Introduction

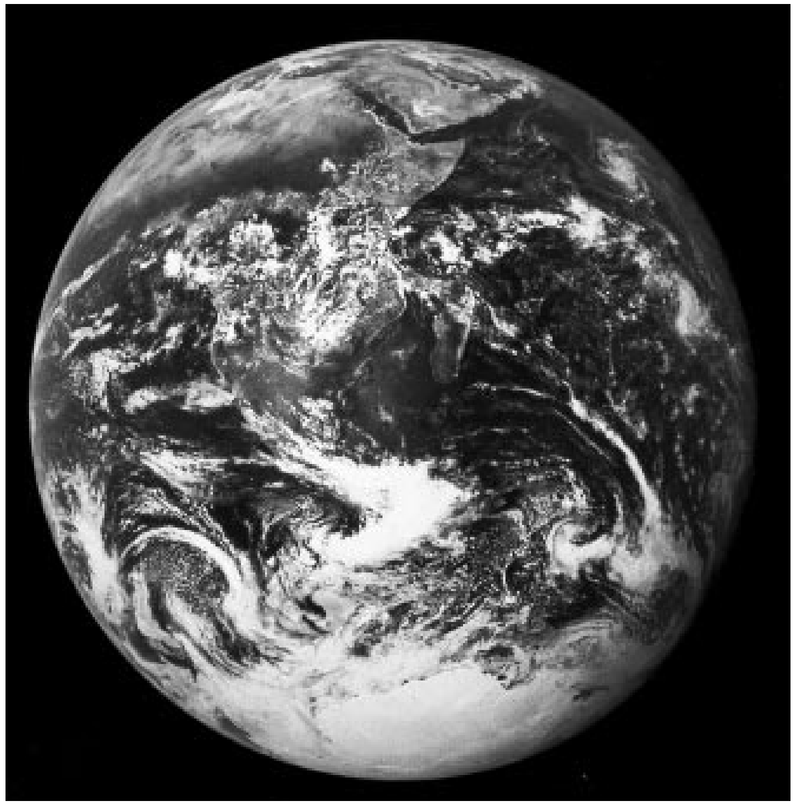
Spacewalking has captured the imagination of generations of children and adults since science-fiction authors first placed their characters on the Moon. But true spacewalking did not actually begin until the mid 1960s with the exploits of Alexei A. Leonov of the Soviet Union and Edward H. White II of the United States. Since those first tentative probings outside a space capsule, astronauts and cosmonauts have logged thousands of hours on extravehicular activities, and some have even walked on the surface of the Moon. The stories of their missions in space are fascinating, but just as interesting is the spacesuit technology that made it possible for them to "walk" in space.

This publication is an activity guide for teachers interested in using the intense interest many children have in space exploration as a launching point for exciting hands-on learning opportunities. The guide begins with brief discussions of the space environment, the history of spacewalking, the Space Shuttle spacesuit, and working in space. These are followed by a series of activities that enable children to explore the space environment as well as the science and technology behind the functions of spacesuits. The activities are not rated for specific grade levels because they can be adapted for students of many ages. The chart on curriculum application at the back of the book is designed to help teachers incorporate activities into various subject areas.

Measurement

This activity guide makes exclusive use of the metric system for measurement. If English-system equivalents are desired, a table of conversion factors can be found in many dictionaries and science textbooks. The metric unit for pressure may be unfamiliar to readers, and an English-system conversion factor for this unit may not appear in some tables. The metric unit for pressure is the pascal. A pascal is equal to a force of one newton exerted over an area of one square meter. Because the pascal is a relatively small unit, the more convenient unit of kilopascal (1,000 pascals) is used here instead. To convert kilopascals to the English-system unit of pounds per square inch, divide by 6.895.

Earth and Space



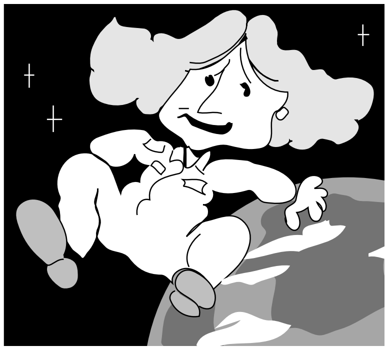
Earth as seen by the crew of the Apollo 17 Moon mission.

If we loosely define an astronaut as someone who travels through space, then everyone is an astronaut. Even though we may be standing still on the surface of Earth, we are actually traveling through space. Indeed, our planet may be thought of as a spaceship on a never-ending voyage. As "astronauts" traveling through space on the surface of Earth, we take for granted the complex environment that sustains life. Earth's gravitational attraction holds a dense atmosphere of nitrogen, oxygen, carbon dioxide, and water vapor in a thick envelope surrounding Earth's entire surface. The weight of this atmosphere exerts pressure, and its movements distribute heat from the Sun to balance global temperatures. Its density filters out harmful radiations and disintegrates all but the largest meteoroids. Earth's atmosphere is a shell that protects and sustains the life forms that have evolved on its surface. Without the atmosphere's protection, life as presently known would not be possible.

When Earth astronauts leave the surface of their planet and travel into space, they must carry some of their environment with them. It must be contained in a physical shell because their body masses are too small to hold it in place by gravitational attraction alone. The shell that is used is called a spacecraft—a rigid collection of metal, glass, and plastic. Though far simpler in function than Earth's, a spacecraft's environment serves well for short missions lasting a few days or weeks. On some flights, the shell is deliberately opened and the astronauts pass through an airlock to venture outside. When doing so, they must still be protected by a smaller and very specialized version of their spacecraft called the Extravehicular Mobility Unit (EMU). This smaller spacecraft is composed of a spacesuit with a life-support system. It differs from the first spacecraft, or mother ship, in its anthropomorphic (human) shape and its flexibility. Astronauts wearing EMUs need to be able to move arms, hands, and legs to perform an array of tasks in space. They must be able to operate many types of scientific apparatus, collect samples, take pictures, assemble equipment and structures, pilot themselves about, and repair and service defective or worn-out satellites and other space hardware. The tasks of astronauts outside their mother ship are called extravehicular activities, or EVAs.

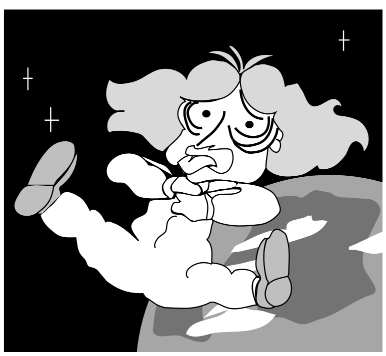
The Outer Space Environment

Outer space is just what its name implies. It is the space that surrounds the uppermost reaches of the atmosphere of Earth and all other objects in the universe. Although it is a void, outer space may be thought of as an environment.

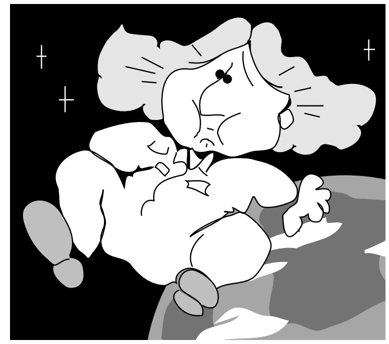


Radiation and objects pass through it freely. An unprotected human or other living being placed in the outer space environment would perish in a few brief, agonizing moments.

The principal environmental characteristic of outer space is the vacuum, or nearly total absence of gas molecules. The gravitational attraction of large bodies in space, such as planets and stars, pulls gas molecules close to their surfaces, leaving the space between virtually empty. Some stray gas molecules are found between these bodies, but their density is so low that they can be thought of as practically nonexistent.

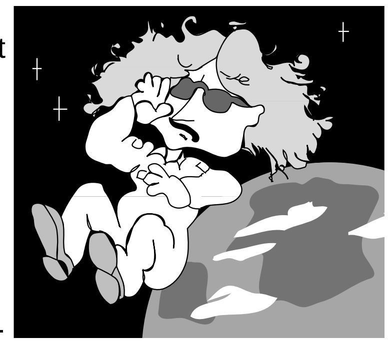


On Earth, the atmosphere exerts pressure in all directions. At sea level, that pressure is 101 kilopascals. In space, the pressure is nearly zero. With virtually no pressure from the outside, air inside an unprotected human's lungs would immediately rush out in the vacuum of space; dissolved gases in body fluids would expand, pushing solids and liquids apart. The skin would expand much like an inflating balloon. Bubbles would form in the bloodstream and render blood ineffective as a transporter of oxygen and nutrients to the body’s cells. Furthermore, the sudden absence of external pressure balancing the internal pressure of body fluids and gases would rupture fragile tissues such as eardrums and capillaries.



The net effect on the body would be swelling, tissue damage, and a deprivation of oxygen to the brain that would result in unconsciousness in less than 15 seconds.

The temperature range found in outer space provides a second major obstacle for humans. The sunlit side of objects in space at Earth's distance from the Sun can climb to over 120° Celsius while the shaded side can plummet to lower than minus 100° Celsius. Maintaining a comfortable temperature range becomes a significant problem.



Other environmental factors encountered in outer space include: microgravity, radiation of electrically charged particles from the Sun, ultraviolet radiation, and meteoroids. Meteoroids are very small bits of rock and metal left over from the formation of the solar system and from the collisions of comets and asteroids. Though usually small in mass, these particles travel at very high velocities and can easily penetrate human skin and thin metal. Equally dangerous is debris from previous space missions. A tiny paint chip, traveling at thousands of kilometers per hour, can do substantial damage.

Spacewalking History

The Extravehicular Mobility Unit worn during spacewalks by NASA's Space Shuttle astronauts represents more than 50 years of development and testing of pressure suits in the U.S., France, Italy, Germany, and other countries. It all began with high-altitude flyers, and one of the first was an American, Wiley Post. Post was an aviation pioneer of the 1930s who was seeking to break high-altitude and speed records. Post, as well as others, knew that protection against low pressure was essential. Through experience, aviators had learned that Earth's atmosphere thins out with altitude.

