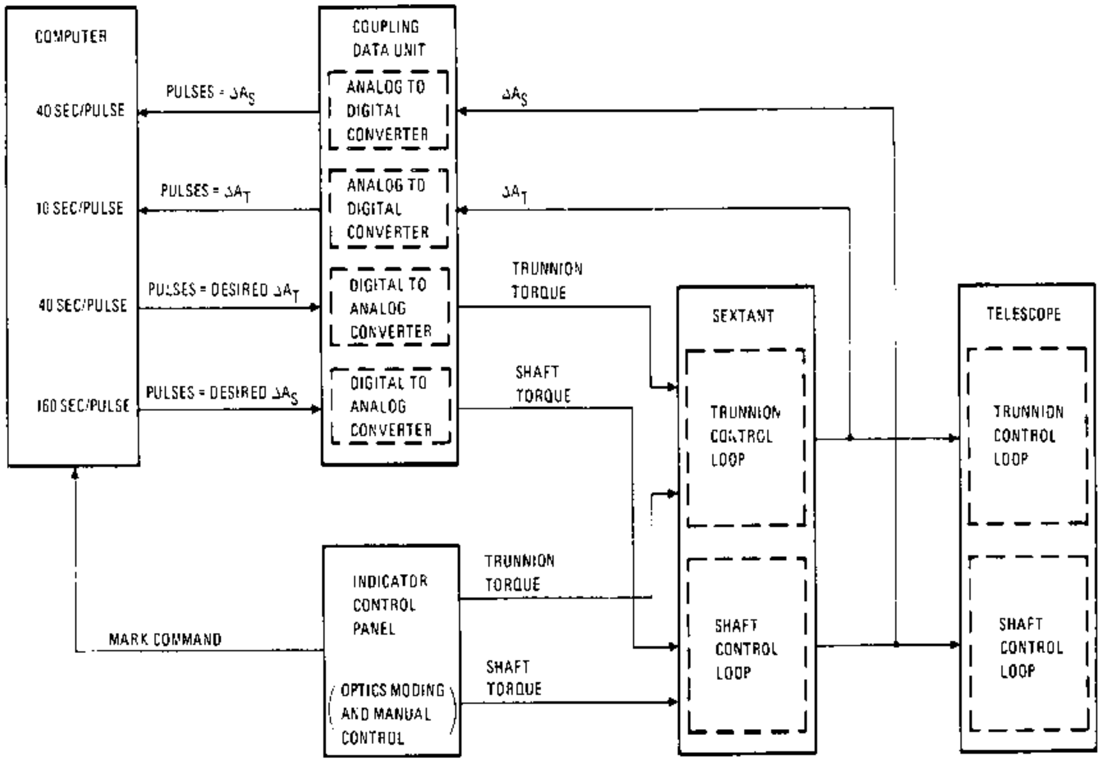
field of view at 1X magnification. This is reduced to about 40 degrees when installed because of obstruction by vehicle structure.

The coupling data unit used in the inertial subsystem is also used as a part of the optical subsystem. Two channels of the unit are used, one for the sextant shaft axis and one for the sextant trunnion axis. These channels repeat the sextant shaft and trunnion angles and transmit angular change information to the computer in digital form.

The angular data transmission in the trunnion channel is mechanized to generate 1 pulse to the computer for 5 arc-seconds of movement of the sextant trunnion which is equivalent to 10 arc-seconds of star line-of-sight movement. The shaft channel issues 1 pulse for each 40 arc-seconds of shaft movement. The location of the sextant shaft and trunnion axes are transmitted to the coupling data units through 16X and 64X resolvers, located on the sextant shaft and trunnion axes. This angular information is transmitted to the units in the form of electrical signals proportional to the sine and cosine of 16X shaft angle and 64X trunnion angle. During the computer mode of operation, the unit provides digital-to-analog conversion of the computer output to generate an ac input to the sextant shaft and trunnion servos. This analog input to the sextant axes will drive the star line of sight to some desired position. In addition, the optical subsystem channels of the coupling data unit perform a second function on a time-sharing basis. During a thrust vector control function these channels provide digital-to-analog conversion of the service propulsion engine gimbal angle command between the computer and the service propulsion subsystem gimbals.

The modes of operation for the optical subsystem are selected by the astronaut using the controls located on the indicator control panel. There are three major modes: zero optics, manual control, and computer control.

During the zero optics mode, the shaft and trunnion axis of the sextant are driven to their zero positions by taking the output of the transmitting resolvers (1X and 64X in trunnion, and 1/2X and 16X in shaft) and feeding them through the two-speed switches to the motor drive amplifier. This in turn drives loops to null positions as indicated



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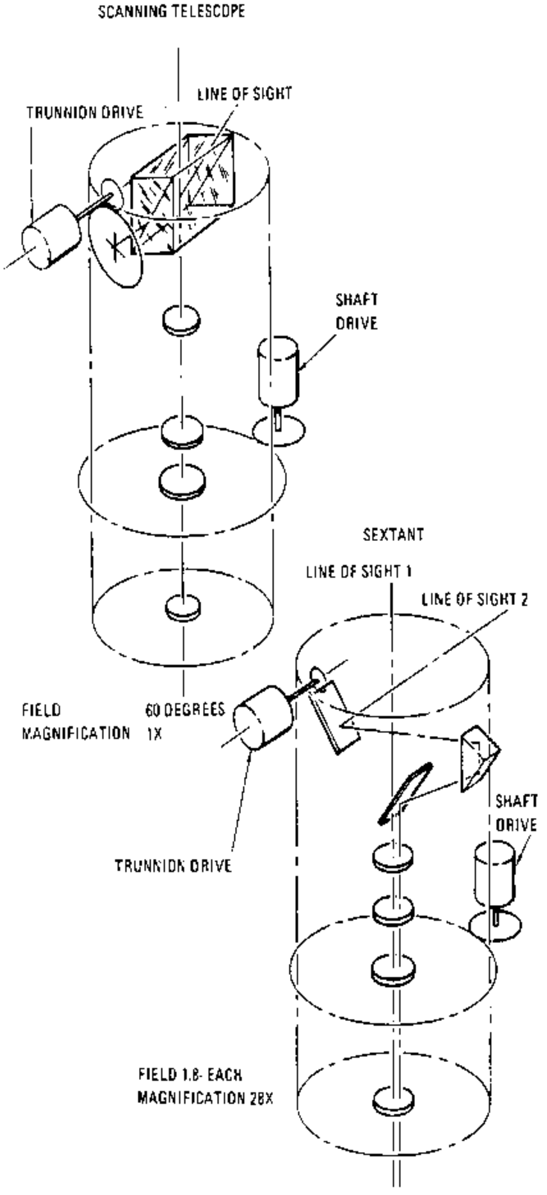
Schematic of optical subsystem

by zero output from the resolvers. The telescope and trunnion axes follow to a zero position. The zero optics mode can be selected either manually by the flight crew or by the computer after the computer control mode of operation has been manually selected.

The manual mode can be selected to operate under either direct hand control or resolved hand control. Independent control of the telescope trunnion is possible in both of these variations.

In direct hand control the hand controller outputs are applied directly to the sextant shaft and trunnion motor drive amplifiers. Forward and back motion of the hand controller commands increasing and decreasing trunnion angles, and right and left motion of the hand controller commands increasing and decreasing shaft angles. The apparent speed of the image motion can be regulated by the flight crew by selecting either low, medium, or high controller speed on the indicator control panel. This regulates the voltage applied to the motor drive amplifier and therefore the shaft and trunnion drive rates.



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Schematic of sextant and telescope

The slave telescope modes provide for alternate operation of the telescope trunnion while the sextant is being operated manually. Three alternate modes can be selected by a telescope trunnion switch: the telescope trunnion axis slaved to the sextant trunnion (the normal operating position), the telescope trunnion locked in a zero position (by applying fixed voltage to the telescope trunnion 1X receiving resolver, causing this position loop to null in a zero orientation. Therefore, this means the centerline of the telescope 60-degree field-of-view is held parallel to the landmark line of sight of the sextant), and the telescope trunnion axis is offset 25 degrees (the centerline of the 60-degree field of view is offset 25 degrees from the landmark line of sight of the sextant). This last position of the telescope trunnion will allow the landmark to remain in the 60-degree field of view while still providing a total possible field of view of 110 degrees if the telescope shaft is swept through 360 degrees.

In manual resolved operation, the hand controller outputs are put through a matrix transformation before being directed to the shaft and trunnion motor drive amplifiers. The matrix transformation makes the image correspond directly to the hand controller motion. That is, up, down, right, and left motions of the hand controller commands the target image to move up, down, right, and left, respectively, in the field of view.

Buttons on the indicator control panel are used to instruct the computer that a navigation fix has been made and that sextant shaft and trunnion position and time should either be recorded or rejected. The "mark" command is generated manually by the flight crew which energizes the mark relay. The mark relay transmits a mark command to the computer. If an erroneous mark is made, the "mark reject" button is depressed.

