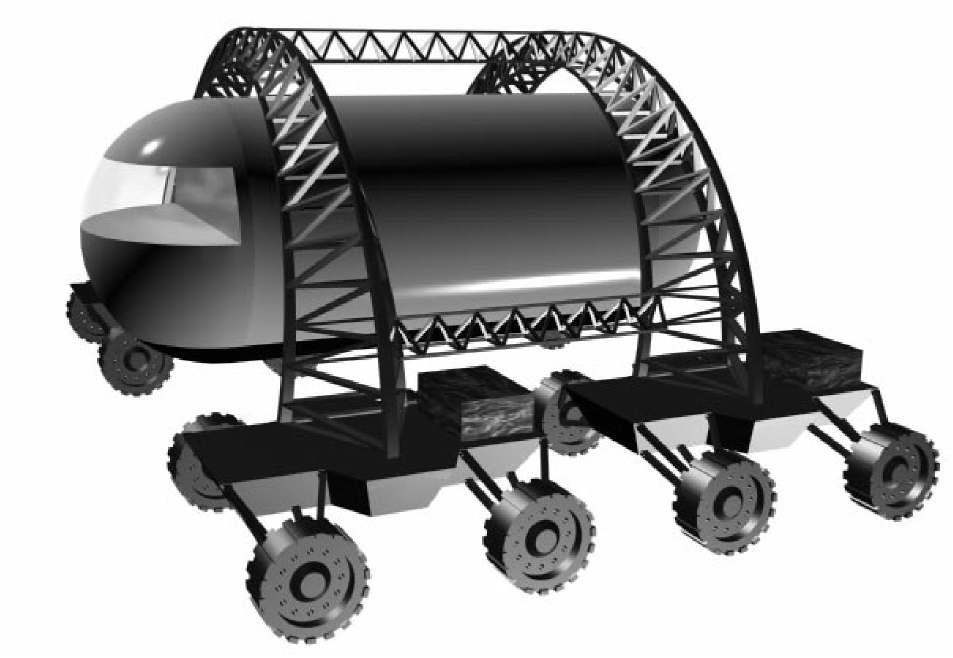
Conceptual Design of A
Mars Surface Transportation System (MSTS)



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1999

EXECUTIVE SUMMARY

We have proposed a design for a Mars Surface Transportation System. The design will support multi-range and multi-purpose scientific/exploratory activities for extended periods. Several assumptions were made before developing a design:

1. This system is to be deployed early in a series of piloted landings on the planet surface.
2. A Mars surface base has already been established.
3. A transport system to and from Mars already exists.
4. The capacity to transport this proposed system exists within the current transport design.
5. Facilities exist at this base for the supply of fuel and other consumables.
6. Medical facilities are a component of the main base.
7. The surface conditions of Mars are known and are accurate.

It was decided that the transportation system design should support a crew of two for up to four weeks away from the primary base. In order to support multiple mission requirements, the system is modular and multi-configurable. The main structural aspects of the design are:

1. An inflatable habitat module.
2. Independently powered and remotely controllable wheel trucks to allow multiple configurations and ease of system assembly.
3. Parabolic space trusses for high structural stability with low overall system mass.

In addition to these design aspects, new and existing concepts for control systems, power, radiation protection, and crew safety have been incorporated into the transportation system design.

1.0 INTRODUCTION

This report presents a proposed design for a Mars Surface Transportation system, abbreviated MSTS. This system is designed around the principle of maximum flexibility while maintaining minimal weight and minimal power requirements. It was the intent of the design team to explore new approaches to ground transportation rather than optimize previous approaches.

The system presented in this report consists of an inflatable habitat/laboratory module, multiple electrically powered trucks, and a supporting space truss. The proposed series of configurations of these components is by no means meant to be comprehensive. The primary function of this system is to allow the development of new configurations as needed for mission requirements not yet identified. Furthermore, additional components and newly developed components of this system can be transported to Mars as they are needed or become available, as the case may be.

Also contained within this report is a discussion of radiation and shielding considerations. Although a detailed discussion of this subject is beyond the scope of this report, the design team believes consideration of these issues is critical for a viable design proposal. Specifically, radiation exposure impacts on shielding requirements, and shielding requirements impact directly on mass, range, and duration away from a more adequately shielded home base.

Finally, this report concludes with a discussion of subject areas in which the design team was unable to complete a thorough evaluation of because of time limitations. Suggestions are also made for further research by the scientific community to clarify issues that prevent a definitive design at this time.

The authors of this proposal encourage feedback from interested parties that may lead to improvement of the design of this system.

2.0 BACKGROUND

2.1 DESIGN HERITAGE

During the late 1960s, the Boeing Company received a contract to build rovers for the Apollo 15, 16, and 17 missions. Engineers developed a simple lightweight rover that could be stowed on the exterior of the Lunar Excursion Module (LEM). These vehicles weighed 464 lbs. and could manage a payload of crew, portable life support systems, communications equipment, scientific equipment, photographic gear and lunar samples totaling as much as 1600 lbs. The lunar roving vehicle, or LRV, was powered by two 36-volt batteries driving four ¼ horsepower electric motors located at each wheel and had an operating range of 57 miles. However, the LRV was restricted to a radius of 6 miles from the LEM due to the limitations of the astronaut's portable life support systems. Figure 2.1 shows the LRV on the lunar surface.

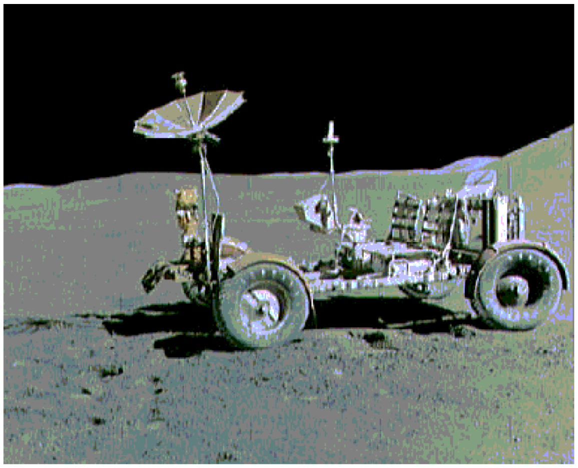

Fig. 2.1 Lunar Roving Vehicle (LRV)

On July 4, 1997 the Mars Pathfinder lander deployed the Sojourner rover which explored the Mars terrain in the vicinity of the lander. Sojourner was a semi-autonomous vehicle, which received command signals from Earth with two way transmission times on the order of 20 to 30 minutes. Much of the control philosophy the J.P.L. engineers incorporated into the rover design will be applied to the Mars Transportation System concept. Navigation systems included inertial measurement units, stereo cameras and other hardware that will be discussed in subsequent sections. Sojourner had a six-wheel rocker bogey suspension system with four corner steering and was built without conventional spring-dampers to increase the traction from the steel cleated wheels.

2.2 CURRENT AND PRIOR TECHNOLOGIES

Technologies that currently exist or that are under development have been considered for incorporation in the design of this transportation system. Emphasis will be placed on modular multi-function lightweight technologies.

2.3 EXTRATERRESTRIAL GROUND CRAFT

Several innovative technologies have been developed in the area of extraterrestrial mobile surface equipment. The Apollo moon rover, for example, provided surface transport for astronauts on the lunar surface. The lunar surface, however, is probably more uniform with fewer rocks than the Martian surface. In addition, robotic rovers have been developed to explore the Martian surface, Sojourner being the most recent.

2.4 INFLATABLE HABITAT TECHNOLOGIES

Various systems have been under development by NASA and the private sector to provide inflatable habitats for either Lunar or Martian missions. In addition, spacesuit manufacturers and NASA have considerable experience with the performance of various fabric composites in the space environment.

