

**MARS INTEGRATED TRANSPORTATION SYSTEM
MULTISTAGE MARS MISSION**

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In accordance with the objective of the Mars Integrated Transport System (MITS) program, the Multistage Mars Mission (MSMM) design team has developed a profile for a manned mission to Mars. The purpose of the multistage mission is to send a crew of five astronauts to the martian surface by the year 2019. The mission continues man's eternal quest for exploration of new frontiers. This mission has a scheduled duration of 426 days that includes experimentation en route as well as surface exploration and experimentation. The MSMM is also designed as a foundation for a continuing program leading to the colonization of the planet Mars.

NOMENCLATURE

AFE	Aero-Assist Flight Envelope
DC	Direct Current
HLLV	Heavy-Lift Launch Vehicle
LEO	Low Earth Orbit
MEV	Mars Excursion Vehicle
MHM	Mars Habitation Module
MITS	Mars Integrated Transportation System
MRV	Mars Roving Vehicle
MSMM	Multistage Mars Mission
MTV	Mars Transfer Vehicle
NTR	Nuclear Thermal Reactor
TEI	Trans-Earth Injection
TMI	Trans-Mars Injection

INTRODUCTION

Long-range plans for NASA have included the development of manned missions to the martian surface. The goal of NASA is to have the manned landing of the Mars mission coincide with the 50th anniversary of the landing of man on the lunar surface. This report is an outline of a design for a manned mission to Mars.

Objectives

1. To place a crew of trained astronauts from Earth on the surface of Mars close to the year 2020.
2. During this initial stay the astronauts are to establish a Mars outpost site and conduct local science and exploration.
3. Return the crew, surface samples, and useful hardware information back to Earth.
4. Accomplish the above tasks in a cost-effective manner with acceptable levels of safety in the design systems.

General Assumptions

1. A minimum configuration space station exists within the 2015-2018 timeframe.
2. A new HLLV will be available and operational.

3. No lunar base will be necessary for the commencement of a Mars initiative.
4. A series of robotic missions will precede a manned Mars mission.
5. Adequate communication facilities exist.
6. A reliable NTR propulsive engine is available.
7. No remarkable advances will be made in the human body's regenerative powers in a zero-gravity environment.

MISSION PROFILE

The mission developed consists of two main profiles with a number of smaller stages incorporated into each of the two larger stages. The two stages use two different types of vehicles. One vehicle has been designed around the mission's cargo and the other is focused on the mission's crew. The MHM is a cargo vehicle. The other main vehicle, the MTV, is the crew's transport vehicle. Each vehicle is launched at different stages throughout the mission. The chronological description that follows describes the mission, vehicles, and their combined purposes.

MHM Mission Profile (Phases A-F)

The MHM (Fig. 1) is the first vehicle/system that is prepared and sent to Mars. The MHM is to serve as the command and control center for the astronauts on the martian surface. It will carry the logistics equipment and supplies needed for the 30-day stay on the martian surface. The MHM does not carry any crew members on its journey; therefore, it can be sent prior to a crew-intensive system. The first step in the MHM flight profile is the launch of the MHM package on board a 200-300-Klb-class Inline ET-derived launch vehicle, (Phase A). Once in space, the MHM enters a specified parking orbit at an altitude of 300 km. Soon thereafter, a second 200-300-Klb-class rocket launches a ET-derived cryogenic booster to rendezvous with the MHM package. This trans Mars injection (TMI) booster docks with the MHM and awaits the proper launch window for reaching Mars. The window for launching the MHM is January of 2014. Once the window is open, the TMI booster fires, placing the MHM in a Mars-bound trajectory (Phase B). The MHM must develop a ΔV of 3.60 km/s to accomplish the TMI burn. Three

