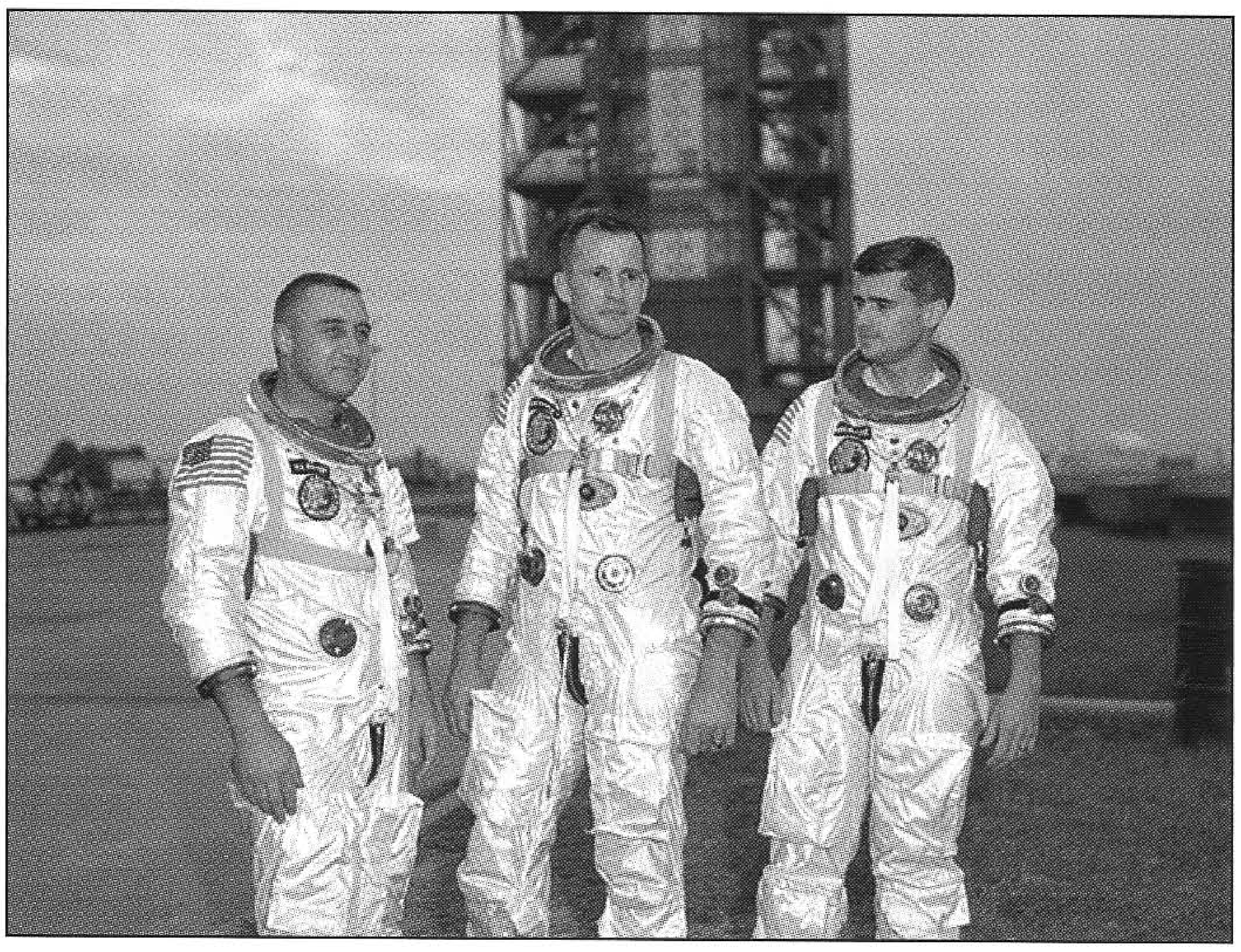
NEAR SPACE

APPROACHING THE FINAL FRONTIER

BY L. PAUL VERHAGE

THE WELL-DRESSED ASTRONAUT

TODAY'S SPACE SHUTTLE SPACESUIT doesn't make a good spacesuit for planetary exploration because of the differences between working in weightlessness for a single mission and working on a dusty, gritty planet with gravity for months on end.



■ A1C SUITS

To make a good planetary suit, the Space Shuttle spacesuit would need to be easier to wear, clean, maintain, and personalize. So with plans to go back to the Moon and then eventually to Mars, astronauts need a new generation of spacesuit, the planetary suit. The International Latex Corporation and the David Clark Company are working with NASA to develop and test the technologies that will go into tomorrow's planetary suit. Before discussing some of these technologies, let's briefly look at the dangers of high altitude flight.

SOME EARLY (AND BAD) EXPERIENCES AT HIGH ALTITUDE

In 1862, aeronauts James Glaisher and Henry Coxwell made their first scientific balloon flight to explore the high troposphere. By the time they reached 30,000 feet, Glaisher had passed out due to the lack of air. Both aeronauts would have died had Coxwell not opened the balloon's vent. The chilling cold made it impossible to use his hands, so Coxwell used his teeth to pull the balloon vent open.

In 1927, Army Air Service Captain Hawthorne Gray made several flights into the high troposphere. He did not wear a pressure suit but did take an oxygen mask on his later flights. Gray made his last flight in November of that year. His final log entry mentions how the cold air was interfering with his ability to function. Gray was found at the end of his flight, in a tree and slumped over in his opened gondola. The cause of death is not certain, although it's believed the lack of oxygen was the primary factor.

PROTECTING HUMAN LIFE AT HIGH ALTITUDE

At first glance, you'd think that providing oxygen and warm clothing would be enough to keep humans alive at high altitude. Unfortunately, breathing at a lower pressure also means getting less oxygen. Not even 100% oxygen is enough to keep a person alive once the air pressure drops below about 0.7 pounds per square inch (PSI).

