THERMAL PROTECTION SYSTEM FOR EXTRAVEHICULAR SPACE SUITS

G. B. Whisenhunt[1] and R. A. Knezek[2]

Chance Vought Corporation, Dallas, Texas

ABSTRACT

A pressure suit system that will provide thermal protection of a worker performing tasks outside a space vehicle as well as provide emergency pressurization within the vehicle is described. The system uses an insulated "coverall" garment with a low solar absorptivity outer cover to minimize the effects of the external environment. Calculations indicate that sufficient heat blockage is obtained with the coverall garment to allow control of temperature levels and distribution with air circulation from a portable environmental unit. The discussion includes the problems, requirements, methods, and design for a cislunar and lunar surface extravehicular space suit.

INTRODUCTION

Manned Space Vehicle study programs have indicated that man will be required to perform functions outside the protective enclosure of the sealed spacecraft. These functions may include repairs to the outside of the vehicle, assembly of space station components, exploration of the lunar surface, and transfer between space vehicles (Fig. 1). Current full-pressure suits will not adequately protect a space worker from the extreme thermal conditions present in space.

Past studies have shown the desirability of developing a multi-purpose pressure suit system which can be used for emergency pressurization within the space vehicle, as well as

---

Presented at the ARS Lunar Missions Meeting, Cleveland, Ohio, July 17-19, 1962.

[1] Engineering Specialist, Power and Environment Section, Astronautics Division

[2] Environment Engineer, Power and Environment Section, Astronautics Division.

protection of the astronaut while performing tasks outside the vehicle. Preliminary analysis indicates that adequate thermal protection for extravehicular operation can be obtained by use of an insulated "coverall" garment worn over the normal vehicular suit. This approach is feasible because of the extremely low thermal conductivities exhibited by standard low density insulations under vacuum conditions. These low vacuum conductivities provide considerable heat blockage for small insulation thicknesses. Preliminary calculations indicate that a "coverall" garment with approximately 1/4 inch of insulation and a porous outer fabric with a low absorptivity to solar radiation will reduce heat inputs and heat losses from the suit sufficiently to allow adequate thermal control of the suit interior to be accomplished by an air circulating and conditioning system. Since the air circulating and conditioning system is required for pressurization and breathing gas, no complicated equipment must be added to accomplish the extravehicular thermal control function.

This paper presents a discussion of the foregoing thermal control concept. The discussion includes the problems, requirements, methods, and design for a cislunar and lunar surface extravehicular space suit.

REQUIREMENTS

The primary requirement for an extravehicular space suit thermal protection system is to protect the space worker from the extremes in thermal environment which will be encountered. In some instances, the worker may be on the sunlit side of a vehicle where he receives heat in the form of radiation from the vehicle, sun, Earth or moon. In other instances, he may be required to work on the shaded side of a vehicle or in the shade of a planet where he is subjected to the extreme cold of space and receives only a small amount of external heating. Operation on the lunar surface also presents a widely varying thermal problem. On the sunlit side of the moon, the surface temperature may reach $250^{\circ}F$, whereas temperatures as low as $-250^{\circ}F$ can occur during the lunar night. In some instances, one side of the worker may be subjected to heating while the other side is radiating to deep space. In addition, maintenance work may be required on cryogenic propellant tankage, or high temperature auxiliary power units. Without suitable thermal protection, severe thermal gradients can occur in the space suit causing discomfort and/or injury to the astronaut.

Design requirements for a system which will provide thermal protection in these extreme environments include the following:

1) Suit components in contact with the body should not vary from 75 ± 5°F at any point. Pressurization gas average temperature shall be maintained within the range of 70 - 80°F at all times.

2) The maximum metabolic heat load is approximately 1000 BTU/hr. The average metabolic heat load is approximately 400 BTU/hr.

3) The design shall function satisfactorily at the following limiting design environments:

a. Steady-state at lunar surface subsolar conditions (extreme hot condition).

b. Steady-state in lunar darkness (extreme cold condition).

c. Steady-state in deep space with any one side facing the sun and the other side facing deep space. (Maximum thermal gradient)

4) The extravehicular stay time shall be four hours.

5) The design shall function satisfactorily with any fixed orientation for the full extravehicular stay time (e.g., one side faces the sun and the other side facing deep space for the full four hours).