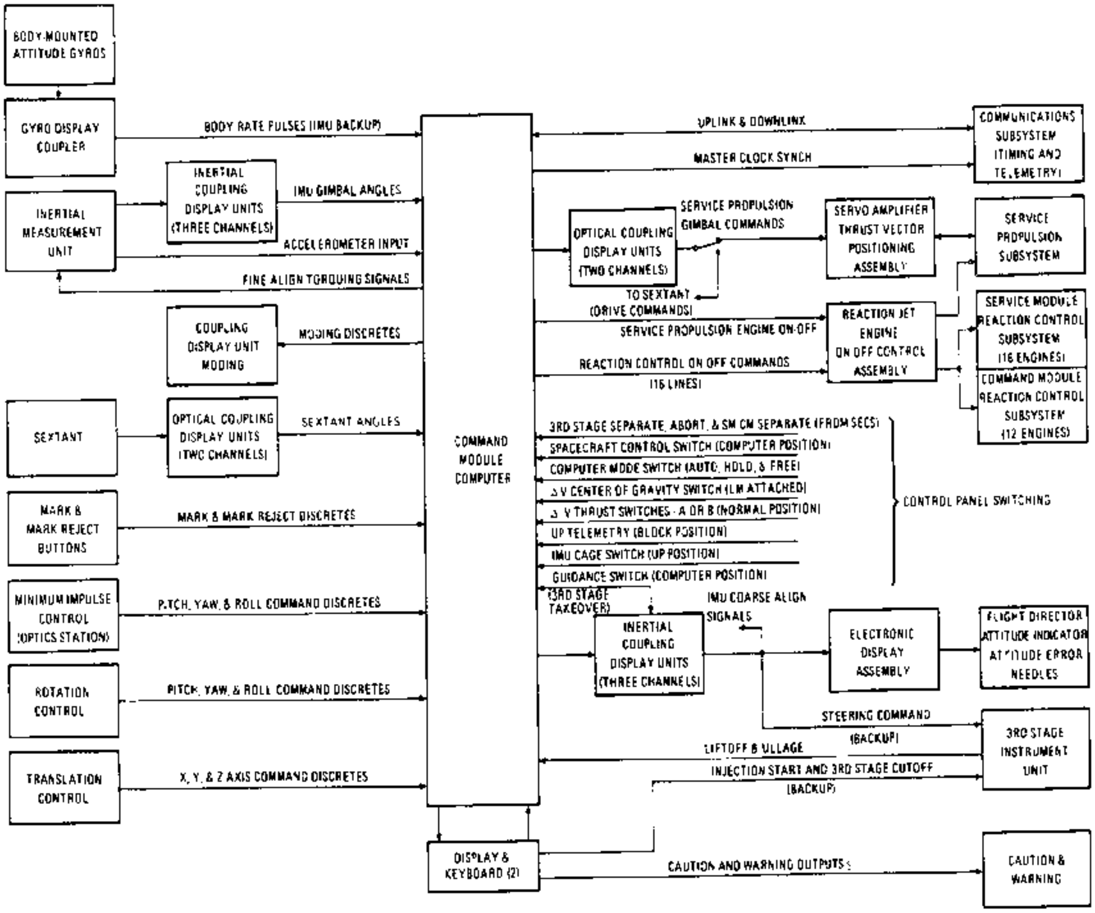
The computer-controlled operation is selected by placing the moding switch in computer position. The mechanization of this loop is chosen by the computer program that has been selected by the flight crew. The computer controls the sextant by completing the circuit from the coupling data unit digital-to-analog converters to the shaft and trunnion motor drive amplifier. The computer can then provide inputs to these amplifiers via a digital input to the coupling data unit which converts it to an 800-cycle signal that can be used by the motor drive amplifier. This mode is used when it is desired to look at a specific star for which the computer has the corresponding star coordinates. The computer will know the attitude of the spacecraft from the position of the inertial measurement unit gimbals and will, therefore, be able to calculate the position of the sextant axes required to acquire the star.

COMPUTER SUBSYSTEM

The computer subsystem consists of the command module computer and two display and keyboard panels. The computer and one keyboard are located in the lower equipment bay. The other keyboard is located on the main display console. All computer controls and displays are located on the keyboards.

The computer is a core memory digital computer with both fixed and erasable memory. The fixed memory permanently stores navigation tables, trajectory parameters, programs, and constants. The erasable memory stores intermediate information.

The computer processes data and issues discrete control signals, both for guidance and control and for other spacecraft subsystems. It is a control computer with many of the features of a general-purpose computer. As a control computer, it aligns the stable platform of the inertial measurement unit in the inertial subsystem, positions the optical unit in the optical subsystem, and issues control commands to the spacecraft thrusters. As a general-purpose computer, it solves guidance problems required for the spacecraft mission. In addition, it monitors the operation



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Block diagram of computer relationships of the guidance and control and other spacecraft subsystems.

The computer computes information about the flight profile that the spacecraft must assume in order to complete its mission. This position, velocity, and trajectory information is used by the computer to solve the various flight equations. The results of various equations can be used to determine the required magnitude and direction of thrust required. Corrections to be made are established by the computer. The spacecraft engines are turned on at the correct time, and steering and engine control signals are generated by the computer to re-orient the spacecraft to a new trajectory if required. The inertial subsystem senses acceleration and supplies velocity changes to the computer for calculating the total velocity. Drive signals are supplied from the computer to coupling data unit and stabilization gyros in the inertial subsystem to align the gimbal angles in the inertial measurement unit. Error signals are also supplied to the coupling data unit to provide attitude error display signals for the flight director attitude indicator. Coupling data unit position signals are fed to the computer to indicate commanded changes in engine gimbal angles. The computer receives mode indications and angular information from the optical subsystem during optical sightings and uses it to calculate present position and orientation and to refine trajectory information. Optical subsystem components can also be positioned by drive signals supplied from the computer.

The computer is functionally divided into seven blocks: timer, sequence generator, central processor, memory, priority control, input-output, and power.

The timer generates the synchronization pulses to assure a logical data flow from one area to another within the computer. It also generates timing waveforms which are used by the computer in alarm circuitry and other areas of the spacecraft for control and synchronization purposes.

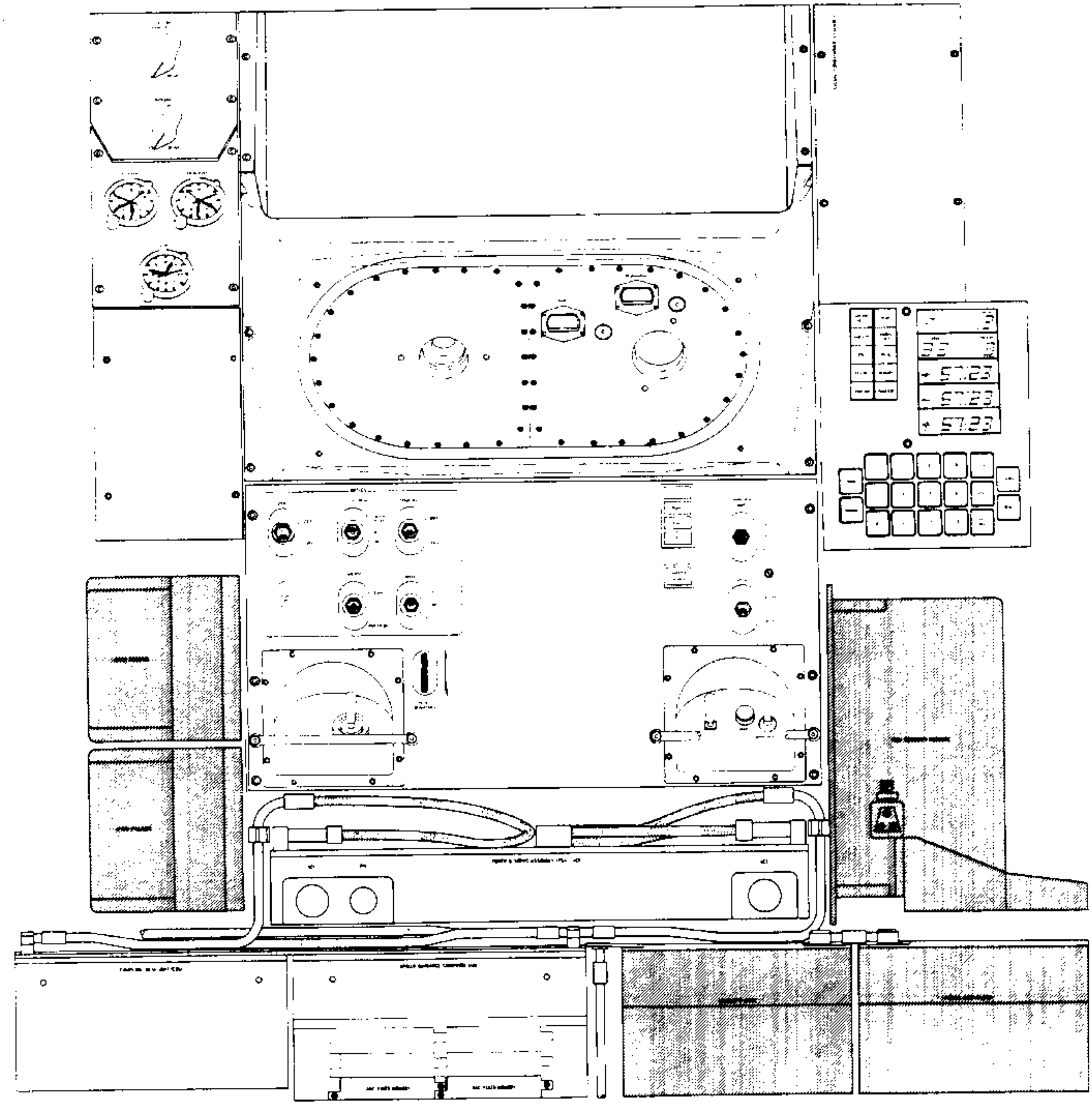
The master clock frequency is generated by an oscillator and is applied to the clock divider logic. The divider logic divides the master clock input into gating and timing pulses at the basic clock rate of the computer. Several outputs are available from the pulses at the basic clock rate of the computer. Several outputs are available from the scaler, which further divides the divider logic output into output pulses and signals which are used for gating, to generate rate signal outputs, and for the accumulation of time. Outputs from the divider logic also drive the time pulse generator which produces a recurring set of time pulses. This set of time pulses defines a specific interval (memory cycle time) in which access to memory and word flow takes place within the computer. The start-stop logic senses the status of the power supplies and specific alarm conditions in the computer and generates a stop signal which is applied to the time pulse generator to inhibit word flow. Simultaneously, a fresh-start signal is generated which is applied to all functional areas in the computer.

