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Small Spacecraft Systems Virtual Institute's Federated Databases and State of the Art of Small Spacecraft Report

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ABSTRACT

NASA's Small Spacecraft Systems Virtual Institute (S3VI) is collaborating with the Air Force Research Laboratory and Space Dynamics Laboratory on the development of a small spacecraft parts database called SmallSat Parts On Orbit Now (SPOON). The SPOON database contains small spacecraft parts and technologies categorized by major satellite subsystems developed by industry, academia and government.

The State of the Art of Small Spacecraft Technology report reflects small spacecraft parts submitted to the SPOON database and technologies compiled from other sources that were assessed as the current state of the art in each of the major subsystems. The report, first commissioned by NASA's Small Spacecraft Technology (SST) program in mid-2013, is developed in response to the continuing growth in interest in using small spacecraft for many types of missions in Earth orbit and beyond. Due to the high market penetration of CubeSats, particular emphasis is placed on the state of the art of CubeSat-related technology. The 2018 report is planned for release in late summer.

A review of SPOON database functionality, federation of additional NASA-internal and external databases along with a common search capability, as well as an overview of the State of the Art of Small Spacecraft Technology report will be presented.

INTRODUCTION

NASA began seriously investing in small spacecraft technologies over a decade ago. The first, and still the majority of these investments, focused on CubeSats and related form factors. In addition, the creation of the CubeSat deployer standards, even if self-imposed, helped to ignite a larger trend in the aerospace industries. For this discussion, small spacecraft are generally defined as having a gross mass of less than 180 kg, and in most instances, are able to be launched as a rideshare or auxiliary payloads.

Small spacecraft are beginning to be adopted within missions for which they previously have not been considered, as their technological sophistication and capabilities are rapidly advancing. Similarly, small spacecraft projects are compatible with small, flexible, innovative teams including those in the civil science and exploration communities. A growing number of NASA-funded programs now allow and solicit the use of small spacecraft to achieve their mission goals.

Over the course of the past decade as the growth in both capability and usage of small spacecraft within NASA accelerated, it became clear that from at least an awareness point of view, that a central information and knowledge-based function was needed to assist various NASA organizations embracing small spacecraft in their program and project portfolios. In January 2017 NASA created the Small Spacecraft Systems Virtual

Institute (S3VI) to serve the agency as this coordination support function. The S3VI is currently jointly funded by NASA's Science Mission Directorate (SMD) and Space Technology Mission Directorate (STMD). The Human Exploration and Operations Mission Directorate (HEOMD), as well as a number of other small spacecraft-related NASA organizations engage in some activities hosted by the S3VI. S3VI is physically located at NASA Ames Research Center, but has affiliates and participation from the NASA spaceflight centers, as well as relationships with other government agencies (OGAs) that have similar small spacecraft programs.

The charter of the S3VI specifically directs the institute to advance clear communication, coordination and consistent guidance regarding NASA's small spacecraft activities across all of NASA. This is primarily achieved through enhanced internal integration across the NASA mission directorates via knowledge exchange and broad-based communications.

The S3VI is the central point of contact for small spacecraft information dissemination for the agency and accomplishes this element of its charter by means of a number of methods. Similarly, the institute serves as a repository for streamlined development approaches and processes that are unique to small spacecraft best practices. The S3VI supports this charter element by providing the national small spacecraft research and development community (industry and academia) with access to mission enabling information and data.

There are four main tenants of the S3VI approach to fulfilling its charter. The first is to engage with the small spacecraft community, NASA stakeholders and OGAs. This is done through participation in working groups, conferences, and related activities. The second pillar is to create and maintain the Small Spacecraft Body of Knowledge (SSBoK), hosted within the S3VI web portal < https://www.nasa.gov/smallsat-institute >, which taken together is a collection of programmatic, technical and related data, information, and knowledge for use by the larger small spacecraft community. Particular content includes small spacecraft parts and systems databases, studies, lessons learned experiences from various missions, and access to other online resources. The final approach relies on broadcasting solicitations, launch opportunities, and other networking opportunities that directly or indirectly support the community.

