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LOWEST COST, NEAREST TERM OPTIONS FOR A MANNED MARS MISSION

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Abstract

This study is part of a NASA/USRA Advanced Design Program project executed for the purpose of examining the requirements of a first manned Mars mission. The mission, classified as a split/sprint mission, has been designed for a crew of six with a total manned trip time of one year.

Acronyms

ACRV	Assured Crew Return Vehicle
ECLSS	Environmental Control and Life Support Systems
EPV	Emergency Pressure Vessel
EVA	Extravehicular Activity
HLLV	Heavy Lift Launch Vehicle
HMF	Health Maintenance Facility
LEO	Low Earth Orbit
LH_2	Liquid hydrogen
LOX	Liquid oxygen
MTV	Mars Transfer Vehicle
PV	Photovoltaic
SSME	Space Shuttle Main Engine
TEI	Trans Earth Injection
TMI	Trans Mars Injection

Program Objectives

This study is part of a NASA/USRA Advanced Design Program project executed for the purpose of examining the requirements of a first manned Mars mission. The primary requirement is to assure that crew exposure to radiation and zero gravity are minimized. As a study of a first manned mission to Mars, no consideration has been given to in-situ resource utilization.

Mission Baseline

This mission is classified as a split/sprint mission. Cargo and return fuel are sent prior to the launch of the Mars Transfer Vehicle (MTV). The cargo phase of the mission is sent on a low energy conjunction transfer orbit. All systems for the return mission will be verified after its arrival at Mars orbit and prior to the launch of the MTV. Once all systems have been checked out, the MTV will be launched on a high energy one-year flyby trajectory to Mars. On arrival at Mars, the MTV will be inserted into Martian orbit where the transfer vehicle fuel pallet will be exchanged with the cargo vehicle fuel pallet , which will coincide with a twenty-day surface mission. On completion of the surface mission, the lander will rendezvous with the MTV and the two will be sent on a return trajectory to the Earth. On arrival at Earth the MTV will be inserted into Low Earth Orbit (LEO) where the crew will descend to the surface directly via an Apollo-style return vehicle.

Requirements

This mission has been designed for a crew of six with a total manned trip time of one year. Assembly of the return fuel pallet as well as the MTV will be accomplished in LEO. The Energia "B" with a payload capacity of 200 tons per launch and a shroud diameter of 8 m is the HLLV that will be used. Assembly will be conducted at a rate of six launches per year.

Assumptions

It has been assumed for the purpose of this mission that precursor robotic missions have been carried out to determine the specific characteristics of the location on Mars to be explored. Another assumption is the availability of the Energia "B" launch vehicle along with the cooperation of the Russians. It is also assumed that the assembly of the mission elements such as the TEI and TMI fuel pallets as well as the final configuration of the transfer vehicle will take place in LEO. Due to the scale of a project such as this, an assumption has been made that funding would take place from many national and international sources and that NASA participation could be kept to a minimum.

Vehicle Descriptions

TMI Fuel Pallet

The TMI fuel pallet is a highly integrated structure consisting of a space frame truss system, eight liquid hydrogen tanks, four liquid oxygen tanks, and a rocket pack with two SSME's. The space frame connects the fuel pallet to the transfer vehicle as well as the SSME rocket pack. Modular LOX and LH_2 tanks, which are 7.62 m in diameter by 10.93 m long, allow for redundant components.

TEI Fuel Pallet

The TEI fuel pallet is identical in every respect to the TMI fuel pallet with the exception that booster rockets would be incorporated in order to place the fuel pallet on a Mars trajectory and then into a Mars orbit in order to avoid firing the SSME's prior to the TEI burn.

Transfer Vehicle

The transfer vehicle is comprised of a habitat, cupola, two emergency airlocks, an EPV, and an ACRV. The transfer vehicle is connected to the fuel pallet by a space frame structure.

