NSBE Space MDRS Projects: Suit Material Requirements

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Abstract - Long Duration Space presents multiple engineering, science, and living challenges. Our current capabilities provide an avenue to test out long duration experiments in a safe environment both here on earth as well as in space on the ISS. An important challenge is the logistics of what to wear in space for long duration space flights. While our current capabilities allow for 2 weeks to 6 months' worth of space duration, traveling to targets further out on the duration of 5-10 years require thinking in a larger viewpoint of what to wear and how to manage the logistics of laundry on a space vehicle. This paper will focus on the requirements behind the material properties of a NSBE Space Suit that can heal itself if there are rips, has anti-bacterial properties, and has alternative cleaning methods.

Keywords: *Long Duration Suits, Material Printing in Space, MDRS, Material Properties*

1 Introduction

Curiosity has always caused man to explore. As new participants enter into the commercial space business, we expect that earth observations -and one day Lunar and Martian colonies- will be within reach of the human space exploration initiative. However, for missions to new star systems and galaxies, an important logistics question comes to mind: What will the explorers wear? Assuming a mission takes about 30 years to get to the nearest star, current practices would require every human to bring a full shipping container's worth of clothes to last them for the journey. In addition to the actual mass of the clothes, the need for creating, mending, cleaning, and recycling clothes is a significant logistical and technical challenge. This paper introduces a concept for a long duration outfit that is easily manufactured, affords repurposing, utilizes alternative cleaning methods, and contains smart technology input to monitor the health of the user.

2 Background Information

Long duration space flight on the magnitude of multiple years has extremely strict requirements. In order to send a human on a long duration mission for 30 years, it would require a freight train worth of clothes for each human for the entire duration. [**Error! Reference source not found.**] This is strictly clothing; no food, water, or essential science experiments and equipment. This begs the question of what are the constraints for a long duration space suit. A few constraints are the growth of bacteria in space, the limited water accessibility for washing clothes, and the environmental constraints of a space vehicle.

These minimal requirements require the designer to think about advanced textile materials that are anti-microbial to minimize the spread and growth of bacteria. This minimizes potential infection, contamination, and odor aboard an enclosed vehicle. In addition to the anti-microbial properties, the designer must also investigate the creation of the fabric, the rip resistance, and the washing capabilities. If it takes a freight car worth of clothes for each human, the amount of water to wash these clothes for 30 years is a large logistics problem that could easily increase the amount of water consumption and therefore size of a space vehicle.

The designer must turn to alternative laundry methods that minimize or do not utilize water as its cleaning alternative. There are multiple methods to sterilize or sanitize items. The space suit designer must therefore develop and test a method that will safely sterilize bacteria and sanitize suits while conserving water. This is the greatest challenge of long duration space flight.

An important aspect of a space suit is to enhance the everyday activities to provide smart technology for the astronaut. This can range from medical monitoring such as heart, hydration and pressure monitoring to medical help such as tightening around a sprained ankle or heating and cooling a bruise. Integrating technology into the suit from the start allows for crew monitoring and early warning systems that could provide vital long duration information to crews throughout the regime.

This type of thinking has immediate advantages here on earth. Specifically, solving the long duration clothing aspect has advantages to conserve water here for our military, provide smart technology to our athletes, and provide new ways to utilize our clothing for health measures. This proposal seeks to investigate the creation of a smart space suit through the development of anti-microbial materials, the integration of smart sensor technology, and the creation of alternative laundry methods for a long duration space flight. This papers is the preliminary design requirements for an innovative long duration space suit that has potential to survive the harsh space environment as well as effectively aid the population here on earth through its innovations.

