SSC20-WKI-04

NASA Centers and Universities Collaborate in Annual Smallsat Technology Partnerships

James J. Cockrell, Elwood F. Agasid, Roger C. Hunter
NASA Ames Research Center
M/S 244-19, Moffett Field, CA 94035; 650-604-2553
James.J.Cockrell@NASA.gov

Christopher E. Baker
NASA Headquarters
300 E ST SW, Washington, DC, 20546-0001; 202-358-2455
Christopher.E.Baker@NASA.gov

ABSTRACT

The Small Spacecraft Technology program within the NASA Space Technology Mission Directorate sponsors the Smallsat Technology Partnerships (STP) initiative. The STP initiative awards cooperative agreements between NASA centers and university teams for technology development efforts that advance the capabilities of small spacecraft to achieve NASA mission objectives in unique and more affordable ways.

NASA's announcement to return humans to the Moon by 2024 raises new opportunities for Smallsats to contribute to missions in cislunar space, though technical challenges are to be overcome to establish their value in this environment. Precursor missions utilizing small spacecraft will blaze the trail for lunar exploration, establishing infrastructure such as communication and navigation networks, and performing assembly and repair services for larger structures and human habitats. To achieve these goals, certain novel Smallsat technologies will need to be developed and demonstrated. The 2020 STP solicitation sought proposals for specific technologies to enable these lunar missions.

For the 2020 STP cycle, NASA selected nine university teams to mature new systems and capabilities in the laboratory, and in some cases, demonstrate in suborbital or orbital spaceflights. This paper describes the STP portfolio, past and present efforts, and the nine partnerships selected.

NASA SMALL SPACECRAFT TECHNOLOGY PROGRAM AND SMALLSAT TECHNOLOGY PARTNERSHIPS

Small Spacecraft Technology Program

The Small Spacecraft Technology (SST) program within NASA's Space Technology Mission Directorate (STMD) expands the ability to execute unique missions through rapid development and demonstration of capabilities for small spacecraft applicable to exploration, science and the commercial space sector. Through targeted development and frequent in-space testing, the program:

- Enables execution of missions at much lower cost than previously possible.
- Substantially reduces the time required for development of spacecraft.
- Enables new mission architectures through the use of small spacecraft.
- Expands the reach of small spacecraft to new destinations and challenging new environments.
- Enables the augmentation of existing assets and future missions with supporting small spacecraft.

In general, the program seeks to enable mission capabilities that are rapid, transformative, and more affordable than previously achievable. In execution of its objectives, SST identifies and supports the development of new subsystem technologies to enhance or expand the capabilities of small spacecraft. The program looks to develop subsystem technologies that are new and revolutionary in their impact, rather than incremental improvements of existing subsystems. The goal is to advance subsystem technologies from a Technology Readiness Level (TRL) of 3 (analytical and experimental critical function and/or characteristic proof of concept) to a TRL of 5 (component and/or breadboard validation in relevant environment).

SST also supports flight demonstrations of new technologies, capabilities, and applications for small spacecraft. The program demonstrates technologies that are new and capabilities that have not previously been demonstrated in space. The goal is to advance from a TRL of 5 to a TRL of at least 7 (system prototype demonstration in an operational environment).

One of the SST program's several elements is the Smallsat Technology Partnerships (STP) – collaborations between universities and NASA in technology development and demonstrations.

STP Portfolio Overview

The SST program sponsors the STP cooperative agreements between NASA centers and university teams for technology development efforts focused on small spacecraft capabilities relevant to NASA's missions in science and exploration. This includes technologies with crosscutting applications to the needs of the broader small spacecraft community in industry, academia, and other government agencies. Beyond the technologies developed, the working relationships formed between universities and NASA centers through the STPs have the addition benefits of:

- Engaging the unique talents and fresh perspectives of the university community to develop new technologies and capabilities for small spacecraft.
- Sharing NASA experience and expertise in relevant university projects.
- Increasing support to university efforts in small spacecraft technology through funding and collaboration with NASA to foster a new generation of innovators for NASA and the nation.
- Educating NASA personnel across the agency in the rapid, agile, and cost-conscious small spacecraft development approaches that have evolved in the university community.