The habitat is 13.45 m X 4.26 m X 7.62 m and contains two pressure vessels for safety and redundancy. The outer vessel contains all secondary functions, while the inner vessel contains living, sleeping, hygiene, galley, emergency communications, and the HMF. In case of emergency, the mission can be carried out from the inner vessel. Along the top of the habitat are modular logistics packs used to store all perishable items. There are four packs oriented linearly within a framing magazine. The packs are docked one at a time to the top hull of the habitat via a central airlock. As materials are used from within the pack, waste is collected and returned to the pack in order to keep the interior of the habitat clear. When a pack has been completely spent, it is undocked from the hull and moved down one position in the magazine, while the next pack is moved into position and docked. PV arrays are located along the bottom of the habitat and supply power throughout the mission. A radiator, for thermal control, is located on the back of the PV array. A communications dish is also located along the bottom of the habitat.

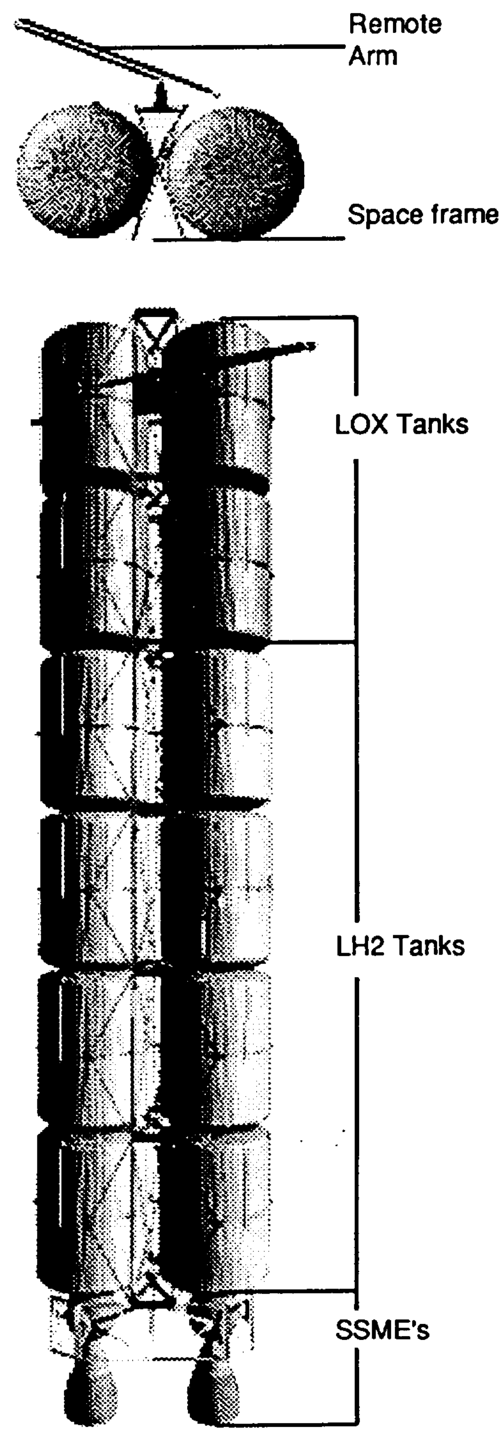


Fig. 11 Typical fuel pallet

A cupola, located centrally between the fuel pallet and the habitat, is used for remote operations as well as for visual inspection of the top half of habitat and logistics packs. The cupola will also be used as a viewing port since it is the only part of the vehicle with windows. The cupola is connected to the habitat by an inflatable tunnel which is connected to an emergency pressure vessel.

An ACRV is located below the EPV opposite the cupola. The ACRV will return the crew directly to Earth at the end of the mission. This vehicle can also be used in the event of an emergency to bring the crew to safety while in LEO.

The EPV is located at the back of the habitat and serves several functions. First, the EPV serves as a storage area for pressure suits and a changing area for donning and doffing the suits. The EPV is also used as an airlock for EVA activity. Finally, the EPV serves to separate the cupola, ACRV, EPV, and habitat into four independent pressure areas. Figures 12 and 13 show the configuration of the transfer vehicle.