6) The maximum heat loss to the space environment shall not exceed 10 BTU/hr-ft^2. The maximum heat gain shall not exceed 6.5 BTU/hr-ft^2.

METHODS

There are a number of methods which could be used for thermal control of extravehicular space suits. The thermal gradients which occur due to the difference in the environment on the different sides of the suit could be controlled by a rigid metal shell surrounding the worker (1).[3] This approach would provide a rigid suit and would be heavy. Liquids such as water anti-freeze solutions circulated through passages in the walls of the pressure suit could be used to distribute heat. This approach would also be heavy and would require continuous power to circulate the fluid. Both of these methods either depend on transient heating and cooling or other systems to maintain the desired temperature level.

---

[3] Numbers in parentheses indicate References at end of paper.

Considering all known methods for thermal control of extravehicular space suits, the concept of minimizing the effects of the external environment with heat blockage by insulation and a thermal control coating appears to be the most desirable. With adequate external heat blockage, the thermal control of the worker may be accomplished in the same manner as with current vehicular type pressure suit systems. In current suit systems, thermal control is accomplished by proper conditioning and distribution of the pressurization gas. For extravehicular operation, the gas conditioning can be accomplished by a portable environmental control unit and the correct distribution can be achieved with proper suit design.

The heat blockage concept for thermal control has the added advantage of providing a multi-purpose pressure suit assembly. The suit may be used inside the vehicle for emergency pressurization (in the event of a cabin decompression) or outside the vehicle as the primary source of protection. The space worker would don a portable environmental unit and an insulated coverall garment (in addition to the basic suit) prior to leaving the space cabin.

The insulated coverall garment will provide the basic heat blockage required for adequate thermal control. Other schemes are required for providing additional protection to critical areas of the suit. These critical areas include the flexible joints, helmet, feet, and hands. Schemes for providing this additional protection include:

Greater thickness of insulation in critical areas

Expendable coolants placed at critical areas

Increased airflow

Electric heating and/or thermoelectric cooling

Fixed heat sinks

"Thermopane" type construction of the face plate

An analysis of the insulation-selective coating approach for extravehicular space suit thermal control is presented in the following section. An analysis of methods for handling critical areas is also included.

ANALYSIS

The two basic functions of a thermal protection system for a man in the space environment are: (1) the control of the total heat load which must be dissipated by the portable environmental control system; and(2) the control of local temperature variations at the inner surface of the pressure suit. Environmental control systems for current space vehicle pressure suits are designed to dissipate the metabolic heat generated by the crewman and all equipment within the pressure shell. There is no requirement for a heating system since the metabolic and equipment heat loads provide adequate heating for all conditions. This same approach is suitable for extravehicular space suits when insulation is used to limit the total heat loss from the suit to the amount of heat generated. Cooling can be accomplished by an expendable coolant or radiator system.

When a space worker is exposed to the radiant energy of the sun and reflected or radiated energy from a vehicle or the hot lunar surface, the exterior of the pressure suit will become hot and add to the environmental control system heat load. Sufficient airflow through the suit must be provided to remove this heat without exceeding the required temperature limits. Comfort of the worker is affected by air velocity, humidity, and temperature. Although the desired combination of these parameters varies widely among individuals, a difference between inlet and outlet suit air temperature of 20 to 30°F is considered to be a practical maximum. Fig. 2 shows the sensible heat removed by the conditioning air as a function of flow rate and temperature rise. Flow rates normally considered for pressure suits are between 5 and 15 standard cubic feet per minute since excessive flow tends to "dehydrate" the worker. These considerations indicate that the additional heat load from the environment must be kept to a minimum if a simple air circulation system is to provide a satisfactory environment within the suit.

Even when the environmental heat loads are maintained within acceptable limits, local temperature variations can cause discomfort or injury. If the worker touches a hot surface, burning of the skin will occur. Similarly, if the surface is allowed to become cold, numbness or frostbite may occur. If the surface becomes colder than the dewpoint of the air in the suit, condensation will occur and will cause a very disagreeable condition. These conditions are used as limiting factors for the analyses that follow.

The low thermal conductivity of insulating materials under high vacuum conditions may be utilized since thermal protection is required only during extravehicular operations. Evacuation of the insulation to space is assured by a porous outer fabric. Considerable heat blockage is obtained with small thicknesses of common insulating materials. Fig. 3 shows the effect of pressure on the thermal conductivity of a typical glass fiber insulation.