Eligibility to participate in the STP initiative is limited to U.S. colleges and university teams, including faculty, undergraduate and/or graduate students. The university team is lead by a principal investigator (PI) affiliated with the university. A collaboration between a university team and a NASA center or NASA's Jet Propulsion Laboratory is required, and the NASA team member must be either a civil servant or a member of the JPL technical staff.

Each STP effort is limited to one of the solicited technology topic areas solicited. An individual is limited to serving as the PI on a single STP effort. Technologies must be at least TRL 3 at proposal submission, with an aim to raise the TRL value to at least 5.

For the purpose of the STP initiative, small spacecraft, or "Smallsats", are defined as those with a mass of 180 kilograms or less. Typically, they are launched into space as an auxiliary or secondary payload though more recent missions feature Smallsats as the primary payload. Smallsats initially were limited to Earth-orbiting satellites, but will be increasingly used as interplanetary spacecraft, cislunar or lunar applications, planetary re-entry vehicles, and landing craft.

All partnership teams are required to demonstrate progress toward targeted Key Performance Parameters (KPP) or Measures of Performance (MOP) values within the nominal two-year period of performance. At a minimum, this must be accomplished in the laboratory environment, though partnership teams are encouraged to propose demonstrations of their STP-developed technology through NASA's CubeSat Launch Initiative (CSLI) or Flight Opportunities (FO) program.

Five STP classes have been awarded between 2013 and 2020. Cumulatively, 28 NASA-university teams in 19 states have been awarded STP partnerships for a wide range of Smallsat investigations including propulsion, power management, science instruments, communications, and autonomous operations for individual and swarms of Smallsats.

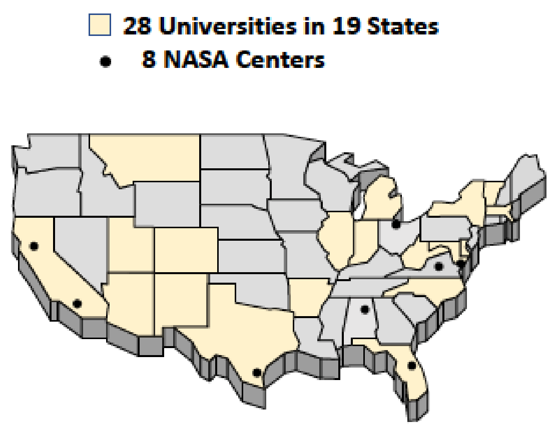

Figure 1: Partnership Award Locations 2013-2020

Progression of Past and Present STP Cycles

The five classes to-date include: 2013, 2015, 2016, 2018, and 2020. In STP classes 2013, 2015 and 2016, the maximum award was $100,000 each year for up to two years ($200,000 maximum) per award. Additionally, a NASA civil servant or JPL employee labor allocation of up to 1.0 full-time equivalent (FTE) per award, per year was available to support NASA involvement.

