N87-17798

PHYSIOLOGICAL AND TECHNOLOGICAL CONSIDERATIONS FOR MARS MISSION EXTRAVEHICULAR ACTIVITY

James M. Waligora
Medical Sciences Division
Melaine M. Sedej
Crew Systems Division
L. B. Johnson Space Center

ABSTRACT

The nature of the suit is a function of the needs of human physiology, the ambient environment outside the suit and the type of activity to be accomplished while in the suit. In the following paragraphs the physiologic requirements that must be provided for in the martian EVA suit will be reviewed. We will elaborate on how the martian environment may influence the EVA suit, EVA capabilities, and will compare the martian environment with the lunar environment and point out differences that may influence EVA design. The type, nature, and duration of activities to be done in transit to Mars on the Mars surface will be evaluated and the impact of these activities on the requirements for EVA systems will be discussed. Furthermore, the interaction between martian surface transportation systems and EVA systems will be covered. Finally, options other than EVA will be considered such as robotics, non-anthropometric suits, and vehicles with anthropometric extremities or robotic end effectors.

DISCUSSION

Extravehicular activity (EVA) refers to excursions outside the spacecraft cabin environment in a suit that provides its own protective environment. The experience of Skylab has demonstrated the value and versatility of micro-G EVA in terms of planned resupply and maintenance of spacecraft components as well as in repair of disabled spacecraft. The Apollo experience on the lunar surface has shown that in a self-contained space suit, man can move about freely on the lunar surface. He can perform useful work, deploy equipment, drill soil samples, make measurements, and select and collect geological samples. The crewman can also explore on foot and using motorized transportation. The Shuttle program has provided even greater experience and definition of what can be accomplished in micro-g EVA with improved suits and support systems. EVA is planned to be a very important component of Space Station. To meet the needs of Space Station, EVA suits will have to be durable and easy to repair; they will have to operate for long periods of time; and all cleaning, refurbishment, and repair will have to be done on board the vehicle. Also Space Station EVA will have to be done with a minimum utilization of expendables.

In meeting the objectives of the Mars missions all the EVA experience of earlier missions and all the evolution of EVA equipment will be required. During the transit between Earth and Mars, EVA outside the vehicle may be required for vehicle repair and suited IVA will surely be to maintain training of crewmen for martian surface EVA. On the martian surface crewmen will be involved in exploring, mapping, surveying and detailing the martian surface. Scientific equipment will be set up and measurements and obervations will be made by crewmen. Finally, crewmen wil be involved in fabricating and extending a martian habitation base.

Certainly a desirable way to perform these activities would be to walk about outside the spacecraft and on the martian surface in shirtsleeves, to pick up samples with bare hands, to use these hands to work with scientific equipment and make fine adjustments, and to ride in open vehicles and to mount and dismount at will. This simple approach is not possible because the martian environment, like the free space environment and the lunar environment, does not provide the physiologic requirements of the crewmen. To modify this environment man will need to be enclosed in a controlled habitable environment. An extravehicular activity suit will provide a minimum enclosure and interdiction between the man and the external environment to most closely approach shirtsleeve activity capability.

The EVA suit will have to provide adequate control of the following environmental factors: pressure, oxygen pressure, temperature, humidity, and radiation. At the same time, the suit will have to accommodate other physiologic needs. The suit will have to remove CO_2 produced by the crewmen. Food will have to be provided in the suit for the crewman if the duration in the suit is long enough to require it. There must be provision for waste management certainly of urine and possibly of feces again if the duration of suit wear is such that this would be required. EVA suits have sometimes been referred to as pressure suits; and although an EVA suit must control much more than pressure, pressure is one of the most critical environmental factors. A minimal atmospheric pressure (about 0.9 psi) is required to keep body fluids in the liquid state. For all practical purposes, however, acceptable pressures for an EVA suit are determined by the required partial pressure of oxygen and by an acceptable change in pressure from the ship cabin pressure to the suit pressure without causing altitude decompression sickness.