At 5,500 meters, air is only one-half as dense as it is at sea level. At 12,200 meters, the pressure is so low and the amount of oxygen present is so small that most living things perish. For Wiley Post to achieve the altitude records he sought, he needed protection. (Pressurized aircraft cabins had not yet been developed.) Post's solution was a suit that could be pressurized by his airplane engine's supercharger.

First attempts at building a pressure suit failed, since the suit became rigid and immobile when pressurized. Post discovered he couldn't move inside the inflated suit, much less work airplane controls. A later version succeeded with the suit constructed already in a sitting position. This allowed Post to place his hands on the airplane controls and his feet on the rudder bars. Moving his arms and legs was difficult, but not impossible. To provide visibility, a viewing port was part of the rigid helmet placed over Post's head. The port was small, but a larger one was unnecessary because Post had only one good eye!

Aviation pioneer Wiley Post.

During the next 30 years, pressure suits evolved in many ways, and technical manufacturing help was gained from companies that made armor, diving suits, galoshes, and even girdles and corsets. Designers learned in their search for the perfect suit that it wasn't necessary to provide full sea-level pressure. A suit pressure of 24.13 kilopascals would suffice quite nicely if the wearer breathed pure oxygen. Supplying pure oxygen at this low pressure actually provides the breather with more oxygen than an unsuited person breathes at sea level. (Only one-fifth of the air at sea level is oxygen.)

Early spacesuit design.

Various techniques were used for constructing pressure garments. Some approaches employed a rigid layer with special joints of rings or cables or some other device to permit limb movements. Others used nonstretch fabrics—laced up corset fashion.

With the advent of pressurized aircraft cabins, comfort and mobility in the suit when it was unpressurized became prime objectives in suit design. The suit could then be inflated in the

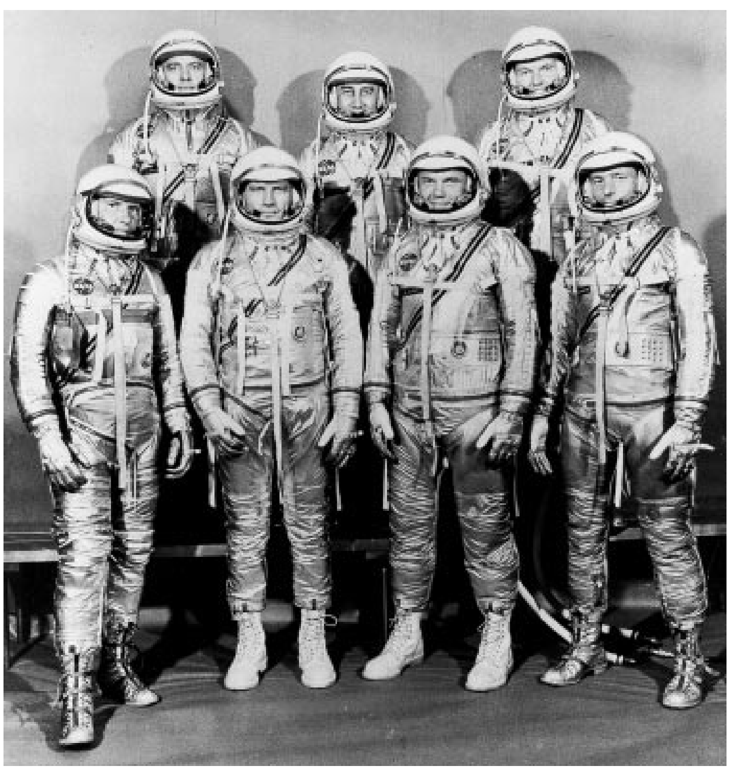
Apollo spacesuit prototype undergoes testing on a simulated Moon walk.

event that the aircraft cabin lost pressure.

By the time NASA began the Mercury manned space flight program, the best full-pressure suit design consisted of an inner gas-bladder layer of neoprene-coated fabric and an outer restraint layer of aluminized nylon. The first layer retained pure oxygen at 34.5 kilopascals; the second layer prevented the first from expanding like a balloon. This second fabric restraint layer directed the oxygen pressure inward on the astronaut. The limbs of the suit did not bend in a hinge fashion as do human arms and legs. Instead, the fabric arms and legs bent in a gentle curve, which restricted movement. When the astronaut moved one of his arms, the bending creased or folded the fabric inward near the joints, decreasing the volume of the suit and increasing its total pressure slightly. Fortunately for the comfort of the Mercury astronauts, the Mercury suit was designed to serve only as a pressure backup if the spacecraft cabin decompressed. No Mercury capsule ever lost pressure during a mission, and the suits remained uninflated.

The six flights of the Mercury series were followed by ten flights in the Gemini program. Suit designers were faced with new problems. Not only would a Gemini suit have to serve as a pressure backup to the spacecraft cabin, but also as an escape suit if ejection seats had to be fired for an aborted launch and as an EMU for extravehicular activity. To increase mobility and comfort of the suit for long-term wear, designers departed from the Mercury suit concept. Instead of fabric joints, they chose a construction that employed a bladder restrained by a net. The bladder was an anthropomorphically shaped layer of neoprene-coated nylon. That was covered in turn with a layer of Teflon-coated nylon netting. The netting, slightly smaller than the pressure bladder, limited inflation of the bladder and retained the pressure load in much the same way automobile tires retained the load in inner tubes in the days before tubeless tires. The new spacesuit featured improved mobility in the shoulders and arms and was more comfortable when worn unpressurized during space flights lasting as long as 14 days.

Edward H. White II's historic spacewalk.



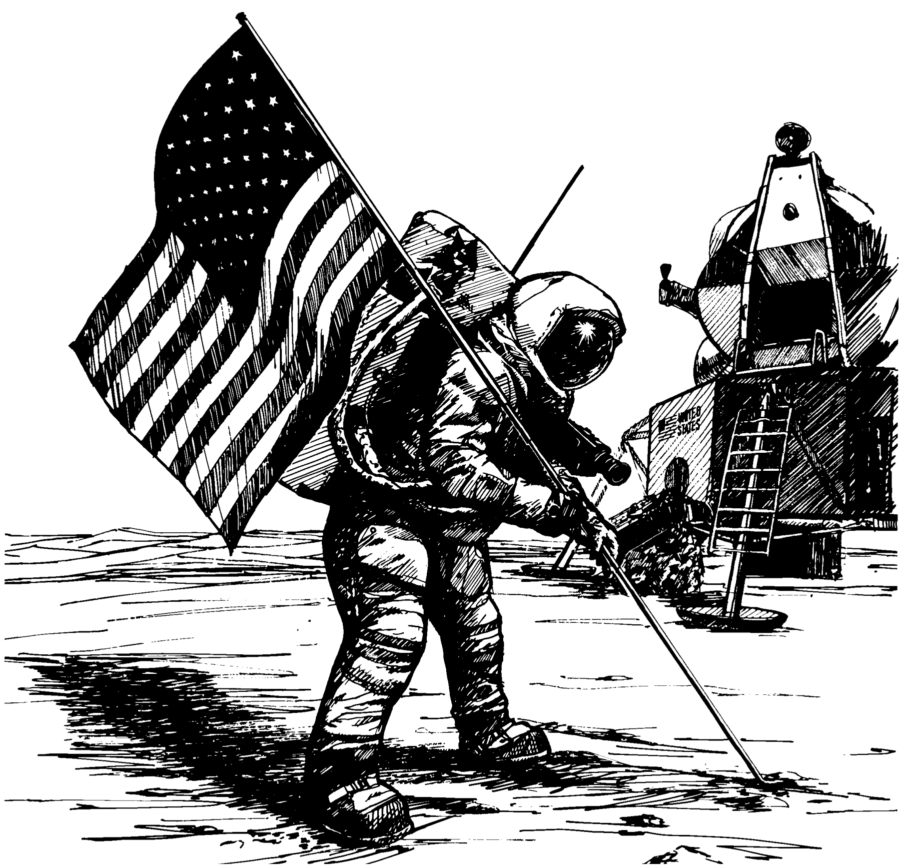
Project Mercury astronauts. (Front row, left to right) Walter M. Schirra, Jr., Donald K. Slayton, John H. Glenn, Jr., M. Scott Carpenter. (Back row, left to right) Alan B. Shepard, Jr., Virgil I. Grissom, L. Gordon Cooper, Jr.

The first Gemini astronaut to leave his vehicle (“go EVA”) was Edward White. White exited from the Gemini 4 space capsule on June 3, 1965—just a few months after Leonov made the first Soviet spacewalk. For a half hour White tumbled and rolled in space, connected to the capsule only by an oxygen-feed hose that served secondary functions as a tether line and a communication link with the capsule. Although the term “spacewalk” was coined for the Gemini program, no actual walking was involved. On his spacewalk, White used a small hand-held propulsion gun for maneuvering in space. When he pulled a trigger, the gun released jets of nitrogen that propelled him in the opposite direction. It was the first personal maneuvering unit used in space.

Upon completion of the Gemini program, NASA astronauts had logged nearly 12 additional hours of EVA experience. Approximately one-half of that time was spent merely standing up through the open hatch.

One of the most important lessons learned during the Gemini program was that EVAs were not as simple as they looked. Moving around in space required a great deal of work. The work could be lessened, however, by extensive training on Earth. The most effective training took place underwater. Wearing specially weighted spacesuits while in a deep tank of water gave later Gemini crewmembers adequate practice in maneuvers they would soon perform in space. It was also learned that a better method of cooling the astronaut was required. The gas cooling-system could not remove heat and moisture as rapidly as the astronaut produced them, and the inside of the helmet visor quickly fogged over, making it difficult to see.

Following Gemini, the Apollo program added a new dimension in spacesuit design because actual spacewalks (on the surface of the Moon) were now to occur for the first time. As with Mercury and Gemini space garments, Apollo suits had to serve as a backup pressure system to the space capsule. Besides allowing flexibility in the shoulder and arm areas, they also had to permit movements of the legs and waist. Astronauts needed to be able to bend and stoop to pick up samples on the Moon. Suits had to function both in microgravity and in the one-sixth gravity of the Moon's surface. Furthermore, when walking on the Moon, Apollo astronauts needed the flexibility to roam freely without dragging a cumbersome combination oxygen line and tether. A self-contained portable life-support system was needed.



