

DEPLOYABLE PROPULSION, POWER AND COMMUNICATIONS SYSTEMS FOR SOLAR SYSTEM EXPLORATION. L. Johnson,¹ J. Carr,¹ and D. Boyd,¹ NASA George C. Marshall Space Flight Center, ED04, Huntsville, AL 35812, les.johnson@nasa.gov.

Introduction: NASA is developing thin-film based, deployable propulsion, power, and communication systems for small spacecraft that could provide a revolutionary new capability allowing small spacecraft exploration of the solar system. By leveraging recent advancements in thin films, photovoltaics, and miniaturized electronics, new mission-level capabilities will be enabled aboard lower-cost small spacecraft instead of their more expensive, traditional counterparts, enabling a new generation of frequent, inexpensive deep space missions. Specifically, thin-film technologies are allowing the development and use of solar sails for propulsion, small, lightweight photovoltaics for power, and omnidirectional antennas for communication.

Solar Sails: Like their name implies, solar sails 'sail' by reflecting sunlight from a large, lightweight reflective material that resembles the sails of 17th and 18th century ships and modern sloops. Instead of wind, the sail and the ship derive their thrust by reflecting solar photons. This continuous photon pressure provides propellantless thrust, allowing for very high ΔV maneuvers on long-duration, deep space exploration. Since reflected light produces thrust, solar sails require no onboard propellant. Solar sail technology has been discussed in the literature for quite some time, but it wasn't until 2010 that sails were proven to work in space.[1]

Studies show that sails of various sizes can propel small spacecraft to multiple destinations in the inner solar system, many of which are otherwise unreachable (from a propulsion point of view) – including asteroids, comets, planets and moons. In some cases, the benefits of a solar sail are in launch window flexibility – providing additional opportunities for space launch.

The Near Earth Asteroid (NEA) Scout reconnaissance mission will demonstrate solar sail propulsion on a 6U CubeSat interplanetary spacecraft and lay the groundwork for their future use in deep space science and exploration missions.[2] The NEA Scout mission, funded by NASA's Advanced Exploration Systems Program and managed by NASA Marshall Space Flight Center (MSFC), will use the solar sail as its primary propulsion system, allowing it to survey and image one or more NEA's of interest for possible future human exploration. A full-scale engineering model of the solar sail can be seen in Figure 1. NEA Scout uses a 6U cubesat (to be provided by NASA's Jet Propulsion Laboratory), an 86 m² solar sail, and will weigh less

than 12 kilograms. NEA Scout will be launched on the first flight of the Space Launch System in 2018.



Figure 1. 86 square meter test sail deployed horizontally during a test at NASA MSFC. A half-scale sail hangs vertically in the background.

Deployable Power Systems: Thin-film photovoltaics are revolutionizing the terrestrial power generation market and have been found to be suitable for medium-term use in the space environment. When mounted on the thin-film substrate, these photovoltaics can be packaged into very small volumes and used to generate significant power for small spacecraft.

The use of thin-film based solar arrays for spacecraft applications has long been recognized as an advantageous power generation option. Thinner materials yield a mass savings, equating to lighter launch loads and/or more payload allocation. Perhaps more importantly for the small spacecraft community, their mechanical flexibility lends itself well to stowage and deployment schemes.

This allows an improvement to both specific power (W/kg) as well as stowed power density (W/m³), enabling higher power generation for small spacecraft. Though several larger scale thin-film or partial thin-film arrays are in development, sub-kilowatt thin-film arrays remain scarce. The Marshall Space Flight Center (MSFC) Lightweight Integrated Solar Array and Antenna (LISA-T) seeks to fill this void, both increasing as well as simplifying small spacecraft power generation.[3]

LISA-T marries the most recent advances in the solar sail and photovoltaics community to create a fully thin-film array. Two configurations are currently under development: (i) the omnidirectional (non-pointed) and

(ii) the planar (pointed). The former stows into a single CubeSat U, while the latter into 1/2U. The omnidirectional array is based on a three-dimensional shape such that no matter how the craft is orientated, power will be generated. This relaxes the need for pointing and greatly simplifies power generation.