The sequence generator directs the execution of machine instructions. It does this by generating control pulses which sequence data throughout the computer. The control pulses are formed by combining the order code of an instruction word with synchronization pulses from the timer. The sequence generator contains the order code processor, command generator, and control pulse generator. The sequence generator executes the instructions stored in memory by producing control pulses which regulate the data flow of the computer. The manner in which the data flow is regulated among the various functional areas of the computer and between the elements of the central processor causes the data to be processed according to the specifications of each machine instruction.

The order code processor receives signals from the central processor, priority control, and peripheral equipment (test equipment). The order code signals are stored in the order code processor and converted to coded signals for the command generator. The command generator decodes these signals and produces instruction commands. The instruction commands are sent to the control pulse generator to produce a particular sequence of control pulses, depending on the instruction being executed. At the completion of each instruction, new order code signals are sent to the order code processor to continue the execution of the program.

The central processor performs all arithmetic operations required of the computer, buffers all information coming from and going to memory, checks for correct parity on all words coming from memory, and generates a parity bit for all words written into memory. It consists of flip-flop registers, the write, clear, and read control logic, write amplifiers, memory buffer register, memory address register and decoder, and the parity logic.

Primarily, the central processor performs operations indicated by the basic instructions of the program stored in memory. Communication within the central processor is accomplished through the write amplifiers. Data flows from memory to the flip-flop registers or vice versa, between individual flip-flop registers, or into the central processor from external sources. In all instances, data is placed on the write lines and routed to a specific register, or to another functional area under control of the write, clear, and read logic. The logic section accepts control pulses from the sequence generator and generates signals to read the content of a register onto the write lines, and write this content into another



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Guidance and navigation station in lower equipment bay register of the central processor or to another functional area of the computer. The particular memory location is specified by the content of the memory address register. The address is fed from the write lines into this register, the output of which is decoded by the address decoder logic. Data is subsequently transferred from memory to the memory buffer register. The decoded address outputs are also used as gating functions within the computer.

The memory buffer register buffers all information read out or written into memory. During readout, parity is checked by the parity logic and an alarm is generated in case of incorrect parity. During write-in, the parity logic generates a parity bit for information being written into memory. The flip-flop registers are used to accomplish the data manipulations and arithmetic operations. Each register is 16 bits or one computer word in length. Data flows into and out of each register as dictated by control pulses associated with each register. The control pulses are generated by the write, clear, and read control logic.

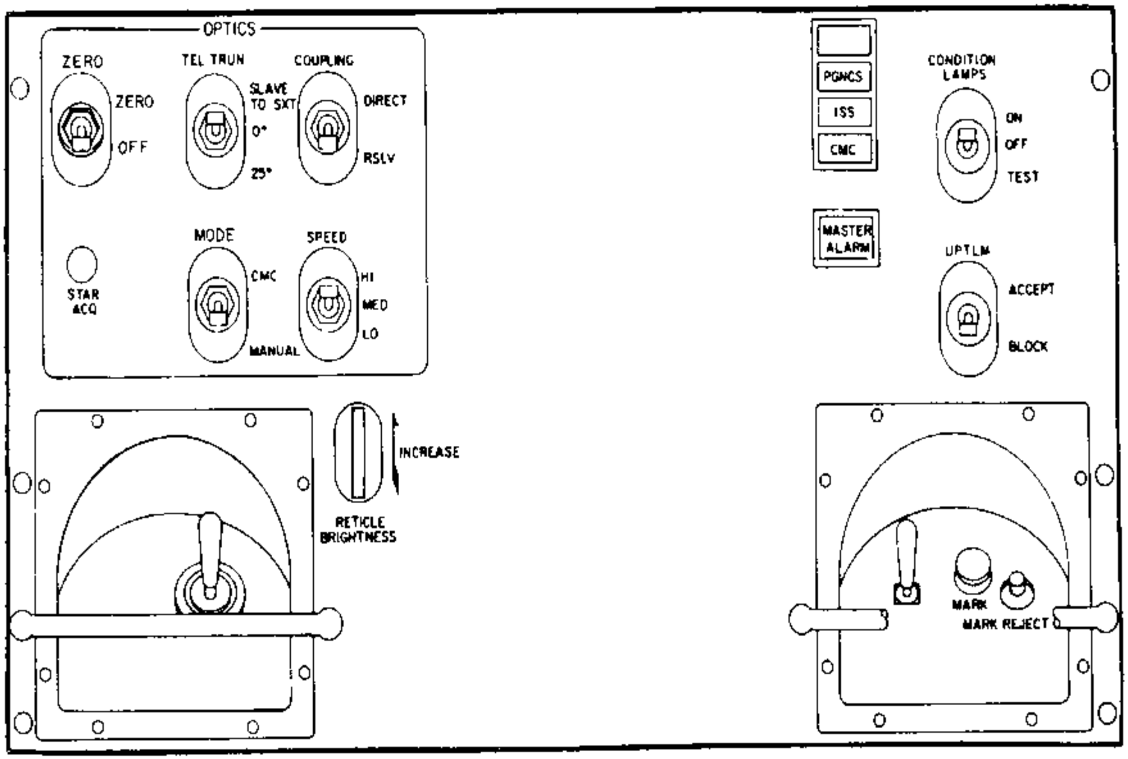
External inputs through the write amplifiers included the content of both the erasable and fixed memory bank registers, all interrupt addresses from priority control, control pulses which are associated with specific arithmetic operations, and the start address for an initial start condition. Information from the input and output channels is placed on the write lines, and routed to specific destinations either within or external to the central processor.

Memory provides the storage for the computer and is divided into two sections: erasable memory and fixed memory. Erasable memory can be written into or read from; it is destroyed when it is read out (displayed); therefore, information required for later use must be restored. Fixed memory cannot be written into and its readout is nondestructive. Erasable memory stores intermediate results of computations, auxiliary program information, and variable data supplied by the guidance and control and other subsystems of the spacecraft. Fixed memory stores programs, constants, and tables. There is a total of 38,912 sixteen-bit word storage locations in fixed and erasable memories. It should be noted that the majority of the memory capacity is in fixed memory (36,864 word locations). The erasable memory uses planes or ferrite (iron) cores as storage devices. A core is a magnetic storage device having two stable states. It can be magnetized in one or two directions by passing a sufficient current through a wire which pierces the core. The direction of current determines the direction of magnetization. The core will retain its magnetization indefinitely until an opposing current switches the core in the opposite direction. Wires carrying current through the same core are algebraically additive. Sense wires which pierce a switched core will carry an induced pulse. The fixed memory is high-density core rope—tiny nickel-iron cores woven together with thousands of copper wires and encapsulated in plastic. Each core functions as a transformer and storage does not depend on magnetization. The advantages of encapsulated core rope for fixed memory are indestructibility, permanence of data, and storage of a vast amount in a small volume. The technique requires, however, that programs for classes of missions be developed and verified before the rope is woven, because the program determines the wiring sequence.

Priority control establishes a processing priority of operations that must be performed by the computer. These operations are a result of conditions which occur both internally and externally. Priority control consists of counter priority control and interrupt priority control. Counter priority control initiates actions which update counters in erasable memory. Interrupt priority control transfers control of the computer to one of several interrupt subroutines stored in fixed memory.

The start instruction control restarts the computer after a hardware or program failure. The counter instruction control updates the various counters in erasable memory upon reception of certain incremental pulses. The interrupt instruction control forces the execution of the interrupt instruction to interrupt the current operation of the computer in favor of a programmed operation of a higher priority.

The input-output section routes and conditions signals between the computer and other areas of the spacecraft. In addition to the counter interrupt and the program interrupts previously described, the computer has a number of other inputs derived from its interfacing hardware. These inputs are a result of the functioning of the hardware, or an action by the operator of the spacecraft. The counter interrupts, in most cases, enable the computer to process inputs representing such things as changes in velocity. The program interrupt inputs are used to initiate processing that must be done a relatively short time after a particular function is present. The other inputs to the computer, in general,



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Optics control panel

enable it to be aware of conditions which exist in its environment. These inputs are routed to computer and are available to its programs through the input channels.

The outputs of the computer fall in one of the following categories: data, control, or condition indications. Some of these outputs are controllable through the computer program while others are present as a function of computer circuitry. All of the outputs which are controlled by the computer programs are developed through the computer output channels.

The power section provides voltage levels necessary for the proper operation of the computer. Power is furnished by two switching-regulator power supplies: a +4-volt and a +14-volt power supply which are energized by fuel cell powerplants in the electrical power subsystem.

The power supply outputs are monitored by a failure detector consisting of four differential amplifiers. There are two amplifiers for each power supply, one for overvoltage and one for undervoltage detection. If an overvoltage or undervoltage condition exists, a relay closure signal indicating a power fail is supplied to the spacecraft.

The display and keyboard panels provide communication between the flight crew and the computer. They operate in parallel, with the main display console keyboard providing computer display and control while crewmen are in their couches.

The exchange of data between the flight crew and the computer is usually initiated by crew action; however, it can also be initiated by internal computer programs. The exchanged information is processed by the keyboard program. This program allows the following four different modes of operation:

1. Display of internal data—both a one-shot display and a periodically updating display (called monitor) are provided.

2. Loading external data—as each numerical character is entered, it is displayed in the appropriate display panel location.

