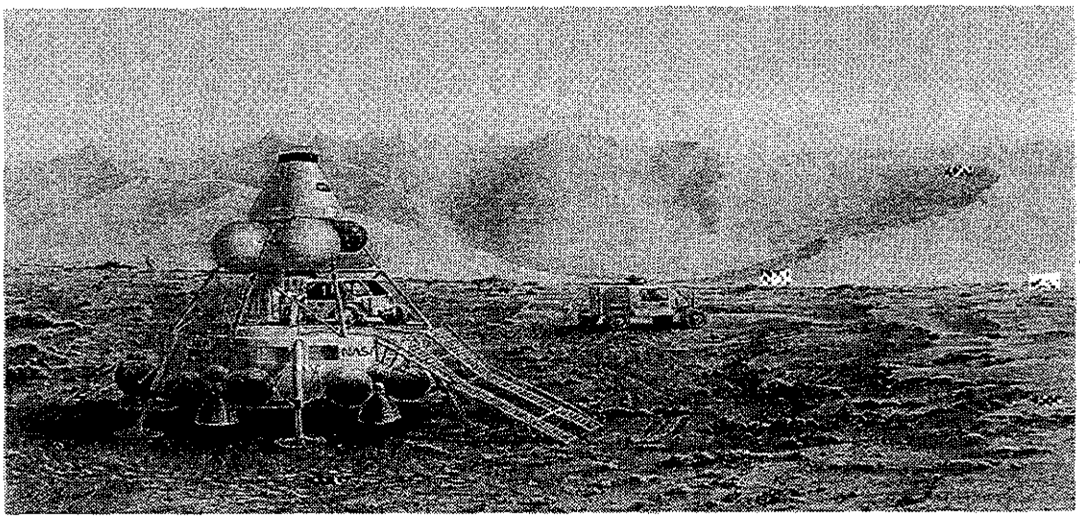
Flag and Footprints Mission to Mars
Preliminary Design Review Two



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SMi

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Space Mission Innovations

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Abstract

SMI has developed a preliminary guideline for a flag and footprints manned mission to Mars. The manned mission is a split mission where the return and ground supplies will be sent on a cargo spacecraft. The crew spacecraft will leave on a high-energy trajectory once the cargo spacecraft has arrived in the prescribed orbit about Mars. The trajectory will be approximately 150-day from Low Earth Orbit (LEO) to the prescribed rendezvous orbit. The crew spacecraft will then dock with the orbiting cargo spacecraft for refuel and resupply. In addition, once safely docked, the crew members will transfer to the Mars Excursion Vehicle (MEV) for transport to the Martian surface. Each vehicle will be equipped with all necessary subsystems. To facilitate the transport of a large payload from Earth to Mars, the cargo spacecraft will utilize Ion propulsion. The Ion propulsion is ideal due to the high I_{sp} characteristics. The crew spacecraft will be propelled with high-thrust RL-10 engines. Due to the smaller mass of the crew spacecraft, the spacecraft will utilize a 150-day high-energy trajectory. The MEV propulsion will be hypergolic. This choice of fuel is due to the reliability and simplicity of use. The crew members will stay on the surface of Mars for 30-days. During the 30-days, the crew will perform a series of scientific and exploratory experiments. To broaden the astronauts range of exploration, the astronauts will have access to three Unmanned Aerial Vehicles (UAV) and one rover while on the surface. The scientific experiments will consist of several soil and rock analyses as well as atmospheric study. Upon completion of the 30-day ground phase, the astronauts will return to the orbiting crew ship for return to Earth. SMI's flag and footprints mission outlines the fundamental systems and general requirements for these systems. SMI feels that with the fulfillment of these fundamental systems, this mission will be a highly desirable and potential candidate for development by NASA.

Executive Summary

This document presents the preliminary design by SMI to provide NASA with a highly desirable manned mission to Mars in the event political interest arises. This Flag and Footprints mission will deliver a manned spacecraft to the surface of Mars within a minimal duration. Additionally, the mission concept will be constrained to use existing technology. Initially, SMI developed concepts for three mission alternatives. Each of these missions offer unique advantages as well as disadvantages. The first scenario investigated by SMI utilizes a single vehicle to conduct the entire mission. The second scenario utilizes the split mission concept and remote rendezvous. The third scenario was also a split mission, but avoided remote rendezvous by using precision landing on the Martian surface. The single vehicle mission was eliminated due to the high fuel requirements to satisfy the designated mission constraints. The other two scenarios offer solutions that greatly reduce the mission fuel requirements. The separation of the cargo and crew phases allows for the feasibility of sending the crew spacecraft on a 150-day sprint trajectory. The primary difference between the second and third scenarios is the remote rendezvous versus precision landing. SMI opted to develop the remote rendezvous mission scenario. The two main reasons for SMI's choice was additional savings in fuel requirements as well as the proven reliability of a remote rendezvous in space. A brief overview of the mission scenario is described in the following paragraph.

