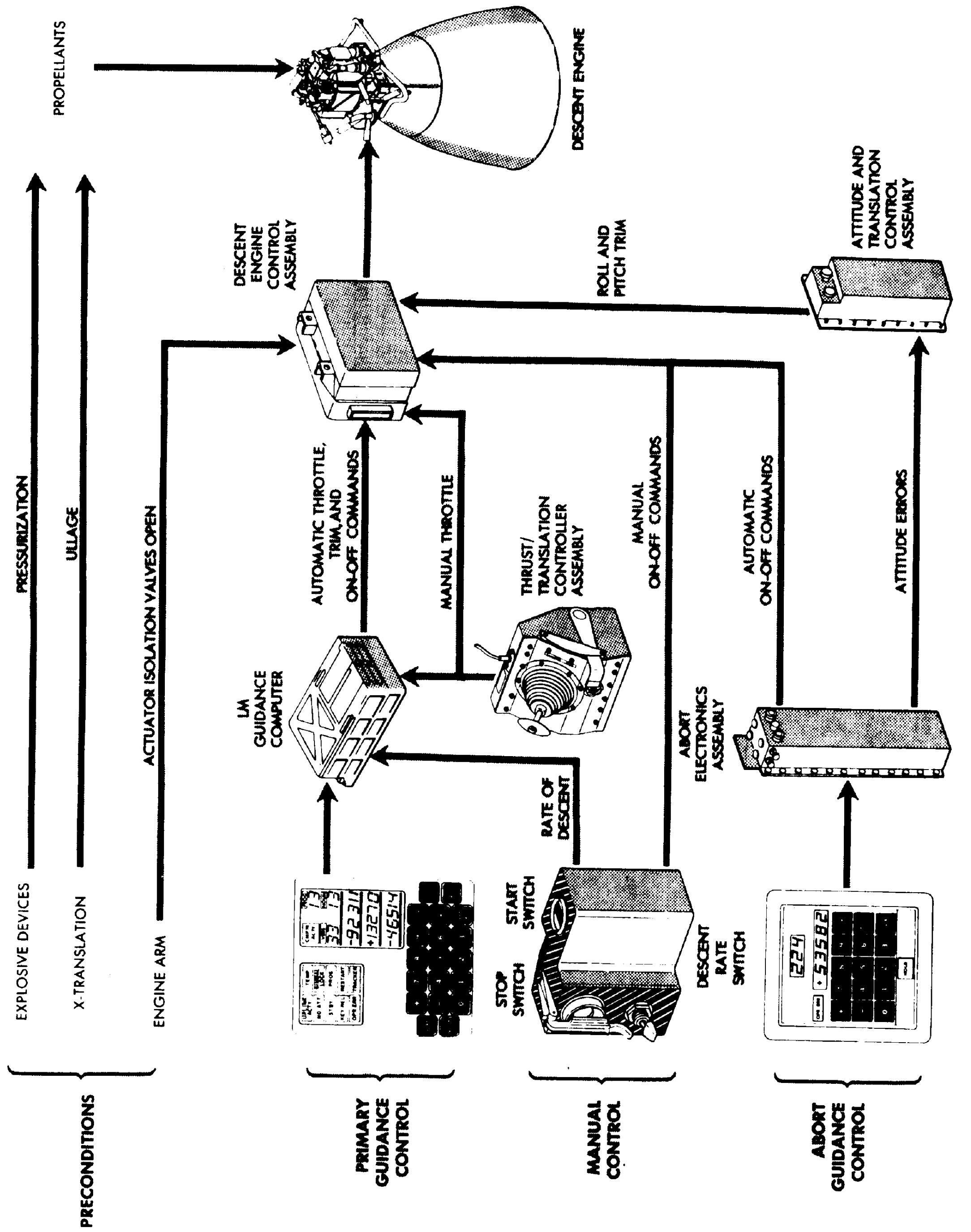
ASCENT ENGINE CONTROL

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 commands. A portion of the S&C control assemblies, devoted to ascent engine control, is designated as the ascent engine latching device. This device provides a positive on command for fail-safe purposes if the engine-on command is interrupted. 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

