The Pharma Innovation Journal 2023; 12(5): 1082-1086

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; 12(5): 1082-1086

www.thepharmajournal.com
Received: 01-02-2023
Accepted: 06-04-2023

Radhika Damuluri
Assistant Professor, Department of Apparel and Textiles, College of Community Science, Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad, Telangana, India

Dr. Sudha babel
Professor, Department of Textiles and apparel Designing, College of Community and Applied Sciences, MPUAT, Udaipur, Rajasthan, India

Corresponding Author:
Radhika Damuluri
Assistant Professor, Department of Apparel and Textiles, College of Community Science, Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad, Telangana, India

Review of functional clothing: Space suits

Radhika Damuluri and Dr. Sudha babel

Abstract
The current scenario of space tourism has created the need for the production of safe and protective space crafts and space suits. Many space companies are exploring the options to establish colonies on other planets and meteoroids. Hence, in the future there is going to be a requirement for a huge number of space suits that can provide not only protection in the hostile environment of space but also should meet functional needs such as longer shelf life, comfort, durability, reusability, flexibility to perform complex tasks and crisis mitigation. This article is an attempt to review about functional and protective properties of space suits.

Keywords: functional, clothing, space suits, environments

Introduction
Exploration of space by humans is dependent on effective spacecraft design, and protective and life-supporting space suits, which enable the astronaut to work in extremely hostile environments. The space suit is an air-tight structure, known as PGA (Pressure Garment Assembly). Without the protection of a space suit, humans cannot sustain themselves in space even for a few seconds [9].
Over the period of past 50 years, space suits have contributed too many breakthrough events such as establishing superiority in space travel, landing on the moon, establishing human presence continuously on earth’s low orbit on the international space station, etc. They may appear simple, but beneath the outer layer of the space suit, a complex entity facilitates motion and provides protection to the wearer from a hostile space environment [1].
Space exploration programs have progressed a lot over the past decades, from suborbital missions, which lasted a few minutes to orbital flights, lasting for a few days. It is evident that humans can survive and work in space. Hence, it is imperative to develop new technologies to send a greater number of people into space for longer durations for significant space exploration [7]. The international space stations revolve around earth at a high altitude (more than 300 km) in extreme environmental conditions such as high vacuum, extreme temperatures, microgravity, space debris, meteoroids, and UV radiation. Space and other protective equipment play a pivotal role in making space exploration a success.
Space suits provide a supply of oxygen, but they also replace the pressure experienced at low altitudes. In space, at an altitude greater than 63,000ft (19km), rapid body changes occur in humans, such as swelling of exposed skin, heating and boiling of body fluids like saliva, and moisture in the eyes. Space suits are pressurized to 4.3 pounds per square inch (30 kilopascals) [8]. Space suits are typically used in earth’s low orbit or on the surface of the moon. They are also, made to perform operations beyond spacewalks, during extravehicular activity, during launching, landing, aborting, or other emergency operations, etc.
There are two major types of space suits. Space suit used for travel primarily provides protection during the emergency launching and landing of the space shuttle. Whereas, a space suit used for spacewalk must meet many performance parameters and protection standards [1].
In earth’s low orbit, the space suit must provide protection from the vacuum in space, extreme thermal conditions ranging from -150 °C to more than 120 °C, gravitational changes, rapid changes from extreme sunlight to extreme darkness, debris in orbit traveling at high speed and micrometeoroids. The moon’s environment is different from earth’s low orbit. It has 1/6 the gravity of the earth, covered with abrasive, sharp-edged lunar dust particles, which can damage the suit materials. On Mars also environmental conditions are totally different from earth. Mars has 3/8th gravity of earth, soli particles may consist of chemical oxidants, which will damage space suit. The space suit must be designed, based on the activities performed.

The extravehicular activity performed includes maintenance, construction, repair, and monitoring of experiments. The suit should not hinder any kind of movement in microgravity while performing these activities [1, 10].
Even though the space suit is heavy, the astronaut can comfortably wear it in space due to the microgravity of space [8].

