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.

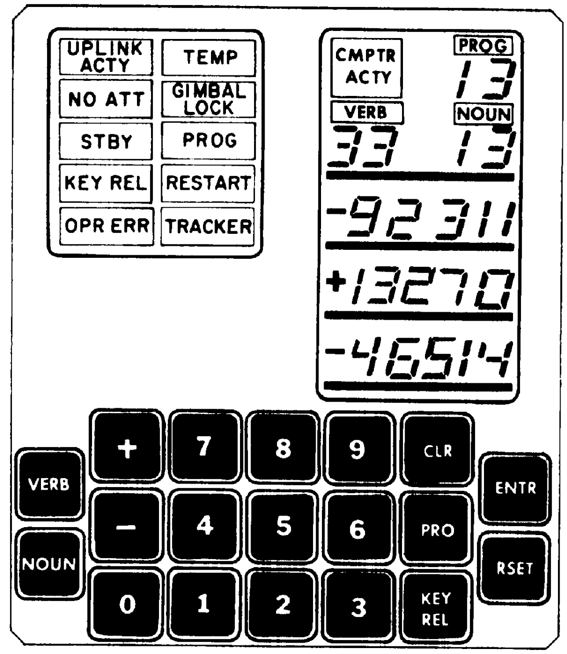
DISPLAY AND KEYBOARD

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 five caution indicators, six 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.

"ApolloNewsRef LM H.GN41.PICT" 370 KB 1999-02-04 dpi: 360h x 360v pix: 532h x 748v

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



R-71

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.

"ApolloNewsRef LM H.GN42.PICT" 273 KB 1999-02-04 dpi: 360h x 360v pix: 533h x 750v

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 $+120^{\circ}$ F, with external temperatures between -65° and $+185^{\circ}$ 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 $+116^{\circ}$ F in 40 minutes. The fine temperature control circuit controls the temperature after $+116^{\circ}$ F is reached and raises the temperature 4°. This operating temperature ($+120^{\circ}$ F) is maintained within 0.20° F.

"ApolloNewsRef LM H.GN43.PICT" 397 KB 1999-02-04 dpi: 360h x 360v pix: 530h x 754v

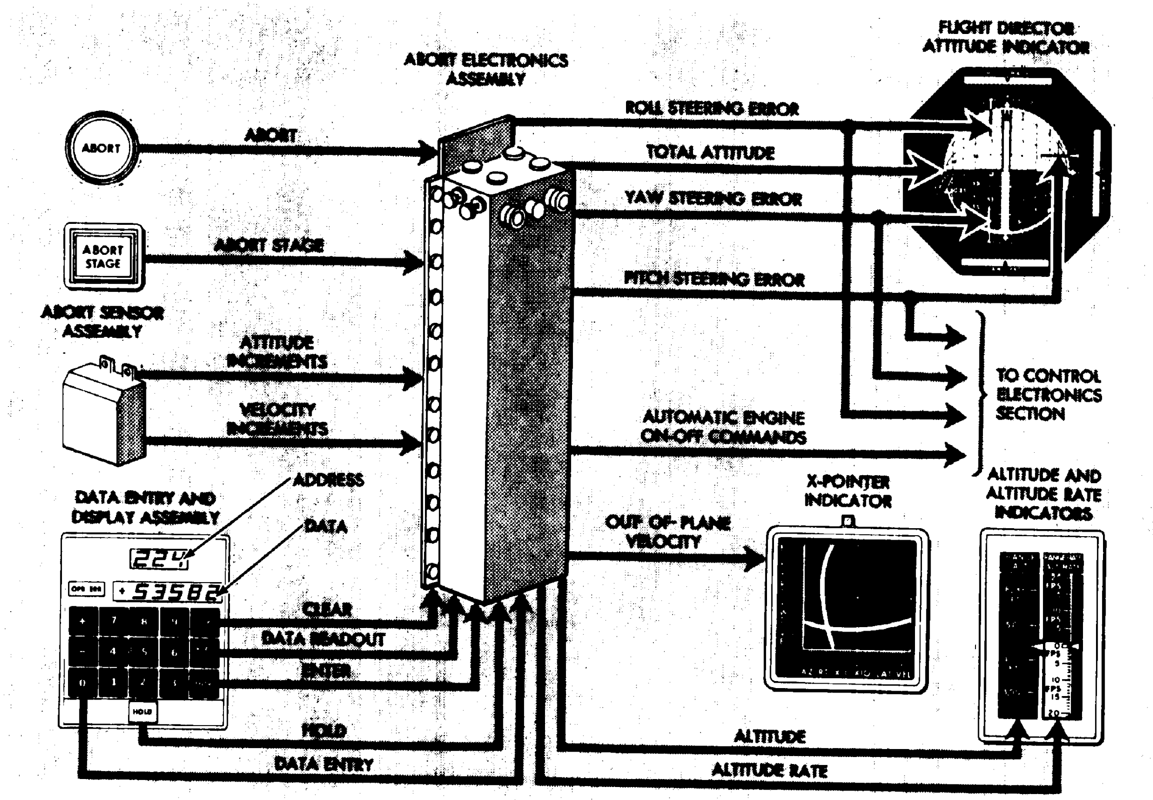


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Diagram of Abort Guidance Section

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

"ApolloNewsRef LM H.GN44.PICT" 365 KB 1999-02-04 dpi: 360h x 360v pix: 534h x 753v

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.