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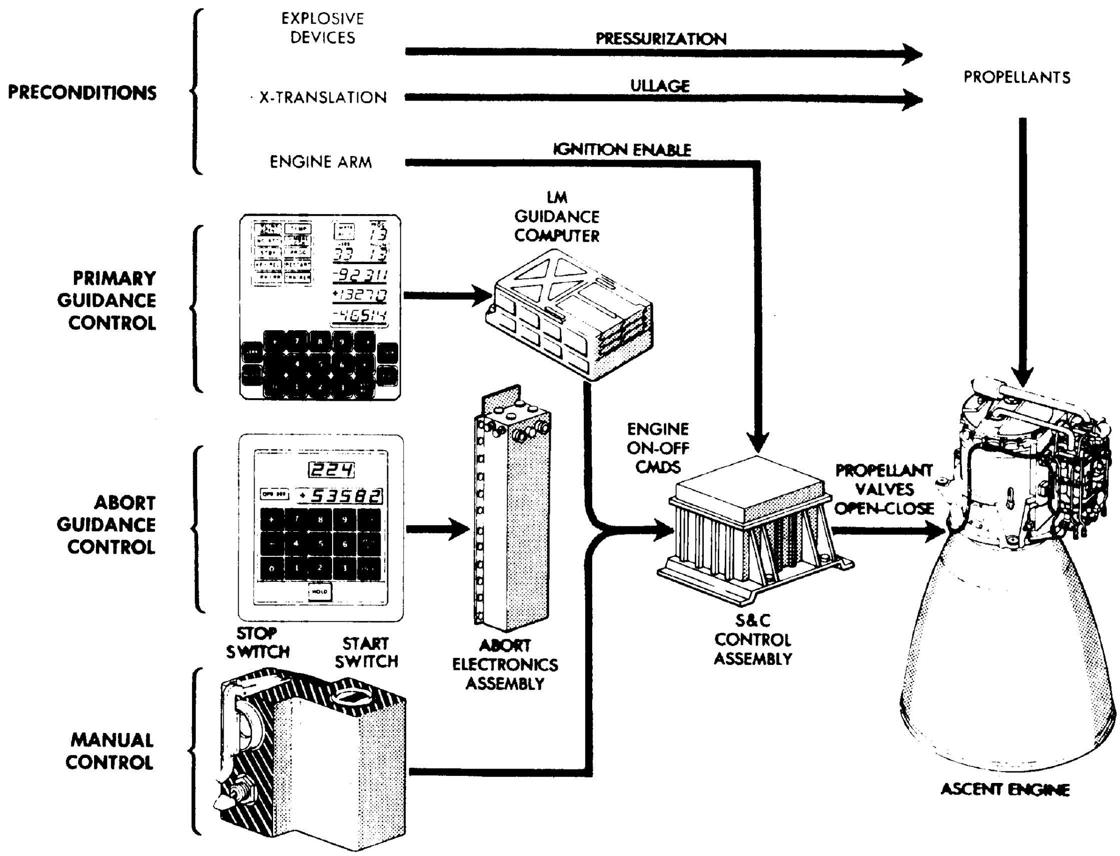

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Functional Diagram of Ascent Engine Control

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.

EQUIPMENT

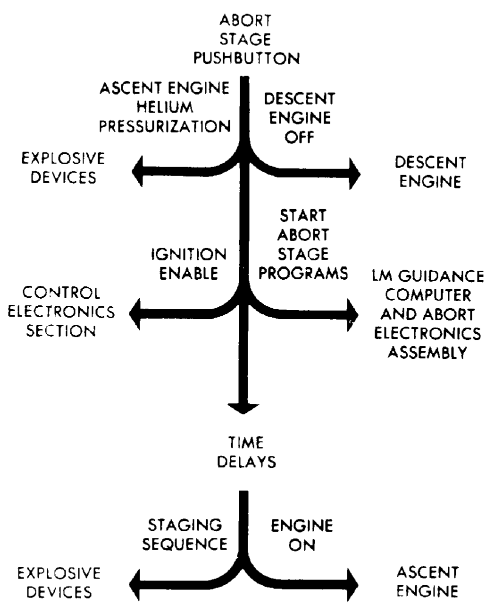
PRIMARY GUIDANCE AND NAVIGATION SECTION

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.



