

## NASA Small Spacecraft Technology Program (SSTP) Overview, Recent Technology Demonstrations, and Upcoming SSTP Demonstrations

Roger C. Hunter <sup>\*(1)</sup>, Elwood I. Agasid <sup>(2)</sup>, James C. Cockrell <sup>(3)</sup>, Julianna L. Fishman <sup>(4)</sup>, Bruce D. Yost <sup>(5)</sup>

<sup>(1)</sup> NASA Ames Research Center, Mountain View, California, United States [roger.c.hunter@nasa.gov](mailto:roger.c.hunter@nasa.gov)

<sup>(2,3,5)</sup> NASA Ames Research Center, Mountain View, California, United States

<sup>(4)</sup> Technology Horse LLC, NASA Ames Research Center, Mountain View, California, United States

### ABSTRACT

The Small Spacecraft Technology Program (SSTP) within the NASA Space Technology Mission Directorate (STMD) is chartered to enable mission capabilities that are more rapid, more transformative, and more affordable than previously achievable. To that end, the SST program seeks to:

- Enable the execution of missions at much lower cost than previously possible.
- Substantially reduce the time required for development of spacecraft, from authority to proceed until initial launch capability.
- Enable and demonstrate new mission architectures that small spacecraft are uniquely suited for.
- Expand the capability of small spacecraft to execute missions at new destinations and in challenging new environments.
- Enable the augmentation of existing assets and future missions with supporting small spacecraft.

This paper will describe the NASA SSTP SmallSat Technology Partnerships (STP), completed and upcoming Missions Capability Demonstrations for technology demonstrations under SSTP<sup>1</sup> and provides a synopsis of the leveraged investments under the Small Business Innovation Research (SBIR) Program and Small Business Technology Transfer (STTR). A brief overview of the Small Spacecraft Systems Virtual Institute (S3VI) and its current activities performed in conjunction with SSTP is also provided.

*Keywords:* small spacecraft missions, technology development, capability demonstrations, CubeSats

### 1.0 NASA SMALL SPACECRAFT TECHNOLOGY PROGRAM OVERVIEW

All efforts focus on small spacecraft capabilities that are relevant to NASA's missions in science and exploration, including those with crosscutting applications to the needs of the broader small spacecraft community in industry, academia, and other government agencies. The program's current focus is systems for communications, propulsion, pointing, power, and autonomous operations.

The program consists of four elements intended to encompass the development and demonstration of a range of technologies and capabilities and to engage the talents of the broad community of researchers and technologists from government, industry, and academia.

*Focused Technology Development and Demonstrations:* full and open solicitations for projects in development and flight demonstrations in focused small spacecraft technology areas such as communications and propulsion, among others.

*Mission Capability Demonstrations:* flight demonstration projects for new mission capabilities involving both

---

<sup>1</sup> Additional information on SSTP including details of funded technology development projects and flight missions are available on the program's website: [https://www.nasa.gov/directorates/spacetech/small\\_spacecraft/index.html](https://www.nasa.gov/directorates/spacetech/small_spacecraft/index.html)

competitive contracts and directed NASA efforts.

*Leveraged Investments*: continuation of selected projects from SBIR or other programs as well as prize challenges and other initiatives.

*Smallsat Technology Partnerships*: a portfolio of small spacecraft technology development projects conducted by universities in collaboration with NASA centers.

Additionally, the Small Spacecraft Systems Virtual Institute (S3VI) provides the SSTP with expertise and support for studies and workshops. Established in 2017, the S3VI advances clear communications, coordination, and consistent guidance regarding small spacecraft activities across NASA. The S3VI also provides the US small spacecraft research community with access to mission enabling information and maintains engagement with small spacecraft stakeholders in industry and academia. Current SSTP studies supported by the S3VI are focused on communications and propulsion.