The cargo spacecraft will utilize low-thrust ion propulsion to travel to Mars. Once the cargo spacecraft arrives in the determined orbit configuration, the crew spacecraft will utilize RL10 engines to depart Earth and enter a high-energy 150-day sprint trajectory to Mars. Upon arrival at Mars, the crew spacecraft will maneuver into the same orbit around Mars as the cargo spacecraft. A remote rendezvous will be required for resupplying and refueling of the crew spacecraft as well as for access to the Mars Excursion Vehicle (MEV). The astronauts, once docked with the orbiting cargo ship will transfer into the MEV for descent to the surface of Mars. Once on the Martian surface, the astronauts will stay 30 days where they will conduct several scientific and exploratory experiments.

SMI's first goal after identifying the mission scenario was to develop a list of necessary subsystems for all the vehicles. The subsystems SMI identified are as follows: Power Systems, Communications, Guidance/Navigation/Control, Propulsion, Environment Control and Life Support System, Thermal Protection System, and Radiation Shielding. This is just a preliminary list and SMI expects that this list will expand as the mission develops. All of these systems play an integral part in the success of the mission. Specific details surrounding each of these subsystems is detailed in Section 4.0.

In addition to identifying the necessary subsystems for the mission, SMI had to investigate methods to develop the trajectory for the crew and cargo spacecraft. The trajectory parameters include launch site and date, initial parking orbit, time of flight, necessary plane changes, Mars orbit insertion, parking orbit regression. SMI utilized these parameters to develop trajectories and launch dates for both the cargo and crew spacecraft. Due to lack of time, actual numerical solutions were not accomplished.

The technical aspects of the project have been broken up into researching and developing specifications for the cargo spacecraft, crew spacecraft, Mars excursion vehicle, and launch vehicles. For each vehicle, the team developed trajectories, necessary subsystems, preliminary mass and size analysis of subsystems, propulsion and fuel requirements for each vehicle.

Each of the mission vehicles will be assembled in LEO. This is due to the size and quantity of supplies necessary for a mission of this nature. Vehicle components will be placed in LEO by a series of launch vehicles. SMI is considering three launch vehicle alternatives. The three launch vehicles are the Titan IVb, the Shuttle, and the Proton rocket. Each of these were selected for their proven reliability and high payload capacity. Each launch vehicle offers unique capabilities and these capabilities will govern the configuration for which the vehicle components will be placed in LEO.

The cargo spacecraft will utilize ion propulsion rockets to transport from Earth to Mars. The initial escape from Earth has not yet been determined. There are two methods for escaping Low Earth Orbit(LEO). The cargo spacecraft can either utilize a high-thrust rocket to propel the craft outside the Earth's sphere of influence or the cargo spacecraft can use the low-thrust ion propulsion the entire time. Using the high-thrust escape will reduce the cargo mission length by up to two years(see Fig. 6.1). The disadvantage of the high-thrust escape is the cost associated with the amount of fuel required. Using low-thrust propulsion the entire time greatly extends the mission time, but reduces the cost and fuel requirements significantly. After the cargo spacecraft escapes Earth's gravitational influence, the cargo will be propelled solely by ion propulsion. Upon arrival at Mars, the cargo spacecraft will autonomously maneuver into a stable Low Mars Orbit(LMO). Once in orbit, the cargo spacecraft will notify Earth so that the crew ship may depart. The cargo spacecraft will be equipped with all surface equipment, included the MEV. In addition, the cargo spacecraft will transport all return supplies and fuel for the crew spacecraft. Initial mass estimates are identified in Table 6.1. The cargo spacecraft, once assembled, is estimated to have a mass of approximately 1,100,000 kg. Approximately a 100,000 kg of the cargo weight is appropriated for the MEV. SMI's conceptual drawing of the cargo spacecraft, without the MEV, is depicted in Figure 6.3 and 6.4.