Space suits provide the following functions

- Space suits protect astronauts from intense solar radiation.
- The space suit provides a stable pressurized environment, preventing inflation of the astronaut's body. The space suit is made of rubberized stretchable material and pressurized oxygen, providing ease of body movements.
- Space suits are puncture-proof, and protect astronauts from space debris, meteoroids, and other sharp objects.
- Space suits provide thermal insulation, provided by heating units, to protect from the extreme cold due to astronauts or spacecraft, staying in the shadow of an object for a longer duration, leading to internal heat dissipating into space.
- Sometimes astronauts are exposed to excessive heat due to solar radiation, heat generated by metabolism, friction in the atmosphere while passing through the earth's orbit, and due to operation of equipment in the spacecraft. Hence space suits are equipped with air conditioning mechanisms [5].
- Pouches installed inside the space suits enable them to contain body waste.
- Over the past decade, space suits are evolved. Smart suits are developed to travel to mars. They will enhance the astronaut's performance with a stretchable, self-healing outer layer. The suit senses threats, damages, and maintenance issues and informs the wearer.
- Another sleek, futuristic space suit is developed by Elon Musk's SpaceX, which is a one-piece, suit that directly connects to the computer in the spacecraft.
- Future space missions to the moon and mars will influence the design of space suits and the development of enhanced technology [4].

Requirements of space suit: in order to create an effective space suit, one must understand the environmental conditions the wearer is exposed to, and the functionality required by the suit. Hence, the set of requirements will provide guidelines to technicians and engineers in the selection of suitable materials, design, evaluation protocols, and overall configuration [2].
An EMU (Extravehicular Mobility Unit), provides enhanced functionality, which consists of a space suit, a PLSS (Portable Life Support System), and an EVA Extravehicular Activity Spacewalk) gloves. This is a reusable, mobile, easy-to-maintain system that is highly reliable for EVA. These EMUs must be made with lightweight materials having high strength so that they can reduce fatigue, provide protection from moon dust and also help in preventing contamination. Care must be taken to maintain less operating pressure and zero pre-breathable conditions [22].

Problems encountered with space suits: From the medical point of view, the space suit reduces mobility and there is a possibility of decompression sickness. The space suit is like a balloon filled with air, when worn by a space traveler, the suit inflates due to the differential pressure, limiting body movements. The space suit is soft but becomes hard to bend. Hence, the internal pressure is normally set to 0.3 atm. But this may cause decompression sickness. The internal pressure can be decreased by reducing the inflation of the space suit to improve mobility but, doing so increases decompression sickness. instead, a space suit can be made using stretch material [2].

Apollo space suits: the space suits made for the Apollo program had rocky ground walking boots and a life support system, which enabled astronauts to move away from the lunar lander. Orange suits are worn by astronauts during the launching and landing of the space shuttle or only inside the space shuttle. The space suit of the Apollo program was a one-piece custom-made suit (to suit each astronaut). Astronauts have entered the suit from the back opening. Each Apollo mission utilized 15 space suits. Generally, astronauts use teethers, to attach themselves, to the spacecraft, during the spacewalk. The EVA is an Extra Vehicular Activity spacewalk. Alexei Leonov during Soviet Union's Voskhod 2 orbital mission in 1965 departed the spacecraft, in order to test EVA. Later, many astronauts tried EVA. The first untethered spacewalk was done by an American astronaut, Bruce McCandless on Feb. 7, 1984. [3] The initial designs for space suits were inspired by women's fashion [25].

Construction of space suit: The weight of a space suit on earth is approximately 280lb, without an astronaut. In the microgravity environment, the spacesuit does not have any weight. It takes 45 minutes to wear a space suit, including wearing the special undergarments that keep the body cool. Wearing a space suit is called "donning" and taking it off is called as "doffing". The astronaut should breathe pure oxygen before going outside the pressurized module, after wearing a space suit, to get acquainted with the low pressure in the space suit. The space suits are made in white colour, as white reflects heat in space, the same way as it does on earth. Not much difference exists between male and female suits, the only difference being, female space suits are smaller than male suits. Astronauts involved in EVA handle 70-110 tools, used for space work.
The shuttle space suits are made with many interchangeable parts such as lower and upper torsos, arms, etc., to suit astronauts of different body sizes. The space suits are designed by cementing and sewing various materials together and attaching metal parts, which enable to join, of different components together. Each space suit is designed with two sets of gloves. They provide adjustable thermal protection, during exposure to extreme temperatures. Thermofoil heaters are assembled inside the layers of fingertips in gloves. They are located in the fingernail area. In the wrist of each glove, the on/off switch will be located [3]. The space suit designed by International Space Suit weighs approximately 280lb (127kg), and on Earth, astronauts find it difficult to balance and bear the weight of the suit [8].
The PGA (EVA7LB suit) has special joints installed at the neck, shoulders, elbows, waist, thighs, knees, and ankles. This enabled bending movements of body parts. This helps the astronaut to preserve body energy to work for long hours on the surface of the moon and to decrease fatigue. Certain force is exerted on the gas-retaining inner layer of the suit, in order

to bend these joints. To reduce friction on the inner layer of the space suit, an inner nylon fabric scuff layer is added to the suit [9].

