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Complex Garment Systems to Survive in Outer Space

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ABSTRACT

The success of astronauts in performing Extra-Vehicular Activity (EVA) is highly dependent on the performance of the spacesuit they are wearing. Since the beginning of the Space Shuttle Program, one basic suit design has been evolving. The Space Shuttle Extravehicular Mobility Unit (EMU) is a waist entry suit consisting of a hard upper torso (HUT) and soft fabric mobility joints. The EMU was designed specifically for zero gravity operations. With a new emphasis on planetary exploration, a new EVA spacesuit design is required. Now the research scientists are working hard and striving for the new, lightweight and modular designs. Thus they have reached to the Red surface of Mars. And sooner or later the astronauts will reach the other planets too.

This paper is a review of various types of spacesuits and the different fabrics required for the manufacturing of the same. The detailed construction of EMU and space suit for Mars is discussed here, along with certain concepts of Biosuit- Mechanical Counter pressure Suit.

Keywords: Extra-Vehicular Activity (EVA), spacesuits, Biosuit-Mechanical Counter pressure Suit

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Introduction

Outer space is an extremely hostile place. On stepping outside a spacecraft such as the International Space Station, or onto a world with little or no atmosphere, such as the moon or Mars, without wearing a spacesuit, the following things would happen [1]-

- One would become unconscious within 15 seconds because there is no oxygen.
- Blood and body fluids would boil and then freeze because there is little or no air pressure.
- Tissues (skin, heart, and other internal organs) would expand because of the boiling fluids.
- One would face extreme changes in temperature:
  - Sunlight: 248 degrees Fahrenheit / 120 degrees Celsius
  - Shade: -148 F / -100 C
- One would be exposed to various types of radiation, such as cosmic rays, and charged particles emitted from the sun (solar wind).
- One could be hit by small particles of dust or rock that move at high speeds (micrometeoroids) or orbiting debris from satellites or spacecraft.

For all these reasons to explore and work in space, human beings must take their environment with them because there is no atmospheric pressure and no oxygen to sustain life. Inside the spacecraft, the atmosphere can be controlled so that special clothing isn't needed, but when outside, humans need the protection of a spacesuit.

A space suit is a complex system of garments and equipment and environmental systems designed to keep a person alive and comfortable in the harsh environment of outer space. This applies to extra-vehicular activity outside spacecraft orbiting Earth and has applied to walking, and riding the Lunar Rover, on the Moon.

Since the beginning of human exploration above and below the surface of the Earth, the main challenge has been to provide the basic necessities for human life support that are normally provided by nature. A person subjected to the near vacuum of space would survive only a few minutes unprotected by a spacesuit. Body fluids would vaporize without a means to supply pressure, and expanded gas would quickly form in the lungs and other tissues, preventing circulation and respiratory movements.

Questions that may arise are: [2]

Why wear a Spacesuit?

Earth's atmosphere has 20 percent oxygen and 80 percent nitrogen. From sea level to about 75 miles up space begins. At 18,000 feet, the atmosphere is half as dense as it is on the ground, and at altitudes above 40,000 feet, air is so thin and the amount of oxygen so small that pressure oxygen masks no longer do the job. Above the 63,000-foot threshold, humans must wear spacesuits that supply oxygen for breathing and that maintain a pressure around the body to keep body fluids in the liquid state. At this altitude the total air pressure is no longer sufficient to keep body fluids from boiling [3].

Spacesuits for the space shuttle are pressurized at 4.3 pounds per square inch (psi), but because the gas in the suit is 100 percent oxygen instead of 20 percent, the person in a spacesuit actually has more oxygen to breathe than is available at an altitude of 10,000 feet or even at sea level without the spacesuit. Before leaving the space shuttle to perform tasks in space, an astronaut has to spend several hours breathing pure oxygen before proceeding into space. This procedure is necessary to remove nitrogen dissolved in body fluids and thereby to prevent its release as gas bubbles when pressure is reduced, a condition commonly called "the bends."

The spacesuit also shields the astronaut from deadly hazards. Besides providing protection from bombardment by micrometeoroids, the spacesuit insulates the wearer from the temperature extremes of space [3].

How thick is the space suit?

A spacesuit is approximately 3/16" thick composed of 11 layers of materials or more depending on the requirement.

How much does it cost to make a space suit?

The space suit costs two million dollars.

What color do they have to be?

The reason that the suits are white is because white reflects heat in space the same as it does here on earth. Temperatures in direct sunlight in space can be over 275 degrees Fahrenheit.

How much air does the space suit hold?

The amount of air in the suit will vary, depending upon the size of the suit. The extra large Shuttle suit, without anybody in it, holds 5.42 cubic feet of air; the extra small size holds 4.35 cubic feet. With an astronaut in the suit, the amount of free space remaining in the suit is 2 cubic feet.

What cloth to use for the suits?

The use of fabric type for spacesuit depends upon

a) How much heat and cold the hostile environment of space presents.

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b) How well various materials will withstand the above established design limits.
c) How long the materials will last when the materials are sewn / cemented together, folded and creased, and moved to different positions by bending or rotating the shoulder, elbow, wrist, waist, hip, knee, and ankle.

History of Spacesuits in USA [2, 4, 5, 6, 7]

A paper by Richard C Wilde et al [7] highlights development of US EVA capability within the context of the overarching mission objectives of the US human space flight program.

(i) Jet Aircraft

When jet aircraft were developed, pilots needed pressurized flight suits to cope with the low atmospheric pressure and lack of oxygen at high altitudes. Most of these suits were designed to be used only when the pressurized cabin failed. The suits consisted of neoprene rubber-coated fabric that could inflate like a balloon and a more rigid fabric over the neoprene to restrain the suit and direct the pressure inward on the pilot. Hoses were attached from the plane to the suit to provide oxygen [4, 5].

(ii) Mercury Spacesuit

The Mercury spacesuit was a modified version of a U.S. Navy high altitude jet aircraft pressure suit. It consisted of an inner layer of Neoprene-coated nylon fabric and a restraint outer layer of aluminized nylon. Joint mobility at the elbow and knees was provided by simple fabric break lines sewn into the suit; but even with these break lines, it was difficult for a pilot to bend his arms or legs against the force of a pressurized suit. As an elbow or knee joint was bent, the suit joints folded in on themselves reducing suit internal volume and increasing pressure [4].

(iii) Project Gemini

Fig. 1. Gemini 4 Spacewalk

Astronauts found it difficult to move in the Mercury spacesuit when it was pressurized; the suit itself was not designed for spacewalking. However, when NASA's Gemini program began, spacesuits had to be designed not only for emergency use, but also for spacewalking, so some changes had to be made. To cope with the space environment, the Gemini spacesuit had a human-shaped neoprene rubber bladder that was constrained by netting. Over the bladder, the suit had layers of Teflon-coated nylon to protect the wearer from micrometeoroids. The spacecraft supplied the oxygen and air-cooling through an umbilical cord. After the Gemini program, astronauts learned that cooling with air did not work very well. Often, the astronauts were overheated and exhausted from spacewalking; and their helmets often fogged up on the inside from excessive moisture. In the following section, we'll talk about the changes that were made to the spacesuit design for the Apollo.

(iv) Apollo Spacesuit [1, 7]

Fig. 2. Apollo Spacesuits as used for Moon Walking

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Apollo spacesuit mobility was improved over earlier suits by use of bellows-like molded rubber joints at the shoulders, elbows, hips and knees. Modifications to the suit waist for Apollo 15 through 17 missions added flexibility making it easier for crewmen to sit on the lunar rover vehicle.

From the skin out, the Apollo A7LB spacesuit began with an astronaut-worn liquid-cooling garment, similar to a pair of "long-johns" with a network of spaghetti-like tubing sewn onto the fabric. Cool water, circulating through the tubing, transferred metabolic heat from the Moon explorer's body to the backpack and thence to space.

Next came a comfort and donning improvement layer of lightweight nylon, followed by a gas-tight pressure bladder of Neoprene-coated nylon or bellows-like molded joints components, a nylon restraint layer to prevent the bladder from ballooning, a lightweight thermal super-insulation of alternating layers of thin Kapton and glass-fiber cloth, several layers of Mylar and spacer material, and finally, protective outer layers of Teflon coated glass-fiber Beta cloth.

