CHAPTER 6
EXTRAVEHICULAR MOBILITY UNIT

by

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Introduction

The Apollo extravehicular mobility unit was designed to meet a unique set of needs. To assure the maximum return of scientific information from the moon, a method was required for collecting samples, deploying/retrieving instruments, and performing experiments on the lunar surface and in free space. Man had to be able to operate safely in free space to provide an emergency mode of translation from the Lunar Module to the Command Module in the event a complete linkup could not be accomplished after lunar lift-off. Since the weight required to provide redundant pressure vessels for each spacecraft would have been prohibitive, a space suit was required.

The extravehicular mobility unit (EMU) design reflected these needs. Figure 1 is a cutaway representation of the EMU. The unit consisted of a highly mobile, anthropomorphic pressure vessel and a portable life support system (PLSS). The pressure vessel, known as the pressure garment assembly (PGA), when operated in conjunction with the Command Module and Lunar Module life support systems, provided pressurization backup during critical mission phases, including launch and return. It provided primary pressurization for the extravehicular activity conducted from the Command Module during the missions of Apollo 15, 16, and 17. Traverses of four to seven hours' duration were made with the PLSS on the lunar surface to perform the lunar science tasks.

A description of the EMU used for the first lunar landing is given here. A short description is included of the changes made in the EMU design during the program to incorporate the results of experience and to provide new capabilities.

The EMU was supplied by three different concerns. The pressure garment assembly was supplied by ILC Industries, Incorporated, and the portable life support system by the Hamilton Standard Division of United Aircraft Corporation. Both were under the monitorship of the Crew Systems Division of the Engineering and Development Directorate of the Johnson Space Center. The communications equipment was supplied by RCA under the monitorship of the Tracking and Communications Development Division, also of the Engineering and Development Directorate.

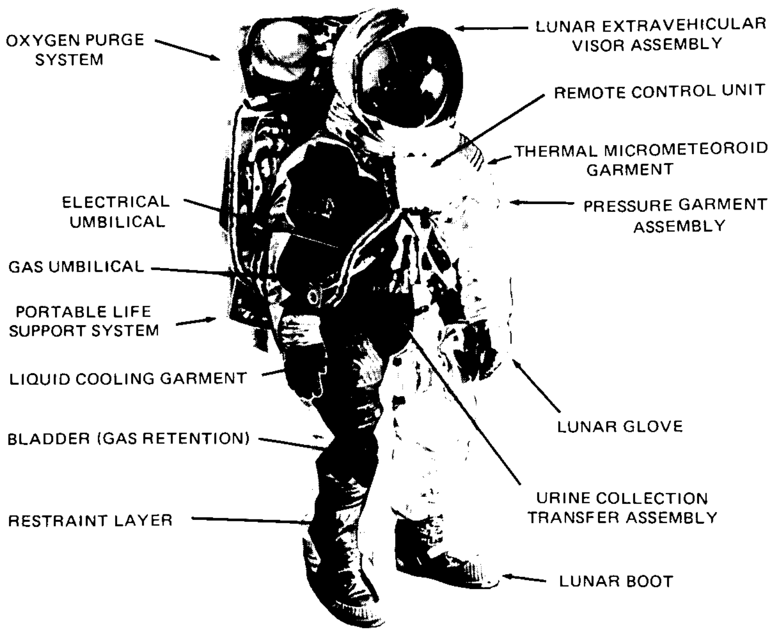


Figure 1. Cutaway of Apollo extravehicular mobility unit.

Apollo 11 Pressure Garment Assembly Configuration

Two configurations of the PGA were worn on the Apollo 11 mission. The intravehicular configuration was worn by the Command Module Pilot (figure 2). The extravehicular configuration, shown in figure 3, was worn by the Commander and Lunar Module Pilot. The two configurations were similar in most respects. However, the intravehicular version was equipped with a lighter weight and less bulky coverlayer and did not include hardware and controls necessary for extravehicular use.

Both versions of the PGA consisted of a torso-limb suit assembly (TLSA) with an integrated protective coverlayer, a pressure helmet, pressure gloves, controls, instrumentation, and communication equipment. In addition, extravehicular equipment consisting of a lunar extravehicular visor assembly, lunar boots, a liquid cooling garment, and fecal and urinary containment systems were provided to complete the EVA PGA configuration. These components of the EMU are pictured in figure 4.

Apollo space suits were individually tailored for each mission. Fifteen suits were required to fully equip the mission. Each prime crewmember had three suits – a training suit and two flight suits, and each backup crewmember had two suits – a training suit and a flight suit.

The following sections describe the components of the extravehicular PGA configuration. Table 1 lists the characteristics of the suit assembly.

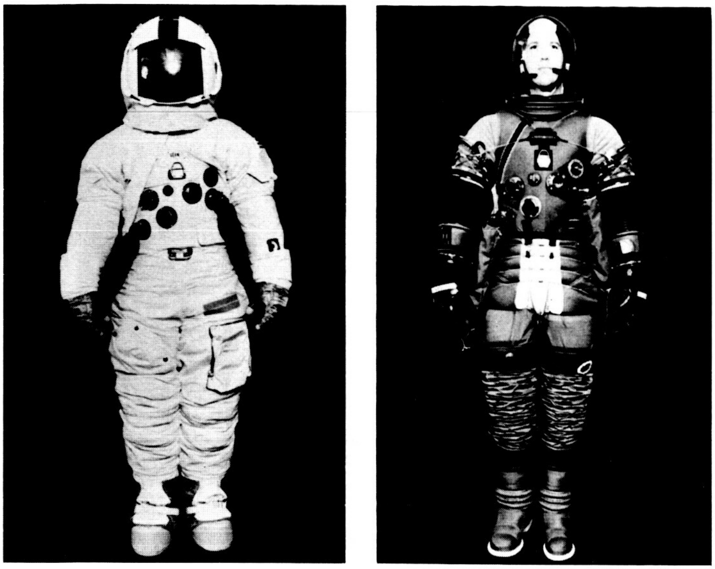


Figure 2. Extravehicular configuration of the EMU.

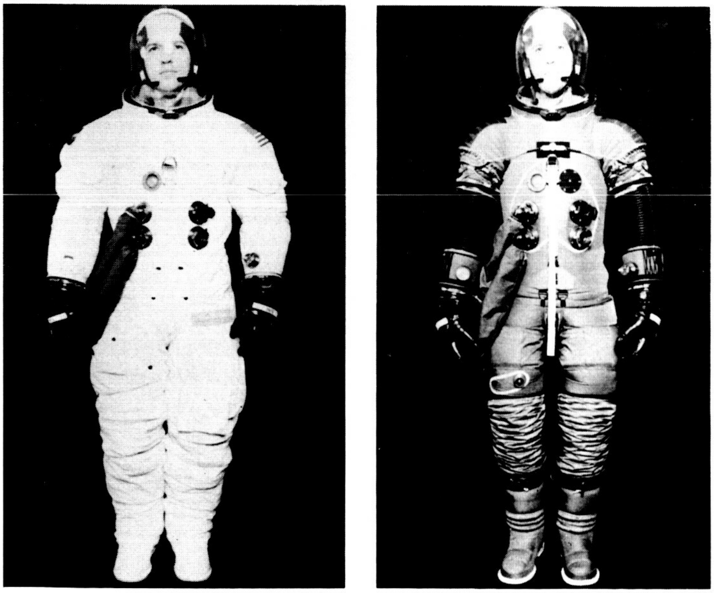


Figure 3. Intravehicular configuration of the EMU.