The ambient pressure on Mars is about 7 torr(1), a level well below that required to sustain human life. So pressure control will be required during EVA. If 100% oxygen is used in the suit, minimum operational suit pressure would be 3.7 psi. This pressure would provide a normal O_2 pressure in the alveoli of the lungs for transmission to the body for use in metabolism(2). A 100% O_2 environment was used in the Apollo Program for both the cabin at 5.0 ps and the pressure suit at 3.7 psi. The Apollo Program included exposures up to 2 weeks in length. For longer exposures some diluent gas is needed to avoid atelectasis in the lung and other potential problems with 100% O_2(3). In the Skylab Program, a 5.0 psi cabin pressure was used with 70% O_2 and 30% N_2 as the diluent gas. There was no indication of physiological problems with this atmosphere for periods of up to 84 days(4).

If different pressures are used in the cabin and in the pressure suit, care must be taken to avoid decompression sickness. Decompression sickness occurs when the pressure of dissolved gases in the tissues exceeds the ambient pressure. Under these conditions, bubbles may form in tissues and be carried by the blood-stream throughout the body. Decompression sickness is not normally a problem when the pressure of the diluent gas in the atmosphere does not exceed the final decompression pressure by more than a ratio of 1.25 to 1. If this ratio is to be exceeded, the crewmen must breathe O_2 prior to decompression to reduce the N_2 pressure in the body. It can be seen, therefore, that the pressure in the pressure suit depends on the cabin pressure as well as the minimum O_2 pressure required in the suit.

Options for different combinations of cabin and suit pressure are now being considered for Space Station (table 1). The main trade consideration for Space Station are the reduction in flammability associated

TABLE 1

CABIN AND SUIT PRESSURE AT THE THRESHOLD OF BUBBLE FORMATION

Cabin Presssure	Nominal % O_2 In cabin	Suit Pressure	Constraints
14.7 psi	21	9.5 psi	None
10.2 psi	28	6.0 psi	Equilibration at 10.2 psi for 72 hours prior to EVA or 1-hour pre-breathe prior to 10.2 psi plus 24 hours at 10.2 psi.
11.0 psi	25	6.7 psi	Equilibration at 11.0 psi for 72 hours prior to EVA or 1-hour pre-breathe prior to 11.0 psi plus 24 hours at 11.0 psi.
12.75	24	8.00 psi	Equilibration at 12.75 psi for 24 hours prior to EVA.
10.0 psi	50	4.3 psi	Equilibration at 10.0 psi for 72 hours prior to EVA or 1-hour pre-breathe prior to 10.0 psi plus 24 hours at 10.0 psi.

with higher levels of diluent gas versus the decreased pressure suit mobility associated with higher suit pressures. For the Mars mission, the tradeoffs may not be the same. High mobility pressure suits are now being worked on, and if they are operationally developed for Space Station, suit mobility may no longer be a tradeoff consideration. On the other hand, increased loss of consumables at higher cabin and suit pressures may become an overriding consideration.

The EVA suit must allow the crewman to maintain thermal balance. That is, a balance between heat production and heat loss. The man's internal heat production can vary from rest to work over a range of 10 to 1 or more on occasion and commonly varies over a range of 4 or 5 to 1. At the same time the outside of the suit may be exposed to a wide range of radiant thermal environment. This makes thermal balance difficult and requires a variable controlled rate of heat loss. The successful approach in EVA systems to date has been to isolate the suit from the external environment and to match heat loss to heat production using a liquid cooled garment bringing body heat to a heat exchanger cooled by sublimating H_2O to the space vacuum. For Space Station other approaches are being looked at to avoid the loss of the water involved in the sublimation and to avoid contamination of the near station space environment with water vapor(5). Typically, options now being looked at rely on change of state of water from solid to liquid as a heat sink. Because of lower quantity of heat involved in the change of state from solid to liquid compared to the heat involved in the change of state from liquid to gas, these systems will tend to be bulkier, heavier, and support shorter EVA's than systems involving sublimation. There may be other alternatives on the martian surface. The temperature environment on the martian surface will depend on the landing site, the martian season and the time of day; however, the Mars environment relative to the Earth environment will typically be cold(1). It may be possible to devise a controlled variable heat loss system from the suit that would use the martian environment as the heat sink. Such a system might involve radiators mounted on the surface of the suit with control of heat loss inplemented by flow of a coolant from the liquid cooled garment. A system of this type would be most effective in the really cold martian environments.