The Apollo suit consisted of the following:

- a) A water-cooled nylon undergarment
- b) A multi-layered pressure suit
  Inside layer - lightweight nylon with fabric vents
  Middle layer - neoprene-coated nylon to hold pressure
  Outer layer - nylon to restrain the pressurized layers beneath
- c) Five layers of aluminized Mylar interwoven with four layers of Dacron for heat protection
- d) Two layers of Kapton for additional heat protection
- e) A layer of Teflon-coated cloth (nonflammable) for protection from scrapes
- f) A layer of white Teflon cloth (nonflammable) [1].

The basic Apollo spacesuit was also used for spacewalking during the Skylab missions.

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(v) Space Shuttle

During the early flights of the space shuttle, astronauts wore a brown flight suit. Like earlier missions, this flight suit was meant to protect the astronauts if the cabin pressure failed. Its design was similar to the earlier flight suits of Apollo. As shuttle flights became more routinely, the astronauts stopped wearing pressurized suits during liftoff. Instead, they wore light-blue coveralls with black boots and a white, plastic, impact-resistant, communications helmet. This practice was continued until the Challenger disaster.

After a review of the Challenger disaster, NASA started requiring all astronauts to wear pressurized suits during liftoff and re-entry. These orange flight suits are pressurized and equipped with a communications cap, helmet, boots, gloves, parachute, and inflatable life preserver. Again, these spacesuits are designed only for emergency use in case the cabin pressure fails or the astronauts have to eject from the spacecraft at high altitude during liftoff or re-entry. Currently used spacesuit for spacewalking from the shuttle and International Space Station is called Extravehicular Mobility Unit or EMU [1, 5, 7].

Basic Requirements of a Spacesuit [1, 8]

Several things are needed for the spacesuit to function properly in space. It must provide:

- A stable internal pressure. This can be less than earth's atmosphere, as there is usually no need for the spacesuit to carry nitrogen.
- Breathable oxygen. Usually a rebreather is used along with a supply of fresh oxygen.
- Temperature regulation. Heat can only be lost in space by thermal radiation or conduction with objects in physical contact with the space suit. Since heat is lost very slowly by radiation, a space suit almost always has only a cooling system

and heavy insulation on the hands and possibly feet.

- Electromagnetic radiation shielding.
- Micrometeoroid protection.
- Mobility.
- A communication system.
- Means to recharge and discharge gases and liquids.
- Means to maneuver, dock, release, and tether on space craft.

An ideal spacesuit provides the following:

(i) Pressurized Atmosphere

The spacesuit provides air pressure to keep the fluids in your body in a liquid state -- in other words, to prevent your bodily fluids from boiling. Like a tire, a spacesuit is essentially an inflated balloon that is restricted by some rubberized fabric, in this case, Neoprene-coated fibers. The restriction placed on the "balloon" portion of the suit supplies air pressure on the astronaut inside, like blowing up a balloon inside a cardboard tube.

Most spacesuits operate at pressures below normal atmospheric pressure (14.7 lb/in^2, or 1 atm); the space shuttle cabin also operates at normal atmospheric pressure. The spacesuit used by shuttle astronauts operates at 4.3 lb/in^2, or 0.29 atm. Therefore, the cabin pressure of either the shuttle itself or an airlock must be reduced before an astronaut gets suited up for a spacewalk. A spacewalking astronaut runs the risk of getting the bends because of the changes in pressure between the spacesuit and the shuttle cabin [1].

(ii) Oxygen

Spacesuits cannot use normal air 78 percent nitrogen, 21 percent oxygen and 1 percent other gases because the low pressure would cause dangerously low oxygen concentrations in the lungs and blood, much like climbing Mount Everest does. So, most spacesuits provide a pure oxygen atmosphere for breathing. Spacesuits get the oxygen either from a spacecraft via an umbilical cord or from a backpack life support system that the astronaut wears.

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Both the shuttle and the International Space Station have normal air mixtures that mimic our atmosphere. Therefore, to go into a pure oxygen spacesuit, a spacewalking astronaut must "pre-breathe" pure oxygen for some period of time before suiting up. This pre-breathing of pure oxygen eliminates the nitrogen from the astronaut's blood and tissues, thereby minimizing the risk of the bends.

(iii) Carbon Dioxide Absorption

The astronaut breathes out carbon dioxide. In the confined space of the suit, carbon dioxide concentrations would build up to deadly levels. Therefore, excess carbon dioxide must be removed from the spacesuit's atmosphere. Spacesuits use lithium hydroxide canisters to remove carbon dioxide. These canisters are located either in the spacesuit's life support backpack or in the spacecraft, in which case they are accessed through an umbilical cord [1].

(iv) Temperature Control

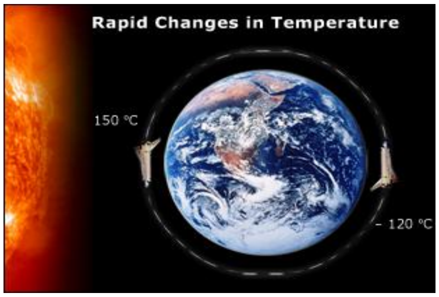

Fig. 3. Changes in Temperature

To cope with the extremes of temperature, most spacesuits are heavily insulated with layers of fabric (Neoprene, Gore-Tex, Dacron) and covered with reflective outer layers (Mylar or white fabric) to reflect sunlight. The astronaut produces heat from his/her body, especially when doing strenuous activities. If this heat is not removed, the sweat produced by the astronaut will fog up the helmet and cause the astronaut to become severely dehydrated; astronaut Eugene Cernan lost several pounds during his spacewalk on Gemini 9. To remove this excess heat, spacesuits have used either fans/heat exchangers to blow cool air, as in the Mercury and Gemini programs, or water-cooled garments, which have been used from the Apollo program to the present. In space, the temperature of an object can go from -120 °C "in the shade" to more than 150 °C when placed directly facing the Sun. Spacesuits can therefore undergo extreme changes in temperature (in the order of 270 °C and sometimes even more) when, for example, astronauts move from one side of the orbiter to the other [9].

(v) Protection from Micrometeoroids

To protect the astronauts from collisions with micrometeoroids, spacesuits have multiple layers of durable fabrics such as Dacron or Kevlar. These layers also prevent the suit from tearing on exposed surfaces of the spacecraft or a planet or moon [1].

(vi) Protection from Direct Radiation

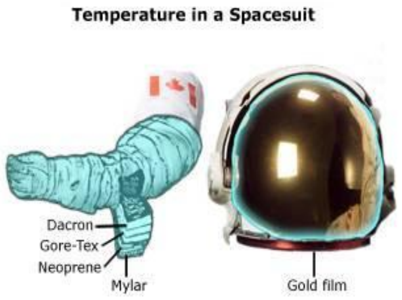

Fig. 4. Fabric Layers Spacesuit

Astronauts must get protection from solar radiation. The Sun's rays can heat objects to temperatures exceeding 150 °C. The effect of solar radiation can be compared to that of a grill. In an oven, two processes are responsible for cooking. Consider the way in which a pizza is prepared. First, there is warm air that ensures equal cooking, even under the dough. Then, there is the direct radiation of heat from the stove's upper element that makes the cheese golden. If we want to keep the cheese from burning, the pizza is covered with a layer of aluminum foil, protecting it from the radiated heat. The same principle is used for spacesuits. Its outer layers are made of insulating materials, such as neoprene, Gore-Tex and Dacron. The outermost layer is white to reflect the maximum radiation and is generally made of Mylar. As for the visor, it is covered with a gold film. This metal is an effective means of protecting the face, and especially the astronauts' eyes, against solar radiation [9].

(vii) Clear Sight

Spacesuits have helmets made of clear plastic or durable polycarbonate. Most helmets have coverings to reflect sunlight, and tinted visors to reduce glare, much like sunglasses. Also, prior to a spacewalk, the inside faceplates of the helmet are sprayed with an anti-fog compound. Finally, modern spacesuit helmet coverings have mounted lights so that the astronauts can see into the shadows [1, 10].

(viii) Mobility within the Spacesuit

Moving within an inflated spacesuit is tough. It is like trying to move fingers in a rubber glove blown up with air. To help this problem, spacesuits are equipped with special joints or tapers in the fabric to help the astronauts bend their hands, arms, legs, knees and ankles.

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(ix) Communications

Spacesuits are equipped with radio transmitters/receivers so that spacewalking astronauts can talk with ground controllers and/or other astronauts. The astronauts wear headsets with microphones and earphones. The transmitters/receivers are located in the chest packs/backpacks worn by the astronauts.