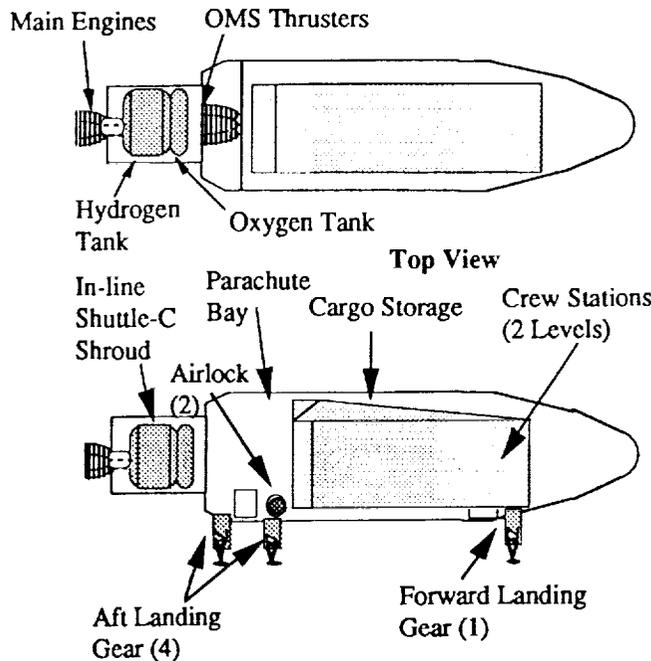


Fig. 1. Component diagram of the Mars habitational module.

space transportation main engines are used as the propulsion system for the MHM, which develops this ΔV for TMI. The actual propulsive burn needed to develop this ΔV is approximately 6 min. Once the TMI burn is completed the spent booster is jettisoned (Phase C).

En route, reaction and control system thrusters fire to perform course corrections as needed. The reaction and control system is used to keep the MHM on a Hohmann transfer path to Mars. The Hohmann transfer route is used because time is a critical factor in the MHM journey. The Earth-to-Mars transfer time for the MHM will be approximately 259 days. The launching of the MHM is approximately two years ahead of the scheduled launch date for the MTV and the mission's crew.

As the MHM approaches the martian atmosphere the MHM orientates itself for aerocapture. The MHM's straight biconic shape and thermal shielding allow it to successfully use the martian atmosphere to bleed off speed and enter a Mars orbit.

The MHM's 40.0-m straight biconic shell is designed with a lift-to-drag ratio of 1.0, and has an ideal velocity window of 4.0-9.5 km/s. The entry velocity of the MHM will be at a ΔV close to 4.5 km/s. The relatively slow ΔV for entry will limit the aeroheating that occurs during the atmospheric entry into Mars. Calculations show the aeroheating induced on the MHM's surface will develop temperatures close to 1600°C.

The outer skin of the MHM is an aluminum silicon-carbide composite and glass-reinforced polyimide honeycomb sandwich. This skin not only withstands the high temperatures developed from aeroheating, but it also exceeds the minimum allowable parameters for internal pressure. This outer skin has a safety factor of two, in reference to both the aeroheating temperatures and the internal pressure.

The MHM continues to use the reaction and control in a deorbit burn and descends to the martian surface (Phase E). After the MHM has slowed down to below Mach 1.0, parachutes will be released to slow the craft down further and guide it to the landing site, 20°N 150°W, just west of the Olympus Mons. Shock-absorbing structures on the base of the MHM are extended to protect the craft from the shock of impact. A secondary landing site has been chosen for contingency purposes. This site is located at 10°S 150°W and is known as Mangala Vallis.

After the MHM has landed, an extensive system check is performed on the MHM. When the MHM is verified intact and operational, the MTV is then cleared for launching. During this period the MHM's radiation protection system is being completed.

The MHM's surface radiation system is a regolith bag system (Fig. 2), whereby bags filled with the regolith of Mars provide radiation protection for the crew. A robotic filling system is used to complete this task. The robotic regolith filling system consists of three main components, each of which accomplishes one part of the task. A small roving vehicle, the gatherer, is used to collect the regolith from various areas near the MHM. The gatherer then dumps the regolith in the second component, the hopper. The hopper includes a swing arm that moves over to the regolith bags and fills them. Once the bags are filled and sealed, a pulley system moves them to their appropriate position on the MHM. Once in the appropriate position, the bags are attached to the MHM in press-type fashion. Once this is completed the MHM is ready for use when the astronauts arrive.

