NASA
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(NASA-PED-117) SPACESUIT GUIDEBOOK (NASA) N91-18603
24 p CSCL 06K Unclas
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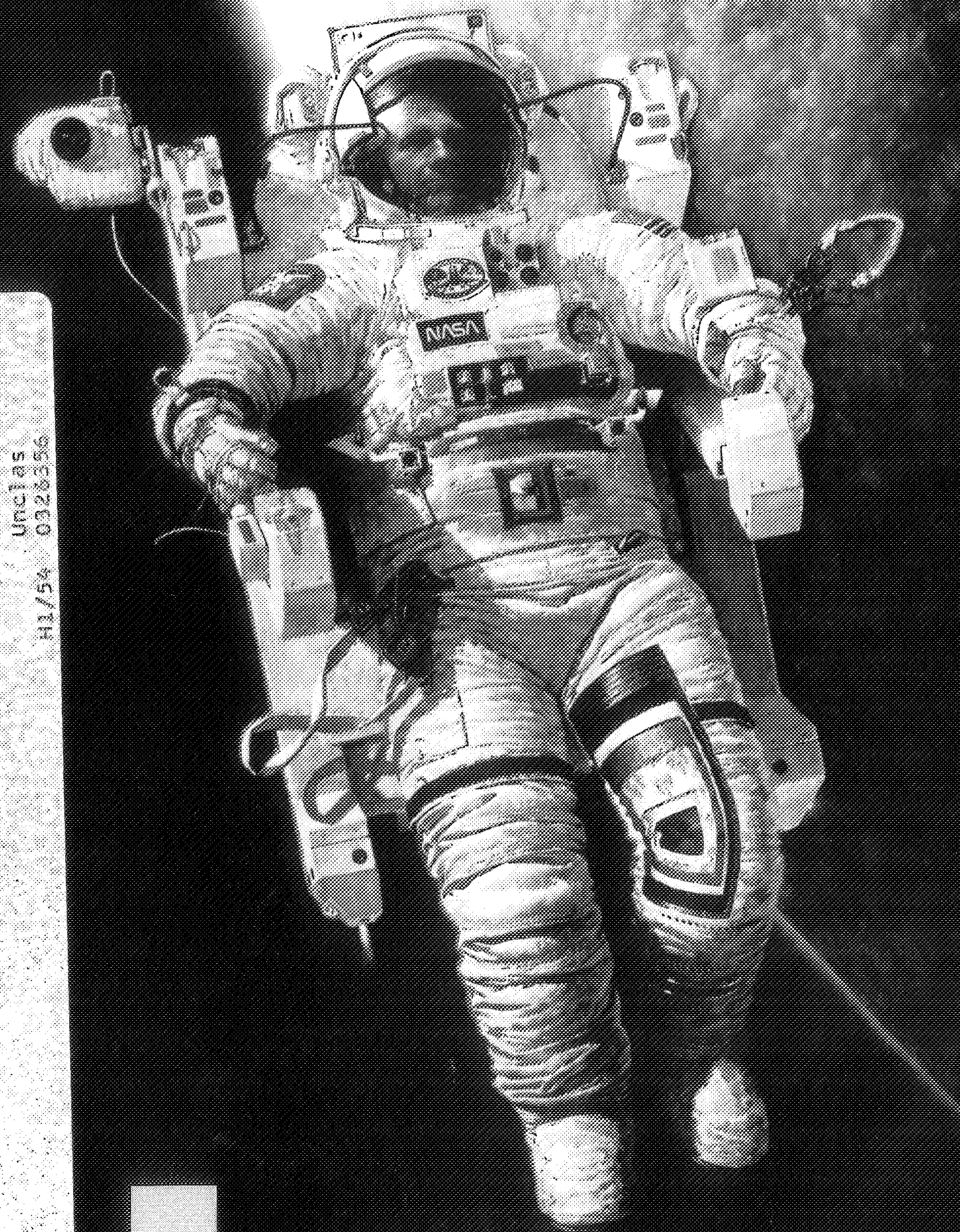
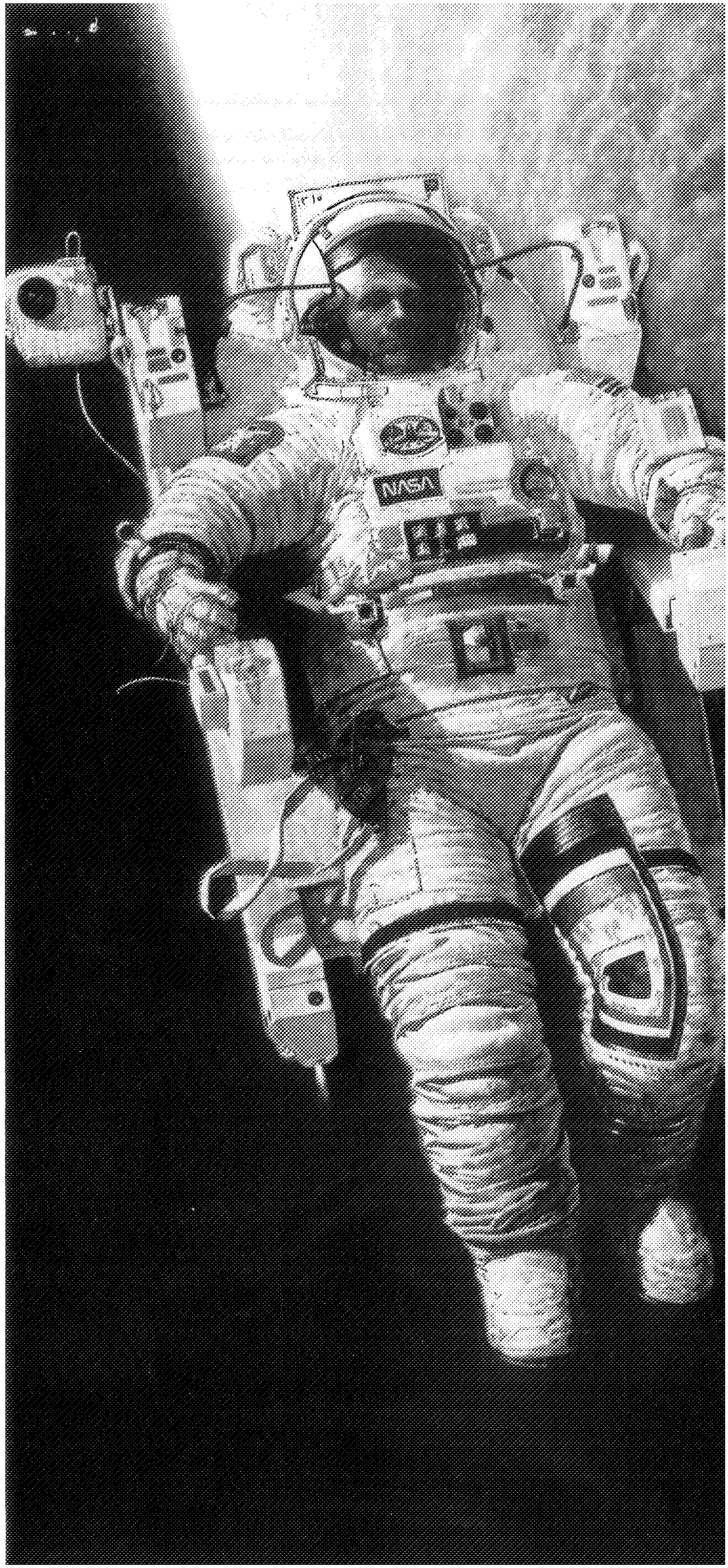


Spacesuit guidebook

Spacesuit Guidebook is designed to supplement *Spacesuit* wall chart (WAL-114), published by the Educational Affairs Division, January 1990. The wall chart depicts Astronuat Bruce McCandless on his historic first untethered spacewalk using the Manned Maneuvering Unit. He flew on Shuttle mission 41-B (February 3–11, 1984), and ventured 100 meters from the Shuttle's cargo bay and returned safely.

The guidebook explains in depth the elements depicted on the wall chart in see-through and cut-away perspectives. Together the wall chart and guidebook show as well as explain the inside workings of the spacesuit and its various components. Forty separate elements are identified with an accompanying numerical legend. Those elements are further explained in this guidebook along with their functions and how they work in relation to other elements. Additional chapters discuss essential components of the spacesuit such as the Primary Life Support System and the Manned Maneuvering Unit, and the method for donning the spacesuit.

The original manuscript for this guidebook was written by Greg Vogt, Oklahoma State University. It was expanded and edited into this format by Robert Haynes, NASA Headquarters. The oil painting, around which the wall chart was designed, was painted by American artist Bruce Wolfe. Many people assisted in reviewing this guidebook from the early stages up to the final booklet. Special thanks go to Keith Hudkins, NASA Headquarters, for identifying the 40 spacesuit components; and to James Poindexter, Johnson Space Center for reviewing the manuscript.



Spacesuit components

The EMU is what Space Shuttle astronauts call their spacesuit. EMU stands for Extravehicular Mobility Unit. It is what protects astronauts from the harsh environment of space outside the Space Shuttle's crew cabin. The EMU includes many individual components that, when assembled, form a single spacesuit.