The Apollo spacesuit began with a garment that used water as a coolant. The garment, similar to long johns but laced with a network of thin-walled plastic tubing, circulated cooling water around the astronaut to prevent overheating. On top of this layer was the pressure garment assembly. The innermost layer of this assembly was a comfort layer of lightweight nylon with fabric ventilation ducts. This was followed by a multilayered outer suit. The innermost layer of this garment was a neoprene-coated nylon bladder surrounded by a nylon restraint layer. Improved mobility was achieved by bellows-like joints of formed rubber with built-in restraint cables at the waist, elbows, shoulders, wrist, knees, and ankles. Next followed five layers of aluminized Mylar for heat protection, mixed with four spacing layers of nonwoven Dacron. Outside of that were two layers of Kapton and beta marquisette for additional thermal protection, and these were covered with a nonflammable and abrasion-protective layer of Teflon-coated filament beta cloth. The outermost layer of the suit was white Teflon cloth. The last two layers were flame resistant. In total, the suit layers provided pressure, served as a protection against heat and cold, and protected the wearer against micrometeoroid impacts and the wear and tear of walking on the Moon.

Capping off the suit was a communications headset and a clear polycarbonate-plastic pressure helmet. Slipped over the top of the helmet was an assembly consisting of sun-filtering visors and adjustable blinders for sunlight protection. The final items of the Apollo spacesuit were custom-sized gloves with molded silicone-rubber fingertips that provided some degree of fingertip sensitivity in handling equipment, lunar protective boots, and a portable life-support system.

The life-support system, a backpack unit, provided oxygen for breathing and pressurization, water for cooling, and radio communications for lunar surface excursions lasting up to eight hours. Furthermore, back inside the lunar lander the life-support system could be recharged for additional Moon walks.

During the Apollo program, 12 astronauts spent a total of 161 hours of EVA on the Moon's surface. An additional four hours of EVA were spent in microgravity while the astronauts were in transit from the Moon to Earth. During those four hours, a single astronaut, the command module pilot, left the capsule to retrieve photographic film. There was no need for the portable life-support system away from the Moon, as those astronauts were connected to the spacecraft by umbilical tether lines supplying them with oxygen.

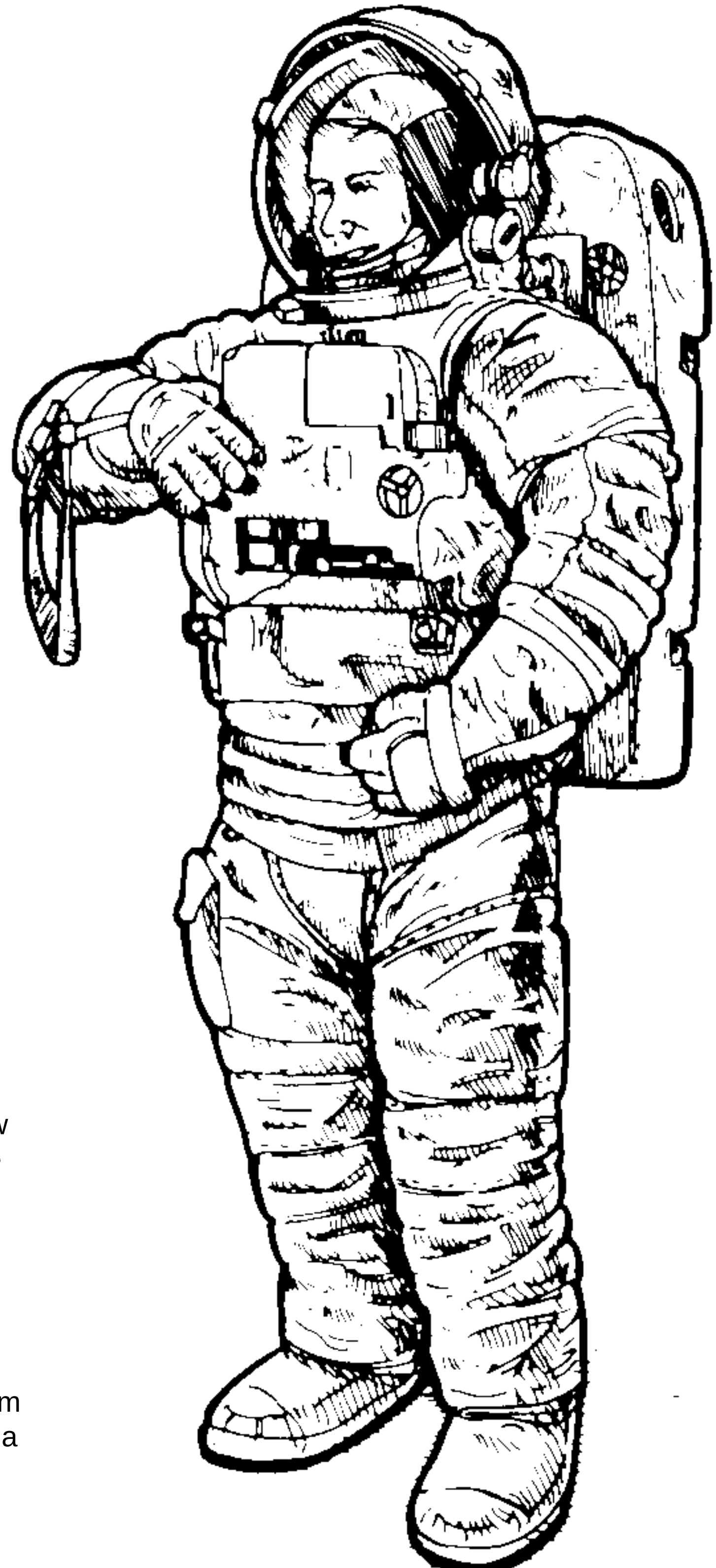
NASA's next experience with EVAs came during the Skylab program and convincingly demonstrated the need for astronauts on a spacecraft. Space-suited Skylab astronauts literally saved the Skylab program.

Skylab was NASA's first space station. It

Astronaut Owen Garriott performs maintenance activities for the Skylab space station.

was launched in 1973, six months after the last Apollo Moon landing. Trouble developed during the launch when a micrometeoroid shield ripped away from the station's outer surface. This mishap triggered the premature deployment of two of the six solar panels, resulting in one being ripped away by atmospheric friction. The second was jammed in a partially opened position by a piece of bent metal. In orbit, Skylab received insufficient electrical power from the remaining solar panels: the station was overheating because of the missing shield. Instead of scrapping the mission, NASA assigned the first three-astronaut crew the task of repairing the crippled station. While still on board the Apollo command module, Paul Weitz unsuccessfully attempted to free the jammed solar panel as he extended himself through the open side hatch. On board Skylab, the crew poked an umbrella-like portable heat shield through the scientific airlock to cover the area where the original shield was torn away. Later, on an EVA, the metal holding the jammed solar arrays was cut, and the panel was freed to open. During an EVA by the second Skylab crew, an additional portable heat shield was erected over the first.

The Skylab EMU was a simplified version of the Apollo Moon suits. There was no need for the portable life-support system, because the crewmember was attached to the station by an umbilical tether that supplied oxygen and cooling water. An astronaut life-support assembly, consisting of a pressure-control unit and an attachment for the tether, was worn on the chest, and an emergency oxygen package containing two supply bottles was attached to the right upper leg. A simplified visor assembly was used over the pressure helmet. Lunar protective boots were not needed. Skylab astronauts logged 17.5 hours of planned EVA for film and experiment retrieval and 65 hours of unplanned EVA for station repairs.



The Space Shuttle EMU

The Space Shuttle has opened an entirely new era in space travel. Launched as a rocket, the Shuttle operates in space as a spacecraft and returns to Earth as an airplane. Both the orbiter and its solid rocket boosters are reusable. Only the external tank is expended and replaced after each mission. The orbiter's payload bay, 18.3 meters long and 4.6 meters in diameter, with its remote manipulator system (RMS), or mechanical arm, makes the Shuttle a versatile space transportation system.

A new EMU enhances the Shuttle's overall capabilities. Like the spacecraft itself, the new Shuttle EMU is reusable. The spacesuits used in previous manned space flight programs were custom built to each astronaut's body size. In the Apollo program, for example, each astronaut had three custom suits—one for flight, one for training, and one for flight backup. Shuttle suits, however, are tailored from a stock of standard-size parts to fit astronauts with a wide range of measurements.

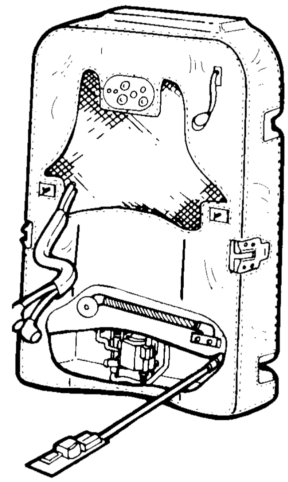
In constructing the new Shuttle spacesuit, developers were able to concentrate all their designs toward a single function—going EVA. Suits from earlier manned space flight programs had to serve multiple functions. They had to provide backup pressure in case of cabin pressure failure and protection if ejection became necessary during launch (Gemini missions). They also had to provide an environment for EVA in microgravity and while walking on the Moon (Apollo missions). Suits were worn during lift off and reentry and had to be comfortable under the high-g forces experienced during acceleration and deceleration. Shuttle suits are worn only when it is time to venture outside the orbiter cabin. At other times, crewmembers wear comfortable shirts and slacks, or coveralls.

Many Layers

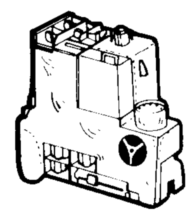
The Shuttle EMU has 12 layers to protect astronauts on EVAs. The two inner layers comprise the liquid-cooling-and-ventilation garment. It is made of spandex fabric and plastic tubing. Next comes the pressure bladder layer of urethane-coated nylon and fabric layer of pressure-restraining Dacron. This is followed by a seven-layer thermal micrometeoroid garment of aluminized Mylar, laminated with Dacron scrim topped with a single-layer fabric combination of Gortex, Kevlar, and Nomex materials.

