Advanced Spacesuit Design

By
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In the last article we introduced you to a universe filled with vacuum and discussed some of the difficulties our intrepid astronauts face when they want to exit their spaceships and explore that universe. Having spent billions of dollars and years of life span preparing for a journey into the unknown, no one wants to sit inside a comfortable cabin and stare out the windows. When human beings find themselves in a new place, the compulsion to explore is overpowering. That is because deep down inside each of us there is that little boy or girl who once pressed their face against a cold, winter window and asked, "Aw, mom, can't I go outside?"

The problem, of course, is that the human body is not designed to withstand the rigors of vacuum. First, there is the matter of breathing, something that we must do continuously if we are to continue living. Exposure to vacuum brings the breathing process to a precipitous halt. Unconsciousness comes within 15 seconds (a bit longer if you have prepared for it by hyperventilating or breathing pure oxygen). After you lose consciousness, you have approximately three minutes before your brain dies of oxygen deprivation – essentially the same period a human being survives the experience of filling their lungs with water.

The good news, however, is that there is no truth to the common misconception that people explode in vacuum. While dramatically exciting on the silver screen, the bulging eyes and popping heads (remember *Total Recall*?) caused by explosive decompression just don't happen. Your skin is a gas-proof membrane that is anchored to the underlying muscle. The natural elasticity will tend to maintain your internal pressure — for awhile, anyway. That will keep your blood from boiling until long after you are dead from other causes. If you are rescued in time, you will likely get away with nothing worse than ruptured eardrums, bloodshot eyes, and varicose veins over a large portion of your epidermis. Of course, there is also the problem of your lungs, which have numerous delicate blood vessels separated from vacuum by only the thickness of a cell membrane. Breathing vacuum will leave you coughing up blood for days afterward.

Nor is lack of oxygen the only problem an astronaut encounters in vacuum. There are lesser dangers to be overcome. If the astronaut has been breathing standard air (an 80% nitrogen/20% oxygen mix) at atmospheric pressure, then suddenly reducing that astronaut's pressure could cause nitrogen bubbles to form in his or her bloodstream. This condition is known as "the bends" or "caisson's disease," and it has been the bane of deep-sea divers for more than 100 years. Nitrogen bubbles in the blood are not dangerous *per se*. The problem arises when a bubble attempts to pass through a capillary too small for it. What follows is a condition known to generations of automobile mechanics as "vapor lock." The bubble plugs the capillary, depriving all tissue downstream of the blockage of its life-giving oxygen supply, causing that tissue to die. If the bubble lodges in a particularly critical spot, nearly instantaneous death follows.

A problem most people don't consider when writing space epics is how one gets rid of the internal heat the human body generates while in vacuum. When working vigorously, our bodies can produce up to 2 million joules per hour of internal heat (a joule is the heat produced by burning a postage stamp). Since vacuum is nearly a perfect insulator of heat, merely sticking an astronaut inside a pressurized rubber balloon is insufficient to ensure his survival. Within a few minutes the suit's internal temperature will rise to unhealthy levels, the astronaut will pass out from heat prostration, and then die of heat stroke. To prevent this, a spacesuit must be equipped with a complex system for collecting body heat and then radiating it away into space. A human body inside a spacesuit cannot cool itself by the convective or evaporative heat transfer mechanisms that are our bodies' normal means for cooling themselves.

Then, of course, there are the more mundane aspects of spacesuit design. How long is your astronaut going to be in the suit? If only for a few hours, then provisions for food, water, and waste disposal can be absent or rudimentary. However, if your astronauts are to spend days or even weeks in their suits, then something more elaborate is required.

Consider, for instance, the total quantity of water a human being needs to consume in a day (about 2.5 liters/quarts) to remain healthy. Where in your spacesuit do you have room to store 17.5 liters/quarts of drinking water for a one week long mission? Obviously, you can't just fill the suit with water and then climb inside. Although that *would* aid the cooling problem, I don't know of anyone who looks forward to drinking week-old bath water. So if you can't carry it inside your suit, you will have to carry it outside — in pressurized containers — and have some mechanism for refilling the helmet reservoir from time to time. If that sounds like an easy thing to invent, consider the difficulties that will arise if that fill mechanism malfunctions and connects the helmet interior directly to vacuum.

Now that you have a concept of the problem of providing the astronaut with a week's worth of water, consider the other consumables the human body needs to function and the wastes that it produces. Providing oxygen is relatively straightforward. Just devise a method for either refilling or replacing your oxygen tanks. But while you're at it, make sure that a lone astronaut can do the job without aid. On second thought, you'd better make your tanks refillable through a hose of some kind. It's doubtful that a human being in a spacesuit will ever be able to change out the oxygen tanks in his backpack — not while wearing the suit, anyway. The human frame wasn't designed to bend in that particular direction.

Then there is the week's worth of food your astronaut requires. Unless suit food is strictly liquid, you will need to have some kind of a mini-airlock to transfer victuals from vacuum to the pressurized interior of the suit. How are you going to get rid of a week's accumulation of fecal and urine waste? The urine, at least, can be boiled away in vacuum, leaving very little residue. The fecal material, however, is a bigger problem. I can't envision how to build an attachment in a spacesuit that serves the same function as the back flap in a pair of long underwear, but something like that will be required for extended mission spacesuits.

