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SINGLE-STAGE MARS MISSION

UNIVERSITY OF MINNESOTA

President Bush established a three phase Space Exploration Initiative for the future of space exploration. The first phase is the design and construction of Space Station *Freedom*. The second phase is permanent lunar base. The last phase of the Initiative is the construction of a Mars outpost. The design contained in this report is the concept of a single-stage Mars mission developed by the University of Minnesota Aerospace Design Course. The mission will last approximately 500 days including a 30-60 day stay on Mars.

ACRONYMS

AM	Ascent Module
ECLSS	Environmental Control and Life Support System
ERV	Earth Return Vehicle
EVA	Extravehicular Activity
HLLV	Heavy Lift Launch Vehicle
LEO	Low Earth Orbit
MITS	Mars Integrated Transportation System
MOC	Mars Orbital Capture
MTV	Mars Transportation Vehicle
NTR	Nuclear Thermal Rocket
SPE	Solar Particle Event
SSF	Space Station *Freedom*
TEI	Trans-Earth Injection
TMI	Trans-Mars Injection

INTRODUCTION

On July 20, 1990, President Bush established the direction for future U.S. space activities with his words, "...And then a journey into tomorrow, a journey to another planet, a manned mission to Mars." The Mars Integrated Transportation System (MITS) design project consists of the conceptual design of a system that will satisfy the following objectives:

1. Transport an expeditionary crew of trained astronauts from Earth orbit to Mars orbit, then descend to a preselected location on the martian surface. This mission will be planned for around the year 2020.
2. Establish a Mars outpost site and conduct local science and exploration investigations including local resource evaluations. The crew will be provided with a habitation module and surface rover and will stay for approximately 30 days.
3. Return crew, surface samples, and appropriate hardware/information safely back to Earth orbit.
4. Accomplish the above tasks in a cost-effective manner with acceptable levels of safety, and design systems that will provide the infrastructure for continued missions.

This report is the design proposed by a team in the NASA/USRA/University of Minnesota Mars Integrated Transportation System advanced design program.

The assumptions for this design are as follows:

1. Space Station *Freedom* (SSF) is in low Earth orbit (LEO) and is capable of supporting the construction and launch operations of the MITS, as well as the eventual recovery of the spacecraft. In its construction supporting role, SSF is expected to house the construction crew while the actual construction takes place near or at SSF.
2. Extensive robotic exploration of Mars has been conducted prior to the MITS mission. The data gathered would verify the landing site, finalize experiment designs, place communications satellites in Mars orbit, and determine available resources.

MISSION OBJECTIVES

There are five main objectives for the first manned mission to Mars. All these goals, while having their own individual purpose, share the common purpose of increasing our knowledge of Mars and of how to get there in order to prepare the way for future missions and, eventually a permanently manned base on the planet. The five goals are

1. Verify the technology used for manned missions to Mars.
2. Approve the landing site for use as a permanent martian base.
3. Establish the necessary groundwork to ensure the success of future missions.
4. Test equipment and procedures that will be used to support and operate the permanent base.
5. Begin the detailed scientific research and exploration of the martian atmosphere, surface, and subsurface, as well as examination of the local space around Mars.

MARS TRANSFER VEHICLE (MTV)

The MTV consists of six main components: the MEV, truss and support structure, propellant, NTR system, ERV, and the habitation area. All six of these subsystems are discussed below. Several considerations were necessary in developing the overall MTV configuration. The necessity of having artificial gravity required locating the habitation area at a distance of approximately 60 m from the center of gravity for the trans-Mars journey (resulting in a force of 1 *g*), and as far away as possible for the trans-Earth journey. This need, coupled with the need to keep the truss as short as feasible, led to a need to keep as much of the mass as possible at a distance from the habitation area.

Truss Design

The design of the truss that forms the nucleus of the MTV will feature a combination of tetrahedral elements. The truss will have a square cross-section of 3-m sides and an overall length of 90 m. The material used for the truss structure is assembled in parts on Earth and launched into orbit in pieces. The truss will be fully assembled near SSF.