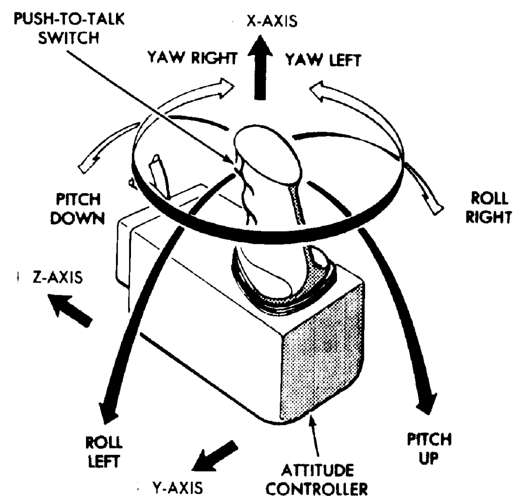
The input/output subassembly consists of four basic types of registers: integrator, ripple counter, shift, and static. These registers operate independently of the central computer, except when they are accessed during execution of an input or output instruction. All transfers of data between the central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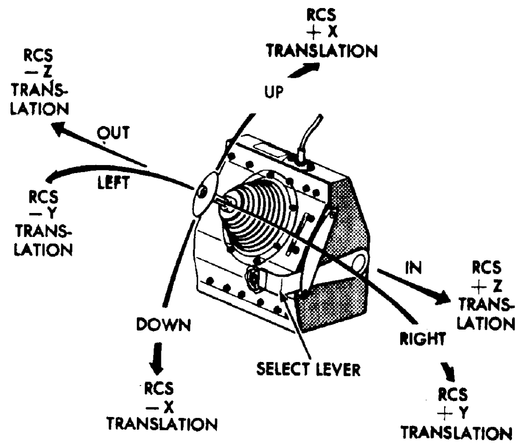
Attitude Controller Assembly Manipulations

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.

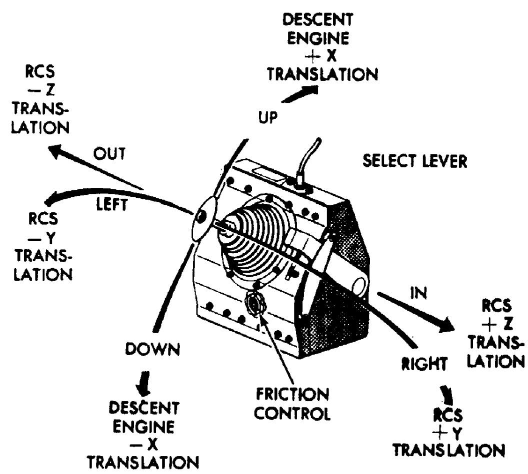
THRUST/TRANSLATION CONTROLLER ASSEMBLIES

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).

"ApolloNewsRef LM H.GN45.PICT" 352 KB 1999-02-04 dpi: 360h x 360v pix: 529h x 750v



SELECT LEVER SET TO JETS



SELECT LEVER SET TO THROTTLE

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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.

"ApolloNewsRef LM H.GN48.PICT" 384 KB 1999-02-04 dpi: 360h x 360v pix: 530h x 754v

MAIN PROPULSION

QUICK REFERENCE DATA

DESCENT PROPULSION SECTION

Pressurization section	
Ambient helium tank	
Volume	1 cubic foot
Initial filling weight of helium	1.12 pounds
Initial helium pressure and temperature	1,600 psia at +70° F
Proof pressure	2,333 psi
Supercritical helium tank	
Volume	5.9 cubic feet
Initial filling weight of helium	48.5 pounds
Initial helium fllling pressure and temperature	80 psia at -450° F
Nominal helium storage pressure and temperature	1.555 psia at -400° F
Maximum helium storage pressure and temperature	1,710 psia at -320° F
Density	8.2 pounds per cubic foot
Proof pressure	2,274 psi
Burst-disk rupture pressure	1,881 to 1,967 psi
Helium filters absolute filtration	15 microns
Helium pressure regulators	
Outlet pressure	245 ±3 psia
Normal operation flow rate range	0.52 to 5.5 pounds per minute
Nominal flow rate at full throttle	5.2 pounds per minute
Inlet pressure range	320 to 1,750 psia
Maximum lockup pressure	253 psia at inlet pressure of 400 to 1,750 psia 255 psia at inlet pressure of 320 to 400 psia
Relief valve assembly	
Burst-disk rupture pressure	260 to 275 psi
Relief valve cracking pressure	260 psi
Fully open flow rate	10 pounds per minute
Minimum reseat pressure	254 psi
Propellant feed section	
Propellant tanks	
Capacity (each tank)	62.8 cubic feet
Total fuel	6,982 pounds
Total oxidizer	11,067 pounds
Minimum ullage volume (each tank)	1,728 cubic inches
Usable fuel	6,759 pounds
Usable oxidizer	10,730 pounds
Nominal ullage pressure (at full throttle position)	235 psia
Nominal propellant temperature	+70° F
Propellant temperature range	+50° to +90° F
Proof pressure	360 psia
Propellant filters absolute filtration	60 microns

"ApolloNewsRef LM I.MP01.PICT" 165 KB 1999-02-07 dpi: 360h x 366v pix: 2636h x 3834v

Engine assembly

Nominal engine thrust (full throttle)	9,870 pounds (94%)
Minimum engine thrust (low stop)	1,050 pounds (10%)
Nominal combustion chamber pressure	103.4 psia
Engine-gimbaling capability	$+6^{o}$ to -6^{o} from center, along Y-axis and Z-axis
Propellant injection ratio (oxidizer to fuel)	1.6 to 1
Engine restart capability	20 times
Engine life	910 seconds or 17,510 pounds of propellant consumption
Approximate weight	360 pounds
Overall length	85 inches
Nozzle expansion area ratio	47.4 to 1
Nozzle exit diameter	59 inches

ASCENT PROPULSION SECTION

Pressurization section

Helium tanks

Volume (each tank)	3.35 cubic feet
Initial filling weight of helium (each tank)	6.5 pounds
Initial helium pressure and temperature	3,050 psia at $+70^{o}$ F
Maximum operating pressure of helium	3,500 psia at $+160^{o}$ F
Proof pressure	4,650 psia at $+160^{o}$ F

