DESIGN IMPLICATIONS FOR EXTRAVEHICULAR ACTIVITY

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ABSTRACT

Extravehicular Activity (EVA) is considered paramount to achievement of mission objectives of the space program and a trend of both increased and more diversified forms of EVA is expected. This trend will require many alternative design configurations of EVA suits according to relative priorities of various issues. Some of these issues are discussed (heating/cooling, protection from ionizing radiation, denitrogenation, visual protection, comfort/dexterity). Previous solutions of the U.S. space program are described.

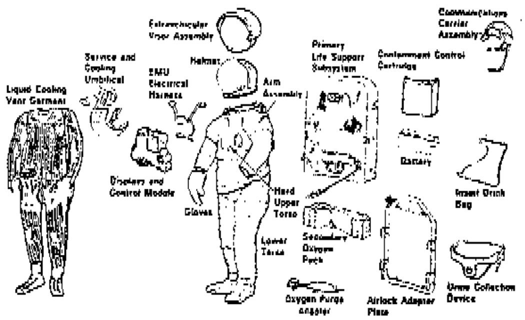
INTRODUCTION

The bourgeoning international emphasis on space programs including the recent U.S. Space Shuttle flight has awakened many to the enormous potential available in space. As new technologies and new applications to old technologies are developed the impetus for space utilization will be increasingly provided by both the regulatory and private sectors. This will represent a greater diversification of spacecraft and a correspondingly increased range of operational demands and objectives.

Extravehicular Activities (EVAs) are fundamental to the success of these objectives and a trend of greater use of EVA is expected (Griswolde and Wilde, 1981). An emphasis on reduced dependence on massive ground stations through the use of improved computer systems and minimization of use of expendables (National Aeronautics and Space Administration, 1979) will promise greater autonomy and operational potential for EVA. Although NASA has had an ongoing interest in the use of teleoperators and robotics (advanced forms of teleoperators that function autonomously or semiautonomously) these are likely to extend rather than replace human capabilities due to the unstructured and nonrepetitive nature of many EVA tasks (National Aeronautics and Space Administration, 1976).

EVA capability is currently baselined for NASA's future Shuttle missions, each operational Orbiter mission providing for three two-man EVAs of seven hour durations as standard procedure. EVA represents personned activity performed in a space suit and in a near vacuum environment. EVA is the only means to guarantee rescue of crews from stranded Orbiters (Brouillet, 1981). In the next decade EVAs will largely constitute tasks such as inspection, repair and deployment of satellites. Beam building will subsequently become important and is expected to incur approximately 50% of the working hours in space (Gunkel and Wolbers, 1977). Eventually EVAs will assume greater correspondence to work characteristic of industrial societies on earth and with greater task specificity (American Institute of Aeronautics and Astronautics, 1979).

Demands will include long term and short term tasks at fixed and temporary worksites at zero g in free space and at varying g factors on lunar and planetary surfaces, during light and dark periods and different thermal environments. Different degrees of skill, strength, and dexterity will be required. Workers will differ substantially in such characteristics as motivation, training and socio-cultural background. As space utilization becomes the norm and missions increase in duration age-related issues may play an increasing role in design decisions. Consequently, in the future there will not be any one design solution for EVA suits and equipment. Rather, a number of issues must be considered of varying levels of priority according to crewmember characteristics and mission objectives. Some basic attributes of EVA suits will be described as well as issues for future design applications.



EXTRAVEHICULAR MOBILITY UNIT

The two primary EVA suits designed for NASA's space program were the Apollo and Space Shuttle suits. Gemini's EVAs were conducted in a modified Air Force high altitude flying suit and suffered a number of constraints, particularly in mobility and visor fogging (Brouillet and Griswolde, 1981). The Skylab EVA suit was substantially the same as the Apollo suit with an improved visor assembly and an umbilically supplied life support (pressure, oxygen, ventilation and cooling). These suits were termed Extravehicular Mobility Units (EMUs).

The Apollo EMU consisted of two primary subsystems (Carson, Rouen, Lutz and McBarron, 1975). The Pressure Garment Assembly (PGA) had to be custom built for each astronaut. The central components of this assembly were the undergarments which contained tubes for circulation of water for cooling and the soft multilaminate outer garment serving as a pressure garment, thermal insulator and some degree of micrometeoroid protection. Dipped rubber convoluted joints were provided with restraint cables to prevent ballooning under pressure. Included in this assembly was a communications cap with earphones and microphones, bubble helmet, EVA over-visor assembly, gloves, drink bag and body waste collection device. The second primary system, the Portable Life Support System (PLSS) was a backpack assembly that supplied breathing oxygen, purified oxygen by removal of carbon

The amount of shielding of space suits may eventually become prohibitive in cost and mobility constraints. This problem may be attenuated by extensive curtailing of EVA duration, the provision of thicker spacecraft walls to reduce overall radiation exposure and thereby provide greater latitude during EVAs, or even utilize completely enclosed transitory work stations. Heavily shielded volumes within spacecraft astronauts may enter during periods of intense radiation (biowells) may also reduce EVA radiation limits and allow for thinner suits (Gunkel and Wolbers, 1977).