Making the EMU is an exacting process. Pressure and restraint layers are enclosed by thermal insulating and tear and puncture resistant layers. One layer's function is just to keep the astronaut from overheating. Suit layers are joined to metal connecting rings and a hard fiberglass upper torso. Each layer and each component must pass stringent inspections before a human life is entrusted to it.

When fully assembled, the EMU becomes a nearly complete short-term, "soft," 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 only thing lacking in the EMU is propulsion, but this can be added by fitting a gas-jet-propelled Manned Maneuvering Unit. On Earth the suit and all its parts weigh about 112 kilograms. In orbit, they have no weight at all, but do retain their mass, which astronauts feel as a resistance to a change in motion.

The list that follows corresponds to the numerical legend on the wall chart. Some items will be self-explanatory, while others are parts of systems. Items 1 and 2 are explained more fully in their own chapters.

1. **Primary Life Support System**
   This portable life support system is an essential component of the spacesuit. It is the backpack unit that the astronaut is wearing (it is only partially visible in the painting, shown on either side of the astronaut's helmet). The life support system contains all the control and monitoring systems required to sustain the astronaut's life while in space. It supplies oxygen for breathing and for suit pressurization, and cleans carbon dioxide and odors from the air inside the suit. A tiny built-in computer warns the astronaut of problems.
2. **Manned Maneuvering Unit Thruster**
   A series of 24 thrusters is located on the Manned Maneuvering Unit (MMU). The astronaut controls them with hand controllers at the ends of the MMU's two arms. (See item 40.) The thrusters may also be operated automatically by turning on an automatic attitude hold system. Compressed nitrogen is moved through feed lines to varying combinations of the 24 nozzles. The nozzles are arranged in clusters of three each on the eight corners of the maneuvering unit, and are aimed along three axes perpendicular to each other (x, y, and z) and permit six degrees of freedom of movement. Movements in space are explained by the terms roll (rotation around y axis), pitch (z axis), and yaw (x axis).
3. **Thruster Lights**
   While flying the Manned Maneuvering Unit, the astronaut keeps track of propellant with two gauges located on either side of the helmet's face plate. An astronaut needs to know how much propellant is left in the unit, because when the propellant is gone, the astronaut is no longer able to maneuver. The astronaut needs to keep enough fuel in reserve to return safely to the Shuttle. Generally, this means an astronaut can use up half the fuel to maneuver away from the Shuttle and keep the remaining half for the return.
4. **Extravehicular Mobility Unit Lights**
   EMU lights are found on either side of the astronaut's helmet and are used to shine light on objects in space. The small built-in flood lamps light up places sunlight and lights in the cargo bay do not reach. The EMU lights have their own battery system and are needed for work in the Shuttle cargo bay or for repairing satellites in space. When the astronauts are building the Space Station *Freedom*, the EMU lights will help them assemble the pieces of the Station while in orbit above Earth.
5. **Color Television Camera**
   The camera's lens system is about the size of a postage stamp, and mounted just over the helmet.

Television monitoring is necessary for certain communications with the Shuttle and Mission Control. The camera is situated in line of view with the astronaut's own line of vision and is equipped with its own batteries and RF transmitter so that the crew inside the Shuttle and mission controllers on Earth can get an astronaut's eye view of the spacewalk. During complicated spacewalks, viewers may be able to provide assistance.

6. **Helmet Solar Shield**
Shown in the wall chart as a cutaway, the solar shield is actually part of an entire assembly that covers the helmet. The visor assembly contains a metallic gold-coated Sun-filtering visor, a clear thermal impact protection visor, and adjustable blinders that attach over the helmet. These shields are necessary to protect astronauts from harmful light and radiation emitted by the Sun.

The helmet itself is a plastic pressure bubble with a neck disconnect ring and ventilation distribution pad. The helmet has a backup purge valve (for use with a secondary oxygen pack worn beneath the Primary Life Support System backpack) and is used to remove expired carbon dioxide. (See item 11.) A tube projects into the helmet near the astronaut's mouth from a plastic water pouch attached inside the spacesuit's hard upper torso. The tube allows the astronaut to drink from it as if from a straw, providing him or her with fresh water. Also mounted inside the helmet near the water tube is an astronaut snack food bar.

7. **Communications Microphone**
Voice communication with the Shuttle and Mission Control are essential at all times. The microphone inside the helmet connects to the radio module located in the life-support unit of the spacesuit. Covering the astronaut's head is the communications carrier assembly, or "Snoopy Cap" as it is sometimes called. The assembly is a fabric skull cap with built-in earphones and a microphone for use with the spacesuit's radio.

8. **35mm Still Camera**
Views of the Shuttle, its cargo bay, satellites, Earth, and other phenomena are captured for study by the 35mm camera. The camera is attached to the Manned Maneuvering Unit and is situated in line of view with the astronaut's own line of vision.

9. **Camera Switch**
The 35mm still camera is operated by a cabled switch connected to the camera and the glove of the EMU. The astronaut merely needs to press a button on the end of the cable attached to his or her glove, and the camera automatically focuses, snaps the picture, and advances the film for the next picture.

10. **Spacecraft Life-Support Connector**
Long before donning the upper half of the EMU, the Shuttle's Service and Cooling Umbilical is plugged into the dispays 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 are conserved during the prebreathing activity that is needed before an astronaut can leave the Shuttle crew cabin. The umbilical remains connected to the spacesuit until the astronaut disconnects it after moving from the airlock into the cargo bay. At the time the umbilical is released, the spacewalk begins. The Service and Cooling Umbilical is also used to recharge batteries and replenish consumables.

11. **Emergency Relief Valve**
Should the Primary Life Suport System malfunction, the astronaut can survive for 30–60 minutes by using the secondary oxygen pack (see chapter 3, "Primary Life Support System"). This system is activated by opening the purge valve. This valve, which has a set of pinchers on either side of it, allows the astronaut to let some of the pressure out of the EMU. To activate the valve, the astronaut simply squeezes the pinchers with the EMU glove, and air pressure is released through the tube-like extension on the EMU chest plate.

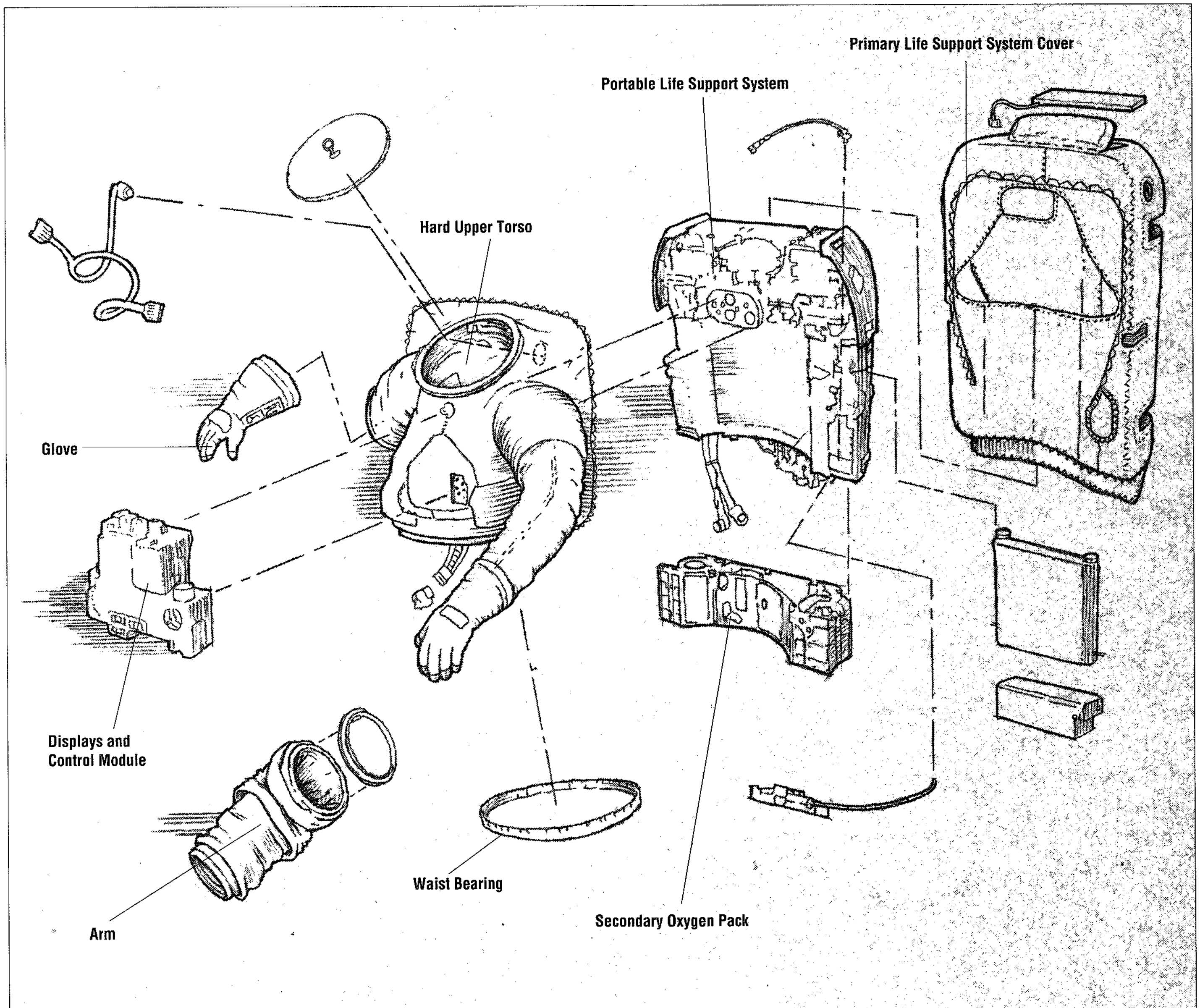
12. **Water Cooling Control Valve**
The astronaut is able to control his or her body temperature inside the spacesuit by controlling the temperature of water circulating through the Liquid Cooling and Ventilation Garment. The garment (item 29) is laced with an intricate network of

plastic tubing, through which water is circulated to keep the astronaut cool and to help control perspiration.