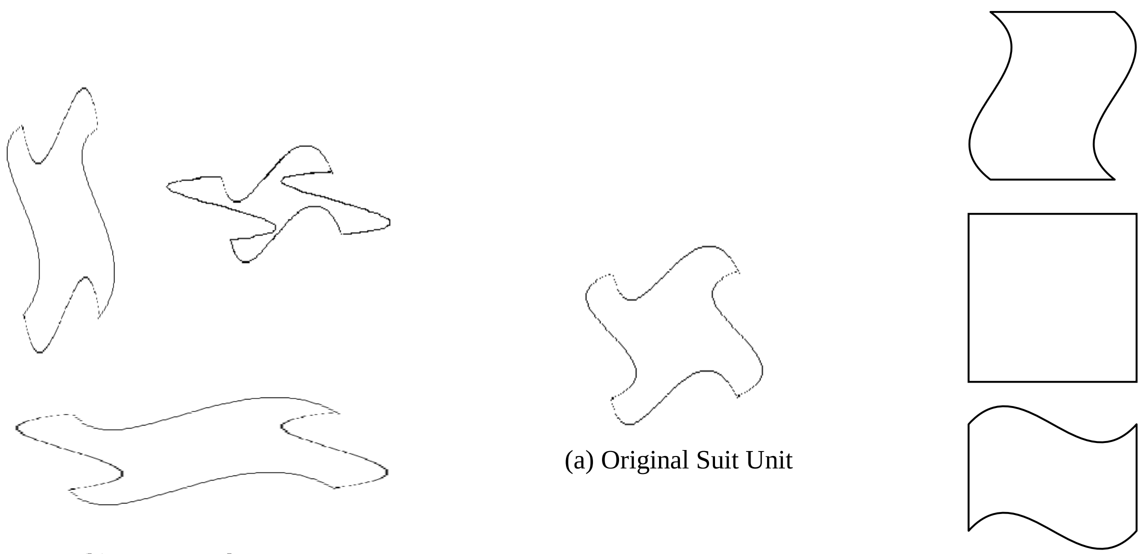
3 Mars Desert Research Station

The Mars Desert Research Station (MDRS), owned and operated by the Mars Society, is a full-scale analog facility in Utah that supports Earth-based research in pursuit of the technology, operations, and science required for human space exploration. [1] Crews work during an eight month rotation during the year to simulation astronaut training sessions. These are two week rotations with a crew of six astronauts that have defined roles to carry out planned experiments and missions in a simulated environment.

The NSBE Space SIG has been going to the MDRS since 2007 with various members going on crew rotation. In preparation for an all NSBE crew mission, an experiment of NSBE space suits was proposed to monitor health effects of the a simulation mission on the body. This research has implications in multiple arenas such as sports medicine and long duration exertions. This preliminary design analysis will show provide the requirements for suits to be printed prior to the NSBE mission to the MDRS, as well as demonstrate that suits can be 3D-printed in the case of rips for various operations during an MDRS rotation. It is assumed that these suits will be worn underneath the EVA suits that MDRS participants wear to go outside. These are strictly for wear inside of the habitat, to reduce the amount of laundry, and clothing each individual would bring to the habitat, which would in turn increase the amount of science payload weight they could transport with them through suitcases in the case of MDRS, but in launch mass for long duration space flights.

4 Suit Requirements

The requirements for a 30 year journey where there are limited supplies require radical innovation in our clothing units. A simple approach is taken to create internal space suits used for everyday use inside a star ship or habitat. The clothing must be light weight, easily manufactured, anti-microbial, wear-and-tear resistant, long-lasting, and very adaptable. This brings the idea down to a basic unit of construction as seen in Figure 1.



(a) Original Suit Unit

(b) Contracted Suit Unit

(c) Expanded Suit Unit

Figure 1: Basic Suit Unit

This basic suit unit is made of a stretching fabric material that is coated with shape-memory polymers at the edges shown in Figure 1 (a). This simple unit is functional. It can expand up to 81% and contract down to 12% of its original size as shown in Figure 1 (b) and (c). This happens by the shape memory polymer contracting one or two sides to form a compact sine wave form in Figure 1 (b). The expansion happens the same way in one or two directions as shown in Figure 1 (c). The fabric has so much give it in it that it can change shape according to the body composition of the user, while the shape-memory change polymer can easily be programmed to accommodate these changes.