Forcing more oxygen into the lungs is not the solution. As little as one PSI over pressure is enough to rupture the lungs. Needless to say, with a pair of ruptured lungs it doesn't matter how much oxygen a person receives. So, along with getting enough oxygen in each breath of air, pressure must be exerted against the torso to make breathing safe.

A spacesuit must also protect the body from the other harmful effects of low pressure. One effect is the release of nitrogen bubbles from body fluids. This effect, called the bends, results in severe pain and even death. Even if the bends are prevented, low air pressure can create severe pain as the internal pressure of the body presses outward on the skin. A second effect of low air pressure is the lowering of the boiling point of liquids. Above an altitude of 63,000 feet, the air pressure is so low that body fluids like blood and saliva boil. If the bends don't kill you, boiling blood will.

Normally, when we exhale, the air dilutes the carbon dioxide in our breath to safe levels. Breathing oxygen through a mask can prevent this dilution. When carbon dioxide is not scrubbed from our breath, its concentration in our blood builds up and, as a result, the cells in our body are poisoned. The effects of carbon dioxide poisoning begin with the brain and result in poor decision making. Eventually, unconsciousness and death are reached. (Note that this is a separate issue from carbon monoxide poisoning.)

The Earth's atmosphere is very cold at high altitude. The cold temperature can be a minor nuisance or can result in frostbite and death. In outer space, it tends to be cold when an astronaut is shaded from the Sun, but direct exposure to sunlight can still result in burns.

When looking at the dangers of high altitude, we can see that a spacesuit must meet the following requirements if the wearer is to stay alive and functional.

- *Provide oxygen to keep the body alive and the brain mentally sharp*
- *Protect the body from the effects of low pressure*
- *Remove (or scrub) carbon dioxide from exhaled air*
- *Maintain a safe and comfortable temperature*

While protecting life, a space suit cannot excessively inhibit the mobility of its wearer. Doing so makes movements fatiguing or impossible. Since there's no protection from micrometeoroids in space, the space suit must also protect its integrity from damage by micrometeoroid impacts. Not only can these impacts compromise the functioning of the spacesuit, they can also injure the wearer.

THE FIRST PRESSURE SUIT

For well over 100 years, knowledgeable people have known that you can't survive at extremely high altitudes, or in outer space, without protection from the cold and vacuum. By the early 20th century, pilots like Willey Post had discovered that aircraft flew faster when they flew higher (they had discovered the jet stream). But without some form of protection from the elements, the pilots and their passengers would suffer from the effects of cold and low air pressure.

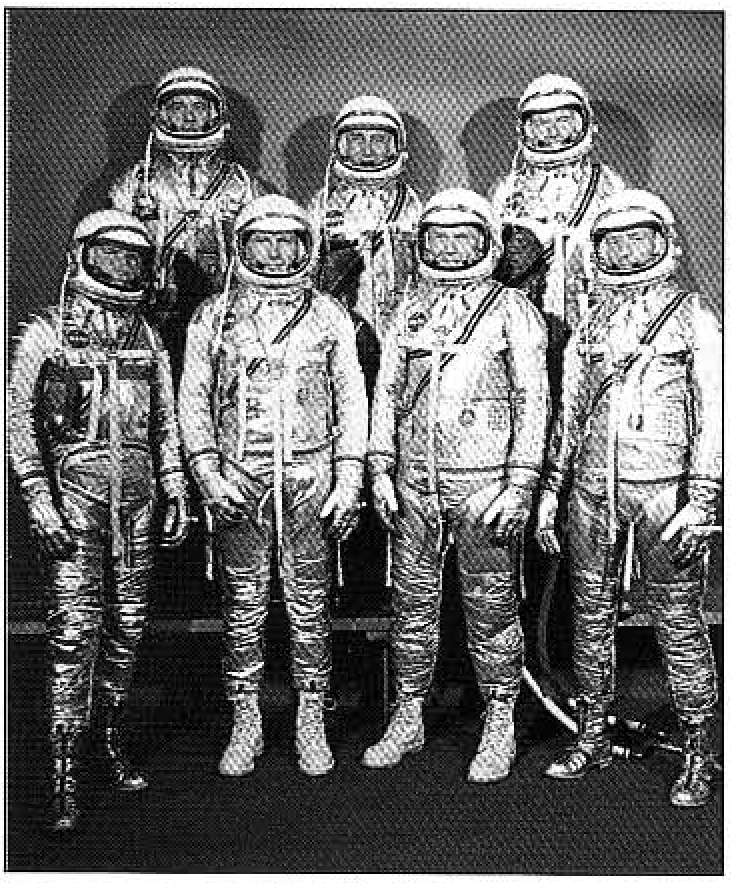
One solution was to make the cabin of the aircraft airtight. This way enough heat and air could be maintained for the crew. However, this required air seals and airtight volumes, which would make the aircraft too heavy. Since only the pilot needed protection, it was decided to build a pressure suit for the pilot instead.

Willy Post asked the B.F. Goodrich Company for help designing a pressure suit. Their first pressure suit was made from rubberized parachute fabric. The fabric was cut and sewn so that it wouldn't stretch from the movements of Post. Gloves and socks were molded into the suit to maintain its airtight seal. Regular leather boots were worn over the socks to protect the feet of the suit from abrasion. The suit's helmet was a simple cylinder that bolted to the neck of the pressure suit. Air entered the helmet on the left side of its round portal window. The cost for the suit was $75 and made Post look a lot like a deep-sea diver.

Before flying with the suit, it was tested on the ground. Entry into the pressure suit was through the neck. After Post donned the suit, its helmet was attached and the suit filled with oxygen. Enough air was added to the suit to simulate the pressure it would experience during flight. The suit design wasn't strong enough to handle the pressure and, as a result, the suit ruptured between the torso and legs.

A metal clamp was added between the torso and legs in the redesigned pressure suit. Post again donned the suit for its pressure test. This test took place on a hot day and before long, Post began suffering from the heat. But, the suit was so tight that Post couldn't remove it. To get Post out of the suit, B.F. Goodrich engineers began cutting him out of it. The tightness of the suit made this a long and difficult procedure, so Post was moved to a refrigerated golf ball storage room where he could remain cool while he was carefully cut out of the suit.

