Mars Orbit Rendezvous Strategy for the Mars 2003/2005 Sample Return Mission

Louis A. D'Amario
Willard E. Bollman
Wayne J. Lee
Ralph B. Roncoli
John C. Smith

Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, CA 91109

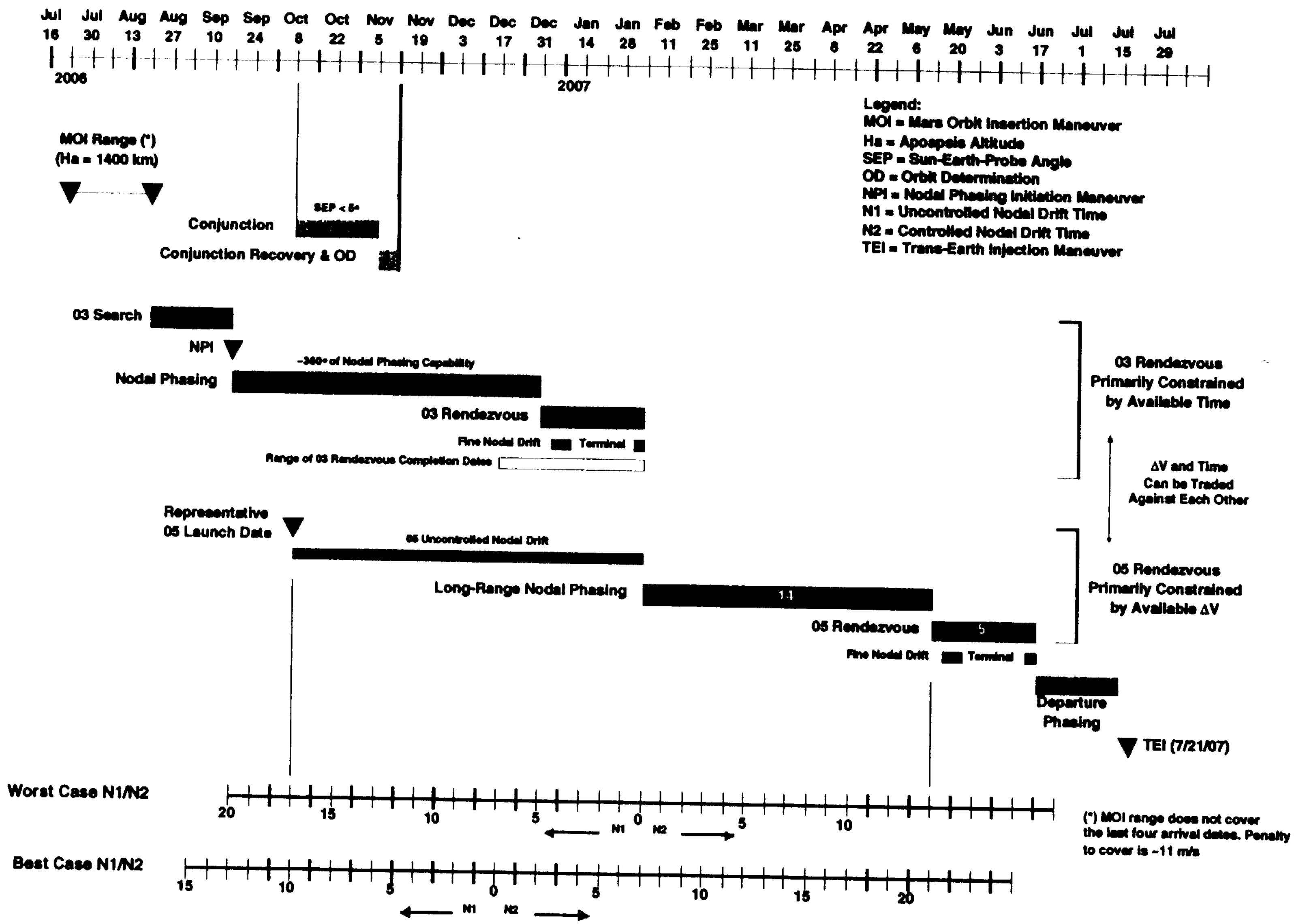
Corresponding Author: Louis A. D'Amario
Propulsion Laboratory, MS 301-276
4800 Oak Grove Drive
Pasadena, CA 91109
louis.damario@jpl.nasa.gov
818-354-3209 (Voice)
818-393-5214 (Fax)