A second alternative for thermal management would be to utilize martian resources as a substitute for the water currently used. Although water will probably not be easily accessible on the martian surface for use as a chage of state heat sink, solid CO_2 is available at the poles and may be absorbed in surface soils in extra-polar regions(1). Solid CO_2 could be used as a heat sink in an EVA system. The combined heat of fusion and of vaporization of CO_2 is about 130 cal/gram compared to the 80 cal/gram heat of fusion of ice. A more reliable source of CO_2 would be the atmosphere. The martian atmosphere is 95% CO_2 to about 7 torr(1), so it would be conceivable to compress, cool, and solidify the martian atmosphere and use the CO_2 as an EVA heat sink.

While working in the EVA suit, the crewmen will generate CO_2 that must be removed from the suit atmosphere or maintained at acceptable levels (about 7 torr)(2). In all of our portable life support systems to date, we have used Lithium Hydroxide (LiOH) to absorb the CO_2 and react with it to form various Lithium carbonates. This reaction is not easily reversible and expended LiOH cartridges are discarded. In Skylab, molecular sieve ion resins were used to absorb CO_2. CO_2 could later be removed from the beds with the application of low pressure(6). For Space Station, recoverable systems are being planned in which not only can the CO_2 absorbent be recovered and reused but the CO_2 itself can be recovered and converted back to O_2(7). Systems of this type will be essential for Mars missions where conservation of consumables will be critical. The CO_2 systems will consist of beds or liquid containers in the EVA back pack that will absorb CO_2. These beds or liquids would be regenerated in the spacecraft, the Mars lander vehicle or the Mars base facility to convert the CO_2 back to O_2. The regenerable CO_2 absorbers tend to be larger than current LiOH system so this will impact EVA capability.

The EVA system will also have to provide protection from environmental radiation. Mars does not have a strong magnetic field(7) and therefore, the martian surface is not protected against space radiation as is the Earth. Galactic radiation will be about one-half of that in open space due to the shielding provided by the planet itself. With pressure suits similar to those that will be developed for Space Station, which will probably provide more radiation protection than our Shuttle suits, galactic radiation on the Mars surface will not limit EVA for martian stays of several months and frequent EVA. Galactic radiation during EVA may be limiting for martian stays of a year or more involving EVA or for Mars colonization. However, galactic radiation is not the only radiation threat. Crewmen on the Mars surface would also be at risk from episodic radiation from solar flares. These potential high radiation flux episodes would require retreat to a radiation "Safe Haven" and may be an important consideration in planning mobile explorations across the Mars surface. The problem of radiation is treated in depth in a separate chapter.

In addition to the environmental considerations already mentioned, the EVA system will have to provide food, water, and waste management to the crewmen. These requirements become more critical and difficult as EVA duration is extended (table 2). Water requirements are 8 oz/hour for EVA durations in excess of 3 hours. Food requirements are: a snack of about 200 kcal for EVAs of less than 6 hours and 750 kcal/8-hour duration for longer exposures. Some urine collection capability should be provided for even short EVAs and a 1000 cc capability should be provided for 8 hour EVAs. Some level of containment of an uncontrollable bout of diarrhea or any other unscheduled defecation must be provided for EVA's up to 8 hours. Stays in the suit in excess of hours would require more serious containment capability. The longest EVAs to date have been about 7 hours in length, and such EVA'S have been done in each of the Apollo, Skylab and Shuttle Programs. The Apollo Program included a contingency capability to return from the Moon over an up to 115 hour period in a pressurized suit(8). To achieve this capability the suit helmet had a feeding port that could be utilized with a 3.7 psi differential pressure to take food and liquids into the suit and into the mouth. The suit also had a urine transfer system to transfer urine out of the suit. The gaseous environment in this situation was supplied by umbilical so the CO_2 system was part of the cabin ECS. The suit system also included a fecal containment system that could be described as a large diaper. This system was designed only as a get-back system aimed at survival. Although there is little doubt that the system would have resulted in crew survival if it had been required the use of an anthropometric form fitting EVA suit for EVA durations in excess of 8 hours is

TABLE 2

CONSIDERATIONS FOR MARS EVA LIFE SUPPORT

THERMAL EQULIBRIUM:

Thermal balance in crewmen at range of EVA metabolic rates.