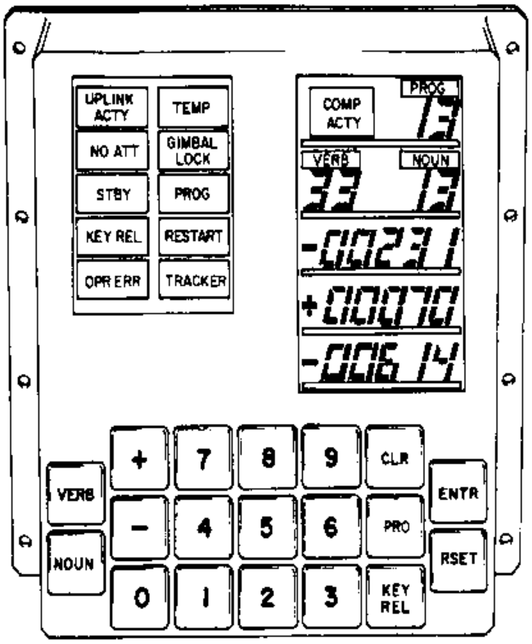
3. Program calling and control—the keyboard is used to initiate a class of routines which are concerned with neither loading nor display; certain routines require instructions from the operator to determine whether to stop or continue at a given point.

4. Changing major mode—the initiation of large-scale mission phases can be commanded by the operator.

The data involved in both loading and display can be presented in either octal or decimal form as the operator indicates. If decimal form is chosen, the appropriate scale factors are supplied by the program. Decimal entries are indicated by entering a plus or minus sign.

The basic language of communication between the operator and the computer is a pair of words known as verb and noun. Each of these is represented by a two-character decimal number. The verb code indicates what action is to be taken (operation); the noun code indicates to what the action is applied (operand). Typical verbs are those for displaying and loading. Nouns usually refer to a group of erasable registers within the computer memory. The program, verb, and noun displays provide two-digit numbers which are coded numbers describing the action being performed. The register 1, 2, and 3 displays show the contents of registers or memory locations. These displays are numbers which are read as decimal numbers if a plus or minus sign is present and octal numbers if no sign is used. The register displays operate under program control unless the contents of a specific register or memory location is desired. The crew may request display of the contents of a specific register or memory location by commanding the display from the keyboard. The only other displays are the "activity" lights which indicate whether the computer is computing or accepting telemetry from the ground and status lights.

The keyboard consist of ten numerical keys (pushbuttons) labeled 0 through 9, two sign keys (+ or -) and seven instruction keys: Verb, Noun, Clr (clear), Pro (proceed), Key Rel (key release), Entr (enter) and Rset (reset). Whenever a key is depressed, 14 volts are applied to a diode encoder which generates a unique five-bit code associated with that key. There is, however, no five-bit code associated with the proceed key. The function of the keys is as follows:



P-267 *Computer display and keyboard*

Pushbutton	Function
0 through 9	Enters numerical data, noun codes, and verb codes into the computer
+ and -	Informs the computer that the following numerical data is decimal and indicates the sign of the data
Noun	Conditions the computer to interpret the next two numerical characters as a noun code and causes the noun display to be blanked
Clear	Clears data contained in the data displays; depressing this key clears the data display currently being used; successive depressions clear the other two data displays
Proceed	Commands the computer to proceed on to the standby mode when depressed, if in standby mode, depression commands the computer to resume regular operation (operate mode)
Key Release	Releases the keyboard displays initiated by keyboard action so that information supplied by the computer program may be displayed
Enter	Informs the computer that the assembled data is complete and that the requested function is to be executed

Reset	Extinguishes the lamps that are controlled by the computer
Verb	Conditions the computer to interpret the next two numerical characters as a verb code and causes the verb display to be blanked

The standard procedure for the execution of keyboard operations consists of a sequence of seven key depressions:

Verb V_2 V_1 Noun N_2 N_1 Enter

Pressing the Verb key blanks the two verb lights on the keyboard and clears the verb code register in the computer. The next two numerical inputs are interpreted as the verb code. Each of these characters is displayed by the verb lights as it is inserted. The Noun key operates similarly with the keyboard noun lights and computer noun code register. Pressing the Enter key initiates the program indicated by the verb-noun combination. Thus, it is not necessary to follow a standard procedure in keying verb-noun codes; it can be done in reverse order or a previously inserted verb or noun can be used without re-keying it. No action is taken by the computer in initiating the verb-noun-defined program until the Enter key is actuated. If an error is noticed in either the verb or noun code before actuation of the Enter key, it can be corrected simply by pressing the corresponding Verb or Noun key and inserting the proper code.

If the selected verb-noun combination requires data from the operator, the Verb and Noun lights flash on and off about once per second after the Enter key is pressed. Data is loaded in five-character words and is displayed character-by-character in one of the five-position data display registers. The Enter key must be pressed after each data word. This tells the program that the numerical word being keyed in is complete.

The keyboard also can be used by internal computer programs for subroutines. However, any operator keyboard action (except error reset) inhibits keyboard use by internal routines. The operator retains control of the keyboard until he wishes to release it. This assures that the data he wishes to observe will not be replaced by internally initiated data displays.

A noun code may refer to a device, a group of computer registers, or a group of counter registers, or it may simply serve to convey information without referring to any particular computer register. The noun is made up of 1, 2, or 3 components, each entered separately as requested by the verb code. As each component is keyed, it is displayed on the display panel: component 1 in Register 1, component 2 in Register 2, and component 3 in Register 3. There are two classes of nouns: normal and mixed. Normal nouns (codes 01 through 39) are those whose component members refer to computer registers which have consecutive addresses and use the same scale factor when converted to decimal. Mixed nouns (codes 40 through 99) are those whose component members refer to nonconsecutive addresses or whose component members require different scale factors when converted to decimal, or both.

A verb code indicates what action is to be taken. It also determines which component member of the noun group is to be acted upon. For example, there are five different load verbs. Verb 21 is required for loading the first component of the selected noun; verb 22 loads the second component; verb 23 loads the third component; verb 24 loads the first and second component; and verb 25 loads all three components. A similar component format is used in the display and monitor verbs. There are two general classes of verbs: standard and extended. The standard verbs (codes 01 through 39) deal mainly with loading, displaying, and monitoring data. The extended verbs (codes 40 through 99) are principally concerned with calling up internal programs whose function is system testing and operation.

SPACE SUIT

A space suit is a mobile chamber that houses and protects the astronaut from the hostile environment of space. It provides atmosphere for breathing and pressurization, protects him from heat, cold, and micrometeoroids, and contains a communications link.

The suit is worn by the astronauts during all critical phases of the mission, during periods when the command module is unpressurized, and during all operations outside the command and lunar modules whether in space or on the moon.

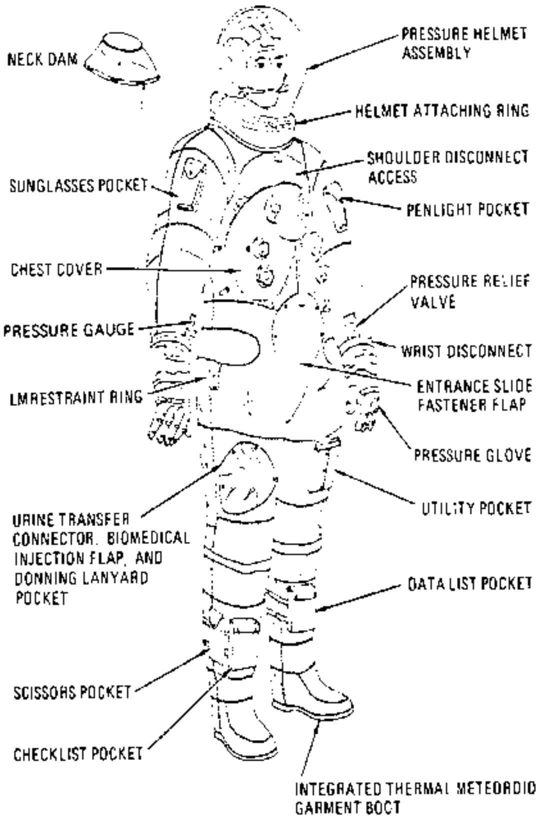
The space suit is produced by the International Latex Corp., an associate contractor directly responsible to NASA.

The suit systems must provide an artificial atmosphere (100-percent oxygen for breathing and for pressurization to 3.7 psi), adequate mobility (lunar gravity is one-sixth that of earth), micrometeorite and visual protective systems, and the ability to operate on the lunar surface for periods of 3 hours. Design of the Apollo spacecraft and suits will permit the crew to operate – with certain restraints – in a decompressed cabin for periods as long as 115 hours.

Insulation must protect the astronaut from temperatures varying from 250°F above (lunar day) to 250° below zero (lunar night). Solar heat flux is calculated at 10,000 Btu per hour. Superinsulation must limit heat leak into the suit to approximately 250 Btu per hour during lunar day and heat out to 350 Btu per hour during lunar night.

The astronauts must be protected from meteoroid particles traveling at speeds up to 64,000 miles per hour and from particles ejected by the meteoroid striking the lunar surface. During the lunar day, the crewmen's faces must be protected from solar ultraviolet, infrared, and visible light radiation.

The complete space suit is called the pressure garment assembly. It is composed of a number of items assembled into two configurations: extravehicular (for outside the spacecraft) and intravehicular. The addition of the backpack to the extravehicular space suit makes up the extravehicular mobility unit. The backpack (called the portable life support system) supplies oxygen, electrical power, communications, and liquid cooling.



NOTE: EXTRAVEHICULAR GLOVES AND LUNAR OVERSHOES NOT SHOWN.

P-268 *Pressure garment assembly (space suit)*

The intravehicular space suit consists of: fecal containment subsystem, constant wear garment, biomedical belt, urine collection transfer assembly, torso limb suit, integrated thermal micrometeoroid garment, pressure helmet, pressure glove, and communications carrier.

In the extravehicular configuration, the constant-wear garment is replaced by the liquid-cooling garment and four items are added to the intravehicular suit: extravehicular visor, extravehicular glove, lunar overshoe, and a cover which fits over umbilical connections on the front of the suit.

The pressure suit is a white, snowsuit-like garment that weighs about 60 pounds with the integrated thermal meteoroid garment. The latter weighs about 19 pounds.