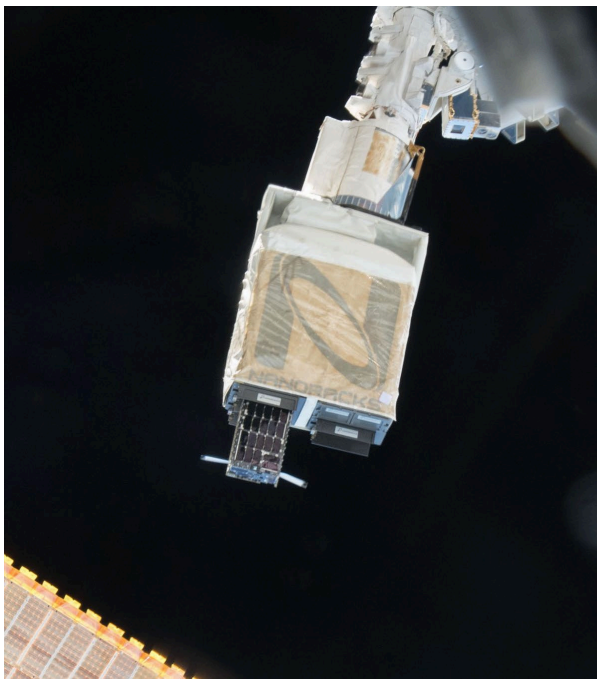


Figure 1: The Dellingr Spacecraft Releasing from ISS on November 20, 2017. Image credit: Nanoracks

SMALL SPACECRAFT BODY of KNOWLEDGE

Over the past several years, significant investments have been made in small spacecraft technology, science payload instruments, launch systems, and related efforts to include workforce development to support and cultivate emerging disciplines and applications created as a result of the platform's continued success. The S3VI is chartered to work with the community to capture and share the knowledge gained through these efforts and continue to build upon not only the technological capabilities enabled by the products of our efforts but also to learn from our lessons along the way.

Database Federation and Common Search

The S3VI works with its stakeholders and members of the community to identify the scope of the databases existing and needed to provide information effective in supporting streamlined development approaches and processes for small spacecraft. The first databases in this collection are listed below.

- Small Spacecraft Parts On Orbit Now (SPOON). The S3VI collaborates with the Air Force Research Laboratory (AFRL) and Space Dynamics Laboratory (SDL) on the development of a small spacecraft parts database called Small spacecraft Parts On Orbit Now (SPOON). This database is intended to capture

information on publicly available small spacecraft (mass <180 kg) components, parts and technologies developed by commercial vendors, universities, and government organizations that have achieved technology readiness level (TRL) 5 or greater. These parts are categorized under the following major satellite subsystems: Power, Propulsion, Thermal Design, Guidance, Navigation and Control (GNC), Command and Data Handling (C&DH), Communications, Structures, Materials and Mechanisms, Integration, Launch and Deployment, and Deorbit Devices. The Aerospace Corporation is collaborating with the S3VI team on a data exchange task to import their small satellite parts database into SPOON.

- Small Spacecraft Technology State of the Art. The S3VI is currently collecting information regarding the state of the art for technology, components, and systems relevant to small spacecraft for Earth and interplanetary mission design. The community is invited to contribute content to this database.

- TechPort. The Technology Portfolio System, TechPort, is NASA's first comprehensive resource for locating information about NASA-funded technology development activities. This system enables the public to explore NASA's technology portfolio and learn about technology programs and projects, as NASA works to mature technologies for aeronautics, space exploration, and scientific discovery missions.

- The Small Business Innovation Research (SBIR)/ Small Business Technology Transfer (STTR). This database offers users to search research and technology development projects in small spacecraft as well as other topic areas funded by SBIR/STTR.

- NASA Electronic Parts and Packaging (NEPP) Program. The NEPP Program generates technical knowledge and recommendations about electrical, electronic, electromechanical (EEE) part performance, application, failure modes, test methods, reliability and supply chain quality within the context of NASA space flight missions and hardware.