The maximum cold condition occurs when the crewman is working in a shadow of a vehicle in space or when a crewman is located on the cold side of the lunar surface. Limiting conditions may be described by an environment at absolute zero temperature. Heat is lost by conduction through the insulating layer and radiation to space. The sensible heat dissipated by the crewman is assumed to be 400 BTU/hr. Part of this number must be reserved for areas that are difficult to protect, such as the helmet, hands and heat shorts in the insulating layer. Allowing approximately 40% of the available heat loss through these areas leaves 250 BTU/hr as a maximum for heat loss through the insulation layer. For a suit with a surface area of 25 ft^2, the maximum heat loss per unit area is 10 BTU/hr-ft^2.

The heat loss is a function of surface emissivity in addition to the thickness and thermal conductivity of insulation. Fig. 4 shows the effect of surface emissivity on the thickness of insulation (typical glass fiber) required to limit the heat loss to 10 BTU/hr-ft^2. White nylon parachute fabric is a suitable outer cover for the insulation and has an emissivity of approximately 0.93. Fig. 4 indicates that 0.25 in. of the glass fiber insulation will be required if this covering material is used. The effect of insulation thickness on heat loss is shown by Fig. 5.

When the crewman is illuminated by the sun, the outer surface of the suit will be heated. The amount of heat conducted from the outer cover through the insulation is small compared with the radiant energy absorbed and re-emitted to space. Therefore, the surface temperature will approach an adiabatic equilibrium temperature. The surface temperature and the resulting heat absorbed per unit area are shown as a function of the solar absorptivity to emissivity ratio in Fig. 6. The white nylon parachute fabric discussed previously has an absorptivity to emissivity ratio of approximately 0.6. Using this outer fabric and 0.25 in. of glass fiber insulation, heat is absorbed by the suit at the rate of approximately 3 BTU/hr-ft^2.

When the crewman is operating on or near the lunar surface, the maximum insulation surface temperature that is likely to be encountered is 250°F. This corresponds to a solar absorptivity to emissivity ratio of approximately 1 in Fig. 6. A heat absorption rate of 6.5 BTU/hr-ft^2 would be obtained. This condition imposes the maximum cooling load on the environmental backpack unit since the entire surface would be heated. This maximum condition could still be handled by airflow, since a good portion of the metabolic heat load under this condition would be dissipated by evaporation of sweat or latent cooling.

Optimum design of an insulation thermal protection layer must give consideration to the availability and mechanical properties of insulating materials as well as thermal conductivities. Some of the super-insulations look very promising from a thermal standpoint and will virtually eliminate thermal losses if they prove to be mechanically suitable. Fig. 7 shows the effect of thermal conductivity on thickness of insulation required. Several current insulations are located on this curve to show the benefit that may be obtained from insulation development. This curve shows that with Linde SI-93 super-insulation, the heat loss to space is practically eliminated.

Another area where new developments are desirable is the outer protective covering. This is illustrated best by Fig. 6, which shows the advantages of a low absorptivity to emissivity ratio.

Seams, zippers, and other irregularities in the insulating layer will cause heat leaks through the insulation and increase the rate of heat loss and heat absorbed. The heat transmitted through these heat shorts is determined by their area and the incident and radiated energy. Up to 1 ft^2 of exposed area can be tolerated in the cold environment without exceeding a total heat load equal to the sensible heat dissipated by the crewman. Special consideration must be given to these areas to prevent discomfort or injury since they may become very cold or very hot. In the maximum heating environment, 1 ft^2 of exposed area (heat shorts) would more than double the heat absorbed, giving a total of approximately 400 BTU/hr. This is equal to the heat generated by the crewman. The heat leaks can be reduced considerably by application of a low emissivity (and also a low absorptivity) surface finish to the exposed areas.

Thermal protection of the crewman's hands presents a particular problem since this must be performed with minimum impairment to mobility. This might be accomplished by locally increasing the airflow. A low emissivity surface would be desirable in reducing the heat load, but it would be extremely difficult to maintain. Another approach is to cover the hand with a mitten which allows the fingers to be extended for detail tasks.