2.5 ANALOGUE ENVIRONMENTS ON EARTH

Currently, academic and national research organizations have development capabilities similar to those outlined in this proposal for the purpose of scientific study of the Arctic and Antarctic. Their experiences should be reviewed since many of the problems encountered may be similar in nature to those of the Martian surface. These may include food and water storage, mobility considerations, terrain difficulty, infrequent servicing capability, etc.

2.6 MINIATURIZED LABORATORY TECHNOLOGIES

Severe weight restrictions and the need for maximum analytic capacity will require the use of highly miniaturized laboratory equipment. Previous micro-laboratory technology from missions such as Viking and Pathfinder should be examined. Current capabilities of nano-electronics should also be reviewed for their potential role in this system.

2.7 POWER TECHNOLOGIES

Current technologies in low weight and non-combustion systems should be examined. In particular space station solutions should be reviewed, including both Mir and the International Space Station. Fuel cell, battery, solar, and nuclear systems should be examined.

2.8 DRIVE-TRAIN AND MECHANICAL TECHNOLOGIES

Many designs already exist for vehicles capable of negotiating irregular terrain. The commercial automotive industry, recreational vehicles (all-terrain, tracked, etc.) and the military have considerable experience in designing vehicles capable of travelling over sandy, rocky and uneven ground. Based on photographic images returned from probes such as Viking and Pathfinder suggest the Martian surface is irregular, sandy and strewn with boulders of varying size.

3.0 PROBLEM STATEMENT

3.1.1 GENERAL REQUIREMENT

Design a transport system for the Martian surface. This system should support multiple capabilities, including mission support, scientific exploration and analysis, and non-scientific mission objectives. Specific requirements and specifications are detailed below. This system will provide an increase in habitability, an increase in safety for the crew, and allow expanded surface exploration. Ideally, this system should entail simple and reliable deployment, a minimal of maintenance, a high degree of ongoing reliability, and maximum flexibility in purpose modification.

3.1.2 MISSION SUPPORT

This system must support the immediate and subsequent needs of an early expeditionary-piloted mission to the planet surface. Earliest of these needs will include the local transportation in the vicinity of the primary base. The system should include a pressurized mobile habitat that can serve multiple purposes. These purposes include, but are not limited to 1) expansion of existing habitat volume, 2) provision of a pressured emergency medical transport capable of retrieving ill or injured personnel from off-base locations, 3) provision of an on-site medical facility, 4) a back up habitat for personnel in the event of a failure or partial failure of the primary habitat/life support

3.1.3 SCIENTIFIC REQUIREMENTS

This mobile surface transport must provide the capability for a crew of two to travel extensively across the planet surface, providing life support for extended periods on the order of four weeks at a time, and allowing advanced on-site analysis. These analysis will include 1) biological analysis over extended and varied terrain, allowing for sample collection and analysis, 2) geological analysis, including the ability to collect samples over the large expanses required to obtain accurate geological mapping of the surface. This system should have the capacity to eventually include a drilling apparatus to satisfy core sampling and seismic/electromagnetic exploration needs. Finally, in support of atmospheric and geophysics sciences, this system should provide a means to transport, deploy, and service monitoring equipment to distant sites.

3.1.4 NON-SCIENTIFIC OBJECTIVES

A third mission objective that this system should support is the exploration of the Martian surface for exploitable resources. The discovery of materials on the planet surface that could be used for construction or support of mission elements would significantly reduce the cost of subsequent missions. Such materials could include water, gases, fuels, and construction materials analogous to concrete. In addition, discovery of any resources that may be exploitable for profit would also serve to underwrite the high cost of future missions.

3.2 ASSUMPTIONS

This design proposal makes the following assumptions:

1. This system is to be deployed early in a series of piloted landings on the planet surface.
2. A Mars surface base has already been established.
3. A transport system to and from Mars already exists.
4. The capacity to transport this proposed system exists within the current transport design.
5. Facilities exist at this base for the supply of fuel and other consumables.
6. Medical facilities are a component of the main base.
7. The surface conditions of Mars are known and are accurate.

3.3 CONSTRAINTS

The proposed design must satisfy the following constraints:

1. Transport weight must be kept to a minimum of 5000kg per transport.
2. The system must be multifunctional.
3. There must be a high degree of interchangeability between components.
4. The system must support a crew of two for up to four weeks at a time away from the primary base.
5. The system must provide the capability to cover a 500km radius of the planet surface.
6. The system must minimize exposure of the astronauts to the external surface environment.
7. Internal configuration must allow variable configuration to support specific tasks.

4.0 PRELIMINARY CONSIDERATIONS OF MARS TRANSPORTATION SYSTEM AND REJECTED DESIGNS

Research in the early stages of the project resulted in a modular concept for a surface transport vehicle. Precise systems were yet undetermined, however, life support, propulsion, and science were relegated into independent interconnected modules. Theoretically, mission parameters would dictate the need for a science module or a life-support habitat for long duration objectives, which could be removed from the system without compromising the operation of the remaining components. The modules linked together as a *train* would be pulled by a manned or unmanned pressurized rover. Figure 4.1 is a sketch of the initial design model.

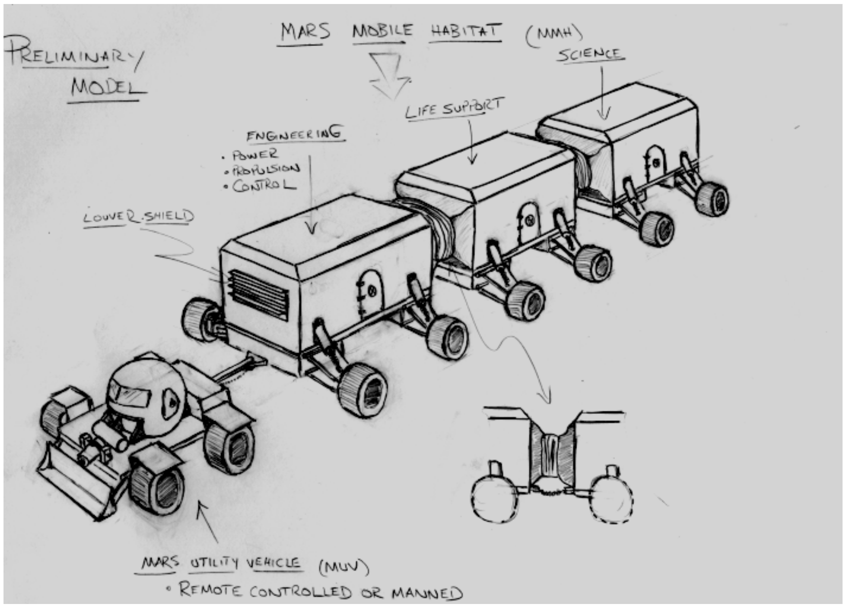

Fig. 4.1 Modular surface transport vehicle concept.

The large hard-shell exteriors of the modules would make Earth-to-Mars transport of the necessary materials for construction impractical. Also, the system does not allow for flexibility of individual components due to their rigid design.

A minimum weight large volume module could satisfy the design constraint and an inflatable habitat proved to be the ideal solution. Relatively little assembly would be required to bring the surface transport system into operation.