Helium filters absolute filtration	15 microns

Helium pressure regulator assemblies

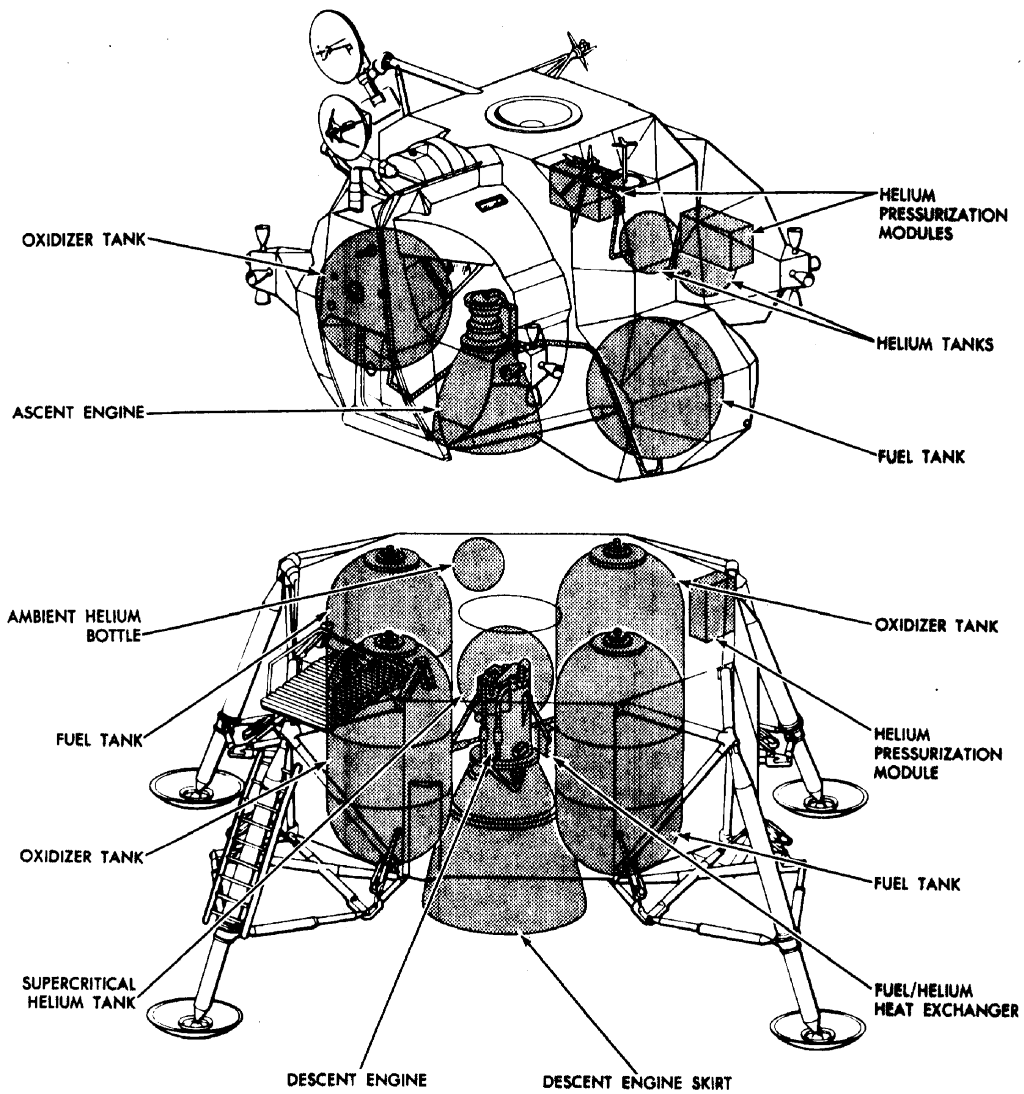
Primary path outlet pressure	
Upstream regulator	184 ± 4 psia
Downstream regulator	190 ± 4 psia
Secondary path outlet pressure	
Upstream regulator	176 ± 4 psia
Downstream regulator	182 ± 4 psia
Maximum lockup pressure	203 psia
Maximum outlet flow rate (each regulator path)	5.5 pounds per minute
Inlet pressure range	400 to 3,500 psia
Nominal helium flow rate	1.45 pounds per minute

"ApolloNewsRef LM I.MP02.PICT" 134 KB 1999-02-07 dpi: 360h x 366v pix: 2481h x 3834v

Relief valve assembly	
Burst-disk rupture pressure	226 to 250 psia
Relief valve cracking pressure	245 psia
Fully open flow rate	4 pounds per minute
Reseat pressure	225 psia
Propellant feed section	
Propellant tanks	
Capacity (each tank)	36 cubic feet
Total fuel	2,008 pounds
Total oxidizer	3,179 pounds
Minimum ullage volume (each tank)	0.5 cubic foot per tank at +90° F
Usable fuel	1,937 pounds
Usable oxidizer	3,087 pounds
Propellant temperature range	+50° to +90° F
Nominal propellant temperature	+70° F
Nominal ullage pressure	184 psia
Proof pressure	333 psia
Propellant filters absolute filtration	200 microns
Engine assembly	
Nominal engine thrust	3,500 pounds
Nominal combustion chamber pressure	120 psia
Fuel flow rate	4.3 pounds per second
Oxidizer flow rate	7.0 pounds per second
Propellant injection ratio (oxidizer to fuel)	1.6 to 1
Injector inlet pressure	
Steady-state operation	145 psia
Engine start	185 to 203 psia
Engine start to 90% of rated thrust	0.310 second
Engine shutdown to 10% of rated thrust	0.200 second
Nominal propellant temperature at injector inlet	+70° F
Restart capability	35 times
Engine life	460 seconds
Approximate weight	200 pounds
Overall length	47 inches
Nozzle expansion area ratio	45.6 to 1
Nozzle exit diameter	31 inches

"ApolloNewsRef LM I.MP03.PICT" 123 KB 1999-02-07 dpi: 360h x 366v pix: 2678h x 3820v

The Main Propulsion Subsystem (MPS) consists of two separate, complete, and independent propulsion sections: the descent propulsion section and the ascent propulsion section. Each propulsion section performs a series of specific tasks during the lunar-landing mission. The descent propulsion section provides propulsion for the LM from the time it separates from the CSM until it lands on the lunar surface, the ascent propulsion section lifts the ascent stage off the lunar surface and boosts it into orbit. Both propulsion sections operate in conjunction with the Reaction Control Subsystem (RCS), which provides propulsion used mainly for precise attitude and translation maneuvers. The ascent propellant tanks are connected to the RCS to supplement its propellant supply during certain mission phases. If a mission abort becomes necessary during the descent trajectory, the ascent or descent engine can be used to return to a rendezvous orbit with the CSM. The choice of engines



Major Main Propulsion Equipment Location depends on the cause for abort, the amount of propellant remaining in the descent stage, and the length of time that the descent engine had been firing.