(x) Mobility in the Spacecraft

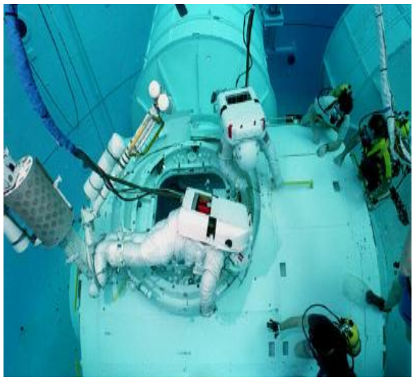

Fig. 5. Mobility in Spacesuit

In weightlessness, it is difficult to move around. If one pushes on something, he flies off in the opposite direction (Newton's third law of motion -- for every action there is an equal and opposite reaction). Spacecraft are equipped with footholds and hand restraints to help astronauts work in microgravity. In addition, before the mission, astronauts practice spacewalking in big water tanks on Earth. The buoyancy of an inflated spacesuit in water simulates microgravity.

NASA has also developed some gas-powered rocket maneuvering devices to allow astronauts to move freely in space without being tethered to the spacecraft [1, 11].

Theories of Spacesuit Design [12]

A space suit should allow its user natural unencumbered movement. Nearly all designs try to maintain a constant volume no matter what movements the wearer makes. This is because mechanical work is needed to change the volume of a constant pressure system. If flexing a joint reduces the volume of the spacesuit, then the astronaut must do extra work every time he bends that joint, and he has to maintain a force to keep the joint bent. Even if this force is very small, it can be seriously fatiguing to constantly fight against one's suit. It also makes delicate movements very difficult. The work required to bend a joint is dictated by the formula

$$W = \int_{V_i}^{V_f} P\, dV$$

Where V_i and V_f are respectively the initial and final volume of the joint, P is the pressure in the suit, and W is the resultant work. It is generally true that all suits are more mobile at lower pressures. However, because a minimum internal pressure is dictated by life support requirements, the only means of further reducing work is to minimize the change in volume.

Different Types of Spacesuits

1. Extravehicular Mobility Unit (EMU)

The earlier version of spacesuit consisted of total 11 layers; the liquid Cooling & Ventilation Garment (LCVG) (2 *layers);* pressure garment (2 *layers);* and the Thermal Micrometeoroid Garment (TMG) (7 *layers).* Simply stated, the LCVG maintains astronaut comfort, the pressure garment provides containment of the breathing air, and the TMG protects against the micrometeoroids which hit the suit, and insulates the astronaut from the extreme temperatures of space [2].

While early spacesuits were made entirely of soft fabrics, the EMU has a combination of soft and hard components to provide support, mobility and comfort. The suit itself has 13 layers of material, including an inner cooling garment (two layers), pressure garment (two layers), thermal micrometeoroid garment (eight layers) and outer cover (one layer) [1]. The materials used include:

- Nylon tricot
- Spandex
- Urethane-coated Nylon
- Dacron
- Neoprene-coated Nylon
- Mylar
- Goretex
- Kevlar (material in bullet-proof vests)
- Nomex
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EMU Facts [1]

- Weight on Earth = 280 lb (127 kg)
- Thickness = 3/16 in (0.48 cm), 13 layers
- Atmosphere = 4.3 lb/in^2 (0.29 atm) of pure oxygen
- Volume = 4.4 to 5.4 ft^3 (.125 to .153 m^3) without astronaut
- Cost = $12 million each

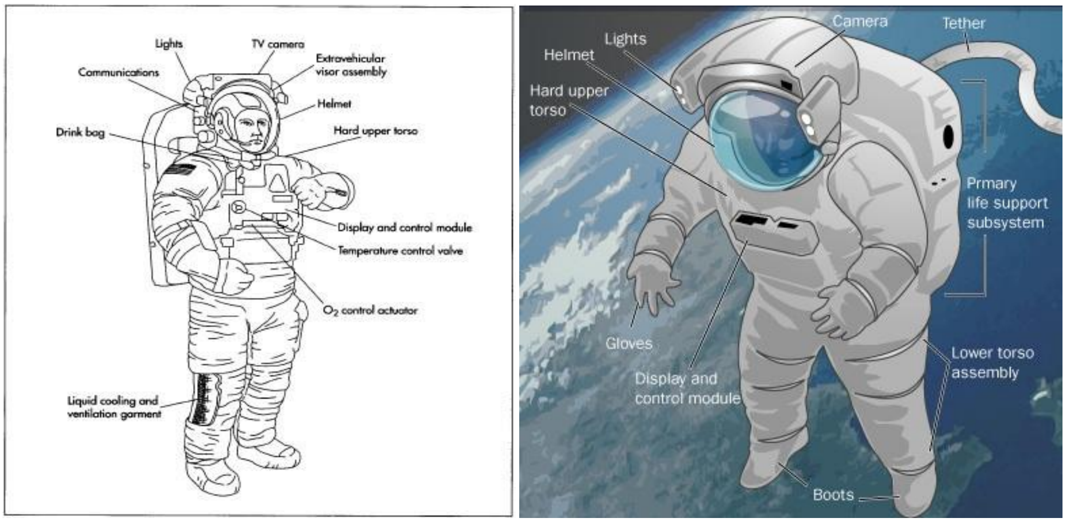

Fig. 6. Extra Vehicular Mobility Unit (EMU)

All of the layers are sewn and cemented together to form the suit. In contrast to early spacesuits, which were individually tailored for each astronaut, the EMU has component pieces of varying sizes that can be put together to fit any given astronaut.

Table 1. Material lay-up of the spacesuit fabric and water filled tube [13]

Material	**Areal density, gsm**
Ortho-fabric Gore-Tex /Nomex/Kevlar	490
Reinforced Aluminized Mylar	140
Neoprene Coated nylon Ripstop	280
Dacron Polyester	210
Urethane Coated nylon Ripstop	140
Nylon/Spandex/water/ethylene vinyl acetate	1540

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The EMU consists of the following parts:

1.1 Maximum Absorption Garment (MAG) [1, 2, 14]

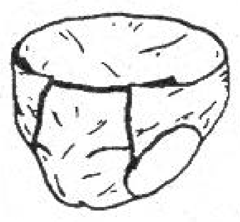

Fig. 7. MAG

Spacewalking astronauts can spend up to seven hours spacewalking. During that time, their bodies produce urine. Because it takes too much time to pressurize and depressurize the spacesuits and the airlocks/spacecraft, astronauts cannot simply go inside the spacecraft and use the toilet to relieve them. Therefore, each spacewalking astronaut wears a large, absorbent diaper to collect urine and feces while in the spacesuit. The astronaut disposes the MAG when the spacewalk is over. The Maximum Absorbency

Garment is worn under the LCVG and provides for hygienic collection, storage, and eventual transfer of astronaut urine and feces discharged during extravehicular activities.

1.2 Thermal Micrometeoroid Garment (TMG) [1, 2, 14, 15]

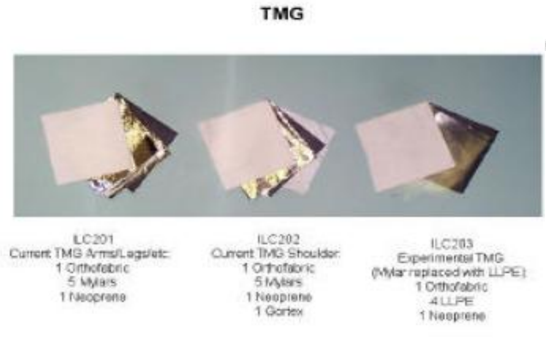

Fig. 8. TMG Material layup

The TMG liner is neoprene-coated rips top nylon and it provides puncture, abrasion, and tear protection. The next five layers are aluminized Mylar thermal insulation which prevents radiant heat transfer. The outer layer is the familiar white covering to the spacesuit and it is made of ortho fabric, which consists of a woven blend of kevlar and nomex synthetic fibers. The ortho fabric itself is very strong and resistant to puncture, abrasion, and tearing and is coated with teflon to stay clean during training on Earth. Sunlight is reflected by the white color of this outer TMG layer. The TMG covers the entire EMU except the helmet, controls and displays, and glove fingertips. The TMG and LSS cooling system limit skin contact temperature to the range of 10^{o}C to 45^{o}C (50^{o}F to 113^{o}F) and additional thermal mittens are used for grasping objects whose temperatures can range from -118^{o}C (-180^{o}F) on the shadow side of an orbit to $+113^{o}$C ($+235^{o}$F) on the light side of an orbit. The following section provides an analytical tutorial on the design of EMU fabric components.