Need: Active temperature, control system & distribution system.

Design Consideration:

Variable insulation or sublimation of H_2O or sublimation of CO_2. Liquid cooled garment or other distribution system.

Supply of O_2 for metabolism, control of CO_2 produced.

Need: 0.2 lb/hr O_2 @ 1000 BTU/hr

0.24 lb/hr CO_2 @ 100 BTU/hr

Design Consideration:

1) O_2 supply
2) Regenerable CO_2 absorption system.

WATER MANAGEMENT:

Avoid dehydration - Allow urination

Need: Provide for collection - 1000 ML

Provide in-suit water at 8 oz/hr after 3 hours

Design Consideration:

1) In-suit water supply and drinking system
2) In-suit urine bag

NUTRITION:

Need: 750 cal/8 hours

Design Consideration:

1) In-suit food system, or
2) Limited duration EVA

MONITORING:

Provide measure of stress and consumables usage to crew and or others.

Need: Physiological monitoring as needed

Design Consideration:

1) O_2 usage
2) CO_2 level
3) Heart rate

TABLE 2 (CONTINUED)

MAINTENANCE:

Suit must be kept operational.

Need: 1) Durability

2) Simplicity

3) Cleanability

4) Repairability

Design Consideration:

1) Largely hard components - high cycle life

2) Anticipated repair time minimal

3) Smooth surfaces,easy cleaning procedures & systems.

4) Component replacability

5) Repair facility

MECHANICAL MOBILITY:

Man must be able to perform useful work in suit without injury or abrasion.

Need: Good low-effort Joint systems - Comfortable fit

Design Considerations:

Improvement over current systems

GRAVITY EFFECTS:

Need: Center of gravity of man in suit must be compatable with walking.

Design Consideration:

Suit design must consider gravity.

not recommended because of limitations related to personal hygiene, waste management, and general crew health and well-being.

EVA has shown the real potential for vehicle repair in space, so designers of the Mars mission may want to assure this capability during the period of travel to and from Mars. However, EVA is not free. The design of equipment that may have to be repaired, the translation aids on the surface of the vehicle, the airlocks and the EVA support systems must be carefully planned to accommodate EVA. One important factor in the decision as to whether or not to provide a trans-martian EVA system may be whether or not artificial gravity is provided in the crew module during this mission phase. If artificial gravity is generated by rotating all or part of the vehicle, then EVA may be much more difficult because it would then be possible to "fall off" the vehicle and certainly moving around and about the vehicle would be much more difficult.

During the long duration of the trans-martian mission phase, IVA will be desirable to maintain training for Mars surface EVA. This training period would be particularly useful if the spacecraft is maintained at Mars' normal g level.

For surface EVA in the area of the landing site, the gravity force field on the martian surface is a consideration that will impact the nature of Mars surface EVA and the systems that support it. Prior to Apollo 11, there was considerable speculation on how well man could walk and move about in the 1/6-g lunar environment. The best simulations of 1/6-g indicated it would be easier to work in 1/6-g(9) and the lunar surface EVA proved the point(10). The Apollo EMU weighed about 200 pounds and had to be supported during the 1-g training exercises to allow crewmen to move. The martian gravity force will be less than .4 times that on the Earth(7). As in the Apollo EVA system, careful attention will have to be paid to the center of gravity of the man/suit complex. Because of the relatively higher weight of the regenerative life support systems and the greater apparent weight of the martian backpack relative to lunar backpacks, it is likely that self-contained EVA systems will be limied to 2 to 4 hours of support capability.