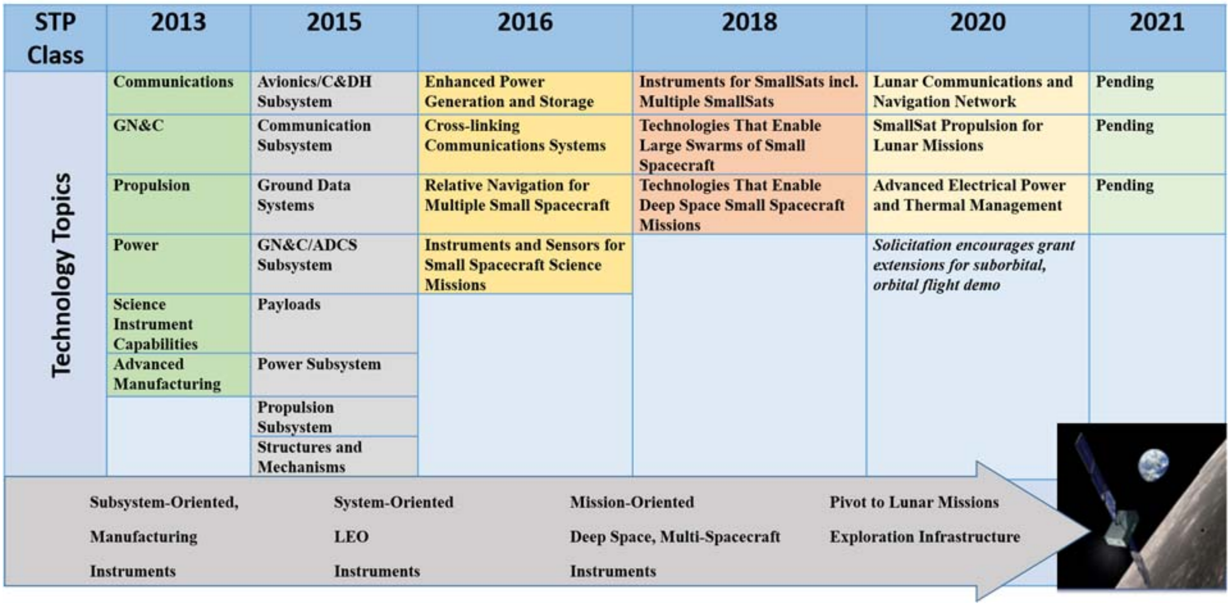

Figure 2: Smallsat Technology Partnership Technical Focus by Year

In the STP class of 2018 and the current 2020 class, the maximum award is $200,000 each year for up to two years ($400,000 maximum) per award. In addition, a NASA civil servant or JPL employee labor allocation of up to 0.5 FTE per award, per year is available to support NASA involvement.

While there is no NASA procurement funding for the first year, proposal teams can request up to $25,000 of procurement funding for the second year of a project to cover NASA expenses as part of the collaboration. This second year procurement funding is for the purchase of hardware, utilization of NASA test facilities, or other expenditures that directly support the effort. Table 1 describes the STP grant awards for each of the five years.

Table 1: Smallsat Technology Partnership Award Caps

Proposal Year	University	NASA/JPL Full Time Equivalent
2013, 2015, 2016	$100k / yr 2-year max	1.0 FTE for NASA/JPL partner $25k procurement to NASA/JPL in second year
2018, 2020	$200k / yr 2-year max	0.5 FTE for NASA/JPL partner $25k procurement to NASA/JPL in second year

Figure 2 shows the progression of technical topics solicited within the respective STP calls for proposals. Initially in 2013 and 2015, NASA's technical interests were in Smallsat subsystems, manufacturing, and instruments. In 2016 the focus turned to systems-level relative navigation and communications *between* multiple Smallsats in low-Earth orbit (LEO). The 2018 solicitation emphasized the systems-level technologies needed for Smallsat swarms including deep space operations and instruments useful for multi-point measurements of distributed phenomena. Finally, the 2020 STP solicitation pivoted to focus on technologies needed for Smallsat cislunar operations.

The 2020 STP Class

The 2020 STP solicitation[1] was announced on September 1, 2019 through the NASA Solicitation and Proposal Integrated Review and Evaluation System (NSPIRES) portal.

NASA's announcement to establish a sustainable presence on the Moon by 2024 highlights several technical challenges that need to be addressed. Precursor missions utilizing small spacecraft will pave the way for lunar exploration, establishing infrastructure such as communication and navigation networks, and performing on-orbit inspection, assembly and repair services for larger structures and human habitats.

For the 2020 STP solicitation, the proposing team needed to:

- Describe in their proposal a specific capability or service needed for lunar exploration precursor missions or for exploration infrastructure. The capability should be an extension or improvement over the performance of missions that NASA already plans to execute in the 2022 time frame, then propose how small spacecraft – or cooperative groups of small spacecraft – can offer a unique, cost-effective solution for the identified capability or service.