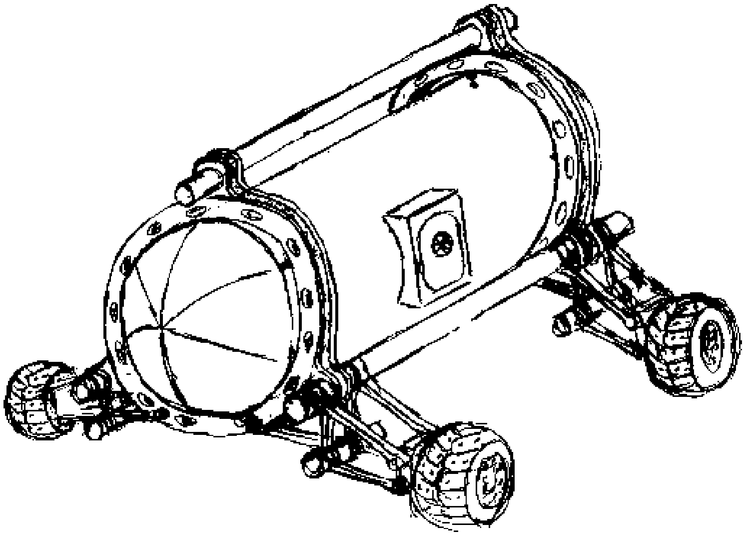

Fig. 4.2 Transport using an inflatable compartment.

Figure 4.2 is a sketch of the redesigned module using the inflatable compartment concept. The design incorporated a conventional independent suspension system and could be self-propelled if necessary. The inflatable body represented a significant reduction in weight and volume for transport to mars.

The final design chosen by the team involved the addition of a supporting truss system to suspend the inflatable module. This design had further advantages over the design illustrated in figure 4.2. The truss system allowed the inflatable module to be lowered to the planet surface, and also allowed for the option to carry other payloads. In addition, the powered wheel assemblies could be detached and used for other purposes. The specifics of this design will be discussed in the next section, and the various advantages will be explored.

5.0 PROPOSED MARS TRANSPORTATION SYSTEM DESIGN

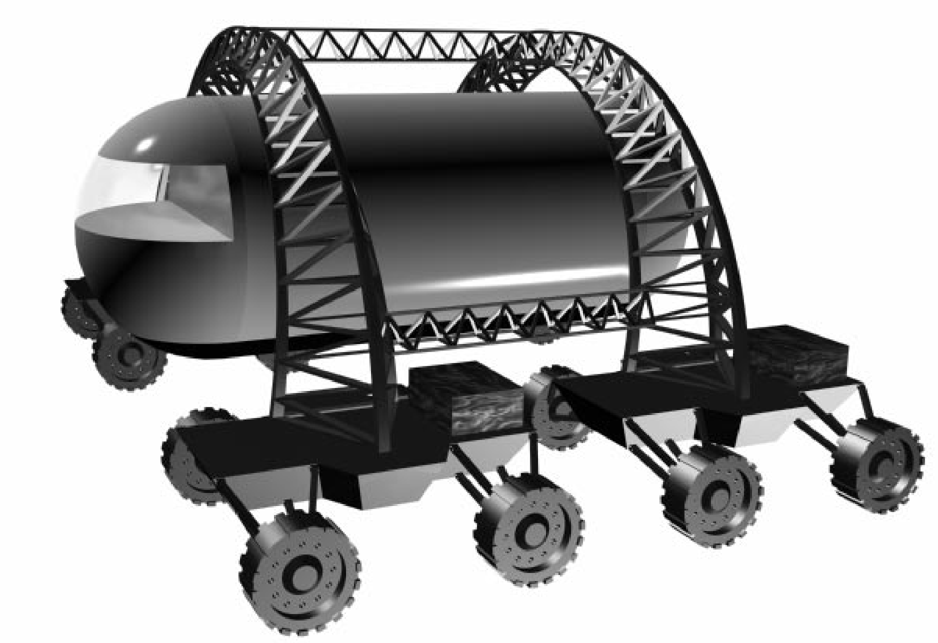

Fig. 5.1. Proposed Mars Surface Transportation System assembly.

5.1.1 INFLATABLE MODULE

5.1.1.1 DESIGN

The habitable module will be an inflatable structure made of kevlar reinforced materials. This concept will utilize technology already under development for the Transhab module currently planned for a Mars mission and possible inclusion on the International Space Station. Extensive analysis of inflatable habitat structures has been performed by the Center for Engineering Infrastructure and Sciences in Space at Colorado State University (see references). The advantages of an inflatable module include low-mass and low storage volume for transport to the Martian surface.

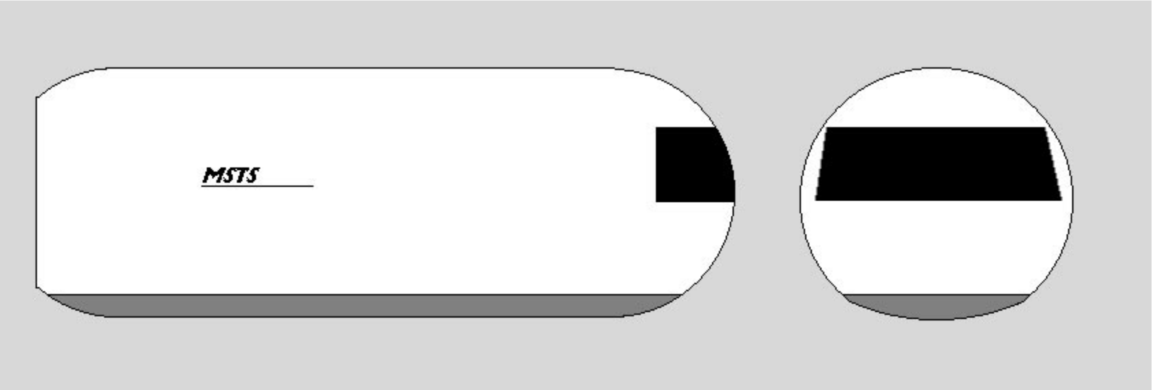

Fig. 5.2. Inflatable laboratory module (IHM), external view

5.1.1.2 INTERNAL CONFIGURATION

The inflatable habitat module (IHM) is designed to allow maximum flexibility in mission support. The design allows for variable internal configurations based on rack-mounted interchangeable equipment modules. The crew can configure the IHM while the module is attached to the main landing craft, allowing the opportunity to test and modify the configuration as needed.

Sleeping chambers will likely be placed above the equipment module to minimize exposure to spallation radiation (Spallation of cosmic radiation occurs when incident particles contact shielding materials and produce a cascade of secondary particles. This problem is discussed in detail later in this report.) In order to shield against periodic solar particle radiation, safe areas could be located under the equipment racks where radiation protection is maximal.

Oxygen, food and water storage will be internal to allow for access and maintenance. Further stores could be configured externally on the system as need. Waste storage will also be required in the module. All of these compounds could be utilized to increase shielding when required. There is no capacity to recycle fluids or waste in this module as recycling capabilities represent excessive equipment and energy requirements for this system. Waste and scrubbed CO2 will be stored for treatment or disposal at the home base.

The underside of this module is envisioned to be constructed of a hard metal or composite material derived from the exterior surface of the landing craft. This concept is expanded upon below. The floor of the module will likely have wiring and gas lines worked into the sub-floor, simplifying connectivity of equipment within the module.

Egress from and entry to this module will be facilitated by a folding ramp on the posterior aspect of the IHM at the airlock entry port. This system will be similar to that found on smaller commercial aircraft.

Power requirements will be supplied by fuel cells and batteries contained in the module. Fuel cells are discussed in detail later in this report.