An alternative to self-contained EVA systems is an umbilical system. In such a system, some of the life support components could be mounted in the martian base or on a mobile vehicle or platform. The crewmen would be tied to the support system with umbilicals. Such a system can extend EVA time but umbilical tending is a constant concern with this type of arrangement and the length of the umbilicals is limited. Umbilical systems would seem to be particularly attractive to allow some EVA in a limited perimeter around a mobile exploration vehicle.

EVA will be a component part of any exploration plan for the martian surface. For short distances some exploration will be done on foot. But to cover greater areas, a motorized vehicle will be needed. Martian rovers are discussed in other papers; however the following paragraphs discuss some of the options of how a vehicle might interact with an EVA system.

One system might be similar to the lunar rover system (figure 1). In this system, the transportation system was completely separate from the EVA systems. The crewmen rode on the vehicle with their own self-contained EVA system. Such a system provides maximum freedom for the crewmen and is limited by the duration of life support provided by the backpacks on the crewmen. Because of considerations mentioned in earlier paragraphs, the duration of life support systems that could be carried on a regenerative backpack system on the martian surface would be relatively short (2 to 4 hours). An alternative would be a similar system with the pressure-suited crewmen tied to the transportation system with umbilicals (figure 2). Such a system would be limited in time and range to the duration that crewmen could stay in the pressure suit (8 to 10 hours). Longer range exploration vehicles would have to provide a pressurized volume for crewmen. In its simplest form, such a vehicle might be a motorized-non-anthropometric pressure suit with arms and hands extending from the pressurized volume (figure 3). With the capability to withdraw from the arms, the crewmen could tend to food, drink, and waste management in a larger volume. Such a system would be range limited by power and consumables. Finally, given sufficent size and volume, a transportation system with a pressurized volume could in addition carry a pressure suit to be used as needed. This would provide the most versatile and far ranging, but not the most complex system of all.

A rover vehicle that could have flexible pressurized arms might instead have mechanical end effectors or robot arms. Robotics is a fast developing field, and it is likely that robotic systems will be developed