Another problem area is the helmet. Insulation inside the helmet would not be as effective as external insulation. Large variations in the helmet temperature would also result. A soft type of insulation on the external surface would not be desirable from the standpoint of possible damage during donning. The soft insulation might also interfere with operation of the visor. This problem could be overcome by using a dual-wall construction and possibly adding insulation between the inner and outer shells. Another possibility is a "hood" for the coverall which encloses the entire helmet except for the visor.

Although the visor covers a small area, it also presents a problem. If the visor temperature drops below the dewpoint of the air, it will cloud and impair the vision of the crewman. Airflows in this region must be kept low because of the sensitivity of the eyes. The visor temperature could be adequately controlled by installing a shield in front of the visor with a low emissivity outer surface. The low emissivity can be obtained by application of a partially transparent metal film. A thin gold film would provide a low emissivity and still allow the crewman to see through. A shield without the low emissivity surface would not be adequate to prevent clouding. An electrically heated shield might also be used for this purpose.

SUGGESTED METHOD

An artist's conception of an extravehicular space suit system for operation on the lunar surface or in the cislunar environment is shown in Fig. 8 and consists of the following major components: (1) an anthropomorphic vehicular pressure suit improved to provide satisfactory mobility; (2) an insulated coverall garment with a porous outer fabric to allow the insulation to outgas quickly (the coverall would be worn over the suit during extravehicular operation); and (3) a portable environmental unit to provide 5-15 standard cubic feet per minute of conditioned air to the suit.

These basic components can provide suitable thermal protection in the space environment. A possible method of construction for an insulation system is shown in Fig. 8. It consists of a layer of insulation quilted between two layers of white nylon parachute fabric. Estimated insulation, outer fabric, and quilting material weights are presented in Fig. 9 as a function of the thickness of the insulation used. For 1/4 in. of insulation, the total coverall weight would be approximately 6 lbs. This weight can be reduced and thermal protection effectiveness increased by a development program aimed at providing a better outer cover and-super insulations.

CONCLUSIONS

The following is a list of conclusions based on the analysis presented herein:

1) An insulated coverall garment with a low absorptivity outer fabric will provide sufficient heat blockage to allow adequate thermal control of an extravehicular space suit to be accomplished by the air circulation and conditioning system.

2) Special protection is required for critical areas of the suit such as joints, closures, helmet, feet, and hands. Simple passive schemes will provide protection for these areas.

3) A development program designed to integrate superinsulations into the coverall garment and to find a better outer cover is desirable in order to reduce system weight and increase thermal protection effectiveness.

REFERENCES

1 Irvine, T. F., Jr., and Cramer, K. R., "Thermal analysis of space suits in orbit," WADD TN 60-145 (May 1960).

2 Cramer, K. R., and Irvine, T. F., Jr., "Analysis of nonuniform suit temperatures for space suits in orbit," ASD Report No. MRL-TDR-62-8.