Which brings up another problem for spacesuit designers. Have you ever thought about what it will *smell* like inside a spacesuit after a week's trek through the lunar highlands? And think of the odiferous conditions that will exist in the suiting cubicle when four astronauts return to the ship and unseal their helmets simultaneously! Perhaps we will need to equip such cubicles with fire hoses and powerful exhaust fans, the better to keep the stink down to an olfactory roar.

We will continue our study of spacesuits by reviewing the most advanced spacesuit yet built, the Space Shuttle EMU.

The Space Shuttle Extravehicular Maneuvering Unit (EMU)

Space Shuttle EMU

Being a government agency, the National Aeronautics and Space Administration (NASA) can't say anything simply. Never use one or two syllables when a few lines of impenetrably dense bureaucrat-ese will do just as well. So NASA calls the spacesuit used on the Space Shuttle an Extravehicular Maneuvering Unit, which I suppose, it is. It allows the astronauts to move around outside of the vehicle.

Like all spacesuits, the shuttle EMU provides an astronaut with the necessities for life support. It provides oxygen for breathing, encases him in a pressurized enclosure, and removes the carbon dioxide that is the primary waste product of the respiratory process. The EMU also removes body heat using a system of small plastic tubes that circulate cold water over the surface of the astronaut's skin. This heat is transported to a heat exchanger in the suit's backpack, where it is radiated out into space. The suit also provides protection against micrometeoroids, tiny pieces of debris that zip through space faster than a speeding bullet.

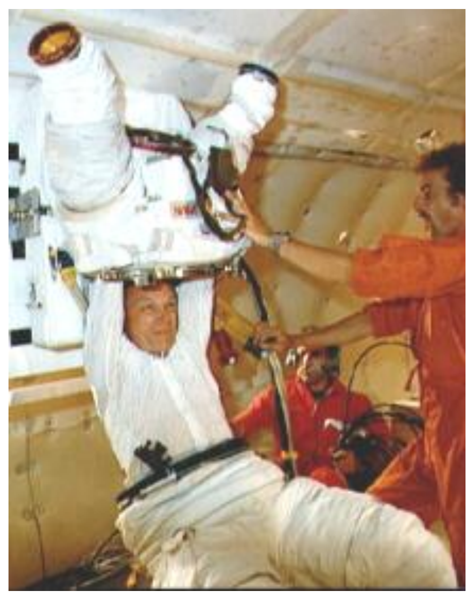
While primitive by the standards against which future spacesuits will be measured, the Shuttle EMU is the culmination of nearly fifty years of research and development. It provides an astronaut with sufficient supplies (what are known as "expendables") to work in vacuum for up to seven hours. Expendables on board the EMU include oxygen, a battery for electric power, water for cooling and lithium hydroxide for carbon dioxide removal. The oxygen is stored under high pressure in two cylinders inside the suit's backpack. In addition to the seven hours worth of breathing gas in the primary tanks, there is a smaller tank that contains a 30-minute supply of emergency oxygen to be used in the event of failure of the primary system. The suit is pressurized to 29.5 KiloPascals, (4.3 pounds per square inch).

The Shuttle EMU has a small computer in its backpack, a microprocessor that monitors the system's vital functions. It automatically alerts the wearer if something is wrong or if expendables are running low. There are a number of dramatic possibilities for science fiction writers concerning this system. Think of having the **OXYGEN LOW** alarm periodically beeping while your hero frantically struggles to force open the outer door of a malfunctioning airlock.

EMU Hard Upper Torso and Helmet with Display Module on Chest

The Shuttle EMU is designed for a lifetime of 15 years, a long time for a piece of complex aerospace equipment. Of course, the suit is cleaned and dried between flights, a process that both lengthens its life and ensures that each successive occupant doesn't have to smell all of his or her predecessors.

Most science fiction stories describe a spacesuit sort of like those suits of armor that decorate the hallways of all the better European castles. Seldom do we worry about how one actually gets into the thing. That is the difference between being a writer and an engineer. A writer merely describes the mechanism whereas an engineer has to design it to not only function, but also to be donned and doffed in something under a week. The engineers who built the Shuttle EMU had another problem. Unlike the Mercury, Gemini, and Apollo programs, where the spacesuits were custom designed and fitted to individual astronauts, the Shuttle EMU is mass-produced (or at least built in quantities that pass for mass production in the space program). It is designed as a series of modules, with each module built in enough different sizes to fit both men and women from the 5th to 95th percentiles of body size. In other words, the spacesuit modules had to be designed to accommodate everyone from a small Japanese woman to a large Swedish man, yet have standard interfaces so that modules can be attached to one another, with sizes mixed and matched at will.



Astronaut Gets Dressed (Note waist ring)

The EMU modules consist of a hard upper torso (chest assembly) with life-support backpack already mounted, a lower torso assembly (the pants) with attached boots. Sleeves and gloves for each arm and finally, the helmet, are attached to the hard upper torso. Early in the planning stages for a mission, the astronaut who is going to be performing an extravehicular activity (EVA) is fitted with a suit constructed of modules in the size that comes closest to fitting his or her individual dimensions. Various internal adjustments are then made to improve the fit of each module (the legs are shortened by tightening up on adjustment straps, for instance) and all of the modules are assembled to make a complete spacesuit.