Each propulsion section consists of a liquid-propellant, pressure-fed rocket engine and propellant storage, pressurization, and feed components. For reliability, many vital components in each section are redundant. In both propulsion sections, pressurized helium forces the hypergolic propellants from the tanks to the engine injector. Both engine assemblies have control valves and trim orifices that start and stop a metered propellant flow to the combustion chamber upon command, an injector that determines the spray pattern of the propellants as they enter the combustion chamber, and a combustion chamber, where the propellants meet and ignite. The gases produced by combustion pass through a throat area into the engine nozzle, where they expand at an extremely high velocity before being ejected. The momentum of the exhaust gases produces the reactive force that propels the vehicle.

The more complicated tasks required of the descent propulsion section – such as propelling the entire LM and hovering over the lunar surface while the astronauts select a landing site – dictate that the descent propulsion section be the larger and more sophisticated of the two propulsion sections. It has a propellant supply that is more than three times that of the ascent propulsion section. The descent engine is almost twice as large as the ascent engine, produces more thrust (almost 10,000 pounds at full throttle), is throttleable for thrust control, and is gimbaled (can be tilted) for thrust vector control. The ascent engine, which cannot be tilted, delivers a fixed thrust of 3,500 pounds, sufficient to launch the ascent stage from the lunar surface and place it into a predetermined orbit.

The primary characteristics demanded of the LM propellants are high performance per weight; storability over long periods without undue vaporization or pressure buildup; hypergolicity for easy, closely spaced engine starts; no shock sensitivity; freezing and boiling points within controllable extremes; and chemical stability. The ascent and descent propulsion sections, as well as the RCS, use identical fuel/oxidizer combinations. In the ascent and descent propulsion sections, the injection ratio of oxidizer to fuel is approximately 1.6 to 1, by weight.

The fuel is a blend of hydrazine (N_2H_4) and unsymmetrical dimethylhydrazine (UDMH), commercially known as Aerozine 50. The proportions, by weight, are approximately 50% hydrazine, and 50% dimethylhydrazine.

The oxidizer is nitrogen tetroxide (N_2O_4). It has a minimum purity of 99.5% and a maximum water content of 0.1%.

The astronauts monitor the performance and status of the MPS with their panel-mounted pressure, temperature, and quantity indicators; talkbacks (flags indicating open or closed position of vital valves); and caution and warning annunciators (placarded lights that go on when specific out-of-tolerance conditions occur). These data, originating at sensors and position switches in the MPS, are processed in the Instrumentation Subsystem, and are simultaneously displayed to the astronauts in the LM cabin and transmitted to mission controllers through MSFN via the Communications Subsystem. The MPS obtains 28-volt d-c and 115-volt a-c primary power from the Electrical Power Subsystem.

Before starting either engine, the propellants must be settled to the bottom of the tanks. Under weightless conditions, this requires an ullage maneuver; that is, the LM must be moved in the +X, or upward, direction. To perform this maneuver, an astronaut or the automatic guidance equipment operates the downward-firing thrusters of the RCS. The duration of this maneuver increases for each engine start because more time is required to settle the propellants as the tanks become emptier.

The MPS is operated by the Guidance, Navigation, and Control Subsystem (GN&CS), which issues automatic (and processes manually initiated) on and off commands to the descent or ascent engine. The GN&CS also furnishes gimbal-drive and thrust-level commands to the descent propulsion section.

DESCENT ENGINE OPERATION AND CONTROL

After initial pressurization of the descent propulsion section, the descent engine start requires two separate and distinct operations: arming and firing. Engine arming is performed by the astronauts; engine firing can be performed by the astronauts, or it can be automatically initiated by the LM guidance computer. When the astronauts set a switch to arm the descent engine, power is simultaneously routed to open the actuator isolation valves in the descent engine, enable the instrumentation circuits in the descent propulsion section, and issue a command to the throttling controls to start the descent engine at the required 10% thrust level. The LM guidance computer and the abort guidance section receive an engine-armed status signal. This signal enables an automatic engine-on program in the GN&CS, resulting in a descent engine start. A manual start is accomplished when the Commander pushes his engine-start pushbutton. (Either astronaut can stop the engine because separate engine-stop pushbuttons are provided at both flight stations.)

The normal start profile for all descent engine starts must be at 10% throttle setting. Because the thrust vector at engine start may not be directed through the LM center of gravity, a low-thrust start (10%) will permit corrective gimbaling. If the engine is started at high thrust, RCS propellants must be used to stabilize the LM.

The astronauts can, with panel controls, select automatic or manual throttle control modes and Commander or LM Pilot thrust/translation controller authority, and can override automatic engine operation. Redundant circuits, under astronaut control, ensure descent engine operation if prime control circuits fail.

Signals from the GN&CS automatically control descent engine gimbal trim a maximum of 6° from the center position in the Y- and Z-axes to compensate for center-of-gravity offsets during descent engine firing. This ensures that the thrust vector passes through the LM center of gravity. The astronauts can control the gimbaling only to the extent that they can interrupt the tilt capability of the descent engine which they would do if a caution light indicates that the gimbal drive actuators are not following the gimbal commands.

DESCENT PROPULSION SECTION FUNCTIONAL DESCRIPTION

The descent propulsion section consists of an ambient and supercritical helium tank with associated helium pressurization components; two fuel and two oxidizer tanks with associated feed components; and a pressure-fed, ablative, throttleable rocket engine. The engine can be shut down and restarted as required by the mission. At the full-throttle position, the engine develops a nominal thrust of 9,870 pounds; it can also be operated within a range of 1,050 to 6,300 pounds of thrust. Functionally, the descent propulsion section can be subdivided into a pressurization section, a propellant feed section, and an engine assembly.