## 2.0 SMALLSAT TECHNOLOGY PARTNERSHIPS

The STP projects are principal investigator-lead collaborations between a US-based university and a partnered NASA center focused on developing transformative technologies for small spacecraft. Recurring STP partnerships are solicited approximately annually and engage the unique talents and fresh perspectives of the university community while sharing NASA's experience and expertise to develop new technologies and capabilities for small spacecraft. These STP collaborations engage NASA personnel in the rapid, agile and cost-conscious small spacecraft approaches common in academia, support university efforts, and foster a new generation of innovators for NASA and the nation.

Each STP solicitation cycle focuses on a set of technical topics specified by NASA to increase the utility of small spacecraft for near-term missions and to benefit the commercial small spacecraft community. Successful proposals are awarded for a duration of two years with a continuation review after the first year. Typical award values are \$200k per year for the university and a half-time position for the NASA partner, along with \$25k for material procurement in the second year. To date, 37 STP projects have been awarded over a series of 4 solicitations.

Completing its fourth solicitation cycle, the STP awards cooperative agreements to spur innovations in such technical areas as advanced data communications, navigation, propulsion, power, thermal management, science capabilities, advanced manufacturing, integrated power and thermal management systems, advanced propulsion, and de-orbit systems for small spacecraft.

The 2018 STP solicitation specified technical topics oriented toward technologies that enable cooperative swarms and deep space operations of small spacecraft. Proposals were requested in three topic areas: instrument technologies for small spacecraft; technologies that enable large swarms of small spacecraft; and technologies that enable deep space small spacecraft missions. Proposers were required to cite a relevant design reference mission; establish quantitative technical performance measures that would be required to conduct the mission; contrast the state-of-the-art for those performance measures versus values targeted by their proposal; and specify how the proposed investigation would increase the technical performance values toward the goal of accomplishing the referenced mission. For the 2018 solicitation, 111 proposals were received and 9 selected for award. The 2018 efforts are currently in their second year of progress.

The 2020 STP solicitation is currently under way. The theme chosen for the current cycle is expected to increase the capabilities of small spacecraft for near-term lunar precursor and exploration missions. NASA will return humans to the Moon by 2024 and thereafter establish a sustainable presence. Precursor missions of small spacecraft will blaze the trail for lunar exploration and will establish infrastructure such as communications and navigation networks; perform on-orbit inspections; and serve to support the assembly and repair services for larger structures and lunar habitats. For the 2020 STP solicitation, prospective university and NASA partners must propose development efforts within one of these 3 technology topics relevant to lunar exploration:

- *Lunar Communications and Navigation Network*: capabilities enabling small spacecraft to operate as communications or navigational nodes that are compatible with, or extend the performance of, NASA's planned

Space Communications and Navigation (SCaN) and lunar Gateway network architecture.

- *Smallsat Propulsion for Lunar Missions*: radical improvements to propulsion systems that enable lunar orbit station keeping, plane changes, or return to Earth trajectories that are compatible with secondary payload constraints typical of small spacecraft.
- *Advanced Electrical Power Subsystem and Thermal Management Technology*: advanced power and thermal management subsystems that solve problems for small spacecraft - typically designed for low-Earth orbit (LEO) operations and constrained by their small surface area for solar power collection and heat dissipation, to successfully operate in the cislunar environment.

Selection and award for the 2020 STP cycle are planned for early calendar year 2020.

### 3.0 MISSION CAPABILITY DEMONSTRATIONS

#### 3.1 Recently Completed Missions

Nodes was a technology demonstration mission that launched to the International Space Station on December 6, 2015. The two Nodes satellites that comprised the mission subsequently deployed from the station on May 16, 2016 to demonstrate new network capabilities critical to the operation of swarms of spacecraft. The Nodes satellites accomplished all of their planned mission objectives including three technology ‘firsts’ for small spacecraft: commanding a spacecraft not in direct contact with the ground by crosslinking commands through a space network; crosslinking science data from one Nodes satellite to the second satellite before sending it to the ground; and autonomous reconfiguration of the space communications network using the capability of Nodes to automatically select which satellite is best suited to serve as the ground relay each day.