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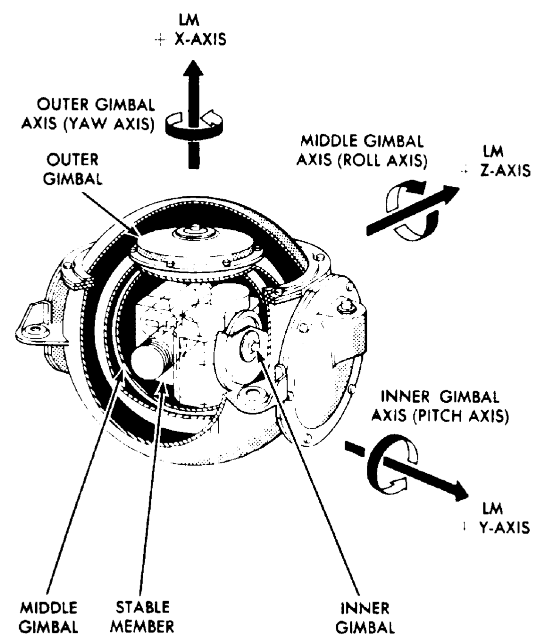
Abort Stage Functions



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Inertial Measurement Unit

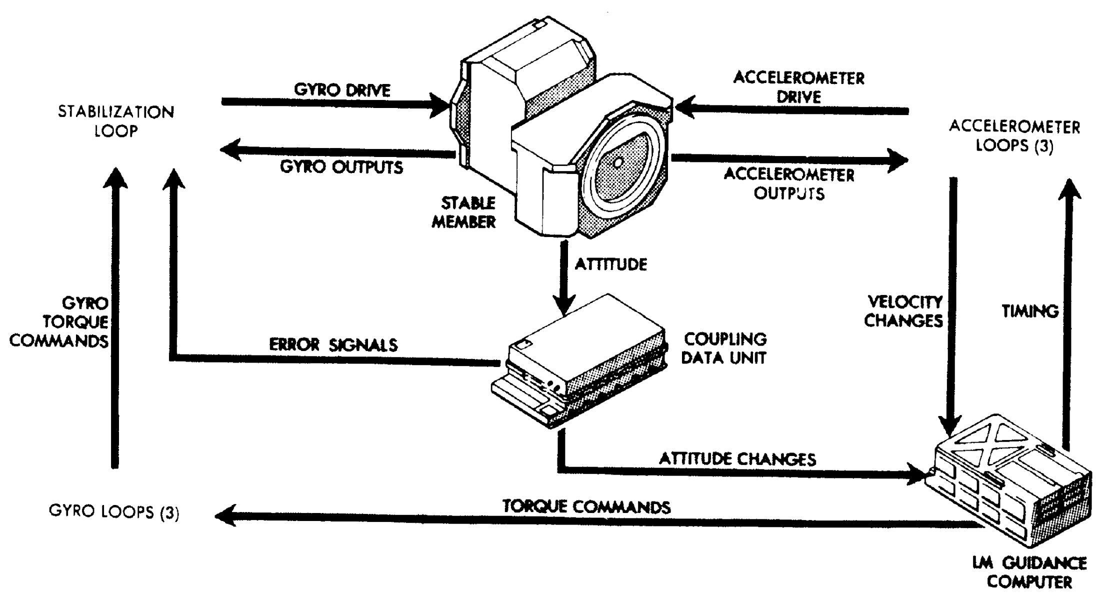
APOLLO NEWS REFERENCE

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.



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Inertial Subsection Functional Loops