PRESSURIZATION SECTION

Before earth launch, all the LM propellant tanks are only partly pressurized (less than 230 psia), so that the tanks will be maintained within a safe pressure level under the temperature changes experienced during launch and earth orbit. Before initial engine start, the ullage space in each propellant tank requires additional pressurization. This initial pressurization is accomplished with a relatively small amount of helium stored at ambient temperature and at an intermediate pressure. To open the path from the ambient helium tank to the propellant tanks, the astronauts fire three explosive valves: an ambient helium isolation valve and the two propellant compatibility valves that prevent backflow of propellant vapors from degrading upstream components. After flowing through a filter, the ambient helium enters a pressure regulator which reduces the helium pressure to approximately 245 psi. The regulated helium then enters parallel paths which lead through quadruple check valves into the propellant tanks. The quadruple check valves, consisting of four valves in a series-parallel arrangement, permit flow in one direction only. This protects upstream components against corrosive propellant vapors and prevents hypergolic action due to backflow from the propellant tanks.

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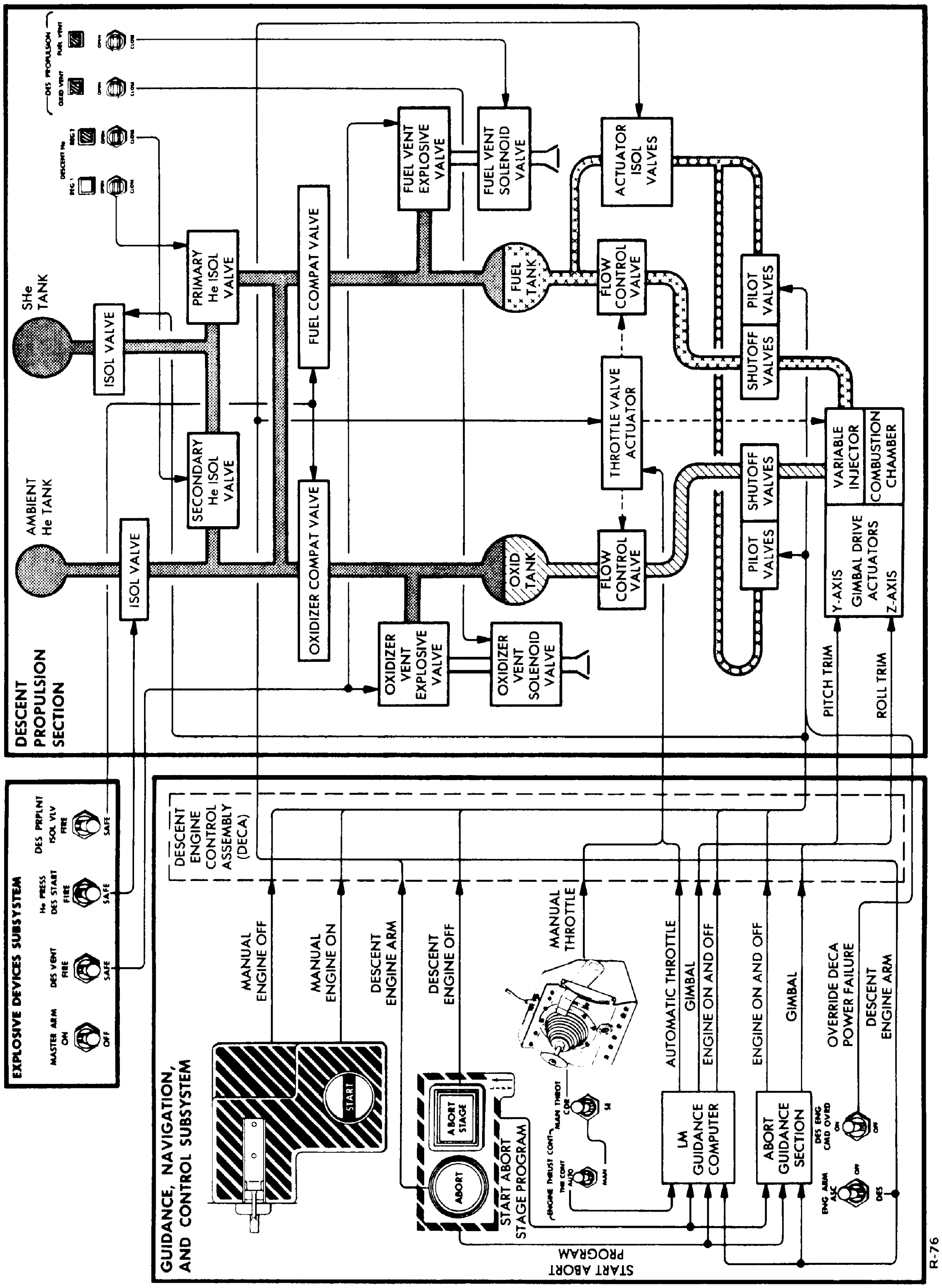
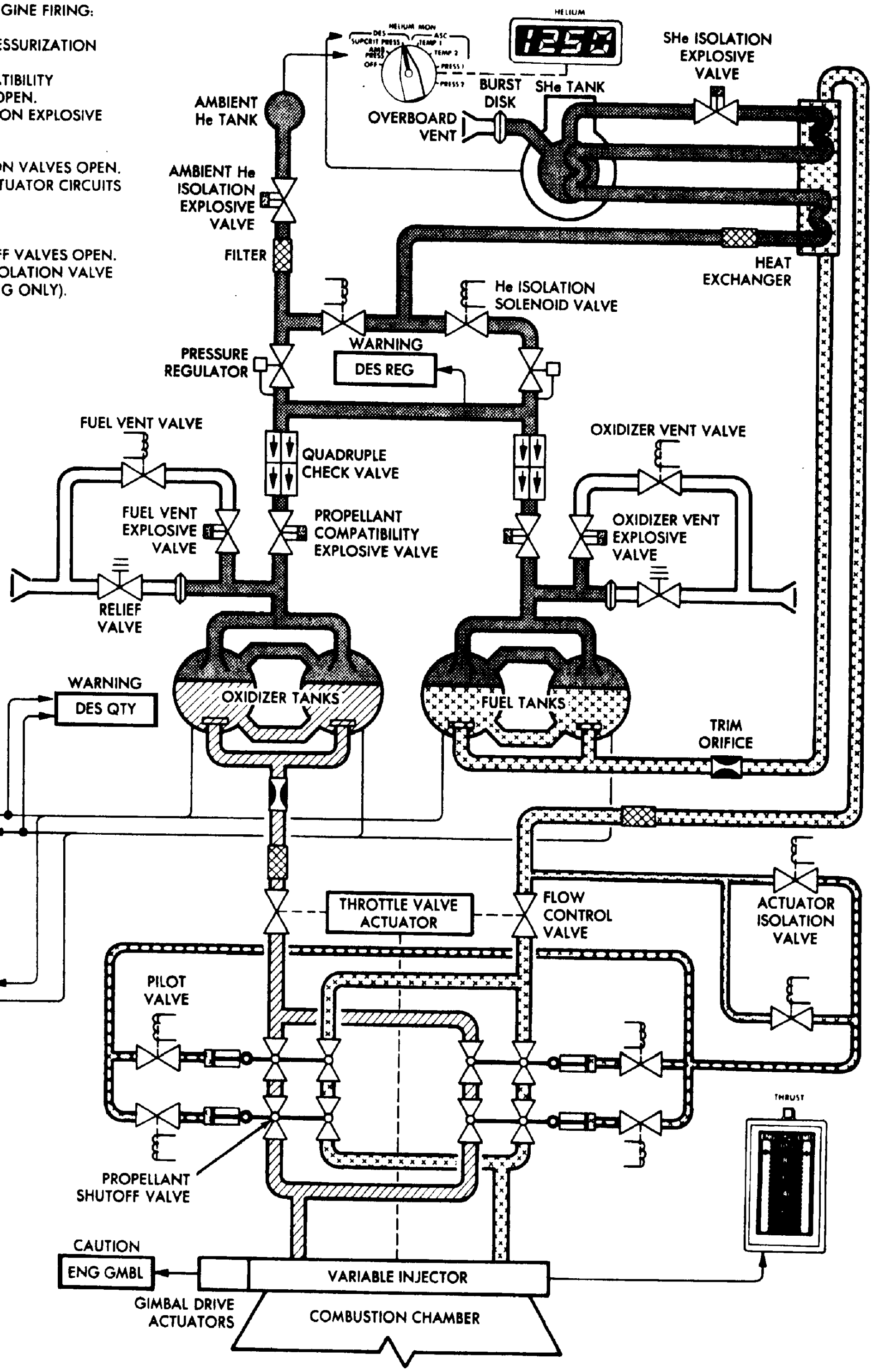