The Optical Communications and Sensor Demonstration (OCSD) mission, a pair of CubeSats, each 1.5-units (U) in size, was completed in 2019. The OCSD mission addressed two cross-cutting capabilities of value to many future small spacecraft missions: high-speed optical transmission of data and small spacecraft proximity operations. The demonstration was a complete success as the technology demonstration showed data rates from the OCSD pair reaching up to 200 megabits per second (Mb/s), a factor of 100 increase over current high-end CubeSat communications systems. The proximity sensors developed for this mission enable relative position measurement between two small satellites - a capability not previously demonstrated.

The OCSD mission was launch to the station on an Orbital-ATK Crew Resupply Mission (OA-8E) in November 2017. The OCSD satellites remained attached to the Crew Resupply Mission capsule until the resupply mission to the station was completed in December 2017. After detaching from the station, the capsule moved to an orbit approximately 100 km higher than the station and deployed the OCSD technology demonstration. The OCSD pair entered systems checkout after deployment with the demonstrations of the laser communications experiment continuing throughout 2018 and into 2019.

Similar to the OCSD launch and deployment, the Integrated Solar Array and Reflectarray Antenna (ISARA) technology demonstration was launched to the station alongside OSCD in November 2017, and subsequently deployed from the Orbital ATK Crew Resupply capsule in December 2017. The ISARA mission demonstrated a reflectarray antenna that increases downlink data rates for CubeSats from the existing baseline rate of 9.6 kilobits per second (kb/s) to more than 100 megabits per second (Mb/s).

The reflectarray antenna consists of three panels, electrically tied together through hinges, which have an array of printed circuit board patches on them. The patch size is adjusted so that the phase of the reflected feed illumination collimates the radiation in much the same way a parabolic dish reflector would. Unlike a parabolic dish, however, the reflectarray panels are flat, which enabled them to be folded down against the CubeSat. On the opposite side of the printed reflectarray antenna, solar cells were added. This makes the overall antenna/solar array panel assembly slightly thicker, but the cells are stowed in the “dead space” between the launch rails that would have otherwise been left empty. This combination of antenna and solar cells makes for a very efficient use of CubeSat volume, leaving plenty of room for payloads such as science instruments or imaging systems. Like OCSD, the technology demonstration

continued through summer 2018 ending in the successful completion of experiment objectives. Within five months of spacecraft checkout functions, the ISARA spaceflight demonstration verified antenna performance to technology readiness level 7 and 100 Mb/s data rate capability [3]. When the ISARA technology demonstration mission completed in summer 2018, the hosted payload mission began.

### 3.2 Hosted-Payload on ISARA

The ISARA CubeSat mission, managed by NASA's Jet Propulsion Laboratory (JPL), operated by The Aerospace Corporation (Aerospace), and sponsored by NASA's SSTP, was the first successful in space technology demonstration of a reflectarray antenna. The antenna's space-saving, flat-panel design allowed for the CubeSat Multispectral Observing System (CUMULOS) to fly as a secondary payload [4], as detailed in the following:

An Aerospace-developed technology, CUMULOS is the first infrared sensor flown as part of Aerospace's AeroCube program which allows infrared weather imagery to be studied by a small satellite. Made of three compact cameras with lenses an inch or less in diameter, CUMULOS has a visible wavelength camera, a short-wavelength infrared camera, and a long-wavelength infrared, microbolometer camera [4].

The CUMULOS payload was a late-addition to the ISARA mission and is an example of the agility of the SSTP to accept rideshare payloads late-in-the-development of the main CubeSat mission.

An impromptu demonstration of opportunity was realized in April 2019 when the OCSD-B flight vehicle was used in conjunction with the CUMULOS payload aboard the ISARA flight vehicle. The demonstration of opportunity showed that the OCSD-B flight vehicle could accurately point and lase the CUMULOS payload, onboard ISARA, at a distance of over 2200 km. This is believed to be a first in which a CubeSat, with a laser communications capability, was able to point with sufficient accuracy at another CubeSat from a great distance [5].