Additional modifications were made to the third design. The third suit had a larger neck opening to make it easier to get into and out of the suit. It was assembled in the seated position so Post wouldn't have to exert effort just to remain seated in the aircraft. Metal rings were molded into the suit above and below joints like the knees and the fabric was then bunched up between the rings to make the joints more flexible. The suit's pressure gauge plugged into the knee and a bottle of liquid oxygen was used to pressurize the suit. Testing showed that Post finally had a functional pressure suit.


■ MERCURY MISSION

Post flew to an altitude of 50,000 feet wearing the suit. Unfortunately, one of the official barometers onboard the airplane failed, so the flight didn't qualify for the record. Upon landing at Murdoc dry lakebed, Post exited his airplane and asked a stranger for help removing the helmet. The wind sail car enthusiast almost passed out from the sight of Post in this pressure suit (think of a similar scene from the movie, *Back To The Future*).

IMPROVING MOBILITY

Willey Post's pressure suit worked, but it was too uncomfortable to wear for long periods of time. When pressurized, the suit was so stiff that it made operating the airplane difficult. An improved method for increasing the flexibility of the pressure suit was required.

To understand the challenges that pressure suit designers face, get a long and narrow balloon. Try bending the balloon before filling it with air. Now fill the balloon with air and try bending it again. The more you fill the balloon, the more difficult it is to bend. This is the problem pilots are up against, except every joint of their body is being restrained from bending.

Balloons resist being bent because, as you bend them, you're decreasing their volume and increasing their internal air pressure. When you bend an inflated balloon you're not working against the rubber skin of the balloon, you're working against the balloon's internal pressure. You can vent some of the balloon's air to make it easier to bend. In fact, this is just what cosmonaut Alexei Leonov did to get back into the airlock of the Voskhod 2 space capsule. However, this is a very dangerous way to solve the bending problem of a pressure suit.

Tomato worms are up against the same bending problem. They have long and narrow bodies that are internally pressurized. The way evolution solved this problem was to add accordion-like ridges or pleats to their bodies. The next generation of pressure suits took a clue from the tomato worm and added accordion-like ridges around the areas where the suit needed to bend, like the knees and elbows.

THE MILITARY FULL AND PARTIAL PRESSURE SUIT

With the advent of high-altitude high-speed jet flight, a new requirement emerged. During high G-maneuvers, pilots risked blacking out when blood left their brain and collected in their torso, arms, and legs. So now, pilots needed protection from the accidental depressurization of the cockpit, as well as help flying high G-maneuvers.

Tight fitting clothing can be used to press against the body and force blood back into the brain during high G-maneuvers. A bladder sewn into the chest and tubes sewn into the outsides of the arms and legs would fill with air and pull the loose suit tightly against the pilot's body, but under normal flying conditions the clothing would be loose and comfortable. These suits are called G-suits. The first example was the S-1, which was developed by the University of Southern California in support of the X-1 program.

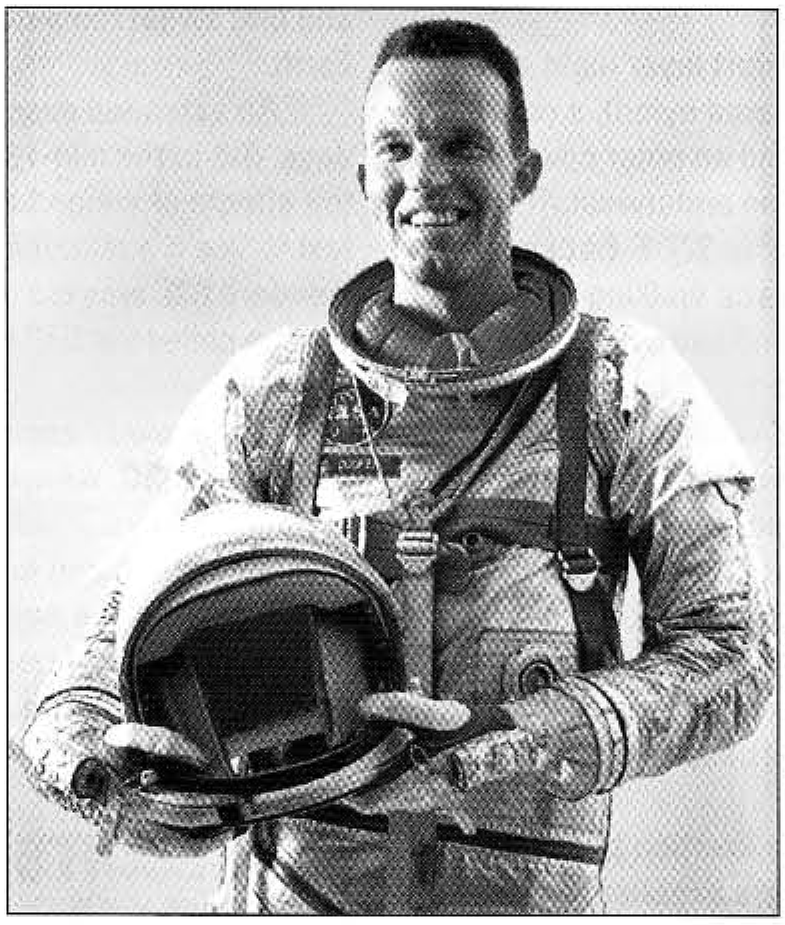
The David Clark Company modified the S-1 into the T-1 by combining a G-suit with the partial pressure suit. In the partial pressure suit, air pressure is only maintained around the pilot's face. The rest of the body only experiences pressure through the constriction of the suit. A tight facemask and neck seal kept pressurized oxygen from leaking out of the mask. It was the T-1 that the early test pilots, such as Chuck

Yeager, wore on flights of the Bell X-1.

The need to fly longer and higher motivated both the Navy and Air Force to develop a full pressure suit. Due to funding constraints, however, development was left to the Navy while the Air Force continued refining the partial pressure suit.