Getting into the EMU is more difficult than putting on your clothes in the morning, but easier than previous spacesuits have been. The astronaut first puts on a liquid cooling and ventilation garment that looks like a pair of woolen "long john" underwear. He (or she) then climbs into the lower-torso assembly, with attached boots. Once the astronaut has his or her pants on, they are ready to get into the main part of the suit, the chest section or upper torso. This is a heavy piece of equipment that is the heart of the spacesuit. It contains all of the environmental controls needed to keep the astronaut alive. These are contained in a large backpack that is permanently attached to the dorsal section of the upper-torso module. Because it is so bulky and difficult to maneuver, the hard upper torso is carried in the Shuttle mounted to one of the airlock bulkheads. The astronaut gets into the torso module by squatting beneath it, placing his arms up through the waist, then standing up. As his hands enter the shoulder section of the upper torso, the astronaut slips his arms into the suit's sleeves, then wriggles the rest of his body into position. Once comfortably ensconced in the upper torso assembly, the astronaut (or a helper) connects the waist ring that attaches the upper torso (chest) module to the lower torso (pants) module.

The waist ring is an extremely important attachment since the pressurized suit will exert approximately one-quarter of a ton of force on that particular joint. The force comes from the internal pressure of the suit. In the pneumatics business (which is my profession), we refer to these as "blow off" loads. That is, the pressure pushes on both the upper and lower halves of the suit simultaneously, attempting to separate them at the waist ring. It is very important to the astronaut that these forces not succeed. Dropping the pants of your spacesuit while in vacuum is more than embarrassing. It's fatal!

Once the astronaut is "all buttoned up" in the EMU, he finds himself hanging on the wall of the airlock like a suit that has been put away in a closet. He then unhooks himself from the airlock attachment fixture and prepares to head into the wild, black yonder.

Unfortunately, going outside the Space Shuttle requires more than merely wriggling into your suit and making sure all of the connections are secure. The process of EVA begins 12-24 hours earlier than that. The reason for this is the relatively low (29.5 KPa, 4.3 psia) pressure maintained inside the suit when the astronaut is in vacuum. This low pressure was chosen for two reasons. The first is NASA's understandable concern over flammability in a pure oxygen atmosphere, an aversion they developed when the three Apollo 1 astronauts were incinerated when fire broke out while their capsule was pressurized to 150+ KPa (20 psia) of pure oxygen. The second concern is the physical work required to move appendages or to bend at the waist while encased in a pressurized balloon. (We discussed the various methods used to minimize the force required for an astronaut to move his arms and legs in the previous article.) The higher the pressure, the more difficult it is to move around.

Unfortunately, the Shuttle's main cabin pressure is maintained at Earth sea level conditions. If an astronaut were to go straight from cabin pressure to spacesuit pressure, it might precipitate a fatal case of the bends. To prevent this, astronauts scheduled for EVA breath 100 percent oxygen for one hour on the day before the EVA. The Shuttle's cabin pressure is then lowered to 70 KPa (10.2 psia) for 12 to 24 hours before the planned space walk. After an extended period at reduced pressure, the astronauts climb into their spacesuits and spend another 40 minutes breathing pure oxygen while they perform status checks on the suits. Only after this long process is complete do they vent the airlock and step out into space.

Science fiction writers should recognize that all this work is due to a technological shortcoming in the Shuttle EMU and will not be required in the future. Future spacesuits will use an oxygen-nitrogen mix at higher pressure to eliminate the pre-breathing requirement. So if you are writing about spacers in the mid-21st Century, having them go through the pre-breathing ritual will appear a little anachronistic. On the other hand, demonstrating some knowledge of the problem of the bends in space may buy you a few points with the more technologically sophisticated members of your audience.

Astronaut Wearing LCVG and Lower Torso

Which brings us to a major danger for science fiction writers who read this sort of "explain how the technology works" article. It is a trap I fall into all of the time, one that I work very hard to avoid. Having spent considerable time learning all of these esoteric little details about how spacesuits (or many other science fiction technologies) work, I have a tendency to include everything I know in my writing. The only problem is that too much technical detail is boring to the readers, who are much more interested in what the hero and heroine are doing after they doff their spacesuits than they are in knowing how those spacesuits actually work.

Don't get me wrong. It is good that you are learning how such "plot props" as spacesuits function. Just be careful how much of this information finds its way into your writing. A little bit of jargon goes a very long way, and while you (the writer) may enjoy reading long technical descriptions delivered in excessive, loving detail – most people find it BORING!

So, in the interest of writer education and after being properly warned against the misuse of the data, let's take a closer look at the parts of a Space Shuttle EMU and the functions they perform. Your spacesuits should be far more advanced than these (see the section on Advanced Spacesuit Design below), but knowing how the current suit works will make things more real for you when you are faced with writing that first scene in which your hero cavorts in vacuum.

Major Parts of the EMU

<u>Liquid Cooling and Ventilation Garment (LCVG)</u>

The LCVG is the inside-the-suit “long john” that the astronaut wears to keep cool. It consists of a mesh, one-piece suit made of spandex and zippered for front entry. Within the LCVG are 100 meters (300 feet) of plastic tubing through which cooling water circulates. The water flow is controlled by a valve attached to the Display and Control Module that is attached to the hard upper torso. It also has air ducts attached that direct oxygen and carbon dioxide along the suit’s arms and legs to the life-support system for purification and recirculation. The garment weighs 4 kilograms (8.4 pounds) when filled with cooling water. It has enough cooling capacity for physical activity that generates up to 2 million joules/hour (2,000 Btu/hour). An astronaut must be engaged in extremely vigorous exercise to achieve this level of heat generation.