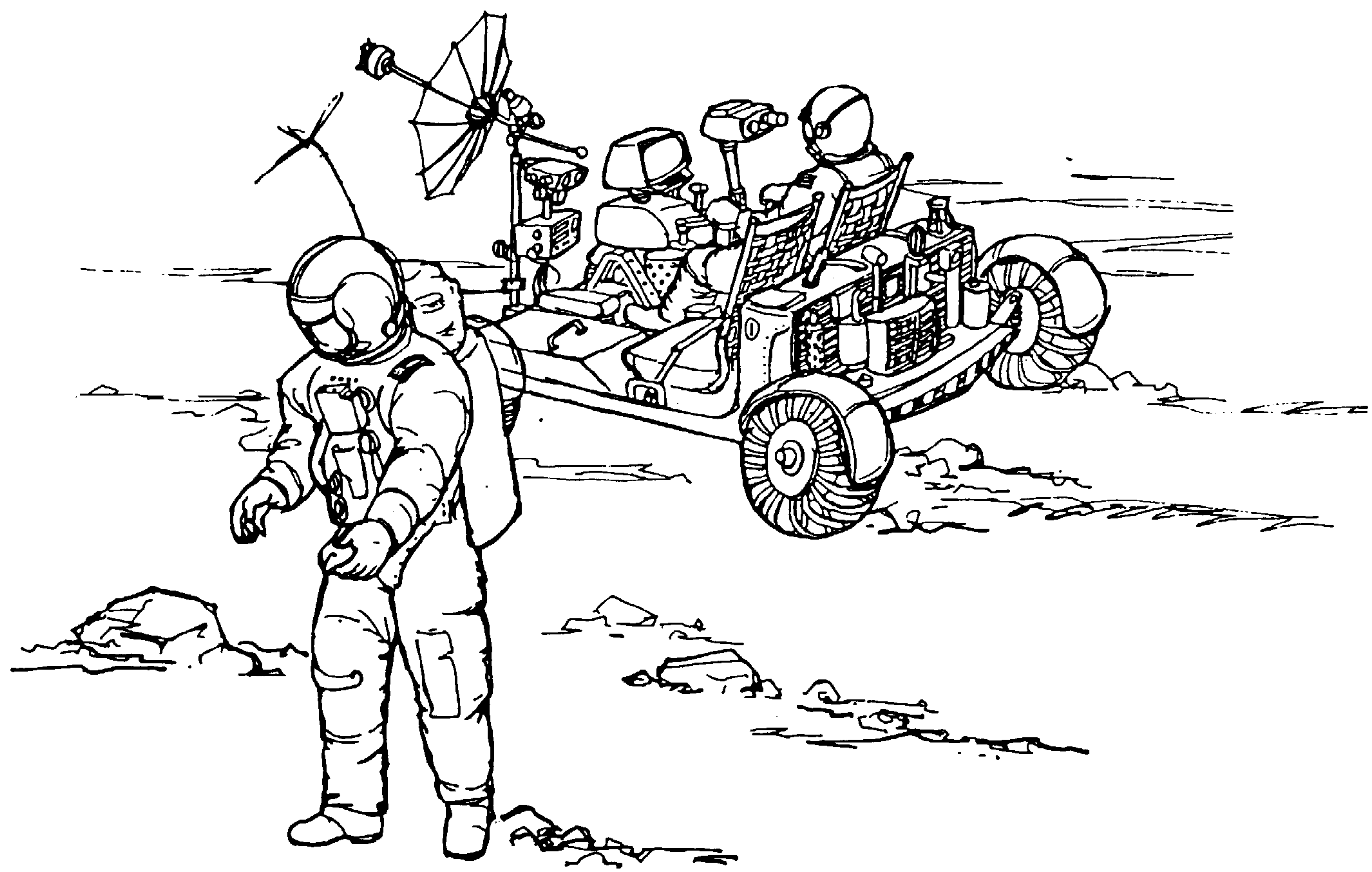

FIGURE 1
Transportation System with Suitmounted ECS Systems

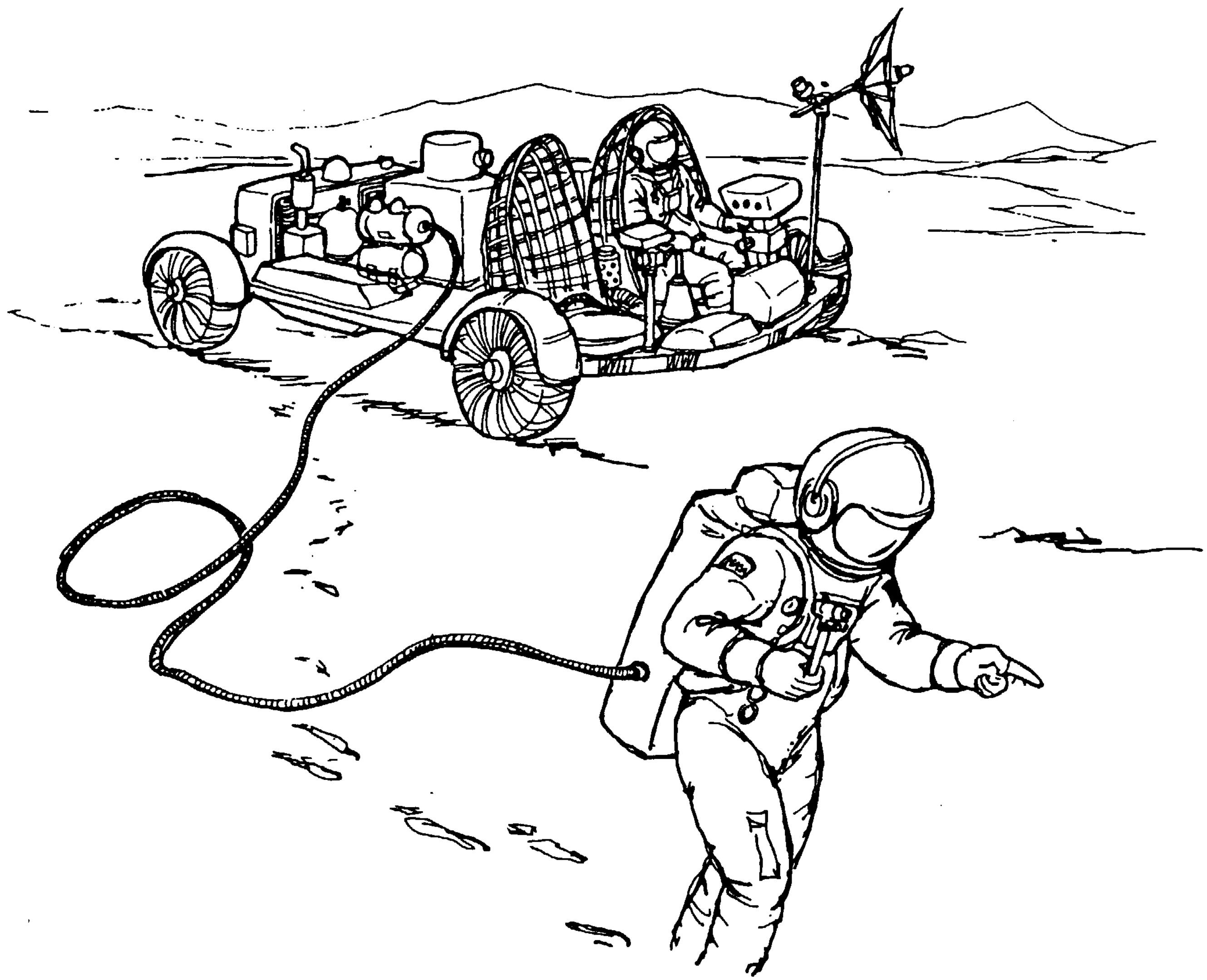

FIGURE 2

Transportation System with Umbilical ECS System

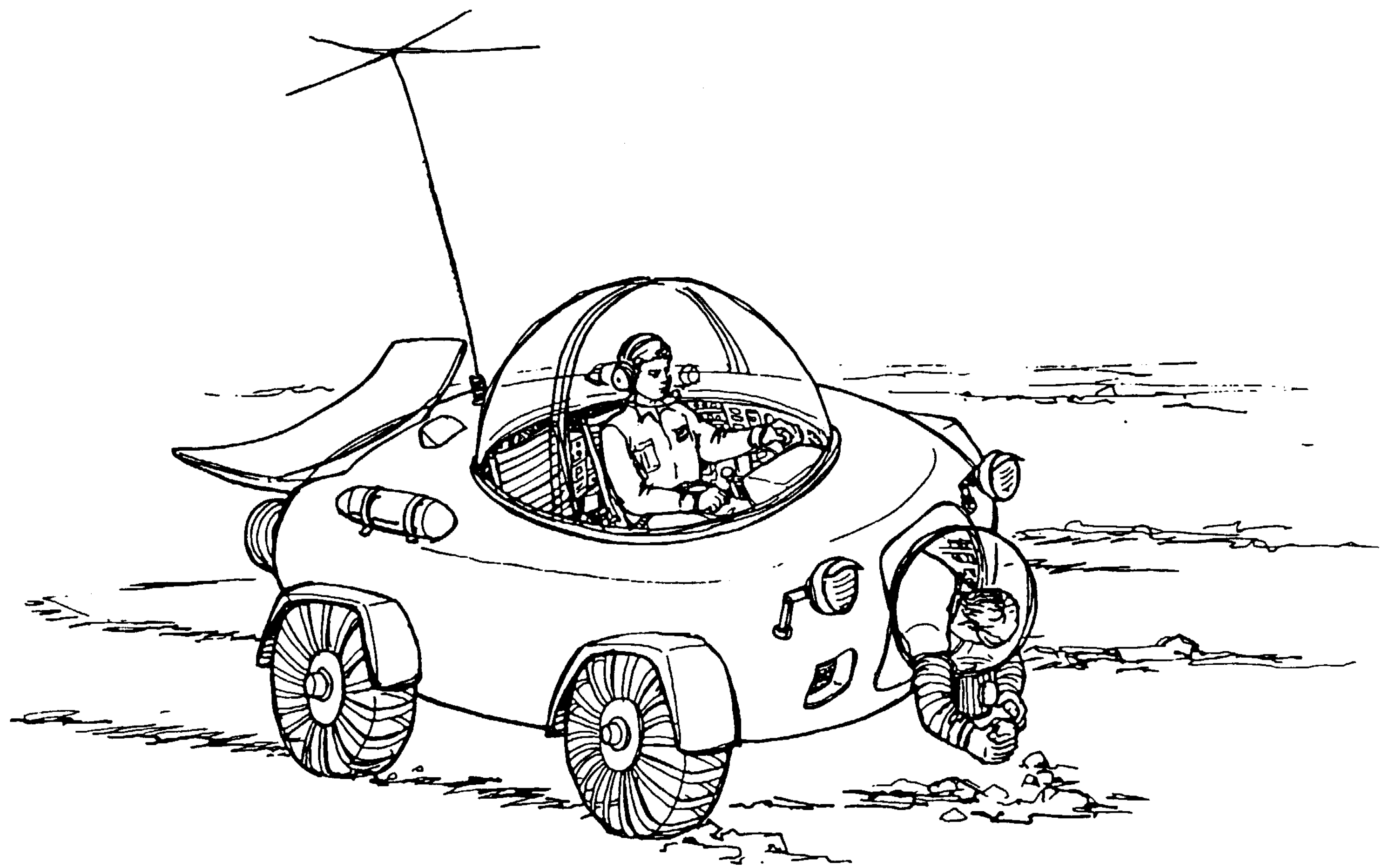

FIGURE 3
Transportation with Pressurized Volume and Anthropomotric Suit Extension

to aid in Space Station construction. It is very likely that some tasks that might be done with an EVA crewman could be done with a robotic systems or with hybrid systems using mechanical end effectors to aid the EVA crewmen. Robotic systems in EVA will probably evolve in a process of using such systems to aid EVA crewmen and considerable use of robotics will be made in developing the Space Station. Depending on the direction and scope of this evolution prior to the Mars