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AN ELASTIC COUNTER PRESSURE SPACE SUIT FOR THE EXPLORATION OF MARS

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ABSTRACT

We describe a different kind of space suit that is made of elastic cloth and has no joints. It provides excellent mobility and improved hand function. It was developed and tested in the 1960's. Recent studies involved vacuum testing of a new elastic glove, then testing the physiological effects of mechanical counter pressure on the hand and arm. New textile technology will allow development of an elastic cloth that will ease donning, and there are other aids to donning under development. Computer-controlled textile machines will make close fitting garments for every astronaut, large or small. Thermal comfort results from physiologically controlled sweating with instant evaporative cooling through the porous elastic cloth. Compared to gas-pressurized suits, the elastic cloth suit has the advantages of low suit weight, small mass of expendables and increased safety. It is practical and effective for the exploration of Mars.

KEYWORDS

Dexterity, Elastic Counter Pressure, Fitting & Sizing, Mobility, Textile Technology

INTRODUCTION

On Mars an explorer must be able to walk, run and jump. He may need to climb a scree slope and scale a cliff. He may want to crawl into a cave and back out again. Acting as a geologist he will stoop, squat and kneel. He may dig and drill. He will free up rocks with the pick end of the hammer, then break them up. Thus he must be mobile, dextrous and

unimpeded. This calls for something other than the familiar gas-pressurized space suit that is currently used for extra-vehicular activity.

There is a different kind of space suit, one without joints, improved mobility and excellent hand function. It is safe, lightweight, durable and inexpensive to make. The suit is made of elastic cloth. Mechanical pressure is applied to the limbs, arms and torso, thereby balancing the physiological effects of breathing oxygen at the pressure needed to support life in a vacuum.

A working prototype was developed in the years 1967-71 (Annis and Webb 1971; Webb 1968; Webb and Annis 1967). It was tested at altitude, and worn comfortably for hours at a time. Subjects walked, crawled, climbed ladders, picked up coins, placed pegs in a pegboard and joined small connectors by hand. Figure 1 shows the original suit and its flexibility. The design was meant to give greater freedom of movement to astronauts during extravehicular activity (EVA) in orbit and while on the surface of the Moon. The approach was innovative and before its time. No one spent time promoting the suit, and the project lay dormant for several decades.

In 1998 Honeywell (then Allied Signal) took an interest in the elastic suit, also called the mechanical counterpressure suit, the Space Activity Suit or “skin suit”. They supported an effort to fashion a prototype elastic cloth glove. The glove was shown to protect the hand and function well in the near vacuum of 1 torr in tests conducted at the Johnson Space Center. Skepticism had dissipated somewhat and NASA funded a project to measure the physiological effects of mechanical counterpressure. We measured the pressure applied to the skin with an array of small sensors (Waldie and others 2003). Microcirculation of the skin was well supported by the glove during low pressure tests at the differential pressure called for in current space flight, 222 torr (4.3 psi or 30 kPa) (Tanaka and others 2002; Tourbier and others 2001). Similar results came in tests of the protected arm. We also defined limits of underpressure and overpressure, both with and without elastic cloth protection (Knudsen and others 2002) .

We are confident that the elastic space suit is inherently safe, improves astronaut capability and effectiveness, and significantly reduces the weight of space suits and their life support systems. A single suit can be developed for all phases of the missions for the Vision for Space Exploration. It is ready for further development using today’s technologies.

BASIC PHYSIOLOGY

In the low-pressure atmosphere of Mars, which is largely carbon dioxide, our explorer will breathe oxygen in her or his helmet at a pressure of 222 mmHg (4.3 psi, 30 kPa). Breathing bladders in the torso of the suit provide volume compensation for the closed respiratory system that removes carbon dioxide, water vapor and adds oxygen. Positive pressure breathing pressurizes the circulation, which would lead to pooling of blood in limbs and abdomen, then edema (swelling). Therefore the elastic cloth supplies mechanical pressure to the limbs and torso to increase tissue pressure so that blood flows through capillaries and veins. Thermal balance comes from physiologically-controlled sweating that evaporates

into the low atmospheric pressure through the porous mesh of the elastic cloth. Finally, there is more than enough tissue pressure than needed to prevent gas forming under the skin.

TEXTILE TECHNOLOGY

There are numerous elastomeric fibers today compared to the limited selection of 35 years ago. We have used a powerful spandex yarn with excellent elongation for the recent prototype glove. With these yarns we will design a textile that is easily stretched when donning a garment, then, when stretched further, becomes more powerful.