The astronaut enters the suit through restraint and pressure-sealing zippers. The back opening of the suit has zippers that extend from the left side of the waist, around the back to the right side of the waist, and diagonally to the right side of the chest. A fellow member will help the astronaut to operate the zippers.

The space suit is made up of two protective layers, the inner pressurizable envelop also known as TLSA (Torso and Limb Assembly), and the outer Thermal Micrometeoroid protective envelope, which includes ITMG (Integrated Thermal Micrometeoroid Garment), a LEVA (Lunar Extravehicular Visor Assembly) or SEVA (Skylab Extravehicular Visor Assembly) and a pair of lunar boots. The TLSA is equipped with a detachable helmet and two detachable gloves. The torso and limb suit consists of an inner comfort layer, a middle nylon bladder with rubber coating and one outer nylon restrain. Only the joints are single-walled, made with integrated restrain and bladder, with a bellow-like structure. The ITMG is made up of an inner rubber-coated nylon layer and alternate layers of aluminized material. These layers are separated by a spacer fabric, which is a low conductor of heat. The ITMG is composed of an outer layer made with fire and abrasion-resistant material. This outer layer functions in the same way as a thermos bottle, when exposed to a vacuum of space.

The LEVA or SEVA is made with a shell assembly with a helmet at the top, which fits around the shell. Two visors to protect from sun rays, two side eye shades, and one centre eye shade are incorporated into the shell. The inner visor is transparent, which has an inner coating, that protects the face of the wearer from being exposed to heat. This inner visor is used to perform operations in shadowy areas. The outer visor and inner visor are combinedly used when there is exposure to sun and heat. These visors and eye shades are adjustable and can be moved to selected positions according to comfort and safety.

The assembly includes lunar boots, which are slip-on boots, made with materials similar to ITMG. Additional materials are used in the soles of the boots, to prevent heat transfer from the surface to the feet. The outer shell of the boots is made with woven metallic fabric to resist high temperatures and abrasion on the lunar surface. The sole of the boot is made with an outer silicone rubber layer, which provides thermal protection.

Each PGA is equipped with two pairs of gloves i.e., extravehicular gloves and extravehicular gloves. The IVG is made with a single wall restraint and bladder structure, that fits the hand of a crewman. An outer gauntlet and palm restraint system (which provides dexterity) are fitted to provide scuff protection and support to the glove. The EVG consists of an IVG with an outer thermal glove, made with the same material as ITMG. The EVG is covered with an outer protective layer made up of metal woven fabric, fingertips are finished with silicone rubber caps. The outer thermal glove covering covers completely the IV glove-TLSA juncture.

Through the suit, oxygen is circulated by the backpack (PLSS) or the Spacecraft Environmental Control System (SECS) to perform the functions such as respiration, ventilation, and pressurization. The inlet gas connectors present in the suit send the oxygen to the helmet, down the body, to the limbs, and then sent through ducts to the exhaust gas connectors. When this gas passes through SECS, the impurities are removed and recirculated through the suit.

The astronaut's body heat produced during IV operatives and other EV activities is removed by the ventilation system. When the metabolic heat produced during lunar excursions exceeds the capacity of the ventilation system, a liquid cooling system removes body heat generated within the PGA and also reduces fatigue due to dehydration caused by excess perspiration. The LCG (Liquid Cooling Garment) is a network of polyvinyl tubing, supported by spandex. This garment is worn next to the skin covering the total body except for the hands and head. Water or liquid coolant from the life support system is circulated through the tubing. Body heat is transferred to the liquid, heat is removed before it is recirculated to the LCG [9].

In order to improve the safety and effectiveness of space travel, it is imperative to develop innovative space suits. Space suits must meet the standards to face the challenges of future missions involving the performance of complex tasks in extremely hostile conditions [15].

Space suits used in ISS (International Space Station) are designed to combat exposure to extreme cold temperatures during EVA (Extra Vehicular Activates). The astronauts face the risk of collision with meteoroid debris and radiation. The space suit must protect astronauts from these hostile conditions. Space suits used for lunar operations need a different configuration, to provide protection from moon dust after performing an EVA. Space suits for future lunar travels require the characteristics such as material resistance, reusability, and easy and safe movement. Most EVA space suits are used several times [10].