Note that the numbers on the Water Cooling Control Valve are printed backwards. The reason is that the location of the display control module on the hard upper torso prevents the astronaut from being able to bend down to look at the controls when he or she needs to adjust them. If you look just to the right of the control valve, you'll see a small mirror strapped to the astronaut's arm. The mirror reflects the numbers in their correct position. Whenever an astronaut must adjust a switch or valve that is not otherwise visible, the mirror helps in locating and adjusting it.

13. Push-to-Talk Switch

This switch operates the micro-



Extended view of the upper part of the EMU phone inside the helmet. The voice radio works much as a CB radio works. The talk button must be pushed to talk, and released to receive voice messages.

14. **Fan Switch**
This switch turns on and off a fan inside the EMU to circulate air through the helmet and other areas of the spacesuit.

15. **Caution and Warning Switch**
This switch starts the caution and warning system to display states of various functions within the EMU.

16. **Communications Volume Controls**
Volume controls are required to keep some messages from blaring in the astronaut's ears, and to better tune in faint ones.

17. **Computer Screen Intensity Controls**
This switch controls the intensity of the readout on the computer display (see item 18).

18. **Computer Display**
The computer display atop the display and control module shows an alpha and numeric readout for monitoring by the astronaut. The readout shows levels of oxygen, fuel, and power remaining in the EMU's Primary Life Support System.

19. **Oxygen Pressure Actuator**
This switch allows the astronaut to select the internal oxygen pressure of the EMU.

20. **Mini-workstation Connector**
Often the astronaut works in or around the Shuttle's cargo bay, performing tasks that require tools. These EMU connections allow the astronaut to attach a small workstation while performing a task requiring it, and to remove it when no longer needed.

21. **Manned Maneuvering Unit (MMU) Release Ring**
When it is not in use and during the donning procedure, the MMU is stowed in the flight support station. In this location, astronauts prepare the MMU for flight, charging batteries and replenishing propellant tanks. In donning the MMU, the astronaut backs into it while it is secured on the flight support station. The MMU is released from the flight support station via these two release rings and the astronaut maneuvers away using the MMU propulsion power.

22. **Safety Tethers**
When astronauts work in the Shuttle's cargo bay, they need to keep from floating too far away from the spacecraft. Sometimes they work in stations with foot restraints, but mostly they wear safety tethers. These tethers can be moved from location to location along the cargo bay to provide the astronaut with a full range of mobility, while still keeping the astronaut within safe working distance of the cargo bay.

23. **Locator Strobe Lights**
Strobe lights are used on the MMU to help EVA astronauts locate each other's position, as well as to help crew members on the Shuttle keep track of EVA progress. Strobe lights are effective means for locating objects in poorly lit regions.

24. **Micrometeoroid/Tear Protection Layer**
This is the outermost layer of the spacesuit. It comprises the outer layer of the Thermal Micrometeoroid Garment. This layer is of Ortho Fabric™, a blend of woven Nomex™ and Teflon™ with Kevlar™ Rip Stops. It protects subsequent layers of the spacesuit, namely the Pressure Restraint Layer and the Pressure Bladder from abrasions and tears.

25. **Super Insulation Layers (Aluminized Mylar™)**
The next five layers of the Thermal Micrometeoroid Garment provide the astronaut with thermal protection. The material in these layers is Aluminized Mylar™ Film, which is reinforced with Dacron™ Scrim.

26. **Second Micrometeoroid Layer (Neoprene™)**
As the inner lining for the Thermal Micrometeoroid Garmet, this layer is the final barrier of micrometeoroid protection. The material is Neoprene™ coated Nylon™ cloth.

27. **Pressure Restraint Layer (Dacron™)**
This layer is composed of synthetic fabric placed over the pressure bladder fabric to give it additional support and shape. (See also items 28 and 31.)

28. **Pressure Bladder (Polyurethane-coated Nylar™)**
Pressure bladders are much like today's tubless tires, composed of rubber (urethane) to seal in the air pressure and Nylon™ to restrain expansion. For the bladder in the spacesuit, Nylon™ is dipped in polyurethane a minimum of six times to create an impermeable barrier between the pressure of the pure oxygen inside the spacesuit and the vacuum of

space on the outside. (See also items 27 and 31.)

29. Liquid Cooling and Ventilation Garment (Ethelene Vinyl Acetate Tubing)
Almost like a pair of longjohns, the Liquid Cooling and Ventilation Garment covers the astronaut's upper and lower body. The garment itself contains ethelene vinyl acetate tubing, through which water is circulated to control the temperature.

30. Body Comfort Lining (Nylon™ Chiffon)
This is the first layer of fabric touching the astronaut's skin. It is made of Nylon™ chiffon, a lightweight material, to be as comfortable as possible. It is positioned between the astronaut and the Liquid Cooling and Ventilation Garment.

31. Pressure Restraint System
The materials used for the EMU pressure restraint system are a composite of items. Airtight linings with comfort fabrics are a significant part, but the spacesuit must also be flexible and retain its shape as well as inside pressure. (See also items 27 and 28.)

Joints for the lower and upper torsos represent an important advance over those of previous spacesuits. The 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.

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

Shuttle EMU Spacesuit Assembly Materials and Application Functions

Material	Function 1	Function 2	Function 3
Ortho Fabric (Woven Nomes and Teflon with Kevlar Rip Stop)	Abrasion and tear protection for pressure restraint and bladder	Thermal control	Micrometeoroid protection as part of Thermal Micrometeoroid Garment
Aluminized Mylar Film Reinformced with Dacron Scrim	Thermal insulation	Micrometeoroid protection as part of Thermal Micrometeoroid Garment	
Neoprene Coated Nylon Cloth	Micrometeoroid barrier layer	Inter-liner for Micrometeoroid Garment	
Fiberglas 8 Ply Layup	Pressure/load structure for hard upper torso assembly	Life support and display module attachment structure and fluids and gas connections	Helmet, arm, and lower torso attachment structure
Dacron Cloth	Pressure restrain/load structure for arms, gloves, and lower torso assembly	Single axis joint flexure for elbow, wrist, finger, waist, knee, and ankle mobility	
Polyurethane-coated Nylon Cloth	Pressure bladder for arms and lower torso assembly		
Dipped Polyurethane Film	Pressure bladder for gloves		
Multi-Filament Stretch Nylon	Attachment restraint for coolant tubing and ventilation gas ducting	Attachment restraint for bio-medical instrumentation and radiation dosimeters	Attachment restraint for body comfort interlining
Ethelene Vinyl Acetate Tubing	Water coolant distribution for body termal control		
Nylon Chiffon	Body comfort lining		

of suit connections. For example, to open or unlock any of the ring seals on the EMU, one or two sliding rectangular knobs are moved to the right or the left. When opened, the two halves come apart easily. To close and lock, one of the rings slides partway into the other against an O-ring seal. The knob is slid to the right, and small pins inside the outer ring protrude into a groove around the inside ring, thereby holding the two together.

33. Glove Disconnect
See item 32 for discription.

34. Inner Glove
The 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.

35. Liquid Cooling and Ventilation Garment Connector to Life Support System
After the astronaut slips into the upper torso section of the EMU, two connections must be made. The first connection joins the plastic tubing of the Liquid Cooling and Ventilation Garment to the Primary Life Support System. The second connection is for the biomedical monitoring sensor on the EMU electrical harness that is also attached to the life support system. Then the astronaut locks the two body-seal closure rings together, sometimes with the help of another crew member.

Shown here, the restraint layer of the EMU glove is placed over the bladder. The bladder is formed when a ceramic cast of a hand is dipped seven or eight times into a vat containing urethane. Then the hand-shaped bladder is stripped from the cerammic cast and inflated to check for defects and leaks.