Descent Propulsion Control Diagram

“ApolloNewsRef LM I.MP07.PICT” 396 KB 1999-02-07 dpi: 360h x 366v pix: 2657h x 3792v

SEQUENCE OF DESCENT ENGINE FIRING:

- PROPELLANT TANK PRESSURIZATION (INITIAL FIRING ONLY)
  PROPELLANT COMPATIBILITY EXPLOSIVE VALVES OPEN.
  AMBIENT He ISOLATION EXPLOSIVE VALVE OPENS.
- ENGINE ARMING
  ACTUATOR ISOLATION VALVES OPEN.
  THROTTLE VALVE ACTUATOR CIRCUITS ARE ENABLED.
- ENGINE FIRING
  PILOT VALVES.
  PROPELLANT SHUTOFF VALVES OPEN.
  SUPERCRITICAL He ISOLATION VALVE OPENS (INITIAL FIRING ONLY).



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Descent Propulsion Flow Diagram

MP-8

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“ApolloNewsRef LM I.MP08.PICT” 323 KB 1999-02-07 dpi: 360h x 366v pix: 2678h x 3841v

After initial pressurization, supercritical helium is used to pressurize the propellants The supercritical helium tank is isolated by an explosive valve, which is automatically fired 1.3 seconds after the descent engine is started. The time delay prevents the supercritical helium from entering the fuel/helium heat exchanger until propellant flow is established so that the fuel cannot freeze in the heat exchanger. After the explosive valve opens, the supercritical helium enters the two-pass fuel/helium heat exchanger where it is slightly warmed by the fuel. The helium then flows back into a heat exchanger in the supercritical helium tank where it increases the temperature of the supercritical helium in the tank, causing a pressure rise and ensuring continuous expulsion of helium throughout the entire period of operation. Finally, the helium flows through the second loop of the fuel/helium heat exchanger where it is heated to operational temperature before it is regulated and routed to the propellent tanks.

The system that reduces the helium pressure consists of two parallel, redundant regulators. If one pressure regulator fails, the astronauts close the malfunctioning line and open the redundant line, to restore normal propellant tank pressurization.

Each propellant tank is protected against overpressurization by a relief valve, which opens at approximately 268 psia and reseats after overpressurization is relieved. A thrust neutralizer prevents the gas from generating unidirectional thrust. Each relief valve is paralleled by two series-connected vent valves, which are operated by panel switches. After landing, the astronauts relieve pressure buildup in the tanks, caused by rising temperatures, to prevent uncontrolled venting through the relief valves. The fuel and oxidizer fumes are vented separately; supercritical helium is vented at the same time.

PROPELLANT FEED SECTION

The descent section propellant supply is contained in two fuel tanks and two oxidizer tanks. Each pair of like propellant tanks is manifolded into a common delivery line. Each pair is also interconnected by a double crossfeed piping arrangement to maintain a positive pressure balance across the upper (helium) and lower (propellant) portions.