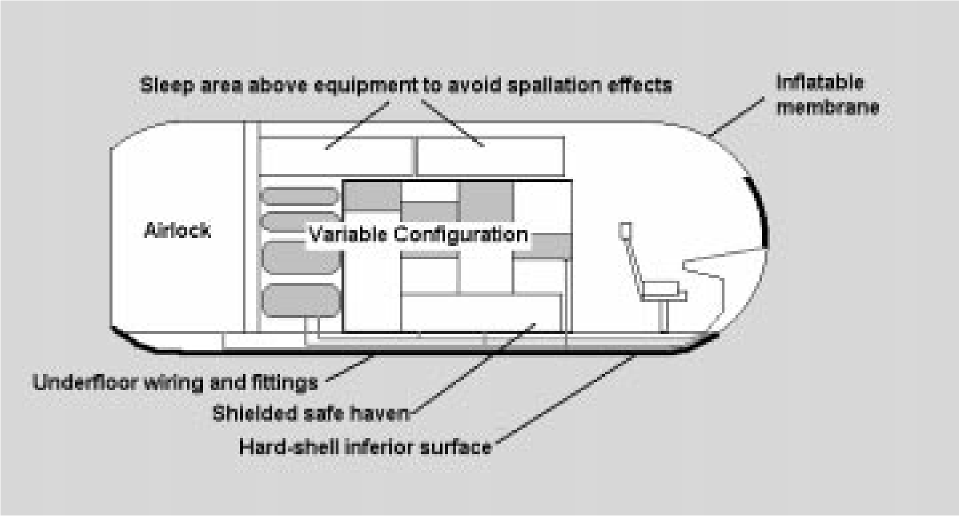

Fig. 5.3. IHM internal configuration

5.1.1.3 AIRLOCK

An airlock is a mandatory feature of the IHM. As an onsite laboratory, there will be a requirement for frequent access to and from the Martian surface. The concept of a suitport has been around for sometime. Although it has not been used in spacecraft prior to the present time, it is the most efficient means yet devised to conserve precious atmospheric gases when astronauts exit and enter a space vehicle. The concept involves a suit mounted on the exterior of a craft. The astronaut enters the posterior of the suit through a portal, which is then closed behind him/her. The suit then separates from the wall of the craft and minimal atmosphere is lost. In addition, the introduction of contaminants would be minimized by such a system. This concept is illustrated in figure 5.3. This concept seems highly appropriate for the IHM as frequent excursions to the planet surface are expected to be the norm.

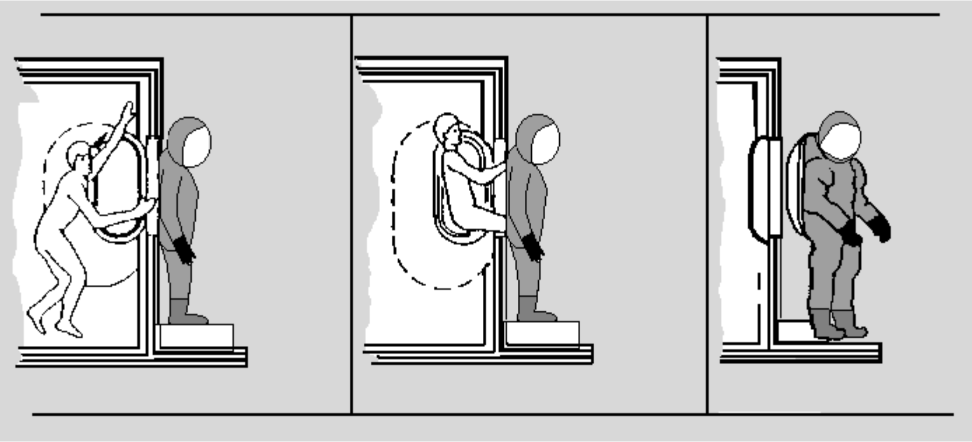

Fig. 5.4. Suitport concept

Combining the suitport concept with a standard airlock creates a system that is both highly safe and highly efficient. For routine use, the airlock would remain unpressurized throughout the egress/ingress process. The airlock, in general, will serve as a failsafe against malfunctions of either the port seal or the suit itself. In case of a decompression or catastrophic failure of the suit/suitport, the airlock could be rapidly pressurized with no external loss of atmosphere. In addition, the airlock provides a storage facility for the suits that is protected from the damaging effects of the external environment. Finally, the airlock could be pressurized for routine or unexpected maintenance of the suits and suitport as required.

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Fig. 5.5. Airlock and suitport combination.

5.1.1.4 IHM DEPLOYMENT

The IHM will be deployed remotely from the exterior surface of the landing module, with a panel of the exterior surface of the landing craft forming the underside of the IHM. In its uninflated state, the IHM will occupy minimal volume on the trip from the Earth to the planet surface. Upon landing, the IHM will fold down from the side of the landing craft, probably onto support legs that deploy on the underside of the IHM. The IHM will be contiguous with the internal cabin environment via the airlock, and inflation will occur through the process of pressurizing the IHM to normal atmospheric pressure.

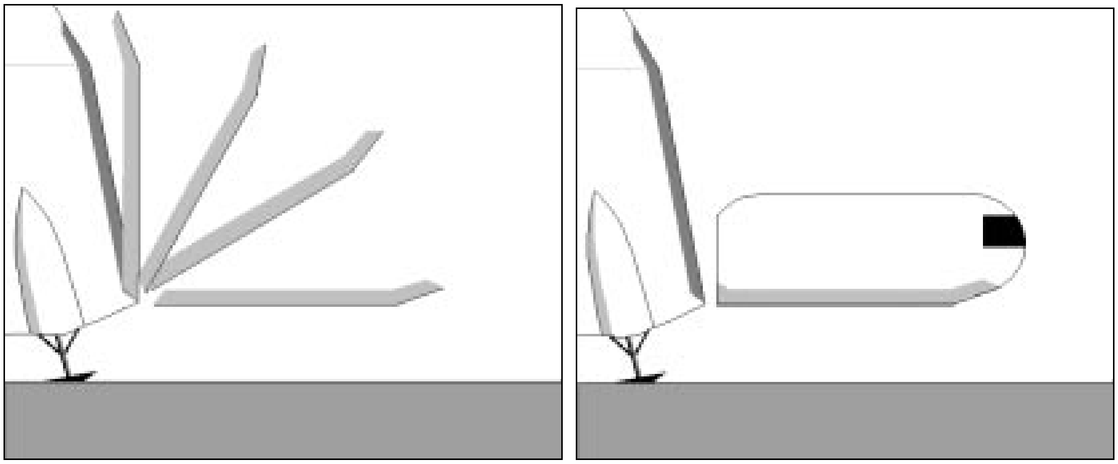

Figure 5.6. Schematic illustrating deployment of ILM from side of landing craft.

5.1.1.5 CONFIGURATIONS

The IHM may remain in this deployed position, connected to the main craft indefinitely. In this configuration, the IHM may serve as extended living or laboratory space to supplement the capacity of the primary base. When the remaining components of the Mars Transportation System (MSTS) are functional, the IHM can serve as the body of a mobile craft that can be ferried around the planet surface as needed. If the mission plan requires a prolonged manned or unmanned facility to be placed for extended periods at a remote location, the IHM can be lowered onto the planet surface and left in place indefinitely.

5.2 WHEEL TRUCKS

The independently powered wheel truck is illustrated below in figure 5.6. Both the configuration with an optional driver seat (rover configuration) and the basic configuration are illustrated.

