

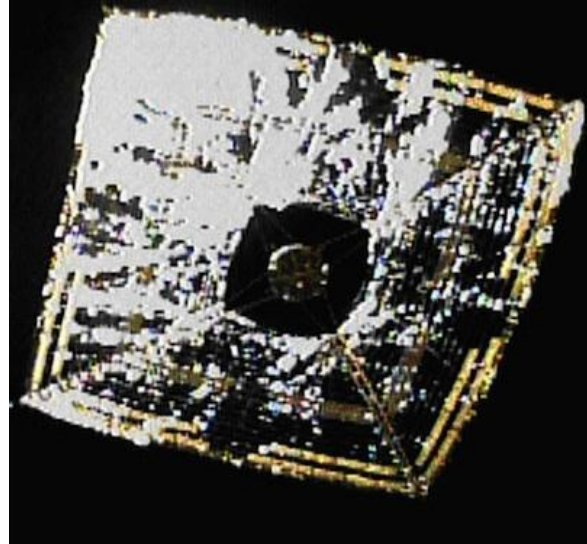
MARS SAMPLE RETURN USING SOLAR SAIL PROPULSION. L. Johnson,¹ M. Macdonald,² C. McInnes,² and T. Percy.³ ¹NASA MSFC (Mail Code ED04, NASA MSFC, Huntsville, AL 35812, charles.l.johnson-1@nasa.gov), and ²Univeristy of Strathclyde (Glasgow, Scotland, malcolm.macdonald.102@strath.ac.uk and colin.mcinnnes@strath.ac.uk) ³Science Applications International Corporation (Huntsville, AL, thomas.k.percy@saic.com)

Introduction: (*Challenge Area 2: Safe and Accurate Landing Capabilities, Mars Ascent, and Innovative Exploration Architectures*)

Many Mars Sample Return (MSR) architecture studies have been conducted over the years. A key element of them is the Earth Return Stage (ERS) whose objective is to obtain the sample from the Mars Ascent Vehicle (MAV) and return it safely to the surface of the Earth.

ERS designs predominantly use chemical propulsion [1], incurring a significant launch mass penalty due to the low specific impulse of such systems coupled with the launch mass sensitivity to returned mass. It is proposed to use solar sail propulsion for the ERS, providing a high (effective) specific impulse propulsion system in the final stage of the multi-stage system. By doing so to the launch mass of the orbiter mission can be significantly reduced and hence potentially decreasing mission cost. Further, solar sailing offers a unique set of non-Keplerian low thrust trajectories that may enable modifications to the current approach to designing the Earth Entry Vehicle by potentially reducing the Earth arrival velocity. This modification will further decrease the mass of the orbiter system.

Solar sail propulsion uses sunlight to propel vehicles through space by reflecting solar photons from a large, mirror-like surface made of a lightweight, reflective material. The continuous photonic pressure provides propellantless thrust to conduct orbital maneuvering and plane changes more efficiently than conventional chemical propulsion. Because the Sun supplies the necessary propulsive energy, solar sails require no onboard propellant, thus reducing system mass. This technology is currently at TRL 7/8 as demonstrated by the 2010 flight of the Japanese Aerospace Exploration Agency, JAXA, IKAROS mission. [2]



In flight photograph of the 14-m JAXA IKAROS solar sail launched in 2010.

Concept Description: In any multi-staged space system it is clear that by minimizing the mass of the final stage, the initial system mass will be reduced by simply reducing the propellant required in earlier stages. It is therefore logical that to minimize the launch mass of a MSR mission the most aggressive technical innovations leading to mass reduction should be focused on the ERS. A minimum mass ERS at sample collection is therefore sought.

Using chemical propulsion, the ERS at sample collection will have a large fuel mass fraction and hence the earlier mission stages will be required to transport this mass to Mars, in turn requiring more propellant in these mission stages. In fact, under current designs, nearly half of the orbiter mass is dedicated to returning samples to Earth and stopping the Earth-return propellant at Mars. By replacing the chemical propulsion system of the ERS with a solar sail, the fuel mass fraction is, in-effect, zero. Resultantly, the fuel mass of earlier mission stages will also be significantly reduced.

The current MSR orbiter is planned to arrive two years ahead of the MSR MAV lander. The orbiter will provide communication links to the lander and monitor the lander's EDL phase. The orbiter is also required to be the active partner in the rendezvous and

capture of the sample canister once the MAV launches it from the surface of Mars.

The general mission scenario proposed here is one where the solar sail performs the Earth return portion of the orbiter mission. All other required propulsive functions would still be performed with traditional storable liquid propellant thrusters. Upon retrieval of the sample canister, the solar sail will deploy and begin the low-thrust spiral out of the Martian gravity well. As a means to save mass and reduce the required size of the solar sail, it is proposed that the liquid propulsion system be jettisoned in Mars orbit, potentially reducing the mass of the return system by an additional 10% - 20%.

The resulting mass savings realized through the use of the solar sail system may be as high as 25% - 50% of the current MSR orbiter design. This mass savings can translate into more secondary science payloads, either orbital (as in Mars Global Surveyor) or perhaps even in the form of atmospheric probes akin to the Huygens probe carried on the Cassini mission.

Extensions of the concept of solar sailing for Mars have further hypothesized that solar sails may be used for the Earth-Mars transfer as well. [3] This would entirely eliminate the orbiter propulsion system, further reducing mass. It also may be possible, given the large surface area of a solar sail, to use the sail to perform an aerocapture maneuver through the extremely thin upper atmosphere of Mars. [4] Both of these extensions of the use of solar sails would have positive impacts on the overall MSR architecture.

Technology Maturity and Description: During the early 2000's, NASA developed many of the technologies required to fly a solar sail mission and matured the technology to TRL-6. [5] In 2011, NASA selected L'Garde, Inc. to develop *Sunjammer*, a 1200m² sail for validation in deep space as early as 2014. At the time this project might begin, the *Sunjammer* will have been space-validated, reducing the risk of mission infusion and satisfying an agency goal of transitioning NASA-demonstrated technology to mission implementation.

Outside of NASA, solar sailing has been tested in space. In the summer of 2010, JAXA launched a solar sail spacecraft named *IKAROS* into deep space. The *IKAROS* (14 m by 14 m) is the first in-space demonstration of solar sailing. [3] The Europeans will soon fly their own demonstration, *Gossamer-1*, which is slated to fly in 2014/15 with two subsequent technology demonstration missions (*Gossamer 2 & 3*) slated before 2020 to develop the technology to full flight readiness within Europe.

Issues: Despite a clear reduction in launch mass and hence cost through the adoption of solar sail propulsion in the ERS, it is not clear that this will result in

a direct reduction in total mission cost, as the mission duration will be increased through the use of low-thrust propulsion. A cost/benefit trade is required.

References: [1] Christensen, P. *Planetary Science Decadal Survey: MRR Orbiter Mission* (2010) [2] Tsuda, Y. et al, *Flight Status of IKAROS Deep Space Solar Sail Demonstrator*, Acta Astronautica, Vol. 69 (2011) [3] Frisbee, R., *Solar Sails for Mars Cargo Missions*, AIP Conf. Proc. 608 (2002) [4] Percy, T. et al, *A Study of Possible Solar Sail Applications for Mars Missions*, AIAA-Joint Propulsion Conference, (2004) [5] Johnson, L., et al, *Recent Advances in Solar Sail Propulsion Systems at NASA*, Acta Astronautica, Vol. 61 (2007).