Shuttle EMU End Items

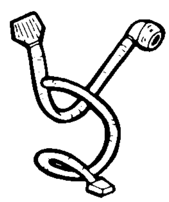
The Shuttle EMU consists of 19 separate items. Fully assembled, the Shuttle EMU becomes a nearly complete short-term spacecraft for one person. It provides pressure, thermal and micrometeoroid protection, oxygen, cooling water, drinking water, food, waste collection, (including carbon dioxide removal), electrical power, and communications. The EMU lacks only maneuvering capability, but this capability can be added by fitting a gas-jet-propelled Manned Maneuvering Unit (MMU) over the EMU's primary life-support system. On Earth, the suit and all its parts, fully assembled but without the MMU, weighs about 113 kilograms. Orbiting above Earth it has no weight at all. It does, however, retain its mass in space, which is felt as resistance to a change in motion.



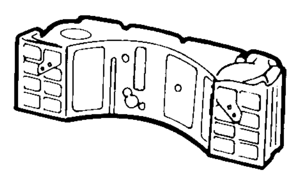
1. Primary Life-Support System (PLSS)
A self-contained backpack unit containing an oxygen supply, carbon-dioxide-removal equipment, caution and warning system, electrical power, water-cooling equipment, ventilating fan, machinery, and radio.



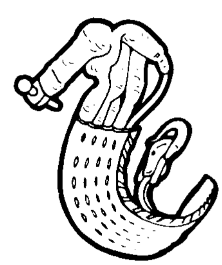
2. Displays and Control Module (DCM)
Chest-mounted control module containing all controls, a digital display, and the external liquid, gas, and electrical interfaces. The DCM also has the primary purge valve for use with the Secondary Oxygen Pack.



3. EMU Electrical Harness (EEH)
A harness worn inside the suit to provide bioinstrumentation and communications connections to the PLSS.

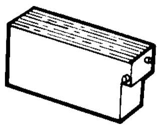


4. Secondary Oxygen Pack (SOP)
Two oxygen tanks with a 30-minute emergency supply, valve, and regulators. The SOP is attached to the base of the PLSS. The SOP can be removed from the PLSS for ease of maintenance.

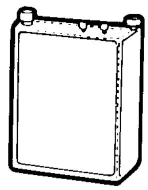


5. Service and Cooling Umbilical (SCU)
Connects the orbiter airlock support system to the EMU to support the astronaut before EVA and to provide in-orbit recharge capability for the PLSS. The SCU contains lines for power, communications, oxygen and water recharge, and water drainage. The SCU con-

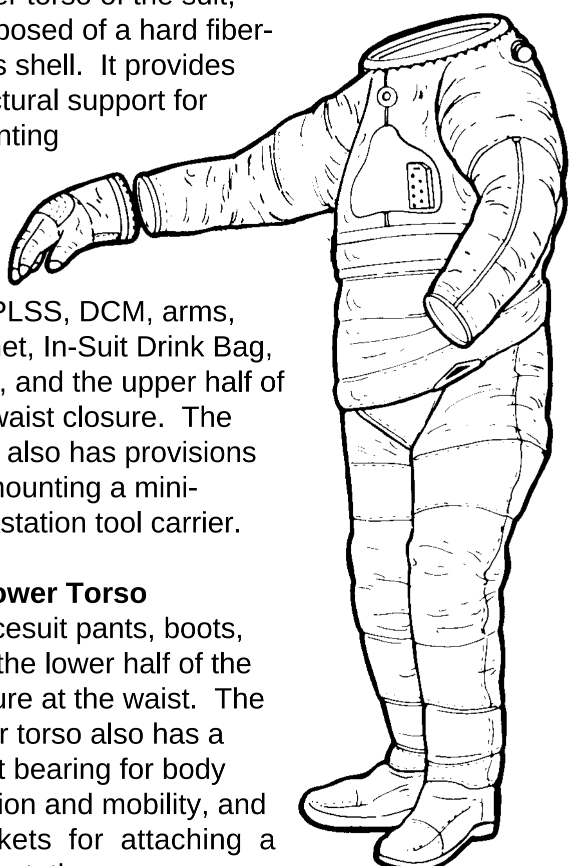
serves PLSS consumables during EVA preparation.



6. Battery
Supplies electrical power for the EMU during EVA. The battery is rechargeable in orbit.

7. Contaminant Control Cartridge (CCC)

Cleanses suit atmosphere of contaminants with an integrated system of lithium hydroxide, activated charcoal, and a filter contained in one unit. The CCC is replaceable in orbit.

8. Hard Upper Torso (HUT)
Upper torso of the suit, composed of a hard fiberglass shell. It provides structural support for mounting

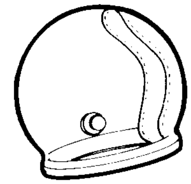


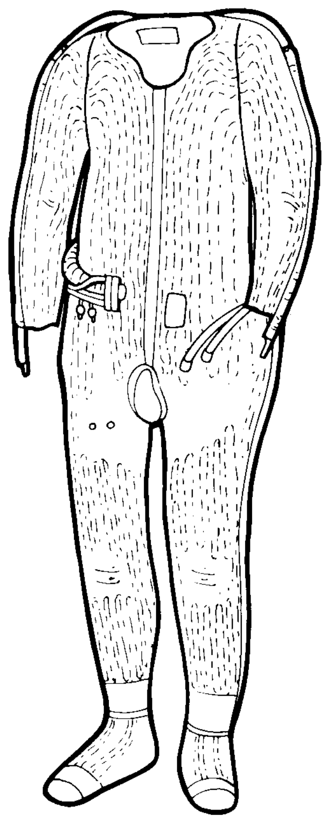
the PLSS, DCM, arms, helmet, In-Suit Drink Bag, EEH, and the upper half of the waist closure. The HUT also has provisions for mounting a miniworkstation tool carrier.

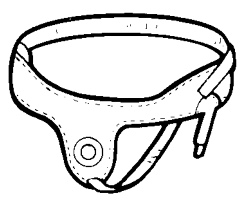
9. Lower Torso
Spacesuit pants, boots, and the lower half of the closure at the waist. The lower torso also has a waist bearing for body rotation and mobility, and brackets for attaching a safety tether.

10. Arms (left and right)
Shoulder joint and armscye (shoulder) bearing, upper arm bearings, elbow joint, and glove-attaching closure.

11. EVA Gloves (left and right)
Wrist bearing and disconnect, wrist joint, and fingers. One glove has a wristwatch sewn onto the outer layer. The gloves have tethers for restraining small tools and equipment. Generally, crewmembers also wear thin fabric comfort gloves with knitted wristlets under the EVA gloves.

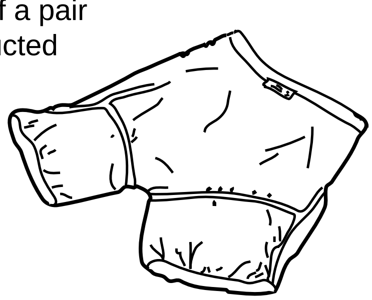
12. Helmet

Plastic pressure bubble with neck disconnect ring and ventilation distribution pad. The helmet has a backup purge valve for use with the secondary oxygen pack to remove expired carbon dioxide.

13. Liquid Cooling-and-Ventilation Garment (LCVG)

Long underwear-like garment worn inside the pressure layer. It has liquid cooling tubes, gas ventilation ducting, and multiple water and gas connectors for attachment to the PLSS via the HUT.

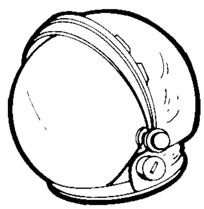


14. Urine Collection Device (UCD)
Urine collection device for male crewmembers consisting of a roll-on cuff and storage bag. The UCD is discarded after use.

15. Disposable Absorption and Containment Trunk (DACT)
Urine-collection garment for female crewmembers consisting of a pair of shorts constructed from five layers of chemically treated absorbent nonwoven fibrous materials. The DACT is discarded after use.

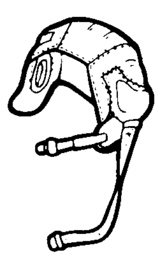


16. Extravehicular Visor Assembly (EVA)
Assembly containing a metallic-gold-covered Sun-filtering visor, a clear thermal impact-protective visor, and adjustable blinders that attach over the helmet. In addition, four small “head lamps” are mounted on the assembly; a TV camera-transmitter may also be added.

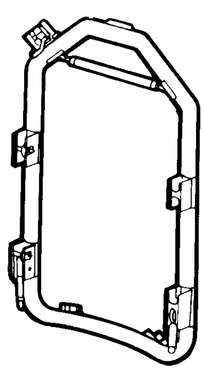


17. In-Suit Drink Bag (IDB)
Plastic water-filled pouch mounted inside the HUT. A tube projecting into the helmet works like a straw.

18. Communications Carrier Assembly (CCA)
Fabric cap with built-in earphones and a microphone for use with the EMU radio.



19. Airlock Adapter Plate (AAP)
Fixture for mounting and storing the EMU inside the airlock and for use as an aid in donning the suit.



Putting On the EMU

Putting on a Shuttle EMU is a relatively simple operation that can be accomplished in a matter of about 15 minutes. However, the actual process of preparing to go EVA takes much longer. When working in the Shuttle cabin, crewmembers breathe a normal atmospheric mix of nitrogen and oxygen at 101 kilopascals. The suit’s atmosphere is pure oxygen at 29.6 kilopascals. A rapid drop from the cabin pressure to the EMU pressure could result in a debilitating ailment that underwater divers sometimes experience—the bends. The bends, also known as caisson disease, are produced by the formation and expansion of nitrogen gas bubbles in the bloodstream when a person breathing a normal air mixture at sea-level pressure is exposed to a rapid drop in external pressure. The bends are characterized by severe pains in the joints, cramps, paralysis, and eventual death if not treated by gradual recompression. To prevent an occurrence of the bends, crewmembers intending to go EVA spend a period of time prebreathing pure oxygen. During that time, nitrogen gas in the bloodstream is replaced by pure oxygen.

