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MARS SAMPLE RETURN MISSION TWO ALTERNATE SCENARIOS

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Two scenarios for accomplishing a Mars Sample Return mission are presented herein. Mission A is a low-cost, low-mass scenario, while Mission B is a high-technology, high-science alternative.

Mission A begins with the launch of one Titan IV rocket with a Centaur G' upper stage. The Centaur performs the trans-Mars injection burn and is then released. The payload consists of two lander packages and the orbital transfer vehicle, which is responsible for supporting the landers during launch and interplanetary cruise. Near Mars, the landers separate—one bound for a polar site and the other for an equatorial site. After descending to the surface, the landers deploy small, local rovers to collect samples. The rovers return these samples to the landers for loading on the direct return rockets, which return the samples directly to the Earth's surface.

Mission B starts with four Titan IV launches, used to place the components of the planetary transfer vehicle (PTV) into orbit. The fourth launch payload is able to move to assemble the entire vehicle by simple docking routines. Once complete, the PTV begins a low-thrust trajectory out from low Earth orbit, through interplanetary space, and into low Mars orbit. It deploys a communications satellite into a one-half sol orbit and then releases the lander package at 500 km altitude. The lander package contains the lander, the Mars ascent vehicle (MAV), two lighter-than-air rovers (called Aereons), and one conventional land rover. The entire package is contained within a biconic aeroshell. After release from the PTV, the lander package descends to the surface, where all three rovers are released to collect samples and map the terrain. The Aereons attempt to circumnavigate Mars and collect samples from a wide variety of sites, while the land rover examines a local area more thoroughly. The Aereons are equipped with small sample return rockets that can return their samples to the lander in the event that an Aereon is incapable of returning to the lander itself. Once all samples have been collected, they are loaded onto the MAV and launched into orbit. The PTV then collects the samples and returns them to Earth orbit for recovery.

INTRODUCTION

Penn State's design project for the 1990-91 academic year was the Mars Sample Return mission, currently under study by the Human and Robotic Spacecraft Office (HRSO) at Johnson Space Center.

The Mars Rover Sample Return Mission Science Objectives Document[1] states, "The objectives of the MRSR mission are twofold: (1) To reconstruct the geological, climatological, and biological history of Mars and determine the nature of its near-surface materials, (2) To obtain key environmental information and test key technologies necessary to maximize the safety and effectiveness of eventual human exploration."

A Mars Sample Return mission will "address the above goals by doing in situ analyses and returning a suite of intelligently selected samples representative of the planet's diversity."

The students participating in this year's design class were given a list of desired sample types and amounts, with the task being to acquire some or all of the sample set and return it to Earth by the year 2010. For the Fall '90 semester, the class was challenged to examine several alternative methods of achieving their mission and to evaluate the alternatives based on their own established criteria. For the Spring semester, the class was divided into two mission design teams, and each was given a mission scenario compiled from interesting features of the previous semester's designs. The two teams were composed of several groups, with each being responsible for a specific mission element of its team's scenario. Figures 1 and 2 depict the two mission scenarios. The suggested sample set is presented in Table 1.

This class comprises the required senior-level design sequence at Penn State and consists of two credits of conceptual and preliminary design in the Fall, followed by two credits of detailed design in the Spring.

TABLE 1. Suggested sample set.

Regolith	50 g
Rock Fragments/Chips	1000 g
Pebbles	2085 g
Boulder Specimens	70 g
Core Sample	1256 g
Atmosphere	160 cm^3

MISSION A

Mission A is a low-cost, low-mass mission scenario satisfying the following mission requirements:

1. All mission elements had to fit on one launch vehicle without assembly or construction in Earth orbit;
2. The trans-Mars injection had to be performed by the upper stage on the launch vehicle;
3. No Mars orbit operations, such as a satellite or a rendezvous, were permitted;
4. The mission had to use two landers, each with a small, land-based rover and a direct launch-to-Earth return vehicle.

These requirements were developed after a review of the previous semester's preliminary design work.

