NASA Centers and Universities Collaborate in Annual Smallsat Technology Partnerships

Jim 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

Since 2013, NASA's Small Spacecraft Technology (SST) program has sponsored a series of Smallsat Technology Partnerships (STP). These PI-lead collaborations between a U.S.-based university and a partnered NASA center are developing transformative Smallsat technologies. Each year the STP competitive solicitation focuses on a chosen set of technical topics. Successful proposals are awarded for a duration of two years with continuation review after the first year. Award values were $200k per year for the university and 0.5 FTE for the NASA partner along with $25k for material procurement in the second year, for the 2018-2019 STP solicitation. Thirty-seven Smallsat Technology Partnerships have been awarded over a series of 4 solicitations.

In this paper, we give the SST program's objectives for encouraging partnerships between universities and NASA centers, and the purpose and aim of the annual NASA-University Smallsat Technology Partnerships. We describe in detail the technical advancements stemming from the STP partnerships. Finally, we present summary results from both the university and NASA perspectives to support the conclusion that the overall STP portfolio has returned positive results compared to resources invested, successfully achieving the stated goals.

NASA STMD SMALL SPACECRAFT TECHNOLOGY PROGRAM

The Small Spacecraft Technology program within the NASA Space Technology Mission Directorate is chartered develop and demonstrate the capabilities that enable small spacecraft to achieve science and exploration missions in unique and more affordable ways. Specifically, the SST program seeks to enable new mission architectures through the use of small spacecraft, to expand the reach of small spacecraft to new destinations, and to make possible the augmentation of existing assets and future missions with small spacecraft.

GOALS FOR UNIVERSITY – NASA PARTNERSHIPS

The SST program sponsors Smallsat technology development partnerships between Universities and NASA Centers in order to engage the unique talents and fresh perspectives of the university community and to share NASA experience and expertise in relevant university projects. The projects are to develop new technologies and capabilities for small spacecraft. These partnerships also engage NASA personnel in the rapid, agile and cost-conscious small spacecraft approaches that have evolved in the university community, as well as increase support to university efforts and foster a new generation of innovators for NASA and the nation.

WHAT ARE SMALLSAT TECHNOLOGY PARTNERSHIPS (STPS)?

For the purpose of STPs, small spacecraft are defined as those with a mass of 180 kg or less and capable of being launched into space as an auxiliary or secondary payload. Although the term "smallsats" is used as a synonym, small spacecraft are not limited to Earth orbiting satellites, but might also include interplanetary spacecraft, planetary re-entry vehicles, and landing craft. Smallsat Technology Partnerships are the development and/or demonstration of new technologies and capabilities for small spacecraft by U.S. colleges and universities in collaboration with NASA through award of cooperative agreements.

Eligibility is limited to U.S. college and university teams, including faculty, undergraduate and/or graduate students. The Principle Investigator (PI) leading a university team must be affiliated with a U.S. college or university (including community colleges), accredited in and having a campus located in the U.S.

Partnering between the university team and a NASA Center or Jet Propulsion Laboratory (JPL) is required. The NASA team member must be either a civil servant or a member of the technical staff from JPL.

Each STP effort must be limited to one of the Technology Topic Areas solicited. An individual is limited to being the PI on a single STP effort. Technologies must be at least TRL 3 at proposal submission, with an aim to raise TRLs to 5 or 6. Projects may be planned to culminate in ground-based technology development and test or development of payloads for suborbital, balloon or orbital space flight technology demonstrations.

There have been four STP procurement cycles ("classes") to-date: 2013, 2015, 2016 and 2018.

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. In addition, 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. Proposal teams can request up to $25,000 of procurement funding for the second year of a project to cover NASA expenses in the collaboration. This procurement funding for the second year could be used to purchase hardware, applied to the use of NASA test facilities, or for other uses that directly support the effort. There is no NASA procurement funding for the first year.

In the current STP class of 2018, the maximum 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 full-time equivalent (FTE) per award, per year is available to support NASA involvement. For the 2018 class, as in previous years, proposal teams could request up to $25,000 of procurement funding for the second year.