Prebreathing begins when the crewmembers who plan to go EVA don the special launch and entry helmets. For one hour they are attached to the orbiter's oxygen supply system and breathe pure oxygen. With a long feeder hose, they can go about their business and initiate the next phase of prebreathing.

The atmospheric pressure of the entire orbiter cabin is depressed from the normal 101 kilopascals to 70.3 pascals while the percentage of oxygen is slightly increased. This step must take place at least 24 hours before the exit into space. By now, much of the dissolved nitrogen gas has been cleared from the EVA crewmembers, and they can remove their helmets. Later, when they don their spacesuits and seal the helmets, an additional 30 to 40 minutes of pure oxygen prebreathing takes place before the suits are lowered to their operating pressure of 29.6 kilopascals.

Most of the EMU-donning process takes place inside the airlock. The airlock is a cylindrical chamber located on the orbiter's middeck. One hatch leads from the middeck into the airlock, and a second hatch leads from the airlock out to the unpressurized payload bay.

Before entering the hatch, but following their initial prebreathing, the crewmembers put on the Urine Collection Device or Disposable Absorption and Containment Trunk. The urine collector for males is simply an adaptation of a device used by people who have kidney problems. It is a pouch with a roll-on connector cuff that can contain approximately one quart of liquid. The device for females consists of multilayered shorts that hold a highly absorptive powder. This system is also capable of containing about one quart of liquid.

Next comes the Liquid Cooling- and-Ventilation Garment. The LCVG has the general appearance of long underwear. It is a one-piece suit with a zippered front, made of stretchable spandex fabric laced with 91.5 meters of plastic tubing. When the EMU is completely assembled, cooling and ventilation become significant problems. Body heat, contaminant gases, and perspiration—all waste products—are contained by the insulation and pressure layers of the suit and must be removed. Cooling of the crewmember is accomplished by circulating chilled water through the tubes. Chilling the water is one of the functions of the Primary Life-Support System. The PLSS device for water cooling and the tubing system are designed to provide cooling for physical activity that generates up to 2 million joules of body heat per hour, a rate that is considered "extremely vigorous." (Approximately 160 joules are released by burning a piece of newsprint one centimeter square.) Ducting attached to the LCVG ventilates the suit by drawing ventilating oxygen and expired carbon dioxide from the suit's atmosphere into the PLSS for purification and recirculation. Body perspiration is also drawn away from the suit by the venting system. These ducts meet at a circular junction on the back of the LCVG after running along each arm and leg. Purified oxygen from the PLSS reenters the suit through another duct, mounted in the back of the helmet, that directs the flow over the astronaut's face to complete the circuit.

Spacesuit technician prepares to put on the Space Shuttle EMU by first donning the Liquid Cooling-and-Ventilation garment.

The EMU electrical harness is attached to the HUT and provides biomedical and communications hookups with the PLSS. The biomedical hookup monitors the heart rate of the crewmembers, and this information is radioed via a link with the orbiter to Mission Control on Earth. When the orbiter is over a ground tracking station, voice communications are also carried on this circuit.

Next, several simple tasks are performed. Antifog compound is rubbed on the inside of the helmet. A wrist mirror and a small spiral-bound 27-page checklist are put on the left arm of the upper torso. The wrist mirror was added to the suit because some of the knobs on the front of the displays and control module are out of the vision range of the crewmember. The mirror permits the knob settings to be read. (Setting numbers are written backwards for ease of reading in the mirror.)

Another task at this time is to insert a food bar and a water-filled In-Suit Drink Bag inside the front of the HUT. The food bar of compressed fruit, grain, and nuts is wrapped in edible rice paper, and its upper end extends into the helmet area near the crewmember's mouth. When hungry, the crewmember bites the bar and pulls it upward before breaking off a piece to chew. In that manner, a small piece of the bar remains extended into the helmet for the next bite. It is necessary to eat the entire bar at one time, because saliva quickly softens the protruding food bar, making it mushy and impossible to break off. The IDB is placed just above the bar. The bag is filled with up to 0.65 liters of water from the water supply in the orbiter's galley before the airlock is entered. A plastic tube and valve assembly extends up into the helmet so that the crewmember can take a drink whenever needed. Both the food bar and drink bag are held in place by Velcro attachments.

During EVAs, the crewmembers may need additional lighting to perform their tasks. A light-bar attachment (helmet-mounted light array) is placed above the helmet visor assembly. Small built-in flood lamps provide illumination to places that sunlight and the regular payload bay lights do not reach. The EVA light has its own battery system and can be augmented with a helmet-mountable television camera system with its own batteries and radio frequency transmitter. The camera's lens system is about the size of a postage stamp. Through this system, the crew remaining inside the orbiter and the mission controllers on Earth can get an astronaut's eye view of the EVA action. During complicated EVAs, viewers may be able to provide helpful advice for the tasks at hand.

Spacesuit technician "dives" into the upper torso of the Space Shuttle EMU.

Next, the Communications Carrier Assembly (CCA), or "Snoopy cap," is connected to the EMU electrical harness and left floating above the HUT. The CCA earphones and microphones are held by a fabric cap. After the crewmember dons the EMU, the cap is placed on the head and adjusted.

When the tasks preparatory to donning the suit are completed, the lower torso, or suit pants, is pulled on. The lower torso comes in various sizes to meet the varying size requirements of different astronauts. It features pants with boots and joints in the hip, knee, and ankle, and a metal body-seal closure for connecting to the mating half of the ring mounted on the hard upper torso. The lower torso's waist element also contains a large bearing.

This gives the crewmember mobility at the waist, permitting twisting motions when the feet are held in workstation foot restraints.

Joints for the lower and upper torsos represent an important advance over those of previous spacesuits. Earlier joint designs consisted of hard rings, bellows-like bends in the pressure bladder, or cable- and pulley-assisted fabric joints. The Shuttle EMU joints maintain nearly constant volume during bending. As the joints are bent, reductions in volume along the inner arc of the bend are equalized by increased volume along the outer arc of the bend.

Long before the upper half of the EMU is donned, the airlock's Service and Cooling Umbilical is plugged into the Displays and Control Module Panel on the front of the upper torso. Five connections within the umbilical provide the suit with cooling water, oxygen, and electrical power from the Shuttle itself. In this manner, the consumables stored in the Primary Life-Support System will be conserved during the lengthy prebreathing period. The SCU also is used for battery and consumable recharging between EVAs.

The airlock of the Shuttle orbiter is only 1.6 meters in diameter and 2.1 meters high on the inside. When two astronauts prepare to go EVA, the space inside the airlock becomes crowded. For storage purposes and as an aid in donning and doffing the EMU, each upper torso is mounted on airlock adapter plates. Adapter plates are brackets on the airlock wall for supporting the suits' upper torsos.

With the lower torso donned and the orbiter providing consumables to the suits, each crewmember "dives" with a squirming motion into the upper torso. To dive into it, the astronaut maneuvers under the body-seal ring of the upper torso and assumes a diving position with arms extended upward. Stretching out, while at the same time aligning arms with the suit arms, the crewmember slips into the upper torso. As two upper and lower body-seal closure rings are brought together, two connections are made. The first joins the cooling water-tubing and ventilation ducting of the LCVG to the Primary Life-Support System. The second connects the biomedical monitoring sensors to the EMU electrical harness that is connected to the PLSS. Both systems are turned on, and the crewmember then locks the two body-seal closure rings together, usually with the assistance of another crewmember who remains on board.

One of the most important features of the upper half of the suit is the HUT, or Hard Upper Torso. The HUT is a hard fiberglass shell under the fabric layers of the thermal-micrometeoroid garment. It is similar to the breast and back plates of a suit of armor. The HUT provides a rigid and controlled mounting surface for the Primary Life-Support System on the back and the Displays and Control Module on the front.

The Space Shuttle EMU.

In the past, during the Apollo Moon missions, donning suits was a very lengthy process because the life-support system of those suits was a separate item. Because the Apollo suits were worn during launch and landing and also as cabin-pressure backups, an HUT could not be used. It would have been much too uncomfortable to wear during the high accelerations and decelerations of lift-off and reentry. The life-support system had to be attached to the suit inside the lunar module. All connections between PLSS and the Apollo suit were made at that time and, with two astronauts working in cramped quarters, preparing for EVA was a difficult process. The Shuttle suit HUT eliminates that lengthy procedure because the PLSS is already attached. It also eliminates the exposed and vulnerable ventilation and life-support hoses of earlier EMU designs that could become snagged during EVA.

The last EMU gear to be donned includes eyeglasses if needed, the CCA, comfort gloves, the helmet with lights and optional TV, and EVA gloves. The two gloves have fingertips of silicone rubber that permit some degree of sensitivity in handling tools and other objects. Metal rings in the gloves snap into rings in the sleeves of the upper torso. The rings in the gloves contain bearings to permit rotation for added mobility in the hand area. The connecting ring of the helmet is similar to the rings used for the body-seal closure. Mobility is not needed in this ring, because the inside of the helmet is large enough for the crewmember's head to move around. To open or lock any of the connecting rings, one or two sliding, rectangular-shaped knobs are moved to the right or the left. When opened, the two halves of the connecting rings come apart easily. To close and lock, one of the rings slides part way into the other against an O-ring seal. The knob is moved to the right, and small pins inside the outer ring protrude into a groove around the inside ring, thereby holding the two together.

All suit openings have locking provisions that require a minimum of three independent motions to open. This feature prevents any accidental opening of suit connections.

With the donning of the helmet and gloves, the spacesuits are now sealed off from the atmosphere of the airlock. The crewmembers are being supported by the oxygen, electricity, and cooling water provided by the orbiter. A manual check of suit seals is made by pressurizing each suit to 29.6 kilopascals d. (The "d" stands for differential, meaning above the airlock pressure.) Inside the airlock, the pressure is either 70.3 or 101 kilopascals. The suit's pressure is elevated an additional 29.6 kilopascals, giving it a pressure differential above the air lock pressure. Once pressure reaches the desired level, the oxygen supply is shut off and the digital display on the chest-mounted control module is read. To assist in reading the display, an optional Fresnel lens inside the space helmet may be used to magnify the numbers. Some leakage of spacesuit pressure is normal. The maximum allowable rate of leakage of the Shuttle EMU is 1.38 kilopascals per minute, and this is checked before the suit is brought back down to airlock pressure.