Denitrogenation

A reduction of environmental pressurization caused by the transition from the Orbiter cabin at 14.7 psia (standard sea level atmosphere) to the planned EMU pressure of 4 psia in the vacuum of space requires controlled conditions to avoid dysbarism. Dysbarism is caused by the reduction of the partial pressure of nitrogen in the blood and body fluids, resulting in nitrogen saturation and the formation of bubbles. This condition, commesurate with the bends, is extremely painful and dangerous and occurs when pressure is reduced by more than 50% of the initial pressure (Bateman, 1951). The standard procedure in avoidance of this phenomenon is through elimination of nitrogen from the blood and tissues by breathing pure oxygen for three to four hours. Once the EMU is donned an oxygen purge adapter rids the EMU of atmospheric nitrogen, repressurizing the suit with pure oxygen.

The denitrogenation process is not a desirable ritual because of the time delay, particularly under emergency conditions demanding EVA and the necessarily high consumption levels of oxygen expendables. One approach would be to reduce the Orbiter cabin pressure permanently or the day prior to the expected EVA. In addition to the problems incurred under emergencies, a reduced cabin pressure requires a proportionately greater level of oxygen pressure and represents a flammability hazard. Other possibilities include an increase of normal suit operating pressure to at least 8 psia or the development of a time variant suit pressure that would decompress during EVA to an ultimate pressure of 4 psia (Griswolde and Wilde, 1981).

Visual Protection

Eye protection from solar radiation is paramount, particularly in visual, ultraviolet and infrared portions of the electromagnetic spectrum. Prolonged exposure to ultraviolet light can damage surface cells of the eye temporarily, interfering with task completion. The EVA visor assemblies provide solar protection but must be manually adjusted. Manual adjustment of helmet visoring is obviously undesirable, particularly during performance of two-handed tasks. Griswolde and Wilde (1981) describe a design concept of an automatic visor wide angle helmet. This helmet would utilize four photo-cell actuated liquid crystal panels to automatically adjust light to appropriate levels.

Comfort/Mobility

A major finding that was not determined until the Skylab flights was that under conditions of weightlessness the body assumes a different posture than the standard one g position on earth. This was termed the Neutral Body Posture and represents that position the body assumes in the absence of external forces. The Neutral Body Posture is a semicrouch, somewhere between a normal standing and sitting position, in which the neck and head drop forward, the feet evidence a fifteen degree droop and the thighs and knees are slightly bent. Deviation from this posture resulted in extreme discomfort and fatigue for the astronauts (National Aeronautics and Space Administration, 1975).

The Space Shuttle EMU design is more amenable to the Neutral Body Posture than was provided by the Apollo design. Apollo EMU joints were rubber convoluted joints, shaped like rubber bellows. These joints were considered constant volume joints, supposedly reducing effort required because the only work was to result from movement of the fabric rather than pressure deviation. The joints did not prove as effortless as expected and the joints provided considerable resistance and resultant fatigue. The present EMU joints are composed of flat patterned fabric and polyurethane sections, closely conforming to the joint curvature at a significantly smaller expense. This joint construction is supposed to provide considerably less joint torque. Joints are easier to bend and do not provide resistance in order to maintain that position. Overall, the joints allowed for 20% greater mobility than Apollo EMU joints (Brouillet and Griswolde 1981).

CONCLUSION

The international space programs have changed dramatically in a short period of time and this trend is likely to continue. EVA will play an increasing role in this new outgrowth. The potential for humans to live and work in space is without historical precedent and many issues must be defined and challenges faced. The most basic of these issues involve design of the EMU, a few of which have been discussed.

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dioxide and other contaminants, maintained suit pressure, controlled temperature, warned of system malfunctions and provided voice communications and telemetry. An Oxygen Purge System (OPS) provided thirty minutes of emergency oxygen.

The Shuttle EMU was an improved version of the Apollo EMU (Brouillet, 1981). Outer garment sections are standardized and modular, allowing a few sizes of each element to fit the entire astronaut population. The pressure assembly is termed the Space Suit Assembly (SSA). The liquid cooling undergarment is similar to that of Apollo but the outer section is substantially improved. The rigid upper torso is of aluminum and fiberglass with the PLSS attached in back. The lower torso section is a soft polylaminated fabric. Joints are of tucked patterned fabric and polyurethane. These joints represented a significant improvement over Apollo's EMU joints. The PLSS is designed for greater operational effectiveness by design for modular subsystems. Machinery is placed in one module on top of the PLSS with expendables on the bottom and outside surfaces. This configuration facilitates turn-around time of rechargeables and allows for future growth potential. The PLSS is designed to conform to the shape of the hard upper torso, resulting in a much smaller and more compact configuration. The fixed backpack, reduced number of attachments and simplified design allows astronauts to dress themselves in a few minutes, while Apollo astronauts required over an hour plus additional aid for the cumbersome task.

