Mission Design Overview for Mars 2003/2005 Sample Return Mission

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EXTENDED ABSTRACT:

In May 2003, a new and exciting chapter in Mars exploration will begin with the launch of the first of three spacecraft that will collectively contribute toward the goal of delivering samples from the Red Planet to Earth. This mission is called Mars Sample Return (MSR) and will utilize both the 2003 and 2005 launch opportunities with an expected sample return in October 2008. NASA and CNES are major partners in this mission.

The baseline mission mode selected for MSR is Mars orbit rendezvous (MOR), analogous in concept to the lunar orbit rendezvous (LOR) mode used for Apollo in the 1960s. Specifically, MSR will employ two NASA-provided landers of nearly identical design and one CNES-provided orbiter carrying a NASA payload of rendezvous sensors, orbital capture mechanisms, and an Earth entry vehicle (EEV). The high-level concept is that the landers will launch surface samples into Mars orbit, and the orbiter will retrieve the samples in orbit and then carry them back to Earth.

The first element to depart for Mars will be one of the two landers. Currently, it is proposed that an intermediate class launch vehicle, such as the Boeing Delta 3 or Lockheed Martin Atlas 3A, will launch this 1800-kg lander from Cape Canaveral during the May 2003 opportunity. The lander will utilize a Type-1 transfer trajectory with an arrival at Mars in mid-December 2003. Landing will be aided by precision approach navigation and a guided hypersonic entry to achieve a touchdown accuracy of 10 km or better. Although the exact landing site has not yet been determined, it is estimated that lander resource constraints will limit the site to between 15 degrees north and south latitudes.

Following touchdown, the lander will deploy a six-wheeled, 60-kg rover carrying an extensive suite of instruments designed to aid in the analysis of the local terrain and collection of core samples from selected rocks. The surface mission is currently designed around a concept called the surface traverse. Each traverse will involve the rover exploring a selected area of terrain up to 100 meters from the lander, the collection of rock core samples, and the delivery of the samples from the traverse back to a sample canister on the lander. Planning estimates indicate that up to three traverses may be possible during the expected 90-sol lifetime of the lander.

The canister that will receive the samples from the rover will be attached to the top stage of a small solid-fueled rocket mounted to the deck of the lander. This rocket is called the Mars Ascent Vehicle (MAV) and consists of three stages weighing a total of about 140 kg. After the conclusion of the surface mission, the MAV will lift-off and insert the sample canister into a near-circular orbit with an altitude of about 600 km and inclination of 45 degrees. The sample canister will wait in this orbit until it is retrieved by the orbiter sometime in early 2007.

In August 2005, the second lander and a CNES-provided orbiter weighing 2700 kg will depart for Mars. Currently, it is proposed that a single Ariane 5 provided by CNES will launch both of these two elements onto a Type-2 transfer trajectory. Although the orbiter and lander will be launched together, they will separate shortly after injection and will fly to Mars as two independent spacecraft. However, both spacecraft will perform a maneuver between 10 and 15 days after launch so that their arrival times at Mars differ by between 12 and 24 hours. This scheme will reduce the operational complexity at the encounter date.

A set of four 60-kg surface probes will ride piggyback on the orbiter to Mars. These CNES-provided probes are called Netlanders and will serve as surface stations for scientific investigations independent of the Mars Sample Return goals. Starting approximately one month prior to arrival at Mars, the orbiter will begin to release the Netlanders one at a time. Each release cycle will take several days, and will include time for precision navigation to execute one or two maneuvers that will target the Netlanders to their proper landing site. All four deployment cycles will be completed prior to 10 days before arrival.

Both the orbiter and lander will arrive in late-July 2006. Upon arrival, the lander will perform a precision landing and surface mission similar in concept to the one that was executed during the 2003 opportunity. Although the landing site for the 2005 opportunity has not been selected, it is expected to be different from the 2003 site to enhance the diversity of the collected samples.

The orbiter's arrival at Mars will be highlighted by the first use of aerocapture to insert a spacecraft into a capture orbit around another planet. The choice of aerocapture, as opposed to a propulsive orbit insertion, was considered mission enabling due to a reduction of over 2000 m/s in mission ΔV. Aerocapture will be targeted to produce a 250 km x 1400 km capture orbit with an inclination of 45 degrees. Current analysis indicates that achieving this goal will require approximately six minutes of flight deep in the atmosphere with a targeted periapsis of approach of about 43 km. After factoring into account the penalty for carrying a heat shield to survive aerocapture, the net savings compared to a propulsive orbital insertion amounts to several hundred kilograms.

After insertion, the orbiter will begin the preliminary rendezvous phase of the mission by searching the Martian skies for the sample canister injected into orbit by the 2003 MAV. This search for and orbit determination of the 2003 sample canister will normally be accomplished by listening for a radio beacon from the canister. However, if the beacon electronics have failed, the orbiter will use a long-range camera to perform an optical search and orbit determination.

Once the 2003 canister has been located, the orbiter will perform a series of maneuvers to align its orbit node, inclination, and semi-major axis to match those of the canister's orbit in a process called intermediate rendezvous. In order to reduce the amount of propellant required for rendezvous, the orbiter will maximize the use of drift orbits and gravity harmonics for orbit alignment at the expense of time. Consequently, this intermediate phase of rendezvous can take up to 20 weeks to complete.

The goal of the intermediate rendezvous phase is to deliver the orbiter to exactly the same orbit as the sample canister, but to a position approximately two kilometers in front of the canister along the velocity vector. During the approach from the two kilometers to capture, a laser radar will continuously pulse the sample canister to provide range and angle data. This information will aid in the final approach and capture of the canister into the EEV. All activities during this terminal rendezvous phase will be performed autonomously.

Sometime during intermediate rendezvous operations to capture the 2003 sample canister, the 2005 surface elements will complete their mission. At that time, the lander will launch the MAV to inject the 2005 sample canister into an orbit similar to that of the 2003 canister. After the orbiter has captured the 2003 sample canister, it will repeat the intermediate and terminal rendezvous process to retrieve the 2005 sample canister.

After both samples have been captured, the orbiter must wait until nodal regression rotates the orbit plane into the departure asymptote of the Earth-bound trajectory. If nodal alignment occurs before the departure date, the orbiter will perform a departure phasing maneuver (DPM) to increase the apoapsis altitude to over 30,000 km. This increase will slow the nodal regression rate to virtually zero.

The optimal date for departure from Mars is 21 July 2007. On that day, the orbiter will perform the trans-Earth injection (TEI) burn to escape Mars and achieve an Earth-return trajectory. Almost three-fourths of the propellant carried by the orbiter will be burned to produce the 2,455 m/s needed for Mars escape.

Arrival back at the Earth will occur on 29 April 2008, nearly 1,000 days after launch. However, the declination of the arrival asymptote is negative and precludes most landing sites in the northern hemisphere. In order to facilitate a continental United States landing, the proposed baseline is to target the Earth return trajectory for an Earth fly-by. The gravity assist from the fly-by will deflect the orbiter below the ecliptic plane and into a six-month Earth-to-Earth transfer trajectory arriving back at Earth on 30 October 2008. At that time, the declination of the arrival asymptote will be positive and northern hemisphere landing sites will be achievable.

Currently, mission design concepts are in an early stage of development and will change as the design team gains a better understanding of the intricacies of this challenging endeavor. This paper will present a summary of the mission design as understood today.