- Select from one or more of the three solicited Technology Topics (listed below) where the state-of-the-art (as projected for the 2022-23 time frame) currenlty inhibits/prevents small spacecraft from achieving solution identified by the proposer (in the step above).
- Explain their proposed two-year development effort that leads to the solution that fills the technology gap identified in the proposal. Prospers must also specify quantifiable KPP(s) or MOP(s) to serve as quantitative measures to contrast the performance of the state of the art with that needed for their proposed solution, and they must explain how the proposed two-year development effort will raise the performance measure to the value needed.

The focus of the 2020 STP cycle is on technical developments that fill specific, identified gaps in any one of the following topics:

Technology Topic 1. Lunar Communications and Navigation Network

Technology Topic 2: Smallsat Propulsion for Lunar Missions

Techology Topic 3: Advanced Electrical Power Subsystem and Thermal Management Technology

To further encourage flight demonstrations of developed technology, the 2020 STP solicitation offered to facilitate funded extensions for teams with successful follow-on proposals to NASA's CSLI or FO programs. Projects may, within a limited time period of the basic STP effort, request a funded extension of their cooperative agreement through the STP Cooperative Agreement Technical Officer. If selected for launch by CSLI or FO, the SST program may grant an extension of the STP cooperative agreement by up to 12 months, and may award additional funds to the project to support the proposed integration, launch cost, operations, and limited post-flight analysis. The amount of additional funds will be determined at the negotiation of the proposed STP cooperative agreement extension. Approval of the funded extension is contingent on satisfactory performance throughout the STP cooperative agreement two-year period of performance, and on the availability of funding resources.

In March 2020, NASA announced the awardees of this latest STP cycle.

2020 STP PARTNERSHIPS AWARDED

The nine partnerships selected for the 2020 STP cycle are briefly described below.

Proposal Title: "Flat Panel Phased Array Antennas with Two Simultaneous Steerable Beams utilizing 5G Ka-Band Silicon RFICs for Tx/Rx Communications between 6U Small Satellite and Lunar surface, Gateway and Earth"

PI: Satish Sharma, San Diego State University

NASA Glenn Research Center Partner: James A. Nessel

This partnership will develop two dual-band flat-panel phased-array antennas utilizing commercial 5G cellular technology. This approach takes advantage of commercially available communications technology to create a high-performance data communications network in a low-cost CubeSat form factor that's capable of simultaneous communications between the Smallsat relay and lunar rovers, Smallsat to Gateway, and Smallsat to Earth terminals. The separate electrically steerable antennas will allow multiple directional signal paths without rotating the spacecraft or employing bulky mechanically rotated antennas.

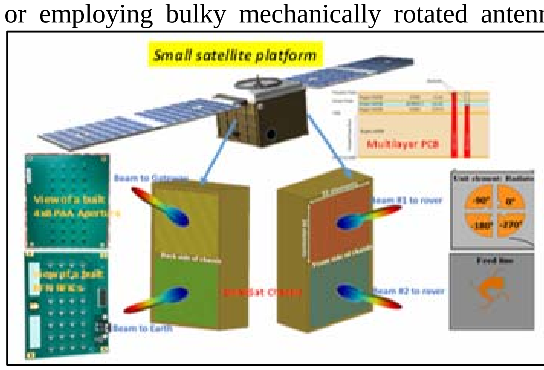

Figure 3: Smallsat Architecture with Polarized Phased Array Antennas. ***Credits: San Diego State Univerity***

The development of the shared platform dual circular polarized phased array antennas (PAAs) (25.5 – 27.5 GHz and 22.55 – 23.55 GHz Tx/Rx bands) utilizing 5G Silicon radio frequency integrated circuit (RFIC) beamformers that will generate four independent electrically steered beams. By leveraging commercial 5G technologies, this will exploit the high volume production and commercial timescales to produce low cost, high performance systems.

Proposal Title: "3-D Printed Hybrid Propulsion Solutions for Smallsat Lunar Landing and Sample Return"

PI: Stephen Whitmore, Utah State University

NASA Marshall Space Flight Center Partner: George T. Story

This collaborative effort will build from successful suborbital testing of a 3D printed plastic and nitrous-oxide and gaseous oxygen hybrid rocket motor. This technology could enable missions of interest to NASA that require high thrust, such as lunar landing and sample return, to be performed by CubeSat-sized spacecraft.