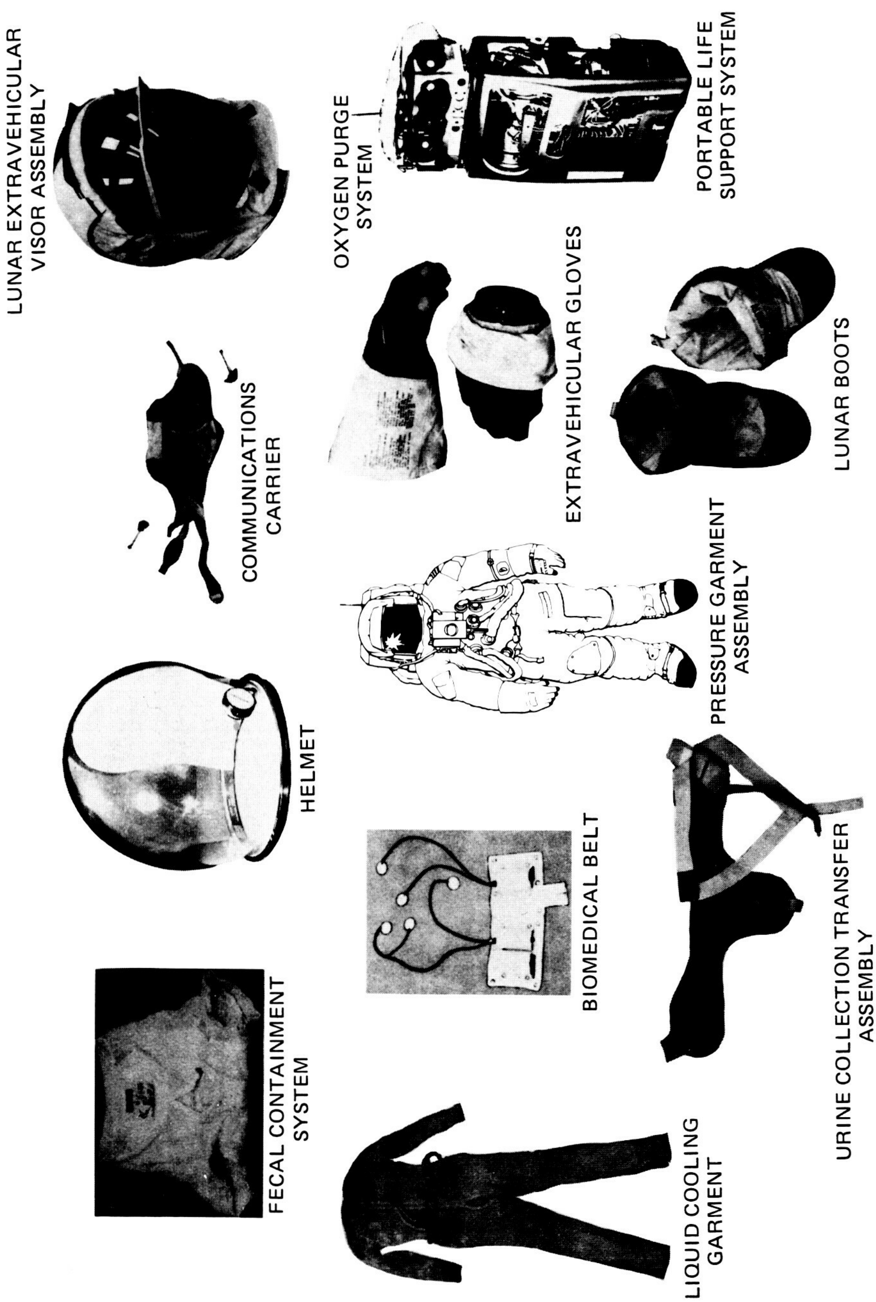


Figure 4. Extravehicular configuration of torso limb suit assembly (TLSA).

Table 1
Pressure Garment Assembly Characteristics

Characteristics	Pressure Garment Assembly with Thermal Micrometeoroid Garment	
Weight	19.69 kg	(43.42 lb)
Operational temperature limitations	± 394°K	(± 250° F)
Leak rate at 25 511 N/m^2 (3.7 psig) (maximum)	180 scc/min	(.0315 lb/hr)
Operating pressure	25 855 ± 1724 N/m^2	(3.75 ± 0.25 psig)
Structural pressure	41 369 N/m^2	(6.00 psig)
Proof pressure	55 158 N/m^2	(8.00 psig)
Burst pressure	68 948 N/m^2	(10.00 psig)
Pressure drop, water		
.34 m^3/min (12 cfm), 24 132 N/m^2 (3.5 psia), ≈283°K (50° F), and inlet diverter valve open (IV position)	11.9 cm	(4.70 in.)
.17 m^3/min (6 cfm), 26 890 N/m^2 (3.9 psia), ≈298°K (77°F), and inlet diverter valve closed (EV position)	4.6 cm	(1.80 in.)
Pressure gage range	17 237 to 41 369 N/m^2	(2.5 to 6.0 psig)

Torso-Limb Suit Assembly (TLSA)

The torso-limb suit assembly consisted of that portion of the PGA which encompassed the entire body with the exception of the head and hands. The extravehicular configuration is shown diagrammatically in figure 5. The torso portion was custom-sized and the limb portions were graduated in size and were adjustable to accommodate individual crewman limb lengths.

A pressure sealing and restraint slide fastener permitted the crewman to enter the suit. A lock assembly prevented inadvertent opening. The pressure-containing bladder of the TLSA was a neoprene-coated nylon fabric. Directly over the bladder outer surface was a nylon restraint layer that controlled the conformal shape and provided structural support to the bladder. Dipped rubber convoluted joints were located at the shoulders, elbows, wrists, hips, knees, and ankles, to permit movement with a minimum expenditure of energy. Restraint cables or cords sustained axial limb loads during pressurized operation and prevented ballooning of the convoluted joints. A biomedical injection patch was built into the right thigh portion of the torso-limb suit to permit a crewman to self-administer a hypodermic injection without jeopardizing the gas retention quality of the PGA.

The arm assembly had a bearing to enhance rotational movements above the elbow. The PGA boot, which was connected to the torso-limb suit, was sized to the individual crewman's foot and had an ankle convolute which permitted ankle extension and flexion movements.

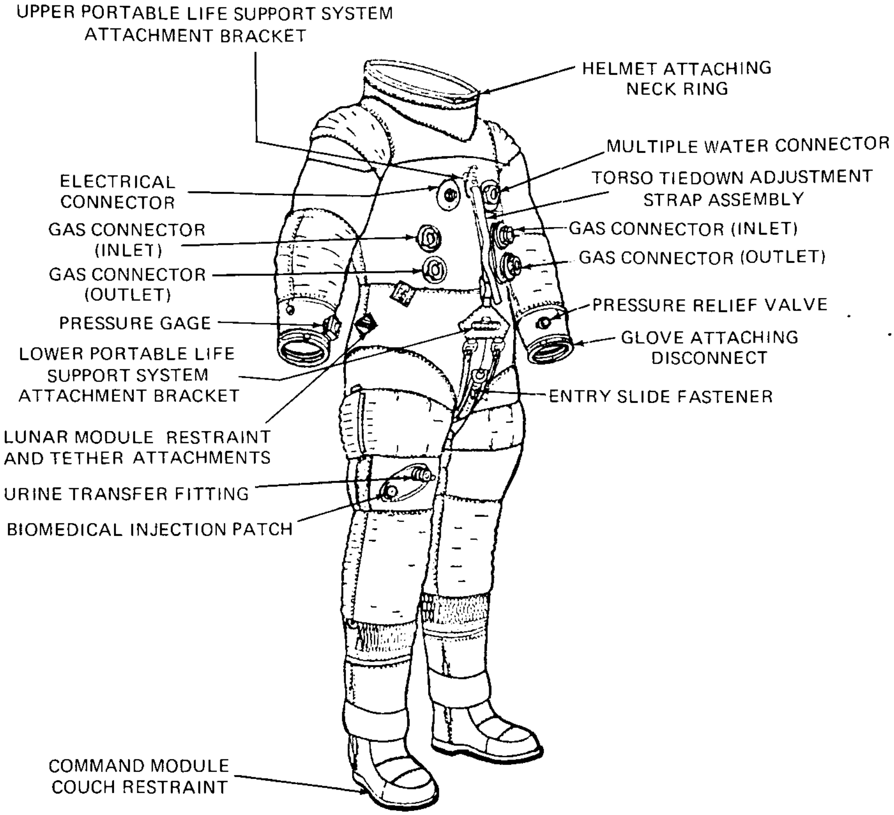


Figure 5. Extravehicular configuration of torso limb suit assembly (TLSA).

The innermost layer of the torso-limb suit was a nylon liner (figure 6) for comfort and improved donning. A series of noncollapsible ducts attached on the inner surface of the pressure bladder served as part of the ventilation system.

The ventilation system directed all inlet gas flow to the helmet for respiration and helmet defogging during lunar surface operations. The gas flow then traveled over the body to the extremities where return ducting routed the flow to the suit outlet. A ventilation flow director valve was located on the inlet gas connectors. The PGA suit pressure was displayed on a gage mounted on the lower arm.

Pressure Helmet Assembly

The pressure helmet was a detachable, transparent closure with provisions for feeding, drinking, and attachment of the lunar extravehicular visor assembly (LEVA). The helmet was made by a special heat forming process from high optical quality polycarbonate plastic. The helmet and neckring which attached it to the torso-limb suit are shown in figure 7. It contained a feedport which allowed insertion of a probe for administering water and contingency food to a crewman while wearing the complete PGA in either the pressurized or unpressurized condition. A synthetic elastomer foam vent pad was bonded to the back of the helmet shell to provide a headrest, and to act as a ventilation flow manifold for directing the flow of gas to the oral-nasal area. This flow caused an efficient exhaust of carbon dioxide from the nasal area through the torso neck opening.