### 3.3 Upcoming Missions

Upcoming SSTP missions include the CubeSat Proximity Operations Demonstrations (CPOD) mission, notionally planned for launch in 2020. During this mission, SSTP will conduct an in-orbit demonstration of rendezvous, proximity operations, and docking (RPOD) of two 3U CubeSats. Each CubeSat is a satellite with the dimensions 4 x 4 x 13 in. (10 x 10 x 33 cm) and weighing approximately 11 pounds (5 kg). This flight demonstration will validate and characterize many new miniature low-power proximity operations technologies applicable to future missions. The mission will advance the state of the art in nanosatellite attitude determination, navigation and control systems, in addition to demonstrating relative navigation capabilities. CPOD will demonstrate the ability of the two spacecraft to remain at determined points relative to each other, which is known as relative station keeping. CPOD will also demonstrate precision circumnavigation and docking. Docking will employ the use of a novel universal docking device, imaging sensors, and a multi-thruster cold gas propulsion system. The two CPOD satellites are scheduled to be launched together to low-Earth orbit in the first half of calendar year 2020.

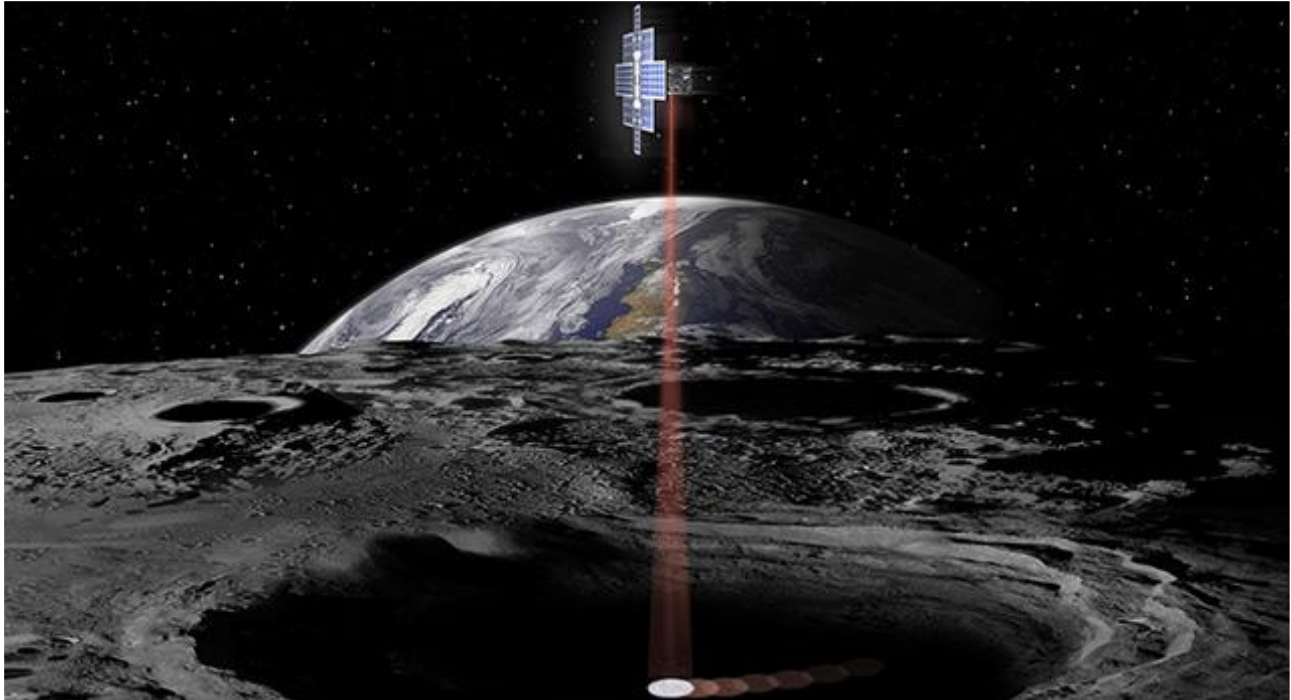
Many of CPOD's proximity operations test scenarios will be performed autonomously using high-performance, on-board processors and flight software. The satellite design leverages existing and next-generation, high-performance systems, including sensors and flight software for guidance, navigation and control. The CPOD satellites have 3-axis attitude determination and control, and large power charging capacity and storage. The system also contains a half-duplex (one-way communication) ultra-high frequency communications system with a high-speed, S-band downlink for payload data transfer.