mission, robotics will have a greater or lesser impact on EVA on Mars, but we can expect that robotics will supplement rather than replace manned EVA in a pressure suit.

REFERENCES

1. Carr, M. H., Saunders S. R., Strom R. C., and D. E. Wilhelms. 1984. The Geology of the Terrestrial Planets. NASA Sp-469, Washington D. C.
2. Horrigan, D. J., 1979. Atmospheres in: The Physiological Basis for Spacecraft Environmental Limits. NASA Reference publication 1045, Washington, D. C.
3. Michel, E. L., Waligora, J. M., Horrigan, D. J., and W. H. Shumate. 1975. Environmental Factors in: Biomedical Results of Apollo. NASA Sp-368, Washington, D. C.
4. Dietlein L. F., 177. Skylab: A Beginning in: Biomedical Results from Skylab. NASA Sp-377, Washington, D. C.
5. Space Station Reference Configuration Description. 1984. JSC - 19989. Lyndon B. Johnson Space Center. Houston, Texas
6. Environmental Cotrol and Life Support System for Apollo Applications Program. 1967. SS-3414-3 Rovi Garrett. Los Angeles, California.
7. Oberg, J. E. 1983. Mission to Mars. Times Mirror, New York.
8. Master End Item Specifications: Performance/Design and Product Configuration Requirements, Extravehicular Mobility Unit for Apollo, Block II, Missions. 1966. CSD-A-096. Lyndon B. Johnson Space Center. Houston, Texas.

9. Wortz, Ec and E. J. Prescott. Effects of Subgravity traction Simulation on the Energy Costs of Walking. Aerospace Med. Vol 37, Sec 1966, pp 1217-1222.

10. Waligora, J. M. and D. J. Horrigan. 1975. Metabolism and Heat Dissipation during Apollo EVA Periods in: Biomedical Results of Apollo. NASA SP-368. Washington, D. C.