The idea of a basic clothing unit provides multiple advantages. The first is that the construction of using shape memory polymers on the edges and programming them to construct a garment means there is no sewing required. If the complete garment is ripped then the crew can simply replace the shape memory polymers on the rip to close it or replace the affected units and recycle the damaged ones. The principle is that a unit is small enough that the edges will interlock when the memory polymer is activated. This creates a plug-n-play clothing repair system for any rip or hole that occurs. If a rip occurs across multiple units, then only the damaged units are taken out and replaced, while the rest of the suit is still wearable, and the damaged units are recycled through the 3D printing capabilities.

The second advantage of the basic unit that can accommodate any shape means that fit will not be an issue. The unit can expand and contract for comfort and fit based upon the user's body type. Also, over the course of decades, the body shapes of the crew will inevitably change, requiring re-fitting. There is even the possibility that crews on longterm missions in a starship or in settlements on Mars will produce children, who will need suits of a different size and shape.

Recently Astronaut Scott Kelly came down March 1, 2016 from a year mission on the ISS where his body has changed drastically. It is suspected that he has lost muscle mass and bone density. [3] These are well documented phenomena that happens regularly to astronauts; however, this translates into a change in their body and how their clothing will fit. Providing smart clothing that will adjust to their body when programmed daily or monitored daily will help them feel comfortable during their missions.

Finally, this functionally allows the individual suit unit to incorporate smart technology to the user. For example, if the user sprained an ankle the shape-memory polymer could be programmed to act as a bandage by simply changing the shape of the unit to contract around the ankle. Later units may incorporate thermal capabilities, health monitoring capabilities (heart rate, blood pressure, hydration, etc.), but these would be added on capabilities not incorporated into the basic unit. These health sensors are discussed in another NSBE paper entitled NSBE Space MDRS Projects: Power and Sensor Requirements for Everyday Health Benefits, but here we will suggest the idea that there may be a way to incorporate resistance training into the system.

5 Suit Capabilities

We must think of how the manufacturing of simple anti-microbial materials will work during a long-duration mission. It is crucial to be able to manufacture the necessary units on-board a starship (or within an extraterrestrial base) with minimal process-chains, as fabrics and fibers will inevitably degrade over time. Even using materials that degrade minimally, damage and wear-and-tear will require replacing suits in part or whole. Therefore, the preliminary requirements are that a 3D printer is available to print out the fabric material as well as coat the edges and material with memory polymer. The question becomes if the memory polymer is biodegradable and how it will react with skin over long durations of time, but for the purpose of this section, it will go into some of the deeper capabilities instead of the general requirements given in previous sections. It makes the assumption that the crew will have limited access to supplies, but not necessarily limited access to energy and power due to solar cells and energy storage in batteries.

5.1 Suit Design

Figure 1 showed the basic unit design. It is a sinusoidal pattern that can expand and contract on either axis to change the amount of pressure provided on the body. The material that is between the unit will expand, but the reason for this basic unit is so that there will be easy rip repair, and more importantly the unit can fit the natural curves of the body. Although pattern makers have provided the basic premise of clothing design, they still have a problem fitting to the exact curves of the body even when a piece of clothing is tailored. The body expands and contracts with each breathe and movement, therefore, any basic unit must move with the natural movement of the body. In this case the suit design will be unique to each individual. The design will consist of the individual units connecting to each other at the edges and the programming that will send an electrical or thermal impulse through the suit so that the units will "memorize" or stay to the wearers' requirements. As the wearer goes through a certain amount of time, their water retention will change, their exercise will change how their clothes fit and flow on their bodies which will require a computer to constantly monitor the fit of the suit to the body and ultimately make adjustments based upon the pressure it finds between the polymer connections. If a pressure threshold is passed, the suit can send out a signal to change the basic units affected to accommodate the expansion or contraction of the suit based upon the user's needs.