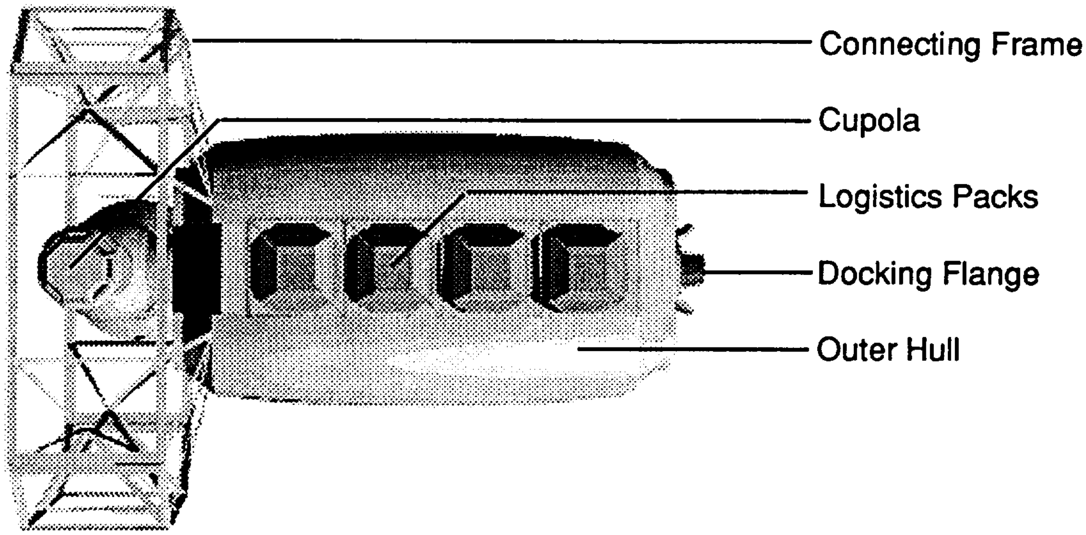


Fig. 12 Transfer vehicle top view

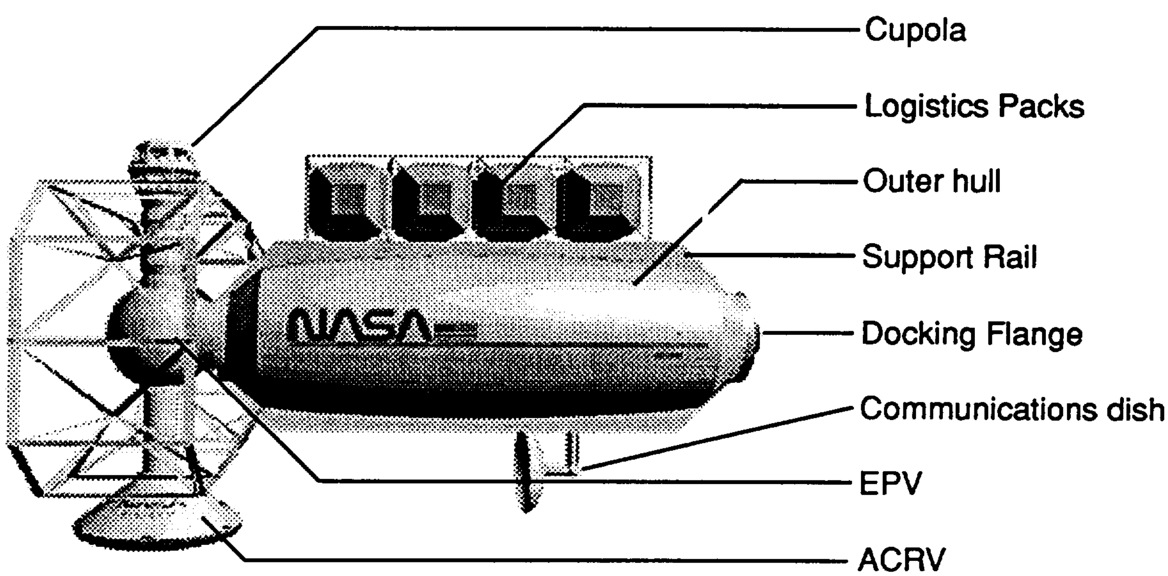


Fig. 13 Transfer vehicle side view

Mars Lander

The Mars lander is used during the crew's 20-day surface stay. The lander consists of three main sections: a habitat, utility core, and support structure.

The habitat, 3.67 m at the base and 5.2 m in height, contains a command control center, two work stations, hygiene area, galley, and two emergency racks.