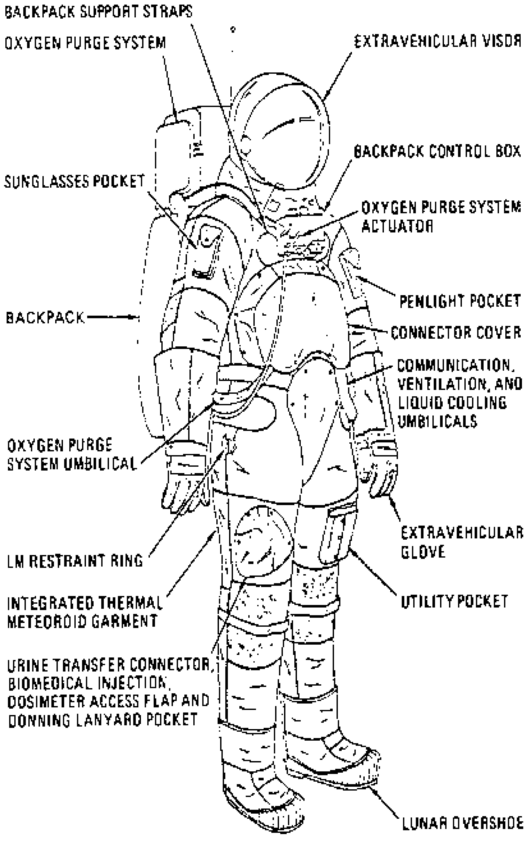
SPACE SUIT

The space suit is in a constant state of change as new and improved designs are developed and as new materials become available. Therefore the description in this section will be generalized and can be considered only as typical.

The basic components of the suit or pressure garment assembly are the torso limb suit, the pressure helmet, the pressure glove, the integrated thermal meteoroid garment, and the extravehicular glove. The constant-wear garment, which is worn under the suit in the intravehicular configuration, is described in the Crew section.

TORSO LIMB SUIT

The torso limb suit is the basic pressure envelope for the astronaut; it encloses all the body except the head and hands. It has three layers: an inner cloth comfort lining, a bladder which serves as the gas-retention layer, and a restraint layer designed to hold elongation to a minimum. The torso section is custom-fitted to each astronaut; the limb sections are graduated in size and adjustable.



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Extravehicular suit

The torso limb suit contains cables to sustain axial limb loads and a block and tackle system to foreshorten the suit for sitting or bending. Ducts on the inner surface of the suit direct oxygen to the helmet for breathing and defogging and also permit flow over the body for cooling. Connectors in the suit include those for oxygen (from the spacecraft's environmental control subsystem or the portable life support system), water (for the liquid cooling garment), and urine (to transfer it to the spacecraft's waste management system). An electrical harness in the suit connects communications and biomedical equipment to either the spacecraft or the portable life support system.

The right wrist of the torso limb suit contains a pressure gauge and the left wrist a pressure relief valve which opens to relieve suit pressure of more than 5.5 psi.

INTEGRATED THERMAL METEOROID GARMENT

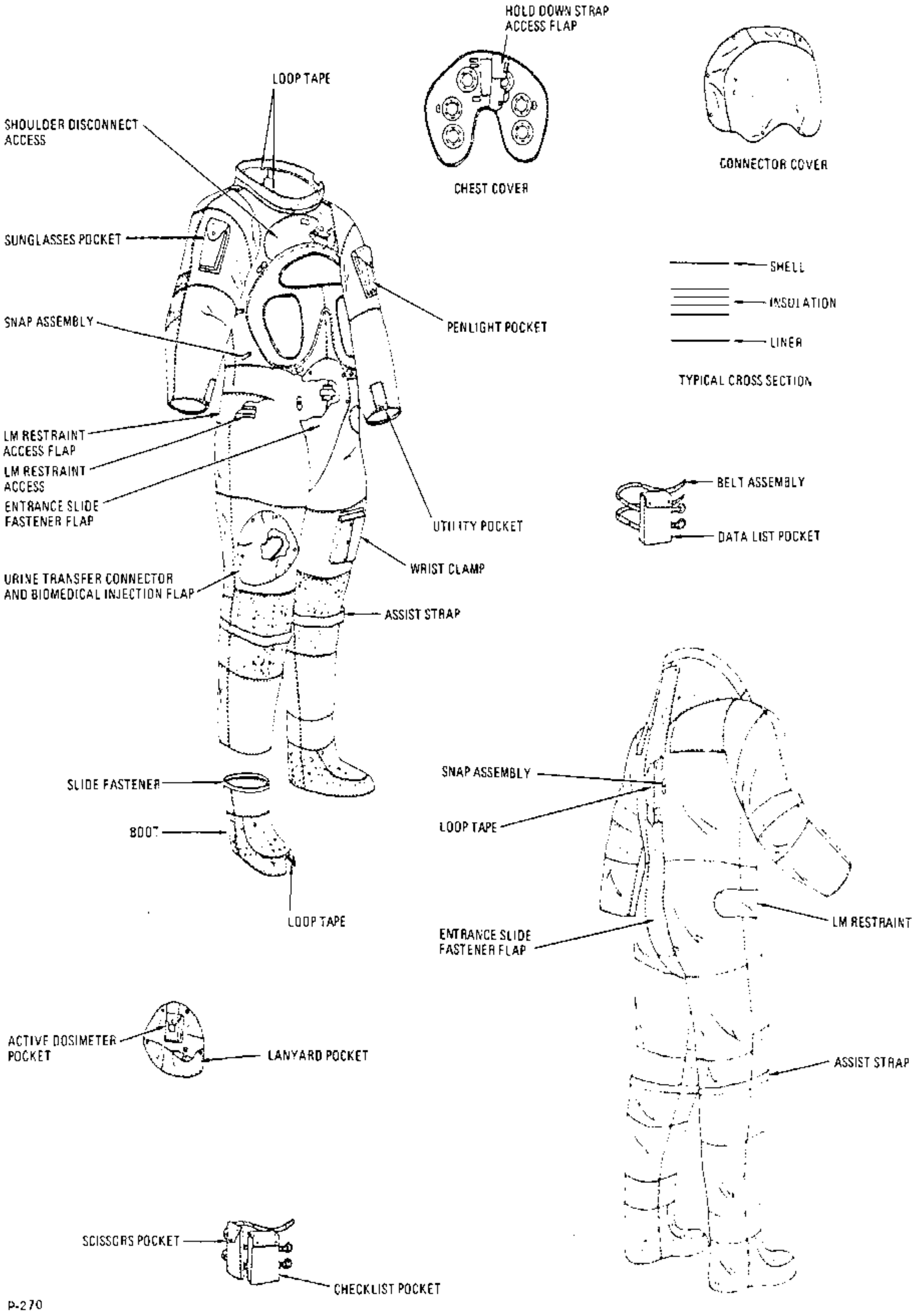
The integrated thermal meteoroid garment is a many-layered structure laced to the torso limb suit. It is composed of an inner and outer shell of Beta cloth, seven layers of aluminized Kapton film separated by six layers of Beta Marquisette, and a liner of two layers of Neoprene-coated nylon Ripstop. A layer of Chromel-R (a woven metal) is added to the knee, elbow, and shoulders to protect the suit against abrasion. Chromel-R also is used to protect the garment's boot from abrasion. The boot is attached to the space suit boot by loop tape.

Covers are provided for the shoulder cable disconnect, LM restraints, the entrance slide, and the urine transfer fitting-medical injection area. The cover for the last-named has four snaps at the top and folds down; the inner side has pockets for a radiation dosimeter and for a lanyard.

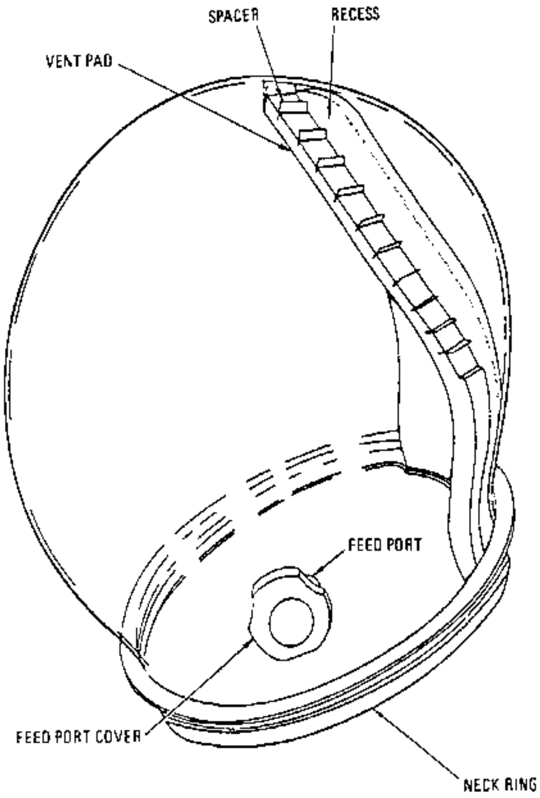
Pockets include one on the upper left arm (for two pens and a penlight), one on the upper right arm (for sunglasses), and one on the upper right thigh (a utility pocket about 1-3/4 by 6 by 8-1/4 inches). In addition, there are strap-on pockets for both legs. These contain a data list (left leg) and checklist and scissors (right leg).

PRESSURE HELMET

The pressure helmet consists basically of an aluminum neck ring and a transparent shell made of polycarbonate (plastic). The shell is bonded to the neck ring, which fits into and locks with a similar



Integrated thermal meteoroid garment



P-271 *Pressure helmet*

neck ring on the torso limb suit. The helmet also contains a feed port and a vent pad. The former is on the left side of the helmet and provides an air-tight attachment for the water and feed probes and for a purge valve. The vent pad (made of synthetic elastomer foam) is bonded to the back of the helmet and has a recess which acts as a ventilation flow manifold.