The scenario designed to meet these requirements can be seen in Fig. 1. A single Titan IV/Centaur G' launch is used to boost the payload on a trajectory to Mars. The payload consists

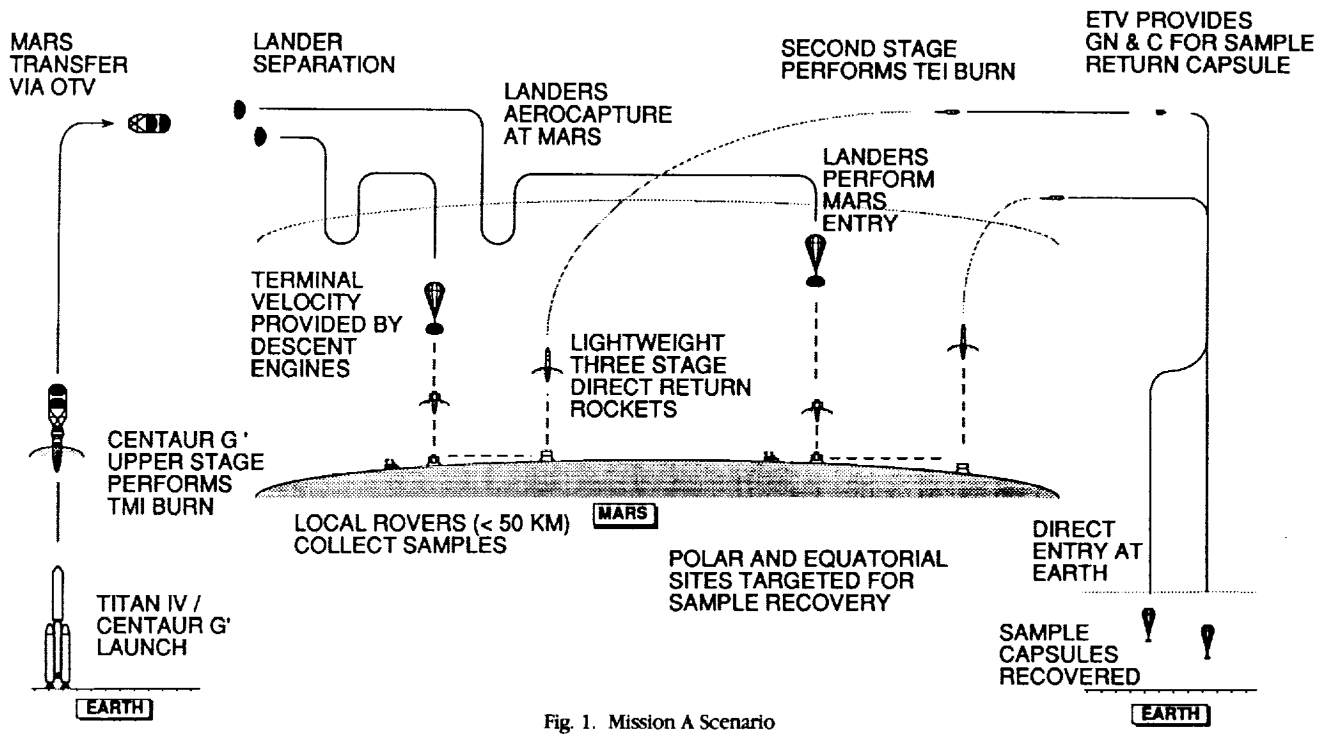

Fig. 1. Mission A Scenario

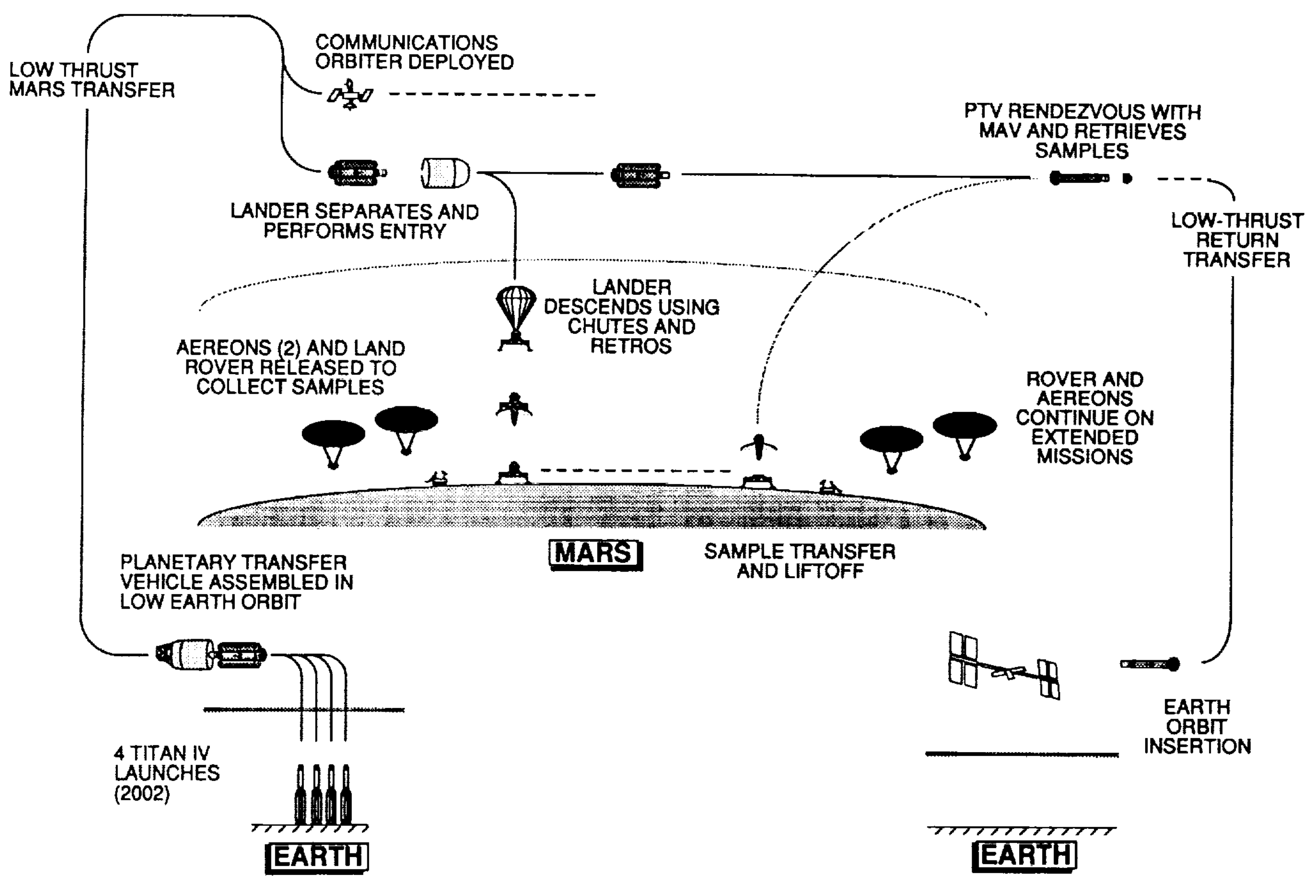

Fig. 2. Mission B Scenario

of two lander vehicles supported by an orbital transfer vehicle (OTV). The OTV supports the landers during launch and interplanetary cruise and uses shared systems to reduce mass and avoid unnecessary duplication. This means that the OTV has access to the landers' communications, power, and computer systems. It does, however, have its own attitude and control system to make course corrections as necessary. As the OTV approaches Mars, it is jettisoned, and the two landers continue on independently—one bound for a polar landing site and one for an equatorial site.

The landers aerocapture into separate orbits, and then proceed to land. They have blunt aeroshells similar in shape to those used on the Viking missions, but made to withstand both an aerocapture and an atmospheric entry. Once the entry process is complete, the aeroshells are jettisoned, and the parachutes deployed. The parachutes slow the landers to a velocity of approximately 60 m/s at an altitude of 1.5 km. At this time, the parachutes are discarded, and the retrorockets begin to fire. There are four retrorockets per lander, and they use a hydrazine/NTO propellant combination to slow the lander for a soft landing.

Once on the surface, the landers collect a contingency sample of regolith and atmosphere to insure at least a partial mission success should a rover fail. The landers are also responsible for collecting the core sample, which they do after obtaining the contingency samples. The mars sample acquisition vehicles (MSAVs) are then deployed.