Several full pressure suits were developed in the 1950s. The David Clark Company developed a full pressure suit that eventually became the A/P22S-2, and B.F. Goodrich developed five full pressure suit models (the Mark I to the Mark V).

The A/P22S-2 consisted of a neoprene-coated nylon inner layer to retain air and outer layers of fabric to protect the airtight inner layer from abrasion and sunlight. The oxygen mask of the partial pressure suit was replaced with a helmet. To prevent the suit from ballooning out when filled, the David Clark Company added a layer resembling a nylon fish net over the air bladder layer. The A/P22S-2 full pressure suit was worn by pilots in the X-15 program.


■ MERCURY PROJECT SUIT

SPACESUITS OF THE MERCURY PROJECT

Project Mercury was tasked with getting an American into space and bringing him back safely. There was no plan for the astronauts to leave the Mercury capsule so it remained airtight for the entire flight. However, in the event of a depressurization, the astronauts needed a spacesuit to keep them alive long enough to return to Earth. For the Mercury spacesuit, B.F. Goodrich modified a version of the Navy's full pressure suit, the Mark IV.

To get into and out of the Mercury spacesuit required manipulating 13 zippers. The spacesuit maintained an atmosphere of pure oxygen at 5 PSI of pressure, so in a vacuum, the astronauts breathed more oxygen that we do at sea level (where the partial pressure of oxygen is only about 3 PSI). The temperature was controlled by adjusting the temperature of the oxygen flowing into the suit. Oxygen entered the suit at the waist, flowed around the body, and exited out of the helmet by the right ear. This movement of air kept the astronaut cool and dry. Air exiting the spacesuit was passed through activated charcoal to remove body odors and lithium hydroxide to remove carbon dioxide.

There were four layers in the Mercury spacesuit. A rubber-coated, double-walled nylon formed the primary pressure vessel, a neoprene-coated layer formed an extra protection layer, and aluminized nylon formed the outer layer for flame and abrasion protection. The long john underwear worn by the astronaut was the fourth and innermost layer of the suit. Since the astronauts remained inside the capsule for the entire flight, there was no need for thermal protection layers as would be needed in the Gemini, Apollo, and the Space Shuttle.

In case of a capsule decompression, the spacesuit rapidly filled with oxygen supplied by the Mercury capsule. The spacesuit was very stiff when filled, but bending in the suit was made a little easier by break lines sewn into the spacesuit. However, the break lines didn't let the spacesuit maintain a constant pressure during bending, so it still took some effort to bend limbs. The cost for each Mercury spacesuit was about $5,000, and half of that was just for the helmet.

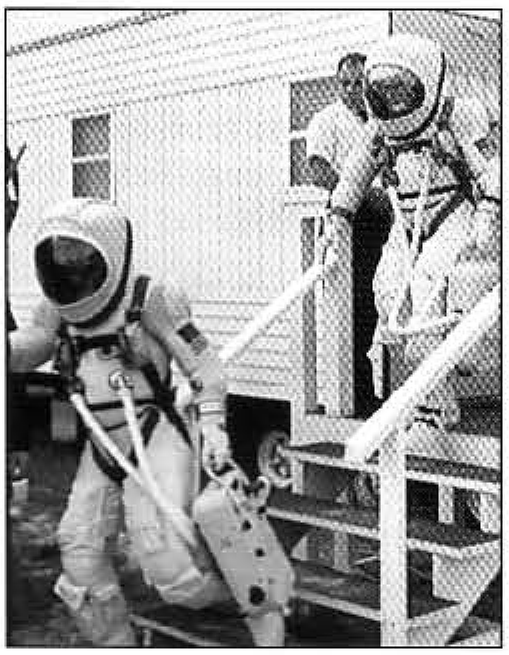
Modifications were made to the Mercury spacesuits throughout the program. Alan Shepard's spacesuit was the only one that didn't include a urine collector, as you may recall in the movie, *The Right Stuff.* After Shepard's flight, this vital comfort was added to the suit. Another change was the inclusion of tiny light bulbs sewn into the gloves so astronauts could read the capsule's panels during orbital night.

SPACESUITS OF THE GEMINI PROGRAM

The Gemini Program flew 12 flights between Mercury and Apollo and taught NASA how to perform extravehicular activities (EVA), dock spacecraft, and live in space for extended periods of time.

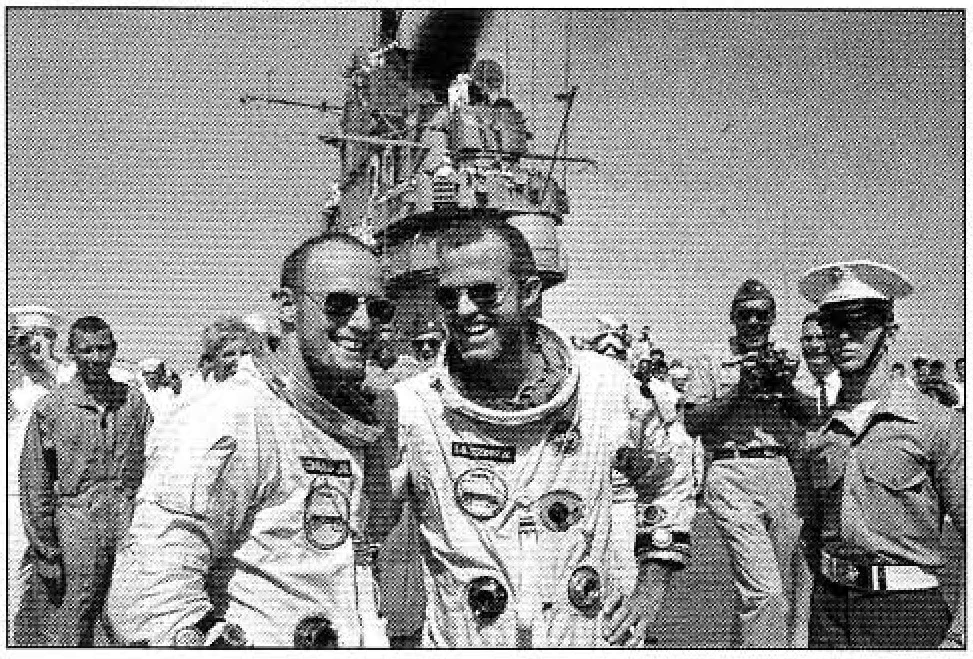
Three types of spacesuits were designed for the Gemini program. The first Gemini spacesuit was the G3C and was worn as an intravehicular suit (for astronauts who weren't leaving the capsule for a space walk). Like the previous Mercury spacesuits, the G3C provided air, temperature, and humidity control through the spacecraft's life support system. This means the spacesuit was left plugged into the spacecraft during the entire mission. Air flowed into the chest, through the helmet to clear the visor, around the body, over extremities, and exited the suit.