The SSA TMG is of a different lay-up in the shoulder area than the standard arm assembly and LTA lay-up. In the shoulder area, there is an additional layer of Gore-Tex fabric under the neoprene coated nylon rips top. A replacement for the arm/leg TMG is also proposed in Table 2. The 5 Mylar layers of the original design are replaced by 4 layers of polyethylene film which has improved radiation shielding characteristics.

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Table 2. Material lay-up for current and proposed TMG

Description	Lay-up	Areal density, gsm
Current TMG Arms/Legs	1 Orthofabric	490
	5 Mylar	150
	1 Neoprene	263
Current TMG Shoulders	1 Orthofabric	485
	5 Mylar	150
	1 Neoprene	264
	1 Gore-Tex	330
Proposed TMG	1 Ortho-fabric	485
	4 LLPE	417
	1 Neoprene	265

1.1 Liquid Cooling and Ventilation Garment (LCVG) [1, 14]

Fig. 9. LCVG Garment

The liquid cooling and ventilation garment (LCVG) is the innermost layer of the spacesuit and provides thermal control by circulating air and water (cooled by a sublimator) over the crew member's body. The LCVG can handle peak loads of up to 500 kcal/hr for 15 minutes, 400 kcal/hr for up to 1 hour, or 250 kcal/hr for up to 7 hours. Average metabolic rates for past missions have been:

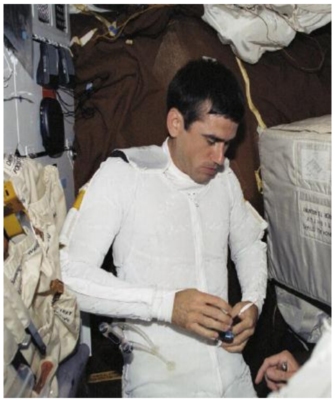

Fig. 10. Astronaut in LCVG

a. Apollo -1/6 g 235 kcal/hr (Apollo spacesuit) 0 g 151 kcal/hr
b. Skylab -0 g 238 kcal/hr (Apollo spacesuit)
c. STS -0 g 197 kcal/hr (Space Shuttle EMU)

LCVG is a set of Nylon tricot and spandex "long underwear" that is laced with thin plastic tubes. Cool water flows through these tubes to remove the heat produced by the astronaut. The cooling water comes from the spacesuit's backpack unit or from the spacecraft through an umbilical cord (used in the airlock while preparing for the spacewalk). The liquid Cooling & Ventilation Garment is a close-fitting undergarment covering the body torso and limbs. It incorporates a network of fine tubing that is maintained in close contact with the astronaut's skin by an outer layer of stretchable open fabric. The space suits so well insulated that normal body heat maintains warmth, except for occasional cold hands, even on the cold, dark side of the spacecraft. However, cooling is required; therefore, water is circulated through the LCVG tubing to remove excess body heat. Water flows through the various inlet and return tubes and must be uninterrupted in order for the garment to be effective. The LCVG also uses ventilation ducting to return vent flow from the body extremities to the EMU Life Support System (LSS).

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Table 4. Material lay-up for current and proposed LCVG Bladder

Description	Lay-up	Areal density, gsm
Proposed LCVG with Spectra	1Thick Spectra 1 Thin Spectra	355 73
Water jacket material sample	1 Urethane/Nylon 1 20-mil /Urethane 1 Urethane/Nylon 1 thin Spectra	240 301 242
Proposed Restraint/ Current Bladder	1 Woven Spectra 1 Urethane/Nylon	112 240
Proposed Restraint/ Proposed Bladder	1 Woven Spectra 1 10-mil LLPE	112 231
Proposed Restraint/ Current Bladder	1 Spectra Webbing 1 Urethane/Nylon	333 244
Proposed Restraint/ Proposed Bladder	1 Spectra Webbing 1 10-mil LLPE	333 228

1.2 EMU Electrical Harness (EEH)

This is a set of communications wires and bio instruments that is worn by the astronaut inside the suit. It provides connections to the radio and bio instruments in the suit's backpack. It allows for communication and for monitoring of the astronaut's vital signs (respiration rate, heart rate, temperature, etc.) [1].

1.3 Communications Carrier Assembly (CCA) [1, 14]

The CCA is a fabric cap worn by the astronaut. It contains microphones and speakers for use with the radio. It allows hands-free radio communications within the suit. The Communications Carrier is a skull cap that interfaces with the Electrical Harness Assembly. It contains a microphone and earphones for voice communications. The skull cap is made of teflon and nylon/lycra fabrics.

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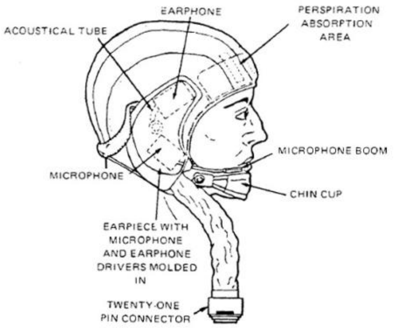

Fig. 11. Communications Carrier Assembly

1.4 Lower Torso Assembly (LTA) [1, 14]

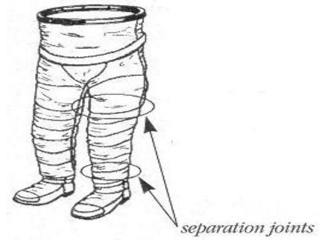

Fig. 12. LTA

The LTA is a one-piece unit that contains the lower half of the EMU, including pants, knee and ankle joints, boots and lower waist. It is fitted to the upper half of the EMU by a metal connect ring. The LTA has loops to tether tools so that they do not float away in space. The Lower Torso Assembly consists of an integrated Body Seal Closure, Waist, Waist Bearing, Leg, Thigh, Knee and Ankle joints, plus Boots. The LTA encloses the lower body and interfaces with the HUT via the body seal closure. The flexible waist section and waist bearing afford the astronaut a large degree of movement about the waist, e.g. bending and hip rotation.

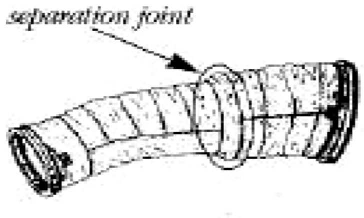

Fig. 13. ARM

1.5 Arms [1, 14]

The upper and lower arm joints are separated by an arm bearing, which allows lower arm rotation, the lower arm also provides for sizing adjustments and for quick connect/disconnect of the glove via a wrist disconnect.

1.6 Hard Upper Torso Assembly (HUT) [14]

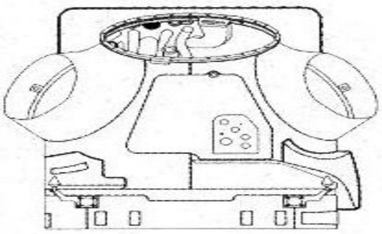

Fig. 14. HUT Assembly

The Hard Upper Torso is a vest-like rigid fiberglass shell which incorporates provisions for Arm, LTA and Helmet attachment (Fig. 17 & 18). Water Line and Vent Tube Assembly is fastened to the shell interior and interfaces with he LCVG and the Life Support System (LSS). The main portion of the LSS, containing water and oxygen storage and circulation provisions mounts on the back of the HUT, while the LSS controls mount on the front within easy reach of the astronaut. The first two target lay-ups are the HUT related materials given in table 5. The fiberglass structure provides pressure retention in the upper torso area, there is no restraint and bladder layer.

Description	Lay-up	Areal density, gsm
TMG/ Fiberglass	1 Orthofabric 7 Mylar 1 Neoprene 1 Fiberglass	499 218 273 4800
LCVG	1Thick Spectra 1 Thin Spectra	355 73
New TMG	1 Orthofabric 4 LLPE 1 Neoprene	485 417 265
Fiberglass LCVG	1 Fiberglass 1Thick Spectra 1 Thin Spectra	4800 355 73

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Table 5. Material lay-up of the Current SSA HUT

1.7 Gloves [14]

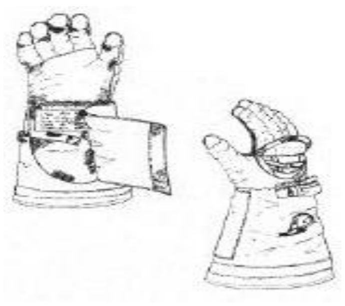

Fig. 15. Astronaut Gloves

Like the arm units, gloves have wrist bearings for easy movement. They fit into the arms by quick-connect rings. The gloves have rubberized fingertips to help astronauts grip things. Astronauts also wear fine-fabric gloves inside the outer glove units for comfort. The outer gloves have loops on them to tether tools. The gloves protect the astronaut's wrists and hands and are attached to the arms at the wrist disconnects. The gloves incorporate a rotary bearing to allow wrist rotation, a wrist joint to provide flexion/extension, fabric joints for thumbs and fingers, plus a hot pad for protection of the hand from extreme hot and cold extravehicular conditions. The glove includes fingertip heaters that are controlled by the astronaut.

