Solar Electric Propulsion for Mars Mission Applications

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The high specific impulse (I_{sp}) of solar electric propulsion (SEP) can be beneficial to many types of Mars missions. The use of SEP, particularly Hall thrusters, is an attractive option because it can provide increased flexibility to mass growth, launch opportunities, orbit selection, rendezvous capabilities, and uncertainty in launch vehicle performance. SEP also has an advantage operationally in that it eliminates critical events incumbent upon ballistic trajectories. Here we present Earth-to-Mars and Mars-to-Earth trajectory options using Hall thrusters for potential Mars exploration architectures. We also examine correlations between engine performance parameters and trajectory characteristics.

For a typical Mars orbiter, SEP does not provide a significant mass savings versus a bipropellant system with aerobraking. Where SEP shines, however, is in the high ΔV requirements of a sample return orbiter. Previous concepts[1] for Mars Sample Return have used chemical propulsion, which led to very large launch masses and extreme sensitivity to additional mission ΔV. SEP thrusters typically have an I_{sp} that is 5-10 times that of chemical thrusters. This reduces fuel mass requirements significantly, which more than offsets the mass required for additional power.

The low thrust and long burn times of SEP missions create a whole spectrum of possible trajectories to and from Mars, in contrast to the discrete trajectories of ballistic missions. Whereas ballistic trajectories are largely independent to mission specifics, SEP trajectories are dependent on thrust, mass, power, duration, launch vehicle, etc. This creates difficulties in exploring the vast mission design trade space. In order to tackle this problem we employed the use of MALTO, a rapid, low-thrust trajectory optimizer. MALTO is a preliminary trajectory design tool that models low-thrust trajectory arcs as a series of impulsive maneuvers applied to patched-conic trajectories. It also analytically models minimum-time spirals to and from circular orbits.

We used MALTO's parametric exploration capability to run thousands of trajectories from Earth to Mars and from Mars to Earth from 2024-2028 and 2028-2033, respectively, over a wide range of flight times and power levels. The thruster used in this study was primarily the BPT-4000 Hall thruster, due to its heritage and capabilities. Both the Falcon 9 v1.1 and the Atlas V 431 were used as candidate launch vehicles.

From this large database of low-thrust trajectories it is possible to see the effects and benefits of SEP as well as characterizing parameter sensitivities in the mission design trade space. The database is also integrated into a sample return orbiter design tool that iterates on

[1] Mattingly, R., and May, L., "Mars Sample Return as a Campaign," 2011 IEEE Aerospace Conference, Big Sky, MT: IEEE, 2011.

mass, power, and time, along with desired margins, as it queries and interpolates the trajectory database.[2] Results and findings from this database and tool will be presented.

[2] Bailey, Z. J., Sturm, E. J., Kowalkowski, T. D., Lock, R. E., and Woolley, R. C., "Round-Trip Solar Electric Propulsion Missions for Mars Sample Return," AAS/AIAA Space Flight Mechanics Conference, AAS Paper 14-365, Jan. 2014.