MTV Earth-to-Mars Mission Profile (Phases G-M)

The actual manned mission of the journey begins with the MTV (Fig. 3). Once the systems in the MHM have been verified as safe and operational, the MTV is cleared to continue the overall mission. The mission continues with the assembly of the MTV in LEO, at an altitude of 300 km (Phase G). The various components of the MTV, including the MEV, are launched

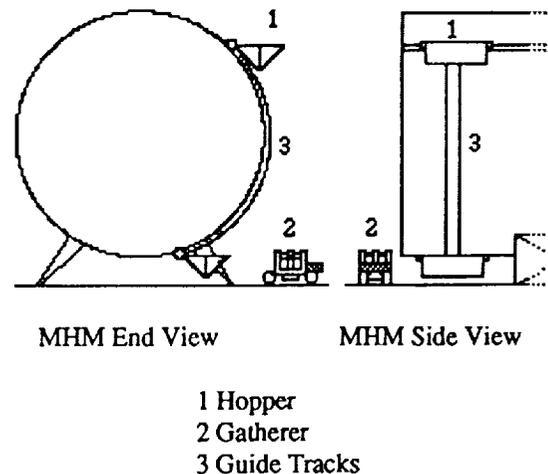


Fig. 2. Robotic regolith system.

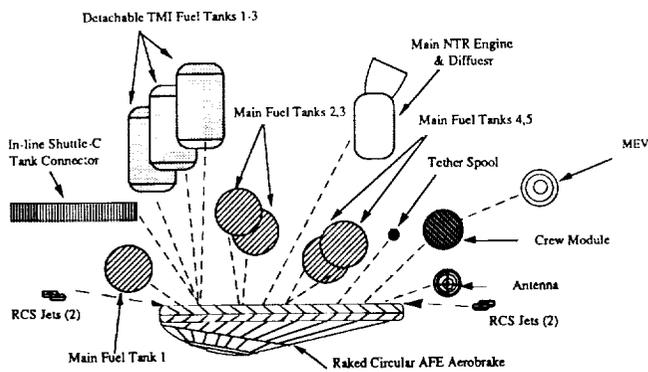


Fig. 3. Mars Transfer Vehicle, by components.

into space and assembled in the vicinity of the space station with the help of the space tug. Once the Earth-Mars transfer window opens (Phase H), during March 2016, final preparations for the mission are made. During this period final connections are made, as well as system checks and verification. The crew for the mission is delivered aboard a shuttle to the space station, and after a ceremonial send-off, the five astronauts are transferred to the MTV. After final systems verification, the MTV is positioned for the TMI burn. The optimum date for this TMI burn is March 21, 2016. This date has been determined with the aid of the SWISTO computer simulator.

The TMI injection burn for the MTV burn is performed using a fluidized particle bed reactor. The reactor must develop a ΔV of 3.99 km/s for the MTV's TMI burn. The propulsive burn for the TMI lasts approximately five hours. During this burn the MTV will use all the fuel from three of its eight fuel tanks. The fuel tanks are all identical and have taken advantage of the space shuttle's manufacturing process. This was done by allowing the tanks to have a common size relationship with the space shuttle main fuel tank. The fuel used in the reactor is liquid hydrogen, which is also used by the space shuttle. Following the TMI burn the three empty fuel tanks are jettisoned (Phase I). Within 24 hours, the craft is beyond the Moon and progressing on a 150-day journey to Mars.

Three days after the TMI burn the artificial gravity system is deployed to develop a gravitational acceleration identical to the Earth's gravitational field (Fig. 4). The artificial gravity system is a tether system that spins two masses around a single point using centripetal acceleration to develop the gravitational field. Due to the effects that centripetal acceleration has on humans, some constraints were placed on the tether system. The tether system operates with a rotational speed of two revolutions per minute to promote safety and wellness for the crew, because the revolution rate allows for a relatively slow velocity, which minimizes the effects of variations in centripetal acceleration. When the tether deploys, the MTV separates into two sections, the Mars Excursion Vehicle and the MTV's crew module, and the aeroshell, remaining fuel tanks, and the reactor. With these masses on each end of the tether the lengths needed will be no more than 400 m and no less than 140 m. The values stated above are using a 0.06-m-diameter tether cable made of Kevlar 49.



Fig. 4. MTV deployed tether configuration.

Kevlar 49 is used because it has a very high tensile strength and a low density compared with other materials. The cable's configuration consists of irregularly bundled strands of Kevlar 49, combined to form the cable (Fig. 5). The irregularly bundled cable offers increased flexibility while maintaining the cable's strength. The tether is deployed and retracted using a winch that receives power from the MTV's power generator. The tether connects to the crew module in three places, so as to better distribute the stresses placed on the outer skin. The tether mount is also made out of Kevlar 49. Because of this it is possible for the tether and mounts to be fabricated as one piece of Kevlar.

