ORBITAL TRANSFER TECHNIQUES FOR ROUND-TRIP MARS MISSIONS D. F. Landau,[1] B. W. Barbee,[2] R. C. Woolley,[1] R. Gershman,[1]; [1]Jet Propulsion Laboratory, California Institute of Technology (4800 Oak Grove Dr., Pasadena, CA 91109 damon.landau@jpl.nasa.gov), [2]NASA Goddard Spaceflight Center.

Introduction: A round-trip mission to Mars presents a particular set of orbital challenges. A well-known issue for human missions is that the ΔV-optimal orbits for Mars arrival are generally out-of-plane for departure, significantly increasing total mission mass [1]. For robotic sample return missions, the orbiting sample container could be in a plane that is inconvenient to reach from the arrival and departure interplanetary trajectories [2]. A hybrid mission where the crew retrieves an orbiting sample from Mars as part of their orbital mission would further compound these issues. However, the potential payoff of a combined robotic/human mission warrants the development of specialized techniques for Mars orbital transfers.

Baseline Scenario: The 2033 short-stay Mars opportunity provides a baseline mission to examine representative orbit transfer requirements. This trajectory has an arrival V_∞ at Mars of 3.7 km/s, 13.7 deg declination, and 6.7 deg right ascension. The departure V_∞ has a magnitude of 6.0 km/s with 12.7 deg declination and -0.9 deg right ascension. The stay time would be 60 days. The crew would arrive in a relatively massive (say 60 t) deep space vehicle (DSV) and enter an orbit that is generally not in plane with the target orbit. Part of the crew could then use a smaller space exploration vehicle (SEV, say an 8-ton pod) with propulsion stages to transfer to the destination orbit and back via a series of optimized transfers. The crew would then rendezvous with the DSV, which maneuvers into the departure plane before performing trans-Earth injection. The orbiting sample is assumed to be placed in a 500 km altitude circular orbit. A range of inclinations from 0 to 45 deg is examined to analyze the effect of different target orbits. These sample return mission scenarios are compared to similar trip scenarios to Phobos and to Deimos.

Transfer techniques: Because the DSV would be much more massive than the SEV, the trajectory optimization stresses minimization of the DSV ΔV. The largest maneuvers for the DSV are Mars orbit insertion and trans-Earth injection, and these maneuvers are minimized by parking the DSV in an orbit with a low periapsis and long period (e.g. 500 km altitude and one-sol period). The minimum ΔV to enter and depart this orbit is achieved with tangential burns at periapsis, however this minimum is usually unattainable because the arrival and departure orbits do not share the same plane. As shown in Figure 1, the cheapest way to reorient the arrival orbit to the departure plane is to either shift the line of apsides at arrival or departure or to “twist” the orbit along the line of apsides. These maneuvers are orthogonal and thus provide a large range of potential orbit orientations when combined. By aligning the apsides of the arrival and departure orbits, the ΔV for the DSV is generally minimized for round-trip Mars missions [3].

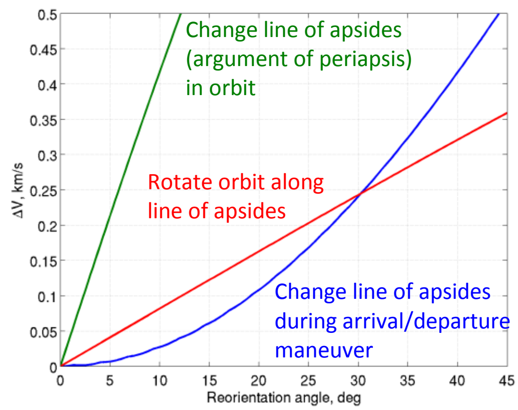

Figure 1 Relative cost of orbit reorientation techniques.

In order for the SEV to reach its target, it must first transfer to the plane of the target orbit, which is also generally not aligned with the arrival orbit of the DSV. If the arrival and departure orbits are designed with the additional constraint of having their line of apsides in the target orbit plane, then the additional ΔV for the SEV to reach its target can be minimized. In this case the SEV simply rotates its orbit along the line of apsides (red line in Figure 1) until it is in the target plane. The circular target orbit is achieved by changing periapsis and then circularizing at the target orbit altitude. At the conclusion of the target orbit mission, the SEV reverses this process to rendezvous with the DSV in the departure orbit for Earth return.

An example sequence to a 500 km, 45 deg inclination orbit is shown in Figure 2, where the arrival orbit, the departure orbit, and the transfer orbit all share a common periapsis with different inclinations. This geometry is possible by changing the line of apsides at the arrival and departure maneuvers (non tangential maneuvers) and by transferring between orbits by rotating along the common line of apsides.