Figure 4: 25-N High Performance Green Hybrid Propulsion System During Test Firing Sequence. *Credits: Utah State University*

The investigation will develop and mature a High Performance Green Hybrid Propulsion (HPGHP) system, compatible with rideshare, that will enable low-cost payload delivery to the lunar surface. The HPGHP system leverages unique electrical breakdown characteristics of Fused Deposition Model (FDM) printed plastics like acrylonitrile butadiene styrene (ABS), polystyrene, and polyamide. Additive manufacturing changes electrical breakdown properties of these materials and is an essential element of HPGHP. This technology will also benefit fully-matured propulsion technology applicable for surface sample return missions for samples up to a 1 kilogram mass.

Proposal Title: "A High-Precision Continuous-Time PNT Compact Module for the LunaNet Small Spacecraft"

PI: Chee Wei Wong, University of California, Los Angeles

NASA Jet Propulsion Laboratory Partner: Andrey B. Matsko

This partnership will develop technology for the lunar environment similar to the GPS system at Earth. To develop a system for precise position, navigation and timing services at the Moon or Mars, the effort will incorporate several key building blocks including an integrated continuous time position, navigation and timing module. This includes a chip-scale optomechanical accelerometer and commercial-off-the-shelf compact optical gyroscope paired with a high-performance mercury ion clock.

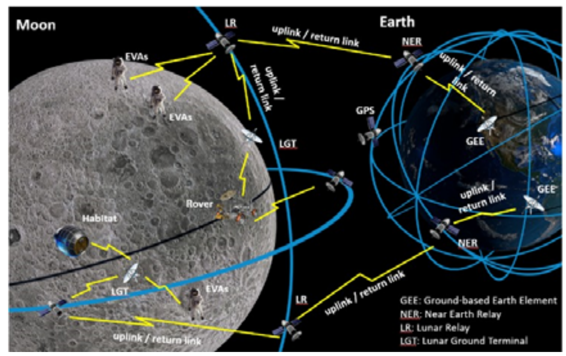

Figure 5: LunaNet Architecture Diagram. *Credits: Univeristy of California, Los Angeles*Proposal Title: "Variable Specific Impulse Electrospray Thrusters for Smallsat Propulsion"

In collaboration with the California Polytechnic State University (CalPoly), this work will demonstrate an engineering model of a high-precision continuous time position-navigation-and-timing chip module for the 2022 LunaNet small spacecraft. This technology will enable a tracking-data relay satellite to serve effectively as the network access node for continuous communications with lunar orbital and surface assets, reducing the reliance on Earth-based instruments for primary lunar navigation. This real-time guidance and control can advance robotic lunar exploration across much of the lunar surface and human exploration at outposts, supporting sorties across a diversity of lunar regions.

PI: Manuel Gamero-Castano, University of California-Irvine,

NASA Jet Propulsion Laboratory Partner: John K. Ziemer

This effort will build on previous fundamental physics modeling of existing propulsion technology that uses electrostatic charges to propel liquid droplets to generate thrust. It will further develop and test a more versatile system capable of operating in either a high-thrust mode when needed, or more efficient low-thrust mode to conserve fuel and save weight. This technology will add mission flexibility to electrospray propulsion systems while keeping within the compact size suited to small spacecraft.

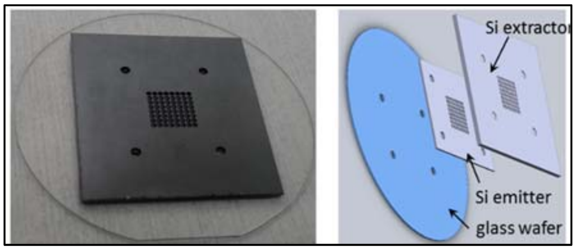

Figure 6: An Additively Manufactured Deployable Radiator with Oscillating Heat Pipes (AMDROHP) to Enable High Power Lunar CubeSats. ***Credits: University of California-Irvine***

The project will demonstrate a TRL 5 electrospray thruster for primary propulsion of a 12U Smallsat for Smallsat-based lunar missions. A CubeSat-class power system for operation of the propulsion system will also be designed. The proposed thruster will offer significant improvements on efficiency, operational flexibility (variable specific impulse operation), and spacecraft scalability over existing technologies. The project aims to study the infusion of the propulsion system into Smallsats and SmallSast-based missions.