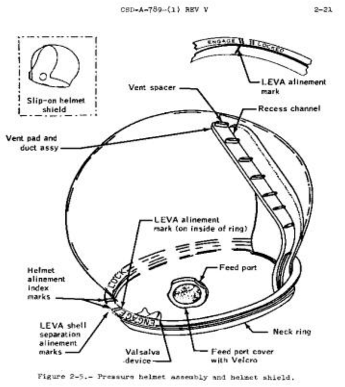

Fig. 16. Astronaut Helmet

1.8 Helmet

The helmet is made of clear, impact-resistant, polycarbonate plastic, and fits to the HUT by a quick-connect ring. In (Fig. 20), the helmet is padded in the rear for comfort, because the helmet remains fixed rather than rotating with the astronaut's head. It has a purge valve to remove carbon dioxide if the backup oxygen supply must be used. In the helmet, oxygen flows from behind the astronaut's head, over the head and down his or her face. The inside of the helmet is treated with an anti-fog compound prior to the spacewalk. The Helmet Assembly (table 6) consists of a transparent Shell, Neck Ring, Vent Pad, Purge Valve. The Helmet is secured to the HUT and provides an unobstructed field of vision.

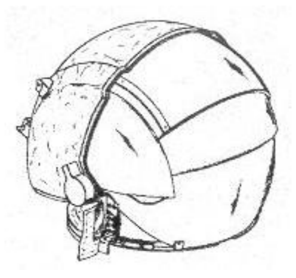

Fig. 17. EVA Assembly

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1.9 Extravehicular Visor Assembly (EVA) [14]

The Extravehicular Visor Assembly is a light-and-heat-attenuating shell which fits over the Helmet Assembly. It is designed to provide protection against micrometeoroid activity and accidental impact damage, plus protect the crewmember from solar radiation.

The EVA fits over the helmet. It has the following pieces:

- A metallic-gold-covered visor to filter sunlight
- A clear, impact resistant cover for thermal and impact protection
- Adjustable blinders to block sunlight
- Four head lamps
- A TV camera

Table 6. Material lay-up of helmet and EVA [1]

Layer	Material	Areal density, gsm
Outer layer	Orthofabric-Teflon/Nomex/Kevlar	490
Insulation	Aluminized Mylar- 5 plys	140
Spacer	Dacron fiber- 5 plys	110
Inner liner	Teflon	280
EVVA shell	Polycarbonate	3810
Sun visor	Polysulfone	1900
Eye shade	Polysulfone	1900
Protective visor	Polycarbonate	1820
Helmet	Polycarbonate	1820

1.10 In-suit Drink Bag (IDB) [13]

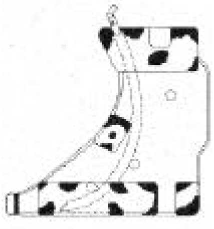

Fig. 18. IDB

Astronauts working in a spacesuit for up to seven hours need water. So the spacesuit has the IDB, which is a plastic pouch mounted inside the HUT. The IDB can hold 32 ounces (1.9 liters) of water and has a small tube, a straw, which is positioned next to the astronaut's mouth. There is also a slot in the helmet for a rice-paper-covered fruit and cereal bar that the astronaut can eat if he or she gets hungry during the spacewalk.

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1.11 Primary Life-Support Subsystem (PLSS) [1]

The PLSS is the backpack worn by the astronaut. It contains the oxygen tanks (1.2 lb / 0.54 kg at 518 atmospheric tank pressure), carbon dioxide scrubbers/filters, cooling water (10 lb / 4.6 kg total), radio, and electrical power, ventilating fans and warning systems. Oxygen flows into the suit behind the astronaut’s head and out of the suit at the feet and elbows. The PLSS provides up to seven hours of oxygen supply and carbon dioxide removal.

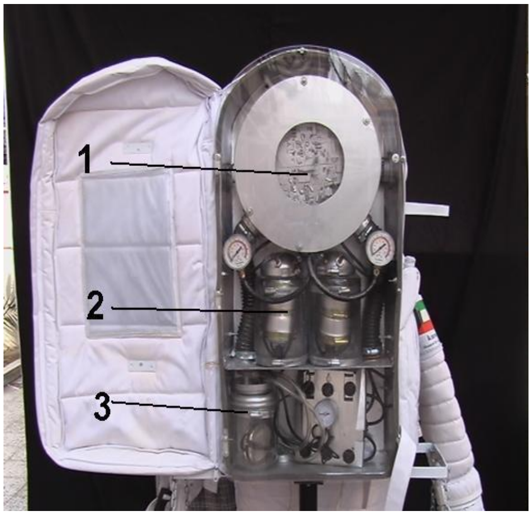

Fig. 19. Back Pack of Spacesuit

1.12 Secondary Oxygen Pack (SOP) [1]

The SOP is an emergency oxygen supply that fits below the PLSS on the backpack frame. It has two oxygen tanks that contain a total of 2.6 lb (1.2 kg) at 408 atm tank pressure. This is enough oxygen for 30 minutes, which is sufficient time to get a crewmember back inside the spacecraft. This oxygen supply automatically turns on when the oxygen pressure in the suit drops below 0.23 atm.

1.13 Display and Control Module (DCM) [1]

The DCM is a chest-mounted unit. It contains all of the switches, gauges, valves and LCD displays necessary to operate the PLSS. The DCM can be seen by the astronaut, sometimes with the aid of a sleeve-mounted mirror.

In addition to these major parts, the EMU has some of the following accessories:

1.14 Servicing and Cooling Umbilical (SCU) [1]

The SCU is an umbilical cord containing tubes for cooling water, electrical wires for power and tubes for oxygen. The SCU is used to provide water, power and oxygen to the EMU while the astronaut is in the airlock preparing for the spacewalk. This helps conserve the EMU's expendable supplies until the astronaut actually leaves the spacecraft.

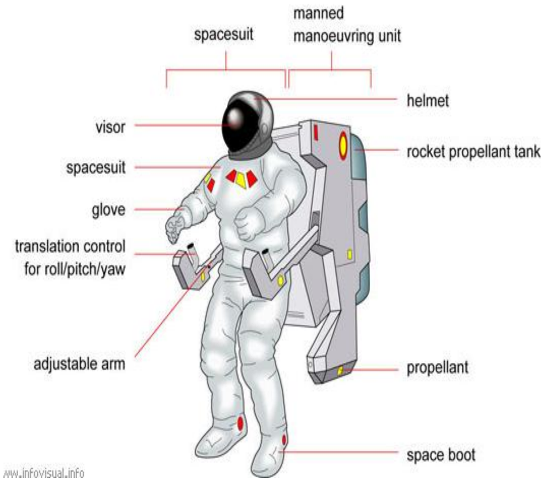

Fig. 20. Astronaut with PLSS

1.15 Airlock Adapter Plate (AAP) [1]

The AAP is a frame mounted to the wall of the airlock that helps hold the EMU pieces while the astronaut is suiting up.

1.16 Helmet Lights and Camera [1]

These devices are mounted on the EVA, which fits over the helmet. They are used to help the astronauts and ground controllers see into dark areas.

1.17 Sleeve-mounted Mirrors and Checklists [1]

These devices fit over the sleeves of the EMU. The mirrors help the astronauts see the DCM displays and see behind them. The checklists help them remember procedures over the course of a seven-hour spacewalk.

2. Mechanical Counter Pressure Bio-Suit (MCP Bio-Suit) [16]

The EMU space suit, which is currently used for NASA EVA’s, has both hard fiberglass and soft fabric components. Mobility features, such as pleats that open as joints bend and rotational bearings are built into all modern space suits. Without these mobility features, a person in a space suit would be virtually immobile. Even though

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space suits are designed to allow mobility, they restrict the wearer's motion in significant and complicated ways.