Table 1. STP 2-Year Funding Levels

STP Grant Award Caps		
STP Proposal Year	**University**	**NASA/JPL FTE**
2013, 2015, 2016	$100k / yr 2-year max	1.0 FTE for NASA/JPL partner $25k procurement to NASA/JPL in second year
2018	$200k / yr 2-year max	0.5 FTE for NASA/JPL partner $25k procurement to NASA/JPL in second year

THE STP SOLICITATION PROCESS

For each annual STP cycle, the SST program reaches out to NASA leadership, chief technologists and subject matter experts to review previous development efforts, identify candidate technology topics, and to choose a small number (ranging from three to six) "Technology Topic Areas" for the current solicitation. Over the four class years to-date, NASA's solicited Technology Topic Areas has trended from initially being aimed at advancement of CubeSat subsystems to focus more on systems-level and CubeSat swarms topics in the last two cycles. CubeSat instruments and sensors have been a common Technology Topic Area each of the four years.

Solicitation is conducted through NASA's NSPIRES web portal as well as through grants.gov. Panels of subject matter experts are convened to review and assess proposals divided by each technology topic. For the 2018 class, assessment weighting criteria were: Relevance and Impact: 45%; Technical and Management Approach: 45%; Cost: 10%. Assessments are compiled and those evaluated most highly are presented to the STMD selection official. The selection official approves those most qualified and releases letter of selection.

Table 2. Annual Technology Topic Areas

STP Class	2013	2015	2016	2018
Technology Topic Areas	Communications	Avionics / C&DH Subsystem	Enhanced Power Generation and Storage	Instruments for SmallSats incl. Multiple SmallSats
	GN&C	Communication Subsystem	Cross-linking Communications Systems	Technologies That Enable Large Swarms of Small Spacecraft
	Propulsion	Ground Data Systems	Relative Navigation for Multiple Small Spacecraft	Technologies That Enable Deep Space Small Spacecraft Missions
	Power	GN&C / ADCS Subsystem	Instruments and Sensors for Small Spacecraft Science Missions	
	Science Instrument Capabilities	Payloads		
	Advanced Manufacturing	Power Subsystem		
		Propulsion Subsystem		
		Structures and Mechanisms		
Proposals	**n/a**	**109**	**80**	**111**
Grants	**13**	**8**	**8**	**8**

PAST TECHNOLOGY PARTNERSHIPS

2013 STP

The inaugural class of Smallsat Technology Partnerships was launched in 2013. The number of partnership proposals submitted is not available at the time of this writing; 13 grants were selected and awarded for this year. Several of these successful technologies have been subsequently incorporated into further development efforts and spaceflight missions.

- 13 grants awarded
- 2 spaceflight demonstrations
  - CSUN, CSUNSat1, OA-7, (May 2015)
  - MSU, RadSat, ISS, (May 2018)
- 1 patent applied for
  - Space Optical Communications Using Modulating Retro-Reflectors (MRR) with Vertical Cavity Semiconductor Optical Amplifiers (VCSOA)
- 6 Technology Topics:
  - Communications
  - GN&C
  - Propulsion
  - Power
  - Science Instrument Capabilities
  - Advanced Manufacturing

Table 3. 2013 STP Partnerships

Project	University	NASA/JPL
High Rate CubeSat X-band/S-band Communication System	University of Colorado, Boulder	GSFC/ MSFC
Space Optical Communications Using Laser Beam Amplification	University of Rochester	ARC
Development of Novel Integrated Antennas for CubeSats	University of Houston	JSC
SmallSat Precision Navigation with Low-Cost MEMS IMU Swarms	West Virginia University	JSC
CubeSat Autonomous Rendezvous & Docking Software (CARDS)	University of Texas, Austin	JSC
Radiation Tolerant, FPGA-based SmallSat Computer System	Montana State University, Bozeman	GSFC/ MSFC
An Integrated Precision Attitude Determination and Control System	University of Florida, Gainsville	LaRC
Propulsion System and Orbit Maneuver Integration in CubeSats	Wester Michigan University, Kalamazoo	JPL
Film-Evaporation MEMS Tunable Array for PicoSat Propulsion and Thermal Control	Purdue University	GSFC
SmallSat Low Mass, Extreme Low Temperature Energy Storage	California State University, Northridge	JPL
Compressive Sensing for Advanced Imaging and Navigation	Texas Engineering Experiment Station	LaRC
Mini Fourier-Transform Spectrometer for CubeSat-Based Remote Sensing	Appalachian State University	GSFC
Printing the Complete CubeSat	University of New Mexico	GRC

2015 STP

NASA SST program did not solicit STP proposals in 2014. The next solicitation was conducted in 2015.