The two CPOD satellites will be deployed into orbit simultaneously while attached side-by-side and will initially undergo a series of checkout steps to ensure proper operation and maneuvering capability. Once the initial checkout is complete, the two spacecraft will then release from each other and will begin the proximity operations maneuvers. The space-to-ground data link from each satellite will enable transmission of images of the other satellite. The two spacecraft will use an inter-satellite link to share GPS and other data.

Using on-board navigation systems, one satellite will perform a series of circumnavigation maneuvers relative to the second satellite in order to validate and characterize performance of the new miniature sensors. After the sensors have been characterized, the chaser satellite will begin closing the distance to the first satellite during a series of planned

maneuvers. Finally, when they have reached a close relative range, they will conduct the last portion of the mission by engaging the docking mechanism and performing a full docking of the two spacecraft.

Another upcoming mission is the Lunar Flashlight (LF) mission planned to launch on the Space Launch System's Exploration Mission-1 (EM-1) flight, now referred to as Artemis-1. Lunar Flashlight is an exciting new mission concept, originally selected by NASA's Advanced Exploration Systems (AES), and now sponsored by SSTP. The LF mission is led by a team from JPL and the Marshall Space Flight Center. This innovative, low-cost secondary payload concept will map the lunar south pole for volatiles and will demonstrate several technological firsts, including being the first CubeSat to reach the Moon; the first planetary CubeSat mission to use green propulsion; and the first mission to use lasers to look for water ice [6]. Figure 1 depicts an artist's concept showing the Lunar Flashlight spacecraft at the Moon.



**Fig. 1** This artist's concept shows the Lunar Flashlight spacecraft, a 6-unit CubeSat designed to search for ice on the Moon's surface using special lasers. The spacecraft will use its near-infrared lasers to shine light into shaded polar regions on the Moon, while an onboard reflectometer will measure surface reflection and composition.

Image credit: NASA/JPL-Caltech

The Advanced Composite Solar Sail System (ACS3), another technology demonstration mission scheduled in the near-term, will serve as a pathfinder for a future large solar sail (approximately 500 square meters). The ACS3 mission will demonstrate a first use of composite booms as well as sail packing and deployment systems for a solar sail in orbit. Also developed for ACS3 is an innovative tape-spool boom extraction system to minimize blossoming, or jamming, of the coiled booms during deployment. NASA anticipates flying ACS3, in LEO, in the 2021-2022 timeframe.

#### 4.0 NASA SMALL BUSINESS INNOVATION RESEARCH PROGRAM and SMALL BUSINESS TECHNOLOGY TRANSFER

The NASA SBIR and STTR programs fund the research, development, and demonstration of innovative technologies that fulfill NASA needs as described in the annual solicitations and have significant potential for successful commercialization. Definitions related to SBIR and STTR, as pertains to NASA, are available on the programs' website [7] and subtopics examples from an earlier solicitation are offered for reference [8].

NASA’s technology, science, exploration, and space operations organizations periodically identify a growing number of potential applications for very small spacecraft. Such spacecraft can accomplish missions at a fraction of the cost of larger conventional spacecraft and can be developed quickly and more responsively. In some cases, their small size and ability to be delivered in relatively large numbers may enable mission applications not possible with larger satellites. A small spacecraft can also serve as a low-cost platform for spaceflight testing of new technologies that are appropriate for spacecraft of any size.

Some of the features that are desirable for small spacecraft technologies across all system areas are the following:

- Simple design
- High reliability
- Low cost or short time to develop
- Low cost to procure flight hardware when technology is mature
- Small system volume or low mass
- Low power consumption in operation
- Suitable for rideshare launch opportunities or storage in habitable volumes (minimum hazards)
- Tolerant of extreme thermal and/or radiation environments
- Able to be stored in space for several years prior to use
- High performance relative to existing system technology [8]

For additional reference, the following website discusses some of NASA’s small spacecraft technology activities: [www.nasa.gov/smallsats](http://www.nasa.gov/smallsats) [9]

Another useful reference is the Small Spacecraft Technology State of the Art Report available at: <https://sst-soa.arc.nasa.gov> [10]

Table 1, below, provides a list of the 2018 Phase II Awardees for Small Business Innovative Research for a NASA solicitation for small-satellite technologies [11].

