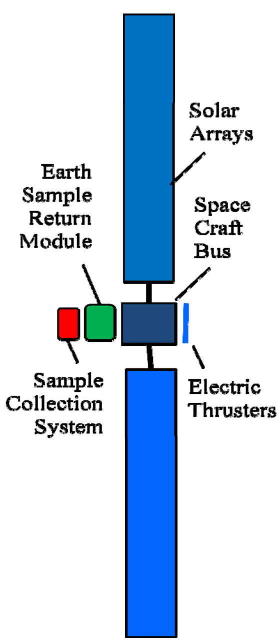
PHOBOS SAMPLE RETURN MISSION USING 20KW HIGH ISP SOLAR ELECTRIC PROPULSION SYSTEM.

B. B. Donahue[1], [1]Boeing Advanced Elements, MC JV-08, 950 Explorer Blvd., Huntsville, AL 35806, benjamin.b.donahue@boeing.com.

Introduction: This investigation presents an evaluation of 20kW Solar Electric Propulsion (SEP) transfer system for a Phobos Sample Return (PSR) mission. A low initial mass mission trajectory is described, SEP propulsion elements are discussed, spacecraft characteristics are set forth and the benefits of using high Isp, Ion electric thrusters for this mission are presented. A mission to Phobos could be done with one launch of a Falcon 9 launch vehicle and at less expense than a PSR mission using a chemical propulsion system. Phobos, the innermost of Mars' moons, is closer to its planet than any other moon in the solar system, and is a very interesting object for exploration science, sample collection and observing Mars. In this scenario, a sample collected from Mars largest Moon is returned to Earth.

The Phobos Mission

Phobos' low gravity level would preclude the need for a separate lander, as the Phobos spacecraft could fly to within a very short distance of the moon and deploy a tethered penetrator or other mechanism to obtain the sample. The PSR craft, flying in very close vicinity to Phobos (within 100 meters) could make detailed Phobos surface observations, investigations and obtain samples from several locations on its surface. A mission to Phobos would provide a validation of all transfer and telecommunication systems and, once completed, could be followed by missions to the surface. Sending a mission to Phobos frees mission planners from the complexities of a Mars descent and ascent from the surface.



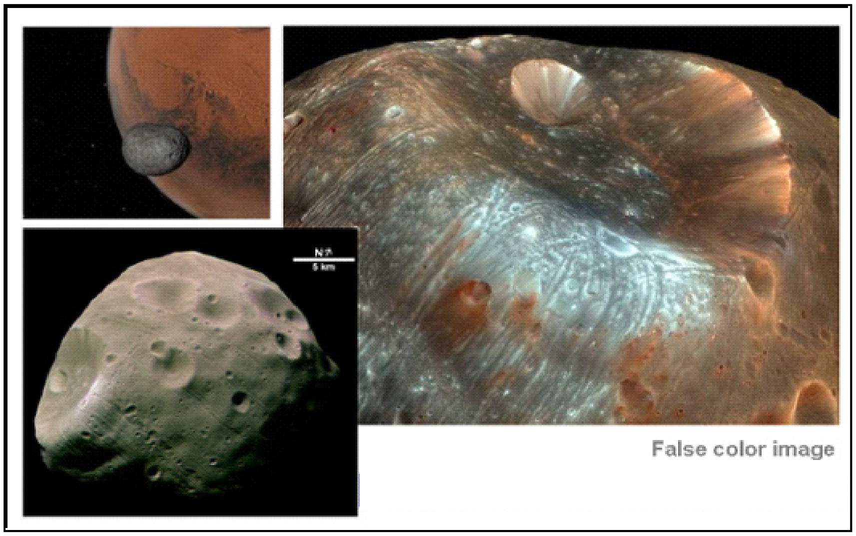
Injected to a C3 of 6.3 from a Falcon 9 launch vehicle, the 20kW PSR SEP vehicle would travel to Mars on a low thrust trajectory via its two Ion thrusters (a third thruster serves as a backup). After rendezvous with Mars, the SEP PSR spacecraft will spiral down to, and rendezvous with Phobos. After closing in on Phobos, and examination will be made of its surface and a sample will be obtained. The sample will be transferred to the Earth Return Module (ERM). After the sample is secured, the PSR craft will conduct further examinations of Phobos and Mars. The PSR then spirals back up to Mars high orbit and departs Mars. About 2 days prior to Earth arrival the ERM will separate from the PSR craft and conduct a direct entry at Earth. The total duration of the mission is about 2.6 years, and Earth departure dates in the 2018-2022 time frame may be appropriate. Further detailed analysis of the mission, array, power, thruster and other spacecraft technologies, mission constraints, science objectives and insights gained from the analysis will be given in the paper. Approaches for evolving the PSR spacecraft for other Mars missions will also be given. The PSR craft SEP system will demonstrate high dimensional precision, array stability, minimal thermal snap, highly tolerant of pointing angle, low susceptibility to combined environment effects and contamination concerns, radiation resistance and high specific density. The benefits and drawbacks of low thrust, high Isp, mass efficient SEP transfer stages for Phobos, and Mars exploration will be presented in the context of resource limited space exploration in the 2018–2030 time frame.