Proposal Title: "An Additively Manufactured Deployable Radiator with Oscillating Heat Pipes (AMDROHP) to Enable High Power Lunar CubeSats"

PI: Yen Kuo, California State University, Los Angeles

NASA Jet Propulsion Laboratory Partner: Benjamin Furst

CubeSats are compact and therefore cannot efficiently radiate heat. Moreover, the CubeSats that will be designed for upcoming lunar missions will demand more electrical power (which produces heat as a byproduct) for equipment, such as more powerful radio transmitters, and simultaneously they will need to deal with the harsh cislunar thermal environment. This technology will address the increasingly critical need to radiate heat efficiently from small spacecraft. The partnership will develop an additively manufactured deployable radiator that uses integrated flexible oscillating heat pipes to provide more efficient heat transfer than traditional thermal straps.

This technology will efficiently transport heat from the spacecraft chassis through deployment joints into the radiator structure. The project goal is to develop an Additively Manufactured Deployable Radiator with Oscillating Heat Pipes (AMDROHP) for a 1U CubeSat capable of dissipating 50 watts in low-Earth orbit and demonstrate an effective conductivity of 5,000 watts per meter kelvin (W/m/K) from the spacecraft to the radiator.

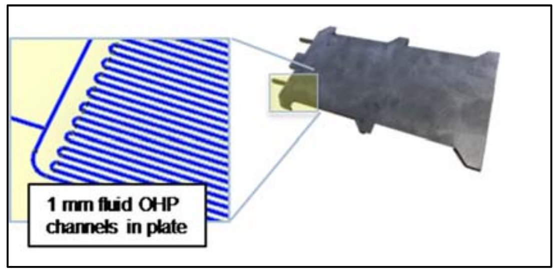

Figure 7: An Additively Manufactured OHP Embedded in a Radiator Plate. ***Credits: Jet Propulsion Laboratory***

Proposal Title: "Deployable Optical Receiver Aperture for Lunar Communications and Navigation"

PI: Daniel Jacobs, Arizona State University

NASA Jet Propulsion Laboratory Partner: Jose E Velazco

This partnership is for a novel deployable wide-aperture optical communications receiver. This technology will enable simpler, quicker optical communications target acquisition by receiving signals from more widely separated locations than other fixed, body-mounted optical systems. The technology will enable small spacecraft to relay data between other assets placed across the lunar surface, other spacecraft in different lunar orbits, and to Earth, simultaneously and more efficiently.

The technology development objective is to build a CubeSat demonstration of a wide-field laser terminal that provides a sustained 1 gigabit per second (Gbps) data rate over 1000 kilometers while requiring only 10 degree spacecraft bus pointing accuracy and stability. The Deployable Optical Receive Aperture (DORA) for inter-spacecraft communications will be capable of up to 1 Gbps data rates at distances of 5,000 to 10,000 kilometers. The novel DORA approach enables a large collecting area, high data rate, and eliminates precision pointing accuracy requirements on the host spacecraft.

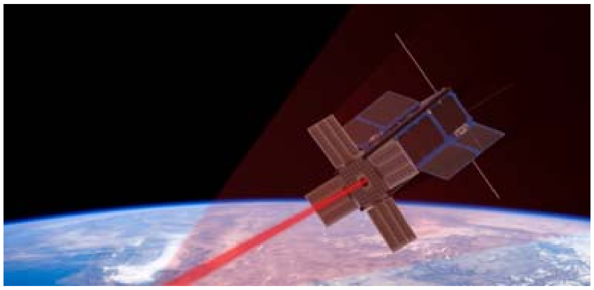

Figure 8: Deployable Optical Receive Aperture CubeSat During Operations. ***Credits: Arizona State University***