PRESSURE GLOVE

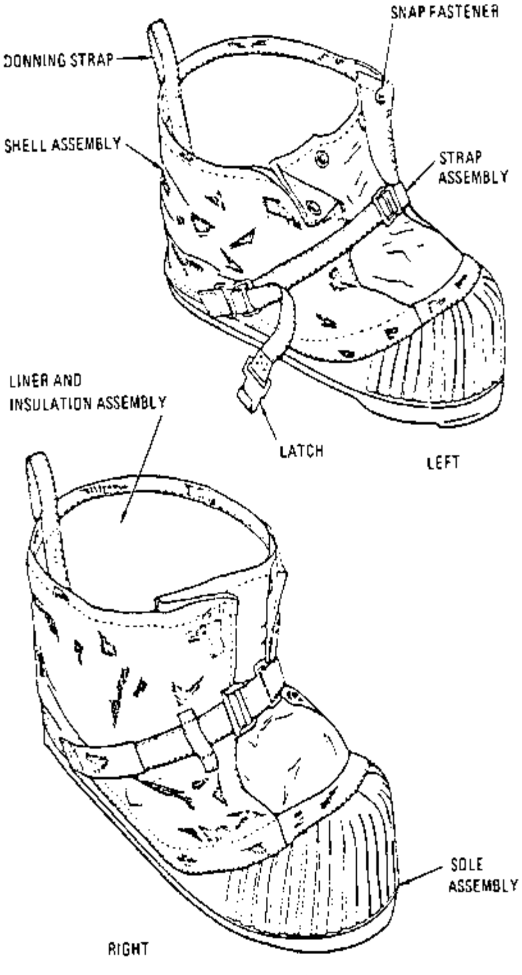
The pressure glove is a flexible gas-retaining device which locks to the torso limb suit. It consists of a bladder, a fingerless glove, inner and outer covers, and a restraint system. The bladder is moulded from a cast of each astronaut's hand. The bladder core, made of nylon tricot dipped in a Neoprene compound, is exposed at the inner thumb and fingertips to give the astronauts feeling in those areas. The fingerless glove is a restraint cemented to the bladder. A restraint strap over the palm minimizes ballooning and thus aids in grip control.

EXTRAVEHICULAR GLOVE

This glove is used for extravehicular activities and is for thermal protection. It covers the entire hand and has a cuff that extends well above the joint between the torso limb suit and the pressure glove. The extravehicular glove consists of a modified pressure glove (called the thermal meteoroid pressure glove) to which a thermal insulating shell is secured. The shell is similar in construction to the integrated thermal meteoroid garment, with additional layers of insulating material in the palm and fingers. The Chromel-R is coated with a silicon dispersion compound to improve the grip.

LUNAR OVERSHOE

This fits over both the thermal meteoroid garment boot and the suit boot and is used for extravehicu-



Lunar overshoe

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lar activity. It consists of an insulation and liner, and an outer shell. The liner is Teflon-coated Beta cloth and the insulation is 13 layers of aluminized Kapton film separated by 12 layers of Beta Marquisette. The sole portion contains two additional layers of Beta felt interspaced between the uppermost film and spacer layers. The outer shell features a silicone rubber sole sewn to a laminated structure made up of four layers of two-ply Beta Marquisette. Chromel-R is used as the outer layer of the shell, except for the tongue, which is Teflon-coated Beta cloth.

EXTRAVEHICULAR VISOR

The extravehicular visor is used over the pressure helmet to protect the astronaut from light, heat, and micrometeoroids, and to protect the pressure helmet. It consists of a polycarbonate shell to which are attached two pivoting visors, one for micrometeroid protection and one for protection from the sun's rays. Both visors are made of polycarbonate and can be set anywhere from their full-up to full-down positions.

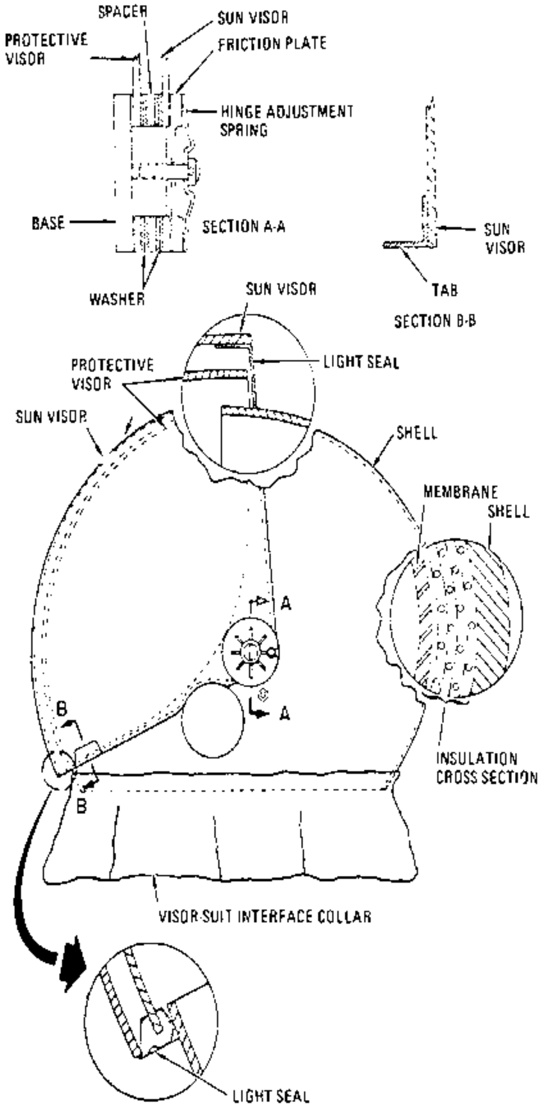
LIQUID-COOLING GARMENT

The liquid-cooling garment is used to cool an astronaut during extravehicular activity. It consists of a nylon Spandex material which supports a network of Tygon tubing through which water from the portable life support system is circulated. The inner surface of the garment is nylon chiffon. The socks attached to the garment do not contain cooling tubes.

PORTABLE LIFE SUPPORT SYSTEM

The portable life support system (backpack) is contained in a fiberglass shell contoured to fit the back. It is 26 inches high, 28 inches wide, and 11 inches thick, and has three control valves, 2 control switches, and a 5-position switch for the radio transceiver. Total weight is about 68 pounds. It is produced by the Hamilton Standard Division of United Aircraft Corp., Windsor Locks, Conn.

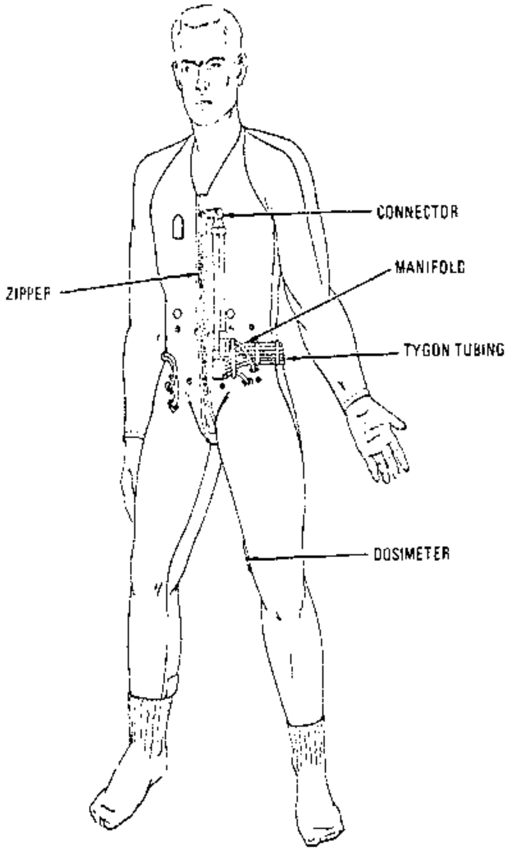
The system will assimilate an average crewman output of 1600 Btu per hour with peak rates of 2000 Btu per hour. It will operate for 4 hours in a space environment before replenishment of oxygen and replacement of the battery. There are four subsystems of the system: oxygen, liquid, telecommunications, and electrical.



P-273 *Extravehicular visor*

The primary oxygen (1.05 pounds) is supplied from a 46.6-cubic-inch tank pressurized at 900 psi. The system is filled through a quick-disconnect before launch or a CM flex line connection during the mission.

Oxygen flows to the suit via the oxygen supply hose at a temperature of 45 to 50°F and returned from the suit at 80 to 85°F laden with impurities such as carbon dioxide, body odor, and water molecules. It passes through a canister containing deactivated charcoal and lithium hydroxide, which absorbs the carbon dioxide and purifies the gas. The gas is then cooled to 40° to 45°F in the sublimator/heat extractor which, during the process,



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Liquid-cooling garment

will condense the water into droplets. As the flow reaches 90 degrees, the heavier water droplets continue straight and impact the water separator wick. The cool and conditioned gas then begins the cycle again.

The transport water subsystem of the backpack absorbs heat from the body surface of the crewman, transports it to the backpack, and loses heat in the sublimator. It is a closed loop with an operating pressure of 20 psi.

The telecommunications subsystem receives biomedical and communications data from the crewman, transmits it to the LM, and receives communications data from the LM, transmitting it to the crewman. The subsystem consists of primary and secondary transceiver (transmitters and receivers in one unit), interconnecting cable, an antenna, and controls. The cable connects the chest connector on the right side of the suit. The antenna is housed in a small fiberglass dome.

The backpack's electrical subsystem distributes power to the other subsystems. It consists of two 16.8-volt batteries, a distribution panel, and power distribution harness. A battery weighs about 4 pounds and has 27 watt-hours of use.