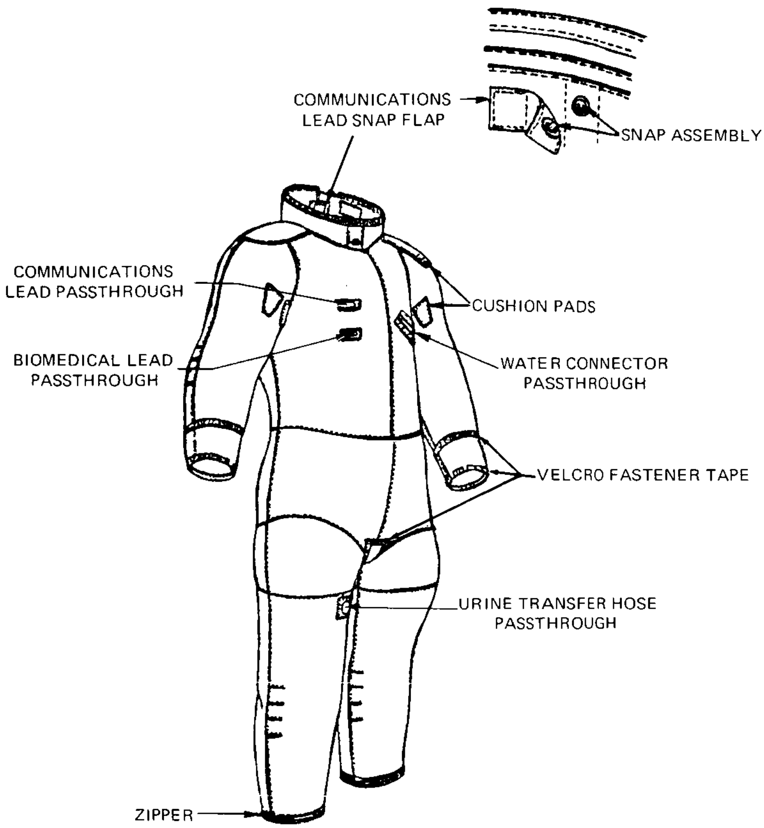


Figure 6. Pressure garment assembly (PGA) liner.

The lunar extravehicular visor assembly, shown in figure 8, furnished visual, thermal, and mechanical protection to the crewman's helmet and head. It was composed of a plastic shell, three eyeshades, and two visors. The outer, or sun visor was made of high-temperature polysulfone plastic. The inner, or protective visor was made of ultraviolet-stabilized polycarbonate plastic. The outer visor filtered visible light and rejected a significant amount of ultraviolet and infrared rays. The inner visor filtered ultraviolet rays, rejected infrared and, in combination with the sun visor and pressure helmet, formed an effective thermal barrier. The two visors in combination with the helmet protected the crewmember from micrometeoroid damage and from damage in the event of falling on the lunar surface. A hard shell protected the sun visor during non-use periods. The eyeshades were adjusted by the crewman to prevent glare from hampering vision during EVA. The central eyeshade was added at the suggestion of the Apollo 11 lunar surface crew who reported the need for greater glare protection.

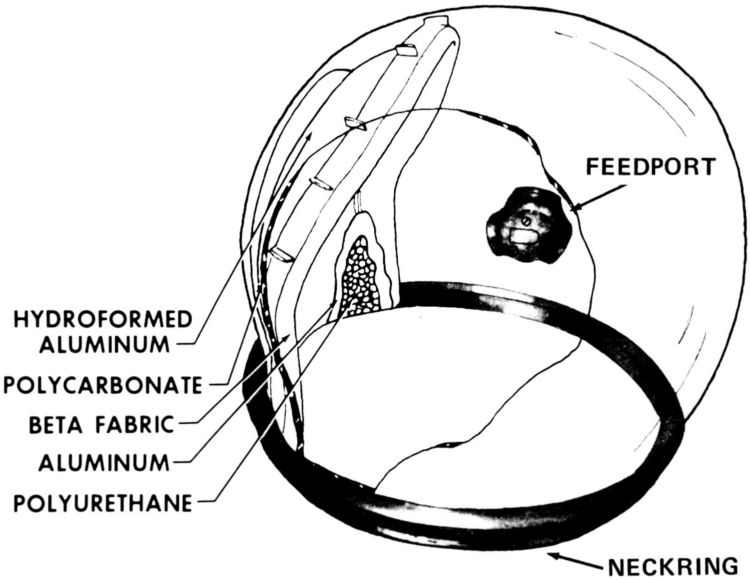


Figure 7. Pressure helmet.

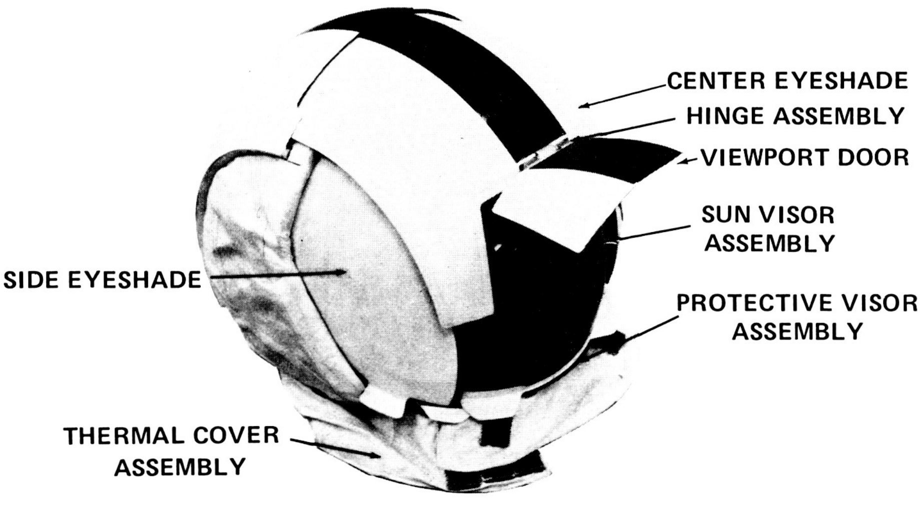


Figure 8. Lunar extravehicular visor assembly (LEVA).

Pressure Gloves

The pressure glove was a flexible, gas-retaining device which was attached and locked to the torso-limb suit by means of a quick-disconnect coupling. The glove (figure 9) was a protective hand covering which was attached to the torso-limb suit prior to egress for extravehicular operations.

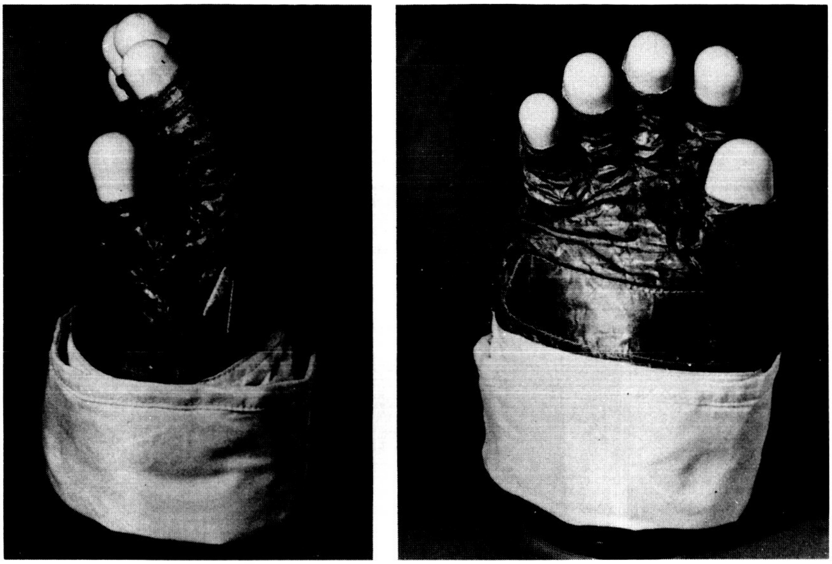


Figure 9. Extravehicular pressure gloves.

The glove consisted of a modified intravehicular pressure glove covered by a glove shell. The shell covered the entire hand and had an integral cuff or gauntlet which extended above the wrist disconnect on the arm as far as the PGA pressure gage or the pressure relief valve. The gauntlet provided a convenient surface on which to put a checklist for lunar extravehicular activities (figure 10).

The extravehicular glove shell was a multilayered assembly which provided scuff, abrasion, and thermal protection to the pressure glove. A woven metal fabric (Chromel-R) was incorporated over the palm and fingers to provide abrasion protection. The thumb and fingertip shells were made of high-strength silicone rubber-coated nylon tricot for improved tactility and strength. A silicone dispersion coating was applied to the palm, around the thumb, and to the inner side of each finger to improve the grip. The outer cover conformed so that it did not appreciably restrict dexterity. A palm restraint strap could be tightened to minimize the ballooning effect of pressurization. The shell assembly was secured to the pressure glove at the back and palm areas of the hand by hook-and-pile fastener tape and near the tip of each finger by two anchor straps and neoprene adhesive.

Figure 10. Extravehicular pressure gloves showing gauntlet checklist.

Cotton wristlets were used to prevent arm chafing caused by the pressure garment assembly wrist disconnects when the gloves were removed and the torso-limb suit was worn. Comfort gloves constructed of nylon tricot were worn under both intravehicular and extravehicular gloves. The comfort glove made donning the pressure glove easier and acted as a sweat absorption layer between the hand and the pressure glove bladder.

Electrical Harness and Bioharness

The PGA electrical harness shown in figure 11 provided electrical connections for the biosensor harness and for communications equipment. A central 61-pin connector was designed to receive the engagement mechanism of the communications and bioinstrumentation umbilical of the spacecraft or the portable life support system.