As the suit pressure is elevated, crewmembers may experience discomfort in their ears and sinus cavities. They compensate for the pressure change by swallowing, yawning, or pressing their noses on an optional sponge mounted to the left on the inside of the helmet ring. Attempting to blow air through the nose when pressing the nose on the sponge forces air inside the ears and sinus cavities to equalize the pressure.

During the next several minutes the two spacesuits are purged of any oxygen/nitrogen atmosphere remaining from the cabin; this is replaced with pure oxygen. Additional suit checks are made while the final oxygen prebreathe takes place.

The inner door of the airlock is sealed, and the airlock pressure bleed-down begins. A small depressurization valve in the airlock latch is opened to outside space, permitting the airlock atmosphere to escape. While this is taking place the EMU automatically drops its own pressure to 66.9 kilopascals and leak checks are conducted. Failure of the leak test would require repressurizing the airlock, permitting the EVA crew to reexamine the seals of their suits.

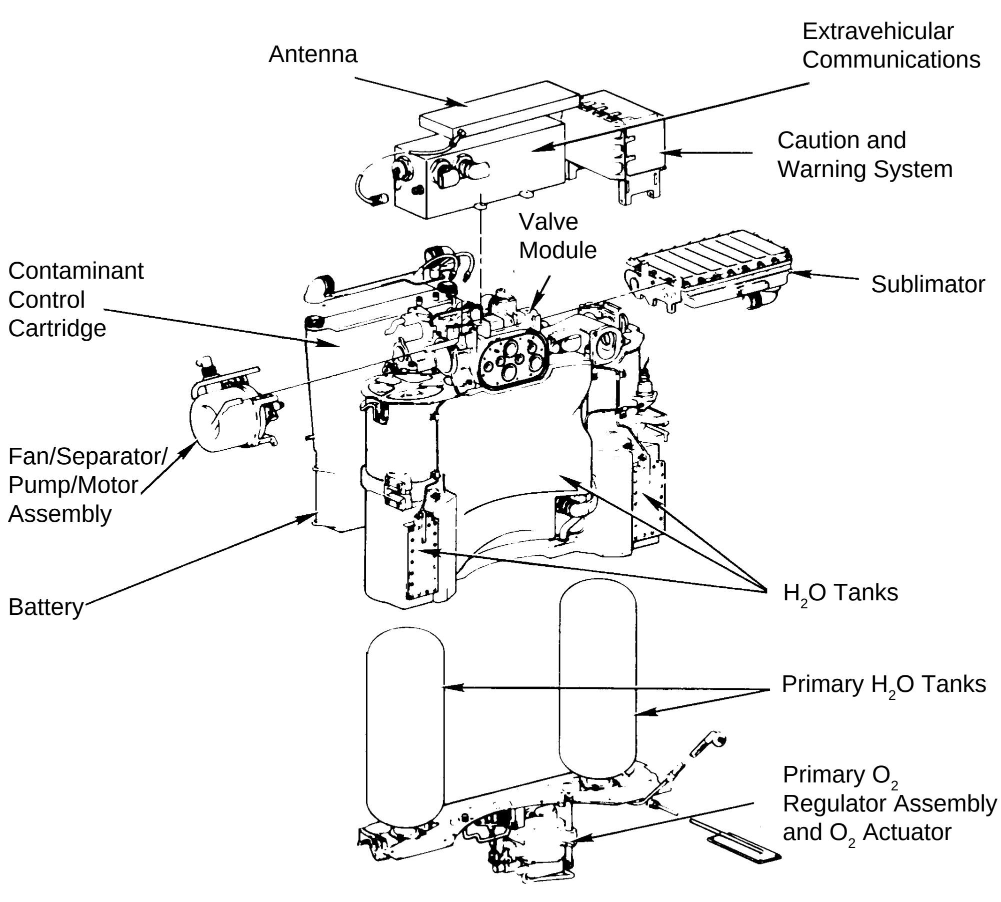
Final depressurization is begun by opening the airlock depressurization valve. The outer airlock hatch is then opened and the suited astronauts prepare to pull themselves out into the payload bay. As a safety measure, they tether themselves to the orbiter to prevent floating away as they move from place to place by hand holds. It is at this point that they disconnect the orbiter Service and Cooling Umbilical from the EMU. The PLSS begins using its own supply of oxygen, cooling water, and electricity. The astronauts pull themselves through the outer airlock hatch, and the EVA begins.

The Primary and Secondary Life-Support Systems

Astronauts experienced their first real freedom while wearing spacesuits during the Apollo Moon-walk EVAs, because of a portable life-support system worn on their backs. All other EVAs up to that time were tied to the spacecraft by the umbilical-tether line that supplied oxygen and kept crewmembers from drifting away. In one sense, the tether was a leash, because it limited movements away from the spacecraft to the length of the tether. On the Moon, however, astronauts were not hampered by a tether and, in the later missions, were permitted to drive their lunar rovers up to 10 kilometers away from the lander. (That distance limit was imposed as a safety measure. It was determined that 10 kilometers was the maximum distance an astronaut could walk back to the lander if a lunar rover ever broke down.)

Space Shuttle astronauts have even greater freedom than the Apollo lunar astronauts, because their EVAs take place in the microgravity environment of space. They do employ tethers when EVAs center in and about the Shuttle's payload bay, but those tethers act only as safety lines and do not provide life support. Furthermore, the tethers can be moved from one location to another on the orbiter, permitting even greater distances to be covered. When activities center some distance from the orbiter, a backpack style of maneuvering system is used, limited in mobility only by the amount of propellants carried in the system.

The freedom of movement afforded to Shuttle astronauts on EVAs is due to the Primary Life-Support System carried on their backs. The PLSS, an advanced version of the Apollo system, provides life support, voice communications, and biomedical telemetry for EVAs lasting as long as seven hours. Within its dimensions of 80 by 58.4 by 17.5 centimeters, the PLSS contains five major groups of compo-



Primary Life-Support System

nents for life support. Those are the oxygen-ventilating, condensate, feedwater, liquid transport, and primary oxygen circuits.

The oxygen-ventilating circuit is a closed-loop system. Oxygen is supplied to the system from the primary oxygen circuit or from a secondary oxygen pack that is added to the bottom of the PLSS for emergency use. The circulating oxygen enters the suit through a manifold built into the Hard Upper Torso. Ducting carries the oxygen to the back of the space helmet, where it is directed over the head and then downward along the inside of the helmet front. Before passing into the helmet, the oxygen warms sufficiently to prevent fogging of the visor. As the oxygen leaves the helmet and travels into the rest of the suit, it picks up carbon dioxide and humidity from the crewmember's respiration. More humidity from perspiration, some heat from physical activity, and trace contaminants are also picked up by the oxygen as it is drawn into the ducting built into the Liquid Cooling-and-Ventilation Garment. A centrifugal fan, running at nearly 20,000 rpm, draws the contaminated oxygen back into the PLSS at a rate of about 0.17 cubic meters per minute, where it passes through the Contaminant Control Cartridge.

Carbon dioxide and trace contaminants are filtered out by the lithium hydroxide and activated charcoal layers of the cartridge. The gas stream then travels through a heat exchanger and sublimator for removal of the humidity. The heat exchanger and sublimator also chill water that runs through the tubing in the Liquid Cooling-and-Ventilation Garment. The humidity in the gas stream condenses out in the heat exchanger and sublimator. The relatively dry gas (now cooled to approximately 13 degrees Celsius) is directed through a carbon dioxide sensor before it is recirculated through the suit. Oxygen is added from a supply and regulation system in the PLSS as needed. In the event of an emergency, a purge valve in the suit can be opened. The purge valve opens the gas-flow loop, permitting the moisture and the carbon dioxide-rich gas to dump outside the suit just before it reaches the Contaminant Control Cartridge.

One of the by-products of the oxygen-ventilating circuit is moisture. The water produced by perspiration and breathing is with-

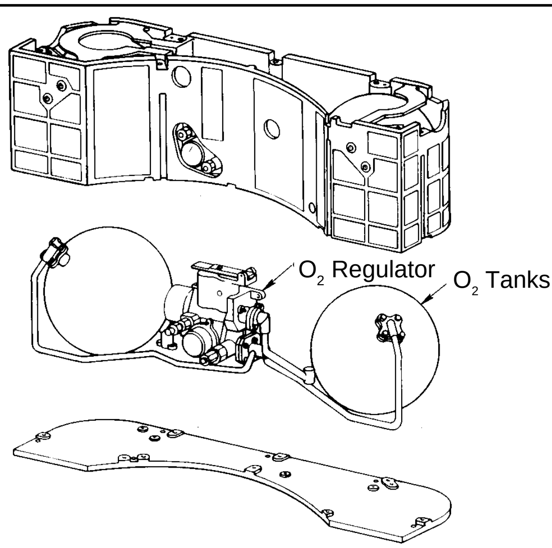
Astronaut Jerry Ross looks into the orbiter windows during the STS-37 mission.

drawn from the oxygen supply by being condensed in the sublimator and is carried by the condensate circuit. (The small amount of oxygen that is also carried by the condensate circuit is removed by a gas separator and returned to the oxygen-ventilating system.) The water is then sent to the water-storage tanks of the feedwater circuit and added to their supply for eventual use in the sublimator. In this manner, the PLSS is able to maintain suit cooling for a longer period than would be possible with just the tank's original water supply.

The function of the feedwater and the liquid transport circuits is to cool the astronaut. Using the pressure of oxygen from the primary oxygen circuit, the feedwater circuit moves water from the storage tanks (three tanks holding a total of 4.57 kilograms of water) to the space between the inner surfaces of two steel plates in the heat exchanger and sublimator. The outer side of one of the plates is exposed directly to the vacuum of space. That plate is porous and, as water evaporates through the pores, the temperature of the plate drops below the freezing point of water. Water still remaining on the inside of the porous plate freezes, sealing off the pores. Flow in the feedwater circuit to the heat exchanger and sublimator then stops.