5.2 Textile Investigation

The shape-memory polymer is expected to be an electro active, triple shape polymer that responds to thermal and electrical signals [4, 5, 6]. A triple shape polymer is a polymer that has two different melting points for shape memory and the memory activation happens at two different temperatures. This will be used because both expansion and contraction is expected; however, the author suspects it is possible to utilize only a double polymer and change the programming. This will increase the complexity of the programming unit, but decrease the supplies needed to create the basic unit.

The expansion and contraction of the basic suit unit will happen at the edges, making it essential that the fabric stretches it accommodate these changes. Manufacturing on board a star ship or habitat is an essential function; however, we do not normally think of astronauts as weavers or tailors. These units should be manufactured easily through 3D-printing since there are only two materials used and solutions to the printing and construction of suits will be examined and experimented with in order to find the mending process in terms of labor, space and plant. Materials that are also inherently recyclable with minimal use of space, chemicals and plant must be identified for this purpose. This may require modification of existing polymers and an examination of recycling processes.

In addition to stretching to accommodate the expansion and contraction of the polymers, the fabric must be anti-microbial. This will reduce the amount of bacteria that can grow on the clothing and provide alternative laundry principles to be performed without the use of water.

5.3 Laundry Alternatives

The next advantage of these units is the perceived cleaning techniques. Water is a precious resource for every mission. Therefore, it is impractical to think that laundry will be done in the same way as done on Earth. For this, we must look at sterilization rather than the traditional idea of washing. These units can be taken apart from a suit, laid down under a UV-ray lamp and sterilized for harmful bacteria. The units may then be reprogrammed to create another "outfit". By breaking down our clothes to these basic units, there are no corners where bacteria can hide from a UV ray lamp; however, cones, corners, and arches can easily be programmed to fit a user's body. The search for materials will also involve –with the assistance of a textile scientist—finding, and if needed developing, those which will balance the physical comfort of the wearer with the ability to resist absorption and retention of bodily fluids and cast-off skin. It is expected that debris and liquid will be easily wiped away from the suit. Wiping away debris and liquid along with the use of UV-ray sterilization will provide an alternative laundry cleaning solution that will utilize power; not water, which is a precious resource.

5.4 Smart Technology

Finally, looking at the last requirement for this long duration suits includes understanding the programming behind the suits. Figure 2 shows the programming aspects expected for the polymer part of the suit technology. The suit would be initialized through some means. This could be by scanning the wearer's body, or taking measurements that are input into a computer and having a suit automatically designed based upon those measurements. The suit is then initialized by an electrical pulse that sets up the suit for the wearer. The user would step into the half made suit, before the final impulse is sent to close the suit around their body. They can then make changes to the suit's program to be tighter or looser on their body as needed. This is within the initialization process.

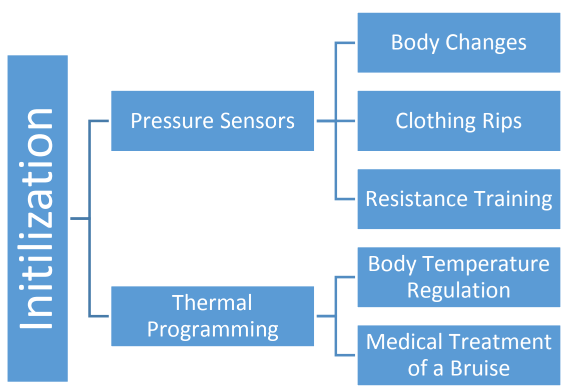


Figure 2: Long Duration Suit Monitoring Programming Chart

As time goes on, the suit will constantly send out signals to monitor the pressure and thermal condition of the suit. These are two smart technologies of the suit that can be utilized for the health of the wearer.