Lower Torso (LT)

The lower torso assembly comes in various sizes and consists of pants and attached boots, as well as joints for the hips, knees and ankles. The LT connects to the hard upper torso by a quick disconnect coupling. It is composed of several layers: a pressure bladder of urethane-coated nylon, a restraining layer of Dacron and an outer thermal micrometeoroid garment made of neoprene-coated nylon, five layers of aluminized mylar and an ortho fabric surface layer of Teflon, Kevlar and Nomex. The lower torso is one of the primary parts of the suit that can be adjusted to fit frames from small to large.

Formal Portrait Showing PLSS Backpack and Helmet

Primary Life-Support Subsystem (PLSS) – Hard Upper Torso

The hard upper torso of the space suit is made of fiberglass and provides the structure for mounting other EMU components (arms, helmet, lower torso, PLSS and display and control module). It is essentially the base onto which everything else mounts. The Primary Life-Support System (PLSS) is the spacesuit’s combined oxygen source, air conditioning, and heat rejection system. It is housed in a backpack mounted to the rear side of the hard upper torso, covering the astronaut’s back from head to buttocks. The PLSS contains oxygen bottles, water storage tanks, a sublimator (a device for condensing water vapor), a fan/separator/pump/motor assembly, a contaminant control cartridge, various regulators, valves and sensors, communications and the microprocessor caution and warning system module.

System ventilation airflow enters the suit from the PLSS at the helmet and flows from behind the head, over the face and down through the suit. Oxygen, carbon dioxide and water vapor exuded by breathing leave the suit through the liquid-cooling and ventilation garment near the astronaut's elbows and feet and return to the PLSS.

Waste air enters the backpack and first goes through the PLSS contaminant-control cartridge, where activated charcoal and lithium-hydroxide remove odors and carbon dioxide from the mixture. Next, the purified air passes through a fan that maintains a flow of about 170,000 cubic centimeters per minute (six cubic feet per minute). Gas flow is then routed to the sublimator, a cooling device that condenses water vapor and permits its removal by a slurper (note the technical terminology!) and by the rotary separator. The water that is removed from the gas flow is pumped primarily into the PLSS water storage tanks for reuse in cooling the astronaut.

The sublimator also cools the ventilation flow to about 13°C (55°F). The oxygen then moves through a flow sensor and back to the suit inlet. Oxygen is added, as needed, to the ventilation flow from the primary oxygen tanks, entering the ventilation loop downstream of the flow sensor. Suit pressure is maintained at approximately 5 KPa differential (0.7 psid) while the astronaut is in the pressurized Space Shuttle cabin, but rises to 29.4 KPa (4.3 psid) as soon as the astronaut enters vacuum. The switchover from one mode to another is controlled by the astronaut, who manually operates an actuator located on the Control and Display Module, which is mounted on the chest of the hard upper torso module. Note: Switching to the low pressure mode while in space is not recommended since an absolute oxygen pressure of 5 KPa is insufficient to maintain consciousness.

Secondary Oxygen Pack (SOP)

The SOP provides 30 minutes of emergency oxygen and attaches to the bottom of the PLSS. This system backs up the PLSS in all life-support functions. When the astronaut is forced to switch on the SOP, it's time to go home … quickly!

Display and Control Module

The display and control module is an integrated assembly that attaches directly to the front of the hard upper torso. The module contains all of the EMU's mechanical and electrical operating controls, and a display that is easily seen by an astronaut wearing the EMU and helmet.

The display and control module interacts with the caution and warning system in the PLSS. This system contains a software program enabling the astronaut to cycle the display through a series of system checks, thereby determining the condition of a variety of components. Display of status information is one of the most difficult problems in spacesuit design. Due to the difficulty of moving around in the suit, there are a limited number of places where one can display suit status information, and generally those places are not the most convenient for the astronaut to read them. We will discuss this problem and its possible solutions in greater detail in the section on Advanced Spacesuit Design.

EMU Expendables

The EMU expendables include 1.2 pounds of oxygen pressurized to 900 psia in the primary bottles, 2.6 pounds of oxygen at 6,000 psia in the secondary pack, 10 pounds of water for cooling stored in three tanks with bladders and lithium hydroxide in the contaminant-control cartridge.

Other Components

Battery – The battery provides all electrical power needed by the EMU. The silver zinc battery is stored dry, and filled, sealed and charged prior to flight. The battery operates at 17.0 volts and is rechargeable.

EMU Electrical Harness – The harness provides instrumentation and communications connections to the PLSS. Among the instruments built into the EMU are several for readout of the condition of the astronaut while he or she is in the spacesuit.

Communications Carrier Assembly – Also known as the “Snoopy Cap,” the assembly fits over the astronaut’s head and snaps into place with a chinstrap. It contains microphones and headphones for two-way communications and for receiving caution and warning tones.