Integrated Thermal Micrometeoroid Garment

The integrated thermal micrometeoroid garment (ITMG) (figure 12) was a lightweight multilaminate assembly which covered the torso-limb suit assembly to afford protection against the thermal and micrometeoroid hazards encountered during free space and lunar excursions. Figure 13 illustrates the makeup of the suit, layer by layer. For protection against abrasion, an additional external layer of Teflon fabric was attached to the knee, waist, elbow, and shoulder areas, and a layer of Chromel-R was added on the back under the PLSS. Pockets and flaps accommodated items needed by the crewman and permitted the use of the urine transfer connector.

Lunar surface boots covered the PGA boots exclusive of the sole and heel. Boots were made of the same material as the garment itself. Tape and lacing cords secured the ITMG boots to the PGA boots at the boot top and around the sole and heel area. A zipper at the top of each boot attached the boot to the leg of the ITMG. A Teflon patch encircling the ankle of the boot prevented abrasion caused by the lunar boot.

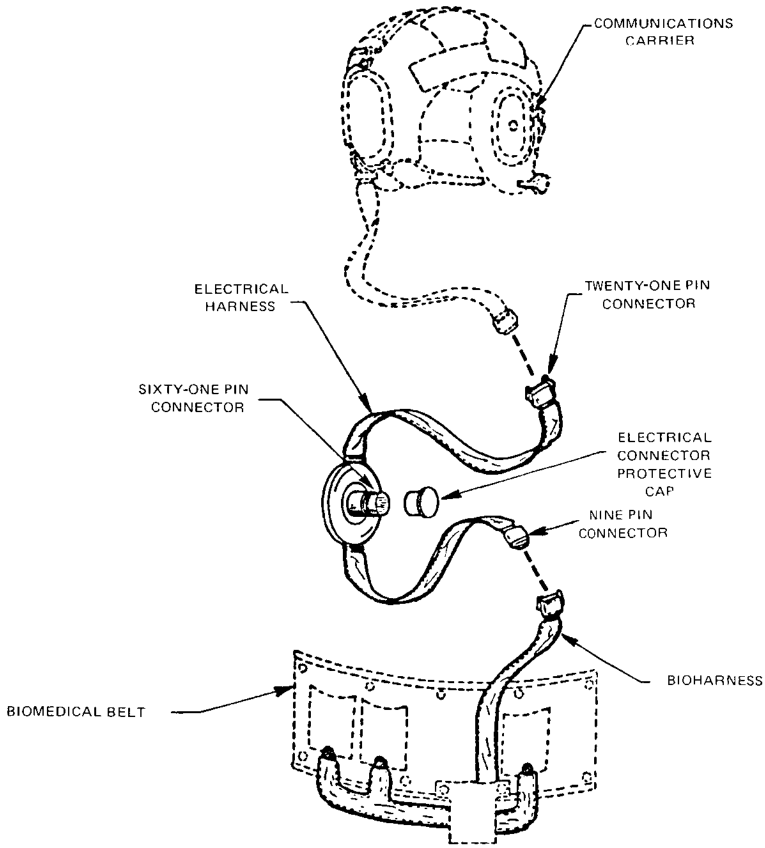


Figure 11. Pressure garment assembly electrical harness.

Liquid Cooling Garment

A liquid cooling garment (LCG) was worn next to the skin under the pressure garment assembly during lunar and free space extravehicular activity. The LCG (figure 14), made of nylon-spandex knit, provided for comfort, perspiration absorption, and thermal transfer. The garment supplied a continuous flow of temperature-controlled water through a network of polyvinylchloride (PVC) tubing stitched to the inside surface of the open-mesh fabric garment (figure 15). A lightweight nylon comfort liner separated the body from the tubing network. The network had a parallel flow path for maximum surface coverage and optimum cooling. The LCG could be supplied with coolant water from the Lunar Module support system and, during EVA, from the portable life support system.

The coolant water was warmed by heat transfer from the crewman's body and was returned to the PLSS through the outlet channel of the multiple water connector. The LCG could remove heat at a maximum rate of 62 112 J/hr (≈2000 Btu/hr). Characteristics of the LCG are listed in table 2.

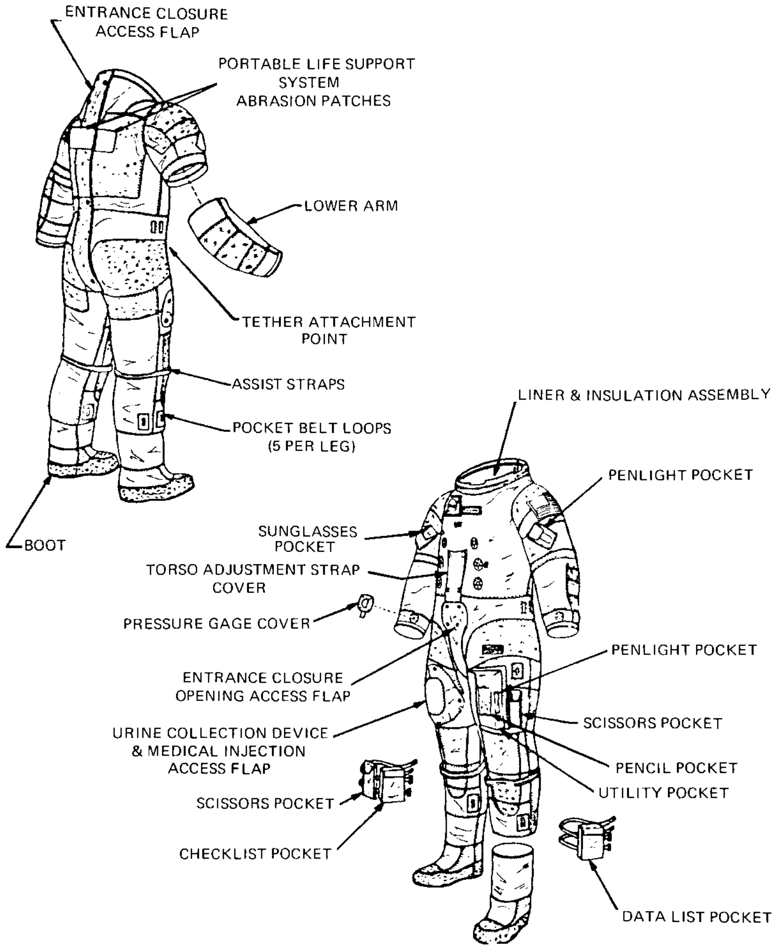
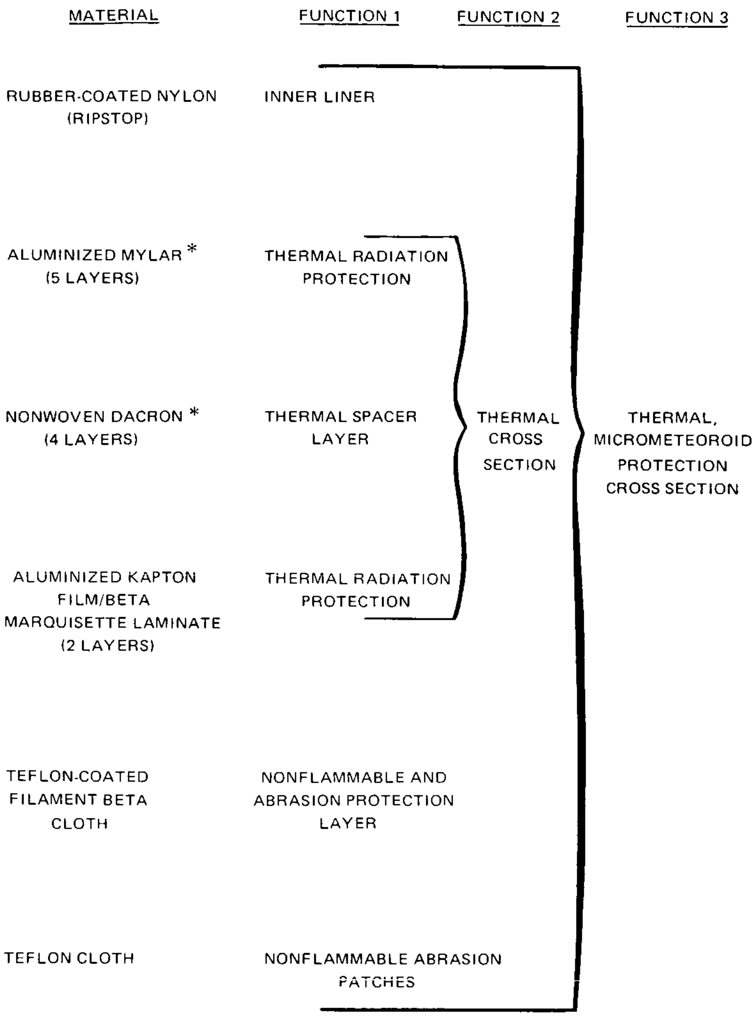


Figure 12. Lunar integrated thermal micrometeoroid garment configuration.