Four days later, when the artificial gravity system is fully deployed, the crew starts its in-flight work schedule. The five-member crew is composed of the flight commander, a pilot, a flight surgeon, and two specialists. The crew's schedule during transit periods consists of a five-day work week. All crew members have Sunday off. During the rest of the week the crew staffing varies as each crew member has the second day off on a rotational schedule.

Throughout, the transit crew members will perform a variety of tasks ranging from astronomical observation to landing simulations, as well as some of their own research. A number of systems are needed during transit for research and life support (Table 1). These systems include the Environmental Control Life Support System, climate control, and various radiation control systems. The communication and navigation systems are two major systems needed for the crew's mission on the MTV.

The communication system in the MTV is provided by a KA band transmitter and receiver at a frequency of 32 GHz, with 10 Mbps audio/video transmission rate, and 200 kbps rate for engineering data. This communication will take place from either direct transmission signals with Earth or through the Tracking Data Relay Satellites. When the communications are sent through the satellite system, data will be relayed to Earth using an S band at 4 GHz. For direct communication there are three surface antenna stations: White Sands, New Mexico; Madrid, Spain; and Canberra, Australia. Primary communication for the mission is through these three stations. The navigation for the MTV is provided by the Star Tracker. The Star Tracker is an optical system that compares angles from 37 different stars to determine position. A back-up navigation system that uses Doppler shift is also provided for the MTV. Besides this communication and navigation equipment the MTV has a number of other systems that are power driven.

Upon arrival at the martian atmosphere, the MTV is oriented to begin the aerocapture maneuver (Phase L). Using a 45-m AFE-derivative aeroshell, it aerodynamically brakes through the

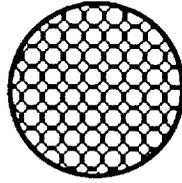


Fig. 5. Irregularly bundled cable.

TABLE 1. Life support power requirements.

System	Power Required, W
Temp. & Humidity Control	7900
Atmos. Control, Supply	67.2
Atmos. Revitaliation	2206
Fire Detection & Suppression	47.2
Water Recovery & Management	804
Waste Management	535.5

upper layers of the martian atmosphere, bleeding off enough speed to be captured into orbit by the gravitational force of Mars. The aeroshell has a lift-to-drag ratio of 0.30. This value seems quite low, but since the aeroshell only needs to sustain a parking orbit and not reach the surface, a high lift-to-drag ratio is not required. The 0.30 lift-to-drag ratio is necessary because of the entry flight corridor and entrance velocities. The MTV enters the atmosphere at an angle of attack of -18.6° (Fig. 6). This helps the aerobrake enter the martian atmosphere with ΔV s of approximately 5.4 km/s. Once the MTV has entered the martian atmosphere it establishes a circular parking orbit (Phase M). The orbit is at an altitude of 300 km, due to the entry velocity restrictions. With the MTV in orbit around Mars, the crew performs an extensive check on the MTV and the MEV.

MEV Descent, Ascent, and Surface Operation Profile (Phase N-Q)

After the verification of all systems, the crew transfers to the MEV (Fig. 7) for descent (Phase N). The MEV uses the same straight biconic shape as the MHM; the only difference is that the MEV is smaller, a 20-m straight biconic vs. the MHM 40-m straight biconic. A biconic shape is required because the MEV needs a relatively high lift-to-drag ratio to reach the MHM base from its specified range and parking orbit. The MEV uses three Pratt and Whitney RL-10 IIC engines in a traditional tripod configuration for retrothrusting in the propulsive descent. The combinations of the MEV's engines and cross-range, provided by its lift-to-drag ratio, will allow the MEV the accuracy to land within 30 km of the MHM base. As the actual touchdown

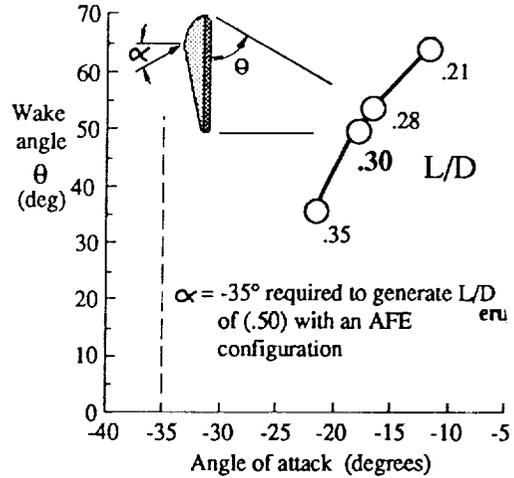


Fig. 6. Wake angle vs. angle of attack.