Energy Intensive Mars Missions Favor High Isp

Missions to Mars are very energy intensive due to the high delta velocity (dV) maneuvers required of the stages, particularly the ascent stage; ascent to Mars orbit from the surface may require up to 5,400 m/s (a function of final altitude). This can be significantly more than either the Trans-Mars Injection, Mars Orbit Insertion or Trans-Earth Injection burns. Consequently, lander systems carrying ascent stages that must ascend from the surface are heavy. Because of the mass of the descent/ascent stage, Mars Sample Return (MSR) mission initial mass in low earth orbit (IMLEO) values are large; the masses required for a PSR mission would be substantially less, and because a dedicated ascent descent or ascent stage is not required, the PSR spacecraft could be procured, and the mission conducted, at a cost significantly less than the cost for procurement and operations of a MSR mission.

Phobos.

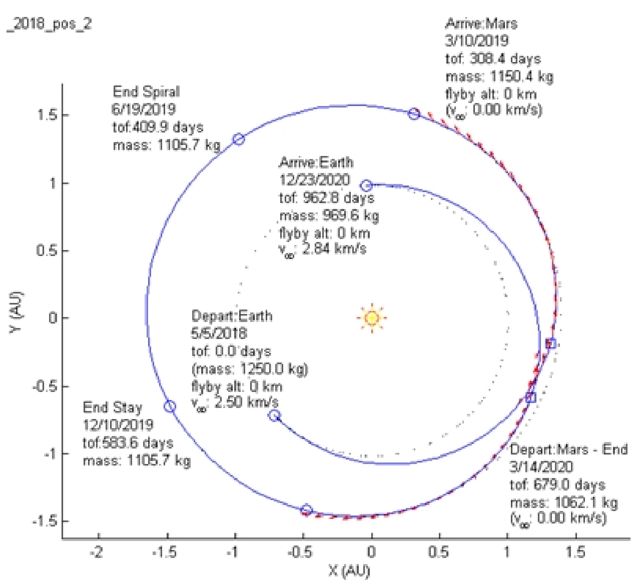
Phobos' density to too low to be solid rock, and it is known to have significant porosity. These results led to the suggestion that Phobos might contain a substantial reservoir of ice. Mapping by the Mars Express probe



and subsequent volume calculations might suggest the presence of large caverns within the moon. The porosity of Phobos was calculated to be about 30%, or nearly a third of the moon being hollow. Phobos orbits so close to the planet that it moves around Mars faster than Mars itself rotates.

Earth-Mars-Earth Trajectory

For a C3=6.3 km2/s2, May 5, 2018 Earth departure, a low thrust trajectory is shown; this data assumes 20kW and 2 NEXT thrusters operating in high Isp mode. 500W is retained for the spacecraft. The outbound transfer requires 308 days; after rendezvous in March 10, 2019, the craft spiral downs (102 days) to Phobos at 9377 km. Stay time at Phobos is 173d. Spiral up is 95d and Mars departure begins on March 14, 2020. The Earth return transfer requires 284d.The Earth return mass is 969kg and the usable Xenon is 280 kg. Vehicle wet mass is consistent with the Dawn spacecraft with a lower xenon requirement. The PSR mission appears very feasible given the assumptions of 20kW and 2+1 NEXT thrusters. The launch wet mass is low enough for the Falcon 9 to provide energy beyond escape. Launching to a C3=0 km2/s2 increases propellant load slightly and total mission time by 100 days.



Advantages of SEP for transfer to Mars.

A mission of this type would provide both an outstanding science return as well as serve as an exploration technology development pathfinder. 4000 sec Isp Ion propulsion coupled with high efficiency solar arrays form an outstanding capability for high dV Mars missions. SEP technology offers several important benefits, including reusability, redundancy, and modularity. Long lived SEP propulsion, power and array technology means that the same hardware can support multiple missions. New array technology is radiation resistant and will allow many passes through the Van Allan belt with little performance degradation. EP systems can also be highly redundant and can have fail safe features to insure mission success; with the failure of a thruster, for example, the SEP can continue on with a slightly longer trip time. Solar cell technology improves at nearly 0.8% eff per year which results in about a 2-3% specific power improvement per year. The modular nature of SEP allows them to evolve using modules validated on earlier systems. As power needs increase, additional modules can be provided. Validating SEP systems at Mars/Phobos at 20kW would provide a milestone with great scientific interest that would inspire even greater missions at levels beyond 20kW.

References:

[1] Donahue B. B. (2010) *Solar Electric Propulsion Transfer Stages for Multiple Destinations*, AIAA Joint Propulsion Conference, Nashville, TN, 216 July, 2010. [2] Donahue B. B. (2010) *Solar Electric and Nuclear Thermal Propulsion Architectures for Human Mars Missions Beginning in 2033*. 46th AIAA/ASME/SAE/ASEE Joint Propulsion Conference, 28 July, 2010 Nashville, TN. [3] Donahue B., Martin J., Potter, S., Henley, M., (2000) *Human Mars Transportation Applications Utilizing Solar Electric Propulsion*, AIAA Space 2000 Conference, Sept 16, 2000 Long Beach California.