Lunar Boots

The lunar boots, donned prior to lunar surface activity, provided thermal and abrasion protection for the pressure garment assembly boots during lunar surface operations. The outer layer of a lunar boot, except for the sole, was fabricated from Chromel-R and the tongue area was made of Teflon-coated Beta cloth. Ribs projected from the bottom of the silicone rubber sole to increase thermal insulation qualities, to provide lateral rigidity, and to provide traction on the lunar surface. The inner layers consisted of two layers of Kapton followed by five layers of aluminized, perforated Mylar. The Mylar layers were separated by four layers of nonwoven Dacron followed by an inner liner of Teflon-coated Beta cloth. Two layers of Nomex felt in the sole provided additional thermal insulation from the lunar surface. Figure 16 shows the lunar boot.



*Alternating layers of insulation and spacer.

Figure 13. Material cross-section of Apollo 10-14 lunar integrated thermal micrometeoroid garment.

Constant Wear Garment

The constant wear garment (CWG) (figure 17) was a cotton fabric undergarment worn next to the skin during intravehicular Command Module operations. It provided for comfort and perspiration absorption, and for attachment of a biobelt which contained the bioinstrumentation system. In the Command Module, the CWG was worn under the pressure garment assembly. A fly opening and a rear buttock port allowed for urination and defecation.

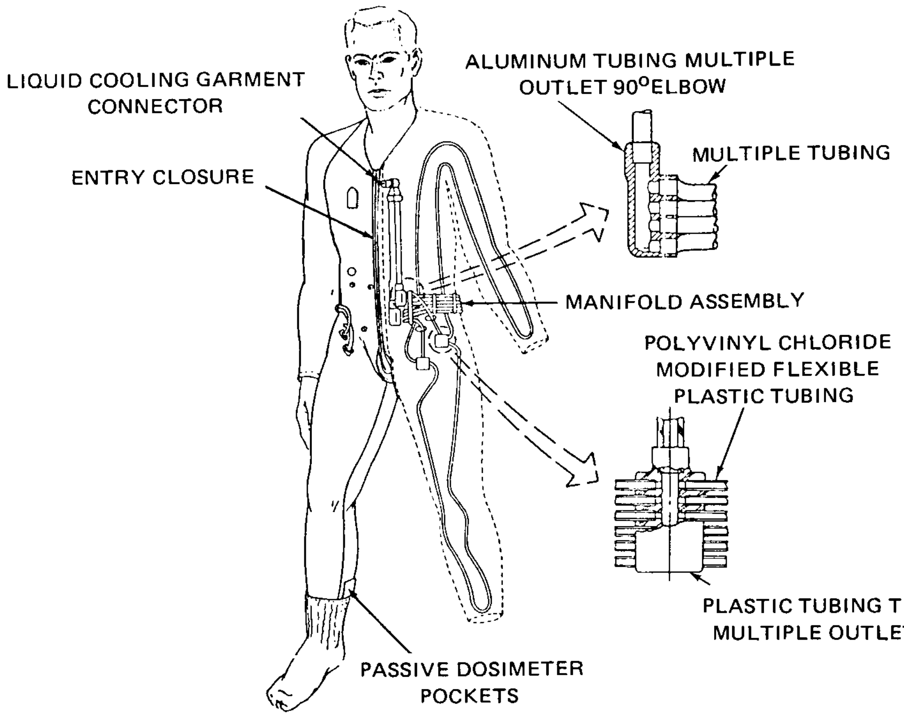


Figure 14. Liquid cooling garment and coolant system.

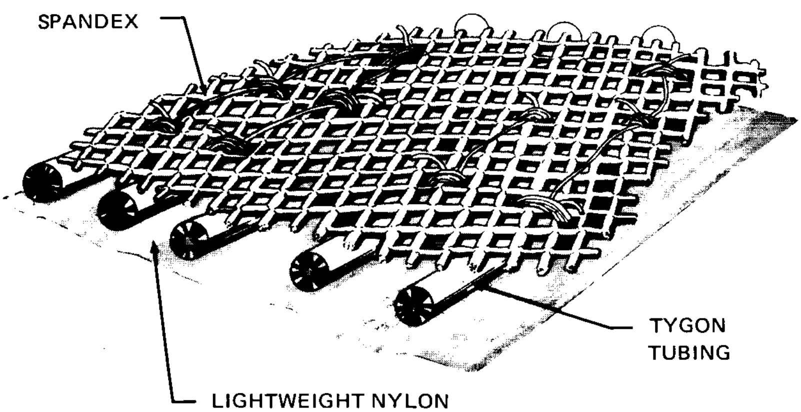


Figure 15. Liquid cooling garment construction.

Table 2

Liquid Cooling Garment Characteristics

Characteristic	Value	
Weight (charged)	2.09 kg	(4.60 lb)
Operating pressure	28 958 to 158 579 N/m^2	(4.20 to 23.0 psig)
Structural pressure	217 185 ± 3447 N/m^2	(31.50 ± 0.50 psig)
Proof pressure	217 185 ± 3447 N/m^2	(31.50 ± 0.50 psig)
Burst pressure	327 501 N/m^2	(47.50 psig)
Pressure drop, 1.81 kg/min (4 lb/min) at ≈ 294°± 5.5°K (70° ± 10°F) inlet	22 063 N/m^2 (including both halves of connector)	(3.2 psi)
Leak rate, 131 000 N/m^2 (19 psig) at ≈ 280°K (45°F)	0.58 cm^3/hr	

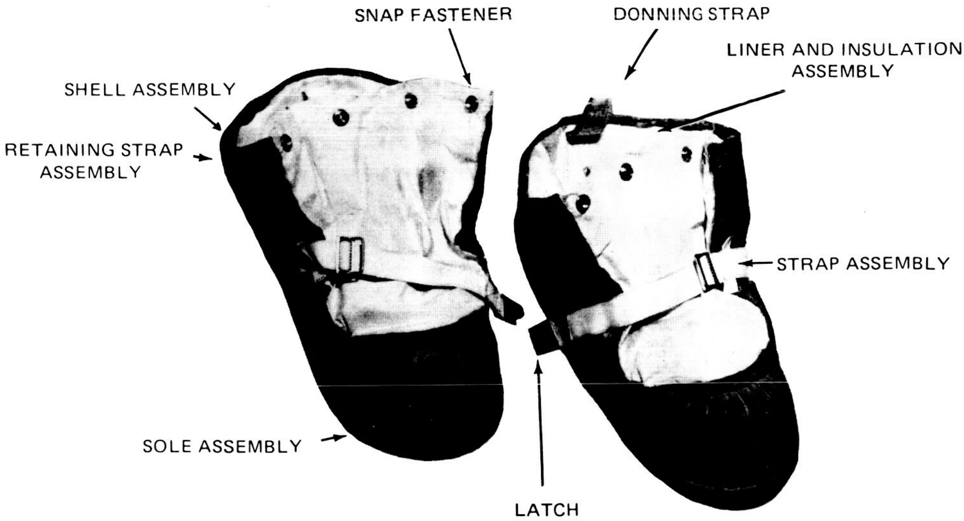


Figure 16. Lunar boots.

Communications Carrier

The communications carrier (figure 18) provided redundant microphones and earphones in a soft-suspension skull cap. Proper fitting insured acoustic isolation between the earphone and microphone. The connection could be made directly to the spacecraft communications system or through the PGA internal communication harness. Bioinstrumentation associated with the PGA is described in Section VI, Chapter 3. The communications carrier permitted suited crewmen to talk to each other, and to the Mission Control Center, through the Lunar Module systems. Telemetry data from both crewmen were also communicated to the ground through the Lunar Module.

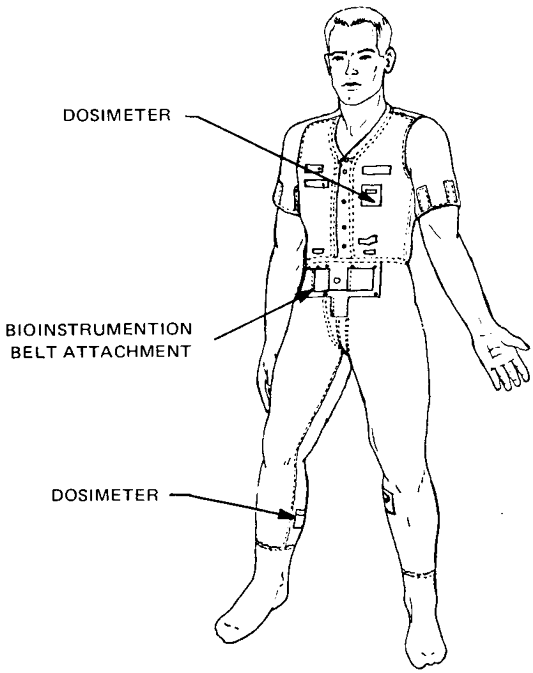


Figure 17. Constant wear garment.