A major challenge faced on the moon is the moon dust. The soil on the moon consists of oxygen, calcium, aluminum, magnesium, titanium, silicon, and iron [14]. It was found that moon dust persisted on the space suit after an EVA in spite of dusting off. Astronauts of the Apollo program informed that moon dust slipped past the filters and zippers of space suits and got deposited on the surface of instruments, leading to surface heating [11].

The dust on the moon is different from the earth's dust. The lunar dust is made up of micrometeorite particles, which are sharp and abrasive and when inhaled deeply by astronauts, cut through lung cells [12]. According to SSA (Soil Society of America) [13], lunar dust also consists of tiny iron specs embedded in dust particles. Hence, a magnetic filter is devised to filter or suction the dust from the air i.e., a dust sucker is used to remove lunar dust. The idea of a lunar vehicle, which can microwave the surface of the moon, roads, and launching pads is formulated. A device to provide insulation from radiation, produce oxygen during heating, and melt soil is proposed [10].

Hiroyuki & Noritaka have developed a cleaning system to remove moon dust from space suits using electrostatic force. The electrostatic field forms a surface barrier on the fabric. They have applied rectangular single-phase voltage to electrode wires stitched inside the insulating layer of a space suit. By operating this system in a vacuum with vibrations, the cleaning action was observed as trapping of less than 10 μm diameter particles was made possible [20].

Metals used in space applications such as protective coatings, mirrors, deployable structures, components of spacecraft, etc. are being replaced by advanced composite materials due to their high strength and lightweight. The hostile conditions of the space environment like VUV (Vacuum Ultra Violet) radiation, risk of erosion due to AO (Atomic Oxygen), and extreme thermal conditions, are a threat to the durability of composites. Specifically, AO exposure in the earth's lower orbit degrades polymers of composites. Hence the latest research on the development of composites for space is focused on evaluating their resistance to VUV and AO. The prerequisites for composites are high glass transition temperature, thermal stability, and better impact resistance to give protection from extreme impacts in space. Commonly used composite materials to perform these functions are cyanate esters, epoxy resins, and polyamides. Research is being conducted to develop next-generation polymers. Nano composites of graphite, carbon, and silica are the most promising [19].

Harmful effects of space travel on astronauts: A lot of research is being carried out to enhance the performance of space suits and to improve the facilities during space travel. Space medicine is one of the major areas of research. space medicine primarily aims at developing water and food production systems, life support, establishing compatible gas composition and cabin atmosphere, toxicology of space habitat, crew hygiene, prevention of infection, and protection from radiation. Space medicine works on the selection of astronauts who are disease free and healthy by conducting clinical evaluations and providing medical care to them. Certain medical conditions are found to be compatible with performing duties and depending on the nature and duration of the space mission, the medical waiver is given to the candidates. Space medicine provides personalized medicine [16].

A report by National Council on Radiation Protection and Measurements in 1989 discussed measures to be taken to treat and prevent radiation exposure to personnel working in standard space crafts and standards to be enforced for protection against radiation [17].

It was found by a study conducted by Cucinotta FA *et al*. the occurrence of cataracts in 295 astronauts, by using individual occupational radiation exposure data. And LSAH (Longitudinal Study of Astronaut Health) data. It was found that, over the past 30 years, astronauts on space travel to the moon or lower earth orbit are exposed to radiation due to high energy protons, particles produced with the collision between human tissue and spacecraft, and exposures to heavy ions. It was found that these exposures are leading to the risks of cancer and cataracts during later stages of life, including increased cases of cataracts with higher lens doses [18].

The fit and mobility of the space suit have a great impact on the performance of the astronaut, working in extreme temperatures and the gravity of space. A small Extravehicular Mobility Unit Development project was established to enhance the mobility and fit of space suits and to improve the size of accommodation. Nancy *et al*. have tested the spacesuits by conducting laboratory pressurized fit checks, and also in the Neutral Buoyancy Laboratory of NASA by simulating microgravity. They were successful in designing space suits for members of new anthropometric measurements, who could not fit into earlier existing space suits. They have also prepared prototypes for future design [6].

Dijk. D. J *et al*. have conducted research to evaluate the neurobehavioral performance, sleep, and circadian rhythm of astronauts. They found that astronauts selected for the study experienced disturbances in circadian rhythm, poor neurobehavioral performance, loss of sleep, and post-flight changes in Rapid Eye Movement (REM) during sleep [23].