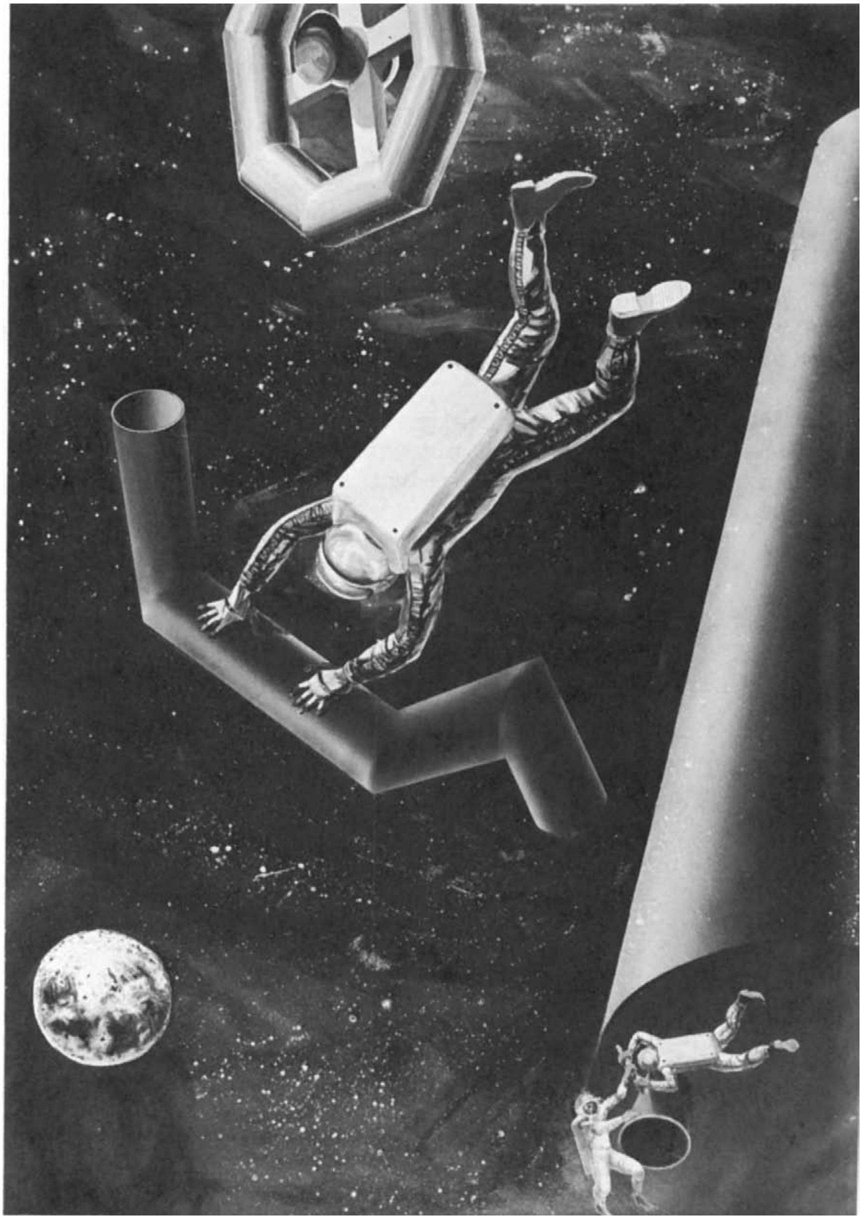

Fig. 1 Manned extravehicular space operations

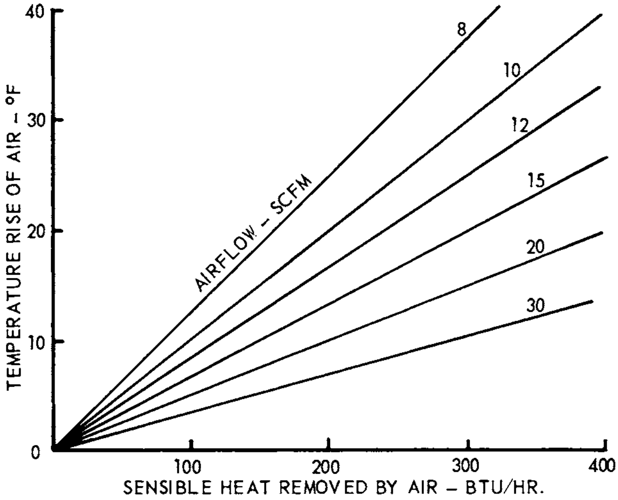

Fig. 2 Sensible cooling capacity of airflow

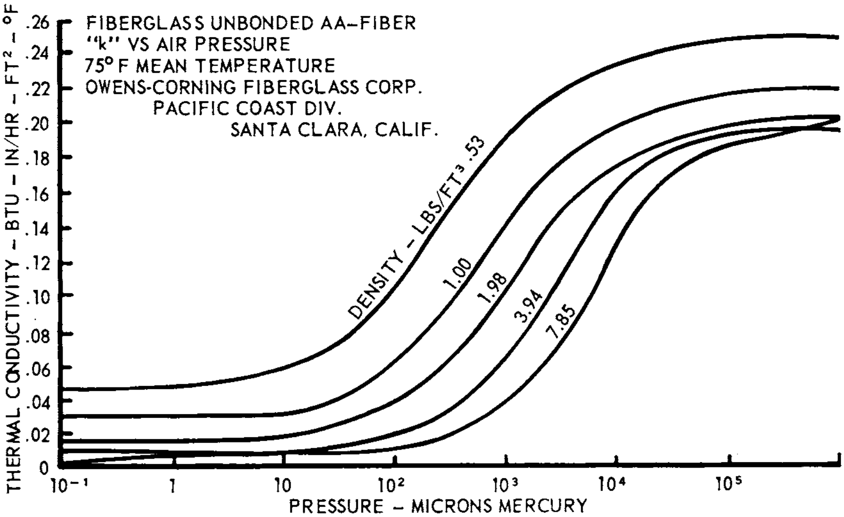

Fig. 3 Thermal conductivity of a typical glass fiber insulation