Proposal Title: "On-Orbit Demonstration of Surface Feature-Based Navigation and Timing"

PI: Brandon Jones, University of Texas, Austin

NASA Johnson Space Center Partner: Christopher D'Souza

This collaboration will extend existing onboard optical navigation techniques by using identification and tracking of lunar craters, instead of conventional star tracking, to create an intermediate range terrain relative navigation solution. Spacecraft near the Moon can incorporate this technology to track their location relative to the lunar surface as an innovative method of navigation independent of GPS or other Earth-based systems. By using the patterns that craters form on the lunar surface, the same way current navigation systems use patterns that stars form to determine a spacecraft's position in space, this technique can build from well-established star tracking capabilities to quickly produce a new capability from existing highly reliable systems.

The focus in this effort is to develop a lunar surface-feature based navigation and timing approach to position, navigation and timing (PNT). This technology allows for estimating spacecraft state and time bias relative to a reference solution using optical tracking of lunar craters. The developed technology integrates crater detection, identification, and state estimation into a unified and unique system for PNT using flight-proven optical cameras.

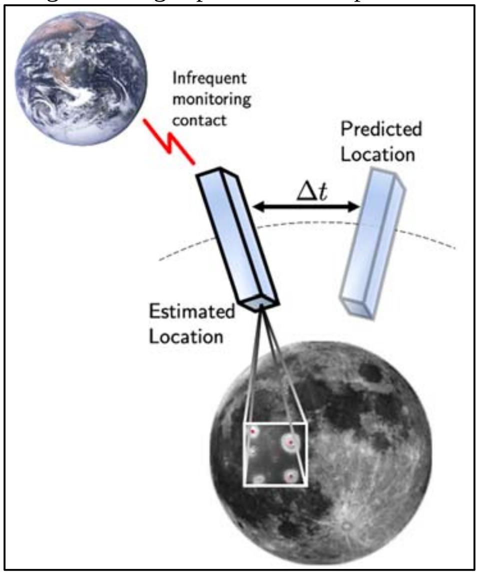

Figure 9: Illustration of the Crater-Based Navigation and Timing System Leveraging Surface Features for Navigation and Timing. ***Credits: University of Texas, Austin***

Proposal Title: "Lunar Missions Enabled by Chemical-Electrospray Propulsion/ Multimode Monopropellant-Electrospray Propulsion System (MEPS)"

PI: Joshua Rovey, University Of Illinois, Urbana-Champaign

NASA Glenn Research Center Partner: Thomas Liu

NASA Goddard Space Flight Center Partner: Khary Parker

This partnership will build from a previous Small Business Innovation Research (SBIR) effort with Froberg Aerospace to test a dual mode — combustion mode and electrospray mode — propulsion system. The system uses the same propellant, feed system, power unit, and thrusters for both modes adding additional mission capabilities while staying within the limited mass and space available on small spacecraft. The chemical combustion mode can provide higher thrust for orbital insertion and fast orbit transfers, while the more efficient electrospray mode used during low-energy maneuvers preserves fuel — reducing size and weight which are critical for small spacecraft.

The goal of this project is an in-space demonstration of a single chemical-electrospray propulsion system that can be operated in and switched between high-thrust chemical monopropellant mode and high-specific impulse electric electrospray mode. It consists of power processing unit (PPU), one green ionic propellant, and one feed system to one or more MEPS thrusters. This will enable a spacecraft to impulsively capture into lunar orbit from a translunar trajectory (chemical mode), while also providing low thrust station keeping once in orbit (electric mode).

