Solar Sail Propulsion for Planetary Missions

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Applicable Missions: *Mercury Scout, Grail at Mercury, and Interstellar Object Interceptor Missions: Opportunities and Challenges*

Abstract: Solar sails have the potential to provide high ΔV for many types of missions. Solar sails are large, mirror-like structures made of a lightweight material that reflects sunlight to propel the spacecraft. The continuous solar photon pressure provides thrust with no need for the heavy, expendable propellants used by conventional chemical and electric propulsion systems. NASA, with industry partners, are developing and flying solar sails applicable to a wide range of space science missions, including those of interest for planetary science. Currently funded technology development activities support two classes of missions: Deep space interplanetary CubeSats (12 – 24 kg) and smallsats (up to ~125 kg).

Deep Space Interplanetary CubeSats

After its deployment from NASA's Space Launch System (SLS), the Near-Earth Asteroid (NEA) Scout mission will travel to and image an asteroid during a close flyby using an $86m^2$ (925 ft^2) solar sail as its primary propulsion, achieving a Characteristic Acceleration (Ac) of 0.06 mm/s^2 [1]. Developed by NASA's Marshall Space Flight Center (MSFC) and Jet Propulsion Laboratory (JPL), the NEA Scout is based on the industry-standard CubeSat form factor. The spacecraft measures 11 cm x 24 cm x 36 cm and weighs less than 14 kilograms. Following deployment from the Space Launch System (SLS), the MSFC developed solar sail will deploy, and the spacecraft will begin its 2.0 – 2.5-year journey. About one month before the asteroid flyby, NEA Scout will search for the target and start its Approach Phase using a combination of radio tracking and optical navigation and perform a relatively slow flyby (10-20 m/s) of the target. The spacecraft bus, developed by JPL, houses a fully functional, though miniaturized, interplanetary spacecraft. The asteroid observations will be achieved using a JPL-provided camera that will observe the asteroid during a close (< 1 km) flyby. Measurements will include the NEA position, global size and regional morphology, rotational properties (spin period, spin position, and spin state), local environment (dust, debris within 10 radii of the target), and characterization of its regolith properties via photometric observations over various phase angles). These observations drove the imaging resolution (ground sampling distance) to be 40 cm on a near global scale and 10 cm over about 30% of the surface. Once the flight is underway, the TRL for this class of mission will be TRL 7+. Figure 1 shows the completed spacecraft, including solar sail, at various stages of development.

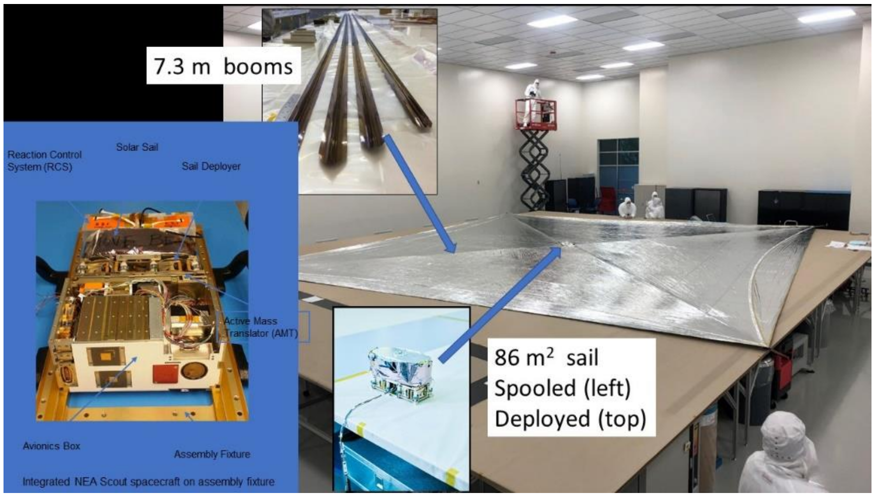

Figure 1 The NEA Scout solar sail and spacecraft components and integrated spacecraft system.