The utility core provides storage for the EVA suits as well as a common shaft for all electrical and plumbing between the ECLSS and the lander habitat. There are two means of egress from the utility. The primary means of egress is an inflatable airlock, which is used to increase usable volume during EVA activities. A second airlock is located opposite the inflatable in the utility core. This airlock will be used in emergencies only and requires that the utility core be depressurized, whereas the inflatable airlock does not. Logistics packs are located around the utility core on the exterior and contain supplies for the surface mission as well as storage for collected materials.

The space frame support structure is located below the utility core. This structure houses the ascent tanks for the lander as well as three RL-10 rocket engines. On ascent, the framing members and landing legs are left on the surface. Figures 14 and 15 show the front and side views of the Mars lander.

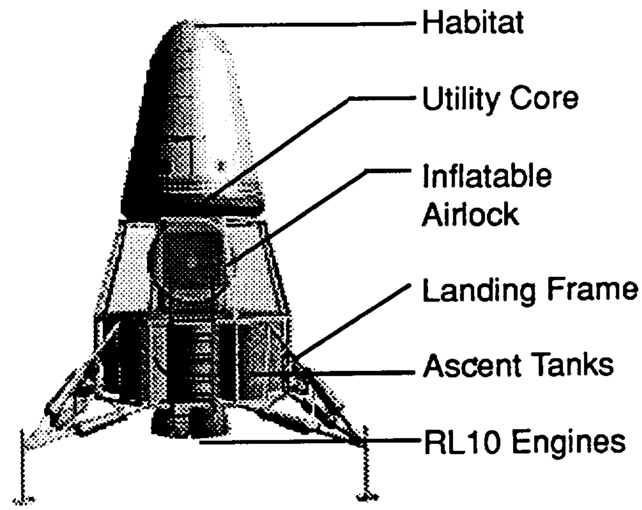


Fig. 14 Lander front view

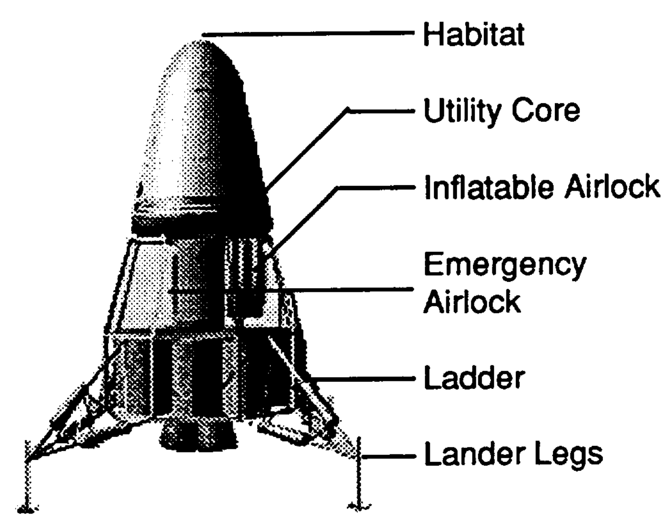


Fig. 15 Lander side view

Modularity

LOX and LH_2 tanks, logistics packs, and space frame members have been designed with a high degree of modularity. This allows for easy replacement in the event of a malfunction or resupply from mission to mission.

Cargo Accommodations

All logistics, supplies, and other cargo are located on the exterior of the transfer vehicle and Mars lander. This serves to reduce the chance of contamination between unrelated materials and contamination of sample materials collected on the surface. This will also help to keep unwanted materials from collecting in the vehicles over the one-year mission.

Propulsion Systems

Cryogenic LOX and LH_2 were chosen because of the high, 475 sec Isp (O_2/H_2), practical maximum for cryogenic fuels, and for its reliability as a proven system. Fuel tanks have been sized (roughly) according to the required delta V's for two SSME's for the TMI and TEI stages. For the purpose of this investigation, it has been assumed that the boiloff is "low" and that a method of recycling the boiloff is available.

Power Systems

Photovoltaics were chosen as the main power supply for the Mars mission. This decision was made due to their availability, high reliability, efficiency, and low level of risk. Unfortunately, the arrays require large amounts of surface area/mass, and are subject to degradation over time. They are also vulnerable to the surrounding solar/environmental conditions. Since the solar intensity on Mars is only about 40% that of LEO, the arrays have to be upscaled accordingly. We hope, however, to minimize these drawbacks by using state-of-the-art photovoltaic technology.