After notification of the orbit injection of the cargo spacecraft, the crew spacecraft will depart on a high-energy sprint trajectory to Mars. The time of flight to reach Mars is approximately 150 days. The primary propulsion system to be utilized by the crew spacecraft is a RL10 engine. The crew spacecraft will dock with the orbiting cargo ship to refuel, resupply, and allow the astronauts to enter the MEV for transport to the surface. The crew spacecraft will provide supplies for the 150-day TOF to mars and all necessary subsystems for survival of the crew. Table 7.4 identifies a list of subsystems identified by SMI and their respective estimated masses. The assembled crew spacecraft is roughly the same mass as the cargo spacecraft with one major difference. The primary mass of the spacecraft is comprised of fuel. After completion of the surface mission, the crew will depart Mars on a similar high-energy 150-day trajectory to Earth. SMI's conceptual design of the crew spacecraft is depicted in Figure 7.5 and 7.6

Figure 8.3 depicts SMI's proposed descent phases for the MEV. Upon departure from the orbiting cargo spacecraft, the MEV will enter the atmosphere at proper enter angle. The heatshield will be used to avoid any damage of the MEV from aerodynamic heating. Once in the atmosphere, the MEV will eject the heatshield and deploy a series of parachutes. Retro-engines will be used to provide a soft landing on the Martian surface. The primary source of propellant will be hypergolic due to the proven reliability and simplicity. Initial mass estimates and subsystem requirements are identified in Table 8.2. Once on the surface of Mars, the crew will initiate the ground phase of the mission. A conceptual design of the MEV is depicted in Figures 8.4 and 8.5.

The astronauts will be responsible for conducting several experiments while on the surface of Mars. The experiments range from soil analysis to remotely piloting Unmanned Aerial Vehicles (UAV) for detailed resolution of the Martian surface. The primary goal of the ground phase is to explore as much of the surface as possible in the limited time allotted. In addition to the UAV's, the astronauts will have a rover to extend the range of exploration and sample collection.

Upon completion of the 30-day ground phase, the crew will depart in the designated ascent vehicle (see Fig. 8.5). Once in orbit, the ascent vehicle will dock with the orbiting cargo spacecraft, and the crew will transfer back into the crew spacecraft. The crew spacecraft will then depart from Mars on a 150-day high-energy return trajectory to Earth. To avoid the high fuel requirements to obtain a new orbit about Earth, the crew will utilize an Apollo style capsule to reenter the Earth's atmosphere and splash down on the surface.

Due to time constraints and limited manpower, a few tasks were not investigated. SMI did not develop any abort mission scenarios for the manned mission to Mars. We recognize the extreme importance, but felt other details of the mission were more critical. In addition, many of the general requirements of the subsystems were not determined. The subsystems general requirements are key to developing detailed analysis of the spacecraft design and layout. Furthermore, many key phases of the vehicles trajectories need refining for precise launch date and TOF determination. SMI hopes that future teams will develop the concepts outlined in this paper.

This semesters work has focused primarily on the development of a skeleton for the manned mission to Mars. Having a strong mission concept will allow for future groups to develop the critical details. This report identifies critical areas of the mission as well as potential solutions for these details. SMI feels that with the fulfillment of these critical areas, this mission will be a highly desirable and potential candidate for NASA.

Presentation Overview

- Problem Statement
- Mission Description
- Mission Overviews
- Crew Spacecraft Details
  - Trajectory Analysis
  - Subsystems
  - Mass Analysis
- Reliability Statement
- Future Work
- Questions

Introduction

- Project Motivation
  - New Millennium people are more open to ideas
  - Scientific Advancement
  - Human Nature to Explore
- Project Background
  - Update of Previous Mission From '91
  - No new technology to increase reliability
  - Limited science to reduce complexity

Problem Statement

To provide NASA with a highly desirable Manned Mission To Mars in the event Political Interest arises

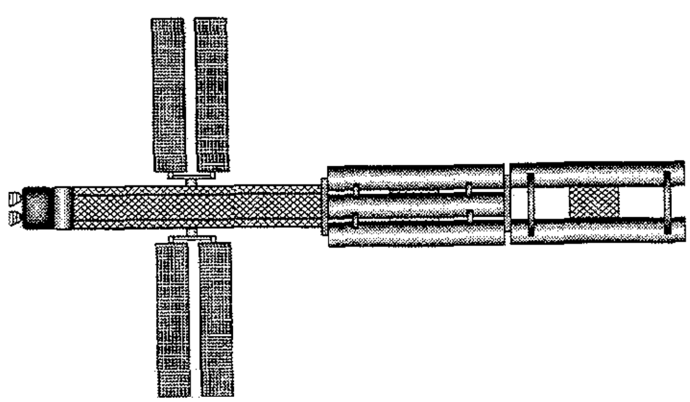
Mission Description

- Split Mission
- Cargo Spacecraft
  - Will Utilize Low-Thrust Ion Propulsion
- Crew Spacecraft
  - Will Utilize High-Energy 150-Day Sprint Trajectory
- Remote rendezvous
  - Required for Resupplying and Refueling of the Crew Spacecraft
- Mars Excursion Vehicle (MEV)
  - Provide Crew with Transportation to and from the Surface of Mars
- 30-Day Ground Phase