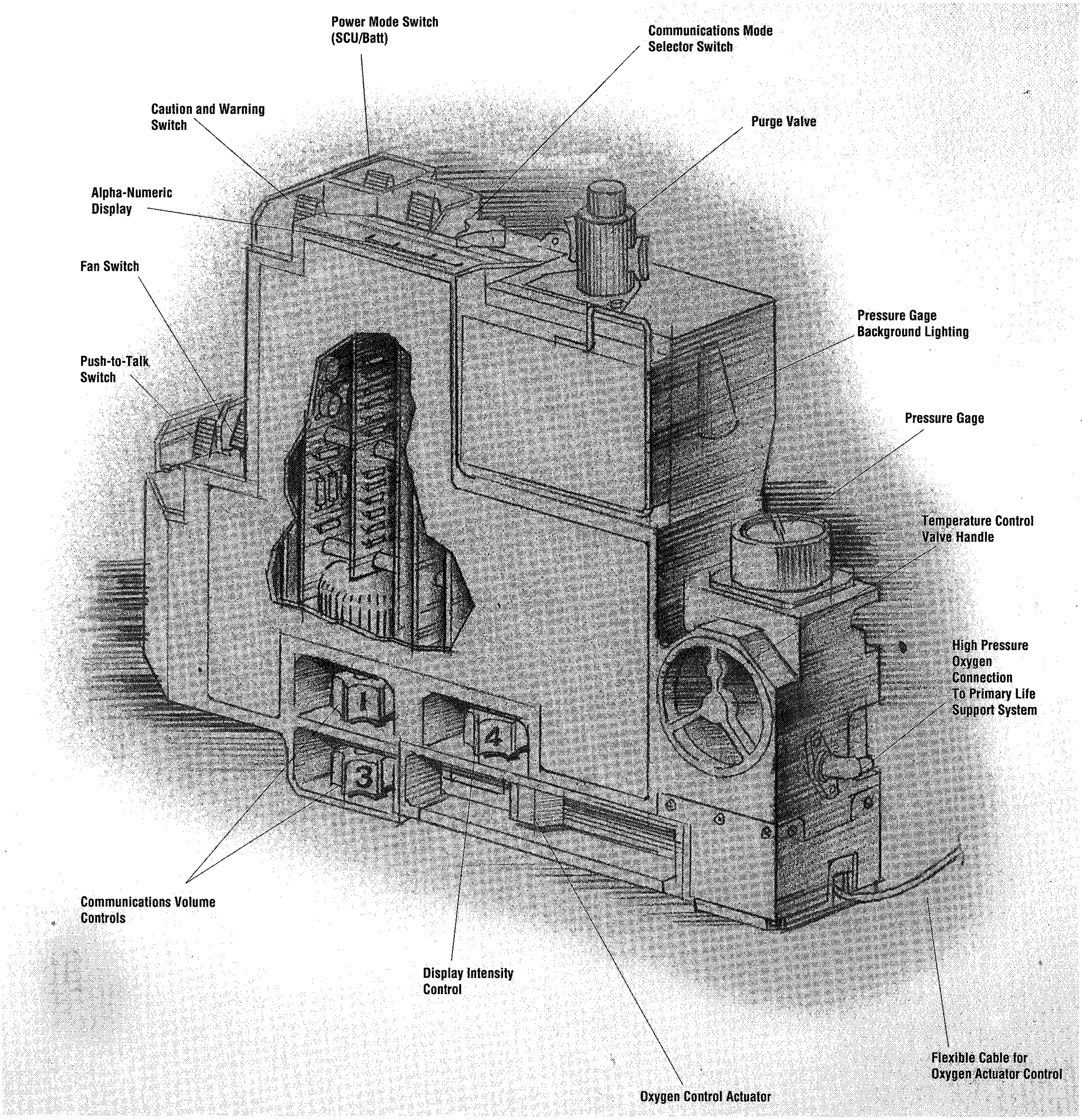
36. Manned Maneuvering Unit Safety Belt
This safety belt harness secures the astronaut into proper position while wearing the Manned Maneuvering Unit.

37. Tool Tether
While in space orbiting Earth, the astronauts experience near weightlessness. For instance, in the Shuttle's cargo bay, anything that is not secured by some method tends to float off. This is true of the small tools required for work in the cargo bay or for repairing satellites in space. The astronauts cannot simply lay the tool down when it is not being used. The tool tether keeps small tools from drifting away, holding them within working range of the astronaut's grasp.

38. Waist Bearing
The upper torso and lower torso sections of the EMU are joined by a metal body-seal closure. Two rings — one on the upper torso and one on the lower torso — lock together in a fashion similar to other ring-seals. There is also a large waist bearing that permits astronauts mobility at the waist. This permits them to make twisting motions when their feet are secured by foot restraints on stationary work platforms.

39. Procedure Check List
A small, spiral-bound, 27-page checklist for various spacewalk procedures is mounted on the left arm of the upper torso. There is also a small wrist mirror. The mirror was added to the spacesuit because some of the knobs that regulate various life-support functions of the EMU on the front of the display and control module are out of the astronaut's vision range. The mirror permits the astronaut to read the knob settings, which are written on the spacesuit backwards to make them easy to read with the mirror.

40. Rotational Hand Controller
A hand controller is built into each arm of the Manned Maneuvering Unit. The hand controllers allow the astronaut to direct the firing of different combinations of MMU thrusters for nearly complete controll over his or her movements. In space, there is no up or down, the direction of movement is discussed with the terms roll, pitch, and yaw.



An extended view of the display and control module

Donning the spacesuit

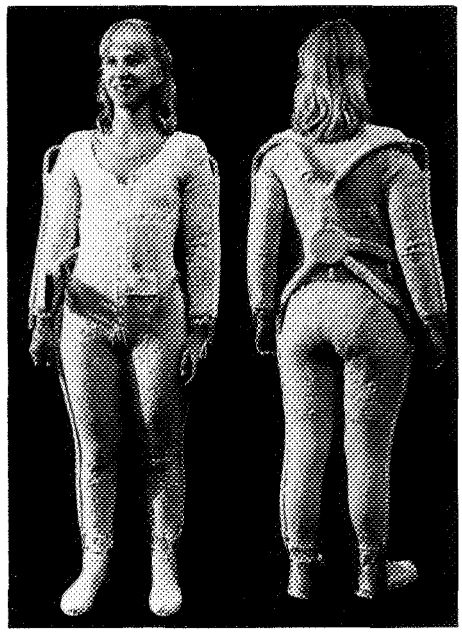
The EMU can be donned in about 10 to 15 minutes. But preparing to go outside the Shuttle crew cabin takes about two hours and twenty minutes. Inside the crew cabin, astronauts breathe a mixture of nitrogen and oxygen at the same air pressure as at sea level on Earth (101 kilopascals). But inside the spacesuit, astronauts breathe pure oxygen at a much lower pressure (29.6 kilopascals, or roughly one-third the cabin pressure). If an astronaut goes directly from the cabin into the spacesuit, the rapid drop in pressure around the body could cause caisson disease. Also known as "the bends," this disease happens when the external pressure around the body drops too quickly, causing bubbles of nitrogen to form and expand in a person's bloodstream. It is the same debilitating problem that underwater divers sometimes experience if they rise to the surface too quickly. The disease can cause severe pains in the joints, cramps, paralysis, and even death if pressure around the person is not gradually returned to normal.

To prevent caisson disease, the astronauts (a team of two) intending to go EVA must remove nitrogen from their bloodstreams. They do this by spending time breathing pure oxygen. Called "prebreathing," this activity begins when the two astronauts don their special launch and entry helmets. They breathe pure oxygen from the orbiter oxygen supply system for one hour. Approximately 12 hours before the astronauts exit into space, the cabin pressure is reduced from the normal 101 kilopascals to 70.3 kilopascals, and the percentage of oxygen is slightly increased. By the end of this phase, much of the nitrogen has been cleared from the astronauts' bloodstreams and the two astronauts can remove their launch and entry helmets. When they put on their spacesuits and seal the helmets, the astronauts prebreathe pure oxygen for an additional 30 to 40 minutes before pressure inside is lowered to 29.6 kilopascals.

After prebreathing, the first items to be put on are the urine collectors. The device for males is called the Urine Collection Device and is simply an adaptation of a device used for people who have kidney problems. It is a pouch that can contain approximately one quart of liquid and is attached via a roll-on connector cuff. For females, the urine collector is called the Disposable Absorption and Containment Trunks. These trunks are multilayered shorts that hold a highly absorptive powder, and are also capable of containing about a quart of liquid.

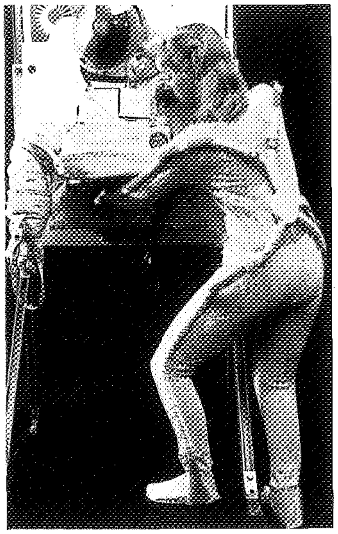
Most of the EMU donning process takes place inside the orbiter's airlock. The airlock is a cylindrical chamber located on the orbiter's mid-deck; one hatch leads from the mid-deck into the airlock and a second hatch leads from the airlock out to the unpressurized cargo bay.

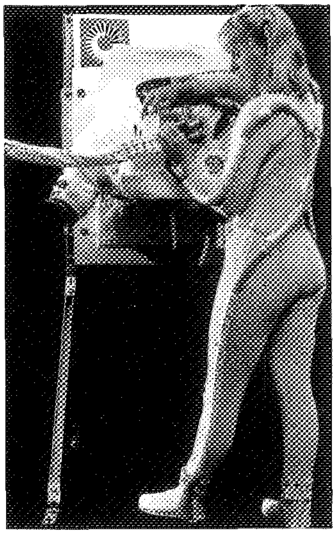
Inside the airlock, the astronauts put on the Liquid Cooling and Ventilation Garment. The garment has the general appearance of long underwear. It is a one-piece suit with a zippered front and is made of stretchable Spandex™ fabric laced with 91.5 meters of plastic tubing. When the EMU is completely assembled, cooling and ventilation become significant problems—body heat, contaminant gases, and perspiration all must be removed.