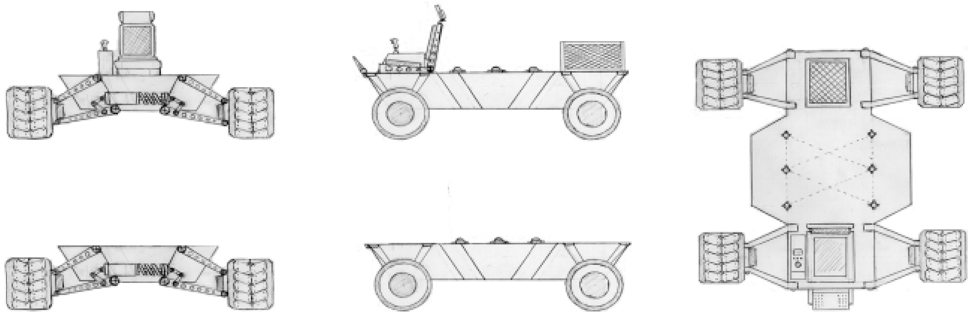

Figure 5.7. Wheel truck with (upper) and without (lower) optional rover seat.

5.2.1 FUNCTION

Two four-wheeled trucks on each hoop frame will provide the Mars Transportation System with its mobility. The wheel trucks are independently functional and individually powered. They will attach at the bases of each hoop frame. By adding the capability of remote control to each of the trucks, the entire system becomes capable of assuming multiple configurations. A winch will be mounted on each wheel truck.

5.2.2 POWER

Each truck will contain a hydrogen/oxygen regenerative fuel cell (RFC). The power systems for the wheel trucks are discussed in Section 6.0.

5.2.3 SUSPENSION

The suspension system for the wheel trucks has not yet been chosen. Suspension systems of existing rovers and all-terrain vehicles will be looked at so that an acceptable system can be developed for our transportation system.

5.2.4 USES

The advantage of having removable, individually powered, independently controllable wheel trucks is that they can serve many purposes. Just a few of the possible functions of the wheel trucks beyond habitat mobility are outlined here.

1. Transportation System Assembly – The wheel trucks can be pre-programmed to deploy from the landing craft, then begin auto assembly of the transportation system before astronauts take over the operation.

2. Equipment Transport for Scientific Tasks – During stationary periods of scientific research, the wheel trucks can be disconnected and used to move research equipment and supplies for the scientists. The trucks would be operated remotely or by an astronaut sitting or standing on the wheel truck.

3. Mobile Power Generators – A single truck could be used as a mobile power generator for the science equipment during research phases. The equipment would simply be connected to the truck through an adapter on the truck.

4. Mobile Crane – When combined with the parabolic space trusses, with the

habitat removed, the trucks will form a mobile crane for lifting large objects. This function would be useful at the mission site when structures are being built and moved. The crane function will also be very important to the initial assembly of the transportation system, and to reconfigurations.

5. Retrieving Payloads – Payloads that land long and out of range from the main base could be retrieved by having several trucks working in unison to lift and move the payload across the planet surface.

5.3 PARABOLIC SPACE TRUSS

The ultimate purpose of the space truss is not to enable a specific configuration; but to deliver a discrete system of tension and compression elements to serve as a set of basic structural building components (building blocks). These elements may be configured to conform to any arbitrary mission requirements within the connectivity restrictions of the nodes of the individual elements.

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Fig. 5.8. Parabolic space truss, three views.

5.3.1 TRUSS MEMBERS

The exact number of truss cascade and cross members has not been determined at the time of writing of this report. An absolute height for the space truss in full (long-range) assembly must be agreed upon first so that the geometry of the parabola can be determined. The full assembly configuration has a center point at the intersection of the base line (y-axis) parallel to the motor truck wheel axis, and the symmetric centerline (z-axis). This will separate the parabola into two distinct half sections from a front view.

The cross members will vary in length from the vertex to the base of the space parabola. All members will be circular, thin walled tubes with a common radius. The material of each member will be homogeneous through out the global system and must satisfy the environmental conditions of Mars, primarily a broad range of thermal loading, as well as meet the constraint for launch weight from Earth.

5.3.2 CONNECTIVITY

The connection couplings at each node of each member are critical to the fulfillment of the design goal for versatility. The arced members must have connection joints that are strategically positioned along the arc length with connection lines intersecting the radial origin of the member’s geometric arc, originating from each connection joint.

In order to promote the "Lego" design aspect, the coupling mechanisms of the connection joints must be designed as simply as possible so that a minimum number tools is required. Each linear truss member will most likely have a standard threading at each end. Concentric coupling fittings should be available to allow two or more linear members to be connected end-to-end. T-couplings could facilitate orthogonal connection of linear elements. The threaded coupling fittings will allow the individual members to be assembled as a frame structure. A separate connection mechanism must be considered for the full assembly so that connections of linear members to the arced members can achieve a *pinned* connection characteristic versus a *rigid* characteristic obtained by the coupling fittings.

5.3.3 DELIVERY PACKAGE

The tension members, defining the (triangular) outer skeletal system, are comprised of three series of arced members that are connected in cascade. The arced members will all have the same distinct contour corresponding to the camber of the aero-brake shield used for entry to the Martian atmosphere. The linear cross members may be packaged in the cylindrical wall of the delivery lander, aligned parallel to the longitudinal axis of the cylindrical shell.

5.3.4 ASSEMBLY

The assembly of the truss components into a usable structure is a manual task to be accomplished by the available Mars surface crew. Assembly instructions for the three primary configurations described below will be provided upon the completion of the final structural design and static analysis of each structural form corresponding to the long-range, intermediate-range, and short-range configurations respectively. All of the tools required for assembly have not yet determined however, an adjustable torque-wrench with a contoured rack of contact teeth will definitely be required.

5.3.5 FUNCTIONS

The truss members will possess sufficient strength and connectivity to support a diverse number of demands that may arise. The three primary configurations for vehicle support are for long-range, intermediate range, and short-range assemblies.

5.3.5.1 LONG-RANGE CONFIGURATION

The long-range configuration will embody the full assembly of the space truss.
The purpose of the truss elements in the full assembly configuration is to provide a parabolic space truss structure capable of sustaining large suspension loads. The long-range configuration consists of two or three fully assembled parabolic space truss structures connected in series by longitudinal connection beams. The longitudinal spacing between the individual truss structures is undetermined at this time because it is a function of the IHM module length. The parabolic structures will be able to suspend inflatable IHM modules where the longitudinal axes of the IHM modules are coincident and concentric with the longitudinal axis of the three connected parabolic trusses. The long-range structural configuration will also be used to support the loading of ballast and water contained in cylindrical shells on the top of the structure as a radiation shield.

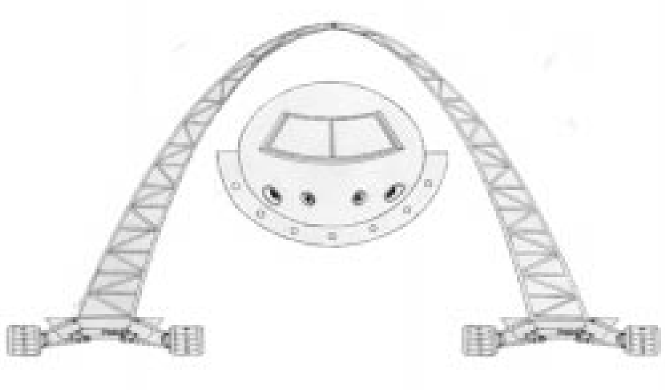

Figure 5.9. Suspended configuration.

5.3.5.2 INTERMEDIATE RANGE CONFIGURATION

This configuration consists of a partial system assembly of selected members to support full weight of a single IHM module and contents. The partial truss assembly will serve as an under truss to rest and secure the IHM between four motor trucks configured in parallel.