EMERGENCY OXYGEN SYSTEM

The emergency oxygen system provides an immediate supply of oxygen to maintain suit pressure. It is doughnut shaped, weighs 2.9 pounds, and has an actuating mechanism, a pressure gauge, and a regulator. The system stores 7.2 cubic inches of oxygen at 7500 psig. The units are stowed on the back of the left couch leg pan or stowage mounting plates. When preparing for extravehicular activity or crew transfer, a unit is mounted on the left side of the backpack below the contaminant control canister.

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Suited astronaut enters spacecraft at Space Division, Downey, Calif.

CHECKOUT AND FINAL TEST

Before any Apollo spacecraft is launched it has "flown" its complete mission a number of times on the ground. These ground flights are part of an extensive series of tests the completed spacecraft must pass before it is committed to launch.

The final checkout and testing of the Apollo command and service modules takes place in two stages: that conducted at North American Rockwell's Space Division in Downey, Calif., to assure that the vehicles are in condition for delivery to NASA, and that conducted at the Kennedy Space Center to assure that the modules are ready for launch.

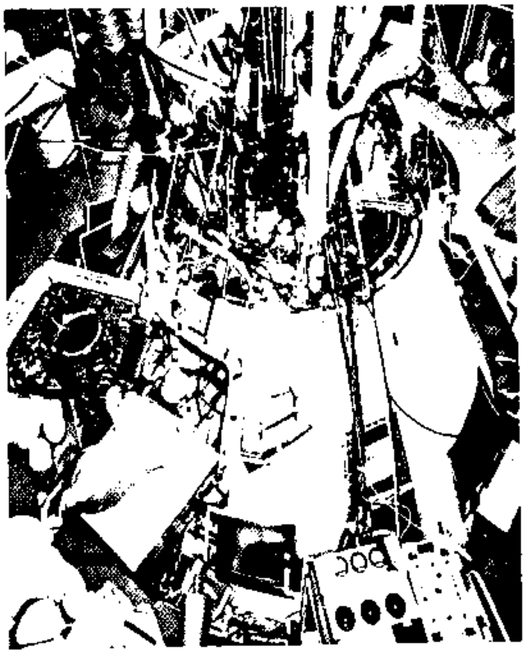
NORTH AMERICAN ROCKWELL SPACE DIVISION

Final assembly of the command and service modules takes place in a large "clean room," at Downey. When components reach this room, they have already gone through many hours of severe testing.

Checkout and testing at Downey can be separated into three broad categories: component and subassembly, individual subsystem tests during buildup, and integrated system testing. The first is at the component and subassembly level, before the equipment is installed in the spacecraft. The second follows installation on the spacecraft and is a long and complex series of tests involving such major operations as pressure cell testing, continuity checks of all wiring, and testing of each subsystem after installation in the vehicle.

The third category—integrated systems testing—is the final operation at Downey. It is conducted in two phases: "plugs-in" and "plugs-out" checkout in which the command and service module subsystems are operated together through a complete simulated mission. In addition, a manned suit loop test is performed with the flight crew to check the environmental control subsystem and all other crew equipment.

The individual and integrated system testing is conducted with acceptance checkout equipment (ACE) similar to that at KSC. This equipment interrogates the spacecraft systems to elicit automatic responses as to their status. The responses are automatically gathered, processed, and displayed to test personnel for immediate evaluation and also are recorded and stored for later detailed analysis. The displays are part of a modular system which allows a staff of engineers to monitor more than 25,600 samples per second of spacecraft test data containing about 1500 separate spacecraft and ground support conditions while the test is being performed.



CM undergoes electrical test in Downey clean room

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The integrated system tests have a number of objectives: to check the operation of each subsystem under mission conditions and assure that all subsystems work together properly, to verify the electromagnetic compatibility of the subsystems, to assure that all crew equipment functions properly, and to check operation of specific alternate and backup equipment and procedures.

The plugs-in and plugs-out tests are similar. The differences are that the former uses ground power and ACE connected to the spacecraft while the latter uses simulated fuel cell power and the ACE is removed so that responses are sent over spacecraft communications equipment as it would operate during the actual mission.

Checkout at Downey; technicians check cabling to command and service modules (left), while others monitor responses to stimuli on battery of computerized display equipment

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The spacecraft is prepared for these tests exactly as it would be for actual flight except that special test devices are installed in place of some equipment such as ordnance and expendable items.

In each phase the proper operation and interaction of all spacecraft subsystems are checked. The checkout equipment enables both automatic and manual operations to be performed, so that manual backups and overrides to automatic operations can be evaluated. When the series of testing at Downey has been completed, the spacecraft and its subsystems are considered ready. Before it is delivered to NASA, however, additional tests are performed to be sure that all the crew equipment, and particularly the environmental control subsystem, works properly with an actual suited crew aboard.

All loose crew equipment is stowed aboard the spacecraft in its proper place. Three crewmen don and check out the space suits and check ease of entering and leaving the command module. The flight crew then enters the cabin and checks the operation and manipulation of all crew equipment while in a pressurized suit, in a ventilated suit, and in shirtsleeves. Operation of the environmental control subsystem's suit loop is checked as the final step in the test sequence.

After the manned suit loop test the modules are prepared for shipment. This preparation involves demating, final checkout of pressure vessels and the reaction control subsystem, installation of the aft heat shield, application of a thermal coating to the exterior of the command module, installation of earth landing subsystem components and ordnance, a tumble-cleaning, and weight and balance checks.

KENNEDY SPACE CENTER

When the command and service modules arrive at Kennedy Space Center, they begin another long series of tests leading up to launch in which every vital part of the spacecraft is checked once again. Inspection, cleaning, fit checks, functional checks, and leak tests all are part of the pre-launch operations.

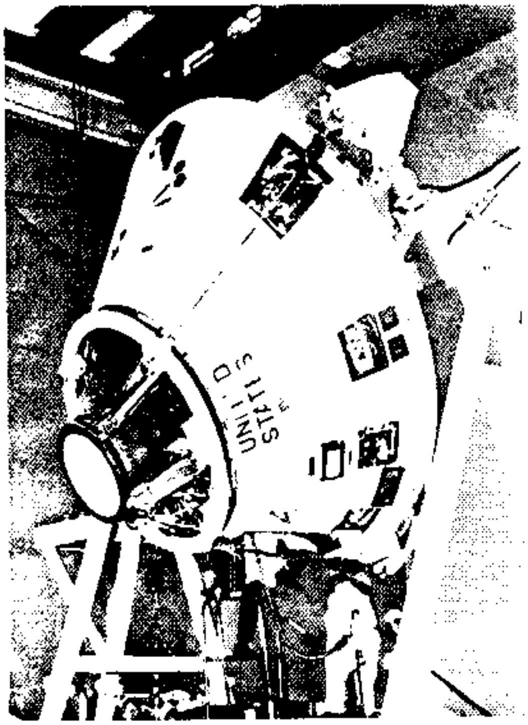
Interspersed with these tests are the spacecraft and launch vehicle handling operations. When the command and service modules arrive at Kennedy Space Center, they are taken to the Manned Spacecraft Operations Building where they undergo inspection, and leak and functional tests. The modules are then moved into the altitude chamber and are mated there.

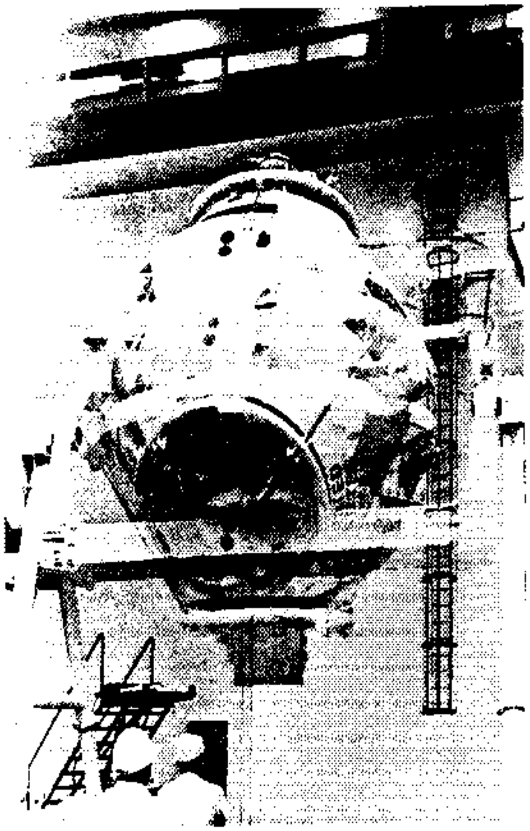
After the chamber and reaction control subsystem tests, the CSM will be moved to a test stand where the service propulsion engine nozzle will be installed and the modules mated with the spacecraft-LM adapter. The latter will already have a lunar module installed.

The spacecraft next is moved to the Vehicle Assembly Building for mating with the launch vehicle and additional tests, including the simulated flight tests. The launch escape subsystem also is mated to the spacecraft in the Vehicle Assembly Building. (On Apollo 7, the first Apollo manned flight, the spacecraft did not go to the Vehicle Assembly Building; instead, it was moved directly to the pad from the Manned Spacecraft Operations Building for testing.)

Two of the most important of the pre-launch operations are the altitude tests and the flight readiness test.

The altitude tests are conducted in a chamber in which conditions at an altitude of more than 200,000 feet can be simulated. The tests consist of four runs: a manned egress test at sea level, an unmanned run at 150,000 feet, and two manned runs at more than 200,000 feet, one with the primary crew and one with the backup crew. All operations in the altitude chamber are televised and recorded.