A Bio-Suit System stands to revolutionize human space exploration by providing enhanced astronaut extravehicular activity (EVA) locomotion and life support based on the concept of providing a 'second skin' capability for astronaut performance. The novel design concept is realized through symbiotic relationships in the areas of wearable technologies; information systems and evolutionary space systems design; and biomedical breakthroughs in skin replacement and materials. The Bio-Suit System would provide life support through mechanical counter-pressure where pressure is applied to the entire body through a tight-fitting suit with a helmet for the head.

Wearable technologies will be embedded in the Bio-Suit layers and the outer layer might be recyclable. Hence, images of 'spraying on' the inner layer of the Bio-Suit System emerge, which offers design advantages for extreme, dusty, planetary environments. Pressurized life support would be accomplished through mechanical counter-pressure where pressure is applied directly to the body compared to current spacesuits where the entire suit volume is pressurized, inflating it similar to a balloon and requiring the astronaut to continuously work against the cumbersome pressurized volume.

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Requirements MCP Bio-suit Concept Strategy: Why MCP? [16]

- As suggested by Paul Webb, Mitchell Clapp and others, Mechanical Counter-pressure suits have the possibility of greatly improving space suits in performance.
- Thus, MCP provides a possible solution to minimizing weight and improving other performance metrics such as flexibility/mobility, don/doff time, system bulk, tactile feedback, and possibly system cost.
- As pointed out by Clapp, "the human skin is almost an ideal pressure suit. Having a high tensile strength, almost no gas permeability, and very good water retention characteristics, the skin require only an applied pressure equal to the pressure of the breathing gas to function normally."
- In addition to being less bulky and heavy, [MCP suits] would be much less costly to produce than current garments."

Material Technologies for MCP Biosuit 618]

Three different types of suit concepts:

(i) Electric Alloy Mesh Suit Concept
(ii) Thermal Gel Suit Concept
(iii) Electric Gel Suit Concept

(i) Electric Alloy Mesh Concept

Electric Alloy Mesh Suit (EAMS) uses a seamless Shape Memory Alloy mesh to generate voltage controlled mechanical counter-pressure. Pressure is distributed by a viscous thermal regulating gel layer. The gel layer moderates the high temperature of the SMA later and protects the body against impacts the skin directly, wicking away perspiration and absorbing body heat.

Technology: Shape Memory Alloys (SMA) are a group of metal alloys that exhibit different sets of physical properties depending on their temperature. In the martensite phase, when the alloy is cool, it becomes soft and ductile and can be easily deformed. If it is heated, it will transform to the austenite phase, where it reverts to its original shape. SMAs are capable of generating large forces it they encounter resistance in the martensitic transformation. SMAs can be heated with an electrical current, they produce large repeatable strokes, and they are proven to be biocompatible.

Application: Counter-pressure must be applied to the body to simulate the correct atmospheric pressure. Small braces or clasps can line along the seams of the organic or synthetic second skin material. To seal the body and provide a uniform distribution of pressure, the bands can be constricted to draw the material together. SMA technology can be used create a constricting clasp.

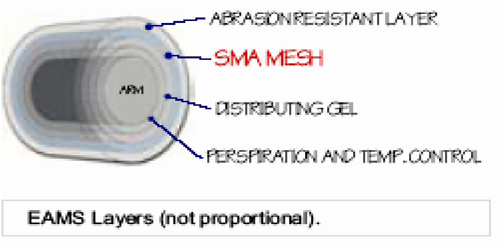

Figure 21. EAMS layers

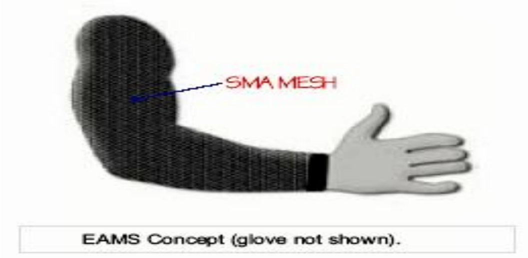

Figure 22. EAMS concept

(ii) Thermal Gel Suit Concept

Thermal Gel Suit (TGS) uses “smart” polymer gels which expand at a threshold temperature to create mechanical counter-pressure. The smart gel is trapped in a quilted layer beneath a stretchless restraint layer. The suit is donned in a relatively cool environment, with ambient temperature well below the gel’s threshold. Once on the astronaut, the TGS can be heated momentarily above the threshold temperature to stimulate expansion. The restraint layer prevents outward expansion of the gel, directing the pressure inwards against the body. The cold temperatures on Mars and in space preserve the gel’s expansion.

Technology: Polyelectrolyte gels are molecular networks within a solvent, usually water. These gels have the ability to contract or swell, often greater than a factor of 100, under various stimuli such as change in temperature, electricity, or pH. The phase change occurs almost instantaneously and can be very sensitive to the change. Currently, PAN is being used to create artificial muscle through pH changes. N isopropylacrylamide (NIPA) has been used and been shown to contact and dilate when stimulated with temperature.

Application: One class of intelligent gels is hydrogels and they exhibit reversible expansion when subjected to a temperature change. The temperature change would be provided by either body heat or atmospheric temperature. Stimulation through body heat would require close monitoring whereas atmospheric temperature would never reach body temperature thereby avoiding the possibility of reaching the phase change. The gel recovers very rapidly and can be reused multiple times.

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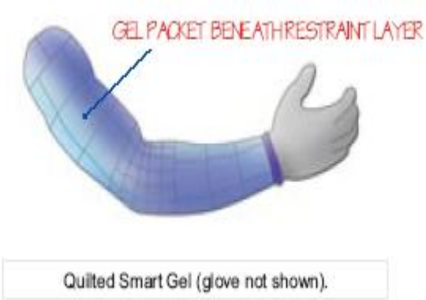

Figure 23. Smart Gel

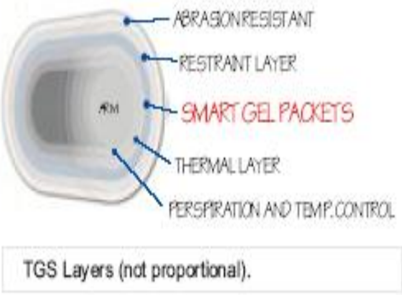

Figure 24. TGS layers

(iii) Electric Gel Suit Concept

This have the same concept as thermal gel suit, only difference is the electrical gel is used instead of thermal gel.

Technology: Polyacrylonitrile (PAN) and polyvinylalcohol (PVA) are two common gels stimulated by pH and electricity, respectively. Currently, PAN is being used to create artificial muscle through pH changes. The PAN fiberscan contract anywhere from one-half to one-tenth their original length and can support four kilograms per square centimeter. Development in this field has led to several successful demonstrations of the feasibility of gel based actuation including a multi-fingered hand.

Application: The dielectric elastomer gels, also known as electrostrictive polymers, are one class of intelligent gels and exhibit reversible expansion when subjected to an electric field. The electric current would be provided by two conductive layers with the gel inserted in between. The gel recovers very rapidly and can be reused multiple times. Advancements in battery technology may make this a feasible option for the Bio-Suit.

3. Spacesuits for Red Planet – Mars [17, 18]

The environment on Mars presents many unique challenges when designing a space suit for use during human exploration. These include a micro-vacuum atmosphere of mostly carbon dioxide, wide temperature fluctuations, and physical hazards ranging from dust storms to micrometeoroids and radiation. Previous NASA suits were analyzed prior to choosing new materials for a Mars suit, using Ashby criteria where applicable, and specific commercial information where necessary. Liquid cooling and ventilation, pressure, and thermo-mechanical garments were developed, using multiple materials and layers in each. Further materials choices were made for bearing materials to allow movement while ensuring sealing integrity of the suit. The overall mass for the design (without life support systems) is just less than 21 kg, significantly (and necessarily) less than earlier designs for lunar and orbital applications.

During the last half-century, the United States and Russia (former Soviet Union) have pioneered designs, innovations, and material selections during the development of space suits for lunar and orbital exploration. The next challenge is exploration of Mars. The red planet, Mars, has unique factors, which complicate the design process and challenge the limitations of current space suit design and materials selection.