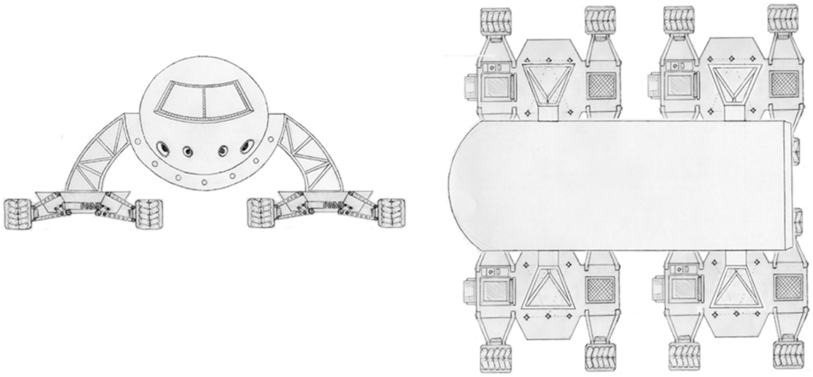

Figure 5.10. Cradled configuration.

5.3.5.3 SHORT-RANGE CONFIGURATION

The system allows for individual operation of the motor truck elements. Pictured below are three views of the motor truck configured with an external seat. This setup allows for an astronaut to use the wheel truck as unpressurized rover for short-range operations.

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Figure 5.11. Wheel truck configured for short-range use

6.0 POWER

6.1 VEHICLE POWER

Each wheel truck will contain a hydrogen/oxygen regenerative fuel cell (RFC). Use of RFC's will allow the vehicle to travel further distances or longer periods without the need to return to the mission base for refueling. A beneficial byproduct of the energy generation process is potable water.

The RFC system components are the fuel cell stack, electrolyzer, reactants, tankage for the O_2, H_2, and H_2O, radiator, and power management and distribution (PMAD). A gallium arsenide on germanium tracking array would also be required to power the electrolyzer . Figure 6.1 shows a block diagram of a regenerative fuel cell.

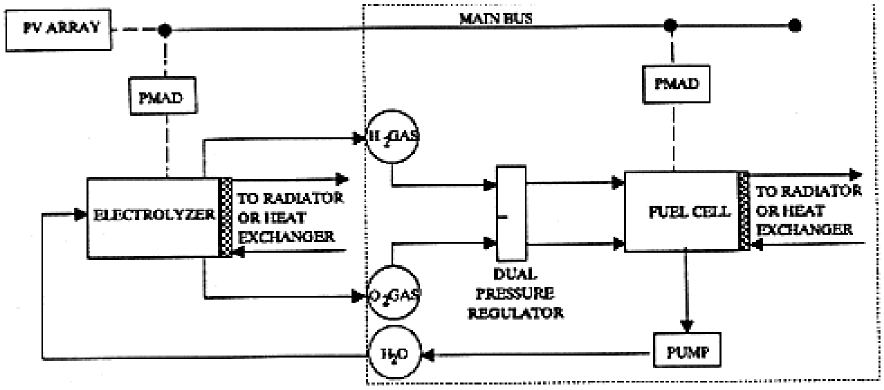

Fig. 6.1 Block Diagram of Regenerative Fuel Cell with Gaseous Storage

6.1.1 REGENERATIVE FUEL CELL OPTIONS

Four RFC options will be considered for vehicle power:

1. Low pressure gas storage.
2. High pressure gas storage.
3. Low pressure gas storage with photovoltaic arrays.
4. High pressure gas storage with photovoltaic arrays.

Each option has advantages and disadvantages. These must be weighed before selecting a power system. High-pressure gas storage RFC's have much smaller tanks than low pressure RFC's, but there is a greater safety concern. Although photovoltaic arrays will add mass to the transportation system, the advantage of being able to use solar power to convert the H_2O byproduct back into H_2 and O_2 make the arrays highly desireable. Options 3 or 4 will most likely end up being the power source for the vehicle. Safety will be the deciding factor in determining which type of storage to use.

6.2 HABITAT POWER

The inflatable habitat module will be powered by its own H_2/O_2 regenerative fuel cells. The placement of the RFC's within the module will be determined once the payload and components of the habitat are known. The additional power produced by the wheel trucks can be redirected to the habitat when the trucks are not in motion. In the same fashion, power produced by the habitat's power systems can be used to supplement the wheel truck power during travel periods.

During the stationary periods, photovoltaic arrays will be deployed so that fuel cells that are not being used can be recharged. The arrays will also be a backup power source in the event of fuel cell failures.

7.0 CONTROLS

7.1 AUTONOMOUS OPERATION

A flexible control package will be incorporated into the truck system design. The system will allow for semi-autonomous and autonomous operation depending on the truck configuration that is required. In autonomous operation the truck will navigate without user interface to a desired position with the aid of an installed digital gyro-compass, inertial measurement units (IMU), and the Mars equivalent of a Global Positioning System (GPS). These units will provide the position quickly and accurately with respect to a Mars centered, Mars fixed (MCF) coordinate system.

GPS requires a constellation of closely monitored satellites in orbit around Mars. A minimum of four satellites is necessary to provide a position solution, longitude and latitude, of the truck. In the event the required numbers of satellites are not within the truck's GPS receiver line-of-sight, the system will revert to inertial navigation mode using the IMU. The IMU will initialize its position based on the last GPS navigation message and operate using the IMU's rate gyros and accelerometers. The gyros are installed in three mutual perpendicular directions to measure the attitude of the vehicle. The accelerometers are installed in a similar manner. They will provide information about the vehicle's acceleration about three coordinate axes.

The system utilizes a close-loop feedback control structure to provide accurate responses to desired outputs. A simplified control structure is described in Fig. 7.1. A program schedule of the truck's travel itinerary is fed into the vehicle's navigation computer. These signals are amplified and sent to the truck's actuators such as the drive motors and steering mechanisms to provide the desired mobility to satisfy the vehicle's next position. Continuous GPS or IMU updates will provide the truck's position in real time. The error between the desired and actual positions will be used as control inputs for the navigation computer to process the necessary course corrections.

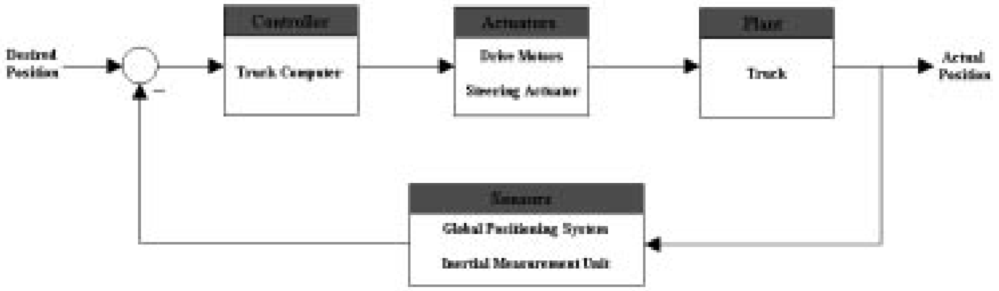

Fig. 7.1 Control architecture for a single truck unit.

7.2 SEMI-AUTONOMOUS OPERATION

The truck's control system allows for user interface via remote control or cable fed inputs to provide a desired response of the vehicle. A typical example of remote operation would be day-to-day work duties such as moving surface components on board the truck from one site to another. The feedback in the control algorithm of the vehicle would simply be "dead reckoning" by the astronaut as to the final position of the truck.

Multiple truck units require a central computer to manage the overall output of the system. Such a configuration is illustrated in Fig. 7.2 where four trucks are used as drive units for a mobile habitat. A pre-programmed travel plan can be installed in the habitat's navigation computer where the system of trucks can deliver the crew autonomously (autopilot) to a desired position. In the event of unforeseen difficulties the crew can remove computer control and operate the system manually using conventional control devices such as wheel and throttle mechanisms. The manual control system is strictly speaking "fly-by-wire" where mechanical inputs are converted into electrical signals for computer processing and routed to the necessary truck unit. Hydraulic actuators incorporated in the mechanical control devices will provide simulated terrain feedback for the pilots.