Helmet and Visor – The helmet is a clear polycarbonate bubble with a neck disconnect mechanism and a ventilation pad. Like the waist ring, the helmet attachment mechanism is safety-critical during a space walk. Having one’s helmet pop off in space is invariably fatal. The extravehicular visor assembly goes over the helmet and contains visors that are manually adjusted to shield the astronaut’s eyes.

Gloves – In some ways, the gloves of a spacesuit are the most difficult part to design. They must be flexible, yet protect the fingers from the vacuum and cold of space. The gloves contain the wrist disconnect, wrist joint, and the heating elements that warm the astronaut’s fingers. They also have insulation padding on the palms and fingers. Since fingers have a surplus of surface area (compared to their volume), an astronaut’s fingers will be the first things to get cold in vacuum. The gloves connect to the arms and are available in nine standard sizes, but can also be custom-made for specific astronauts when an acceptable fit is not obtained with standard-sized gloves. Crewmembers can manually turn the finger heating elements on and off with a switch located on the glove.

In-Suit Drink Bag – The drink bag is installed in the upper torso of the EMU and supplies water to the crewmember. Two sizes are available, the standard 0.6-liter and full liter size. A drink valve and mouthpiece extend into the helmet to permit the astronaut to drink. The drink bag must be designed to keep the water inside the bag until such time as the astronaut wants a drink. Getting a hole in the bag will allow water to leak into the suit’s interior. This could be potentially dangerous in microgravity because the water will tend to float around in the helmet where floating globules can be inhaled. It will also get into the PLSS air circuit, with potentially deleterious effects on the life support system. Not the least problem involves the stress and erosion on the blades of the high-speed fan should they be turned into a pumping device for liquid water.

Urine Collection Device – The urine collection device is basically a custom designed adult diaper. It stores 950 milliliters (roughly one quart) of urine. The urine collection device is a single-use disposable item that is changed between space walks and handling it in microgravity following a space walk is a touchy business. Those who are parents of young babies will understand why.

Service and Cooling Umbilical – The umbilical contains power, oxygen, cooling water and communications lines that allow the astronaut to be plugged into the systems aboard the Space Shuttle Orbiter while checking out the EMU. Otherwise, the astronaut would tend to exhaust his or her total supply of expendables before getting outside the ship. In addition, the umbilical is used to recharge the EMU between space walks. The umbilical is disconnected from the EMU prior to leaving the orbiter's airlock.

Airlock Adapter Plate – Strictly speaking, the adapter plate isn't really part of the spacesuit. It is the "hook" on which the hard upper torso is "hung" inside the airlock, positioning it so that an astronaut can don and doff the space suit with a minimum of contortions. It also anchors the chest assembly during launch and flight.

Space Suit Assembly Power Harness (SSAPH) – The SSAPH provides electrical power to the gloves. It was originally mounted on the glove, but has been moved to the PLSS in order to reduce the profile of the glove. Each glove contains one heater element per fingertip powered by a single 3.1 volt, D-size battery located on the right side of the PLSS. The battery, which will provide up to eight hours of operation, is connected to the heater elements via approximately 3 meters (9 feet) of copper cabling that runs from the battery down through the arms of the EMU.

Advanced Spacesuit Design

The Space Shuttle Extravehicular Maneuvering Unit is the most advanced spacesuit ever built and considering how little time we have been building spacesuits, it's a pretty good product. It is not, however, the last word in cavorting about in vacuum. In many ways, it's merely a start. There is, for instance, that inconvenient 12-24 hour pre-breathing time required before one can don an EMU and go outside. As we discussed in the previous section, pre-breathing is only required because of the low-pressure oxygen atmosphere used in the suit. In the future, spacesuits will use oxy-hydrogen gas mixtures at a high enough pressure to make pre-breathing unnecessary.

And, of course, there are other improvements to be made. A Shuttle EMU has an endurance limit of approximately 9 hours; exceptional when measured against previous suits, but still far short of what will someday be required. Is 9 hours sufficient? Before answering, consider the following scenario: You are a crewman aboard a space destroyer patrolling the badlands of the Asteroid Belt. The enemy attacks from behind a nearby rock, punching through your ship's defenses and cutting it in two with laser fire. You, the hapless crewman in the Number Three Missile Turret, clamp your helmet into place just as the last of the atmosphere disappears into vacuum. You have nine hours for your fleet to rescue you, after which they will only find only a blue-faced, open-mouthed corpse floating in the wreckage. If you were to find yourself in such a situation, wouldn't you prefer to have a spacesuit capable of longer endurance?

Advanced spacesuit design means more than merely improving on current systems, however. Over the years engineers and science fiction writers have come up with some truly advanced concepts in spacesuit design. Some have even been tested out – successfully. So, since you are undoubtedly writing stories set anywhere from a couple of decades to a couple of centuries ahead, let's look at the possibilities:

Body Stocking Spacesuits

As we noted in the previous chapter, the human body is not designed for exposure to vacuum. When subjected to zero external pressure, the human body swells up like a balloon. Because it is anchored to the underlying muscle, the skin won't explode. It will, however, suffer overstress in localized areas. Blood vessels near the surface will rupture and hernias are liable to occur at various places across the epidermis.

One thing your skin won't do, however, is leak. That is because it is an impermeable membrane that keeps your blood sealed inside your body and external environments out. In this respect, it functions like rubber impregnated spacesuit fabric, the layer that keeps the air in the suit.