On the opposite side of the other steel plate is a second chamber through which water from the liquid transport circuit passes. The liquid transport circuit is a closed-loop system that is connected to the plastic tubing of the Liquid Cooling-and-Ventilation Garment. Water in this circuit, driven by a pump, absorbs body heat. As the heated water passes to the heat exchanger and sublimator, heat is transferred through the aluminum wall to the chamber with the porous wall. The ice formed in the pores of that wall is sublimated by the heat directly into gas, permitting it to travel through the pores into space. In this manner, water in the transport circuit is cooled and returned to the LCVG. The cooling rate of the sublimator is determined by the work load of the astronaut. With a greater work load, more heat is released into the water loop, causing ice to be sublimated more rapidly and more heat to be eliminated by the system.

The last group of components in the Primary Life-Support System is the primary oxygen circuit. Its two tanks contain a total of 0.54 kilograms of oxygen at a pressure of 5,860.5 kilopascals, enough for a normal seven-hour EVA. The oxygen of this circuit is used for suit pressurization and breathing. Two regulators in the circuit step the pressure down to usable levels of 103.4 kilopascals and 29.6 kilopascals. Oxygen coming from the 103.4-kilopascal regulator pressurizes the water tanks, and oxygen from the 29.6-kilopascal regulator goes to the ventilating circuit.



Secondary Oxygen Pack

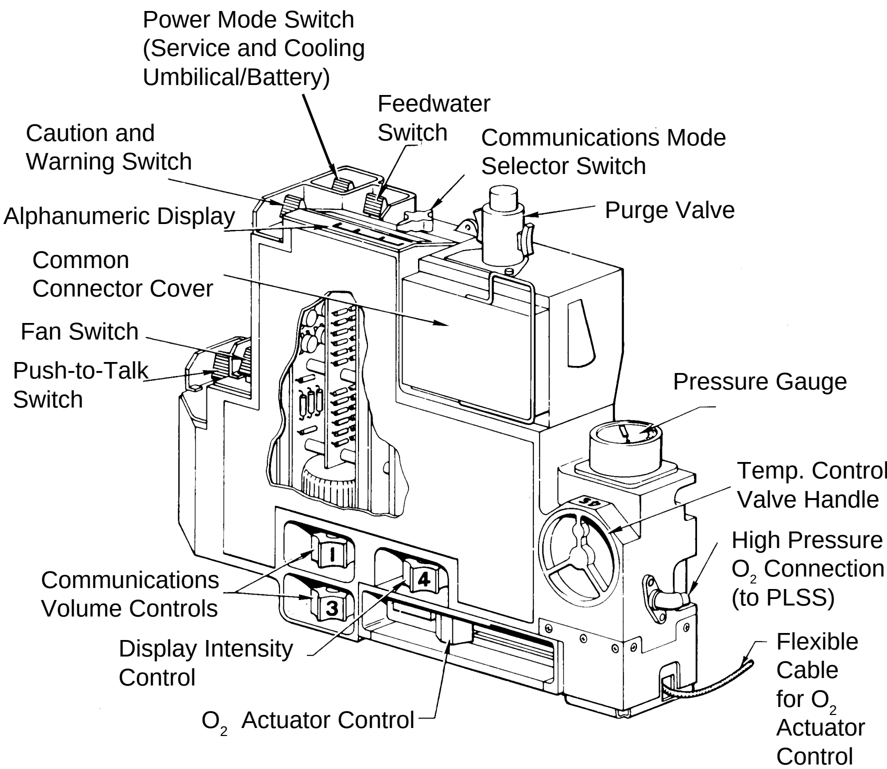
To insure the safety of astronauts on EVAs, a Secondary Oxygen Pack is added to the bottom of the PLSS. The two small tanks in this system contain 1.2 kilograms of oxygen at a pressure of 41,368.5 kilopascals. The Secondary Oxygen Pack can be used in an open-loop mode by activating a purge valve or as a backup supply should the primary system fall to 23.79 kilopascals.

If the Displays and Control Module purge valve (discussed below) is opened, used-oxygen contaminants and collected moisture dump directly out of the suit into space. Because oxygen is not conserved and recycled in this mode, the large quantity of oxygen contained in the SOP is consumed in only 30 minutes. This half-hour still gives the crewmember enough time to return to the orbiter's airlock. If carbon dioxide control is required, the helmet purge valve may be opened. That valve has a lower flow rate than the DCM valve.

Displays and Control Module

The PLSS is mounted directly on the back of the Hard Upper Torso, and the controls to run it are mounted on the front. A small irregularly shaped box, the Displays and Control Module, houses a variety of switches, valves, and displays. Along the DCM top are four switches for power, feedwater, communications mode selection, and caution and warning. A suit-pressure purge valve projects from the top at the left for use with the emergency oxygen system. Near the front on the top is an alpha-numeric display. A microprocessor inside the PLSS permits astronauts to monitor the condition of the various suit circuits by reading the data on the display.

Stepped down from the top of the DCM, on a small platform to the astronaut's right, is a ventilation-fan switch and a push-to-talk switch. (The astronaut has the option of having the radio channel open at all times or only when needed.) On a second platform, to the left, is an illuminated mechanical-suit pressure gauge. At the bottom, on the front of the DCM, are additional controls for communications volume, display lighting intensity, and oxygen flow.



Display and Control Module

Working In Space

One of the great advantages of working in space is that objects, including the astronauts themselves, have no weight. Regardless of the weight of an object on Earth, a single crew-member can move and position that object in orbit with ease provided that the crewmember has a stable platform from which to work. Without that platform, any force exerted to move an object will be met with a correspond-ing motion of the astronaut in the opposite direction. A simple Earth task, such as turning a nut with a wrench, can become quite difficult, because the astronaut—and not the nut—may turn.

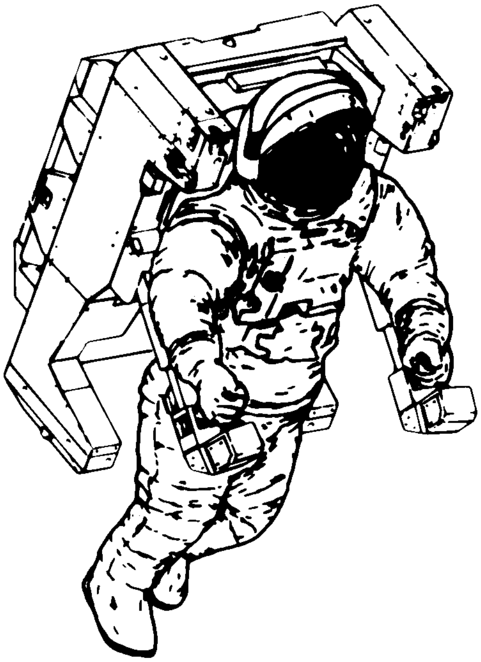
The physics of working in space is the same as that of working on Earth. All people and things contain matter and have mass. Because of that mass, they resist any change in motion. Physicists refer to that resistance as inertia. The greater the mass, the greater the inertia. To change the motion of objects, an application of force is required. According to Sir Isaac Newton's Third Law of Motion, a force causing an object to move one way is met with an equal and opposite force in the other direction. The third law is more familiarly stated as, "For every action there is an equal and opposite reaction." A person planted firmly on the ground can lift heavy objects because the equal and opposite force is directed downward through the legs and feet. The inertia of Earth is so great that the corresponding response to that downward force is infinitesimal.

In space, astronauts do not have the advantage of having a planet to stand on to absorb the equal and opposite force during work activities. Although orbiting objects do not have the property of weight, they still resist change in motion. Pushing on an object causes the object and the crewmember to float away in opposite directions. To gain any advantage over objects, the crewmember must be braced by a stable platform, such as the massive and actively stabilized Shuttle orbiter itself, or must have a self-contained maneuvering system—a kind of "rocket" backpack.

Manned Maneuvering Unit

During the first American EVA, Edward White experimented with a personal propulsion device, the Hand-Held Maneuvering Unit (HHMU). The HHMU tested by White was a three-jet maneuvering gun. Two jets were located at the ends of rods and aimed back, so that firing them pulled White forward. A third jet was aimed forward to provide a braking force. By holding the gun near his center of mass and aiming it in the direction in which he wanted to travel, he was able to propel himself forward.

Stopping that movement required firing the center jet. The propulsive force of the HHMU was produced by releasing compressed oxygen from two small built-in tanks.



Although the HHMU worked as intended, it had two disadvantages. To produce the desired motion, it had to be held as close to the astronaut's center of mass as possible. Determining the center position was difficult because of the bulky spacesuit White wore, and was a matter of guesswork and experience. Furthermore, precise motions to position an astronaut properly during an activity such as servicing a satellite were difficult to achieve and maintain, and proved physically exhausting.

On the Gemini 9 mission, a backpack maneuvering unit was carried. However, problems with the unit prevented Gene Cernan from testing it.

Following the Gemini program, the next space experiments that tested maneuvering units for EVAs took place during the second and third manned Skylab missions. The device was tested only inside the spacecraft, but the experiment confirmed that a maneuvering device of that design was both feasible and desirable for future EVA use. The experiments were dubbed M-509. Five of the six astronauts who flew in those two missions accumulated a total of 14 hours testing the advanced device, called the AMU, or Astronaut Maneuvering Unit. The AMU was shaped like a large version of a hiker's backpack. Built into the frame was a replaceable tank of compressed nitrogen gas. Controls for the unit were placed at the ends of "arm rests." To move, the astronaut worked rotational and translational, or nonrotational, hand controls. Propulsive jets of nitrogen gas were released from various nozzles spaced around the unit. The 14 nozzles were arranged to aim top-bottom, front-back, and right-left to produce six degrees of freedom in movement. The AMU could move forward and back, up and down, and side to side, and could roll, pitch, and yaw. With the 11 additional nozzles, precise positioning with the AMU was far simpler than with the HHMU of the Gemini program. The astronaut was surrounded by the unit, taking the guesswork out of determining center of mass and making control much more accurate. The astronaut could move closely along the surface of a curved or irregularly shaped object without making contact with it.

