T5.05 Solar and Electric Sail Embedded Technologies for Communications, Control, or Ancillary Functions

Lead Center: MSFC

Participating Center(s): ARC, GRC, JPL

Scope Title:
Solar and Electric Sail Control Systems Modeling and/or Development

Scope Description:
One of the challenges with higher performance solar sails remains to be a highly resilient yet low-resource and low-complexity control system. Traditional solar sail options under consideration have previously considered impulsive systems (chemical and electric), mechanical systems (translation tables, guy wires, and moving masses), reflective control devices, and advanced diffractive metafilms. Further electric solar wind sail (E-sail) control systems are lower maturity and require new modeling and analysis tools for higher fidelity performance assessment. This solicitation seeks either embedded sail control technologies for traditional solar sails or the development of advanced modeling capabilities for E-sail control systems.

Expected TRL or TRL Range at completion of the Project: 2 to 5

Primary Technology Taxonomy:
Level 1: TX 01 Propulsion Systems
Level 2: TX 01.4 Advanced Propulsion

Desired Deliverables of Phase I and Phase II:

- Prototype
- Software

Desired Deliverables Description:
For a traditional solar sail, the anticipated final product would be a prototype-tested control solution with potential to enable high performance for long-duration (>10-year) missions. For Phase I, the final deliverable must include very clear Key Performance Parameters (KPPs) of the control system approach based on preliminary proof-of-
concept testing and/or analysis. The proposal must indicate anticipated KPPs for system-level implementation for a known design reference mission (e.g., Solar Polar Imager). The Phase II product must contain hardware development with laboratory performance testing to validate anticipated KPPs.

For an E-sail, the anticipated final product would be a high-fidelity modeling tool for performance assessment of solar sail control system performance. The Phase I product must include the identification and assessment of the key driving elements for total control system performance and control system performance uncertainty in addition to the approach to mitigate flight system performance uncertainty in the Phase II development. The Phase II product must include the delivery of a fully functional control system modeling tool suitable for high-fidelity performance assessment applied to missions of interest (e.g., Solar Polar Imager and Interstellar Probe).

State of the Art and Critical Gaps:

State-of-the-art solar sail systems use translating masses (so-called AMT (Active Mass Translator)) and reflective control devices. Solar sail thrust, though miniscule in size, can produce large-velocity deltas over a multiyear mission. These small forces also create disturbance torques caused by misalignment in the center of mass (CM) and center of pressure (CP). NEAScout (current NASA Sail mission) estimates that the CP/CM offset is large enough to overload control systems and requires a mechanical system to adjust the CM and trim the spacecraft—the AMT. However, the scalability of the AMT to larger sail missions, such as the Interstellar Probe is currently unknown.

Attitude can also be controlled by varying solar radiation pressure directly on the sail itself. So-called reflectivity control devices (RCDs) were demonstrated on JAXA’s first solar sail mission, IKAROS, and are currently being investigated by NASA and academic partners. A typical RCD utilizes a polymer-dispersed liquid crystal whose optical properties can be adjusted via an applied electric voltage. These devices show promise, although challenges exist in yielding control in all three axes. Further, space environments survivability in extreme environments, especially the hot thermal of a high-inclination Solar Polar Imager, for example, also remains a challenge.

E-sails have low-fidelity simulations for control systems. Multitethered bodies coupled with varying plasma environments throughout the mission profiles, spacecraft charging, tether dynamics, and the like, are critical gaps.

Relevance / Science Traceability:

The resulting product should improve the performance or lower the subsystem mass for a solar-sail-based spacecraft optimized for the high-inclination Solar Polar Imager, advanced generation Solar Storm Warning systems, as well as the interstellar probe.

References:

- Overview of NEAScout Sail mission with AMT: [https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20170012287.pdf](https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20170012287.pdf)
AMT Translation Table Development at NASA: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20160008126.pdf

SOA RCDs being evaluated by NASA: https://drum.lib.umd.edu/bitstream/handle/1903/19291/Ma/umd_0117E_17785....

SOA RCDs at JAXA: https://www.semanticscholar.org/paper/Optimal-Design-of-Advanced-Reflect...