Some engineers noted this interesting fact about human skin in the early 1960s, and began to lobby NASA to research the possibility of building spacesuits that were not airtight. Their vision was to place a pressurized helmet on an astronaut's head, anchor it to his shoulders, and then dress the astronaut in a spacesuit that resembles a nylon body stocking. The fabric of the spacesuit is not airtight. In fact, it is an open weave that will not allow air to be trapped inside. The body stocking is designed to expose the astronaut's bare skin to vacuum.

Many readers are wondering if something has been left out of the previous passage. Let me assure you that you have read it correctly. Instead of encasing the astronaut in a thick layer of rubberized fabric, you just "let it all hang out." As noted above, skin is a membrane that is impervious to passage by either gases or liquids in either direction – except for one important exception. There are times when liquid appears on the surface of our skin; specifically, when we are hot. When our bodies become overheated, we have an automatic cooling mechanism. We perspire!

We will perspire whether our skin is exposed to a cool spring breeze or hard vacuum. If you place your astronaut in a mesh body stocking, his sweat glands will begin to operate the moment he begins to overheat. However, since water boils at body temperature in vacuum, the tiny sweat droplets will evaporate instantly on being exposed to the surrounding environment, and therefore, will carry away excess heat with efficiency unknown on Earth. In fact, the boiling of perspiration will be so immediate that astronauts will likely not even be aware that they are perspiring.

"But wait a minute!" you exclaim. "Throughout this discussion you keep saying that the human body is not designed for exposure to vacuum, so how can we put an astronaut into a suit that is not airtight?"

Through the magic of science, that's how!

The engineers who came up with the idea of the body stocking spacesuit had a thought that turned their idea from a harebrained scheme into a stroke of genius. The reason a person's skin suffers damage in vacuum has to do with something called "hoop stress." When you blow up a balloon, the rubber fabric is stretched in all directions. That stretch is opposed by the natural spring rate of the rubber right up until the moment the balloon pops. Human skin is like the rubber of a balloon, but not as stretchy. It is also fairly weak in tension. The reason exposure to vacuum damages the skin is because it is overstressed locally by the residual internal pressure of the human body.

So skin is impermeable enough to act as the outer layer of a spacesuit, but lacks the tensile strength to withstand the forces generated by internal pressure. That is where the open weave mesh of the "body stocking" comes in. For fabrics such as nylon are far stronger in tension than is skin, and by supporting the skin all over the body, the problems associated with exposure to vacuum are theoretically eliminated. The skin performs its normal function of keeping our internal fluid inside, while the mesh fabric takes the load generated by internal pressure. If this concept is alien to you, think of a layer of tissue paper spread across a very fine net and then sprayed with water. The paper prevents the water from flowing through the holes and the net takes the weight of the water that would normally rip a hole in the tissue.

Since the human body's cooling system is fully automatic, there is no need for a complex heat removal system. The spacesuit is reduced to a nylon body stocking, a pressurized helmet, and a set of high-pressure oxygen tanks.

To work, of course, the nylon mesh will have to support the skin over every square centimeter of its surface. This means that it will have to fit very tightly and not have the same degree of stretch as normal body stockings. It also means that it will have to be padded anywhere there is a concave cavity – the abdomen, for instance, if the astronaut happens to be in good shape. This problem could be avoided if all astronauts were required to have beer bellies, the better to fit into their suits without having any unsupported areas. However, I doubt the readers will approve of such an idea. They prefer their heroes strong and muscular.

If you are writing a science fiction story, putting your characters into a body stocking spacesuit will go a long way toward convincing your readers that they are really in the future.

Spacesuit Display and Control

One of the biggest problems in spacesuit design is where to put the various suit controls such that the astronaut can get at them. If this seems trivial, remember that the astronaut's hands and arms are encased in thick gloves, and that their ability to flex those arms is severely limited. Furthermore, where do you put all of the dials and knobs with which early science fiction was so populated?

The EMU places a few rudimentary controls on a chest pack mounted to the hard upper torso module. However, because the gloves are so clumsy, only a few hand controls can be placed side-by-side on the display and control module. Some of the gages are actually out of sight on the front of the module, a problem for which NASA provides a mirror to be attached to one of the spacesuit arms so that they can reflect the gage reading up to the astronaut. The gages are, of course, printed mirror image in order to allow them to be read in a mirror.

The age of computers has vastly simplified the problem of displaying information. A logical advancement in spacesuit design is to build a head-up display (HUD) into the helmet and project information onto the front bubble of the helmet. A HUD would allow all manner of information to be displayed such that it would appear to be hovering a couple of meters in front of the astronaut's face.

One of the knottiest problems facing spacesuit designers is how to control the suit's various functions. On Earth we tend to lean in the direction of hand controls. For instance, I am imparting this information to you at the moment by moving my fingers rapidly across a QWERTY-style keyboard on my laptop computer. Have you ever considered what it must be like to type in spacesuit gloves? Have you ever thought about how large the keyboard of the computer would have to be just to prevent the astronaut from depressing three or four keys simultaneously?

It is the lack of mobility and dexterity in the fingers and arms that is one of the largest problems in spacesuit design. If you would like an appreciation of the problem, try a little experiment. In my youth, one of the most popular quiz shows on television was called "Beat the Clock." In it the contestants were asked to answer nearly impossible questions, then when they failed, they were given a challenge. One of the most memorable involved a couple of men who were blindfolded, given heavy work gloves to wear, and then asked to put on a pair of nylon stockings. The results were hilarious. Try it sometime and you will see what I mean.

