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SPACE SUITS

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INTRODUCTION

The goal of NASA to land a vehicle and place an astronaut on the surface of the moon has brought the space suit out of the comic strips to reality. Few realize, however, that in 1934, Wiley Post first entertained the idea of breaking the high-altitude record with the use of what might be termed today, the granddaddy of space suits. Wiley's suit was a simple rubberized inflatable garment. The suit had virtually no mobility, with the arms designed to assume a fixed position of stick and throttle enabling him to control the aircraft marginally. Also, there was no effort made to provide any comfort facilities. However, Wiley's suit, though primitive in comparison to our present-day, Wally's (Schirra) suit, did what it was required to do. It provided Post with the protection he needed to fulfill his mission - that of attaining a new altitude record. Since that time, engineers and scientists of the Department of Defense, NASA, and industry have been trying to overcome the two major difficulties of complete mobility and comfort. The question of complete mobility is a complex design problem within itself, notwithstanding its being compromised by the comfort criteria which impose numerous problems to the space suit design engineer. For the purposes of clarification, comfort is interpreted to include suit fitting as it relates to pressure points; thermal balance as provided by the environmental control system in conjunction with the suit ventilation distribution efficiency; and perhaps the most complex, that of waste management. Mobility is interpreted as those functions required by the astronaut to complete a mission either in an unpressurized or a pressurized state, whether it be vehicular or extravehicular. The development of one suit to meet the afore-mentioned general requirements for all missions would constitute a major breakthrough~~s~~; and design achievements for items, although desirable, are not specifically required for the mission intended. In this respect, the philosophy for suit design was selected to be mission oriented, with mission time and spacecraft compatibility as paramount parameters.

PROJECT MERCURY

The Project Mercury suit (fig. 1) is utilized in the same manner as the Navy Mark IV suits are used in fighter aircraft; that of an emergency garment, a backup to spacecraft integrity. The design of the spacecraft controls and limited amount of space available to the astronaut, reduced the mobility requirements to the areas of the shoulders and hands. Waste management in the short-term mission is satisfactorily accomplished by proper dieting and the use of a well-designed, constant-wear urine-collection device. The one primary role the suit does play is providing temperature control by an efficient ventilation distribution system. The system is such that oxygen is led into the suit via a torso-located connector and distributed to the extremities. A percentage of this gas is bled directly to the torso area. All the flow is then exited through a headpiece connector back into the environmental control system. This system has permitted Mercury to operate with cabin temperatures approaching 100° ±5°F. In view of the short-term capabilities of Mercury, major emphasis was placed on unpressurized comfort. This comfortable environment was accomplished by trade-offs in ventilation distribution in which the number of lines and subsequent routing of the lines were minimized. The suits were also individually tailored to eliminate bulk and possible pressure points caused by folds from excess material.

The point in effect is that the Mercury suit has provided and will, in the completion of project Mercury, continue to provide the astronauts with emergency protection and maximum functionability as a component in the Mercury machine complex.

PROJECT GEMINI

Looking toward Project Gemini, which will have mission potentials of up to 14 days, some of the short-term design advantages gained in the Mercury suit are lost. In Project Gemini, some of the problems presently confronting suit design are: provision for thermal protection as required in the event of a pad abort and suit ejection seat interfaces needed to provide a satisfactory escape capability. These are but a few of the additional design problems; however, though difficult, we may consider them as exterior to the suit, and we are still faced with the man-suit habitability problem, only to a much greater degree than in Project Mercury. Considering the confinement of the two-man Gemini spacecraft and the long-term mission capabilities, NASA is developing a partial-wear space suit (fig. 2). Interesting features in this concept are that the headpiece and arm and leg sections of the suit can be removed within the confines of the spacecraft. These components may be easily re-placed in a minimal period of time and will provide protection in an emergency. This capability is undoubtedly a recognized comfort advantage. The ventilation system is designed in such a manner that the gas enters at the waist into a chamber, is distributed directly to the facial area, arms and legs, and then exits at the waist, as opposed to Project Mercury in which the gas exited through the helmet. This routing eliminates the possibility of the astronaut inhaling toxic gases or body odors. The ventilation system is such that when the headpiece is removed, pure oxygen is continuously directed toward the oral-nasal area. Since the partial-wear concept continuously encumbers the astronaut with the torso section of the suit, the matter of waste disposal still remains a difficult one. Donning of the suit is accomplished primarily by the pressure-sealing entrance zipper. The entrance zipper runs from just below the abdomen through the crotch and up the back of the suit to the helmet combination bearing disconnect. Thus, this zipper also serves as the access portal for purposes of urination and defecation. Early in the program, it was determined that a body-waste collection system, as an integral part of the ejection seat, could seriously compound the seat design and delay the program. In view of this, a program was initiated in which prototypes of what might be termed a "defecation mitten" are presently being evaluated for usage in the confines of the Project Gemini spacecraft. The one-handed collection device is simply managed, has a self-contained germicide and can be easily sealed and stowed after usage. The dual-purpose donning zipper access portal makes possible the elimination of a constant-wear urine-collection device, as in Project Mercury. Once the craft is in orbit, the collection device utilized during the time on the launch complex is removed and subsequent elimination is uniquely transferred into the environmental control system. The transfer method will also allow for the collection of samples for postflight analysis.