Table 1 Small Business Innovative Research 2018 Phase II Awardees

	AWARDEE	TECHNOLOGY TITLE
1	Alameda Applied Sciences Corporation	High-Impulse, Scalable, Metal Plasma Thruster for CubeSat Missions
2	Blink Astro, LLC	Delay-Tolerant Radio for Cooperative Groups of Small Spacecraft
3	Busek Company, Inc.	Low Impulse Bit Electro Spray Thruster Control
4	ExoTerra Resource, LLC.	Modular Xenon Micro Electric Propulsion System
5	Fibertek, Inc.	Technologies Enabling Distributed Spacecraft Missions (DSM)
6	Masten Space Systems, Inc.	PermiAM; Engineered Porosity In-Situ with Fully Dense AM Structure

## 5.0 REFERENCES

- 1 NASA Small Spacecraft Technology Program. (2019). Retrieved from [https://www.nasa.gov/directorates/spacetech/small\\_spacecraft/index.html](https://www.nasa.gov/directorates/spacetech/small_spacecraft/index.html) Accessed 20 October 2019
- 2 NASA Space Technology Mission Directorate. (2019). Retrieved from <https://www.nasa.gov/directorates/spacetech/home/index.html> Accessed 20 October 2019
- 3 Hodges, R.E., Lewis, D.K., Radway, M.J., Toorian, A.S., Aguirre, R.H., Hoppe, D. J., Shah, B.N., Gray, A.A., Rowen, D.W., Welle, R.P., Kalman, A.E., Reif, A.W., Martin, J.M.: The ISARA Mission – Flight Demonstration of a High Gain Ka-Band Antenna for 100Mbps Telecom. *Proceedings of the Small Satellite*

*Conference*, The Year in Review 2, SSC18-VI-03.

<https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=4104&context=smallsat> (2018). Accessed 20 October 2019

- 4 Mission Success for CUMULOS and ISARA CubeSat. The Aerospace Corporation. <https://aerospace.org/article/mission-success-cumulos-and-isara-cubesat> (2018). Accessed 20 October 2019
- 5 ISARA (Integrated Solar Array and Reflectarray Antenna). Earth Observation Portal hosted by the European Space Agency. Retrieved from <https://directory.eoportal.org/web/eoportal/satellite-missions/i/isara>. Accessed 20 October 2019
- 6 Lunar Flashlight Mission Information. Jet Propulsion Laboratory (2019). [https://www.jpl.nasa.gov/cubesat/missions/lunar\\_flashlight.php](https://www.jpl.nasa.gov/cubesat/missions/lunar_flashlight.php). Accessed 20 October 2019
- 7 NASA SBIR/STTR Basics. (2019). Retrieved from <https://sbir.nasa.gov/content/nasa-sbirsttr-basics>. Accessed 20 October 2019
- 8 NASA SBIR/STTR 2017 Program Solicitation. (2019). Retrieved from <https://sbir.nasa.gov/solicit/58007/detail?data=ch9&s=58001>. Accessed 20 October 2019
- 9 NASA Small Satellite Missions. (2019). Retrieved from [www.nasa.gov/smallsats](http://www.nasa.gov/smallsats). Accessed 20 October 2019
- 10 NASA Small Spacecraft Technology State of the Art Report. (2019). Retrieved from <https://sst-soa.arc.nasa.gov>. Accessed 20 October 2019
- 11 NASA 2018 SBIR Program Phase II Selections - Focus Area List. (2019). Retrieved from [https://sbir.nasa.gov/award\\_topic\\_list/selection\\_nid/61538](https://sbir.nasa.gov/award_topic_list/selection_nid/61538). Accessed 20 October 2019