Conclusion

The idea of space exploration and space tourism has gained popularity due to the recent space expeditions [24]. Many more people are aspiring to go on space exploration, with the intention of colonizing. Innovative prototypes for developing space suits to meet the needs of people with a wide array of anthropometric requirements and diverse functionality is the need of the hour.

References

1. https://www.americanscientist.org/article/the-past-and-future-space-suit
2. https://global.jaxa.jp/article/special/eva/tanaka_e.html#:~:text=There%20are%20two%20major%20problems,that%20greatly%20limits%20your%20movement.
3. https://www.nasa.gov/audience/foreducators/spacesuits/facts/index.html
4. https://interestingengineering.com/13-out-of-this-world-facts-about-spacesuits-that-you-should-know
5. https://www.britannica.com/science/temperature-stress#ref106959
6. Nancy. Currie, David Graziosi. Space Suit Design Enhancements to improve Size Accommodation and Mobility. HFES. 2003;47(1):1-5.
7. Robert Thirsk, Andre Kuipers, Chiaki Mukai, David Williams. The space-flight environment: The International Space Station and beyond. CMAJ. 2009;180(12):1216-1220. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2691437/
8. BBC – Understanding space suit technology. https://www.bbc.com/news/science-environment-20433089
9. Space Suit Evolution from Custom Tailored to Off-The-Rack. https://sma.nasa.gov/SignificantIncidentsEVA2018/assets/space_suit_evolution.pdf.
10. Julio Rezendo, Nikolay Moiseev, David Machado de Souza, Dalmo Santos Space suits: Challenges and researches. Conference paper - 50th International Conference on Environmental Systems; c2020.
11. Futurism. The Biggest Health Risk for Lunar and Martian Explorers: Tiny Dust. https://futurism.com/extraterrestrial-dust-moonmars-health. (Accessed April 16, 2020).
12. Spector, Brandon. Moon Dust Is Super Toxic to Human Cells. https://www.livescience.com/62590-moon-dust-bad-lungsbrain.html (accessed April 14, 2020).
13. Soil Science Society of America. NASA's Dirty Secret: Moon Dust. Science Daily. www.sciencedaily.com/releases/2008/09/080924191552.htm (accessed April 14, 2020).
14. Washington University in St Louis. Some meteorite information. https://sites.wustl.edu/meteoritesite/items/the-chemicalcomposition-of-lunar-soil. (Accessed April 14, 2020).
15. Newman DJ. Life in extreme environments: How will humans perform on Mars? Gravit Space Biol

Bull. 2000;13:35-47. [PubMed] [Google Scholar]
16. Nicogossian EA, Huntoon CL, Pool SL, editors. Space physiology and medicine. Philadelphia (PA): Lea and Febiger; c1994. p. 167-93. [Google Scholar]
17. National Council on Radiation Protection and Measurements. Guidance on radiation received in space activities. Bethesda (MD): The Council; Report; c1989. p. 98. ISBN 0-929600-04-5. [Google Scholar]
18. Cucinotta FA, Manuel FK, Jones J, *et al*. Space radiation and cataracts in astronauts. Radiat Res. 2001;156:460–66. [PubMed] [Google Scholar]
19. Dr. Ian Hamerton. Special issue Developing polymers/ Composites/ Coatings for Space/ Satellite applications. A special issue of Molecules; c2020. (ISSN 1420-3049). https://www.mdpi.com/journal/molecules/special_issues/materials_for_Space_Satellite_application
20. Hiroyuki Kawamoto, Noritaka Hara. Electrostatic Cleaning System for Removing Lunar Dust Adhering to space Suits. Journal of Aerospace Engineering, 2011, 24(4).
21. https://ascelibrary.org/doi/abs/10.1061/(ASCE)AS.1943-5525.0000084
22. Joseph J Kosmo. Design Considerations for Future Planetary Space Suits. SAE Technical Paper; c1990. p. 12. https://doi.org/10.4271/901428
23. Dijk DJ, Neri DF, Wyatt JK, *et al*. Sleep, performance, circadian rhythms, and light-dark cycles during two space shuttle flights. Am J Physiol Regul Integer Comp Physiol. 2001;281:R1647-64. [PubMed] [Google Scholar]
24. Lauren Miyoko Furushima. Speculative Fashion: A Spacesuit for Life Outside Earth. Thesis. Rochester Institute of Technology; c2020. https://scholarworks.rit.edu/theses
25. How Women Helped to Develop the First Space suit – JSTOR https://daily.jstor.org/how-women-helped-to-develop-the-first-spacesuit/