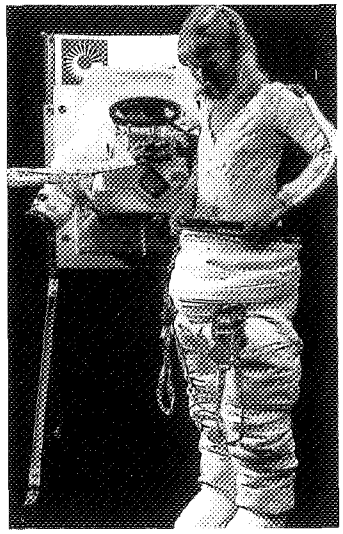


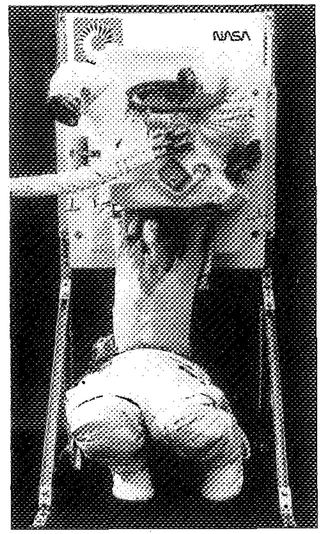
The fabric of the Liquid and Cooling Garment is laced with plastic tubing to circulate cooling water

Cooling of the crew members is accomplished by circulating chilled water through the plastic tubes in the garment. Chilling the water is one of the functions of the Primary Life Support System. Oxygen and expired carbon dioxide are drawn from the suit's atmosphere through ducts into the Primary Life Support System for purification and recirculation. Body perspiration is also drawn away from the suit by the venting system.


The upper torso of the EMU is prepared for donning.


The Service and Cooling Umbilical of the orbiter is hooked up to the upper torso.

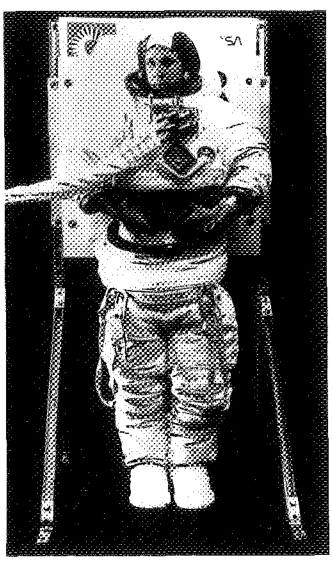

The lower torso of the EMU is donned

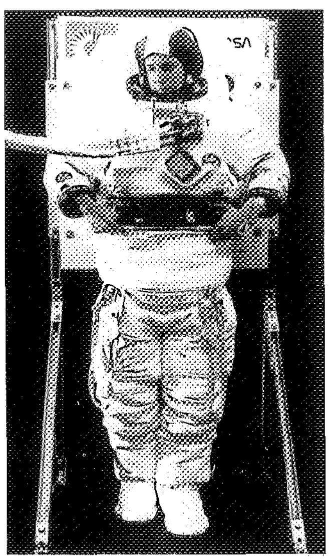

With a diving motion, the astronaut dons the upper torso.

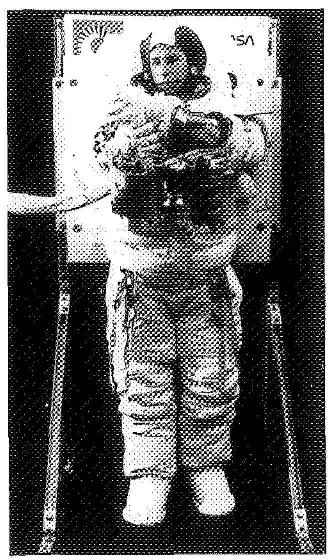
Purified oxygen from the Primary Life Support System reenters the suit through a duct in the back of the helmet, which directs the flow over the astronaut's face to complete the circuit.

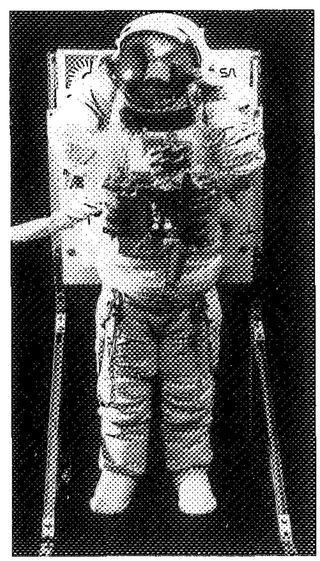
Next, the EMU electrical harness is attached to the hard upper torso. The electrical harness provides biomedical and communications hookup with the Primary Life Support System. The biomedical hookup monitors the heart rate of the astronaut, and radios this information via a link with the orbiter to Mission Control on Earth. Voice communications are also carried on this circuit.

Next, several simple tasks are performed. Antifog compound is rubbed on the inside of the helmet. The wrist mirror and checklist are put on the left arm of the upper torso. Also at this time a food bar and


The Liquid Cooling and Ventilation Garment is connected.


The upper and lower rings of the waist entry closures are joined and sealed


The EMU gloves are donned.


The helmet and visor assembly is donned.

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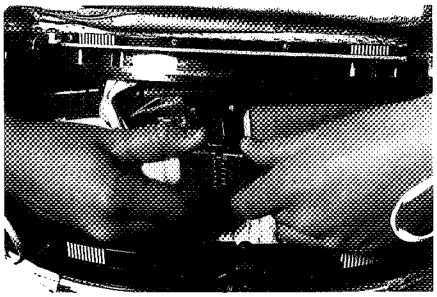
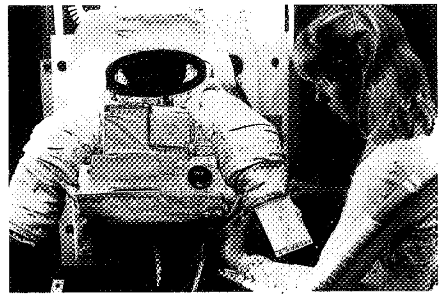
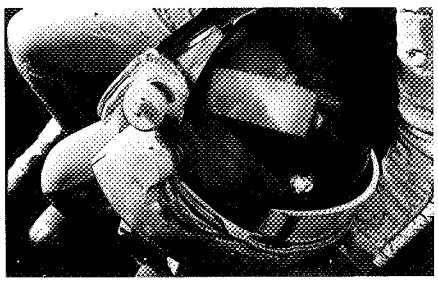
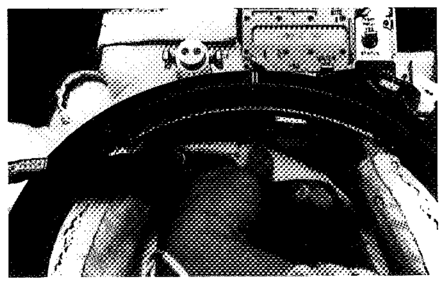

The Biomedical Unit is connected.


An EVA checklist is attached to the upper torso's left sleeve.


An antifog compound is applied inside the helmet.


A food bar and the In-suit Drink Bag are inserted inside the neck ring of the upper torso.

water-filled In-suit Drink Bag are inserted inside the front of the hard upper torso. 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 astronaut's mouth. When the astronaut is hungry, he or she merely 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 piece, making it mushy and impossible to extract. The In-suit Drink Bag is placed just over the bar. The bag is filled with up to 0.65 liters of water from the water supply in the Shuttle's galley prior to entering the airlock. A plastic tube and valve assembly extends up into the helmet, and a drink can be taken whenever needed. Both the food bar and drink bag are held in place by Velcro™ attachments.

Next, the communications carrier assembly or "Snoopy Cap" is connected to the EMU electrical harness and left floating above the hard upper torso. The communications carrier assembly earphones and microphones are held by the fabric cap. After the astronaut 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, are pulled on. The lower torso comes in various sizes to meet the varying size requirements of different astronauts. It features the pants with boots, 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 crew member mobility at the waist, permitting twisting motions when the feet are held in workstation foot restraints.

The fabric of both the lower and upper torso is multilayered. The inner layer is a pressure bladder made of urethane-coated Nylon™. Above this layer is a restraining layer of Dacron™. Enclosing this layer is an outer thermal garment of neoprene-coated Nylon™, five layers of aluminized Mylar™ laminated with Dacron™ scrim, and the outermost layer, a combination of Gortex™, Kevlar™, and Nomex™.

Long before donning the upper half of the EMU, 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 orbiter itself. In this manner, the "consumables" stored in the Primary Life Support System will be conserved during the lengthly prebreathe period. The Service and Cooling Umbilical is also used for recharging batteries and replenishing consumables between EVAs.