The transfer vehicle will derive most of its power from photovoltaic cells and use fuel cells during occultation while in Mars orbit. The transfer vehicle will require 20 kW: 1.5 kW for the life support systems for each of the six crew members and the balance for other systems and equipment. Cell degradation is estimated at 5% within the first two years. Tandem photovoltaic cells (manufactured by Boeing and presently undergoing testing) will be used. The solar panels are made up of stacked gallium arsenide (Ga As) and gallium antimonide (Ga Sb) cells, which provide a combined efficiency of 23.5%. The arrays would need to be 150 m^2 in order to supply the MTV with 20 kW at Mars (50 kW at LEO). The array itself would weigh 366 kg, and the weight of the supporting structure would add approximately the same amount of weight. The array would also be laminated with a layer of microglass to prevent damage from radiation and micrometeorites.

The Mars lander will be powered solely by fuel cells. The vehicle will require an estimated 10 kW of power for its 20-day separation: 1.5 kW to cover the life support systems of each of the three crew members and the rest to cover other systems and equipment.

Thermal Systems

Thermal control for the transfer vehicle is accomplished by a passive system located on the back of the PV array. The back surface of the array is coated with alumina for high emissivity and use as a radiator.

Environmental Control and Life Support Systems

Life support for this mission is a partially closed loop system in which physical/chemical regeneration occurs and oxygen and water are recycled. Food, however, is not recycled, and waste is collected and stored. This system was chosen for its weight advantages over a purely open system and its compatibility with long-duration missions.

Mission Sequence

Trajectories

The TEI (Figure 16) is sent on a low energy conjunction trajectory prior to the launch of the transfer vehicle. The modified one year flyby trajectory of the transfer vehicle during the TMI and the TEI stage after the exchange of the fuel pallets is illustrated in Figure 17.

Mission Stages

Assembly of the TEI fuel pallet begins with the insertion of the transfer vehicle into LEO. All components of the transfer vehicle are delivered with the first launch. Six additional launches are required to deliver the twelve fuel tanks of the TEI fuel pallet. These tanks are put into orbit and assembled over the course of approximately one year. On completion of the TEI fuel pallet, all systems are confirmed and the fuel pallet is sent on a low energy conjunction trajectory, which will take 270 days to reach Mars.

Next, seven additional launches are required to deliver the twelve fuel tanks of the TMI fuel pallet and the Mars lander. This assembly also requires approximately one year.

After the arrival of the TEI fuel pallet at Mars and the confirmation that "all systems are go," the transfer vehicle with the lander will be launched on a high energy 80-day trajectory to Mars. Near Mars the remaining fuel in the TMI fuel pallet will be used in order to establish an elliptical orbit around Mars.

Once in orbit around Mars, the lander will undock from the transfer vehicle and descend to the surface where its three crew members will conduct a 20-day mission on the surface. While the lander is on the surface, the three remaining crew aboard the transfer vehicle will maneuver the transfer vehicle in order to exchange the TMI fuel pallet with the TEI fuel pallet.