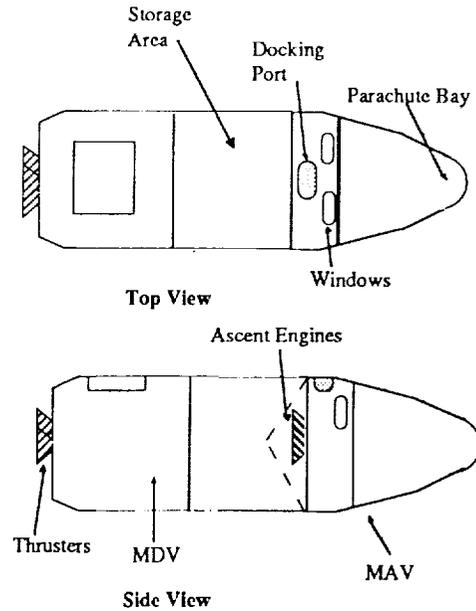


Fig. 7. Component diagram of the Mars excursion vehicle.

approaches, the MEV will extend landing legs and a parachute cluster will provide the MEV a gentle landing on the martian surface.

After the MEV has touched down on the martian surface, the crew perform a complete check on their gear in the MEV and the contained MRV. Once this system check is completed, the astronauts prepare to take their first steps on Mars (Phase O).

Once the astronauts are situated on the surface, they need to rendezvous with the MHM. The crew may need to travel up to 30 km to complete this rendezvous. The crew will travel this distance in the MRV (Fig. 8).

Because the MRV needs to carry the entire crew from the MEV to the MHM, it has a seating capacity for five astronauts in full gear. The MRV is designed to be very versatile while

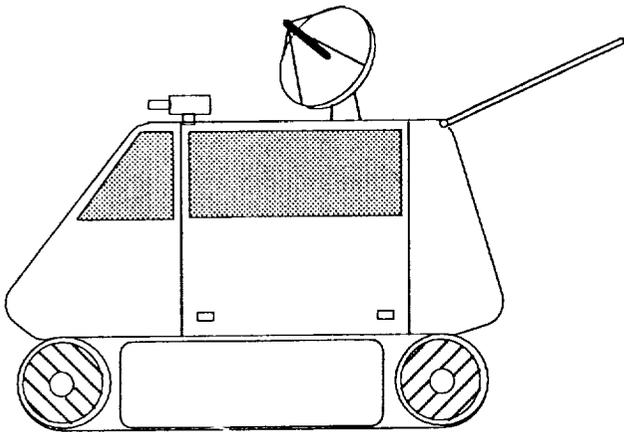


Fig. 8. Mars roving vehicle, side view.

also being very simple. The vehicle travels via a two-track system, which allows the rover to negotiate various terrains easily, while also allowing it to rotate without any forward movement. The power system for the MRV is provided by a conventional-fuel power cell system, which provides 4.5 KW_e. This system allows the rover to have a power safety factor of 1.5. The power system is rechargeable, which will allow the MRV to be used numerous times throughout the surface stay. Interior power and accessory systems in the rover are powered by simple DC motors. This system provides power for the rover's communication, navigation, and lighting systems. The MRV is fully enclosed to protect the astronauts and sensitive equipment inside the rover.

The MRV is carried inside the MEV, and is driven down a ramp from the MEV to the martian surface. From here the crew boards the MRV and travels to the MHM to complete the surface stay. With the rover's maximum operational speed of 15 km/hr it will take no more than three hours for the rover to rendezvous with the MHM. Once this rendezvous is completed, the actual surface operations begin.

The tasks that the crew will perform while on the surface of Mars are wide ranging and include geological, geochemical, biological, and astronomical experiments and research. One area that the crew will spend a large amount of their surface time researching is *in situ* resource utilization. The primary focus of *in situ* resource utilization is extracting usable materials from the martian surface. On Mars this would be principally hydrogen, oxygen, and H₂O. The crew on this mission would seek to verify the technology and possibly start an oxygen producing facility. This facility would then be used for follow-on missions.