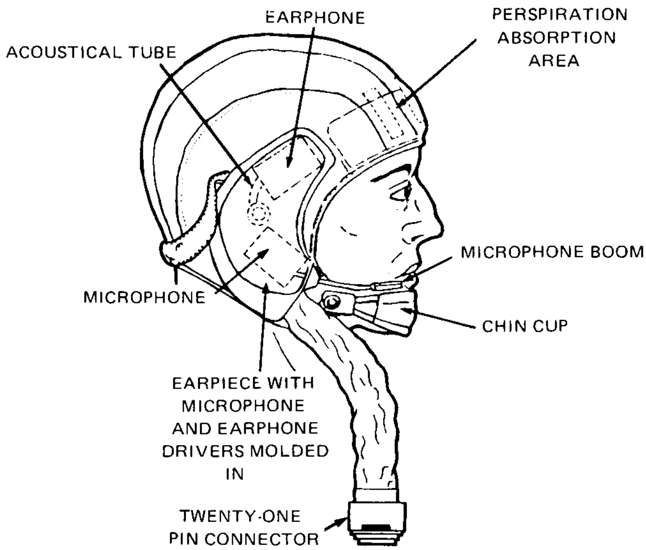


Figure 18. Communications carrier.

Portable Life Support System

To provide a suitable protective environment during both lunar surface and free space excursions, the astronaut carried on his back a compact assembly of various environmental control devices, which formed the portable life support system (PLSS), pictured in figure 19. Figure 20 shows two views of the system packaged as it would be for a mission. The PLSS supplied breathing oxygen; controlled suit pressure; recycled oxygen by removing carbon dioxide, odors, moisture, and some trace contaminant gases; controlled temperature; provided warnings of system malfunctions; and provided voice communications and telemetry data. Table 3 lists the specifications for the PLSS. A separate emergency system provided oxygen for breathing, suit pressure, and cooling in case of PLSS failure. This system was called the oxygen purge system (OPS) and was manually activated.

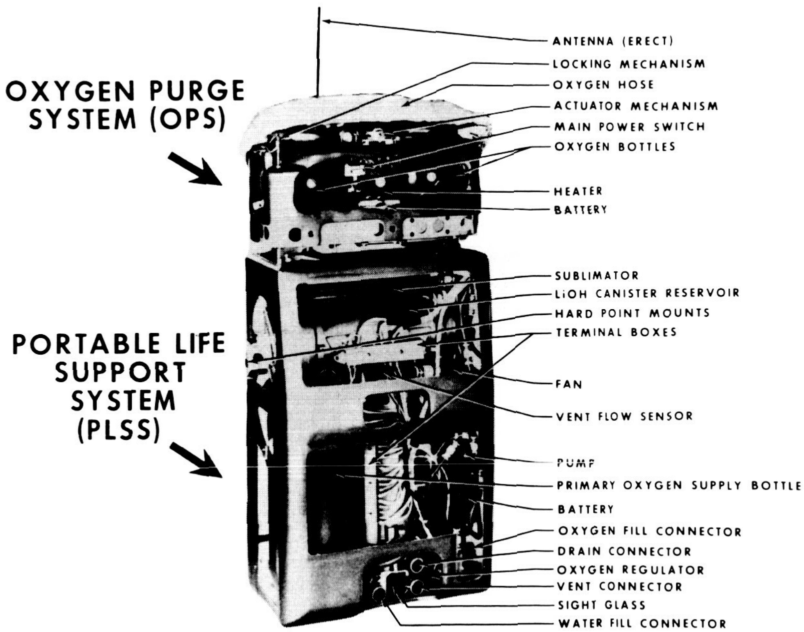


Figure 19. Portable life support system and oxygen purge system.

The portable life support system supplied oxygen to the pressure garment assembly and cooling water to the liquid cooling garment. The PLSS subsystems were an oxygen ventilating circuit, a primary oxygen subsystem, a liquid transport loop, a feedwater loop, and an electrical power subsystem.

Oxygen Ventilating Circuit

The oxygen ventilating circuit (figure 21) provided temperature, humidity, and contaminant control of breathing oxygen. Recycled gas and fresh oxygen entered the suit, absorbing heat, moisture, and body contaminants. The contaminated gas was then returned to the PLSS contaminant control assembly where contaminants were removed. The decontaminated gas then entered the sublimator (heat exchanger) where heat was given up, and the excess moisture in the stream was condensed. Next, water was removed by a water separator and transferred to a storage reservoir. A fan forced the air through a back flow check valve, finishing the recycling process.

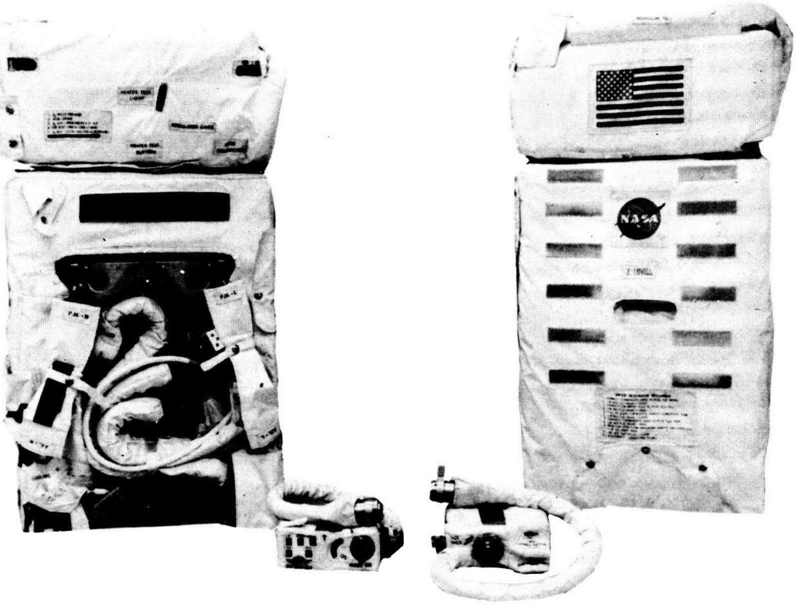


Figure 20. Operational packaging of portable life support system.

Table 3

Specifications for the Portable Life Support System

Design Requirements	Specifications	
	Apollo 11 – 14	Apollo 15 – 17
Average metabolic load	6694 J/hr (1600 Btu/hr)	6694 J/hr (1600 Btu/hr)
Peak metabolic load	8368 J/hr (2000 Btu/hr)	8368 J/hr (2000 Btu/hr)
Maximum heat leak in	1046 J/hr (250 Btu/hr)	1255 J/hr (300 Btu/hr)
Maximum heat leak out	1046 J/hr (250 Btu/hr)	1464 J/hr (350 Btu/hr)
Maximum CO_2 partial pressure	2000 N/m^2 (15 mm Hg)	2000 N/m^2 (15 mm Hg)
Pressure garment assembly pressure	26 545 N/m^2 (3.85 psia)	26 545 N/m^2 (3.85 psia)
Ventilation flow	.1557 m^3/min (5.5 cfm)	.1557 m^3/min (5.5 cfm)
Duration	4 hr	7 hr
Oxygen charge pressure at ≈ 294°K (70°F)	7 032 652 N/m^2 (1020 psia)	9 721 607 N/m^2 (1410 psia)
Battery capacity	279 W-hr	431 W-hr
Emergency oxygen		
Duration (minimum)	30 min	30 min
Maximum flow	3.63 kg/hr (8 lb/hr)	3.63 kg/hr (8 lb/hr)
Pressure garment assembly pressure	25 510 N/m^2 (3.7 psia)	25 510 N/m^2 (3.7 psia)

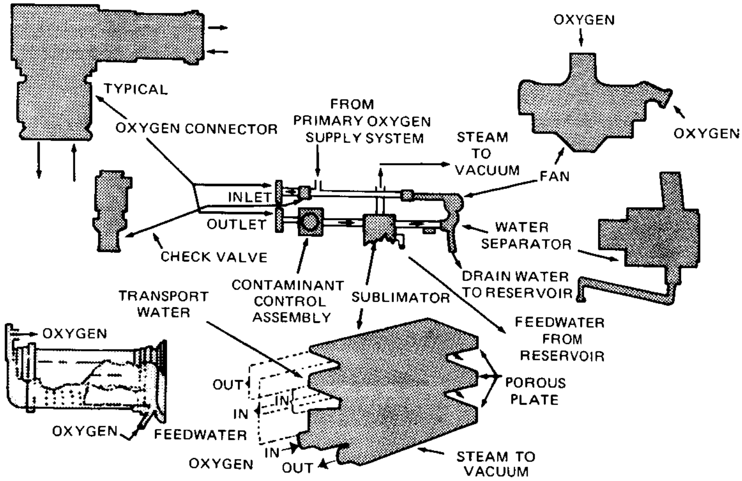


Figure 21. Oxygen ventilating circuit schematic

Primary Oxygen Subsystem

The gaseous oxygen in the portable life support system primary oxygen subsystem (figure 22) provided oxygen for suit pressurization and astronaut breathing. Oxygen, stored in the primary bottle, was regulated to the correct pressure before entering the rest of the system. A quick-fill connector allowed for oxygen recharging.