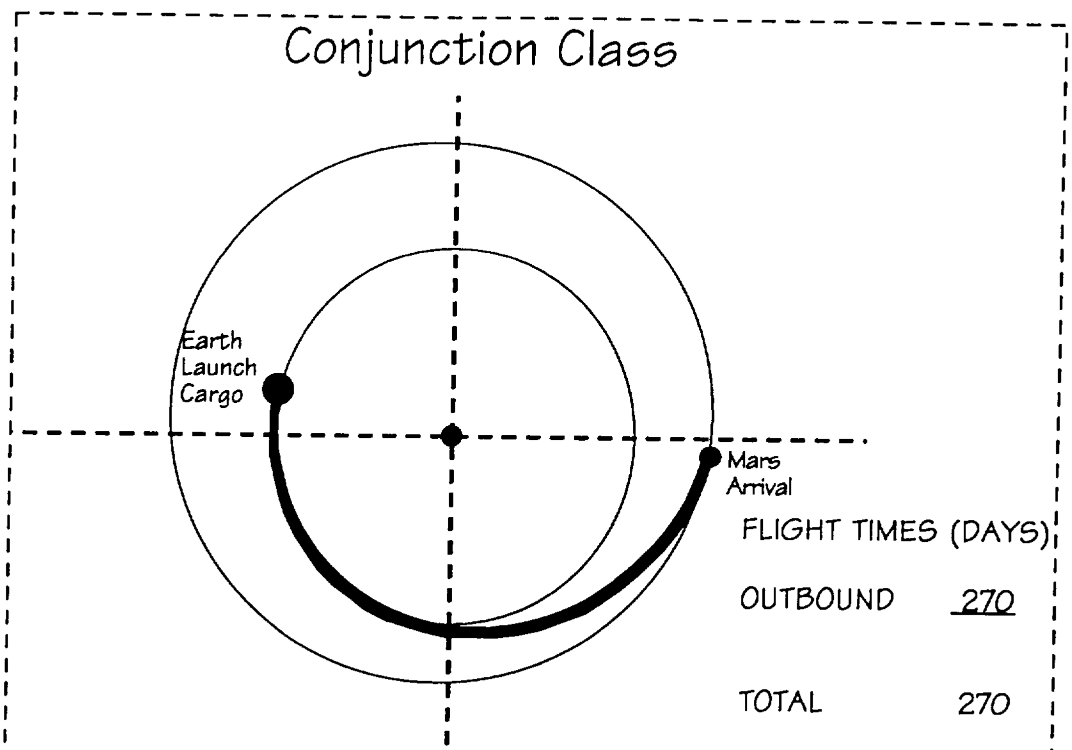


Fig. 16 Cargo trajectory

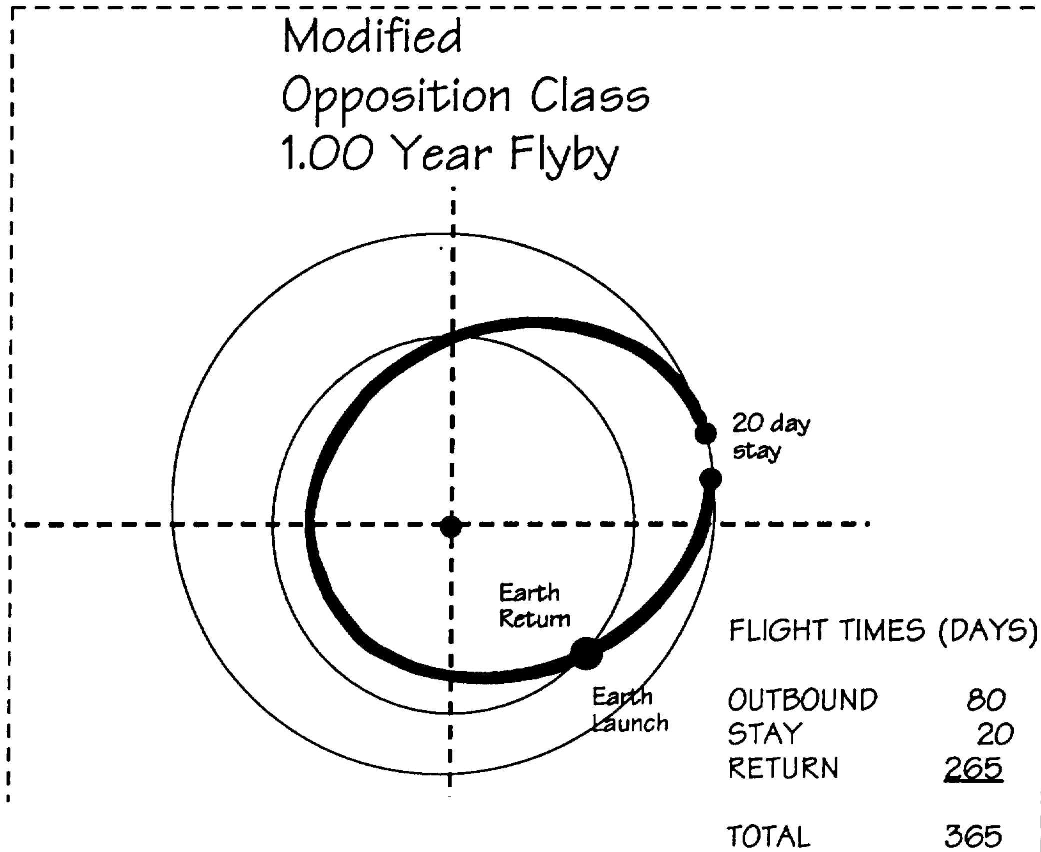


Fig. 17 Transfer vehicle trajectory

With the conclusion of the surface mission and the successful exchange of the fuel pallets, the lander ascends to Mars orbit and docks with the transfer vehicle.