Cargo Mission Overview

- Spacecraft is designed to deliver surface exploration equipment and return trip supplies
- Cargo spacecraft equipped with a Mars lander loaded with exploratory equipment and supplies
- Cargo spacecraft sent on low energy trajectory
- Ion propulsion
- Crew module will dock with the cargo spacecraft for supplies, refueling, and lander usage

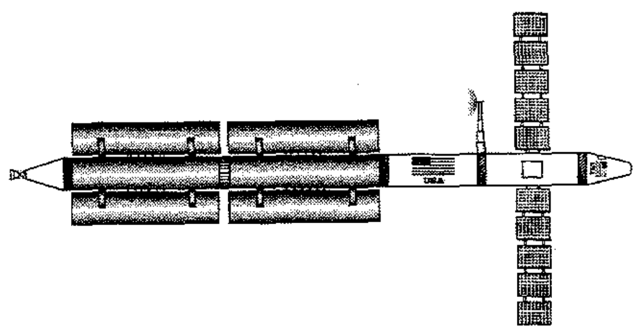
Cargo Spacecraft Conceptual Design



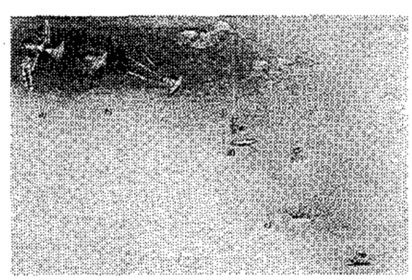
Crew Mission Overview

- Manned Spacecraft
- Spacecraft is a Transfer and Return Vehicle
- Cryogenic Propulsion (LOX/LH2)
- Spacecraft Sent on a High Energy "Sprint" Trajectory
- Spacecraft will Dock with the Cargo Spacecraft to Resupply, Refuel, and Access Lander

Crew Spacecraft Conceptual Design



MEV Mission Overview



MEV separates from cargo spacecraft and enters Martian atmosphere

Parachutes are deployed to slow fall and heatshield is jettisoned

Parachutes jettisoned, legs of MEV extended, and retro-engines fired for final deceleration

MEV touches down

Ground Phase Mission Overview

- One month stay
- Perform UAV experiments
  - Set up all equipment
  - Determine areas of interest
  - Remotely pilot the aircraft
- Perform observatory/science experiments
  - This has yet to be determined
- Collect Martian samples for analysis at Earth
  - This has yet to be determined

Crew Spacecraft Details

TRAJECTORY ANALYSIS

- Trajectory Utilizing Lambert Targeting
  - Requires Only the Present Location, Arrival Destination, and Time of Flight
  - ΔV's can be Easily Determined
- Approximately 150 days (1 way)
- Arrive in Low Mars Orbit (LMO)
- Conduct Rendezvous with Cargo Spacecraft

Trajectory Analysis: Sample Optimized ΔV's:
(Source: Tim Crain's Web Page)

Year 2007: 150 Days

	Launch	Arrival	Combined
Departure Day	275.0	328.0	295.0
Arrival Day	60.0	113.0	80.0
ΔV (km/s)	4.397	3.226	9.027

Year 2008: 150 Days

	Launch	Arrival	Combined
Departure Day	1.0	1.0	1.0
Arrival Day	150.0	150.0	150.0
ΔV (km/s)	13.66	5.033	18.693

Year 2009: 150 Days

	Launch	Arrival	Combined
Departure Day	311.0	365.0	333.0
Arrival Day	96.0	150.0	118.0
ΔV (km/s)	4.445	3.778	10.113