Propellent Tanks

The propellant tank layout can be seen in Fig. 1. The layout consists of eight tanks; four for the TMI maneuver and two each for the MOC and TEI maneuvers. All tanks use the 8.4-m-diameter of the current space shuttle external tank design. This provides some commonality in the design. The lengths of the tanks have been chosen to house the fuel required for each leg of the mission without allowing excess room for "sloshing" of the propellant. This sizing allows for the jettison of the TMI and MOC tanks immediately following their usage, thereby reducing the mass of the vehicle and required propellant.

Nuclear Thermal Rockets

NTRs will be used for MITS propulsion. While nuclear propulsion has many advantages over chemical propulsion, the radiation given off is a problem. Radiation from the NTRs is a major safety risk in the design of the MTV. Several methods of reducing radiation have been considered.

Distance is one of the most effective radiation shields. Radiation falls off at a rate of the distance to the fourth power. This form of shielding was a driving factor for the design of the MTV.

In addition to distance, propellant is an effective and cost-reducing source of shielding. The problem with using the propellant as shielding was that as the propellant was used, the amount of shielding decreased. By the time the MTV starts the trans-Earth portion of its journey (the longest phase of the mission), less than 10% of the initial propellant will remain. This is not an adequate shield. However, this concern will be incorporated in the design. The propellant used for the TEI will be placed between the habitation area and the NTRs to provide extra shielding for the first part of the mission.

A fourth method of increasing the radiation protection between the NTRs and the habitation area is the use of a massive shield. The amount of shielding depicted in the drawings is 30,000 kg of lead.

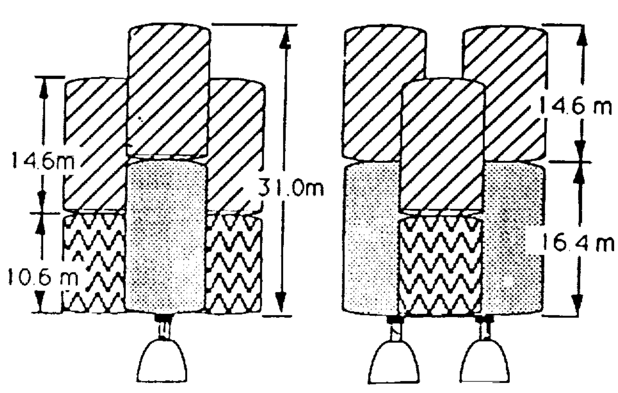

Fig. 1. Propellent tank configuration.

Earth Return Vehicle (ERV)

The ERV will be the only part of the MTV to return to Earth. Upon arrival at Earth the ERV will consist of the Earth aerobrake, the AM, and the propellant for maneuvering into orbit with Space Station *Freedom*. The ERV will dock at Space Station *Freedom* and transfer the astronauts, soil samples, and data obtained from experiments along the entire mission to the laboratory modules on Space Station *Freedom* and ultimately back to Earth.

HABITATION MODULE LAYOUT

There will be two cylindrical modules in which the crew will spend the majority of the trip. Both modules will have two floors. With access between the two modules on both floors, Fig. 2 shows the dimensions of the modules. The modules have been designed so that either one could provide living quarters for the crew in the event that one of them was rendered inoperable during a catastrophe.

There will also be two modules that will be brought down to the surface of Mars where the crew will spend approximately 30 days. These modules will be 5 m (16.4 ft) in diameter and 14 m (45.9 ft) in length. There will only be one floor on each of these MEV modules. The size of the MEV modules is smaller than the MTV modules because the crew will be spending less time on the surface of Mars than on the trip through space. Also, the astronauts will have the option to go outside the MEV modules, but they will be confined to the MTV for many months.

MTV Hab Module

The Hab module of the MTV will contain most of the facilities the crew will use while eating, sleeping, or during recreation and relaxation times. Figure 3 shows the floor plans for the upper and lower floors of the MTV Hab module.

The crew quarters will include a fold-out bed so that space may be conserved and additional storage may be accessed. A desk will be provided as well as a personal computer networked to the ship's computer for personal use. The crew quarters should allow for privacy, so individual quarters are provided.