The S3VI uses web technologies, databases, and virtual collaboration tools to collect, organize, and disseminate small spacecraft knowledge for the benefit of NASA and the small spacecraft community. The S3VI web portal serves as an entry point to the SPOON database and S3VI is currently working to develop a federated search capability to allow the public to search multiple small spacecraft databases for parts and technologies. Their results will be displayed as direct links to particular databases related to their search inputs. The current year plan is to federate additional databases consisting of: TechPort, NEPP, and migration of The Aerospace Corporation's small satellite parts database in to SPOON.

The SSBoK also provides access to study reports, manuscripts and presentations from workshops and conferences focused on various topics associated with small spacecraft.

- Achieving Science with CubeSats: Thinking Inside the Box (2016).
- Improving Mission Success of CubeSats
- CubeSat Developers' Workshop Archives
- Small Satellite Conference Proceedings
- Deep Space Symposium / Cube Quest Ground Tournament 4
- Secure World Foundation's (SWF) Handbook for New Actors in Space

Small Spacecraft Community of Practice

The NASA Office of the Chief Engineer hosts a collection of NASA-internal Communities of Practice (CoP) centered on engineering disciplines with each comprised of a distributed, peer-driven network of individuals, engaged in a specific discipline, who come together to share their collective knowledge and to learn from one another. The Small Spacecraft CoP provides information, resources, access to peer expertise, and opportunities for knowledge sharing and collaboration in sound management, engineering, manufacturing, and verification practices for development of small spacecraft projects including but not limited to, scientific research, aerospace research, and technology development for space activities. The CoP serves as a forum for representatives from many different areas supporting small spacecraft to share challenges, approaches, and lessons learned for development of small spacecraft projects, including the implementation of safety, mission assurance, design, and test guidelines. The S3VI supports and coordinates the CoP and hosts NASA internal seminars on various topics of interest to the community.

SMALL SPACECRAFT TECHNOLOGY STATE OF THE ART

The Small Spacecraft Technology State of the Art report provides an overview of the current state of the art of small spacecraft technologies in each of the major spacecraft subsystems. It was first commissioned by NASA's SST program in mid-2013 in response to the rapid growth in interest in using small spacecraft for

many types of missions in Earth orbit and beyond, and further revised in mid-2015. In the 2013 and 2015 versions of this report, information was collected primarily through desk research, acknowledging this assessment would not be comprehensive. Since the last publication in 2015, this report was acquired by the S3VI and in 2016 the decision was taken to migrate to an online report with the intention to further expand the collaboration with other government agencies and the aerospace industry and present current information on spacecraft technology.

Assessment

The state of the art assessment of a technology is performed using NASA's TRL scale for small spacecraft applications. The NASA TRL definitions are found in the NASA Research and Technology Program and Project Management Requirements, NASA Procedural Requirements 7123.1B Appendix E, Technology Readiness Levels (TRLs).

In preceding editions, technologies were considered technology state of the art when the TRL of a particular technology was larger than or equal to 6. This indicates the desired component prototype, in terms of performance, weight, and volume, has been simulated in a high fidelity operational and relevant environment (2). For the 2018 update, the decision was made to consider technology state of the art with TRL larger than or equal to 5. Here, not all components need to be operated in the operational environment in order to satisfactorily address performance margin requirements, and this allows for the expansion of state of the art technology considered.

Technology with a TRL lower than or equal to 4 is not considered state of the art, but categorized as "on the horizon". Information on such developing technology is important to highlight for subsequent mission design and capabilities in the smallsat community. Finally, dated technology with a TRL larger than 6 that is applicable on a small spacecraft will not be considered in this report as state of the art. The bias in the definition has been recognized and care has been taken in the report to exclude obsolete technology from the study.

Update Overview

Starting in summer 2018, the State of the Art report will be updated annually to identify and provide an overview of the following: current technologies that were inadvertently missed in previous editions of this report, new developed technology, and emerging technologies with matured TRL values. The update process will encompass parts that were submitted to the SPOON database throughout the year, as well as research compiled from other sources. While the report will be published annually, the online version will be updated throughout the year to capture ongoing technology available to smallsat missions. TRL 9 technology identified in previous editions of the report will be removed only if there is a new 'best in class' TRL 9 components, thereby informing the public of the currently available innovative, space proven small satellite technology.