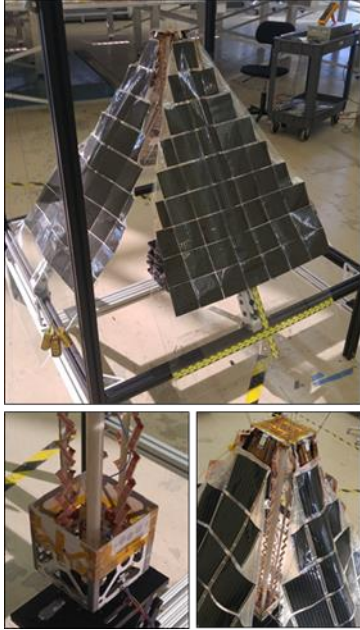


Figure 2. Deployed LISA-T omnidirectional configuration prototype. The complete, deployed power system and antenna were stowed in $\frac{1}{2}$ U.

Power levels up to 125W peak beginning of life are currently achievable in this configuration. The planar array is based on a traditional flat configuration. Though it requires solar pointing, it maximizes solar cell use and the array parametrics. Power levels up to 300W are currently achievable in this configuration. Options for leveraging both a high performance (~28% efficient @ ~\$250/W) triple junction thin-film solar cell as well as a low cost (~10% efficient @ ~\$15/W) single junction are being developed for both configurations. Stowage efficiencies approaching 400kW/m³ with specific powers approaching 250W/kg are currently achievable

Work to date has brought both configurations to Technology Readiness Level (TRL) 6. NASA's Space Technology Mission Directorate is funding a flight demonstration study of the LISA-T with a Mission Concept Review (MCR) planned for later in 2017.

Deployable Antennas: Embedded antennas are being developed that can be adhered to thin-film substrates to provide lightweight, omnidirectional UHF and X-band coverage, increasing bandwidth or effective communication ranges for small spacecraft.

Non-pointed missions benefit from antenna system designs with customizable radiation patterns. Antenna arrays provide opportunities for custom radiation patterns, overall gain increases, diversity reception, directional interference cancelling or steering, and incoming signal direction determination. The created surface area of these deployable propulsion and power systems creates new opportunities for the inclusion and positioning of multiple lightweight deployable antennas. LISA-T integrates lightweight axial mode helical antennas into the deployable power system. These lightweight antennas are flexible for stowage and can be positioned on either the center point of a panel package or on the panels themselves. Antennas on the panels can be placed on either side of the panel as desired.

Custom lightweight helical antennas have been created for S band and X band communications. Simulations show both S band and X band helical antennas to have a main beam gain greater than 10db. By placing multiple antennas in various positions on the structure, desired coverage patterns or phased array implementations can be achieved.

In addition to S and X bands, integrated UHF dipole antennas with a simulated gain of 1.6db have also been developed. These dipole antennas can be integrated into the panel between or beside solar cell elements. Further details on the antenna development are published elsewhere.

Benefits: Considered individually, each of the innovations described above are enabling for the emerging use of smaller spacecraft for solar system science and exploration. Taken together, they may enable a host of new deep space destinations to be reached by a generation of spacecraft smaller and more capable than ever before.

References: Use the brief numbered style common in many abstracts, e.g., [1], [2], etc. References should then appear in numerical order in the reference list, and should use the following abbreviated style:

[1] Y. Tsuda et al., "Achievement of Ikaros – Japanese Deep Space Solar Sail Demonstration Mission," 7th IAA Symposium on Realistic Near-Term Advanced Scientific Space Missions, Aosta, Italy, 2011. [2] L. Johnson, L. McNutt and J. Castillo-Rogez, "Near Earth Asteroid Scout: Using Solar Sail Propulsion to Enable Affordable NEA Reconnaissance," IEEE Aerospace Conference, Big Sky, MT, 2016. [3] J.A. Carr, et al, "The Lightweight Integrated Solar Array and Transceiver (LISA-T): second generation advancements and the future of SmallSat power generation," 30th Annual AIAA/USU Conference on Small Satellites, Logan, UT, 2016.