With the lower torso in place and the orbiter providing consumables to the suits, each astronaut "dives" with a squirming motion into the upper torso. To dive into it, each 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 astronaut slips into the upper torso.

Two connections are made. The first joins the cooling-water tubing and ventilation ducting of the Liquid Cooling and Ventilation Garment to the life support system. The second connects the biomedical monitoring sensors to the EMU electrical harness that is connected to the life-support unit. Then the astronaut locks the two body-seal closure rings together, usually with the assistance of another crew member who remains on board.

One of the most important features of the upper half of the suit is the hard upper torso, a hard Fiberglas™ shell covered by the fabric layers of the Thermal Micrometeoroid Garment. The hard upper torso is similar to the breast and back plates of a suit of armor. It provides a rigid and controlled mounting surface for the Primary Life Support System on the back and the display and control module on the front.

The last EMU gear to be donned includes eyeglasses, if needed, the communications carrier assembly, comfort gloves, the helmet with lights and optional TV, and gloves. 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 astronaut to move his or her head around.

With the donning of the helmet and gloves, the spacesuits are now sealed off from the atmosphere of the airlock and the astronauts are being supported by the oxygen, electricity, and cooling water provided by the Shuttle. A manual check of suit seals is made by pressurizing each suit to 29.6 kilopascals d. (The "d" stands for differential.) 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. 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 and the oxygen supply is turned back on.

As the suit pressure is elevated, the astronaut may experience discomfort in the ears and sinus cavities. The astronauts compensate for the pressure change either by swallowing or yawning, or by pressing their noses on an optional sponge mounted to the left on the inside of the helmet ring and blowing. This forces air inside the ears and sinus cavities to equalize the pressure.

The Communications Carrier Assembly is placed over the head.

During the next several minutes the two spacesuits are purged of any remaining oxygen/nitrogen atmosphere from the cabin, which 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. When the airlock pressure reaches 34.48 kilopascals, the bleed-down is temporarily stopped to check for leaks. If the EMU is found to have any leaks, the airlock is repressurized, permitting astronauts and crew members to reexamine the EMU seals.

If there are no leaks, final depressurization is begun. The outer airlock hatch is then opened and the suited astronauts prepare to pull themselves out into the cargo bay. As a safety measure, they attach tethers to the orbiter to prevent floating away as they move from place to place by hand holds. At this point, the astronauts disconnect the Orbiter Service and Cooling Umbilical from the EMU and pull themselves through the outer airlock hatch. The Primary Life Support System begins using its own supplies. The EVA begins. When in space, the two astronauts are identified by the use of red stripes on the EMU pants legs. One EMU will have stripes and the other will not.

Primary life support system

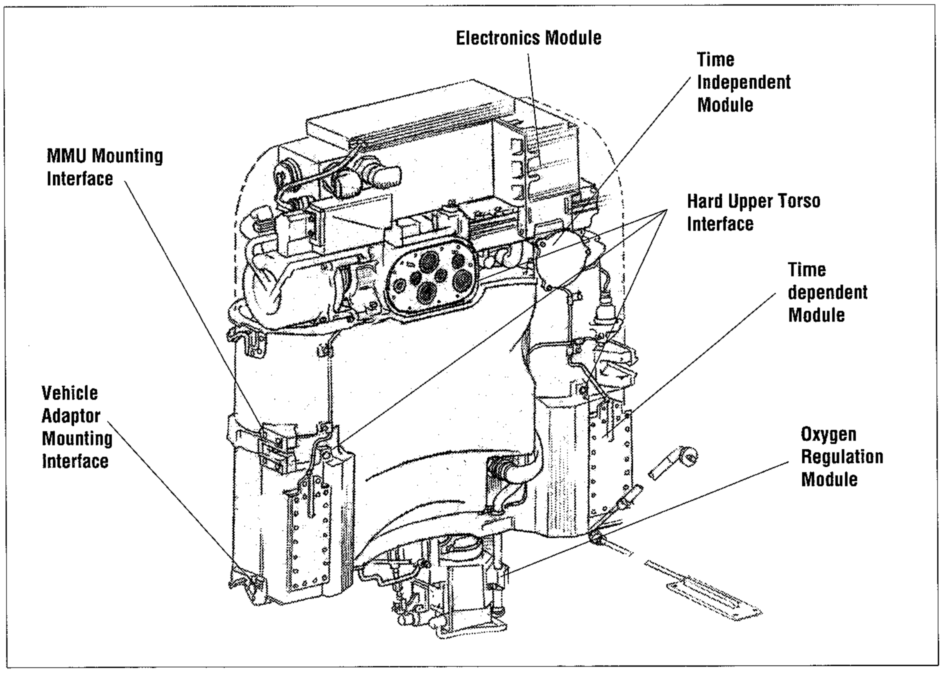
During the Apollo Moon walks, astronauts experienced their first real freedom inside spacesuits because of a portable life support system worn on their backs. Up to that time all EVAs were tethered to the spacecraft by an umbilical line that supplied oxygen and kept astronauts from drifting away.

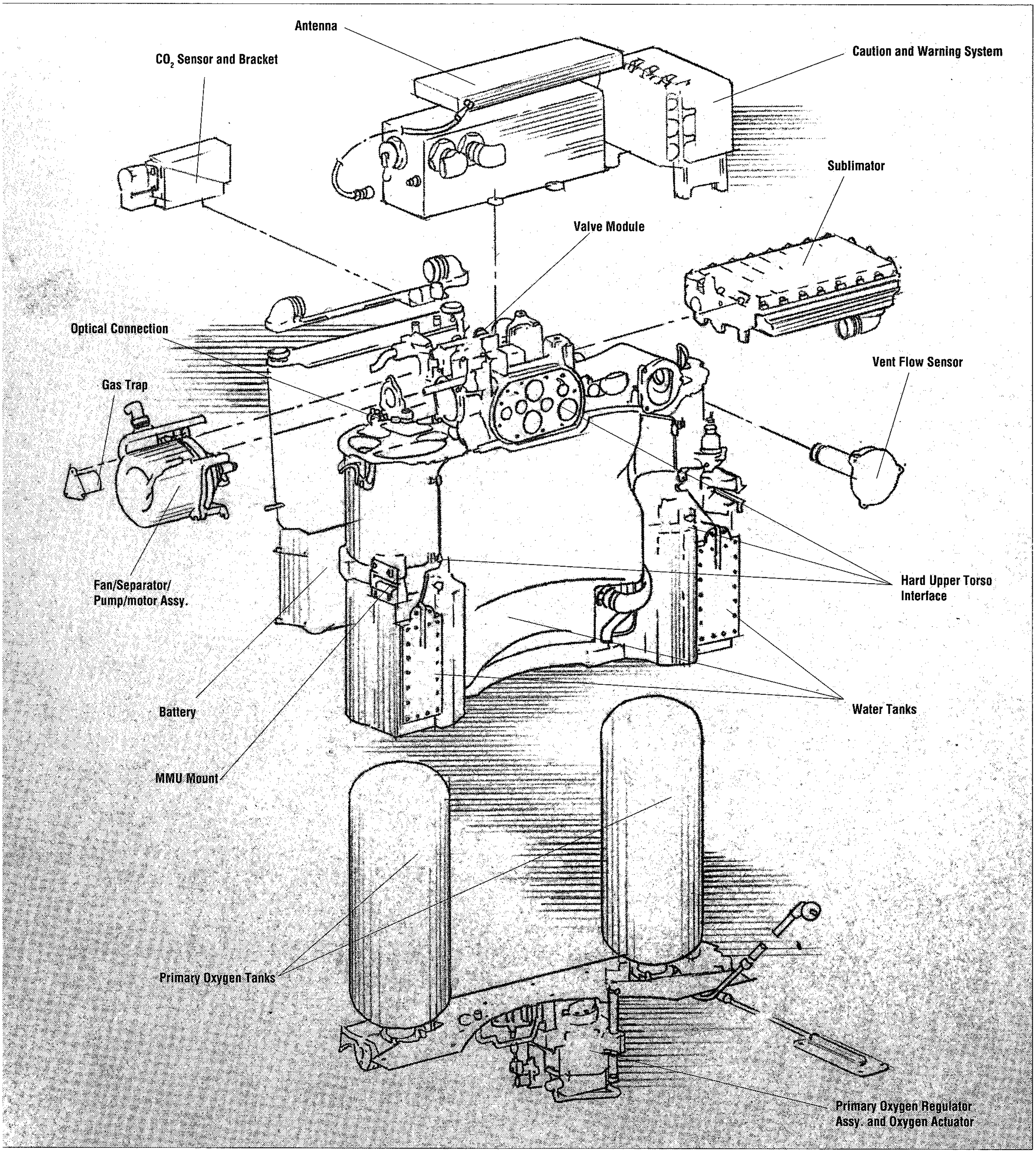
EVAs aboard the Space Shuttle allow astronauts greater freedom. Because Shuttle EVAs take place in the near weightless environment of space, astronauts do employ tethers, but these act only as safety lines and do not provide life support.