Seamless gloves are state-of-the-art for automatic knitting machines, and the newest versions allow laying the elastomeric yarn circumferentially. Also, seamless tubes for arms and legs can now be made with yarns running circumferentially, and the latest versions produce full fashioned garments, i.e. the garments are shaped to fit changing dimensions along the length of the limb. Running the elastomer circumferentially keeps applied pressure more uniform as joints move. There is less work done by the astronaut when flexing fingers and other joints. It also eases donning, since stretch is limited in the lengthwise direction.

New textile machines are computer-controlled, so that every glove, sleeve, boot and stocking can be exactly sized for each individual astronaut. This is a great advance over the earlier cut-and-sew approach to making powerful elastic garments. Since the applied pressure results from a calculated reduction in garment dimension in small steps along a limb, and these must be accurately positioned, the computer-controlled machine can make these dimensions precisely and correctly. Each astronaut will be scanned by laser beam to yield precise individual body dimensions. These data are then used to control the automatic textile machines. Much labor is eliminated and the resulting garment has the best possible fit for each person, large or small, tall or short.

The torso part of the garment contains breathing bladders that cover the front of the chest and abdomen for volume compensation during inhalation and exhalation. At the same time the torso must twist and bend to avoid restrictions in walking, kneeling and bending down. A mixture of elastic and non-elastic cloth enables these separate functions.

DONNING AND DOFFING

We expect that pulling on gloves, boots, sleeves and stockings will be relatively easy with garments made with the new textile. We have also developed a mechanical device for donning gloves quickly and with little effort. A similar principle can be used for making a quick-don device for stockings or sleeves. The torso section is not stretched tight until the breathing bladders inflate. It can be donned easily with zippers and Velcro closures. The goal is make the whole garment readily donned by the wearer without assistance. Doffing garments is easy. They can be stripped off quickly by pulling down and inverting the limb garments.

COMFORT

When first donned the elastic space suit is a comfortable, snugly conforming suit that applies only slight pressure to the skin. The suit has two layers. First donned is a comfort layer that protects the skin from possible abrasion when joints move under elastic pressure. Its slippery outer surface aids donning the power layer, and this first layer wicks moisture readily when the subject has to sweat. The second layer is the power layer, which is worn relaxed in the vehicle during launch and entry. Should cabin pressure be lost, limb bladders or capstans will change suit tension to match raised breathing pressure. When used for programmed extravehicular activities, in space or on Lunar or Martian surface, a different set of sleeves and trousers will be at full power when donned. Note that these limb garments are quite small and take up little storage space. Looking ahead, we may be able to incorporate electrically activated fibers that will do the final tensioning in a single garment for all situations.

THERMAL COMFORT

For the thermal comfort of the astronaut during extravehicular activity we rely on natural physiological mechanisms. Note that the astronaut needs to dissipate his/her body heat, but has little external thermal load. He/she is like a person in a Dewar flask. There is no convective heat loss or gain in a vacuum; radiant heat loss to cold space is blocked by a thermal micrometeorite garment that also blocks radiant heat input from the sun. Conductive heat loss is limited to such situations as grasping a cold tool or metal support bar, and this problem is handled by electric heating in the glove.

The astronaut's metabolic heat production is higher when active than at rest. During EVA his/her activity may cause heat production to vary irregularly between 100 to 800 watts. Since the astronaut cannot dissipate heat by normal pathways of convection, radiation or conduction, body heat is stored, which leads to sweating. In a vacuum environment there is instant and effective heat loss from evaporation. This cooling is precisely controlled by the body. The rate of sweating is continuously adjusted to maintain thermal balance. No special cooling garments or cooling equipment are needed.

ADVANTAGES

The Vision for Space Exploration calls for a single suit for all phases of the mission. The elastic counter pressure suit can meet this requirement by its very nature.

In broad terms the elastic cloth space suit reduces risk, improves efficiency and reduces mass and storage space. The suit is inherently safe, since rips and punctures do not cause a catastrophic loss of pressurizing gas. Improved mobility allows the astronaut to escape from dangerous situations.

Great mobility and unlimited reach are obvious advantages. Dexterity is greatly enhanced, the fingers can feel, and small objects can be picked up and manipulated. Constant hand use is not fatiguing, and there is little risk of injuring hands when reaching and grasping.

Instead of special tools for mechanical repairs common wrenches and screwdrivers will suffice. Training for specific missions will be shorter and less elaborate than presently needed.