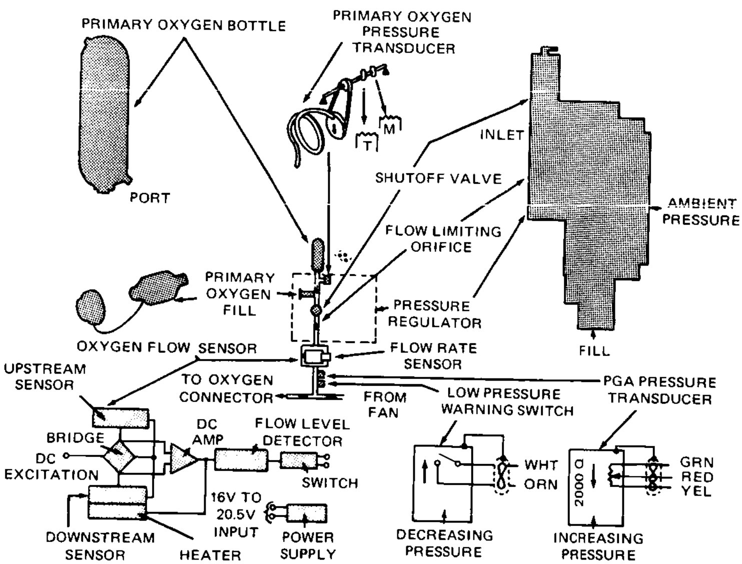


Figure 22. Primary oxygen subsystem.

Liquid Transport Loop

The liquid transport loop (figure 23) was the primary means of crewman temperature control. Water from the liquid cooling garment entered the loop through the multiple water connector. The water was then pumped through the sublimator where heat was given up. The cooled water was used for fan motor cooling before return to the LCG through the multiple water connector.

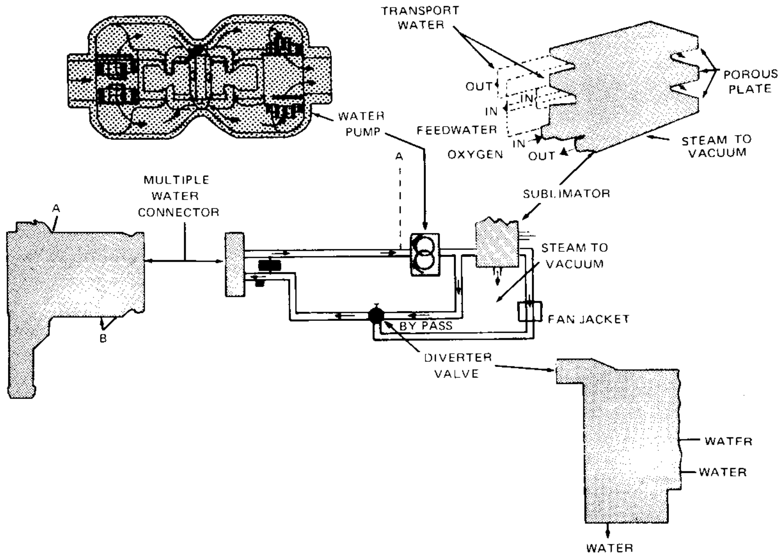


Figure 23. Liquid transport loop schematic.

Feedwater Loop

The feedwater loop (figure 24) supplied expendable water to the sublimator for cooling, and stored condensation removed by the water separator in the oxygen ventilation circuit. As the water passed through the sublimator, it absorbed system heat. The hot water was then discharged to the outside.

Electrical Power Subsystem

The electrical power subsystem provided electrical power to the fan and pump motor assemblies, the communications system, and the instrumentation. The extravehicular communications system (EVCS) provided voice communications and telemetry transmission of system operation. The capabilities included voice communication between the spacecraft and the astronaut, voice communication between astronauts, and voice communication between Earth and astronaut. The EVCS consisted of two extravehicular communicators that were integrated with the PLSS. The first extravehicular communicator (EVC-1) consisted of two amplitude-modulated (AM) transmitters, two AM receivers, one frequency-modulated (FM) receiver, signal-conditioning circuits, a telemetry system, a warning system, and other components required for operation. The EVC-2 was similar to the EVC-1 except that the EVC-2 had an FM transmitter instead of an FM receiver.

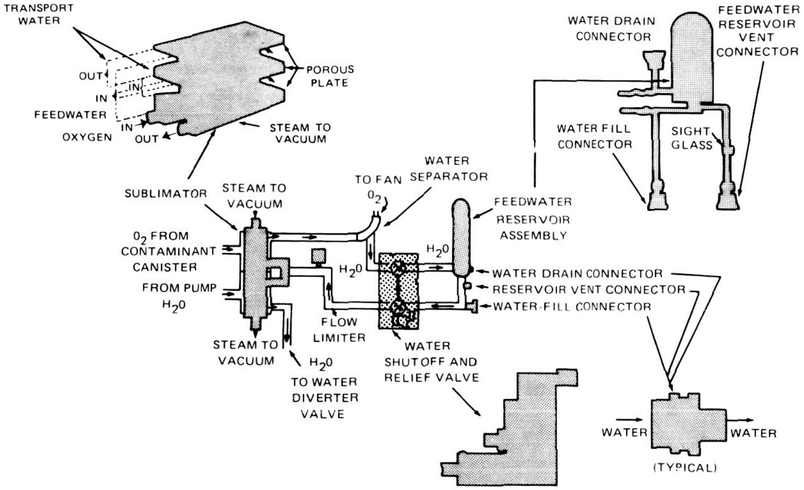


Figure 24. Portable life support system feedwater loop schematic.

Much of the instrumentation was located in the remote control unit. This chest-mounted unit, shown in figure 25, housed electrical controls for the PLSS, a primary oxygen quantity indicator, and warning devices. The warning devices would signal the astronaut if system components failed to work properly. Malfunctions checked were low feedwater pressure, low ventilation flow, low PGA pressure, and high oxygen flow. In an emergency, the mission would be aborted or the emergency oxygen purge system activated.

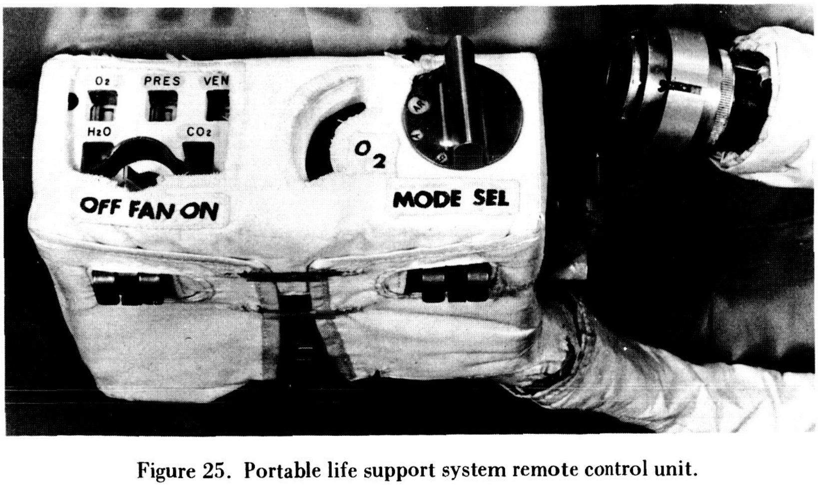


Figure 25. Portable life support system remote control unit.

Oxygen Purge System

The oxygen purge system (OPS) (figure 26) provided an oxygen supply and pressure control for certain failure modes. In the normal EVA configuration, the OPS was mounted on top of the PLSS and used only for emergencies. The OPS was self-contained, independently powered, and nonrechargeable. The OPS provided a minimum of 30 minutes of operation. The system consisted of two interconnected bottles of high pressure oxygen, an automatic temperature control module, a pressure regulator, a battery, an oxygen indicator, and the necessary checkout instrumentation. The OPS had no communications capability, but provided the mount for the PLSS very-high-frequency (VHF) antenna.

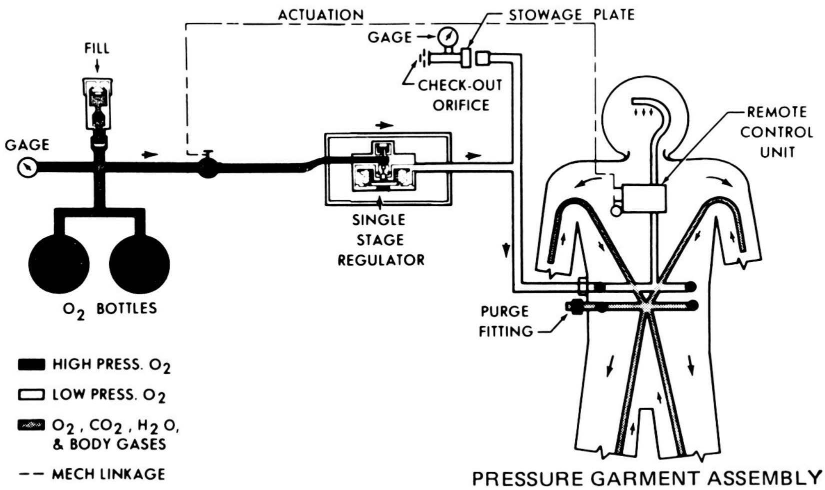


Figure 26. Oxygen purge system.