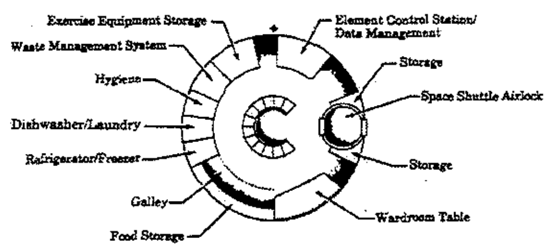
Subsystems

- Propulsion
  - Pratt & Whitney RL-10 A-4-1's
  - LOX/LH2 Propellant
  - Max. Thrust (vac.) 22,300 lb.
  - Isp 451 sec.
  - Special Features:
    - Multiple Starts in Space
    - Expander Cycle provides Self-Starting Capability

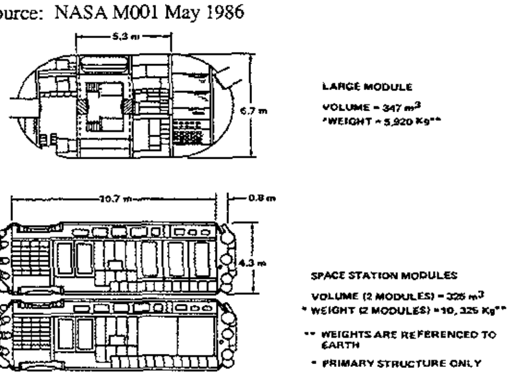
Source: Pratt & Whitney Co.

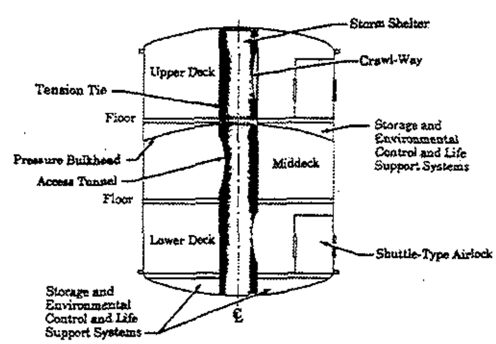
Subsystems

- Crew Modules
  - 3 or 5 Crew Members
  - Multiple Sections
  - Multiple Decks



Source: NASA M001 May 1986





Subsystems

- Environmental Controls and Life Support Systems (ECLSS)
  - Food (pre-packaged, no vegetation)
  - Hygiene (shower)
  - Exercise Equipment (bicycle or treadmill)
  - Water and Waste Management (recycle)
  - Space Suits
  - Temperature and Humidity Control
  - Atmospheric Pressure and Composition Control

Subsystems

- Radiation Shielding
  - WHY?
    - Protection Against Solar Flares and Galactic Cosmic Rays
  - HOW?
    - Place Matter Between the Crew and Radiative Rays
    - Aluminum Shielding, Water, Propellant
    - Existing Equipment
  - EFFECTS?
    - Cell Damage, Vomiting, and Nausea

Crew Mass Analysis: Mars Crew Transfer Vehicle

Spacecraft System	Specifications	Mass (kg)
RCS/Attitude Control	Gyro/Guide Star Telescope	8236.0
Avionics	TBD	1000.0
Radiation Shielding	TBD	9000.0
Crew Module	TBD	25000.0
ECLSS	Standard	14875.0
Earth Re-entry Vehicle	(Apollo Type)	5500.0
Power Systems	Solar/Fuel Cell/Battery	1600.0
Propellant	LOX/LH2	992176.0
Propulsion System	RL-10 (5)	1400.0
Structure	TBD	3977.0
Tankage	TBD	25330.0

Total Vehicle Mass: 1,100,000 kg (~1200 Tons)

Reliability Statement

- Thoroughly Researched
  - Mission Concept
  - Trajectory Analysis
  - Propulsion Systems
  - Remote Rendezvous
  - Preliminary Subsystems
  - Technological Requirements
- More Research Needed
  - Mass Analysis
  - Spacecraft Structural Design
  - Subsystems Power & Volume Requirements
  - Ground Phase

Future Work

- Investigate:
  - Abort Scenarios
  - Science Equipment/Experiments
  - Spacecraft Mass
  - Spacecraft Structural Design
  - Subsystems Power & Volume Requirements
  - Ground Phase
  - Human Factors

Conclusion

Mission Description:

Cargo Spacecraft

Low-Thrust Trajectory to Mars

Cargo Includes: Return Supplies and Fuel, MEV

Crew Spacecraft

High-Energy Sprint Trajectory to Mars

150 Day (1-Way)

Remote Rendezvous

Crew S/C Docks with Cargo S/C in LMO

Crew Transfer to MEV

Conclusion

Mission Description:

- MEV
  - Provide Crew Transportation to Martian Surface
  - Possible Habitat for Crew
- Ground Phase
  - 30-Days
  - For Exploration and Experimentation