DESIGN ISSUES

Heating/Cooling

The utilization of thermal insulation on the outer section of the EMU provides an additional constraint of dissipation of the astronauts' heat production, particularly under conditions of high work load. Excessive heat was a problem in some of the Gemini EVAs (Waligora and Horrigan, 1977). Overheating can also create a state of dehydration through excessive sweat loss. The extent of metabolic demand for a given task is difficult to predict for zero g because of nonlinear metabolic variances between different tasks at zero and one g. However, analysis of Gemini missions determined that task difficulty (and thereby metabolic rate) could be greatly improved through the use of adequate body restraints, preflight training in water "neutral buoyancy tanks" that simulate conditions of weightlessness and detailed scheduling of activities (Waligora and Horrigan, 1975).

There are two primary means of cooling (Carson, Rouen, Lutz and McBarron, 1975). The liquid cooling system consists of plastic cooling tubes on the inside of the undergarment that circulate cooled water. The expendable water required for EMU heat rejection is periodically supplied by the Environmental Control and Life Support System (ECLSS) of the spacecraft, which drains and refills the cooling tubes to meet demands as high as 19kg/day (Thiele, Secord, and Murphy, 1977). The second system provides ventilation via oxygen flow, serving as heat rejection in addition to other functions. This system provides a closed loop of oxygen from the PLSS into the helmet, over the oronasal area, and down to extremities. Ventilation was provided with an umbilical connected to the vehicle during Skylab and Apollo fifteen to seventeen missions. Although heat removal capacities were equivalent, the umbilicals were inconvenient because they were cumbersome, got in the way and limited EVAs to the sixty foot length of the umbilical.

The cooling systems of EVA for Apollo, Skylab and the Space Shuttle are similar, allowing sustained operations at metabolic rates up to 2×10^6 J/hr (approximately 475 kcal/hr) under normally functioning operations (Waligora and Horrigan, 1975). Although there is some concern that the EMU may not perform sufficiently under unusually demanding work conditions Waligora and Horrigan (1977) determined that the metabolic rate of long duration EVAs of Apollo and Skylab were remarkably consistent, maintaining a metabolic range of 8.37×10^5 J/hr (200 kcal/hr) to 1.05×10^6 J/hr (250 kcal/hr). This was considered a result of self-pacing of crew activity rather than engergy requirements of tasks.

Space vehicles in the future will probably evidence a shift in reliance of energy generated by fuel cells to solar power. Use of fuel cells provide water as a byproduct from the fusion of hydrogen and oxygen for energy and serve as a readily available supply for EVA liquid cooling requirements. Consequently, alternative configurations will need to be provided for future missions. One possible design was described by Griswolde and Wilde (1981). During crewmember transition from the Orbiter to the worksite a phase change material such as ice provided by the Space Shuttle would serve as a temporary heat sink. The remaining and primary heat rejection requirements could be met by a radiator as part of several possible configurations, e.g. located at a semipermanent worksite.

Radiation (Ionizing)

Protection from ionizing radiation represents a major constraint for EVAs and will become increasingly important as greater mission durations are planned due to the cumulative nature of ionizing radiation dosage. The amount of ionizing radiation astronauts are subjected to is a function of suit thickness, orbital attitude and inclination, EVA exposure time and mission duration.

Low earth orbit (LEO) at 370 to 425 km, is most intensive in the area of the Van Allen Belts, reaching a peak at the South Atlantic anomaly (near Rio de Janeiro). Radiation levels at geosynchronous earth orbit (GEO) consist of some cosmic radiation but are primarily determined by the size and frequency of solar flares. These flares are generally of either high intensity but short duration or low intensity but lasting a few days (Gunkel and Wolbers, 1977). Because GEO radiation is considerably more intense and continuous than levels at LEO most EVAs will probably occur at LEO for some time. Shuttle EMUs, with a thickness of 0.1 to 0.3 gm/cm^2 may provide sufficient shielding because of the expected short mission durations and by scheduling EVA tasks outside of the South Atlantic anomaly (standard procedure during Skylab EVAs).

An additional hazard is caused by the collision of ionizing radiations such as alpha and gamma particles with the EMU or spacecraft wall producing secondary radiations, primarily in the form of x-rays. Hamilton Standard, designers of the EMU are investigating a space suit design with outer layers of a low atomic weight serving to decelerate primary radiations and with flexible high density inner layers to absorb secondary emissions (Griswolde and Wilde, 1981). Custom tailoring the pressure garments to suit the particular mission characteristics is also under investigation to avoid excessive suit thickness.

As radiation duration and intensity increases the required suit thickness increases correspondingly.

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