One personal hygiene center is located on each floor of the MTV. A galley for food preparation is located on the upper floor. It will contain storage for dishes, silverware, and pots and pans. The pantry, refrigerator, and freezer will store 3900 kg of food. Appliances will include an oven, a microwave, a mixer, and a hydrator.

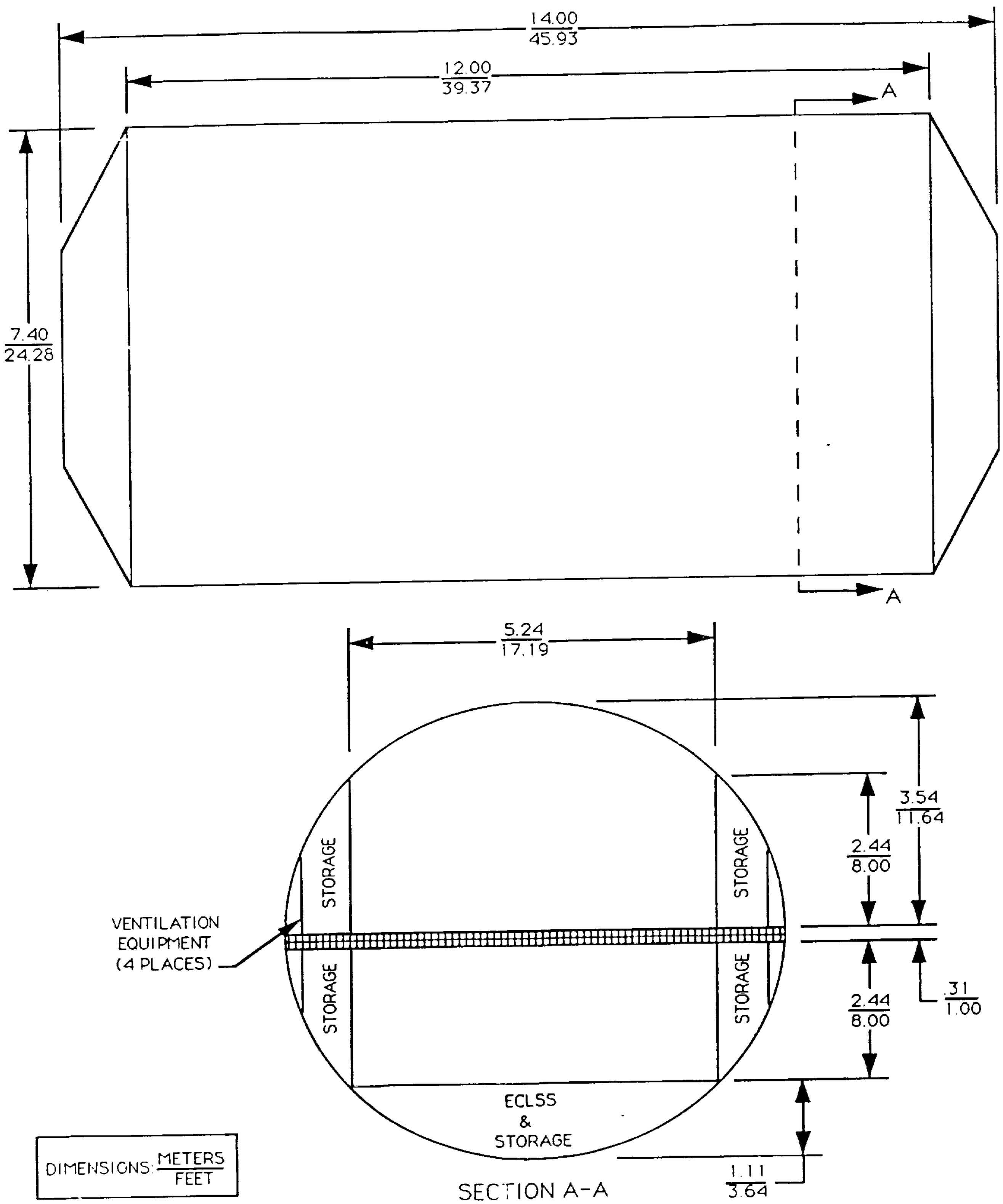

Fig. 2. MTV Module dimensions.