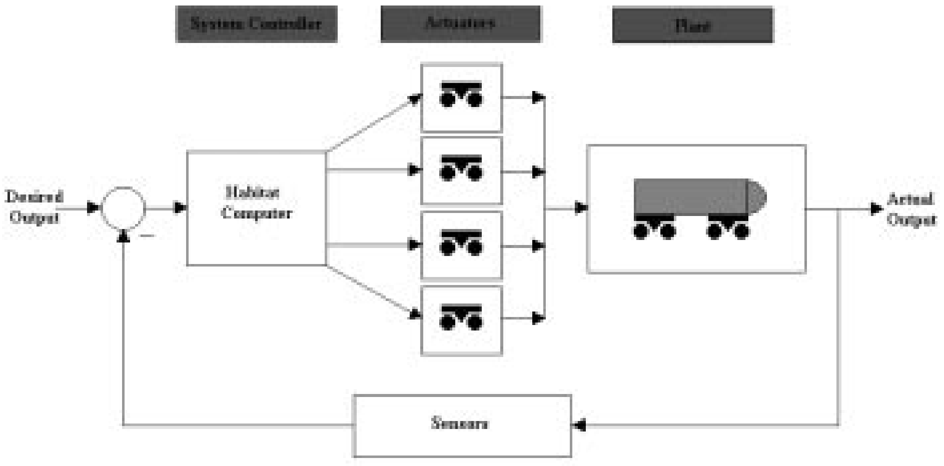

Fig. 7.2 Control architecture for a mobile habitat.

7.3 SYSTEM HARDWARE

The planned hardware systems incorporated into each truck unit would include stereo cameras, laser ranging capabilities, wheel optical encoders, GPS receiver and an IMU. It should be noted that the truck design has a programmable control system structure that can be configured to what is required for a specific operation.

Stereo cameras would provide a remote user who operates the vehicle with a real time image of the terrain around the vehicle. Distances to obstacles are measured using lasers mounted at various positions around the truck's chassis. The orientation of the truck is measured using the IMU's rate gyros. The optical wheel encoders monitor the position of the drive wheels by measuring the steering angle and the shaft position of the wheel unit.

The navigation hardware would include a GPS receiver and an IMU unit. The navigation control systems are managed by the truck's central computer, in which diagnostic subroutines are written to provide reports of system status.

8.0 HUMAN CONSIDERATIONS

A detailed discussion of the effects of space travel on human physiology and psychology is beyond the scope of this report. The conditions of weightlessness and reduced gravity, sunlight deprivation, radiation exposure and many other aspects of spaceflight have been shown to have significant and deleterious effects on human beings. Bone demineralization, immune dysfunction, cardiac and muscle deconditioning and increased cancer risk are but a few of the damaging outcomes of space travel on human physiology. This section will concentrate on two aspects that impact most heavily on the design of mission components – radiation and life-support systems.

8.1 RADIATION PROTECTION

8.1.1 RADIATION ENVIRONMENT

Consideration of the radiation environment on the Martian surface is of tremendous importance in the design of a Mars surface mission (Wilson, 1993, 1998). Furthermore, the radiation exposure and the resultant health risks for any particular component of such a mission should be examined in light of the exposure and health risks of the complete planetary expedition.

Radiation can be subdivided into non-ionizing and ionizing radiation. Non-ionizing radiation such as ultraviolet and X-rays, while of significance in the design of sun exposed materials, will not be discussed in depth. This section will instead concentrate on ionizing radiation. Ionizing radiation consists of high-energy particles that exert their deleterious effects by stripping electrons from matter through which they pass. These particles possess energies on the order of tens to hundreds of MeV. Ionizing radiation poses significant dangers to a manned mission to the surface of Mars, and an understanding of these dangers is essential in the design of habitable structures. This section will review what is currently known about the radiation risks of the Mars surface and what the implications will be to personnel on the surface. Shielding considerations will be reviewed, and recommendations made for both design considerations and for further research into the problem. An assessment is made as to the feasibility of shielding against the various component radiations and what the mass and design implications are of attempting such shielding.

Note: Measurement of radiation in SI is generally expressed in terms of grays (Gy) for absorbed dose and sieverts (Sv) for dose equivalents. Dose equivalents are calculated by adjusting radiation dosages to better compare for effects such as cancer.

Absorbed dose:
1 gray = 1Gy = 1 joule/kilogram = 100 rads = 10000 ergs/gram

Dose equivalent: 1 sievert = 1 Sv = 1 joule/kilogram = 100 rems = 10000 ergs/kilogram

8.1.1.1 COSMIC RADIAITION

Cosmic radiation, otherwise known as Galactic Cosmic Rays (GCR), is radiation of galactic origin. Comprised of ionized atomic particles ranging from hydrogen to heavier particles such as carbon (C) and iron (Fe), these particles are extremely energetic on the order of tens to millions of electron volts. The penetration of these highly energized particles into the inner solar system is limited somewhat by the solar magnetosphere. Penetration of these particles to the surface of the Earth is further limited by both the Earth's magnetosphere and by the Earth's atmosphere, resulting in the observation that cosmic rays of little serious concern to living organisms on this planet. On Mars, however, the reduced strength of that planet's magnetic fields and the relative absence of an atmosphere result in GCR flux that poses a risk to living systems (Wilson, 1993). These risks are discussed below.

8.1.1.2 SOLAR RADIATION

Solar radiation, otherwise known as Solar Energetic Particles (SEP) is of solar origin, as the name suggests. SEP consist largely of ionized hydrogen nuclei (protons), and are of lower energy than GCR (lETAW, 1997). As is the case for GCR, SEPs are shield from Earth's surface by the Earth's magnetosphere and pose little risk to living organisms on Earth. Under normal circumstances, solar radiation poses little risk to astronauts either in space or (presumably) on the Martian surface. Large bursts of SEP occur periodically with sunspots and solar flares, and these bursts do pose a significant threat to living organisms. These bursts can be enormous and do pose tremendous threat to all living organisms. On Earth, the Van Allen Radiation Belts and the Earth’s atmosphere afford adequate protection from these events. At the present time, observed sunspot activity affords only several hours of advance warning of such events. The danger posed to astronauts by these infrequent SEP events is severe enough to necessitate consideration of shielding and mission timing in the planning of any piloted mission to Mars (Simonsen, 1993). Unless a crew has access to a safe haven, or is able to return to their shielded home base in several hours, they would have to rely upon adequate shielding capability in the design of their mobile craft. The specific risks posed by these high intensity radiation bursts are discussed below.

8.1.1 HEALTH IMPLICATIONS

These two types of radiation, GCR and SEP will pose significant, though different, risks to human life on a mission to Mars. Mission design requires an appreciation of these risks, and solutions to this problem require consideration of shielding materials, mission timing, and an assessment of acceptable risk. A complete discussion of radiation concerns for deep space missions is beyond the scope of this report. Thorough discussions of this problem can be found in the reference section of this. What follows is a brief overview of the problem faced by the design team.

The health implications from radiation exposure are divided into stochastic effects and deterministic effects. The main stochastic effect of importance is cancer, and exposure is calculated in terms of total dose and in terms of lifetime risk for developing cancer. Deterministic effects include prodromal response (radiation sickness), temporary sterility and optic lens opacity (Letaw, 1997).

