

DEMONSTRATIONS OF DEPLOYABLE SYSTEMS FOR ROBOTIC PRECURSOR MISSIONS. J. Dervan¹, L. Johnson¹, T. Lockett¹, J. Carr¹, and D. Boyd¹, NASA George C. Marshall Space Flight Center, ES11, Huntsville, AL 35812, Jared.Dervan@NASA.gov.

Introduction: NASA is developing thin-film based, deployable propulsion, power, and communication systems for small spacecraft that serve as enabling technologies for exploration of the solar system. By leveraging recent advancements in thin films, photovoltaics, deployment systems, and miniaturized electronics, new mission-level capabilities will be demonstrated aboard small spacecraft enabling a new generation of frequent, inexpensive, and highly capable robotic precursor missions with goals extensible to future human exploration. 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 as demonstrated by recent advances on the Near Earth Asteroid (NEA) Scout and Lightweight Integrated Solar Array and anTenna (LISA-T) projects.

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 for primary propulsion. 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 ΔV limited small spacecraft to numerous destinations in the inner solar system, many of which may otherwise be unreachable in such a small form factor. Examples include discrete targets such as asteroids, comets, planets and moons but also include polar-sitter missions, observations requiring high inclination maneuvers, multiple rendezvous missions, and missions requiring long cruise periods to near Earth asteroids with high uncertainty error ellipses. In some cases, the benefits of a solar sail are in launch flexibility – providing opportunities for mission success with uncertain launch windows.

The Near Earth Asteroid (NEA) Scout mission will demonstrate solar sail propulsion on a 6U CubeSat interplanetary spacecraft and serve as low cost reconnaissance platform for future human exploration

and science destinations.[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 a NEA of interest for possible future human exploration. Given the constraints intrinsic to a CubeSat form factor, folding methodologies had to be devised to maximize the sail size for the available volume thereby minimizing time of flight requirements. Benchtop and full scale engineering unit testing (Figure 1) helped further mature the design and demonstrate its ability to meet mission requirements. NEA Scout utilizes an 86 m² solar sail and will weigh less than 14 kilograms at launch. Fabrication of the flight unit has begun in preparation for launch on the first flight of the Space Launch System in 2018.

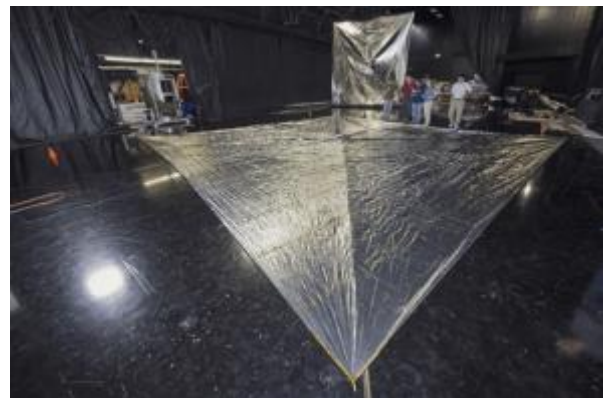


Figure 1. 86 square meter test sail deployed horizontally during a test at NASA MSFC. A half-scale sail hangs vertically in the background.

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 and robotic precursor missions, 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 with only limited use of volume and mass allocation. 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 (Figure 2) is based on a three-dimensional shape such that no matter how the craft is orientated, power will be generated, i.e. 3-axes of power generation. This relaxes the need for pointing, greatly simplifies power generation, and is scalable up to 120W at ~50W/kg and ~60kW/m³ illuminated.

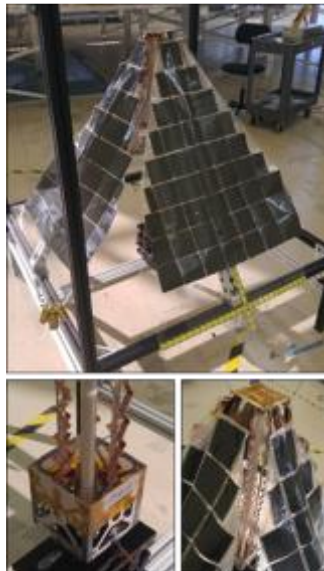


Figure 2. Single-side, deployed LISA-T omnidirectional configuration prototype. The complete, deployed power system and antenna were stowed in 0.6U.

The planar array (Figure 3) is based on a traditional pointed configuration such that performance characteristics are maximized. This configuration is scalable up to 230W (with potential to reach 500W and beyond) at ~379W/kg and ~462kW/m³.

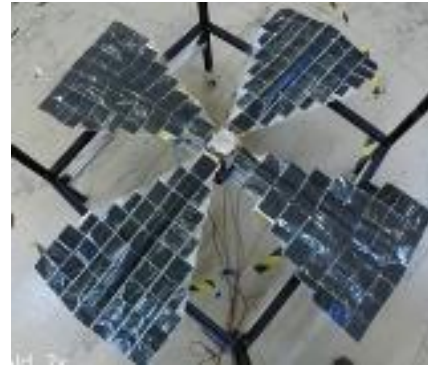


Figure 3. Deployed LISA-T planar configuration prototype. The complete, deployed power system and antenna were stowed into 0.4U.

In both configurations options to use a low cost (<\$21/W) moderate performance (10-12% Air Mass-0 (AM0)) solar cell as well as a normal cost (\$250-\$300/W) high performance (>26% AM0) solar cell has been developed. Different material sets have been tested for survivability in both a Low Earth Orbit and Interplanetary space environment. 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.

This power system has great potential to enhance robotic precursor mission for future human exploration. Small satellite and other miniaturized spacecraft represent low cost alternatives to traditional unmanned space vehicles. By improving power generation on these crafts without depleting volume and mass resources, capabilities can be greatly increased. High powered systems enable solar electric propulsion, deep space communication, sufficient solar power generation at >1AU, and the like in these low cost small spacecraft. In turn, this enables cheaper, rapid schedule, high capability robotic missions as precursors for human exploration.

Deployable Antennas: Embedded antennas also are being developed for LISA-T. These antennas can be adhered to thin-film substrates to provide lightweight, omnidirectional and/or high powered UHF, S and X-band coverage, increasing bandwidth or effective communication ranges for small spacecraft. Other bands, such as Ka and L are also being explored.

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.

Summary: As thin film deployable technologies mature and associated robotic missions flown, so to will our insight into what human exploration missions should be pursued given the limited resources available. 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 and human exploration mission architectures to be reached by a generation of spacecraft smaller and more capable than ever before.

References: [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.