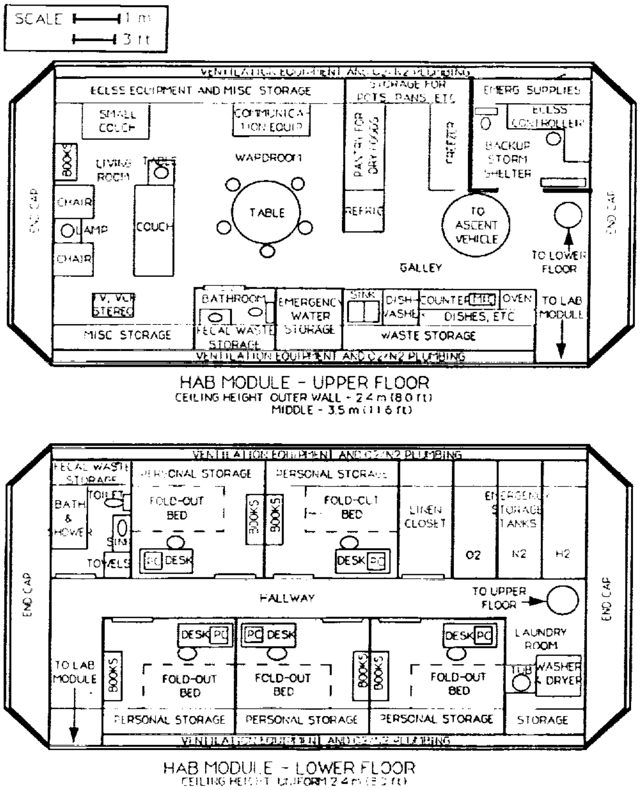

Fig. 3. MTV hab module floor plans.

A wardroom will consist of a dining area with table and five chairs, and video equipment for communication with Earth. The Hab module will also include a living room that the crew can use during recreation and relaxation. A backup radiation shelter will be included in the module that will double as the ECLSS control room. Also located in the Hab module will be emergency storage tanks for oxygen, nitrogen, hydrogen, and water.

MTV Lab Module

The Lab module contains most of the facilities involving work-related activities. Included will be the command/control center, the nerve center of the ship, which will provide access to all ECLSS systems, as well as to computers and communications equipment.

The lab maintenance facility will include the tools necessary to perform the required research and analysis of data aquired during the mission. Astronomy, biology, chemistry, physics, and geology are only a few of the kinds of research that can be performed. Additionally in this area, there will be a general shop with the tools necessary for the construction and repair of the ship's system.

A medical facility capable of surgical procedures will be needed. A general examination table, as well as the necessary tools and instruments will be accessible on racks in this area. Dental procedures will also be performed in this facility.

A physical fitness center will include variable resistance machines as well as aerobic machines. The medical facility will have access to the physical fitness center so that the crew can be monitored during exercise.

A radiation shelter will be designed according to recommendations given in this report. It must be self-sufficient since the duration of a SPE may last from several hours to a day. Therefore, personal hygiene facilities, ship monitoring equipment, and food preparation and storage will be included in the storm shelter. A computer will allow acess to the main computer for monitoring of the ship's functions during an SPE. Recreation may be had by means of books and games, which will be stored in the shelter.

The NTRs had to be kept as far away from the habitation area as possible to reduce radiation exposure of the crew. The propellant will serve as shielding from the NTRs. The loading of the vehicle must to be as symmetric as possible to reduce the structural loads in the truss. If possible, all habitation areas (including those on the MEV and AM) should be located in the same area. This allows for alternate living areas in case of an emergency, and eliminates or reduces EVAs. The antenna system must be located near the center of gravity for uninterrupted communication with Earth. This resulted in a need to keep the center of gravity in a fixed location, or as close to the same location as possible for the trans-Mars and trans-Earth portions of operation.

Based on these requirements the MTV has been developed as shown in Figs. 4-6. Figures 4-6 also indicate the names of the major components of the MTV. The overall length of the vehicle is approximately 97 m. The design has a width of approximately 20 m across the propellant tanks, again needing support structure finalization, and 30 m across at the MEV.