E-Sail Control: https://arxiv.org/abs/1406.6847

Advanced Diffractive MetaFilms: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20190025234.pdf

Scope Title:

Lightweight Deployable (Solar Sail) Embedded Interplanetary Communication Solutions

Scope Description:

The Mars Cube One (MarCO) mission demonstrated the potential of SmallSat spacecraft to perform interplanetary missions. SMD is continuing to invest in technologies and interplanetary missions due to the high science value enabled by SmallSat spacecraft; several of those being solar-sail-based missions. However, MarCO was extremely limited in communication rates. Also, future interplanetary missions will be carrying science instrumentation with higher data requirements. This solicitation is seeking deployable embedded technology solutions for higher gain, enabling higher data rate communications for interplanetary spacecraft with an emphasis on applicability to solar sail missions (very low SWaP-C (Size, Weight, Power, and Cost)). The NEAScout solar sail architecture can be used as a sample design reference for the proposed technologies. However, the proposed technologies should be extensible to solar sails in general (that is, not be tied to NEAScout-specific requirements) as well as to stand-alone devices (that is, to be applicable to nonsolar sail missions).

Expected TRL or TRL Range at completion of the Project: 3 to 5

Primary Technology Taxonomy:
Level 1: TX 05 Communications, Navigation, and Orbital Debris Tracking and Characterization Systems
Level 2: TX 05.5 Revolutionary Communications Technologies

Desired Deliverables of Phase I and Phase II:

- Prototype
- Analysis

Desired Deliverables Description:

The anticipated Phase I product of this solicitation would be a proof-of-concept demonstration of the technology with determination of the Key Performance Parameters.
by test and/or analyses leading to a higher fidelity prototype(s) and relevant environmental demonstrations in Phase II.

**State of the Art and Critical Gaps:**

The current state of the art for SmallSat/CubeSat missions is led by ISARA (Integrated Solar Array and Reflectarray Antenna) flown on MarCO. Using a combination reflectarray and patch array, it demonstrated an 8-kbps X-band downlink from Mars orbit with a 28-dB-gain design in a small form factor of <1 kg and 272 cm$^3$ at 5 W. For reference, the Mars Reconnaissance Orbiter is a large spacecraft communicating from approximately the same distance as MarCO with a 46.7-dB 3-m dish that varies from 500- to 4,000-kbps X-band downlink at 100 W.

Outside of ISARA, various arrays of 16 patch antennas or fewer are available from places like Endurosat and Clyde Space with gains from 11.5 to 16 dB. Thin-film solutions such as the Lightweight Integrated Solar Array and anTenna (LISA-T) are in development. However, the ultimate scalability (mechanically, mass, stowage volume, etc.) is limited. Thus, a critical technology gap exists in higher data rate communication solutions for SmallSats outside Earth orbit. The current NASA Small Spacecraft Strategic Technology Plan states this need in several ways including large deployable apertures. This gap is especially critical for deployable solar sail missions such as interstellar probe and potentially for second- and third-generation space weather monitoring platforms. In short, low SWaP-C, high-gain communication techniques that will push small spacecraft data rates towards their larger spacecraft brothers and sisters are needed. To enhance future solar sail missions, these concepts should be amenable if not directly embedded onto the solar sail itself.

**Relevance / Science Traceability:**

The SIMPLEX solicitation opportunities would benefit significantly from higher data rate communication solutions for SmallSat missions. Further specific solar sail mission such as the high-inclination Solar Polar Image mission and second- and third-generation space weather monitoring missions would be enhanced by this technology, and specific solar sail missions such as the interstellar probe would be enabled by this technology.

**References:**

- Review of CubeSat Antenna for Deep Space:
- LISA-T:
  [https://docs.google.com/viewer?a=v&pid=sites&srcid=ZGVmYXVsdGRvbWFBWpbnxgb2huYW50aG9ueWNhcj8Z3g6YzcxMGZjY2Y4MDYwMmJ](https://docs.google.com/viewer?a=v&pid=sites&srcid=ZGVmYXVsdGRvbWFBWpbnxgb2huYW50aG9ueWNhcj8Z3g6YzcxMGZjY2Y4MDYwMmJ)