The MSAVs are small, local rovers that range no more than 1 km from the lander. Each MSAV is an articulated, three-body, six-wheeled vehicle powered by a modular radioisotope thermoelectric generator (MOD-RTG). It is semiautonomous, and therefore dependent on instructions from Earth to execute complicated procedures. The MSAV has two arms: one for high-strength work and one for high-precision work. Both arms have access to a number of tools for acquiring samples and a variety of analysis equipment to determine the fitness of a candidate sample. Samples worth keeping are placed in small teflon bags that are then placed in a basket on the rover. When the MSAV has completed collecting samples, it returns to the lander. The lander uses its robotic arm to remove the basket from the rover and place it aboard the direct return rocket (DRR).

The DRR is a three-stage vehicle capable of returning a sample return capsule directly from the martian surface to an Earth splashdown. The first two stages are simple, solid-propellant rocket stages using an advanced, high specific impulse propellant. Together these stages move the payload into a low Mars orbit, and then perform the trans-Earth injection. The third stage of the DRR is the Earth transfer vehicle (ETV). It is based on the kinetic kill vehicle (KKV) developed for the Strategic Defense Initiative and provides guidance, navigation, and control for the sample return capsule as it returns to Earth. Once the capsule has been placed on its reentry trajectory, the ETV detaches and the capsule continues on an unpowered entry. The small size of the capsule keeps it from generating much heat, so an ablative heat shield and passive thermal control devices are sufficient to protect the samples from damage.

This mission was costed using the Advanced Space Systems Costing Model developed by Kelly Cyr at Johnson Space Center[2]. Each mission element was costed separately, and the results are shown in Table 2.

TABLE 2. Mission A costs (in millions of U.S. dollars).

Launch Costs (Titan IV/Centaur G')	265
Orbit Transfer Vehicle	552
Landers (2)	1746
Mars Sample Acquisition Vehicles (2)	708
Direct Return Rockets (2)	230
Total Mission Cost	3236

MISSION B

Mission B is a high-science-return, high-technology scenario, and was designed under the following requirements:

1. Multiple launches were permitted, but Earth-orbit assembly was limited to simple docking routines (i.e., no on-orbit construction);

2. An orbital transfer vehicle, using radioisotope engines for propulsion, was to be used to transfer all mission elements from low Earth orbit to low Mars orbit and then back again upon completion of the mission. The transfer vehicle was to remain in Mars orbit while surface operations were conducted;

3. A communications and tracking satellite was to be included and deployed in an appropriate Mars orbit;

4. A lander was required, and was to be responsible for delivering three rovers to the planet's surface. Additionally, the lander was to include an ascent vehicle that would deliver the collected samples to the waiting transfer vehicle;

5. Two of the rovers were to be small, lighter-than-air (LTA) vehicles based on the Aereon principle. These rovers were required to attempt to circumnavigate Mars, collecting small amounts of samples from a large variety of sites. In case an LTA rover failed to return sufficiently close to the lander, a minirocket could be included to attempt to launch the collected samples to the vicinity of the lander;

6. The third rover was to be a large, land-based rover responsible for investigating the area near the lander in detail. This rover was also to collect the majority of the samples, including those the LTA rovers were unable to collect due to weight limitations;

7. All rovers were to deliver their samples back to the lander for delivery to orbit via the ascent vehicle.

These requirements were developed after a review of the preliminary scenarios developed during the Fall '90 semester.

The mission designed to fulfill these requirements can be seen in Fig. 2. Four Titan IVs launch their payloads into low Earth orbit. The first two payloads consist of one tank of ammonia each. The third payload consists of the communications satellite and the lander package, which contains all the vehicles operating on the martian surface. The final launch contains the central module of the planetary transfer vehicle (PTV), which consists of the third and final ammonia tank, the sample retrieval bay, and the transfer vehicle's subsystems. The central module then maneuvers on-orbit to rendezvous with and connect to the other sections.