EMU Performance

The life support system underwent changes during the program to meet new requirements and incorporate improvements based on experience. The PLSS was redesigned for Apollo,15, 16, and 17 to allow longer lunar missions by increasing oxygen storage pressure, adding more contaminant control material, increasing the size of the power supply, and adding an auxiliary feedwater tank. A longer duration emergency system was required for Apollo 14, 15, 16, and 17 because of the greater distances of traverse from the Lunar Module. This requirement was accomplished by the addition of the buddy secondary life support system (BLSS) shown schematically in figure 27. It could provide backup cooling in the event of a failure of the PLSS cooling loop.

The extravehicular mobility unit was one of the outstanding engineering successes of the Apollo Space Program. While there were some minor problems experienced with the suit, for example, the lunar visor tended to scratch easily and finger dexterity was not optimum, never was a major or even minor failure experienced with the suit or backpack system.

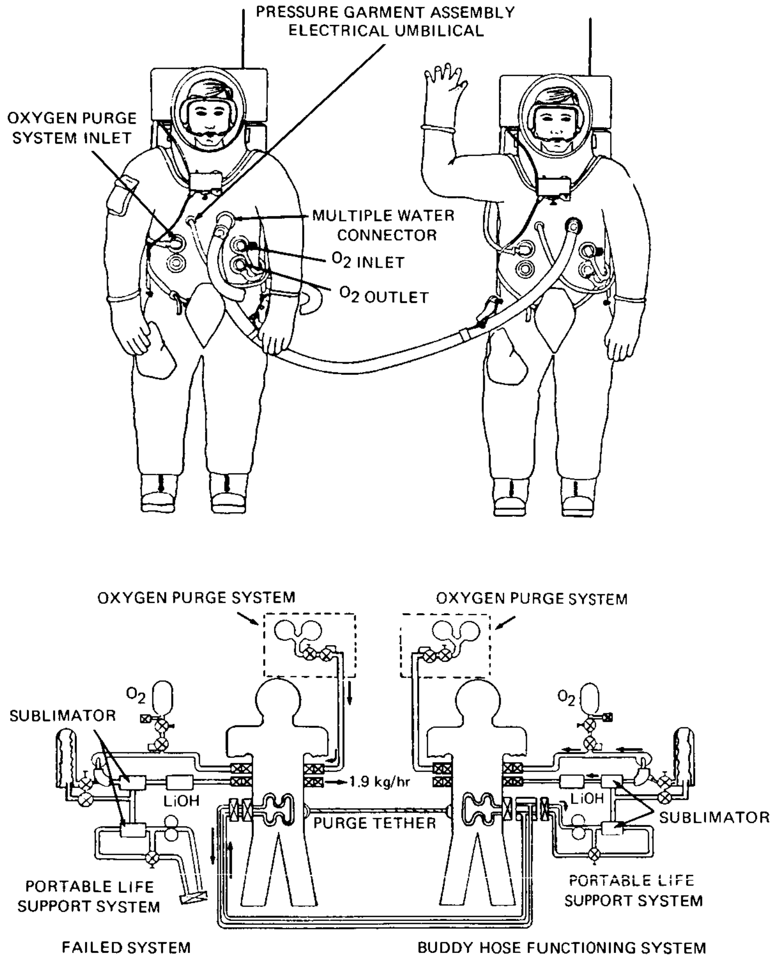


Figure 27. Buddy secondary life support system.

Rigorous preflight testing was accomplished during suit development, and each individual flight suit was tested prior to every mission. The Apollo suits were impact tested against various objects, including extremely sharp devices, for resistance to penetration and rips. Quality control was meticulous. Pins used in the manufacture of the garment were accounted for and each suit was X-rayed to preclude the possibility of an oversight. Training suits were used in most preflight tests rather than flight suits to ensure there would be no compromise of the integrity of the flight suit. However, each flight suit was tested in a limited number of altitude chamber tests, after which the suits were thoroughly inspected for any possible damage.

The helmet used during EVA had an extremely high resistance to impact. The helmet material, Lexan, will not break even upon impact with a hammer. Lexan was substituted for the Project Gemini visor material. The latter lacked the impact resistance necessary for lunar operations. During one Gemini reentry, the visor cracked when the astronaut lurched forward, hitting the instrument panel.

The extravehicular mobility unit and its associated components, the pressure garment assembly, the portable life support system, and the oxygen purge system, were used in various configurations in the Apollo 7 through 17 missions. Components were operationally tested before integration into the EMU. In all cases, the components performed effectively.

No outside spacecraft activities were performed during the missions of Apollo 7 and 8. The only EMU system aboard the spacecraft, therefore, was the pressure garment assembly for use as a backup to the pressure and environmental control system and for protection against noise and vibration during launch and reentry. The pressure garment assembly performed satisfactorily during these missions, and crews reported that ventilation in the PGA was adequate during the orbital phase. Further, donning and doffing were found to be much easier at zero g than at one g.

The first use of the complete EMU under flight conditions was accomplished during the Apollo 9 mission. The Lunar Module Pilot, wearing the complete EMU, opened the side hatch of the LM and stepped out to simulate contingency transfer to the Command Module. At the same time, the Command Module Pilot operating with an interface with the environmental control system, opened the Command Module side hatch and stood up in the hatch area several times to retrieve thermal samples and take photographs. Both crewmen reported that they were comfortable and experienced no visual problems with the extravehicular visor assembly.

After completion of the EVA, the Lunar Module Pilot doffed the PLSS, the OPS, and the LEVA with no problems. At this point, the PLSS was successfully recharged in the Lunar Module cabin for possible contingency reuse and for demonstration of this operation under actual flight conditions. Each Apollo 9 crewman wore his PGA for approximately 52 hours, for most of this time with the helmet and gloves off.

The Apollo 10 mission was similar to the Apollo 7 and 8 missions in that the EMU was not used for extravehicular activities and the PGA was used only as backup to the Command Module environmental control system. Again, the performance of the PGA was satisfactory.

The Apollo 11 mission was the first mission during which the EMU was exposed to the lunar environment for which it had been designed. All aspects of EMU operation demonstrated during testing and on previous flights were proved on the lunar surface. No significant problems were noted at Lunar Module egress. The crew stated that they were comfortable wearing the PLSS/OPS and that the mass of the unit was not objectionable. In fact, the lunar surface crewmen reported that they were so comfortable in the suits that, after a brief period of time on the lunar surface, they virtually forgot they were wearing them. Mobility and balance were sufficiently adequate to allow stable movement while performing lunar surface tasks. The Lunar Module Pilot demonstrated the capability to walk, run, change directions while running, and stop without difficulty.

The liquid cooling garment worn by the crew was controllable by each astronaut to maintain a temperature suitable for his needs. During the Apollo 11 mission, the

Commander kept his LCG temperature much higher than did the Lunar Command Pilot, at his own option.

The Apollo 12 mission was the first mission involving two periods of extravehicular activity. Both crewmen spent approximately four hours on the lunar surface during each of the EVAs, with the EMU performing satisfactorily. Because of the additional EVA, a recharge of each PLSS was performed for the first time. No problems were noted.

The full EMU was not used during the Apollo 13 mission, as the mission was aborted and a lunar landing was not made. The pressure garment assemblies were worn, however, as backup to the spacecraft environmental control system.

The Apollo 14 mission included two EVA periods, and was the first mission during which the buddy secondary life support system was carried as the crewmen traversed approximately 1.5 kilometers from the Lunar Module. Again, performance of the EMU was satisfactory.

The lunar roving vehicle was used for the first time during the mission of Apollo 15. The vehicle allowed the astronauts to travel farther from the Lunar Module than on earlier missions. For the mission, the portable life support system carried additional expendables (water, power, lithium hydroxide for absorption of carbon dioxide, and oxygen) which allowed for much longer extravehicular activities than had been possible before. In addition, the number of EVA periods was increased from two to three to permit more extensive lunar exploration.

The Apollo 15 mission included an EVA from the Command Module in addition to the lunar surface EVAs. During the return to Earth from the moon, the Command Module Pilot performed the EVA to retrieve a film package from the Service Module portion of the spacecraft. Oxygen was supplied for this EVA by an umbilical from the Command Module life support system, and the astronaut wore the oxygen purge system as a backup.

The Apollo 16 and 17 missions, like the Apollo 15 mission, involved three lunar surface extravehicular activity periods and one Command Module EVA on each mission. The longest EVA of the Apollo Program was the second lunar surface EVA on Apollo 17, which lasted seven hours and thirty-seven minutes.

Summary

On July 20, 1969, man took his first step onto the surface of another planet and collected scientific data while his life was sustained by the extravehicular mobility unit. Throughout the course of the Apollo Program, the EMU was used to provide a habitable environment for astronauts on seven different missions. During its entire span of performance, no significant problems were experienced with any part of the system. The emergency oxygen system provided never had to be used.