The Manned Maneuvering Unit of the Space Shuttle is an advanced version of the Skylab AMU. It is designed to operate in the microgravity environment of outer space and under the temperature extremes found there. The MMU is operated by a single space-suited astronaut. The unit features redundancy to protect against failure of individual systems. It is designed to fit over the life-support system backpack of the Shuttle EMU.

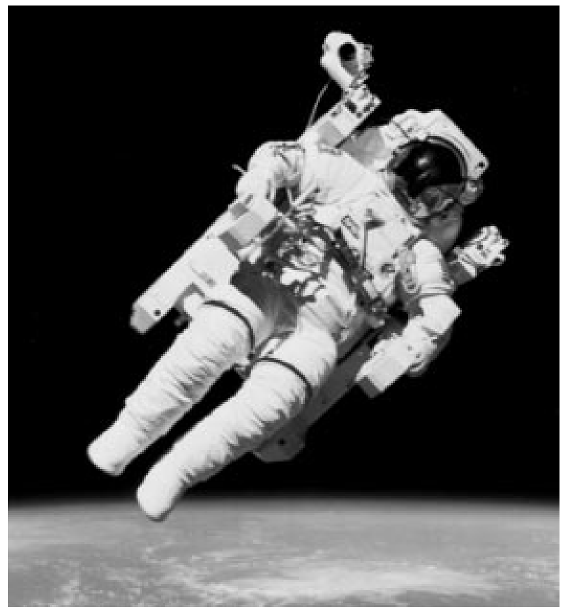
The MMU is approximately 127 centimeters high, 83 centimeters wide, and 69 centimeters deep. When carried into space by the Shuttle, it is stowed in a support station attached to the wall of the payload bay near the airlock hatch. Two MMUs are normally carried on a mission, and the second unit is mounted across from the first on the opposite payload bay wall. The MMU controller arms are folded for storage, but when an astronaut backs into the unit and snaps the life-support system into place, the arms are unfolded. Fully extended, the arms increase the depth of the MMU to 122 centimeters. To adapt to astronauts with different arm lengths, controller arms can be adjusted over a range of approximately 13 centimeters. The

MMU is small enough to be maneuvered with ease around and within complex structures. With a full propellant load, its mass is 148 kilograms.

Gaseous nitrogen is used as the propellant for the MMU. Two aluminum tanks with Kevlar filament overwrappings contain 5.9 kilograms of nitrogen each at a pressure of 20.68 kilopascals, enough propellant for a six-hour EVA, depending on the amount of maneuvering done. In normal operation, each tank feeds one system of thrusters. In the event some of the thrusters fail, crossfeed valves may be used to connect the two systems, permitting all propellant from both tanks to be used. At the direction of the astronaut, through manual control or at the direction of an automatic attitude-hold system, propellant gas is moved through feed lines to varying combinations of 24 nozzles arranged in clusters of three each on the eight corners of the MMU. The nozzles are aimed along three axes perpendicular to each other and permit six degrees of freedom of movement. To operate the propulsion system, the astronaut uses his or her fingertips to manipulate hand controllers at the ends of the MMU's two arms. The right-hand controller produces rotational acceleration for roll, pitch, and yaw. The left controller produces acceleration without rotation for moving forward-back, up-down, and left-right. Orders pass from the hand controls through a small logic unit (Control Electronics Assembly) that operates the appropriate thrusters for achieving the desired acceleration. Coordination of the two controllers produces intricate movements in the unit. Once a desired orientation has been achieved, the astronaut can engage an automatic attitude-hold function that maintains the inertial attitude of the unit in flight. This frees both hands for work. Any induced rotations produced by the astronaut's manipulating payloads and equipment or by changes in the center of gravity are automatically countered when sensed by small gyros.

Using the MMU

When it becomes necessary to use the MMU, an astronaut first enters the orbiter's airlock and dons a spacesuit. Exiting into space, the astronaut attaches a safety tether and moves along handholds to the MMU. The maneuvering unit is attached to the payload-bay wall with a framework that has stirrup-like foot restraints. Facing the MMU and with both feet in the restraints, the crewmember visually inspects



Bruce McCandless II pilots the MMU in space for its first flight.

the unit. If battery replacement is necessary or if the propellant tanks need recharging, those tasks can be accomplished at this time. When ready, the astronaut turns around and backs into position. The life-support system of the suit locks into place, hand-controller arms are unfolded and extended, and the MMU is released from the frame.

While maneuvering, the astronaut must use visual cues to move from one location to another. No other guidance system is necessary. The only contact with the orbiter during maneuvering is through the EMU radio voice-communication equipment.

While flying the MMU, the crewmember keeps track of the propellant supply with two gauges located on either side of his or her head. Keeping track of the supply is important because when it is depleted no additional maneuvering is possible. This means that the astronaut must keep in reserve for the return to the orbiter at least as much propellant as was expended in flying out to the satellite. The rest of the load can be used for maneuvering on station with the target. Generally, a total velocity change of 20.1 meters per second is possible on one flight. Furthermore, that delta velocity, as it is called, must be divided in half so that propellant will be available for the trip back. It is divided in half again to allow for rotational accelerations. Generally, astronauts fly the MMU at velocities of only 0.3 to 0.6 meters per second relative to the Shuttle. While these velocities may seem small, they accomplish much in the microgravity environment of Earth orbit. Once an astronaut begins moving in a new direction or at a new velocity, he or she will keep moving indefinitely until an opposing thrust is applied.

Upon completion of assigned tasks, the astronaut returns to the payload bay and reverses the unstowing procedure. To assist in realignment with the mounting frame, large mushroom-like knobs, built into the frame, are available for grasping by the crewmember as he or she pushes backwards onto the frame.

Future Space Suits

The Space Shuttle Extravehicular Mobility Unit, Manned Maneuvering Unit, and all the associated EVA systems are the result of many years of research and development. They now comprise a powerful tool for orbital operations, but they are not end-of-the-line equipment. Many improvements are possible: the spacesuit of the future may look dramatically different from the Space Shuttle EMU.

Advanced versions of the EMU are being studied, including spacesuits that operate at higher pressures than the current EMU. The advantage of higher operating pressures is that virtually no time will be lost to prebreathing in preparation for EVA.

To build an operational high-pressure suit requires improved joint technology and integration of those joints into the suit. Under consideration are fabric and metal suits and suits with a hard external shell. Most of the technology needed for these suits has already been tested. One of the biggest challenges is to make a highly mobile glove. At higher operating pressures, fingers of older-style spacesuit gloves become so increasingly stiff that finger dexterity is severely reduced. Research to address this problem has led to the development of high-pressure gloves made with metal bands for knuckle and palm joints. These gloves show potential for use with future suits as well as with current suits.

A prototype of a next-generation spacesuit is tested.

Another potential advantage of high-pressure suits is that they can be designed to be serviced and resized in orbit. Current EMUs can be used in space for up to 21 hours before they have to be completely cleaned and checked out on Earth. One new EMU potentially could be used for several hundred hours in space before a return to Earth is necessary. This capability will be vital when the United States constructs its first permanent space station in orbit. There,

A spacesuit technician tests a high-pressure hard suit.

crewmembers will remain in space for months at a time, and EVAs for station maintenance could become a routine event.

Another suit improvement is a “heads-up display” for reading the instruments on the EMU chest-mounted displays and control module. Heads-up displays are currently being used in the cockpits of commercial and military aircraft as well as on the flight deck of the Shuttle orbiter. These displays reflect instrument readings on a transparent screen so that a pilot can look straight out the window while landing instead of continually tilting his or her head down to check readings. A heads-up display should make DCM readings easier to see in sunlight and eliminate the need for Fresnel lenses or bifocals for some crewmembers.

The Manned Maneuvering Unit is also undergoing redesign. Although the exterior of the MMU is likely to remain the same, important changes are due on the inside. Larger nitrogen tanks, with greater operating pressures, could lead to substantially increased operational range in space.

Still further into the future, spacesuits will change to meet the demands of new missions. For the most part, the design of a spacesuit is based on the environment in which it is designed to operate. Space Shuttle spacesuits for use in Earth orbit are designed to operate in a vacuum and microgravity. A spacesuit for use on the surface of Mars, however, will require a different design. A Space Shuttle style of spacesuit would weigh about 43 kilograms on Mars. Consequently, lighter EMU structures will be needed to lessen the load a future Martian explorer will carry. In addition, the thin Martian atmosphere provides too much pressure for a cooling sublimator to work. Some other cooling strategy will have to be devised. Still another concern is to provide protection from dust that is carried by Martian winds and will be kicked up by the explorers. These and other properties of the Martian environment provide interesting and exciting challenges to spacesuit designers and builders.

EVA

Starting with Edward White’s spacewalk in 1965, American astronauts have logged many hundreds of hours of extravehicular activity in space. Mission planners correctly foresaw the role EVA would play in future space missions. The early Gemini experience was primarily experimental. During the Apollo and Skylab programs, EVA was critical to success. With the Space Shuttle, it is even more critical. The Shuttle, in spite of its complexity, is really a kind of space truck. It is a means—an economical transportation system—for getting payloads into space and returning them to Earth. Enhancing the Shuttle’s capability is the Extravehicular Mobility Unit. By donning the EMU and attaching a Manned Maneuvering Unit, an astronaut becomes a small, short-term spacecraft. Space-suited crewmembers can manipulate payloads, make adjustments, repair broken parts, join pieces together, and handle a host of other activities. Most important, they bring with them the human ability to cope with unexpected or unusual situations that occur in the hard and unforgiving vacuum of outer space.

With the capability of astronauts to go EVA, the Space Shuttle is more than just a transportation system. It is a satellite servicing vehicle, a space structure assembly base, an assembly tool for future space station construction, and a way station for preparing for deep space research missions. EVA is a vital part of America’s future in space.