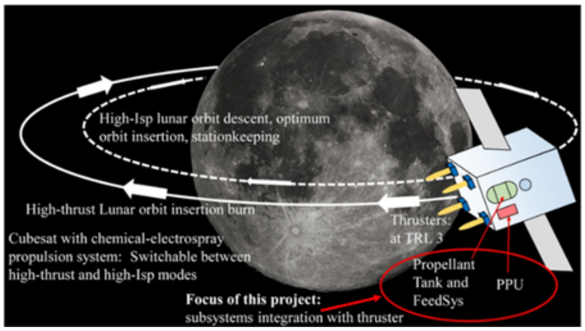

Figure 10: Demonstration of a Multimode Monopropellant-Electrospray Propulsion System on a Lunar Spacecraft. ***Credits: University of Illinois, Urbana-Champaign***

Proposal Title: "A Small Satellite Lunar Communications and Navigation System"

PI: Scott Palo, University of Colorado Boulder

NASA Jet Propulsion Laboratory Partner: Courtney Duncan

This collaboration will develop and demonstrate a communications, navigation and time signal distribution system using a communications protocol similar to that used by cell phones on Earth. The high data rates and communications protocol will support dozens of users simultaneously while also being capable of broadcasting text and alert messages. This draws from a variety of current and prior development and flight demonstration activities with the goal of integrating these various technologies into a single reliable, yet low-cost satellite that can be copied and deployed as a constellation to form a communications relay network at the Moon.

The objective of this work is to mature the TRL of a low size, weight, and power, ultra high frequency-based PNT and communications system. The capability of the system for lunar communications networking will be demonstrated, including UHF two-way PNT signals, Ku- band intersatellite links and X-band links to and from Earth. This effort will enable cell phone level performance PNT and text messaging at the Moon.

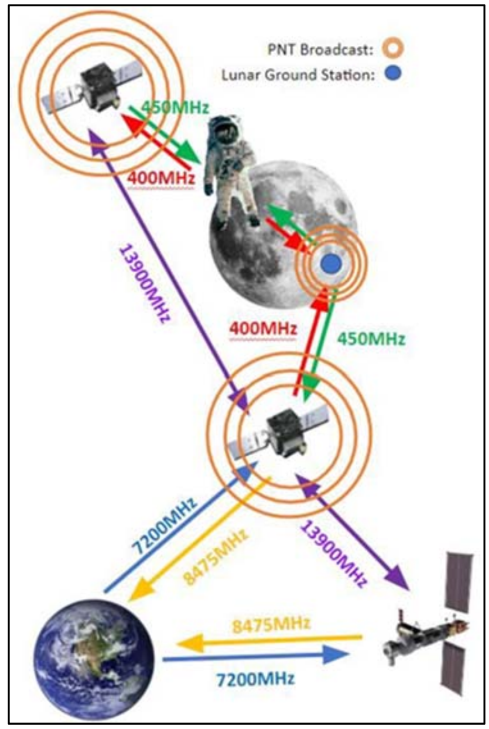

Figure 11: Illustration of Ultra High Frequency-based Position, Navigation, and Timing and Lunar Communications System. ***Credits: University of Colorado Boulder***

NEXT STEPS

2020 STP Planned Outcomes and Reporting

Each of the nine technology development projects will be monitored for satisfactory progress over their two-year period of performance. After the end of the second year, all the partnerships will deliver technical closeout reports. Projects are expected to report progress toward TRL advancement and demonstrated achievements of the technical success measures (KPPs, MOPs) identified in their respective proposals. As in previous years, there is the expectation that each project will publish a number of technical reports and papers, patent new inventions, and report their new technologies through NASA's New Technology Reporting (NTR) System.[2] Universities retain the rights to their own intellectual property developed under the STPs. Interested parties may learn how to license the new technologies through the NTR portal.

2021 Solicitation

The SST program plans to release a 2021 STP solicitation later this year. Technology topic areas for the 2021 solicitation will likely continue the deep space exploration theme started begun in the 2020 solicitation. Announcements will be made on the NASA NSPIRES portal and via the SST program web portal[3] and social media.

References

1. Smallsat Technology Partnerships 2020, (2019, September 11). Retrieved May 31, 2020 from https://nspires.nasaprs.com/external/solicitations/summary!init.do?solId={1CC0D04C-2870-B7CB-4661-1E3D8B546EA2}
2. NASA Technology Transfer Program. New Technology Reporting System. Retrieved May 31, 2020, from https://invention.nasa.gov
3. Small Spacecraft Technology Program. (2020, March 9). Retrieved May 31, 2020, from https://www.nasa.gov/directorates/spacetech/small_spacecraft/index.html