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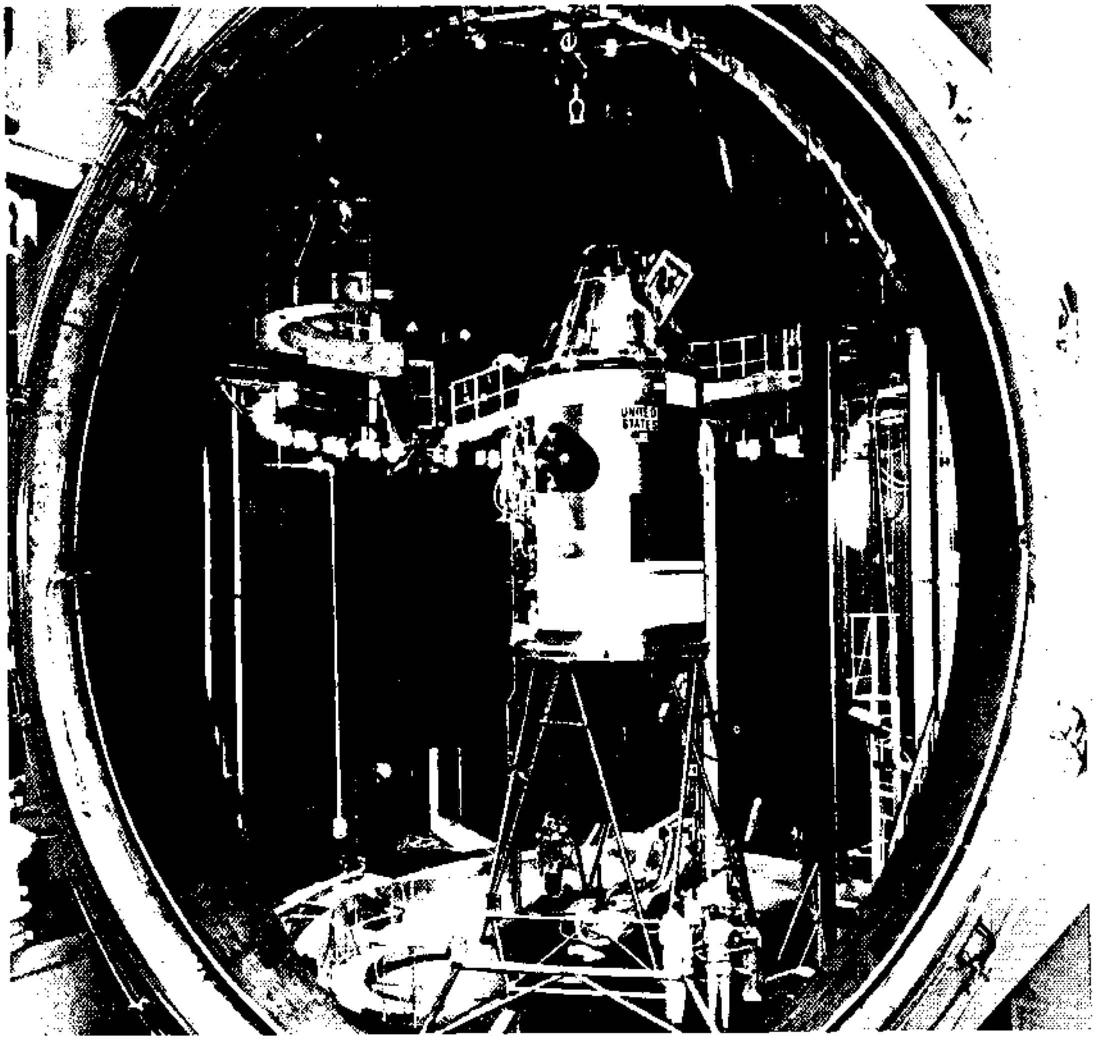
Tumbling shakes dust and debris from CM



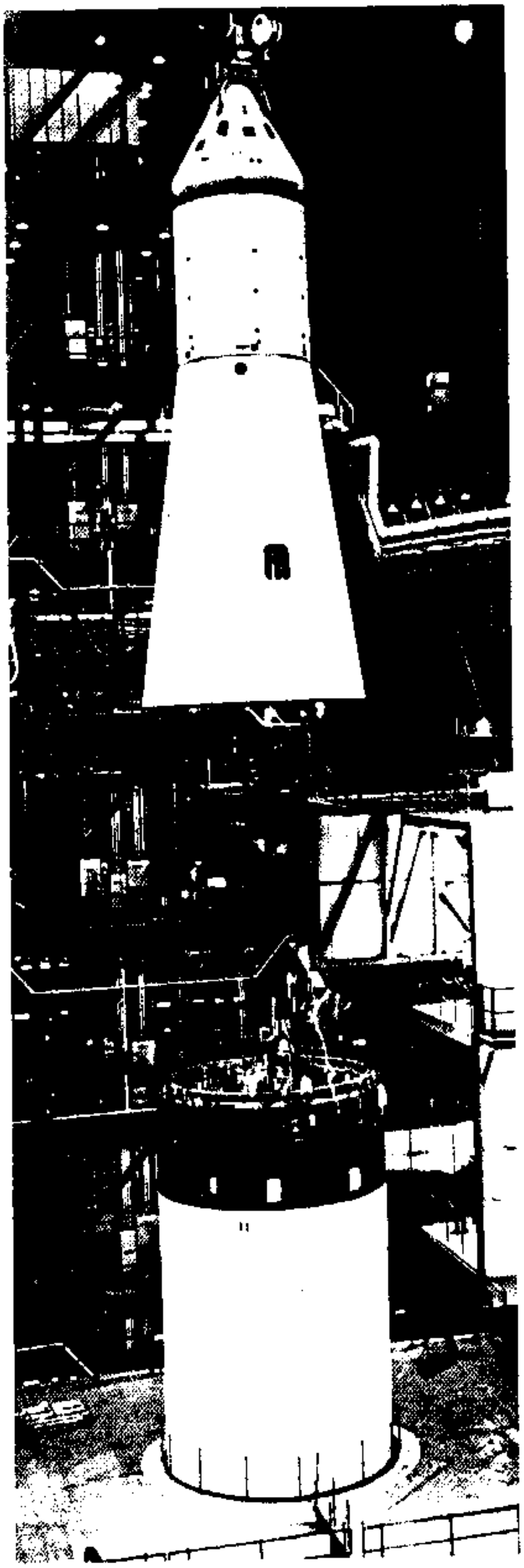
P-278 *Apollo command and service modules are prepared for thermal-vacuum tests in huge test chamber at NASA's Manned Spacecraft Center*

The altitude tests verify spacecraft operation and integrity at high altitude. Among the specific tests conducted in the chamber runs are suit integrity, manual manipulation of controls and equipment with the cabin depressurized, cabin repressurization (rapid and normal), fuel cell operation, environmental control subsystem cooling and water boiler operation, manual and automatic operation of the guidance and navigation and stabilization and control subsystems, urine dump, emergency breathing system, and entry while both pressurized and unpressurized.

The emergency exit tests are performed in the chamber but before the altitude runs. This test consists of verifying the quick opening of the side hatch after the boost protective cover has been installed.

The countdown demonstration test is one of the final hurdles before launch. In it a complete countdown is performed to verify proper timing and sequence of operations and to check spacecraft-ground communications.

The flight readiness test is the last test of the whole spacecraft before launch. It is designed to check out all subsystems and assure that the craft is ready to proceed to countdown. The electrical power, environmental control, instrumentation, and communications subsystems are first checked to assure proper operation and so that they will support the test. Then the operation of a number of subsystems is checked individually: guidance and navigation, stabilization and control, service propulsion, reaction control, and entry monitor. Next, the



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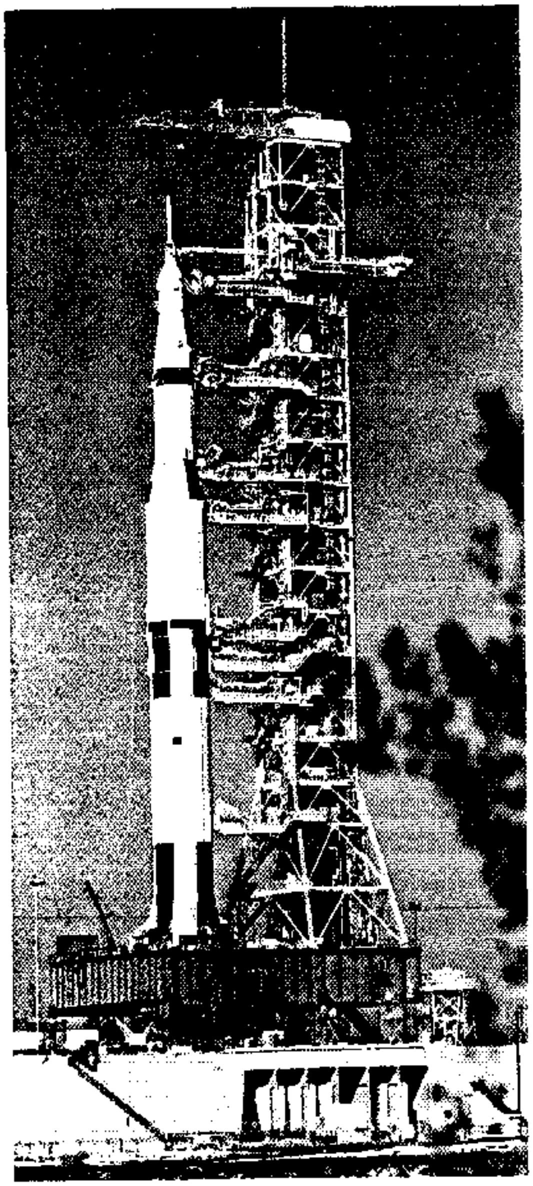
Spacecraft is mated with Saturn V

integrated operation of these subsystems is checked. Finally, the spacecraft is taken through several simulated aborts and then a complete mission from liftoff to splashdown. The same kind of acceptance checkout equipment used at Downey is used for these tests.

When the flight readiness test is completed satisfactorily, the spacecraft is essentially ready for launch. The only thing left is a final leak and functional test of the service propulsion and reaction control subsystems. After that propellants and cryogenics are loaded and the launch countdown is begun.



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Apollo spacecraft at Kennedy Space Center