- 109 proposals submitted
- 8 grants awarded
- 2 Spaceflight demonstrations:
    - UofA, ARKSAT-1, CSLI (in dev)
    - UofIllinois, CAPSat, CSLI (fall 2018)
- 2 NTRs/Patents Applied for:
    - Film-Evaporation MEMS Tunable Array thruster
    - Method for Inflating In-space Gossamer Structures with Solid-State Gas Generator Arrays
- 4 Technical Topics
    - Precise attitude control and pointing systems for CubeSats (33)
    - Power generation, energy storage, and thermal management systems (30)
    - Simple low cost deorbit systems (14)
    - Communications and tracking systems and networks (32)

Table 4. 2015 STP Partnerships

Project	University	Center
Solid State Inflation Balloon Active Deorbiter	University of Arkansas, Fayetteville	ARC
Miniaturized Phonon Trap Timing Units for PNT of CubeSats	University Of Michigan, Ann Arbor	GSFC
Design and Validation of High Date Rate Ka-Band Software Defined Radio of Small Satellite	University of Vermont Worcester Polytechnic Institute	GSFC
Propellantless attitude control of solar sail technology utilizing reflective control devices	University of Maryland, College Park	MSFC
Integrated Solar-Panel Antenna Array for CubeSats (ISAAC)	Utah State University	GSFC
Small Spacecraft Integrated Power System with Active Thermal Control	University Of Illinois, Urbana-Champaign	ARC
MEMS Reaction Control and Maneuvering for Picosat beyond LEO	Purdue University	GSFC
Active CryoCubeSat	Utah State University	JPL

2016 STP

The popularity of the STP solicitation remained high in the subsequent STP class year, 2016. Technology topics trended away from Smallsat subsystems, to include inter-satellite communications and relative navigation. As in previous years, an instrument/sensor topic was included.

- 80 Proposals Submitted
- 8 Grants Awarded
- 1 New Technology Report
    - Solid-State Structural Battery Composite Materials
- 6 Balloon / Spaceflight Demos Planned
    - Highly-integrated THz Rx, GUSTO balloon
    - Low-resource magnetometer, M-BARC (planned)
    - Miniature Tether Electrodynamics Experiment, MITEE-1, ELaNa 2018
    - MOCT, CLICK, 2020? (plan)
    - Ominidirectional Optical Comm (intent to fly)
    - Smoothing-Based Relative Nav, ISS exp
- 4 Technical Topics
    - Enhanced Power Generation and Storage (18)
    - Cross-linking Communications Systems (24)
    - Relative Navigation for Multiple Small Spacecraft (13)
    - Instruments and Sensors for Small Spacecraft Science Missions (25)

Table 5. 2016 STP Partnerships

Project	Univ.	Center
Highly Integrated THz Receiver Systems for Small Satellite Remote Sensing Applications	Arizona Sate University	JPL
Development of New Low-Resource Magnetometers for Small Satellites	Univ. of Mich. Ann Arbor	GSFC
Precision GNSS-Based Navigation and Timekeeping for Miniaturized Distributed Space Systems	Stanford University	GSFC
Smoothing Based Relative	Massachusetts	JPL

Navigation & Coded Aperature Imaging	Institute of Technology	
Fast, power efficient pulsed modulators and receivers for space-to-space optical communications	Univ. of Florida, Gainsville	ARC
Development of Lightweight CubeSat with Multifunctional Structural Battery Systems	Univ. of Miami, Coral Gables	GRC KSC
Omnidirectional Inter-satellite Optical Communicator	UC Irvine	JPL
Demonstration of a Nano-Enabled Space Power System	Rochester Institute of Technology	GRC

Current 2018 Technology Partnership

For the current year, the Technology Topic Areas were oriented toward swarms of Smallsats (including instrumentation that enable time-correlated multipoint measurements) and technologies for deep space missions. This solicitation also emphasized that proposals directly address technology gaps identified for relevant science or exploration missions.

- 111 proposals submitted
- 8 grants awarded
- 4 Technology Topics:
    - Instrument Technologies for Small Spacecraft
        - Incl. multipoint measurements from multiple SmallSats
    - Technologies that Enable Large Swarms of Small Spacecraft
    - Technologies that Enable Deep Space Small Spacecraft Missions

Table 6. 2018 STP Partnerships

Project	University	Center
Autonomous Nanosatellite Swarming using Radio Frequency and Optical Navigation	Stanford	ARC
SPRINT: Scheduling Planning Routing Intersatellite Network Tool	MIT	ARC/ GSFC
Application of Machine-learning Algorithms for On-board Asteroid Shape Model Determination and Spacecraft Navigation	University of Arizona	GSFC
Milli-Arcsecond (MAS) Imaging with Smallsat-Enabled Super-resolution	University Of Illinois, Urbana-Champaign	GSFC
Distributed Attitude Control and Maneuvering for Deep Space SmallSats	Purdue University	GSFC/ MSFC
Active Thermal Architecture for Cryogenic Optical Instruments	Utah State	JPL
High Specific-impulse Electrospray Explorer for Deep-space (HiSPEED)	MIT	JPL
Move to Talk, Talk to Move: Tightly Integrated Communication and Controls for Coordinated Swarms of Small Spacecraft	Colorado School of Mines	JPL