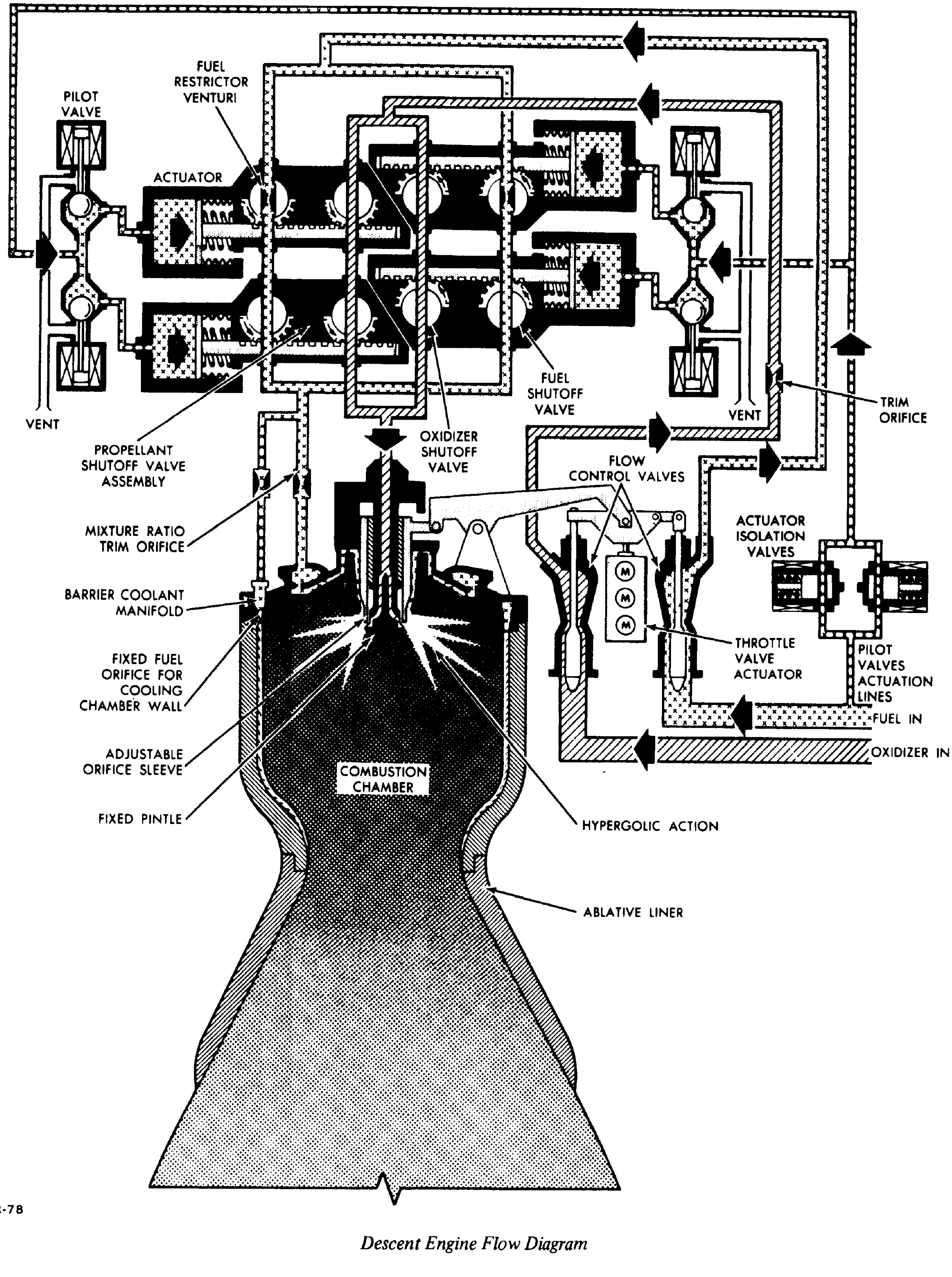
Pressurized helium, acting on the surface of the propellant, forces the fuel and oxidizer into the delivery lines through a propellant retention device that maintains the propellant in the lines during negative-g acceleration. The oxidizer is piped directly to the engine assembly; the fuel circulates through the fuel/helium heat exchanger before it is routed to the engine assembly. Each delivery line contains a trim orifice and a woven, stainless-steel-wire-mesh filter. The trim orifices provide engine inlet pressure of approximately 220 psia at full throttle position. The filters prevent debris, originating at the explosive valves or in the propellant tanks, from contaminating downstream components.

ENGINE ASSEMBLY

The descent engine is mounted in the center compartment of the descent stage cruciform. Fuel and oxidizer entering the engine assembly are routed through flow control valves to the propellant shutoff valves. A total of eight propellant shutoff valves are used; they are arranged in series-parallel redundancy, four in the fuel line and four in the oxidizer line. The series redundancy ensures engine shutoff, should one valve fail to close. The parallel redundancy ensures engine start, should one valve fail to open.

To prevent rough engine starts, the engine is designed to allow the oxidizer to reach the injector first. The propellants are then injected into the combustion chamber, where hypergolic action occurs.

The propellant shutoff valves are actuator operated. The actuation line branches off the main fuel line at the engine inlet and passes through the parallel-redundant actuator isolation valves to four solenoid-operated pilot valves. From the pilot valves, the fuel enters the hydraulically operated actuators, which open the propellant shutoff valves. The actuator pistons are connected to rack-and-pinion linkages that rotate the balls of the shutoff valves 90° to the open position. The



Descent Engine Flow Diagram

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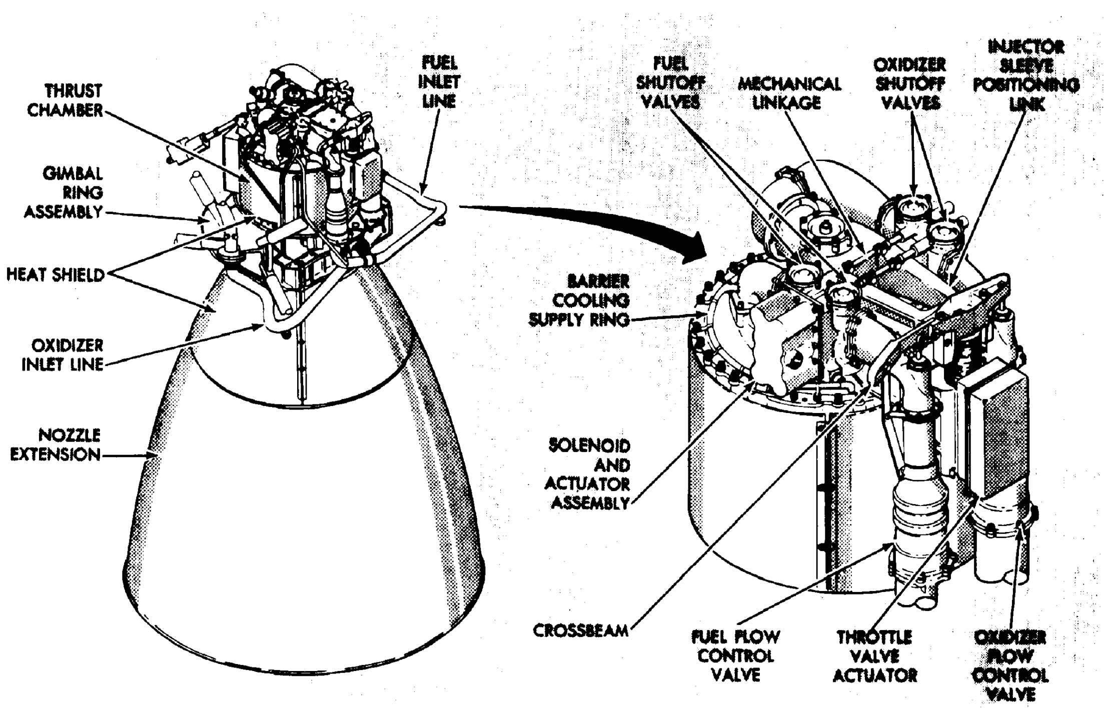
"ApolloNewsRef LM I.MP10.PICT" 412 KB 1999-02-07 dpi: 360h x 366v pix: 2664h x 3813v