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

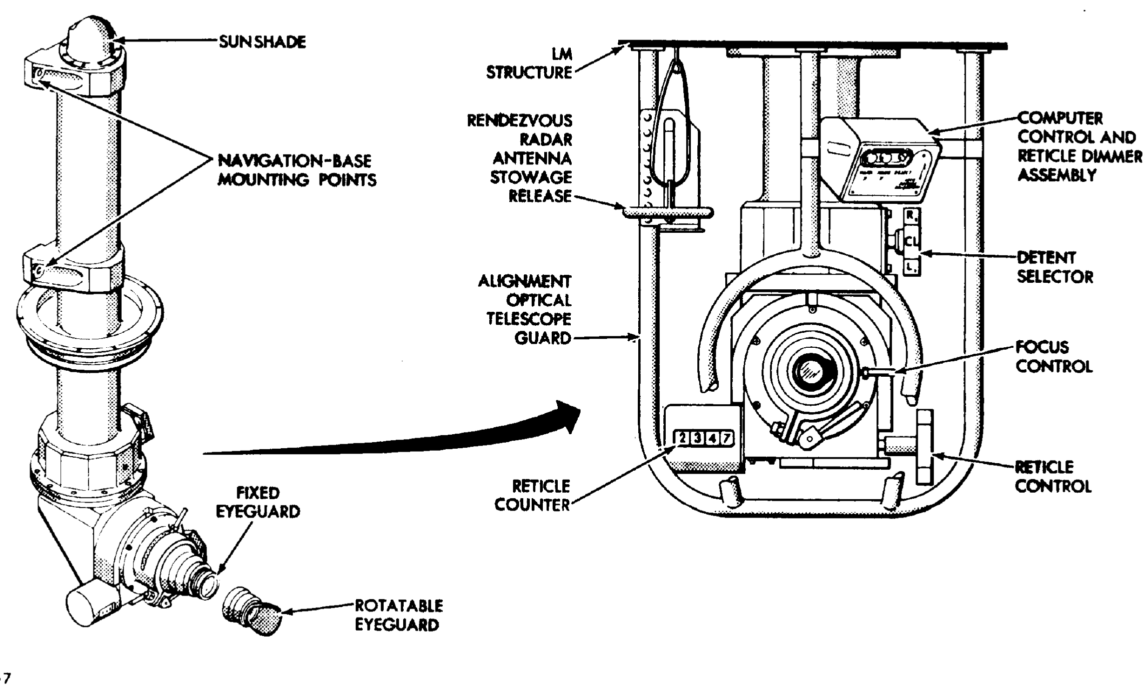
The signal conditioner assembly preconditions primary guidance and navigation section measurements to a 0- to 5-volt d-c format before the signals are routed to the Instrumentation Subsystem.

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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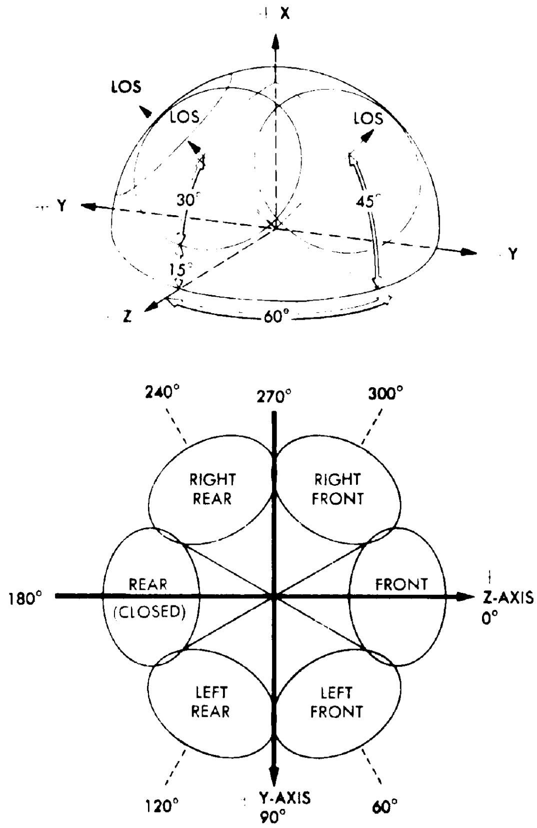

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Alignment Optical Telescope – Detents and Field of View

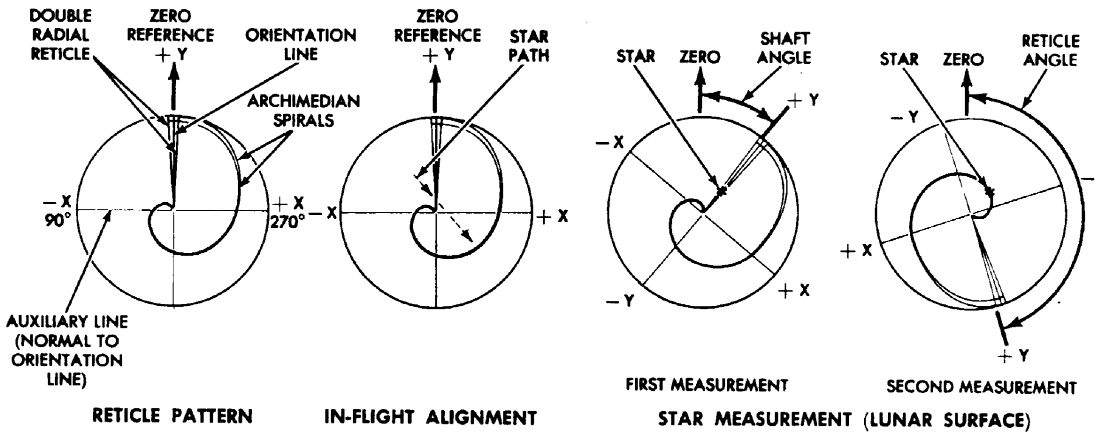
measurements. The reticle pattern within the eyepiece optics consists of crosshairs and a pair of Archimedes spirals. The vertical crosshair, an orientation line designated the Y-line, is parallel to the LM X-axis when the reticle is at the 0° reference position. The horizontal crosshair, an auxiliary 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.