Next, the transfer vehicle with the lander attached makes the TEI burn and begins the 265-day trip back to the Earth where it will reestablish LEO. With the mission complete, the crew will descend to the surface in the ACRV.

A subsequent shuttle mission will be required in order to retrieve the lander and any other items needed for examination. Figure 18 shows the mission sequence in storyboard format.

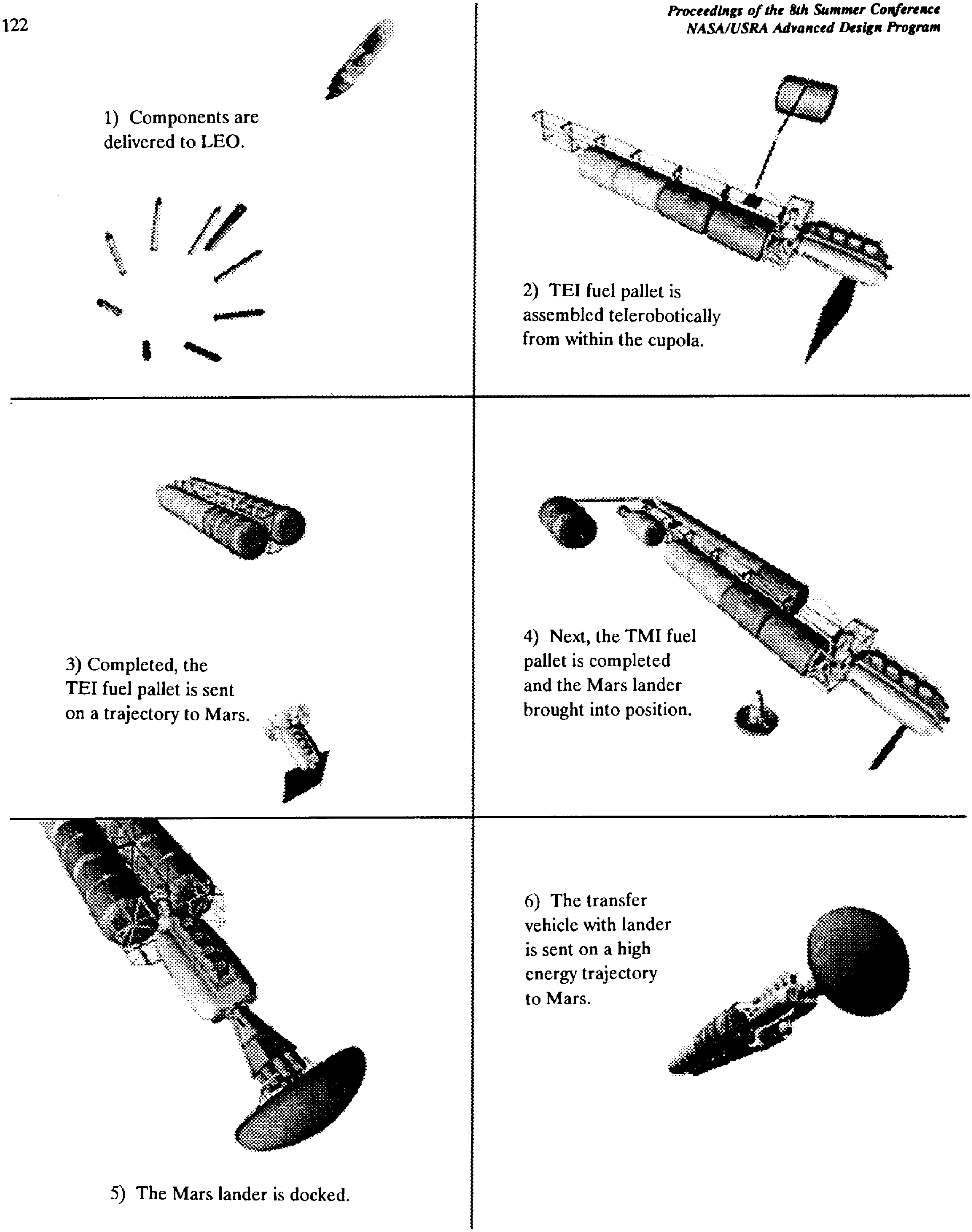
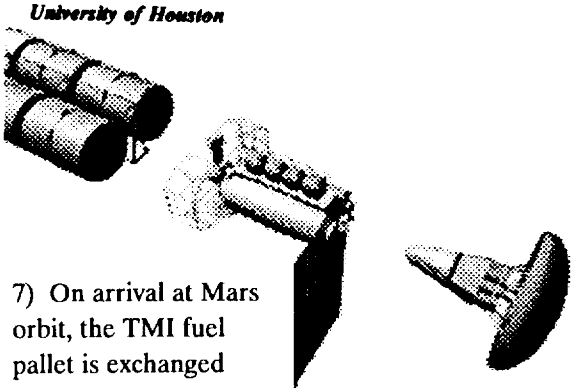
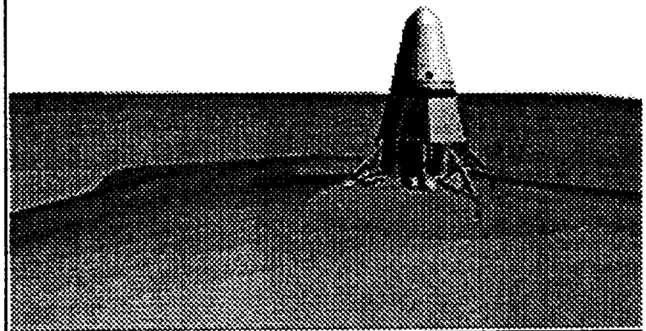