■ MERCURY G5 SUIT



■ GEMINI G4C SUIT

■ GEMINI G3C SUITS



The G3C weighed 24 pounds.

The layers of the G3C consisted of a comfort layer (light weight oxford nylon), pressure bladder (neoprene coated nylon), a restraint layer (linknet restraint layer), bumper layers, and an outer covering of Nomex. The astronaut still wore cotton long john underwear. The G3C was designed for a temperature range of -76°F to 327°F. Because the G3C couldn't be used to make an EVA, if a space walking astronaut was unable to get back to the Gemini, the second astronaut (who was wearing a G3C) would be unable to get out and help him.

The second spacesuit was the G4C and was designed for the astronauts who performed an EVA. The G4C was the G3C with added layers of thermal and micrometeoroid protection. The micrometeoroid and thermal protection consisted of several alternating layers of aluminized Mylar and Dacron covered with a felt layer. You can picture the thermal layers as alternating layers of aluminized space blanket and wedding veil material. The additional layers were located between the bumper layer and the outer Nomex layer. These layers made the G4C 10 pounds heavier than the G3C.

The G4C was unable to handle strenuous exertion by the astronauts. A good illustration of this is Gene Cernan's experience. Cernan was to test the Astronaut Maneuvering Unit, or AMU, during *Gemini 9*. The AMU used hydrogen peroxide rocket engines to create thrust and, to protect Cernan's legs from the hot exhaust, he worn a pair of metal chaps over the legs of the suit (made from linked Chromel-R).

As Cernan struggled to walk to the back of *Gemini 9* and attach himself to the AMU, he started overheating and fogged the inside of his visor. Remember, water doesn't drip down in the weightlessness of space. So the fogged visor prevented Cernan from seeing clearly out of his visor. The other Gemini astronauts wiped anti-fog compound on the inside of their visors, but Cernan was not told about this. In his struggle, Cernan ripped the insulation layers in the back of his spacesuit, allowing solar heat to penetrate the suit and add to his discomfort.

Upon getting back into the Gemini, he experienced extreme discomfort trying to bend enough to sit on his couch and shut the hatch of the Gemini. Not until the Gemini was repressurized could Cernan bend enough to get comfortable. Cernan sweated off about 10 pounds, and that sweat remained inside of his spacesuit until they returned to Earth.

An extended mission to the Moon could be completed within 14 days. But in the mid-1960s, it was not known if humans could handle the effects of weightlessness that long. *Gemini 7* was an endurance test to see if a manned mission to the Moon was possible. Since the standard G3C was too uncomfortable for a 14-day mission, a 16-pound version called the G5C was designed for astronauts Frank Borman and Jim Lovell.

The *Gemini 7* astronauts could don and doff the G5C on their own, unlike the G3C, which required the help of a ground crew. In the cramped Gemini, it still took the astronauts about an hour to don and doff the suits. A soft helmet was sewn into the suit and was opened by a zipper in the neck. The helmet could be rolled up to form a headrest for the astronaut. It should be noted that Mission Control was hesitant about having both astronauts out of their spacesuits at the same time.

SPACESUITS OF THE APOLLO PROGRAM

The Gemini program demonstrated the limitations of the Gemini spacesuit design. If Apollo astronauts were going to work on the Moon, then their spacesuits would need to be more flexible and comfortable.

Two spacesuits were designed for Apollo. The first design, which was worn by the *Apollo 1* and *7* astronauts, closely resembled the Gemini G3C spacesuit. This spacesuit was developed by the David Clark Company and called the A1C. The second spacesuit was developed for the moonwalkers and a variation of it was also worn by the astronaut that remained in lunar orbit.

This spacesuit was called the A7L and was developed by the International Latex Corporation (ILC). Later, the A7L was modified into the A7LB for the extended stays on the Moon by the last three Apollo missions. The moon suits were referred to as an Extravehicular Mobility Unit, or EMU. A total of 60 Apollo EMUs were built at a cost of $90 million.

Some of the differences between the Gemini and Apollo spacesuits were brought about because of the differences between the Gemini and Apollo missions. For example, the A7L supported an astronaut who was totally free of the spacecraft, or Lunar Module in this case, while the G4C supported an astronaut tethered to the space capsule. The boots of the A7L were designed for walking while the G4C boots only protected the feet of the spacesuit. The gloves of the A7L allowed moonwalkers to use geologic tools on the lunar surface and have an improved sense of feel, while the G4C gloves provided only for flexibility and not tactile sense. Finally, the visor of the A7L helmet increased visibility over the G4C visor.

FREEDOM FROM THE LUNAR MODULE

The life support backpack developed for Apollo was called the Portable Life-Support System, or PLSS (pronounced *pliss*). Developed by Hamilton Standard, the Apollo PLSS carried oxygen, batteries, lithium hydroxide carbon dioxide scrubbers, water cooler, fan, radio, and emergency oxygen. Oxygen was pressurized to 3.7 PSI and fed into the astronaut's helmet and suit. The first Apollo lunar missions had a four-hour supply of oxygen and the PLSS weighed 65 pounds on Earth, or 11 pounds on the Moon. Because of the PLSS, Apollo astronauts kept cool in a way entirely different than the earlier Mercury and Gemini astronauts.