actuator isolation valves open when the astronauts arm the descent engine. When an engine-on command is initiated, the four pilot valves open simultaneously, permitting the actuation fuel to open the propellant shutoff ball valves, thus routing fuel and oxidizer to the combustion chamber.

The flow control valves, in conjunction with the adjustable orifice sleeve in the injector, control the descent engine thrust. At full throttle, and during the momentary transition from full throttle to the 60% range, throttling takes place primarily in the injector and, to a lesser degree, in the flow control valves. Below the 60% thrust level, the propellant-metering function is entirely controlled by the flow control valves. The flow control valves and the injector sleeve are adjusted simultaneously by a mechanical linkage. Throttling is controlled by the throttle valve actuator, which positions the linkage in response to electrical input signals.

The fuel and oxidizer are injected into the combustion chamber at velocities and angles compatible with variations in weight flow. The fuel is emitted in the form of a thin cylindrical sheet; the oxidizer sprays break up the fuel stream and establish the injection pattern at all thrust settings. Some fuel is tapped off upstream of the injector and is routed through a trim orifice into the barrier coolant manifold. From here, it is sprayed against the combustion chamber wall through fixed orifices, maintaining the chamber wall at an acceptable temperature.



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Descent Engine and Head End Assembly

"ApolloNewsRef LM I.MP11.PICT" 322 KB 1999-02-07 dpi: 360h x 366v pix: 2664h x 3799v

DESCENT PROPULSION SECTION EQUIPMENT

SUPERCRITICAL HELIUM TANK

Supercritical helium is stored at a density approximately eight times that of ambient helium. Because heat transfer from the outside to the inside of the cryogenic storage vessel causes a gradual increase in pressure (approximately 10 psi per hour maximum), the initial loading pressure is planned so that the supercritical helium will be maintained within a safe pressure/time envelope throughout the mission.

The supercritical helium tank is double walled; it consists of an inner spherical tank and an outer jacket. The void between the tank and the jacket is filled with aluminized mylar insulation and evacuated to minimize ambient heat transfer into the tank. The vessel has fill and vent ports, a burst disk assembly, and an internal helium/helium heat exchanger. The inner tank is initially vented and loaded with cryogenic liquid helium at approximately 8° R (-452° F) at a pressure of 14.7 psia. The cryogenic liquid becomes supercritical helium when the fill sequence is completed by closing the vent and introducing a high-pressure head of gaseous helium. As the high-pressure, low-temperature gas is introduced, the density and pressure of the cryogenic liquid helium are increased. At the end of pressurization, the density of the stored supercritical helium is approximately 8.2 pounds per cubic foot and the final pressure is approximately 80 psi.

The burst disk assembly prevents hazardous overpressurization within the vessel. It consists of two burst disks in series, with a normally open, low-pressure vent valve between the disks. The burst disks are identical; they burst at a pressure between 1,881 and 1,967 psid to vent the entire supercritical helium supply overboard. A thrust neutralizer at the outlet of the downstream burst disk diverts the escaping gas into opposite directions to prevent unidirectional thrust generation. The vent valve prevents low-pressure buildup between the burst disks if the upstream burst disk leaks slightly. The valve is open at pressures below 150 psia; it closes when the pressure exceeds 150 psia.

FUEL/HELIUM HEAT EXCHANGER

Fuel is routed directly from the fuel tanks to the two-pass fuel/helium heat exchanger, where heat from the fuel is transferred to the supercritical helium. The helium reaches operating temperature after flowing through the second heat exchanger passage. The fuel/helium heat exchanger is of finned tube construction; the first and second helium passages are in parallel crossflow with respect to the fuel. Helium flows in the tubes and fuel flows in the outer shell across the bundle of staggered, straight tubes.

PROPELLANT STORAGE TANKS

The propellant supply is contained in four cylindrical, spherical-ended titanium tanks of identical size and construction. Two tanks contain fuel; the other two, oxidizer. Each pair of tanks containing like propellants is interconnected at the top and bottom to ensure even distribution of propellant and pressurizing helium. A diffuser at the helium inlet port (top) of each tank distributes the pressurizing helium uniformly into the tank. An antivortex device in the form of a series of vanes, at each tank outlet, prevents the propellant from swirling into the outlet port, thus precluding inadvertent helium ingestion into the engine. Each tank outlet also has a propellant retention device (negative-g can) that permits unrestricted propellant flow from the tank under normal pressurization, but blocks reverse propellant flow (from the outlet line back into the tank) under zero-g or negative-g conditions. This arrangement ensures that helium does not enter the propellant outlet line as a result of a negative-g or zero-g condition or propellant vortexing; it eliminates the possibility of engine malfunction due to helium ingestion.

PROPELLANT QUANTITY GAGING SYSTEM

The propellant quantity gaging system enables the astronauts to monitor the quantity of propellants remaining in the four descent tanks. It is in operation during the final powered descent phase from start of the braking maneuver (10 seconds after engine turn-on) until lunar touchdown. The propellant quantity gaging system consists of four

"ApolloNewsRef LM I.MP12.PICT" 438 KB 1999-02-07 dpi: 360h x 366v pix: 2678h x 3834v