This experimentation, completed on the surface, continues the mission's goal of not only putting humans on the martian surface, but doing surface experimentation that will set up a base for continuing missions (Figs. 9, 10). At the end of this 30-day stay the crew will again use the MRV to rejoin the MEV. Once the crew reaches the MEV, they will embark and prepare to leave the surface.

The MEV has a built-in section that will transport the crew from the surface back to the MTV, which is in a low Mars parking orbit. This section, the Mars Ascent Vehicle (MAV) is propulsively

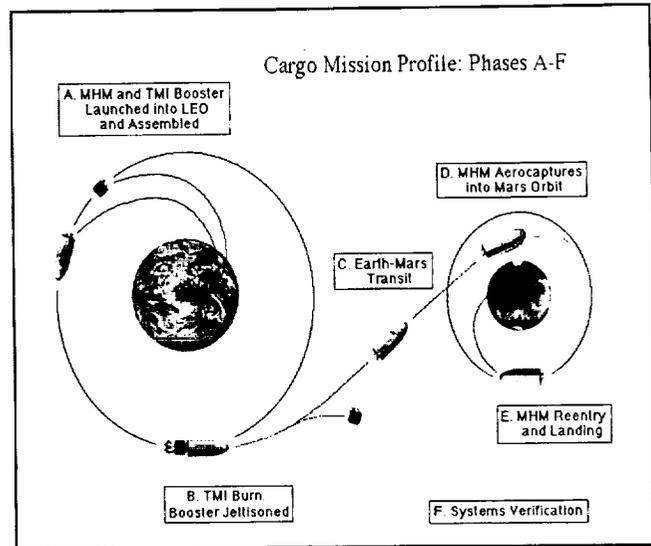


Fig. 9. Cargo mission profile, phases A-F.

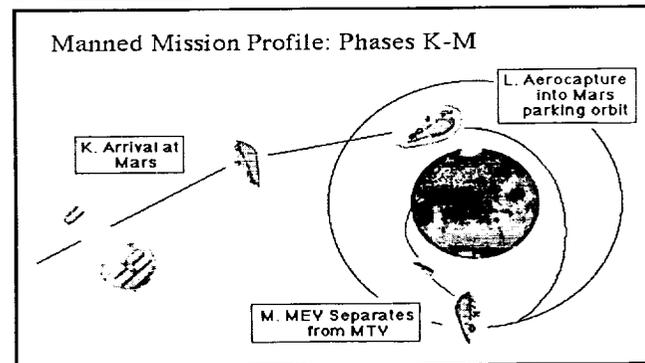
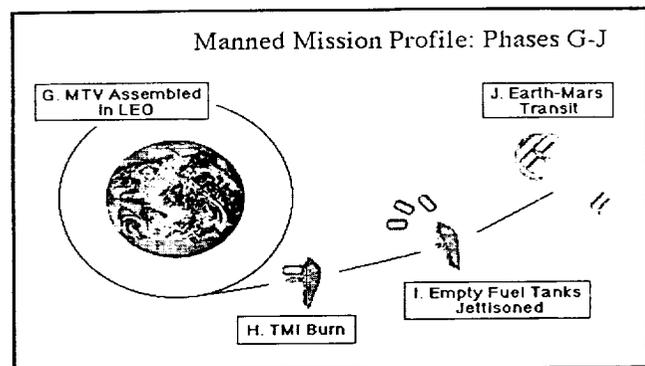


Fig. 10. Manned mission profile, phases G-M.

lifted into an orbit that coincides with the MTV. The MAV's propulsive unit comprises three Pratt and Whitney RL-10 IIC engines in a traditional tripod configuration. These engines will produce enough thrust to propel the MAV into a concurrent

orbit with the MTV (Phase P, Fig. 11). Once the orbit has been established, a docking maneuver is performed by the MAV to complete its rendezvous with the MTV.

MTV Mars-to-Earth Mission Profile (Phases Q-T)

Once the docking procedure is completed the crew will transfer back into the crew module of the MTV. The crew then finishes preparations for the trip back to Earth and jettisons the MAV before firing for the TEI (Phase Q). The TEI burn is again done by the fluidized particle bed reactor. The burn stage has a duration of approximately three hours, while developing the needed ΔV to escape Mars's gravitational field. This is the beginning of the 240-day trip back to Earth. The artificial gravity system will continue to produce a gravity environment until the MTV approaches Venus approximately 110 days later. As the MTV approaches Venus the tether is retracted for the Venus swing-by, (Phase R, Fig. 12). The Venus swing-by stage of the mission will use the gravity of Venus to help develop a higher ΔV , which will enable the crew to return healthier and at an earlier date. During the swing-by stage the crew will perform studies of Venus and observations of the Sun at a vantage point far closer than that of our own planet. Following this pass around Venus, midcourse corrections are made by the nuclear thermal reactor. Once the midcourse corrections have been completed, the tether system is redeployed, once again producing artificial gravity. The Venus-to-Earth transit will last