SUMMARY - STP TECHNOLOGY PORTFOLIO RESULTS AND MEASURES OF SUCCESS

The quantitative and qualitative results from both the university and NASA perspectives support the conclusion that the overall STP portfolio has returned positive value compared to resources invested and has successfully achieved its stated goals.

Quantitative Results

The STP portfolio has yielded significant advancements in TRL and has demonstrated, in both lab and flight demonstrations, the achievement of key performance parameters for a very wide array of mission-enabling technologies. The returns on investment are cost effective when compared to costs for similar developments in-house at NASA. Moreover, STPs avail to NASA a larger number of experts in greater range of technical subjects within a compressed time than NASA would have available internally.

Investments:

- Over $20,569,000 awarded
- 8 of 10 NASA Centers partnered
- 24 Universities in 19 states
- 37 partnerships in 4 class years

Returns:

- 4 New Technology Reports / Patents
- 10 flight demonstrations planned
- 27+ Conference presentations
- 46+ Papers published
- 100+ Students involved
- Many TRLs raised

Qualitative Results

Assessed using the qualitative programmatic goals above (in section titled "Goals for University-NASA Partnerships"), it can be claimed that the STP portfolio is successfully meeting all the stated objectives. Table 7 restates the STP goals and cites results supporting the claim of success.

Table 7. STP Goals Achieved

Goals		Results
Develop new technologies and capabilities for small spacecraft	✓	Many patents, licenses, papers, presentations, flight demonstrations, TRLs elevated
Leverage unique talents, fresh perspectives of the university community	✓	Broad range of novel and innovative technologies developed beyond NASA's traditional portfolio
Share NASA experience and expertise in relevant university projects	✓	Students gained hands-on experience; access to NASA test facilities, processes, expertise and launch opportunities; often students work alongside NASA staff
Engage NASA personnel in rapid, agile and cost-conscious small spacecraft approaches that characterize university teams	✓	NASA benefits from access to broad array of investigations, quick results, validation of low-cost components, and diverse skills and expertise of university teams
Foster a new generation of innovators for NASA and the nation.	✓	More than 100 students participated. Students pursue careers in STEM in industry, academia – and at NASA?

Partnership Participant Survey Results

To get the participants point of view, on April 12 2018 the SST program sent a questionnaire to both the NASA and the university participants of the 2013-2017 STP classes. The purpose of the questionnaire was for feedback on the perceived benefits of the partnerships to the participants, and for feedback regarding the STP portfolio solicitation and management process. The results here are scrubbed so as not to show identifying information.

Survey questions included:

1. Your name and role (PI, NASA Partner, etc). Home institution/NASA center. Name of your STP project.
2. How many students participated in this STP project (estimate)?
3. How many papers published, conference presentations, about this project?
4. Number of patents applied for? Number of New Technology Reports?
5. More generally, how did your home institution/NASA center benefit from this partnership, directly or indirectly?
6. How did your students benefit? NASA partners: how did you and your center benefit from the university partnership?
7. What were the challenges and difficulties in your STP partnership experience?
8. How difficult was it to find a NASA partner? Find a university partner?
9. Suggestions for new technology topics in potential future STP solicitations (if any)?
10. Specific suggestions for improvements to the STP solicitation, grant award, and grant management processes?

90 queries were emailed to all the University PIs and NASA partners in each of the 2013, 2015 and 2016 class years. 23 responses were received.

Table 8. Partners Survey Responses

23	Total responses received
4	NASA partners responded
19	University PIs responded
19	University PIs cited the NASA partner's contributions as critical to project success
2	NASA partner cited the university partner's contributions as critical to project success
8	University PIs stated the STP effort is likely to result in future business opportunities, technology commercialization, garnered financial contribution from other entities, or likely to result in a future spaceflight mission
8	University PIs indicated the STP partnership positively influenced students to pursue STEM careers, NASA internship, or resulted in opportunity for future employment in STEM
3	Partners stated that amount of required reporting as too much overhead in proportion to the STP effort
7	Partners cited insufficient funding as a limit to STP effectiveness