Apollo astronauts wore the liquid cooled garment, or LCG, to keep cool. The LCG was made of thin PVC tubing (Tygon) sewn into a nylon spandex suit and inner layer of nylon tricot for comfort (Klingons probably use a wool comfort layer). The water temperature was set to 70°F and kept the astronaut cool at various levels of exertion. Water flowing through the LCG was chilled through a sublimator in the PLSS.

THESE (MOON) BOOTS ARE MADE FOR WALKING

Like the spacesuit, moon boots were made up of fabric layers for thermal, abrasion, and micrometeorite protection. The boots looked a lot like oversized rain boots. The soles of the boots were made from molded silicon rubber for insulation, flexibility, and traction.

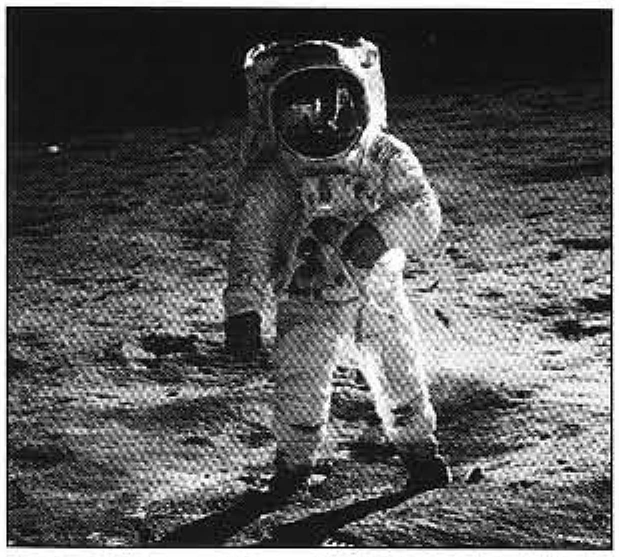
GLOVES AND HELMET

The gloves of the Apollo EMU were more flexible than those in the Gemini spacesuit. To add a sense of touch to the gloves, silicon rubber pads were sewn into the fingertips. The outer layer of the gloves consisted of a layer of Chromel-R for high temperature resistance. The gloves were not perfect, however. The astronauts had to cut their fingernails short and exercise their hands while training for their mission. Apollo astronauts still experienced painful fingertips after working on the Moon.

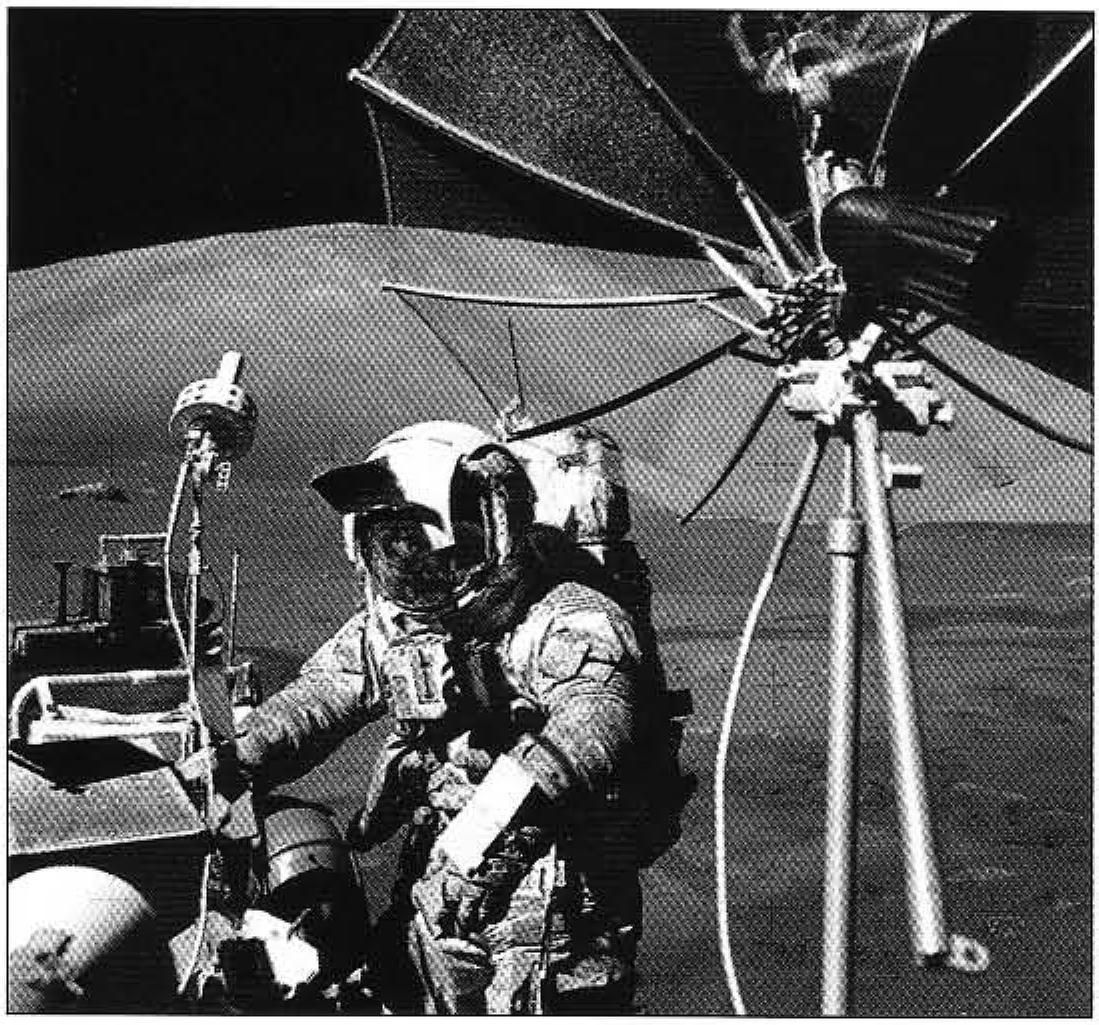
For increased visibility, the Gemini helmet and visor were replaced with a single-piece clear bubble helmet of polycarbonate plastic. A fabric hood went over the early Apollo helmets to block sunlight from shining into the helmet. In addition to increasing visibility, the single piece helmet also increased the A7L's reliability by removing the airtight seal needed in the Gemini helmet visor. The outside of the helmet had two visors that could be lowered, similar to sunglasses.