The whole range of sizes and shapes of women and men will be precisely fitted. No one is left out. It will not be necessary to maintain an inventory of suits since suits can be made quickly for each crew member before a mission begins.

A suit will be reused with little maintenance and serve for many periods of wear. The elastic suit also adjusts to the changes in dimensions of individuals that can occur during long exposure to microgravity, or from major change in body weight. This can be handled by controlling the tensioning. In addition, spare suits or suit parts of increased or decreased size would take up little storage room. Manufacturing costs will be low because automatic textile machines replace most of the labor intensive cut-and-sew process. Complex body measurements and patterns are no longer needed. There is no need to make a range of sizes or to procure a tariff of sizes.

The weight of elastic suits is far less than that of gas-pressurized space suits. We estimate 85 pounds versus 300 pounds, which includes the lower weight of the portable life support system. The standard water cooled underwear is unnecessary, as are pumps and the stored power to circulate the water; there is no sublimator to cool the water and no stored water supply. The astronaut will drink water to replace the sweat he/she loses. There is a reduction in oxygen stores needed owing to the low leak rate of a suit without joints that leak. There is a lesser need for oxygen also because the oxygen cost of activity is far lower than it is with a gas-pressurized suit (Annis and Webb 1971).

CONCLUSIONS

Elastic cloth space suits improve astronaut capability, enhance safety and lower the weight and cost of equipment and stores. They are practical and effective for the human exploration of the Moon and Mars. Developing these suits with new technology will be a visible step forward in manned space flight.

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FIGURES

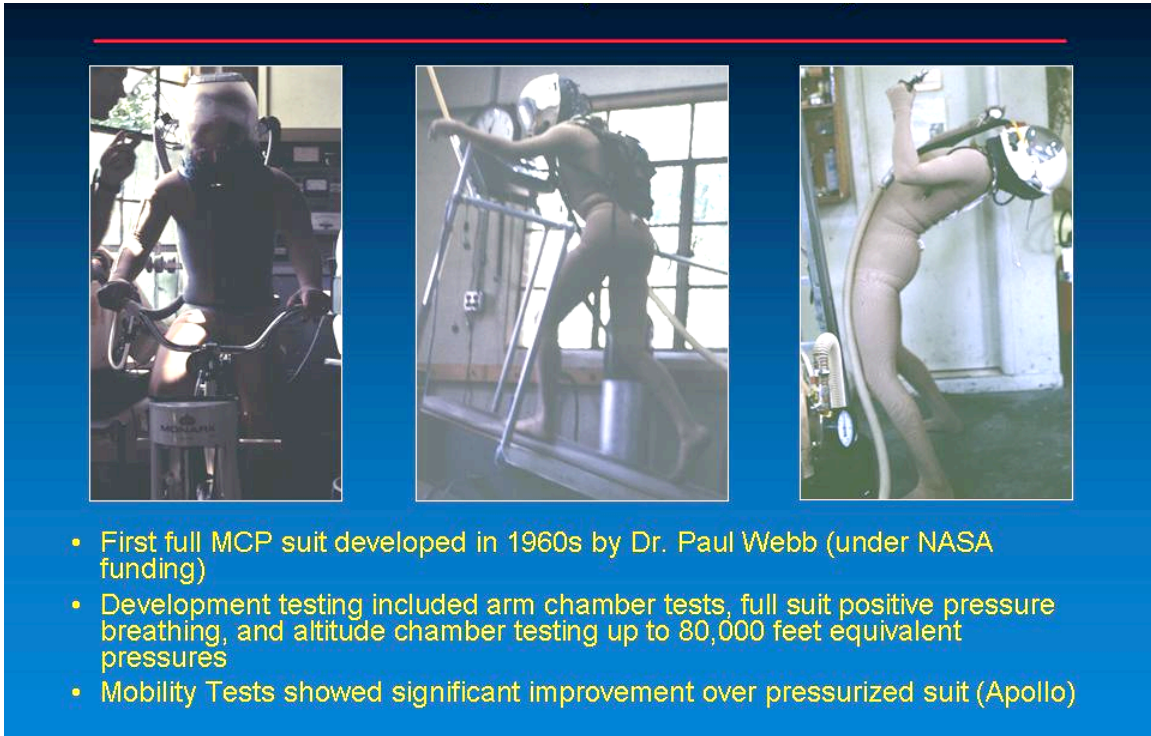


Figure 1. The original elastic “space activity suit” in 1969 showing flexibility