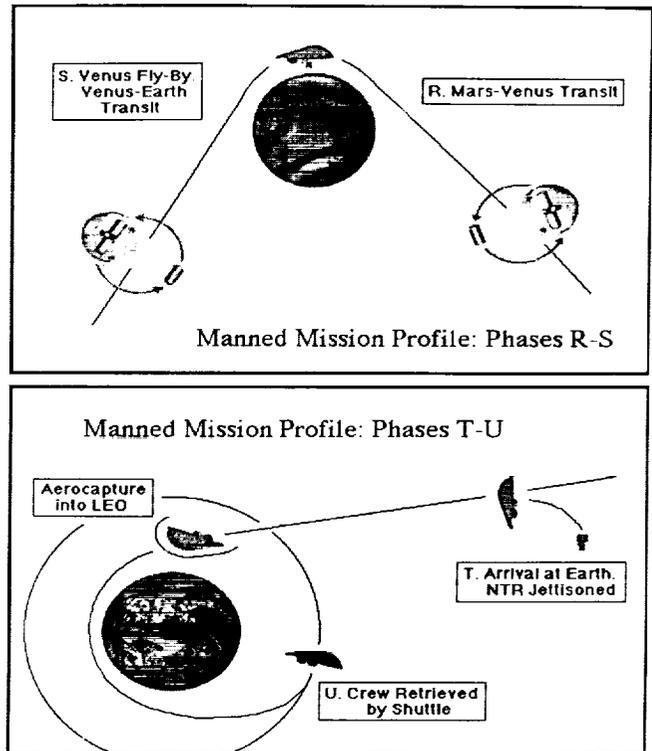


Fig. 12. Manned mission profile, phases S-U.

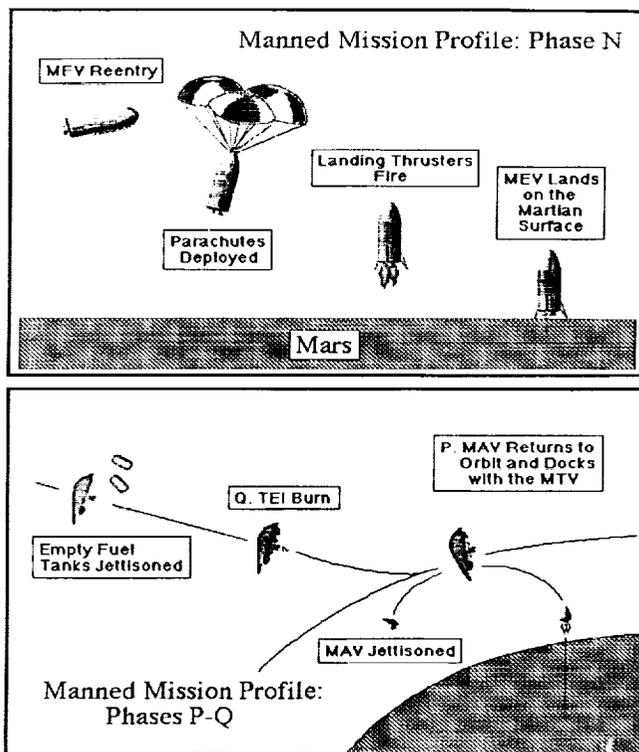


Fig. 11. Manned mission profile, phases N-Q.

approximately 130 days. Near the end of this stage the tether is retracted, in preparation for the entry into Earth's atmosphere (Phase S). The MTV will enter the Earth's atmosphere using the aerobrake in the same manner as it entered the martian atmosphere. After the MTV aerocaptures into Earth orbit, it then establishes the same LEO as used to start the mission. The MTV then rendezvous with the space station, where the astronauts will wait for the space shuttle. The space shuttle will return them to Earth for a hero's welcome, after a quarantine period of two weeks (Phase T). This period is used for testing and evaluation of the astronauts' mental and physical health.