A7LB MODIFICATIONS

The later, long duration missions used a modified PLSS that held seven hours of oxygen, more cooling water, more lithium hydroxide, and 75 minutes of emergency oxygen. The weight of this PLSS was 212 pounds on Earth, or 35 pounds on the Moon. Modifications in the PLSS also allowed astronauts to buddy breathe (share oxygen from a single PLSS) should one PLSS fail. The helmet's



■ APOLLO A7L SUIT



■ APOLLO A7LB SUIT

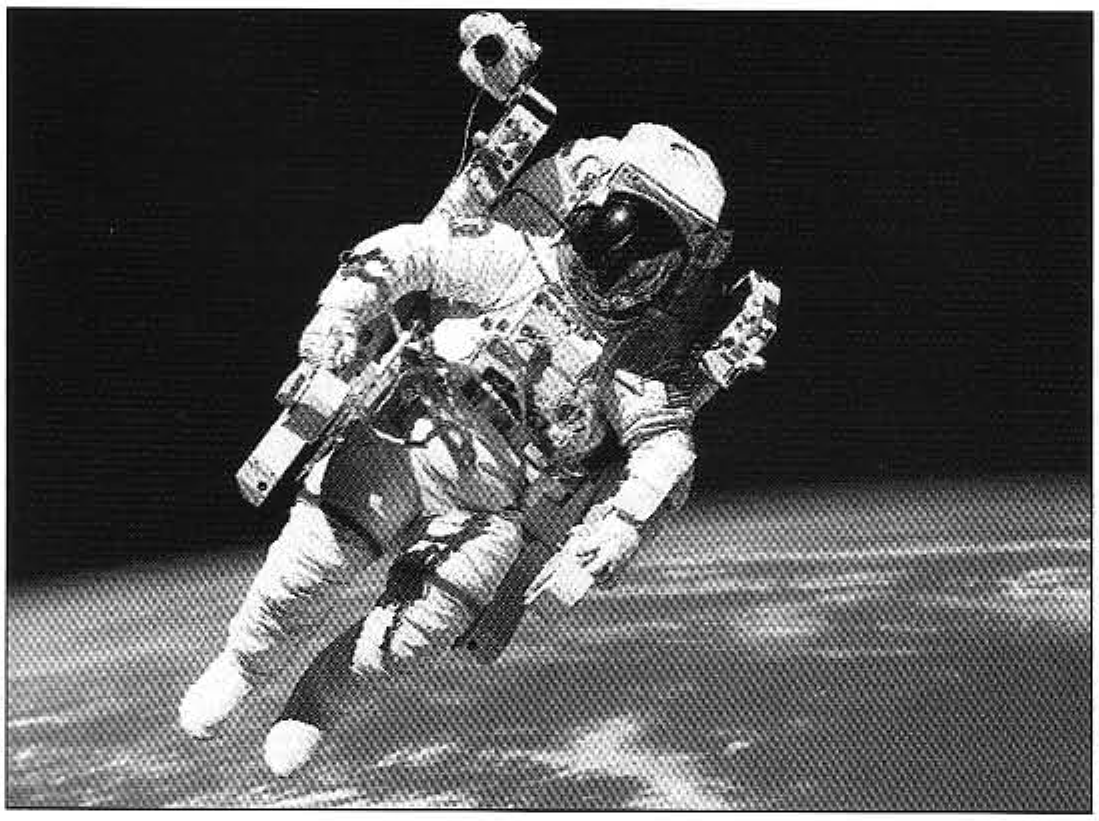
cloth hood was replaced with a set of flaps that the astronaut could position to block sunlight. A minor modification involved identification. Once inside an EMU, it was difficult to tell who was who. By *Apollo 14*, the commander was identified by the red stripes sewn into his EMU.

SPACESUITS OF THE SPACE SHUTTLE

There are a lot more Space Shuttle astronauts than there were Mercury, Gemini, and Apollo astronauts combined. To keep the cost of spacesuits from getting out of hand, the Space Shuttle spacesuits, or EMUs, are designed to fit multiple astronauts. Unlike past spacesuits, the EMU only serves one function, and that's for making space walks. The Space Shuttle EMU is not worn during launch or reentry. So, not all Shuttle astronauts need an EMU.

Each Space Shuttle EMU is assembled from interchangeable parts. Various size arms, legs, and bodies are combined as needed to fit an astronaut for his or her flight. The variation in the sizes of available parts can be combined to create spacesuits capable of fitting something like 95% of the population. After each Space Shuttle mission, the EMUs are taken apart, cleaned, and stored. After several more flights, the suits are taken completely apart for more thorough maintenance.

■ SPACE SHUTTLE EMU SUIT



Like the earlier spacesuits, the Space Shuttle EMU consists of multiple layers. Like the A7L, the inner layer of the Space Shuttle EMU consists of a liquid cooling garment. For comfort, this inner layer is made from nylon tricot. The pressure-retaining layer is made from urethane-coated nylon and an outer layer of Dacron that keeps this inner layer from ballooning out. Neoprene coated ripstop nylon is the next layer, and keeps the suit sealed in the event of a micrometeoroid strike. Additional protection from temperature extremes and micrometeoroid impacts comes from seven alternating layers of aluminized Mylar and Dacron scrim. The outermost layer protects the inner layers and consists of a mix of fibers (Nomex, Gortex, and Kevlar). Even with all these layers, the EMU is only 3/16-inch thick

Instead of using zippers to seal the suit, the EMU is only split at the waist. The upper torso of the EMU consists of a fiberglass hard shell called the Hard Upper Torso, or HUT. There are bearing seals in the HUT where the arms, helmet, and lower torso attach. The Space Shuttle EMU PLSS is affixed directly to the HUT, so there are no external hoses like those on the Apollo spacesuits. There is no need for a pressure-retraining layer in the HUT; only the thermal and micrometeoroid protection cover the HUT. It only takes an astronaut 20 minutes to don the Space Shuttle EMU, and a majority of the work is done by the individual.