Evaluation programs are being initiated to determine water requirements and metabolic outputs of a Gemini suited subject in the completely donned versus the partially donned condition. These programs will be conducted under various simulated activity levels and environmental conditions. Spacecraft and suited-subject compatibility tests (presently in the preliminary stages) are being conducted to assess the extended wear acceptability for periods of 2, 7, and 14 days. Emergency pressurization time will be included to simulate abort situations.

Before dealing with the Project Apollo space suit it should be clear that although our suit programs are project oriented, much of the data gained from utilization of both the Mercury and Gemini suits and the developments acquired, will be a strong foundation for the Apollo suit program.

PROJECT APOLLO

The Project Apollo suit is no doubt the most complicated suit and supporting equipment development program ever attempted. The lunar suit will require as much or more engineering effort than the combined pressure-suit-development efforts by the Department of Defense, industry, and NASA from Wiley Post days to the present. Most important, is that the suit must be truly a space suit and removed from the status of an emergency garment to that of the primary "life" sustaining ensemble.

In setting forth the design criteria for the lunar suit, comfort and mobility are still present, but pressure protection now attains equal emphasis. Astronaut safety, now being a primary factor, requires that the pressure protection afforded by the suit meet a triple nine reliability factor. This one failure in a thousand can be attained in items of hardware such as suit fittings, and connectors and approached in closures. The possibility of losing pressure integrity, however, because of an accidental tear or puncture in present state-of-the-art suits greatly reduces this factor. The suits used in Project Mercury and the ensuing Project Gemini are considered as secondary personal protection to the astronaut in the event of a loss of spacecraft pressure. In order to provide the astronaut the similar advantage or safety measure, a secondary pressure-protection system was incorporated in the lunar suit. In general terms, this might be considered as a suit within a suit. Needless to say, this feature will institute a trade-off in suit mobility but one that is well justified. In providing for mobility in the areas of flexion, maximum efficiency is attained with the use of constant volume joints constructed of restrained bellows as shown in the suit made by International Latex Corporation (fig. 3). The advantage of a constant volume bellows is that bending of the joint does not require any expenditure of energy to compress the pressurizing gas medium.

Maintaining the astronaut in thermal balance and satisfying his metabolic requirements present a severe challenge in the Apollo suit design. The resultant design of the assembly necessitates a well integrated suit and life-support system. Factors weighed for the design analysis were: conditions of the lunar surface, length of exposure, and tasks to be performed during a typical lunar exploration.

The heat load to be carried by the extravehicular lunar crewman's portable life-support system, for example, is the summation of his metabolic output and inputs from the lunar environment. The first problem, that of metabolic output, has been determined for subjects under various environmental conditions and work levels. However, very little data have been compiled for subjects wearing space suits. Recently, NASA has instituted programs to obtain this information. The lack of this data is in part due to the nonexistence of mobile suits which would warrant experimentation of this nature—the need for which has only arisen to fulfill the Apollo requirements. The effect that the 1/6 gravity of the moon will have on metabolic output is thought to be between that obtained from the aforementioned experiments and that during the weightless phase of the Project Mercury orbital flights. The second factor, the determination of the thermal input to the astronaut, is a complex one. The complexity will become apparent by the following discussion of the analysis of the problem. Although a number of thermal sources are available to the lunar crewmen, only five sources were considered in the suit analysis: direct solar, lunar emitted, lunar reflected, crater emitted, and crater reflected. The crater concept was introduced to subject the crewmen to the most severe thermal situation. Figure 4 illustrates this condition in which the crewman is standing on an infinite plane adjacent to an infinitely long wall. The crewman is 200 feet from the wall so as to eliminate the effect of the wall when the configuration factor between the infinitely horizontal plane and the man is calculated. The wall is 14,000-feet high and sloped 20°. In keeping with the most severe thermal condition, the position of the sun was assumed to be displaced 20° from the normal to the horizontal. Other factors to complete the picture were an internal suit temperature of 75°F and an insulation constructed of aluminized mylar 0.10 in. thick with a thermal conductivity (K) equal to 5×10^{-4} Btu/hr-ft-°F. This value of (K) has been determined during experiments in which multilayer aluminized coated mylar insulation was used. The absorptivity (α) and emissivity (ϵ) were selected as 0.10 and 0.05, respectively. The crewman's shoe soles were considered as adiabatic surfaces. An explanation of the five thermal inputs follows:

1. Direct Solar. - The quantity of thermal radiation emitted by the sun is 440 Btu/hr-ft^2. Because the receiving surface is not normal to the sun's rays, the intensity of the incident radiation is reduced by a configuration factor. The incident radiation is further decreased by suit reflection. The remainder of the energy is absorbed and either reradiated to the surroundings or conducted through the garment to the man.

2. Lunar Emitted. - The lunar body is subjected to a wide variety of temperatures varying from plus 250°F at subsolar to minus 250°F during the middle of the lunar night. The relatively slow spin of the moon allows it to acquire different "equilibrium" temperatures at distinct lunar locations. A lunar emission value of 375 Btu/hr-ft^2 could be computed for the assumed position of the sun, since these values are directly proportional to the fourth power of the temperature of a body. A portion of this thermal energy is also received by the man.

3. Lunar Reflected. - Of the total amount of direct solar energy incident on the lunar surface, a small percentage (7 percent termed albedo) is reflected to the man and partially absorbed.

4. Crater Emitted. - Before the amount of crater emission could be obtained, a separate analysis was conducted to determine the energy received by the crater. It was assumed that the crater was a body that emitted everything it absorbed. Three thermal inputs were used for the crater analysis: direct solar, lunar emitted, and lunar reflected. A summation of the above inputs yielded a crater wall emission value of 275 Btu/hr-ft^2. Again, a part of this was transmitted to the man.

5. Crater Reflected. - The final thermal input to the space suit is crater reflected. This refers to the solar radiation that is directly reflected to the man from the crater wall and absorbed. Summation of the above thermal inputs resulted in a suit surface temperature determination. This analysis indicates that, during the lunar day, the suit surface temperature will reach 155°F with a corresponding thermal input into the suit of 120 Btu/hr. On the lunar night side, the skin temperature of the suit will stabilize at plus 7°F with an outboard heat leak from the suit of 100 Btu/hr. Conclusions drawn from this analysis are that the suit surface temperatures to be encountered are well within the present day state-of-the-art materials and are easily tolerated by the aluminized mylar pile. It is also obvious that the portable life-support system must be designed to eliminate an additional 120 Btu/hr over and above the anticipated crewman's metabolic rate.

A 4-hour length of stay time on the lunar surface was selected for the extravehicular crewman. This stay time was determined by trade-offs on weight and size of the expendables required in the portable life-support system. Size was a most important factor in that ingress and egress clearance in both the command and lunar excursion modules is minimal. The type of portable life-support system selected is essentially a miniature version of the Mercury spacecraft closed-loop system. This system was chosen as a matter of expediency in that no design breakthroughs would be required to obtain a workable system. Operation of the system is as follows: dry oxygen is forced into the space suit at a suitable torso location by a battery powered electric blower. Distribution of the oxygen provides body cooling and a portion of this oxygen is consumed to satisfy the astronaut's metabolic needs. A gas mixture of CO_2, water vapor, and oxygen leaves the suit and enters a physico-chemical treatment cycle. Odors are removed with activated charcoal, CO_2 by chemical absorption through lithium hydroxide, and heat by a water-evaporative heat exchanger. The water vapor condensed in the heat exchanger is removed by a mechanical means. Suit pressure is maintained at 3.5 psia by an aneroid-controlled oxygen-demand regulator.

There is another phase related to the suit programs, although it is not considered glamorous, it is of equal importance in the overall success of the space program, that of earth survival. In this area, great strides have been made in the development of improved water-survival equipment. New techniques in the fabrication of inflatables have increased reliability and made possible a large reduction in weight and space required for packaging. Items (figs. 5 and 6) such as a minature lifevest which will keep an astronaut afloat with his suit completely filled with water; a liferaft (figs. 7 and 8) which will support a man standing on its rim without capsizing; and a corner reflector (figs. 9 and 10) which packages in a 1/2-by 3-by 6 in. volume and weighs approximately 2 oz; have been developed and successfully evaluated. The uniqueness of the radar-reflector development is that only three breaths are required to inflate the reflector to a diameter of 39 in. and it can be tracked by radar within a 50-mile radius.

The programs just described are considered to have been designed in such a way that the flight hardware developed will be particularly mission oriented.