Once the PTV is fully assembled, it begins a low-thrust spiral out of Earth orbit. The PTV's radioisotope engines produce thrust by heating a working fluid and expanding it out from a diverging nozzle in a similar manner to a nuclear thermal engine. A decaying radioactive isotope provides the heat. Ammonia was chosen to be the working fluid due to its relatively high density and high specific impulse. This configuration results in a total thrust of approximately 10 N, with a specific impulse between 800 and 1200 s.

Upon reaching the vicinity of Mars, the PTV spirals into a low orbit. Along the way, it releases the communications satellite into a roughly circular 9300-km orbit that has an orbital period of approximately one-half a martian day. This will allow the satellite to be in contact with each vehicle on the surface, including the Aereons, for a considerable amount of time each day.

After the PTV settles into a 500-km orbit, it releases the lander package, which subsequently begins an atmospheric entry. The lander package is contained in a biconic aeroshell that slows the lander to Mach 2 at an altitude of 6 km. At this time, the aeroshell is jettisoned, and the parachutes are deployed to slow the lander further. The conical ribbon chutes are made of Kevlar and are designed to bring the lander's speed to 60 m/s at an altitude of 1.5 km before being discarded as the retrorockets begin to fire. The retrorockets use a hydrazine/H_2O_2 combination and slow the lander sufficiently to provide a soft landing.

Once on the ground, the lander collects the contingency samples and loads them onto the Mars ascent vehicle (MAV) prior to releasing the rovers. The rovers are then deployed to collect their samples. The landing site is at Candor Mensa, a proposed landing site for a manned mission, and has a number of geologically interesting features within range of the land rover.

The Aereons' primary mission is to collect information about the martian surface as they attempt to circumnavigate the planet. The principal means of doing this is by using the instruments on board to conduct *in situ* analysis. Additionally, the Aereons will collect a few regolith and atmospheric samples along the way. The Aereons function using the Aereon principle developed by Andrews in 1862; it holds that certain orientations of an ellipsoid balloon generate thrust as the vehicle ascends or descends. Using this thrust, the Aereon can pilot its way to a specific location with some accuracy. The Aereon is filled with hydrogen gas that is stored in tanks on the lander until the Aereons are deployed. Additionally, there are ballast balloons that can be filled with martian air as needed to cause the Aereon to ascend or descend. Once an Aereon has collected its samples (totalling no more than 7 kg per vehicle), it will attempt to return to the lander. Since the accuracy of the Aereons' navigation may be insufficient to bring them within range of the land rover, each is equipped with a small sample return rocket with a range of approximately 200 km and capable of carrying all the Aereon's collected samples. These rockets are equipped with radio beacons so that they can be located by the land rover.

The land rover is a large, three-bodied, six-wheeled vehicle with a range of at least 200 km. It is equipped with the sample acquisition robotic system (SARS), a set of tools and scientific instruments that permit the rover to be very selective when examining a candidate sample. The SARS is also equipped with two robotic arms for acquiring the samples. A 6-degree-of-freedom (DOF) acquisition arm will perform jobs requiring high strength, while a 7-DOF manipulator arm will perform those jobs that require more precision. The rover will use the SARS to collect almost 60 kg of samples, including regolith, core samples, boulder chips, pebbles, and rock fragments. As the samples are collected, the rover will make periodic stops at the lander to have its samples loaded onto the MAV. This procedure will prevent all the samples from being lost in the case of a mission-ending accident for the rover. The rover also supports the Aereons by moving to retrieve samples from them or their sample return rockets, in the event that they are unable to return precisely to the lander.

This mission was also costed using the Advanced Space Systems Costing Model[2]. Each mission element was costed separately, and the resulting mission costs are shown in Table 3.

TABLE 3. Mission B costs (in millions of U.S. dollars).

Launch Vehicles (4 Titan IVs)	1000
Planetary Transfer Vehicle	1200
Communications Satellite	367
Lander and MAV	2936
Land Rover	905
Aereons (2)	1266
Total Mission Cost	7674

REFERENCES

1. Carr M. et al. Mars Rover Sample Return: Science Objectives Document. JPL Document No. D-6247. February 1, 1989.
2. Cyr K. "Cost Estimating Methods for Advanced Space Systems." SAWE Paper No. 1856, Index Category No. 29. July 29, 1988.