The Space Shuttle PLSS holds seven hours of oxygen, carbon dioxide scrubbing equipment (lithium hydroxide canisters), a warning system, batteries, water cooler, fan, and radio. A microcontroller monitors conditions of the EMU and provides audio and visual warnings to the astronaut. Perspiration and body odor are sucked out of the EMU near the hands and feet and are filtered out of the air stream within the PLSS. Anti-fog compound is still wiped on the inside of the helmet. At the base of the PLSS is a secondary oxygen pack that provides 30 minutes of emergency breathing should the PLSS fail. Between spacewalks, the PLSS is recharged inside the Space Shuttle airlock.

The Space Shuttle operates at 14.7 PSI of atmospheric pressure in a mixed oxygen and nitrogen atmosphere. The EMUs operate at about 4 PSI of pressure and at 100 percent oxygen. So, part of the process of donning an EMU is for the astronauts to pre-breathe pure oxygen while preparing for an EVA.

For comfort, a drink bag is placed inside the HUT. Astronauts can drink from the bag through a straw attached to the bag. The astronauts also wear an adult diaper. Gloves attach to the ends of the arms through a bearing seal (no zippers) and contain heaters to keep the astronaut's hands warm.

SPACESUITS OF THE INTERNATIONAL SPACE STATION

Currently, Russian and American spacesuits are carried onboard the ISS. Modifications being designed for the American suits will make them easier to fit the variety of astronauts and cosmonauts that will eventually visit the station. Currently, spacesuit technicians assemble a spacesuit for each astronaut making a space walk on the Space Shuttle. Because there will be no technicians onboard the ISS, it isn't practical, in the long run, to send new spacesuits up with each visiting astronaut.

Therefore, work is being done to design sizing rings for the ISS spacesuits. The rings are designed to fit between suit joints, such as between the arms and gloves, and extend the length of spacesuit elements. Sizing rings are made from aluminum and come in several lengths. With sizing rings, astronauts can modify spacesuits to fit while they work on ISS.

THE NEW PLANETARY SUIT

We've seen some of the changes made in American spacesuits as they evolved from Project Mercury's emergency-only spacesuits to the Apollo and Space Shuttle working spacesuits. The new planetary suits will build on this history to create suits that are lighter in weight and easier to work in and maintain.

REDUCING BENDING EFFORT

To allow an astronaut to bend his or her arms without reducing the interior volume of the suit, rotating bearings will probably be added to planetary suits. So, instead of flexing the fabric in the arm of a planetary suit, an astronaut will instead rotate his or her arm up and down through the bearing surface in the shoulder. This reduces the degree of rotational freedom in the shoulders and "programs" the movements of the astronaut. However, they will easily learn how they must move their arms and they will grow accustomed to it.

Restraint layers (linknet) are being made from more advanced fibers than the spectra currently used in modern EMUs. By using stronger materials that stretch less in the linknet layer, a thinner linknet layer can be used. And the thinner this layer, the less torque required to bend the layer.

Some stretch in the planetary suit fabric can be desirable. In the right place, stretch can prevent the build-up of stress points in the suit. As a result, the fabric of the planetary suit in that location doesn't have to be as strong or as thick. Stretching also reduces the chances of material failure from over stressing.

REDUCING WEIGHT

To reduce planetary suit weight, ILC is replacing the old Space Shuttle EMU HUT with a soft upper torso made from fabric. Points on the suit where parts are connected together are being replaced with machined titanium. The titanium creates lighter weight attachment points with the same strength as the old steel swivels and brackets used in current spacesuits.

Aluminum has replaced steel as the material in the bearing rings that seal together elements of the suit. However, some bearings — like those in the shoulder — are being replaced with experimental graphite epoxy rings that save a pound of weight over the aluminum rings. Further weight savings may occur by using materials that provide multiple functions. As an example, a single layer of new material may be able to replace two layers, such as a pressure-retaining layer and a thermal layer.

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- The Space Shuttle Extravehicular Mobility Unit (EMU), NASA
- The Right Stuff, *Design Magazine*, vol. 59, no. 12, 09.13.04
- The ILC Dover website, **www.ilcdover.com/**

So far, ILC has managed to reduce the weight of the planetary suit from the 107 pounds of the Space Shuttle EMU to just 65 pounds.

REDUCING SUIT MAINTENANCE

During the last of the Moon landings, Apollo astronauts performed maintenance on seals and zippers of their space suits. Maintenance on the planetary suits will be different. Instead of regularly applying lubricants to bearing surfaces, the bearings in these surfaces will be treated with low friction coatings.

Planetary suits will be made ready for different sized astronauts quickly and with less work. The use of sizing rings and lacing allows astronauts to customize the fit of a planetary suit for themselves. Before joining parts like the waist and legs, the proper sized sizing rings are first snapped into the suit. Now the suit elements can be joined to make a perfectly fitting planetary suit. Lacing in the arms can be loosened or tightened to change the length of the arms.

The planetary suits are just experiments, so they're not ready yet. More tests, like the number and position of rotating bearing surfaces, still need to be finalized. Also, the ability of new materials used in the suits to stand up to the expected environmental conditions found on the Moon and Mars still needs to be tested.

Electronics and logic will certainly play a larger role in the operation of the planetary suit. Control switches sewn into the suit will allow astronauts to control suit functions like temperature and lighting. With embedded microcontrollers, astronauts may not have to even use switches; instead they may speak or gesture to enable suit functions. It sounds like NASA will be looking for those with microcontroller experience to help design their future planetary suits. If I were you, I'd begin designing and programming with microcontrollers now! ■