Fig. 18 Mission storyboard

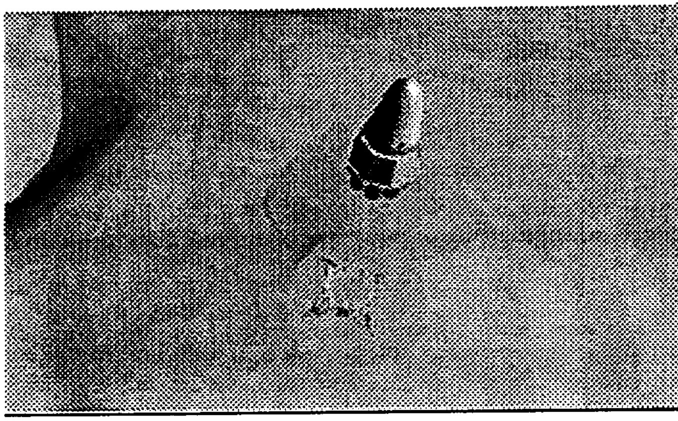


7) On arrival at Mars orbit, the TMI fuel pallet is exchanged and the lander descends to the surface.

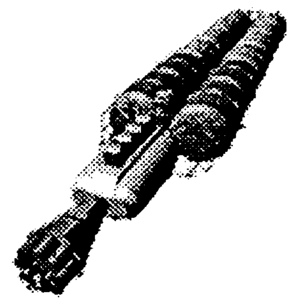
8) On the surface, the crew conducts a 20-day surface stay.



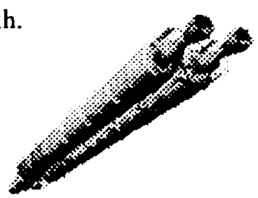
9) The lander returns to the transfer vehicle, leaving its landing frame behind.



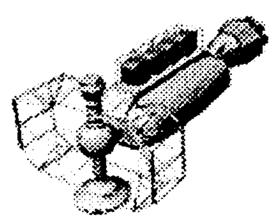
10) The lander docks with completed transfer vehicle.



11) The transfer vehicle with lander begins the 265-day journey back to Earth.



12) At Earth the transfer vehicle and lander are injected into LEO.



13) The crew returns to Earth in the ACRV.

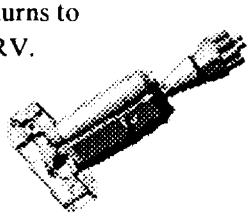


Fig. 18 Mission storyboard (continued)