HUMAN & ROBOTIC MISSION APPLICATIONS OF LOW-ENERGY TRANSFERS TO PHOBOS & DEIMOS

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Introduction: It is well known that the exploration of Phobos & Deimos is quite valuable for future human missions to Mars. However, current chemical propulsion technology limits this exploration. Fortunately, it is possible to utilize the weak-stability boundary (WSB) [1] region in the Sun-Mars system to decrease the ΔV required to rendezvous with Mars' moons.

Description: After an Earth-departure transfer to Mars, the spacecraft targets a braking maneuver at closest Mars-approach (200 km altitude) to enable a loose capture in a highly elliptical Mars orbit which extends to the Sun-Mars WSB region (Fig. 1). At apoareion, the spacecraft performs a small targeting maneuver to change planes and set up a relatively low-energy rendezvous with either moon (Fig. 2). Although stable pseudo-orbits exist around Phobos and Deimos, such orbits do not spend extended periods of time within 10 km of either moon [2] (Fig. 3). As a result, it may be better (and safer) to plan for a rendezvous with (and eventual landing on) the Martian moons.

Although the WSB transfer lasts ≈90 days, the ΔV savings is significant. Defining the ΔV savings as the ratio between the actual ΔV saved (direct rendezvous vs WSB method) and the total ΔV (direct rendezvous) results in ΔV savings of ≈12% (Phobos) or ≈20% (Deimos). These savings vary with the launch opportunity, and for this short study, only 2016 (direct injection) & 2017 (multiple revolution about the Sun) launch opportunities were chosen for analysis.

Applications: For long-stay Mars opportunities, astronauts can utilize this WSB transfer trajectory to trade ΔV for surface time spent on a Martian moon. If a contingency occurs en route to Mars (e.g., leaked propellant), flying a WSB transfer trajectory may be needed. For short-stay Mars opportunities (surface time < 3 months), a less eccentric ellipse (with period < 45 days) can be flown instead of the WSB ellipse, which can still save significant ΔV and allow astronauts ample time for surface science. Flying WSB transfer trajectories may also prove valuable for future Mars colony pilots wishing to conduct training exercises to test certain spacecraft components or maneuvers near deep-space. And even before astronauts arrive, supplies or other equipment (including sample-return robotic precursor spacecraft) can be sent on these WSB transfer trajectories with relatively low propellant loads.

References: [1] Belbruno E. A and Miller J. K (1993) *JGCD, Vol. 16, 4,* 770-776. [2] Wiesel W. E (1993) *JGCD, Vol. 16, 3,* 434-440.

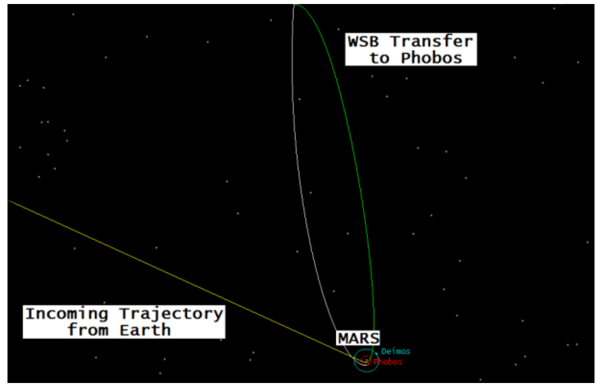

Figure 1. Entire ≈90-day Sun-Mars WSB transfer trajectory can be seen above; the apoareion is ≈850,000 km.

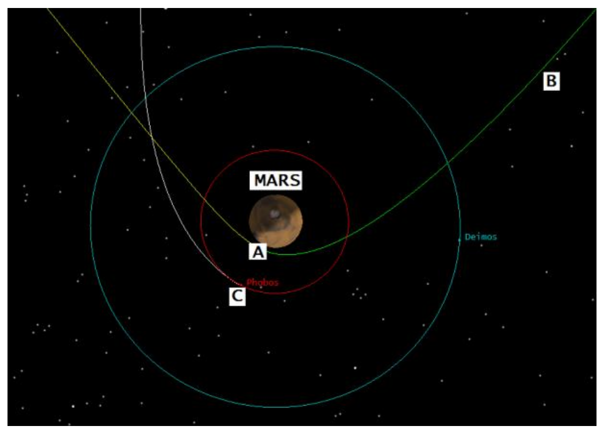

Figure 2. Incoming braking maneuver performed during 200 km Mars flyby (A), followed by WSB transfer trajectory (B & Fig. 1), and finally rendezvous with Phobos (C).

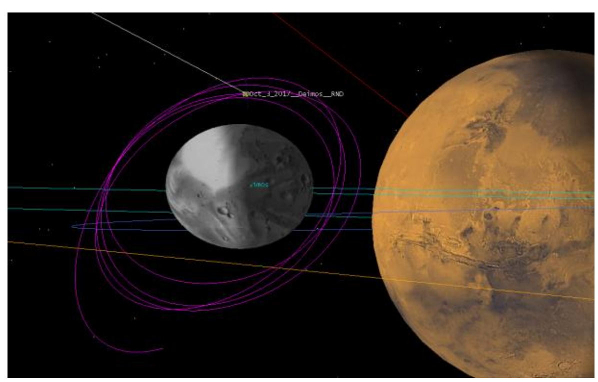

Figure 3. It's difficult to remain <10 km from Deimos (or Phobos) without frequent station-keeping maneuvers.