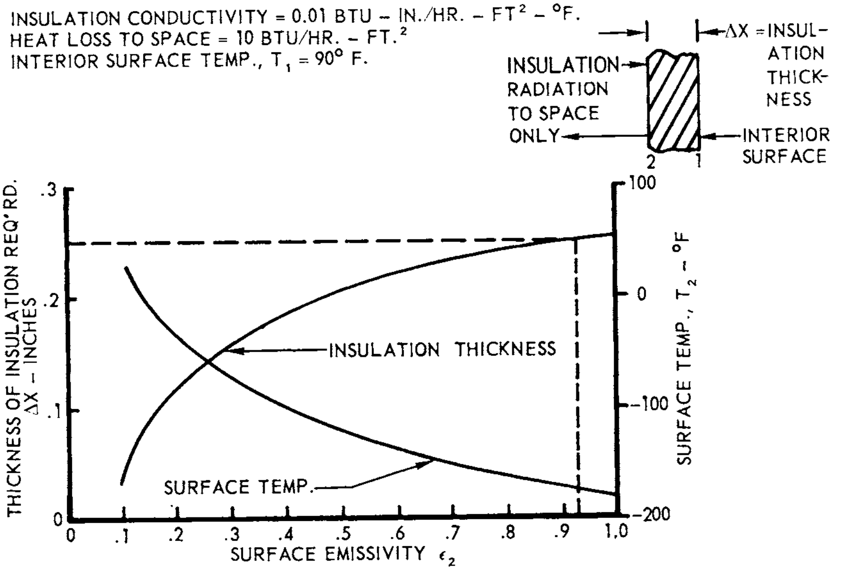

Fig. 4 Effect of surface emissivity on insulation thickness required

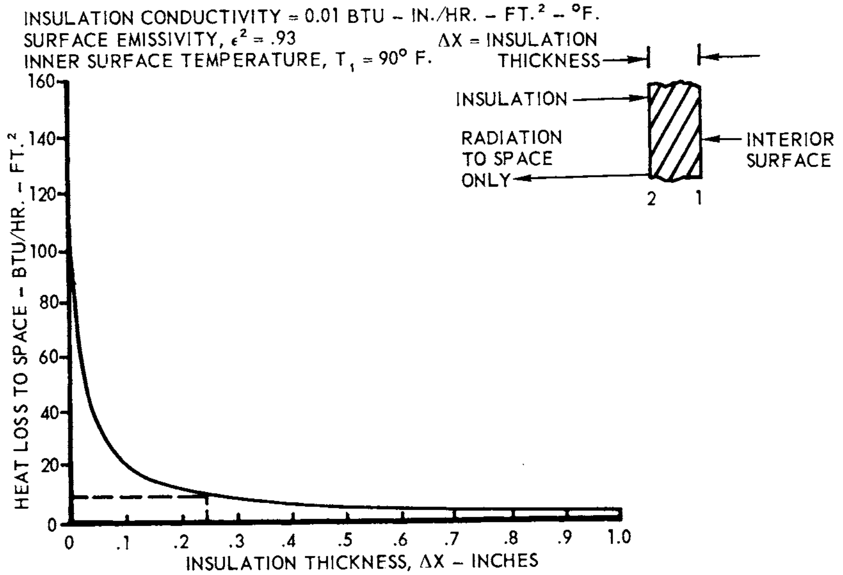

Fig. 5 Effect of insulation thickness on heat loss to space with no external heating