The freedom of movement afforded Shuttle astronauts is owed to the Primary Life Support System carried on their backs. The Primary Life Support System provides life support, voice communications, and biomedical telemetry for EVAs lasting as long as 7 hours. Within its dimensions of 80 by 58.4 by 17.5 centimeters, the system contains five major groups of components for life support. These 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 Primary Life Support System 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 helmet, where it is directed over the head and then downward along the inside of the helmet face plate. Before passing into the helmet, the oxygen warms sufficiently to prevent fogging the visor. As the oxygen leaves the helmet and travels into the rest of the suit, it picks up carbon dioxide from the astronaut's respiration. 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, at a rate of about 0.17 cubic meters per minute, back into the Primary Life Support System, where it passes through a filtration cartridge.

Carbon dioxide and trace contaminants are filtered out by lithium hydroxide and activated charcoal layers. The gas stream then travels through a heat exchanger and sublimator for chilling and removal of humidity. The heat exchanger and sublimator also chills water that runs through tubing in the Liquid-Cooling and Ventilation Garment. The humidity in the gas stream condenses in the heat exchanger and sublimator and relatively dry gas (now cooled to approximately 13° Celsius) is directed through a carbon dioxide sensor before recirculating through the suit. Oxygen is regulated by the Primary Life Support System 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-




Antenna
CO_2 Sensor and Bracket
Caution and Warning System
Sublimator
Valve Module
Optical Connection
Vent Flow Sensor
Gas Trap
Fan/Separator/
Pump/motor Assy.
Hard Upper Torso
Interface
Battery
Water Tanks
MMU Mount
Primary Oxygen Tanks
Primary Oxygen Regulator
Assy. and Oxygen Actuator

rich gas to dump outside the suit just before it reaches the contaminant control cartridge.

A byproduct of the oxygen ventilating circuit is moisture. The water, which is produced by perspiration and breathing, is withdrawn 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 system is able to maintain suit cooling for a longer period than would be possible with just the tank's original water supply.

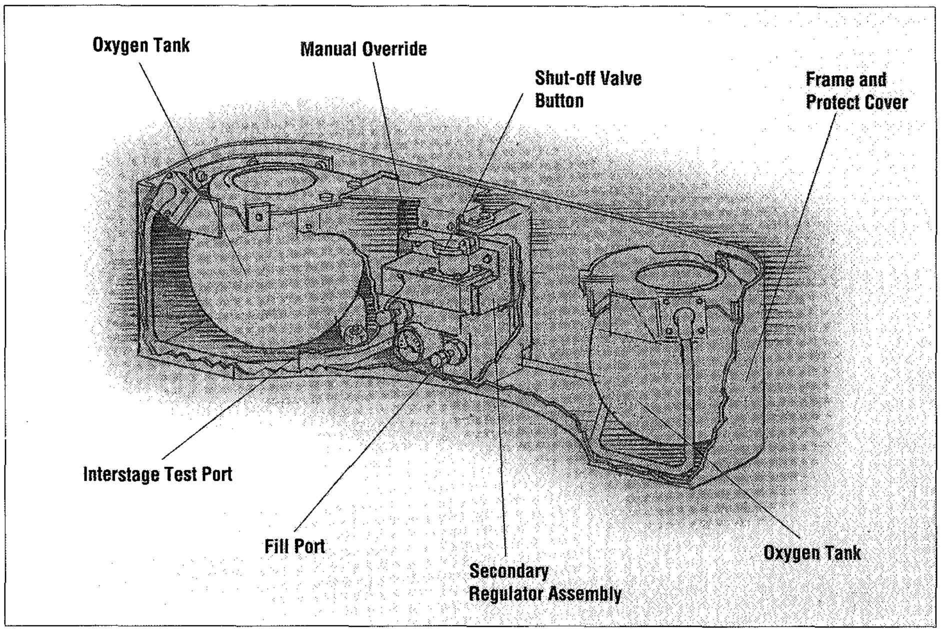
The job of cooling the astronaut is the function of the feedwater and the liquid transport circuits.

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 Liquid Cooling and Ventilation Garment. 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 main 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 7-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.

To insure the safety of astronauts on EVAs, a secondary oxygen pack is added to the bottom of the Primary Life Support System. The two small tanks 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 makeup supply should the primary system fall to 23.79 kilopascals.



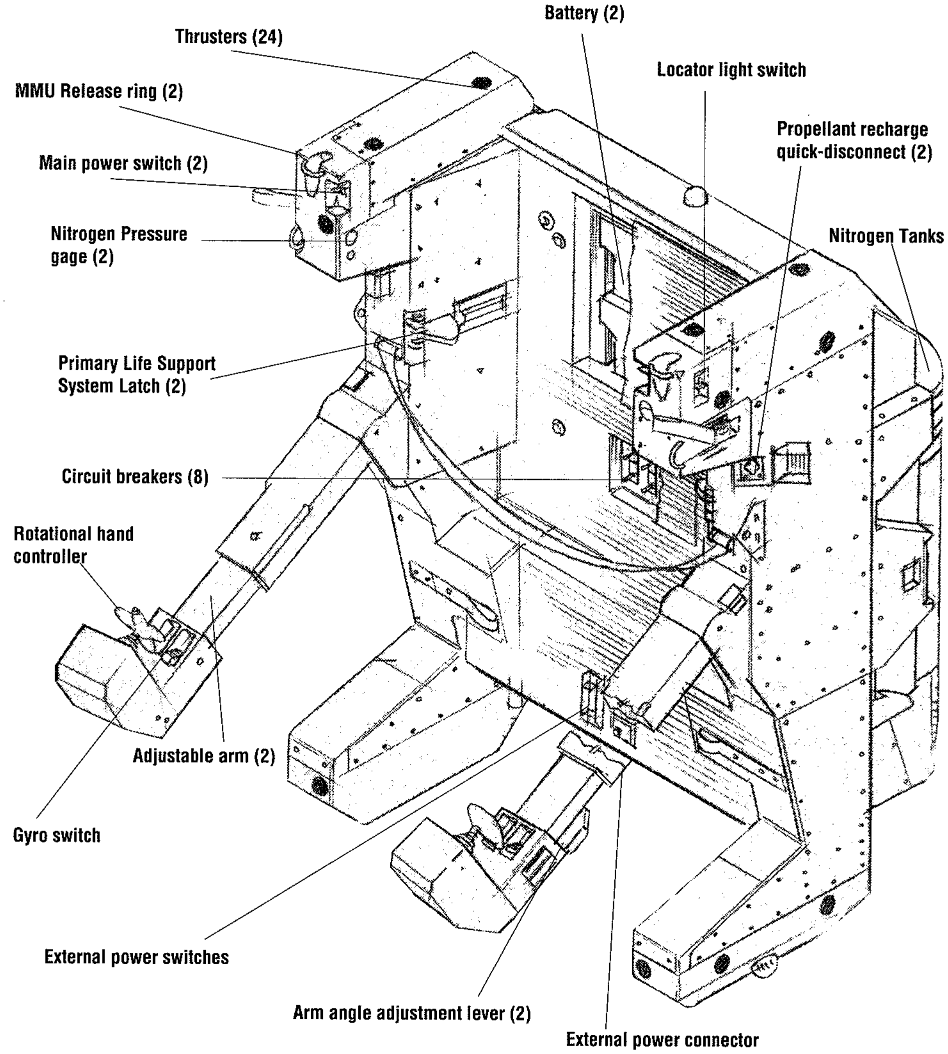
Extended view of the secondary oxygen pack.

Manned maneuvering unit

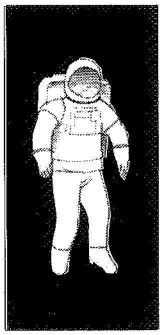
The Manned Maneuvering Unit (MMU) of the Space Shuttle is designed to operate in the weightless environment of outer space and under the temperature extremes found there. The MMU is operated by a single spacesuited astronaut and has six degrees of freedom of movement. The unit features redundancy to protect against failure of individual systems. It is designed to fit over the life support system backpack of the EMU.

The first flight test of the Shuttle MMU took place on flight 41-B. On the fifth flight day of the February 1984 mission, astronauts Bruce McCandless (depicted in the wall chart) and Robert Stewart suited up and entered the payload bay. McCandless got into the MMU and moved away from the Shuttle to a distance of 45.75 meters. He returned to the cargo bay and then moved out again to more than twice the earlier distance, all the time checking out the MMU's capabilities. Later, he used a special latching mechanism with a practice target. This was an important test on preparation for the planned capture and repair of ailing satellites on future missions.

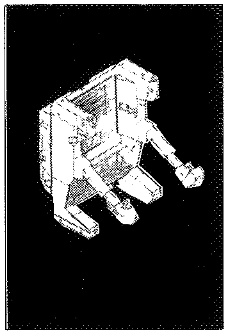
Stewart also tested the MMU on the same mission, and on the seventh flight day, both tested a second MMU for precision in maneuvering and stopping. The MMU proved itself, paving the way for future satellite repair and retrieval, space construction, and possible rescue of astronauts from disabled space vehicles.



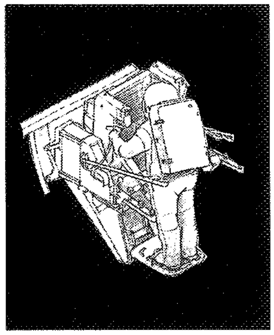
The MMU is approximately 127 centimeters high by 83 centimeters wide by 69 centimeters deep. When carried up into space by the Shuttle, it is stowed in a support station attached to the wall of the cargo bay near the airlock hatch. Two MMUs are normally carried on a mission, with the second unit mounted across from the first on the opposite cargo 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 for 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.