Galactic cosmic rays are of primary concern in stochastic effects. A two or three year mission to Mars will involve a significant cumulative exposure to cosmic rays, and implications for long term risk of cancer are must be considered. Current recommendations for safe exposure to heavy particle radiation are largely derived from the nuclear industry. Such recommendations are based on the somewhat arbitrary level of an acceptable risk increase of 3 percent of a fatal cancer over the lifetime of an individual (Curtis, 1998).

Solar radiation, arriving as it does in large bursts, is of concern primarily for deterministic effects. The most severe deterministic effect of radiation is death from acute radiation sickness. Health effects of acute radiation exposure are probabilistic in nature and vary somewhat from individual to individual. In high doses, radiation affects primarily rapidly dividing cells and symptoms result accordingly. In human beings, these cells are found largely in the bone marrow (the source of new blood and immune cells), the intestinal lining, the skin, and ocular lens. Symptoms resulting from radiation exposure therefore include immune suppression (marrow cells), diarrhea, nausea, vomiting, skin edema, and lens opacities. High exposure may well result in death. Estimations for dosing effects are taken largely derived from the therapeutic radiation exposure of cancer patients. These limits are adjusted in an effort to apply them to a healthy astronaut population. A graph demonstrating the probability of death resulting from acute exposure is reproduced below.

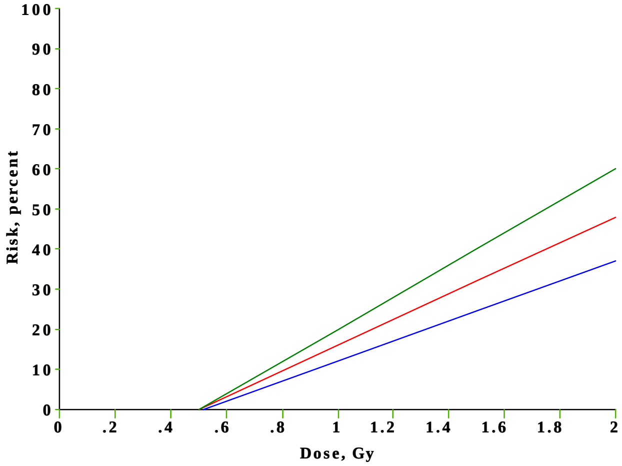

Fig. 8.1 Risk Of Death at 60 Days from Radiation Exposure. Lower line represents average, with 1 standard deviation in the middle, and 2 standard deviations above.

For comparative purposes, the frequently cited event of August, 1972 produced exposures on the order of 1 to 5 Gy. (Letaw, 1997)

8.1.3 SOLAR CYCLE AND RADIATION

Both GCR and SEP vary over the course of the 11 year solar cycle. During the period of solar maximum, GCR penetration to the inner solar system is minimal due to the improved protective influence of the of the solar magnetosphere. Solar maximum occurs at the midpoint of the solar cycle, approximately between years 4 and 9. Unfortunately, the occurrence of increased sunspot activity and therefore of SEP activity is also increased at this time. This relationship is shown in figure 8.2.

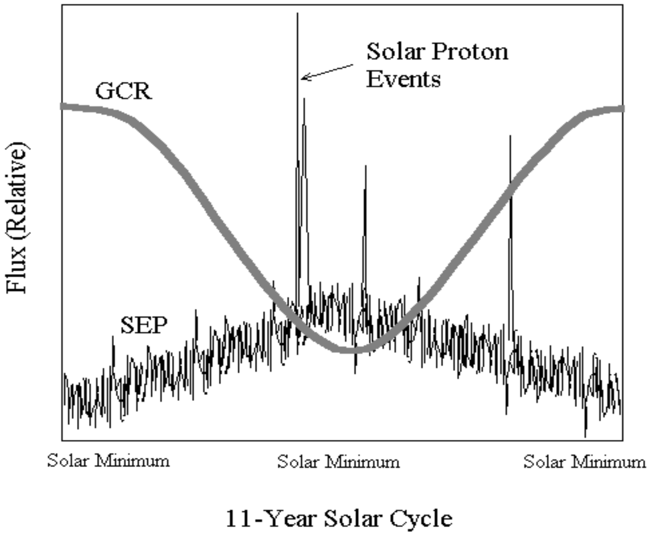

Fig. 8.2 Timing of GCR and SEP with respect to solar cycle - note, fluxes are not comparable in magnitude.

Ideally, the design team should have knowledge of when in the solar cycle a mission to the planet surface would be launched. In the absence of such information, the design must allow for the worst case scenarios for both GCR and SEP exposure.

8.1.4 SHIELDING

Shielding presents a difficult problem, particularly because of the two types of radiation involved. In general, GCR is too energetic to shield against, whereas shielding against SEP events will be required periodically. Further complicating the issue is the effect of nuclear spallation of GCR. Spallation is the process by which the heavy and highly charged cosmic rays impact the shielding materials, causing a cascade of less energetic but equally damaging atomic particles. Calculations by Letaw (1997) and others demonstrate that with materials such as aluminum, even 30 cm of solid shield does little to lessen the damaging effect of GCR. Furthermore, some theorists have demonstrated that shielding with heavy elements such as metals actually produces an increase in radiation dosing. This would suggest that when not protecting against the less energetic SEP radiation, astronauts would be best served by being minimally shielded from the background radiation of the Mars surface. An exception to this problem occurs with hydrogen shielding, as the atoms of hydrogen are unable to be broken down into smaller particles.

8.1.5 DESIGN CONSIDERATIONS

Although hydrogen is a safe shielding material to use against GCR, the sheer amount of hydrogen required precludes an effective shield on a mobile habitat. Such is not the case for SEP, and the protection provided by stored consumables and the laboratory equipment should provide sufficient cover to allow construction of a shielded chamber for the astronauts located on the bottom of the habitat module.

(include shielding calculations for maximum SEP dosing)

8.2 LIFE SUPPORT SYSTEM

Since the design assumptions for the MSTS include a fully functioning home base, the generation and recycling of life supportive materials is not a design requirement of this system. The IHM must include the capacity to store oxygen, water, and food for the two crew members for periods up to four weeks, along with a reserve in event of loss or unexpected delay in return to home base. CO2 scrubbing and environmental control should be easily accomplished with systems similar to those devised for Skylab, Soyuz, Mir, Shuttle, and the International Space Station (ISS).

9.0 WORK REMAINING

The following is a list of areas that represent incomplete analysis by the design team at the time of this report.

1) Sizing and mass estimates.
2) Stress analysis of inflatable materials.
3) Power requirements.
4) Solutions for dust accumulation problems.
5) Suspension system design.
6) Traction calculations in reduced gravity.
7) Explore Transhab work for conversion to this project

10.0 RECOMMENDATIONS

1) Highly effective radiation shielding at a home base increases the safety margin for a poorly shielded excursion on the planet's surface. Consideration should be given to construction of a maximally shielded home base (regolith protection, etc.) for two reasons: 1) A complete picture of the radiation risk does not yet exist on the Martian surface, and 2) Increased protection at a home base will compensate somewhat for unexpected dosing either in transit to and from Mars or while on the Martian surface.

2) Consideration should be giving to launching a prolonged surface mission to the moon prior to a Mars mission. The general consensus from many sources is that the uncertainty of both the deep space radiation environment and the effect of that environment on living organisms poses an unacceptable risk to an astronaut crew. A lack of firm data on this subject also leads to extreme difficulty in the design of safe and adequately shielded mission components.

3) Consideration should be given to landing and expeditionary mission within a Martian canyon. Advantages would include a lowered dose of continual background radiation as a result of natural shielding, and the possibility of using the canyon walls as a safe haven in the event of a solar event.

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