The Mars Excursion Vehicle (MEV)

The MEV will be used to transfer the crew from the MTV to the martian surface. The design, as shown in Figs. 7-10, includes an AM having 19,000 kg of descent propellant dispersed into six spherical tanks, two habitation modules having a diameter of 5 m and a length of 11 m, and a martian rover. The total height of the vehicle is 11 m.

The inner space of the AM will consist of one chair for each astronaut and space for items that will be brought back to Earth (i.e., soil and data). The AM will be used only to transport the astronauts from Mars back to the MTV, and then from the MTV into LEO and ultimately Space Station *Freedom*. Other features of the MEV include multiple airlocks, a support platform and a tunnel system connecting the habitation module. The airlocks are located on each of the habitation modules and connect to a tunnel system extending between both the AM and the habitation modules. A passageway out of the tunnel leads to the rover, which is located between the habitation modules. A platform supports the entire descent vehicle.

MISSION PROFILE

There are many distinct stages to the MITS mission, and the vehicle changes drastically as the mission progresses from launching the vehicle components into LEO to docking with SSF upon return from Mars. Figure 11 depicts a sketch of the mission profile.

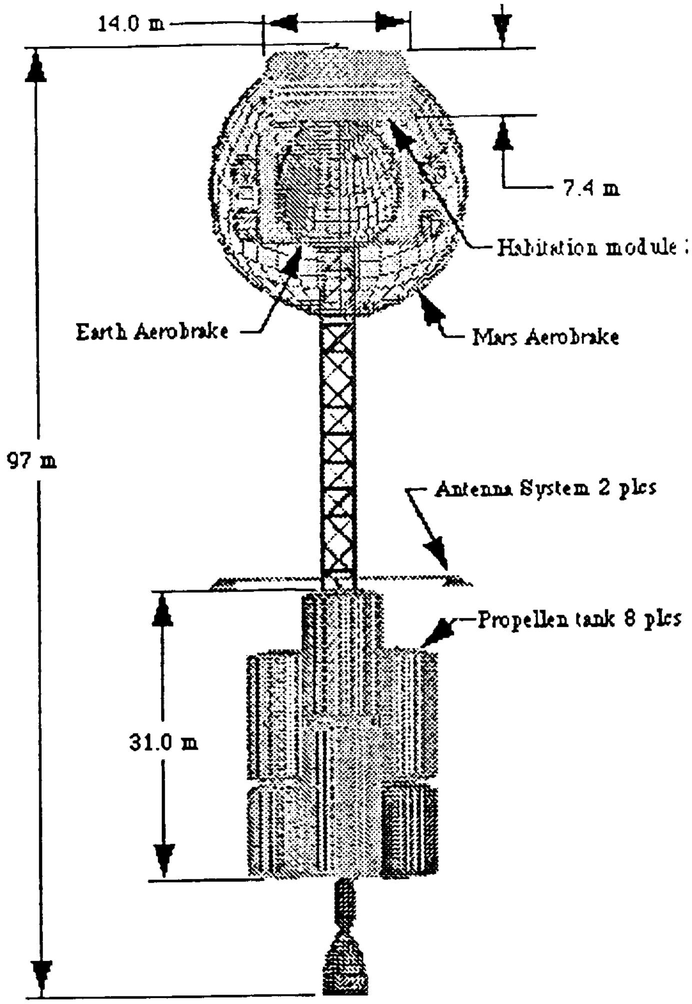

Fig. 4. MTV configuration front.