Smallsats

The NASA Science Mission Directorate (Heliophysics Division) is funding to TRL-6+ the next-generation solar sail propulsion system at NASA MSFC. The system, called Solar Cruiser, will provide this class of missions with a scalable spacecraft platform with pointing stability, jitter, and accuracy suitable for optical imaging instruments [2]. The project is managed by NASA MSFC who are developing the solar sail attitude, determination, and control system software, mission concept designs, and mission operations requirements. Redwire is integrating the solar sail system, including the sail membrane from their Subcontractor NeXolve, the Triangular, Rollable and Collapsible (TRAC^{TM}) Booms, and the active mass translator (AMT), which moves the sail relative to the bus to control momentum in the pitch/yaw directions. The Solar Cruiser solar sail, measuring 1,653 square meters/17,793 square feet, will be capable of providing high ΔV propulsion, station keeping in a sub-Sun/Earth L1 halo orbit and other novel orbits, and inclination changes. The system is designed to be scalable by simply making the booms longer (with commensurate sail area, hence propulsive capability) in 1-meter increments, achieving Ac of 0.11 – 0.14 mm/s^2. Figure 2 shows one quadrant of the four (identical) quadrant sails in a test deployment at NASA MSFC in early November 2022.

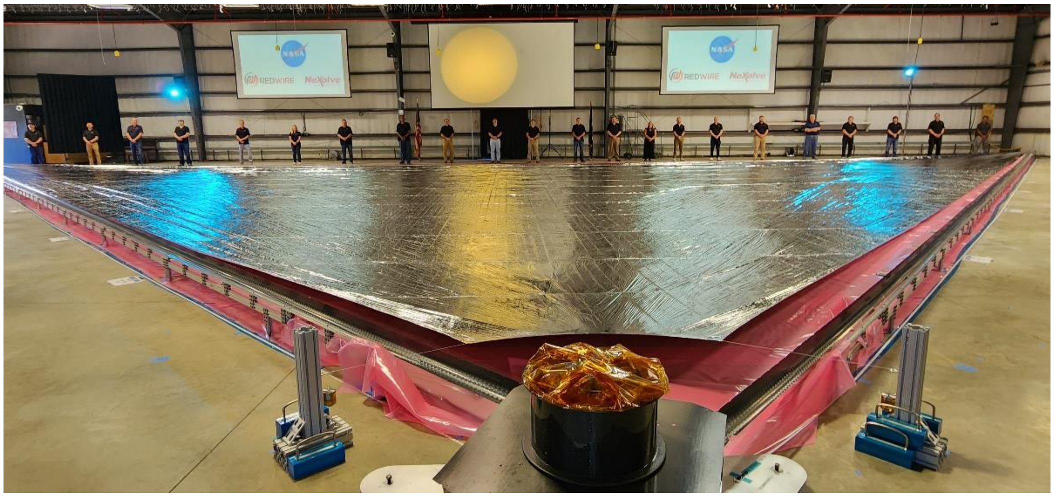

Figure 2 Shown is 1 quadrant of the 17,800 square foot Solar Cruiser solar sail after deployment testing at NASA MSFC in November 2022. The quadrant measures approximately 4,450 square feet.

<u>Mission Applicability</u>

Mercury Scout: A solar sail propulsion system fits the need of high delta V, low cost, and long duration. With no delta V from the launch vehicle (rideshare), transit times would be ~5.3 years, assuming a solar sail similar in size to the one on the Solar Cruiser mission. With a dedicated launch, transit times could be as low as 4 years. Once at Mercury, it takes ~50 days to maneuver the orbiter into a polar orbit (nominal altitude = 100 km), and 176 days to map the surface. Because the solar sail will not run out of fuel, mission duration could be extended indefinitely. Use of a solar sail for orbiting will require gimbaling of all imaging systems to maintain pointing at the surface.

Grail at Mercury: The propulsive requirement could be met by a solar sail propulsion system in much the same manner as described above (Mercury Scout).

Interstellar Object Interceptor Missions: Addressing Option #3 in the science abstract, multiple spacecraft placed at various locations in the solar system (to provide solar system wide coverage) are outfitted with small solar sail propelled spacecraft that could then be released into a 'freefall' trajectory and use the solar sail to provide the ΔV required for a flyby intercept of the interstellar object [3].

<u>References</u>

[1] Johnson, Les, Joe Matus, Matt Pruitt, Anne D. Marinan, Calina Seybold, Julie Castillo-Rogez, Gregory Lantoine, and Ted Sweetser. "Near Earth Asteroid Scout Mission Update." (2020).

[2] Johnson, Les, Jason Everett, David McKenzie, Danny Tyler, Darren Wallace, Jeff Newmark, Dana Turse, Matthew Cannella, Jeff Wilson, and Max Feldman. "The NASA Solar Cruiser Mission-Solar Sail Propulsion Enabling Heliophysics Missions." (2022).

[3] Linares, Richard, Damon Landau, Daniel Miller, Benjamin Weiss, and Paulo Lozano. "Rendezvous Mission for Interstellar Objects Using a Solar Sail-based Statite Concept." arXiv preprint arXiv:2012.12935 (2020).