If computer technology can make the display of data relatively easy, perhaps it can also make the input of data the same. We now have systems that will interpret the spoken word and type what we are saying (although my experience is that they aren't quite ready yet). A voice activated command system would seem to be perfect for controlling a spacesuit without the use of the hands. I know the military has evaluated voice recognition systems in aircraft for years, and it is probably an excellent choice for routine control problems. However, voice recognition could cause a few problems in an emergency. We do many control functions with our hands because our hands are tied into our brains at a very primitive level. When we stumble, for instance, we put our hands out instinctively to catch our fall. Speech, on the other hand, is a higher brain function and is liable to be put out of action whenever the astronaut is excited or frightened. Just as voice recognition technology will likely never be viable for aerial combat (it is unlikely that "Shoot the fucker!" will ever be a valid computer command), spacesuits of the future are likely to have a backup control system that relies on musculature-activation. After all, you can't very well yell "repressurize!" after all of the air has leaked out of your suit. You can yell it, of course, but since there is no sound in vacuum, your suit's computer will never hear the command.

And just how would you go about typing a report in a spacesuit? Easy. Just equip your gloves with a few pressure sensitive devices, bring up the word processing program on the helmet HUD, and then move your fingers inside the gloves to simulate typing.

<u>Conclusion</u>

There are probably a few hundred advanced concepts for spacesuit design that we could discuss, but I find that I am running long. The above discussion should give you some ideas on which to base your own spacesuit designs. And remember, the competition goes to the most original science fiction writer, the one who manages to convince the readers that what he or she is describing is not only possible, it's inevitable! Happy cavorting in vacuum, and don't forget to keep your spacesuit's fly zipped. You don't want anything to get vacuumed out of your suit, and possibly ripped off in the process!

The End

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NOVELS

1. Life Probe - ^{US}\$5.00

The Makers searched for the secret to faster-than-light travel for 100,000 years. Their chosen instruments were the Life Probes, which they launched in every direction to seek out advanced civilizations among the stars. One such machine searching for intelligent life encounters 21st century Earth. It isn't sure that it has found any...

2. Procyon's Promise - ^{US}\$5.00

Three hundred years after humanity made its deal with the Life Probe to search out the secret of faster-than-light travel, the descendants of the original expedition return to Earth in a starship. They find a world that has forgotten the ancient contract. No matter. The colonists have overcome far greater obstacles in their single-minded drive to redeem a promise made before any of them were born...

3. Antares Dawn - US$5.00

When the super giant star Antares exploded in 2512, the human colony on Alta found their pathway to the stars gone, isolating them from the rest of human space for more than a century. Then one day, a powerful warship materialized in the system without warning. Alarmed by the sudden appearance of such a behemoth, the commanders of the Altan Space Navy dispatched one of their most powerful ships to investigate. What ASNS Discovery finds when they finally catch the intruder is a battered hulk manned by a dead crew.

That is disturbing news for the Altans. For the dead battleship could easily have defeated the whole of the Altan navy. If it could find Alta, then so could whomever it was that beat it. Something must be done…

4. Antares Passage - US$5.00

After more than a century of isolation, the paths between stars are again open and the people of Alta in contact with their sister colony on Sandar. The opening of the foldlines has not been the unmixed blessing the Altans had supposed, however.

For the reestablishment of interstellar travel has brought with it news of the Ryall, an alien race whose goal is the extermination of humanity. If they are to avoid defeat at the hands of the aliens, Alta must seek out the military might of Earth. However, to reach Earth requires them to dive into the heart of a supernova.

5. Antares Victory – First Time in Print – US$7.00

After a century of warfare, humanity finally discovered the Achilles heel of the Ryall, their xenophobic reptilian foe. Spica – Alpha Virginis – is the key star system in enemy space. It is the hub through which all Ryall starships must pass, and if humanity can only capture and hold it, they will strangle the Ryall war machine and end their threat to humankind forever.

It all seemed so simple in the computer simulations: Advance by stealth, attack without warning, strike swiftly with overwhelming power. Unfortunately, conquering the Ryall proves the easy part. With the key to victory in hand, Richard and Bethany Drake discover that they must also conquer human nature if they are to bring down the alien foe …

6. Thunderstrike! - US$6.00

The new comet found near Jupiter was an incredible treasure trove of water ice and rock. Immediately, the water-starved Luna Republic and the Sierra Corporation, a leader in asteroid mining, were squabbling over rights to the new resource. However, all thoughts of profit and fame were abandoned when a scientific expedition discovered that the comet's trajectory placed it on a collision course with Earth!

As scientists struggled to find a way to alter the comet's course, world leaders tried desperately to restrain mass panic, and two lovers quarreled over the direction the comet was to take, all Earth waited to see if humanity had any future at all…

7. The Clouds of Saturn - US$5.00

When the sun flared out of control and boiled Earth's oceans, humanity took refuge in a place that few would have predicted. In the greatest migration in history, the entire human race took up residence among the towering clouds and deep clear-air canyons of Saturn's upper atmosphere. Having survived the traitor star, they returned to the all-too-human tradition of internecine strife. The new city-states of Saturn began to resemble those of ancient Greece, with one group of cities taking on the role of militaristic Sparta...