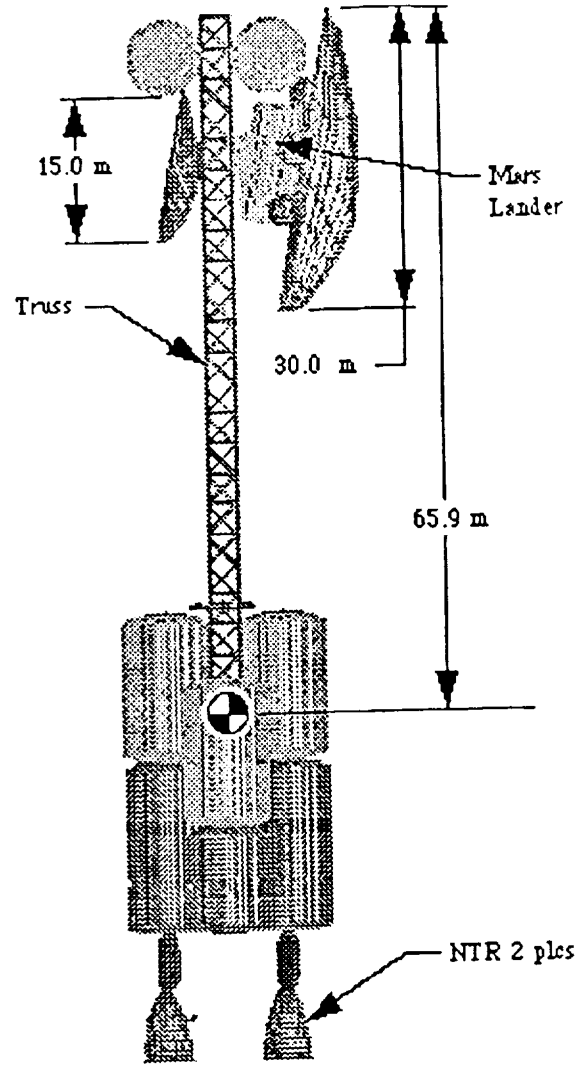

Fig. 5. MTV configuration—Side.

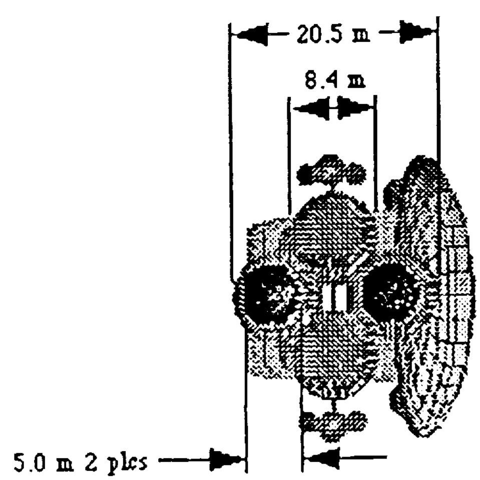

Fig. 6. MTV configuration—Bottom.

I. Launch of Vehicle Components into LEO

In this phase of the mission, the individual parts of the MITS are launched into LEO by an HLLV. The components are taken to construction facilities near SSF.

II. Assembly of Vehicle near SSF

This phase of the mission consists of the on-orbit assembly of the MITS at the appropriate facilities near SSF. At the end of this phase, the MITS crew is transferred from SSF to the Mars vehicle. The vehicle performs a maneuver to distance itself from SSF, then proceeds to phase III.

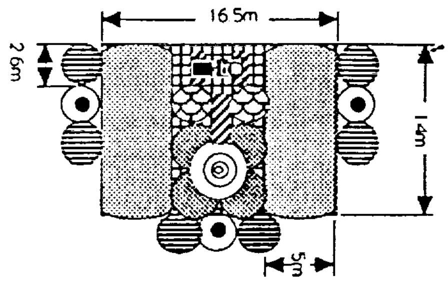

Fig. 7. MEV configuration—Top.

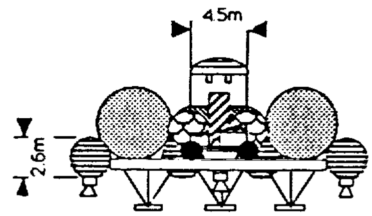

Fig. 9. MEV configuration—Back.

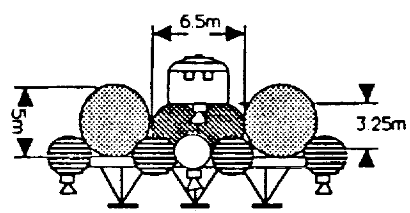

Fig. 8. MEV configuration—Front.