The primary objective of the Mars 2003/2005 Sample Return Project is to return Martian surface materials to Earth from two different sites by the year 2008. The baseline mission plan relies heavily on the use of a Mars orbit rendezvous strategy similar to the lunar orbit rendezvous scheme used for the Apollo missions. The 2003 mission consists of a single spacecraft comprised of a Lander, Rover, and Mars ascent vehicle (MAV). The 2003 mission will be launched on a Delta-III-class launch vehicle in May/June 2003 and arrive at Mars in December 2003/January 2004. The Lander deploys the Rover to collect surface samples from several sites and return them to the Lander where they are transferred to a sample canister onboard the MAV. The MAV is launched into a low Mars orbit (targeted for 600 km circular, 45 deg inclination) and releases the sample canister to await retrieval by an Orbiter launched in 2005. (The sample canister is a passive vehicle with no maneuvering capability.) The duration of Mars surface operations is at most about 90 days. The 2005 mission consists of two separate spacecraft: a Lander/Rover/MAV spacecraft identical to that used for the 2003 mission and an Orbiter carrying an Earth Entry Vehicle (EEV). Both spacecraft will be launched on a single Ariane-5 in August 2005 and arrive at Mars in July/August 2006. A second sample canister is delivered to Mars orbit using the same scenario as was used for the 2003 mission. The Orbiter uses aerocapture for insertion into Mars orbit (targeted for 250 x 1400 km, 45 deg inclination). During its approximately one-year stay at Mars, the Orbiter will search for and attempt to rendezvous first with the 2003 sample canister and then with the 2005 sample canister. After retrieval, each sample canister is transferred to the EEV. The Orbiter departs Mars in July 2007 and returns to Earth in October 2008 on a trajectory targeted for landing at the Utah Test and Training Range (UTTR). After deploying the EEV, the Orbiter performs a deflection maneuver to avoid reentry into Earth's atmosphere.

Mars orbit rendezvous operations (for each sample canister) are divided into three phases: preliminary rendezvous, intermediate rendezvous, and terminal rendezvous. There are two main goals for the preliminary rendezvous phase. The first is to find the sample canister either by means of an Orbiter radio direction finding (RDF) system acquiring a beacon signal transmitted from the sample canister or by means of an optical search using the Orbiter long-range rendezvous camera. The second is to accurately determine the orbit of the sample canister using data downlinked to Earth: radiometric data from the RDF system and/or optical images from the long-range rendezvous camera. The preliminary rendezvous phase may last up to 4 weeks.

During the intermediate rendezvous phase, the Orbiter performs a series of maneuvers to align the orbit node, inclination, semi-major axis, eccentricity, and line of apsides of the Orbiter with those of the sample canister. The goal is to deliver the Orbiter to exactly the same orbit as that of the sample canister and to a position approximately 2 km in front of the sample canister (i.e., along the velocity direction). In order to reduce the amount of propellant for these orbit-change maneuvers, the intermediate rendezvous strategy maximizes the use of nodal drift orbits and perturbations from gravity harmonics to align the orbit planes of the Orbiter and the sample canister. The intermediate rendezvous phase may last up to 20 weeks due to long periods spent in nodal drift orbits. (The timeline for the current baseline rendezvous strategy is shown in Figure 1.) During the

Figure 1. Rendezvous Timeline



intermediate rendezvous phase, ground-based navigation is used for orbit determination and maneuver calculations using data from the RDF system and/or the rendezvous search camera.

The terminal rendezvous phase starts at the 2-km separation point defined above and ends with retrieval of the sample canister inside a capture cone onboard the Orbiter. Terminal rendezvous operations are accomplished by an autonomous onboard rendezvous guidance and control system using data from a laser radar which provides range and direction from the Orbiter to the sample canister. The terminal rendezvous phase is expected to require up to 2-3 days.

The main focus of this paper is the strategy to accomplish the intermediate phase of rendezvous while using the minimum amount of ΔV for Orbiter maneuvering. The current baseline strategy has been developed to accommodate many factors that tend to cause the intermediate rendezvous phase to require either an excessive amount of time or an unacceptably large total ΔV. The total time available at Mars to rendezvous with both the '03 and '05 sample canisters is constrained to be about one year. For the timeline given in Figure 1 and the expected MAV orbit injection errors (± 100 km semi-major axis and ± 1.0 deg inclination, both 3-sigma values), the 3-sigma value (equivalent to ~99% probability) for the ΔV required for the intermediate rendezvous phase (combined '03 and '05 rendezvous) is 461 m/s, with a mean of 342 m/s and a one-sigma value of 40 m/s. The ΔV allocation for the terminal rendezvous phase (assuming two attempts for each sample canister) is 50 m/s. Thus, the total ΔV required for rendezvous with the '03 and '05 sample canisters is 511 m/s. This requirement is consistent with current estimates of the ΔV available for rendezvous (based on injected mass capability, propulsion system characteristics, and subtracting out ΔV required for all other mission phases).