8. The Sails of Tau Ceti – US$5.00

Starhopper was humanity's first interstellar probe. It was designed to search for intelligent life beyond the solar system. Before it could be launched, however, intelligent life found Earth. The discovery of an alien light sail inbound at the edge of the solar system generated considerable excitement in scientific circles. With the interstellar probe nearing completion, it gave scientists the opportunity to launch an expedition to meet the aliens while they were still in space. The second surprise came when *Starhopper's* crew boarded the alien craft. They found beings that, despite their alien physiques, were surprisingly compatible with humans. That two species so similar could have evolved a mere twelve light years from one another seemed too coincidental to be true.

One human being soon discovered that coincidence had nothing to do with it...

9. Gibraltar Earth – First Time in Print — $6.00

It is the 24th Century and humanity is just gaining a toehold out among the stars. Stellar Survey Starship *Magellan* is exploring the New Eden system when they encounter two alien spacecraft. When the encounter is over, the score is one human scout ship and one alien aggressor destroyed. In exploring the wreck of the second alien ship, spacers discover a survivor with a fantastic story.

The alien comes from a million-star Galactic Empire ruled over by a mysterious race known as the Broa. These overlords are the masters of this region of the galaxy and they allow no competitors. This news presents Earth's rulers with a problem. As yet, the Broa are ignorant of humanity's existence. Does the human race retreat to its one small world, quaking in fear that the Broa will eventually discover Earth? Or do they take a more aggressive approach?

Whatever they do, they must do it quickly! Time is running out for the human race…

10. Gibraltar Sun – First Time in Print — $7.00

The expedition to the Crab Nebula has returned to Earth and the news is not good. Out among the stars, a million systems have fallen under Broan domination, the fate awaiting Earth should the Broa ever learn of its existence. The problem would seem to allow but three responses: submit meekly to slavery, fight and risk extermination, or hide and pray the Broa remain ignorant of humankind for at least a few more generations. Are the hairless apes of Sol III finally faced with a problem for which there is no acceptable solution?

While politicians argue, Mark Rykand and Lisa Arden risk everything to spy on the all-powerful enemy that is beginning to wonder at the appearance of mysterious bipeds in their midst…

11. Gibraltar Stars – First Time in Print — ^{US}\$7.50

The great debate is over. The human race has rejected the idea of pulling back from the stars and hiding on Earth in the hope the Broa will overlook us for a few more generations. Instead, the World Parliament, by a vote of 60-40, has decided to throw the dice and go for a win. Parliament Hall resounds with brave words as members declare victory inevitable.

With the balance of forces a million to one against *Homo sapiens Terra*, those who must turn patriotic speeches into hard-won reality have their work cut out for them. They must expand humanity's foothold in Broan space while contending with a supply line that is 7000 light-years long.

If the sheer magnitude of the task isn't enough, Mark and Lisa Rykand discover they are in a race against two very different antagonists. The Broa are beginning to wonder at the strange two-legged interlopers in their domain; while back on Earth, those who lost the great debate are eager to try again.

Whoever wins the race will determine the future of the human species… or, indeed, whether it has one.

12. Gridlock and Other Stories - US$5.00

Where would you visit if you invented a time machine, but could not steer it? What if you went out for a six-pack of beer and never came back? If you think nuclear power is dangerous, you should try black holes as an energy source — or even scarier, solar energy! Visit the many worlds of Michael McCollum. I guarantee that you will be surprised!

Non-Fiction Books

13. The Art of Writing, Volume I - US$10.00

Have you missed any of the articles in the Art of Writing Series? No problem. The first sixteen articles (October, 1996-December, 1997) have been collected into a book-length work of more than 72,000 words. Now you can learn about character, conflict, plot, pacing, dialogue, and the business of writing, all in one document.

14. The Art of Writing, Volume II - US$10.00

This collection covers the Art of Writing articles published during 1998. The book is 62,000 words in length and builds on the foundation of knowledge provided by Volume I of this popular series.

15. The Art of Science Fiction, Volume I - US$10.00

Have you missed any of the articles in the Art of Science Fiction Series? No problem. The first sixteen articles (October, 1996-December, 1997) have been collected into a book-length work of more than 70,000 words. Learn about science fiction techniques and technologies, including starships, time machines, and rocket propulsion. Tour the Solar System and learn astronomy from the science fiction writer's viewpoint. We don't care where the stars appear in the terrestrial sky. We want to know their true positions in space. If you are planning to write an interstellar romance, brushing up on your astronomy may be just what you need.

16. The Art of Science Fiction, Volume II - US$10.00

This collection covers the *Art of Science Fiction* articles published during 1998. The book is 67,000 words in length and builds on the foundation of knowledge provided by Volume I of this popular series.

17. The Astrogator's Handbook – Expanded Edition and Deluxe Editions

The Astrogator's Handbook has been very popular on Sci Fi – Arizona. The handbook has star maps that show science fiction writers where the stars are located in space rather than where they are located in Earth's sky. Because of the popularity, we are expanding the handbook to show nine times as much space and more than ten times as many stars. The expanded handbook includes the positions of 3500 stars as viewed from Polaris on 63 maps. This handbook is a useful resource for every science fiction writer and will appeal to anyone with an interest in astronomy.