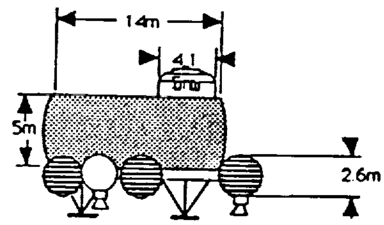

Fig. 10. MEV configuration—Side.

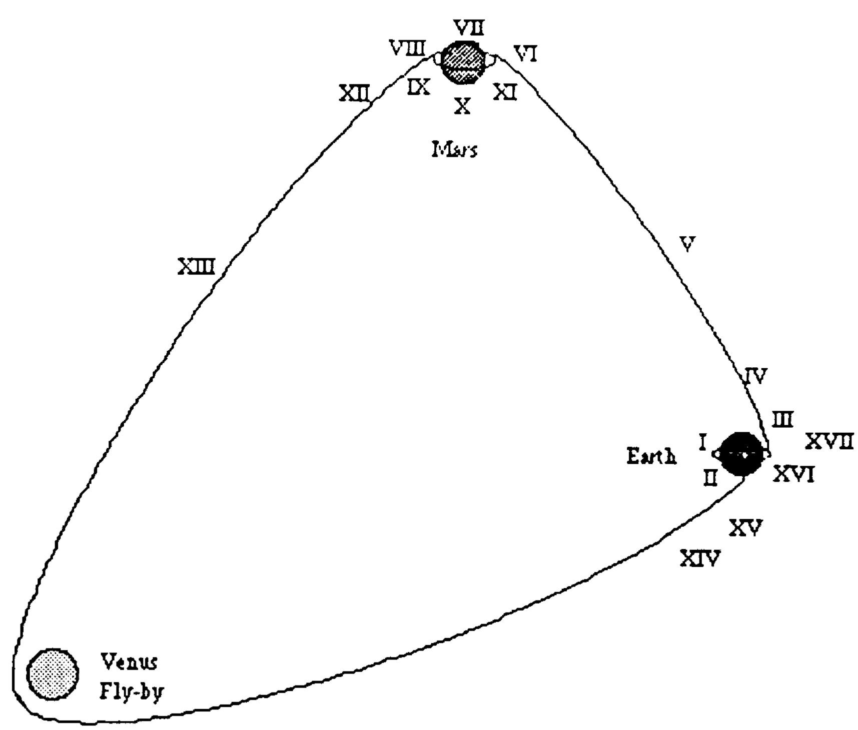

Fig. 11. Mission profile.

III. Trans-Mars Injection Burn

At this point, the NTR engines of the MITS perform the necessary burn to take the vehicle out of Earth orbit and into a Mars-bound trajectory. After the burn, the engines idle to supply power to the vehicle for the rest of the trip.

IV. Expend Used Fuel Tanks

After the trans-Mars injection burn, which will require an enormous amount of fuel, the empty tanks are expended.

V. Earth-Mars Transit Phase

This is the second longest phase of the journey, lasting approximately 170 days. For most of this period, the MITS will be rotating, creating artificial gravity for the crew. However, this rotation will be stopped at least once, and possibly twice for periods of around one week. During these times, experiments and observations will be performed that require a zero-*g*, or nonrotating environment. Also during these times, course corrections are made if necessary.

VI. Propulsive Capture at Mars

This phase of the mission involves the MITS entering Mars orbit by propulsive capture. The NTR engines will slow the entire vehicle into an equatorial or near-equatorial orbit. At this point, a number of scientific studies will take place including martian surface observations and studies of the martian moons Phobos and Deimos. The crew will make final preparations, testing the various systems and equipment on the MEV before embarking on the surface.

VII. Separation of MEV from MTV

At this point, the crew boards the MEV and separates it from the MTV. All five crew members will be on the ground crew, leaving the MTV to orbit Mars unmanned.

VIII. Landing of MEV

During this phase, the MEV enters the martian atmosphere and lands in the Tharsis volcanic region of Mars (see next section for more details on Tharsis). During the descent, the entire crew is in the AM, which also serves as a control center for the MEV. The crew remains on the surface for 30-60 days, conducting local science and exploration.

IX. Ascent Module Launches Crew into Orbit

After the surface phase of the mission, the crew boards the ascent module and fires the ascent engines. The Mars habitation module, landing equipment and engines, rover, and other equipment are left behind for possible future use. The AM carries the crew into orbit.