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 nondestructive.

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.

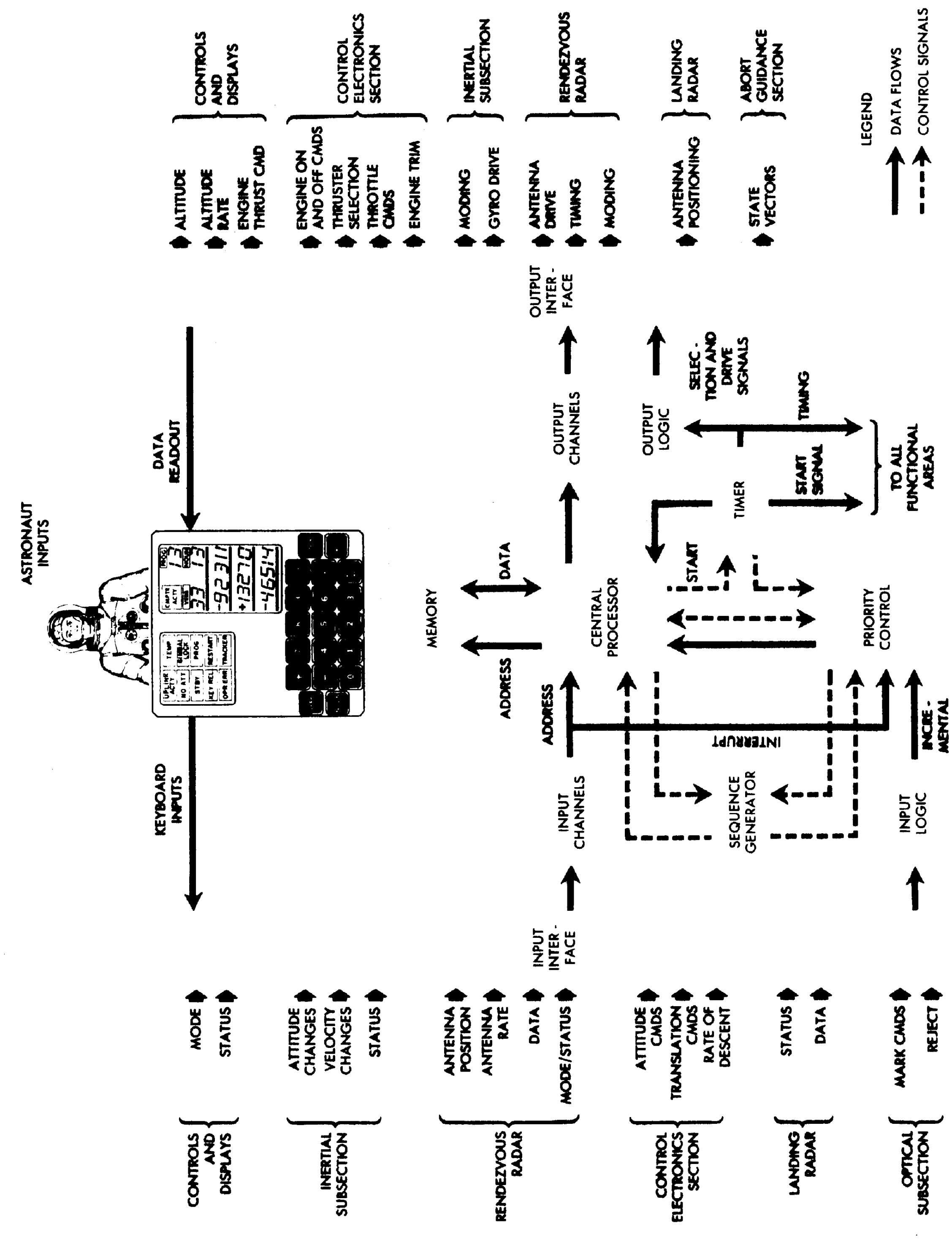


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Diagram of LM Guidance Computer