Mars is further from the sun than the Earth and experiences significantly lower surface temperatures. The maximum, minimum, and mean surfaces temperatures are 20, −120, and −63 °C, respectively. Materials must behave in a non-brittle manner at these subzero temperatures. In addition, the suit will need to provide thermal insulation to maintain the body at a comfortable temperature. The atmosphere is significantly different— on the Earth's surface, the atmospheric pressure is 1.013 bars, while on Mars the surface pressure is only 0.007 bars. The Mars atmosphere is composed mainly of CO_2, N_2, and Ar at 95.3%, 2.7%, and 1.6%, respectively. The oxygen content of the low-pressure environment is only 0.13%. Therefore, no breathable environment exists, and the suit must provide one. Materials that are non-permeable and non-degradable in the largely CO2 environment are necessary. The gravitational pull on Mars is approximately 1/3 of that felt on Earth. The relatively high surface gravity, in comparison to the moon (1/6 of Earth), requires new suit design and material selection. For a highly mobile suit for use during an 8-h mission, current designs would require a significant weight reduction.

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3.1 Liquid Cooling and Ventilation Garment (LCVG) Design

3.1.1. Wicking Thin Film

To address the poor wicking properties, a very thin (25 μm) thermoplastic elastomer (TPE) film was added to the Mars suit closest to the body to allow for water vapor (perspiration) to travel out, away from the skin. The TPE film, which is a monolithic membrane, was selected over common microporous fabrics (e.g, Gore-Tex) due to superior permeability, water-vapor transmission, and tear strength properties. The TPE film will not allow water to penetrate in the opposite direction, back to the skin. Thus, the thin film's function was to allow for a one-way water transport and to maintain a comfortable microclimate between the fabric's surfaces closest to the skin.

Table 7. Liquid Cooling and Ventilation Garment (LCVG) Selection Parameters

Layer	**Constraints**	**Objectives, Properties**
TPE Film	One-way water-vapor transport "wicking" material	Maximize: tear strength, toughness, water-vapor transmission Minimize: density
SAP	Compatible with other layers	Maximize: shear modulus, swelling ratio (absorbency) Minimize: density
LCVG Fabric	Compatible with other layers	Maximize: thermal conductivity and capacity. Minimize: density, linear expansion Optimize: strength, stiffness, water-vapor/gaseous transmission

The TPE is composed of a multi-block co-polymer with hard and soft-segments that act semi-independently and can be individually engineered, designed, and selected. The soft segment largely determines the water-vapor transmission WVT) properties, while the hard segment dominates the mechanical properties.

3.1.2 Super-Absorbent Polymer-Absorbent Core

Working in tandem with the TPE film is a super-absorbent polymer (SAP) that promotes wicking and increases comfort for the LCVG. The SAP is manufactured into a physical blend with fibers, such as cellulose or thermoplastic, forming an absorbent core. The core's function is to trap any condensed sweat and pull it away from the skin. This new design concept is not common to any previous suits. A unique feature of SAPs is that the processing and synthesis essentially controls the two main properties of interest, specific absorbency (swelling ratio) and shear modulus.

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3.1.3 LCVG Fabric Layer.

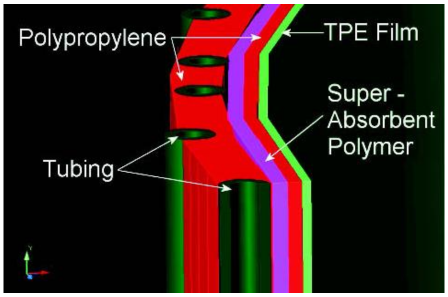

Fig. 25. 3D view of LCVG

Previous suits used a spandex- nylon (Spandex) bilayered fabric in the LCVG to provide a form-fitting garment, control perspiration, and allow for heat transfer. This layer could not possibly perform all these combined functions at once. Thus, earlier LCVG garments were marred by poor wicking, water absorption, and ventilation properties, which have now been addressed by the TPE thin film and SAP absorbent core. The fabric layer must be compatible with the TPE and SAP.

3.1.4. Cooling Medium

The function of the cooling medium is to transfer heat away from the body and reject the energy to space. Water, which was used in previous suits, proved to have the best combination of thermal and physical properties, while exhibiting no toxicity concerns.

3.1.5. Heat Exchanger

A phase change material (paraffin) isothermally absorbs heat energy as it changes from a solid to a liquid and is analogous to a heat sink. Subsequently, since the paraffin is housed in a special metal matrix “exposed” to the space environment, heat energy is radiated efficiently into space.

3.2. Pressure Suit Design

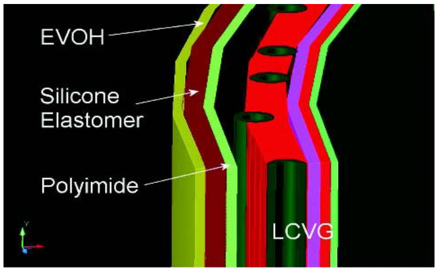

Fig. 26. 3D Pressure Suit (with LCVG)

Several improvements have been made to the pressure suit, including the incorporation of the dampening protective layers, which were found in the TMG in previous suit deigns. A barrier material has been incorporated in the pressure suit to minimize gaseous and moisture losses to the environment.

The garment includes three layers performing three distinct functions. The inner layer (closest to the body) includes an ethylene vinyl alcohol (EVOH) film to provide a barrier to oxygen and moisture losses. This layer essentially acts like a balloon. The middle-dampening layer is made from a silicone elastomer. This material is present in case of impact and can help to absorb any external energy. The outer layer functions as a structural member to stop the balloon/ barrier and dampening layers from continued expansion, maintain a constant volume within the suit, and provide the pressure to keep the body at a comfortable level. This garment is modeled as a pressure vessel.

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Table 8 : Pressure Suit (PS) Garment Selection Parameters

Layer	**Constraints**	**Objectives, Properties**
Pressure (Balloon)	Excellent barrier properties Compatible with other layers	Maximize: strength, flexibility, gaseous barrier properties Minimize: density
Dampening	Compatible “backing-layer” for thin films	Maximize: strength, flexibility, heat dissipation Minimize: density
Structural	Compatible with other layers	Maximize: high strength, rigidity Minimize: elongation, density, gaseous permeability

3.3. Thermo Mechanical Garment (TMG) Design.

The TMG provides protection from excessively cold temperatures, impact, fire, heat, wear, abrasion, and chemical degradation. The insulation layer protects from thermal conduction and radiation heat losses and is composed of several thin layers of aluminized polyester. A thin layer of nylon, located between the polyester layers, allows for relative movement to avoid thermal stress buildup. A rigid-rod polymer called polyphenelyene benzobioxazole (PBZO) was found to be the best material to use for impact and fire protection. This multifunctional material replaces two separate layers on previous suit designs. A new polymer called Demron provides energetic radiation protection. Wear and abrasion protection is provided by a thermally stable nylon 6,6. Finally, on the outside of the suit, chemical resistance and ultraviolet (UV) protection is provided by a fluoropolymer called PTFE that does not become brittle at low temperatures, is extremely inert, and does not degrade under UV radiation. The overall layer structure is illustrated in Fig. 32.

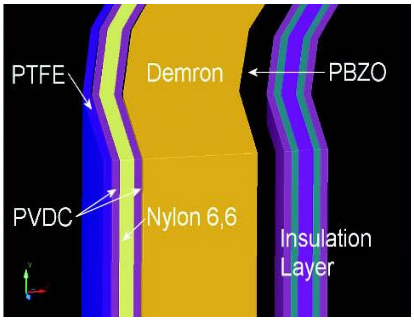

Fig. 27. 3D view of TMG

3.3.1. Insulation (Conduction and Radiation) Layer.

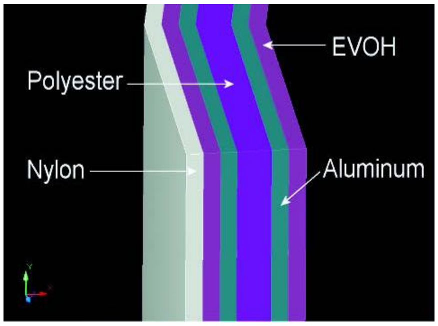

Fig. 28. 3D view of Insulation Layers

The function of the insulation layer is to maintain a comfortable temperature range, even when exposed to the extreme Martian surface temperatures (down to about −120 °C). The microvacuum on Mars makes heat losses by conduction and convection less significant, and therefore, the major concern lies in radiation heat loss. Among the design objectives listed in Table 9, other important considerations included minimizing heat losses while ensuring dimensional stability through the large temperature gradients. Polyethylene therephlalate (PET) was found to be the best material for the function. PET is strong, provides a good barrier to moisture and oxygen, and can be extruded into a thin film of approximately 13 μm. It can be used in a wide range of temperatures (−250 to +200 °C) and is readily combined with a variety of polymers and other materials. It has good puncture resistance properties and also has good chemical resistance.