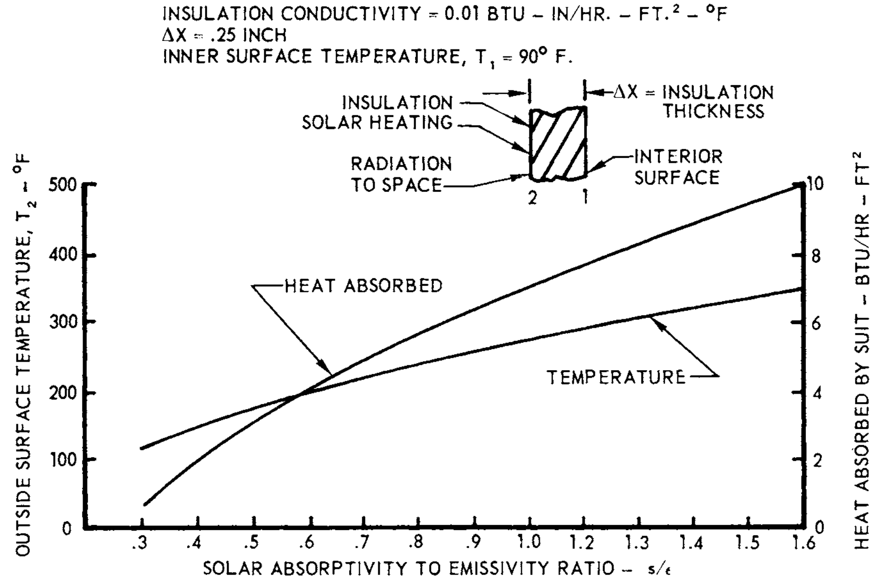

Fig. 6 Effect of radiation properties of heat load of suit exposed to sun

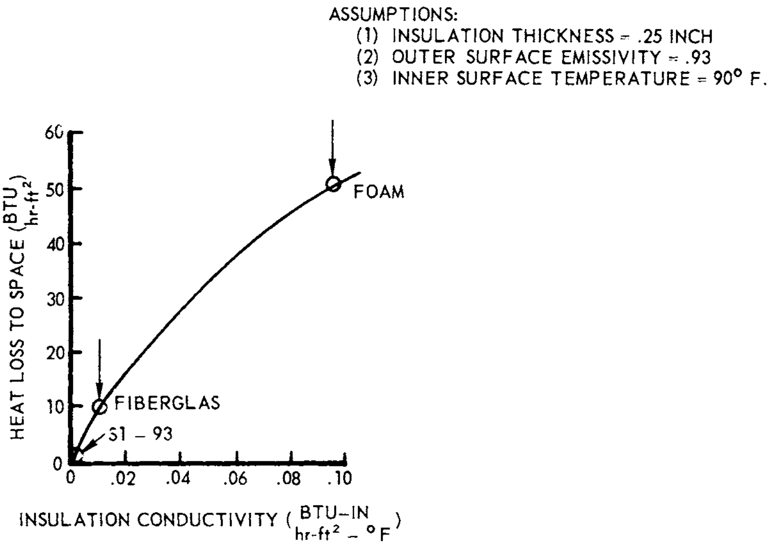