X. Ascent Module Docks with MTV

At this point, the AM performs the required maneuvers to rendezvous with the MTV, and docks with the Earth return aerobrake. The crew is transferred to the MTV habitation modules.

XI. Jettison of Mars Capture Fuel Tanks

Before leaving Mars orbit, the fuel tanks that were emptied during Mars capture will be expended.

XII. Trans-Earth Injection Burn

In this phase, the NTR engines fire, causing the MTV to leave Mars orbit and enter a trajectory that will ultimately carry it back to Earth, with a Venus swingby.

XIII. Mars-Earth Transit

This is the longest phase of the mission, lasting approximately 270 days. As in the Earth-Mars transit phase, most of this time will be spent in artificial gravity, with some interruptions for experimentation and course corrections. When the MITS performs a Venus swingby, observations will be made, with possible probes sent to make more detailed studies.

XIV. Separation of ERV from MTV

Before the MITS reaches Earth, the crew separates the ERV from the MTV. The ERV consists of the Earth return aerobrake and the AM.

XV. MTV is Expended

This phase involves letting the MTV continue past Earth, as the ERV is captured. The rest of the MTV is discarded.

XVI. ERV Aerobrakes into LEO

After separating from the MTV, the ERV performs an aerobraking maneuver to enter LEO.

XVII. ERV Docks with SSF

Finally, the crew, data, and samples are transferred from the ERV to Space Station *Freedom* for return to the surface of Earth.

LANDING SITE—THARSIS RIDGE

Although smaller than Earth, Mars is still a large planet with many interesting features. Picking a landing site was a difficult task. The criteria used to determine the best landing site were low altitude, low wind speeds, equatorial location (to assist in AM launch), moderate temperatures, smooth terrain for landing, and interesting geological and other scientific prospects.

The site that best fits the criteria is the Tharsis region, with Eden as an alternate site. Tharsis is located at 8°S, 84°W at an altitude of 10 km above zero reference. Wind speeds vary from 14-40 m/s and temperatures range from 170 to 250 K. The terrain is mostly flat with a few craters. Several major volcanoes exist in the area. The soil consists of dune sand, loess, lag gravel, and young volcanic lava.

CREW ACTIVITIES

In Transit

The duration of the first mission to Mars will be roughly 488 days. Since over 90% of this time will be spent in transit, it is necessary to have a schedule for the crew to follow to use this time to its full potential. Each day has been divided into five periods. They are as follows:

- 8 hours of sleep
- 3 hours for meals
- 2 hours of personal/leisure time
- 8 hours of work
- 2 hours for exercise

The proposed activites for leisure are reading books and journals, watching movies, listening to music, exercising, receiving current news transmissions from Earth, and audio and/or video communication with family.

The hours of work have been divided into two groups: scientific activities and mission duties. Some of the scientific activities being considered include observations through a moderate-sized telescope, studies of X-ray and gamma-ray radiation, radio astronomy, cosmic-ray astronomy, and the collection of interplanetary dust particles. The mission duties include monitoring the computer control system for any possible problems, monitoring the path of the MTV for any necessary course corrections, keeping a log of all activites onboard, maintaining audio contact with Earth on progress/problems, and preparations for landing on Mars.

On Surface

During their surface stay, the astronauts will perform geologic sampling and surface drilling, petrology, geochemistry, and physical properties experiments. They will also spend time on rover missions deploying Surface Science Telemetry Stations (SSTS), which will transmit data on wind speed and direction, radiation seismic activity, and atmospheric composition for years to come.

In preparation for a future permanent base on Mars, several experiments will be performed on *in situ* resource utilization, though *in situ* resources will not be counted on to sustain the first manned mission. Since water and oxygen are the most important resources that may be obtained from Mars, these will be studied first.

CONCLUSION

This proposed design for a Mars Integrated Transportation System meets all the objectives necessary to satisfy President Bush's long-range plans for the future of NASA as it reaches out for Mars.

This report is respectfully submitted with the hope that it will provide a meaningful contribution in the effort to place humans on Mars.