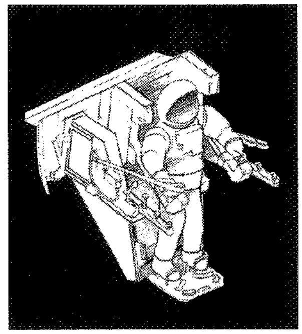
Preparations for a flight with the MMU begin with the astronaut donning an EMU.



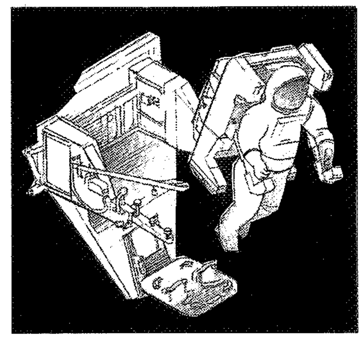
The MMU is towed in the flight support station for launch and reentry and for on-orbit servicing.



Astronaut prepares the MMU for flight and charges propellant tanks or changes batteries if necessary.



Astronaut backs into the MMU and prepares for release.



Astronaut releases the MMU from the flight support station and maneuvers away using the MMU's power.

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 6-hour EVA depending upon the amount of maneuvering done. Under normal operation, each tank feeds on a system of thrusters. In the event of some failures, crossfeed valves may be used to connect the two systems, permitting all propellant from both tanks to be used. The right hand controller produces rotational acceleration for roll, pitch, and yaw. The left controller produces translation acceleration in the degrees of forward-back, up-down, and left-right. Hand controller inputs pass through a small unit 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 of payloads and other 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 hand holds to the MMU. The maneuvering unit is attached to the cargo bay wall with a framework that has stirrup-like foot restraints. Facing the MMU, with both feet in the restraints, the astronaut visually inspects the unit. If the battery needs replacing or if the propellant tanks need recharging, these tasks can be done at this time. When ready, the astronaut turns around and backs into position. The life support system of the EMU locks into place, hand controller arms are unfolded and extended, and the MMU is released from the frame.

During the 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 Shuttle during maneuvering is through the EMU radio voice communication equipment.

Generally, a total velocity change of 20.1 meters (66 feet) 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 weightless environment of Earth orbit. Once an astronaut begins moving in a new direction or at a new velocity, that astronaut 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 crew member to push backwards onto the frame.

Spacesuit history

The EMU represents more than 50 years of development and testing by the United States, France, Italy, Germany, and other countries. It all began with high-altitude flyers, and among the first of them was an American, Wiley Post. Post was an aviation pioneer of the 1930s and was seeking to break high-altitude and speed records. Post, as well as others, knew that pressure protection 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 oxygen present is so scarce 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 failed when it was discovered that Post's pressure suit became rigid and immobile when inflated. He couldn't move inside the suit, much less work airplane controls. A later version succeeded when the suit, as constructed, was already in a sitting position. This allowed Post to place his hands on his airplane controls and his feet on the rudder bars. Moving his arms and legs was difficult, but not impossible. To provide visibility, a rigid helmet with a viewing port was placed over Post's head. The port was small, but a larger one was unnecessary because Post had only one good eye!

During the next 30 years, pressure suits evolved in many directions, 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.)

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, unpressurized comfort and mobility became prime objectives in spacesuit design. Suits served as pressure backups should the aircraft cabin lose pressure.

By the time NASA began the Mercury manned space-flight program, the best full-pressure suit design consisted of an inner gas-barrier layer of neoprene-coated fabric, and an outer restraint layer, of aluminized Nylon™. The first layer retained pure oxygen at 34.5 kilopascals and the second prevented the first from expanding like a balloon. The restraint layer directed the oxygen pressure inward on the astronaut. Mobility for the head and hands was provided by rigid bearings. In spite of the bearings, 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 that restricted movement. When the astronaut moved an arm, 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 the comfort of the suit for long-term wear, designers departed from the Mercury spacesuit concept. Instead of fabric joints, they chose a construction that employed a bladder restrained by a link net. The bladder was an anthropomorphic-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 from inner tubes in the days before tubeless tires. The new spacesuit featured improved mobility in the shoulders and arms and was more comfortable to wear unpressurized during space flights lasting as long as 14 days.

The first Gemini astronaut to "go EVA" was Ed White. White exited from the Gemini 4 space capsule on June 3, 1965. 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. On his "spacewalk," White used a small hand-held propulsion gun for maneuvering in space. The gun released jets of oxygen that propelled him in the opposite direction when he pulled a trigger. It was the first personal maneuvering unit used in space.

At 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 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 a specially weighted spacesuit while in a deep tank of water gave later Gemini crew members adequate practice in the 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. Particularly the inside of the helmet visor quickly fogged over, making it difficult to see through.

The Apollo program following Gemini added a new dimension in spacesuit design. Although the term "spacewalk" was coined for the Gemini program, no actual walking was involved. Actual spacewalks would not occur until the Apollo EVAs on the Moon.

As with the Mercury and Gemini spacesuits, 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. On the Moon, bending and stooping were necessary to pick up samples. Suits had to function both in near-weightlessness and in the one-sixth gravity on 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 (Primary) Life Support System was needed.

Donning an Apollo spacesuit began with a cooling garment, similar to long johns, which was laced with a network of thin-wall plastic tubing. This 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™ fabric with fabric ventilating ducts. This was followed by a multi-layered 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, waist, knees, and ankles. On top of that was a layer consisting of a chloroprene-coated Nylon™ rip stop that protected against micrometeoroids. Next came two layers of Kapton™ and Beta™ Marquisette and five layers of aluminized Mylar™, alternated with nonwoven Dacron™ spacing material. The outermost layer of the suit was white Teflon™-coated Beta™ glass-fiber cloth. This last layer was flame resistant; it also served as a protection against heat and cold 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 boots, and a portable life support system. The backpack unit provided oxygen for breathing and pressurization, water for cooling, and radio communications for lunar surface excursions lasting up to 8 hours. Furthermore, back inside the lunar lander the life-support unit 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 4 hours of EVA were spent in weightlessness while the astronauts were in transit from the Moon to Earth. During those EVAs a single astronaut, the command module pilot, left the capsule to retrieve photographic film. There was no need for the life-support unit, because 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. The need for astronauts on a spacecraft was convincingly demonstrated. Spacesuited Skylab astronauts literally saved the Skylab program.

Skylab was NASA's first space station. It 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 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 due to the missing shield. Instead of scrapping the mission, the crew was assigned 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 crew to occupy Skylab, 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 a life-support system, because the astronaut 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, and 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.

Outer space is just what its name implies. It is the space, or vacuum, beyond the uppermost reaches of the atmosphere of Earth, surrounding our planet and all other objects in the universe. Although it is a void, outer space can be thought of as an environment. Radiation and objects pass through it freely. An unprotected human or any other unprotected living being placed in the outer space environment would perish in a few brief, agonizing moments.

The temperature range found in outer space provides a second major obstacle for humans. Lacking the filtering and heat-transferring effects of an atmosphere, at Earth's distance from the Sun, the sunlit side of objects in space may climb to over 120° Celsius while the shaded side may plummet to lower than –100° Celsius. Maintaining a comfortable temperature range becomes a significant problem.

Enhancing the Shuttle's overall capabilities is the EMU. Like the spacecraft itself, the Shuttle EMU is reusable. 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 over a wide range of individual variations.

In constructing the Shuttle spacesuit, developers concentrated all of their designs toward a single function—going EVA. Spacesuits from earlier manned space flight programs had to serve multiple functions. They had to provide backup pressure in case of cabin pressure failure, protection if ejection became necessary during launch, EVA in weightlessness, and EVA while walking on the Moon in one-sixth Earth's gravity. 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, crew members wear comfortable shirts and slacks or coveralls.

During the first American EVA (Gemini 4) Ed White experimented with a personal propulsion device, the Hand-Held Maneuvering Unit. The unit White tested 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 by 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 Hand-Held Maneuvering Unit was produced by releasing compressed oxygen from two small built-in tanks. Although the unit worked as intended, it had two disadvantages. To produce the desired motion, it had to be held as near to the astronaut's center of mass as possible. Determining the actual position was difficult because of the bulky spacesuit White wore, and was a matter of guesswork and experience. Furthermore, precise motions were difficult to achieve and maintain, and using the unit 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 experiments were dubbed M-509. Five of the six astronauts who flew in those two missions accumulated a total of 14 hours testing an advanced device called the AMRV, or Astronaut Maneuvering Research Vehicle. The AMRV 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 end of "arm rests." To move, the astronaut worked rotational and translational bank controls. Propulsive jets of nitrogen gas were released from various nozzles spaced around the unit. The nozzles, fourteen in number, were arranged to aim top-bottom, front-back, and right-left to produce six degrees of freedom in movement. The AMRV could move forward and back, up and down, and side to side, and could roll, pitch, and yaw. With the eleven additional nozzles, precise positioning with the AMRV was far simpler than with the Hand-Held Maneuvering Unit 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 translate closely along the surface of a curved or irregularly shaped object without making contact with it. During the Skylab experiments with the EMU, 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 EVAs.

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PED-117