Fig. 7 Effect of insulation conductivity on heat loss to space

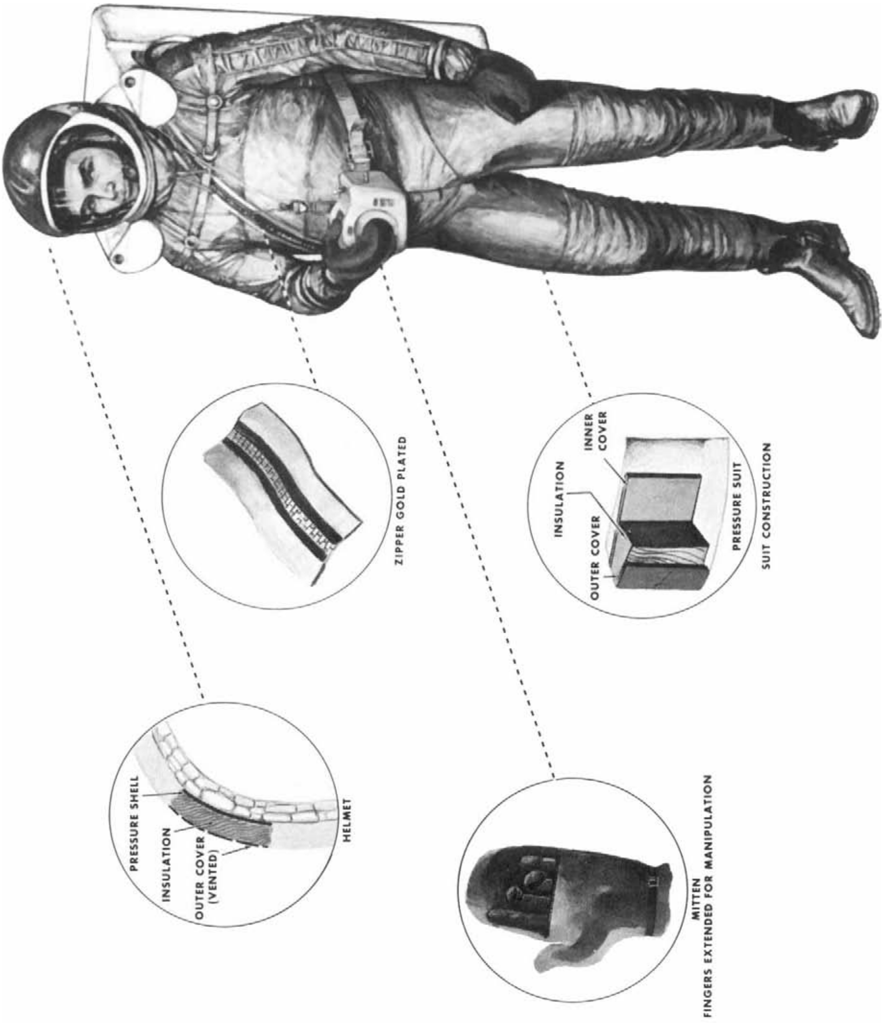

Fig. 8 Thermally protected suit

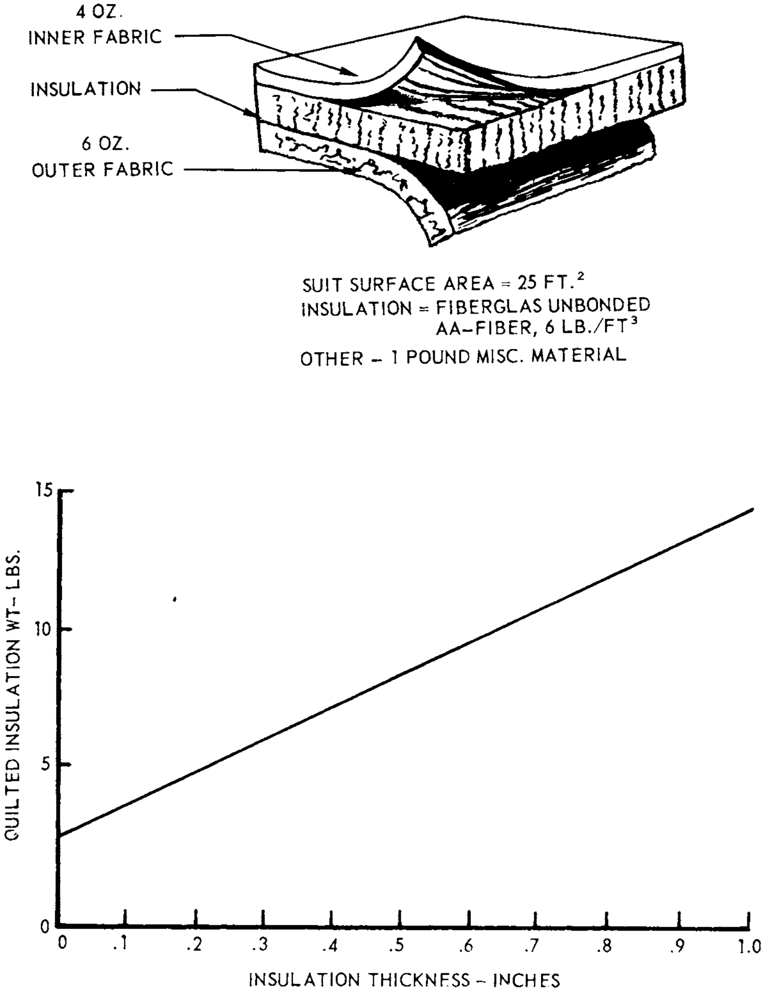

Fig. 9 Quilted insulation weight