The pressure monitor will determine if the suit is too tight or loose. More importantly it will determine any disconnections in the suit at the seams as well as identify if there is a rip somewhere that crosses multiple seams. It will be able to do this by the fact that the pressure will change throughout a given radius if there is a rip across multiple units. This will allow the user to make a quick fix where they either replace the given units, recycle or refurbish units from another suit, or change the programming of their suit. The pressure sensors should automatically respond to body changes such as muscle tension and relaxation or water retention since it will constantly be monitored. Any changes will result in a re-initialization in the suit to fit the wearer comfortably. This pressure utilization also has the potential to be of some medical use. If the wearer sprains or rolls their ankle for instance, the suit can act as a bandage by applying constant pressure that is comfortable for the users, but benefits the sprain. Also in the unlikely event of a broken bone, the suit can act as a cast by not allowing any movement with a constant electrical pulse that keeps the user's limb in a permanent position. This would be a programming capability to be tested down the line but it would be beneficial for long duration wear. Currently, astronauts on the ISS are required to workout at least two hours per day where they do cardio. However, they have muscle loss due to the fact that they are not constantly resistance training against gravity. Another advanced programming capability would be to program resistance training into the suit so that the wearer's movements would work against the pressure exerted on their bodies as they move.

The thermal programming on the other hand has two possibilities: body regulation and medical treatment. Working here on earth, the MDRS is in the middle of the Utah desert which can become extremely cold at night. While participants have provided covers, it could work that that there are thermocouple integrated into the suit that would provide warmth to the user or act as a radiation to radiate out heat away from the skin after a workout or a long EVA. The suit could help regulate body temperature by being programmed to constantly monitor the temperature of the suit and determine if warmth is needed or if radiating heat away is needed as necessary for the comfort of the wearer. The other medical treatment possible is for that same possibility of providing warmth or radiating it away could be utilized for a bruise. On earth, a bruise or sprain may become inflamed where heat must be radiated away from injury. Or conversely, the users' extremities, such as toes, feet, fingers, and hands may need more warmth than their body is currently providing them. This may be a programming possibility to change the temperature at different parts of the body to accommodate the health and comfort of the user.

6 Conclusions

Star and galaxy exploration is decades away; however, solving the logistics of clothing and laundry is a significant challenge. Our approach is a step in the direction of reducing mass and defining cleaning techniques and procedures. As the space program grows towards lunar and Martian colonies, these same techniques sill prove useful to those missions as well. These preliminary requirements for long duration smart suits have the possibility to be tested out at the MDRS through a NSBE mission.

For a 2-week MDRS mission, it is expected that each participant would need 3-4 suits that would supply a suit for everyday use, one to clean, and one in case there are rips. In theory, each user could have 9-10 long duration suits that can be rotated through the cleaning phase instead of the hundreds of cotton garments that would need to be transported for a 30-year mission, to be worn for a few days or weeks and jettisoned, as is now the routine practice. The suits would also weigh less than each individual garment that a user would bring, not be susceptible to the degradation of traditional fabrics over time due to the 3D-printing manufacturing capability, and finally reduce mass as well as energy on both the amount of clothing and water used for cleaning.

This research has implications for other aspects here on earth as well as in space. For example, a smart technology can be adapted for smart braces where a doctor does not have to cut off a cast. Instead the wearer would have a light weight piece of clothing that they can simply program stiffness into the garment that they will program the suit to release the stiffness when their body has healed. Being able to reduce the amount of laundry could have applications for hikers or desert people who do not have access to water for cleaning, but can utilize solar energy for cleaning their clothes. It also has the possibility of changing the fashion industry if innovations such as color changes could happen to make the same garment a different color according to the user's preferences. There are many other aspects that this technology could be utilized in the health, sports, and in dry climates as well as industries that this author has not even thought of yet.

This paper first went through the background information of why such a suit would be required for long duration missions. It then briefly introduced the MDRS habitat as a potential test bed, and finally gave the broader requirements before diving into the specific long-duration capabilities. While the idea is to provide preliminary requirements and capabilities, the implications are endless to change multiple fields as smart technology is integrated into clothing.

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