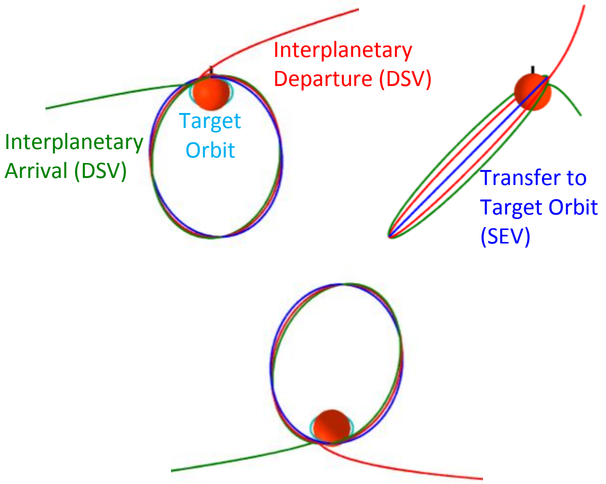

Figure 2 Transfer from arrival interplanetary trajectory to a 500 km, 45 deg orbit, then to departure.

The ΔV for the SEV to achieve a range of target orbits is provided in Figure 3. The ΔV ranges from 2.3–3.2 km/s depending on the orbit orientation, while the absolute minimum ΔV (from an energy standpoint) is 2.3 km/s. Thus the additional ΔV to account for the arrival and departure orbits is 0–0.9 km/s. The ΔV for the (much larger) DSV optimizes to approximately 4.9 km/s regardless of target orbit orientation. The minimum ΔV from an energy standpoint (tangential periapsis burns) is 4.6 km/s, thus the orbit transfer method has minimized additional ΔV to the DSV and places more of the ΔV burden on the smaller SEV.

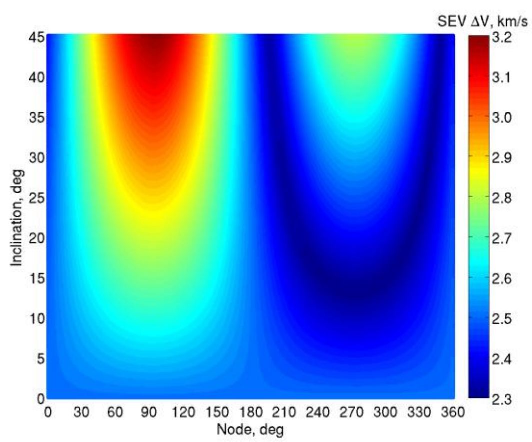

Figure 3 Orbital transfer cost of the SEV to reach a variety of potential target orbits at 500 km altitude.

In all cases the orbit transfer design satisfies the objectives of connecting the arrival V_∞ to the departure V_∞ with the DSV, while connecting the arrival and departure orbits to the target orbit via the SEV.

A potential round-trip mission to Phobos or Deimos is also possible by rotating between transfer orbits. In this case the transfer orbit also requires a maneuver to raise periapsis from the arrival orbit (low periapsis for efficient capture) up to Phobos altitude. An example trajectory is shown in Figure 4, where the ΔV for the DSV is 4.935 km/s and the ΔV for the SEV is 1.616 km/s. The ΔV for the SEV to transfer to Deimos from the same capture orbit is 1.282 km/s. For comparison, the Homann transfer ΔV for a round trip between Phobos and Deimos is around 1.5 km/s.

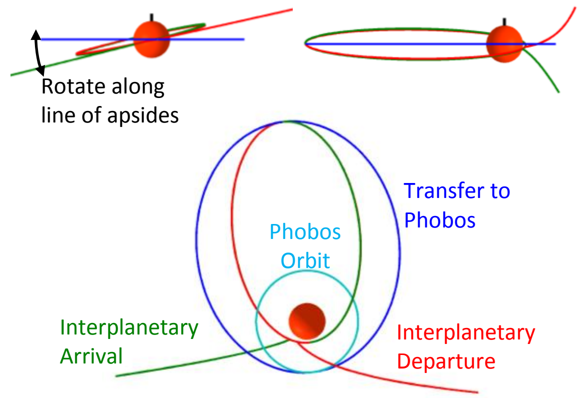

Figure 4 Example transfer to Phobos.

References:

[1] Luidens R. W. and Miller B. A. (1966) NASA TN D-3220. [2] Planetary Science Decadal Survey MSR Orbiter Mission Concept Study (2010). [3] Landau D. F. and Longuski J. M. (2005) *Spacecraft and Rockets*, 42, 517–522.