However, PET can be co-extruded with EVOH (ethylene vinyl alcohol), which was used as the gaseous barrier on the balloon layer. Addition of a thin, 15 μm EVOH film on the outside of each layer of polyester would not increase the weight dramatically, but would reduce carbon dioxide permeation, and conduction and convection heat losses.

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Table 9. Thermomechanical Garment (TMG) Selection Parameters

Layer	Constraints	Objectives, Properties
Insulation	Stable over temperature range	Maximize: dimensional stability Minimize: heat losses, density, CO2 permeability
Energetic Radiation	Protection for Martian radiation Stable over temperature range	Maximize: flexibility, radiation protection Minimize: density, low-temperature brittleness
Fire/ Impact	Stable over temperature range Both fire and impact protection	Maximize: projectile impact strength, fire protection Minimize: density, dimensional instability, low-temperature brittleness
Abrasion V (wear)	Stable over temperature range	Maximize: dimensional stability, low-temperature ductility Minimize: density, coefficient of friction Optimize: hardness, strength
Chemical	Stable over temperature range	Maximize: chemical/UV resistance, low-temperature ductility, flexibility Minimize: density

3.3.2. Impact, Puncture, Fire and Heat Protection Layer

These are the secondary functions of this layer. The suit's low permeability to oxygen helps to avoid a situation where a fire may be encountered, but puncture from impact, wear or tearing might compromise this protection. A family of polymers with enhanced properties has recently evolved. Rigid-rod polymers are a new innovation in the realm of high strength polymers. The polymer fibers have superior tensile properties, excellent thermal stability, flame resistance, barrier properties, low smoke generation, and low moisture sensitivity (compared with almost all other polymers).

They have high dampening properties upon impact or vibration, and fatigue resistance as well. PBZO (polyphenylene benzobioxazole) was chosen as the rigid-rod polymer for use in the Mars suit. It is the strongest (i.e., its fibers are almost twice as strong as Kevlar fibers) and most heat-resistant (i.e., almost twice as flame resistant as Nomex) polymer in its family. It is the only rigid-rod polymer available for industrial manufacturing. PBZO is made by the Japanese manufacturer Toyobo and sold under the name Zylon (Osaka, Japan).

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3.3.3. Energetic Radiation Layer

The actual nature of the energetic radiation present on Mars remains relatively unknown, but the main radiation types believed to be present include electrons, protons, alpha, and heavy nuclei particles. Thus, this layer's function is to provide resistance to energetic radiation that may cause damage to the entire suit. Further, according to the objectives listed in Table 9, this must be a lightweight and flexible layer providing resistance to energetic radiation down to low temperatures.

3.3.4. Abrasion (Wear) Resistance Layer

The actual nature of Martian dust remains relatively unknown, but dust storms do exist on Mars. Thus, resistance to flying debris must be considered for the abrasion layer. The function is to avoid wear due to abrasive dust that may cause damage to the TMG and the rest of the suit. Further, according to the objectives listed in Table 9, important considerations include low coefficient of friction and low-temperature toughness to avoid fracture. In previous suits, this layer was polytetrafluoroethylene (PTFE). PTFE has a very low coefficient of friction and does not degrade in almost all solvents. On the Apollo suit, PTFE was the outermost layer providing UV radiation resistance and will also be on the Mars suit to serve this purpose (see the Chemical Resistance section below). PTFE is not particularly strong and is very soft, which highlighted nylon as a viable alternative for the wear layer, should the PTFE layer be worn away. Nylon 6, 6 has good strength, decent hardness (for a polymer), fairly good toughness at low temperatures, and a low coefficient of friction, and it provides good wear and abrasion resistance. Nylons are hydroscopic, meaning that they readily absorb moisture. To avoid problems due to exposure to a vacuum (i.e., spontaneous boiling of absorbed moisture causing damage to the material) a layer of polyvinyldiene chloride (PVDC), an exceptionally good barrier to moisture, is suggested. This film would be adhered to both the outside and the inside of the nylon to avoid moisture absorption. PVDC can be produced in a film about 13 μm thick that would make a negligible thickness difference for the suit. Nylon can be produced in several grades and by several methods. For low temperature ductility, nylon 6, 6 would be required. Dartek, a nylon 6-6 made by Dupont, should be able to provide these properties. It is a readily available film, can be made into 25 μm thick layers, and can be co-extruded with other polymers.

3.3.5. Chemical Resistance Layer.

The chemical resistance layer is found on the outside of the suit. The function is to protect the astronaut from hazards such as UV radiation and chemical contamination (organic and inorganic solvents) down to low temperatures (see Table 9 for all design objectives). The chemical resistance layer appeared to have been made of a polyimide film on a cloth in previous suits. This layer also provided extra insulation and some energetic radiation protection. CES 4.0 indicated that polyimide chemical resistance is considered only "good." Polytetrafluoroethylene (PTFE) is thus, the material that was chosen for this layer. Along with being one of the most inert materials known, highly crystalline PTFE has several other useful properties. PTFE is a white (opaque) film that performs well even at temperatures of −200 °C and can shield the suit from UV radiation as the layer on the outside of the suit. To avoid dust collecting on the suit and wearing away at the surface layers, the PTFE layer provides anti-static protection and the dust merely falls off the suit instead of building up. PTFE has a very low coefficient of friction, providing fairly good wear resistance. It therefore acts in tandem with the nylon wear layer beneath it. A thin extruded membrane (approximately 25 μm thick) of PTFE, similar to a Gore-Tex material (Newark, DE) (PTFE processed by Gore and Associates), should be able to provide adequate protection.

4. Chameleon Suit – An Alternative Paradigm [19]

Natural biological systems suggest an alternative paradigm and design approach that may reduce the difficulty of dramatically reducing the mass and mission penalties for future EVA systems. Biological systems thrive through a strategy of adaptive interaction with their environment using multi-functional materials and systems.

Thus, protective and structural materials also mediate heat and material exchange processes, and energy from the environment is harvested to drive the processes that make this possible. This is the case in even the most extreme environments using a wide variety of mechanisms that adapt to changing environmental conditions and needs of the organism. To do so, we must consider the walls of the spacesuit as much more than a barrier between a hostile environment outside and a fragile human inside. The essence of the Chameleon Suit concept is viewing the spacesuit walls as an extension of the wearer's skin and membrane tissues to better match their already robust adaptive capabilities to a new and challenging set of conditions. In the process, a wide range of potential functions of the membranes and fabrics in the suit wall

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and mechanisms for their control are considered. The objective is to move life support processes from an external back pack into the spacesuit itself and to connect them more closely and naturally to the biological processes of the person wearing the suit. Benefits which can be derived from this approach include:

- Reduced penalties for mass and energy transport between the human and the life support process locus – less plumbing, pressure drop, temperature difference, parasitic heat loss or gain, etc.,
- Increased use of and benefit from inherent adaptive capabilities of human systems,
- Increased available surface area for desirable environmental interactions,
- Increased diversity of access and flexibility for orientation dependent processes,
- Decreased complexity, mass, and volume of life support equipment and supplies,
- Inherently better system center of gravity management,
- Greater radiation shielding benefits from life support systems and materials.

Entry types of Spacesuits [20]

One of the key features of any space suit is the entry method. Historical examples of different entry types include waist entry, rear entry, bi-planar entry, and soft zipper type entry. Suit entry type plays a critical role in defining the overall suit architecture. Some of the critical suit features affected by entry type are suit don/doff capability, suit sizing, suit mass, suit volume, and suit comfort. In general, rear entry designs provide better don/doff capabilities. However, mass and limitations to vertical torso length may be disadvantages of the rear entry design. Entry type is also affected by the vehicle and habitat interfaces such as air locks, hatches, and manned rovers. One concept for planetary exploration is to have an unpressurized vestibule attached to the habitat and have the spacesuit attached to the habitat wall acting as an air lock. This scenario is best supported by a rear entry design minimizing the amount of dust and dirt entering the habitat.

Figure 29. Waist Entry

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Figure 30. Rear Entry

Future Space Suits

When working on the moon, Apollo astronauts had difficulties moving around in their spacesuits. The Apollo suits were not nearly as flexible as the EMU used today; however, the EMU weighs almost twice as much as the Apollo suit (not a problem because the EMU was designed for work in microgravity, not on a planet's surface). For future space missions to Mars, NASA is developing "hard suits" that are more flexible, more durable, lighter-weight and easier to don than current spacesuits. And chameleon suits are the cake with red cherry on top.

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