Vendors interested in having their TRL 5 or greater small spacecraft technology included in the report, should submit an email to the address found at the end of the appropriate subsystem chapter. Requests are received by the State of the Art website editor who disseminates the information to appropriate NASA subject matter experts (SME) for TRL verification.

Subject Matter Experts

Subject matter experts are technical professionals cognizant of a particular technical discipline, such as radio frequency (RF) communication technology or photovoltaic arrays. They have been identified as an expert in their field by NASA management. These experts are frequently used by NASA to do deeper technical review on projects, but are also used to provide peer review in technical papers, and other technical documents, such as engineering analyses.

For the SPOON database, the S3VI identified a set of SME's to review information provided to SPOON, and selected for the NASA Small Spacecraft State of the Art report. The experts' primary activity is to insure completeness and consistency with NASA standards used in the information such as TRL. Specific SME's are identified for the following subsystems: eElectrical Power Systems; Propulsion Systems; Thermal Systems; Guidance, Navigation and Control (GNC), Attitude determination; Command and Data Handling (C&DH); Software (including software architecture / methodology); RF Communications; Structures, Materials and Mechanisms; Small Spacecraft Integration; Small Spacecraft Launch and Deployment; Small Spacecraft Deorbit Devices; Complete Small Spacecraft Systems; and Optical Devices.

Advantages

This report benefits different users within the small satellite community where small satellite mission design is performed and researched. Within government organizations, this report is used as a vital resource for possible subsystem component selection for small spacecraft mission proposals. In academia, students and

teachers utilize this report for inexpensive space mission design. For industry, contents of this report encourage competition, maintaining the forefront of small spacecraft innovation.

ACTIVE WORKING GROUPS

The S3VI supports and coordinates working groups on small spacecraft topics of interest. In 2017, the Small Satellite Reliability Initiative (SSRI) was established. The S3VI also supported a number of activities related to small spacecraft rideshare during the year.

Small Satellite Reliability Initiative – A Public-Private Collaboration

At present, CubeSat components and buses are generally not appropriate for missions where significant risk of failure, or the inability to quantify risk or confidence, is acceptable. However, in the future, we anticipate that CubeSats will be used for missions requiring reliability of 1-3 years for Earth missions and even longer for planetary and heliophysics missions. In addition, Small spacecraft could be developed using CubeSat components and subsystems but will not have the CubeSat form factor. Both CubeSats and small spacecraft could then be used where their attributes could otherwise enable or enhance mission objectives or provide other meaningful benefits—e.g. lower cost, increased coverage (spatial, temporal, spectral), agility, resiliency, etc. Historically, it was understood and accepted that "high risk" and "CubeSat" were largely synonymous; expectations were set accordingly. However, their growing potential utility is driving an interagency effort to improve and quantify CubeSat reliability, and more generally, small satellite mission risk.

The SSRI—an activity with broad collaborative participation from civil, Department of Defense, and commercial space systems providers and stakeholders—targets this challenge. The Initiative seeks to define implementable and broadly accepted approaches to achieve reliability and acceptable risk postures associated with several Small spacecraft mission risk classes—from "do no harm" missions, to those associated with missions whose failure would result in loss or delay of key national objectives. These approaches will maintain, to the extent practical, cost efficiencies associated with small satellite missions and consider constraints associated with supply chain elements, as appropriate.

The SSRI addresses this challenge from two architectural scopes—the mission- and system-level, and the component- and subsystem-level. The mission- and system-level scope targets assessment approaches that are efficient and effective, and mitigation strategies that facilitate resiliency to mission or system anomalies while the component- and subsystem-level scope addresses the challenge at lower architectural levels. The initiative is not limiting recommended strategies and approaches to proven and traditional methodologies, but is focused on fomenting thought on novel and innovative solutions.

The membership publishes the presentations and results of each on the S3VI web portal < https://www.nasa.gov/small spacecraft-institute/reliability-initiative >

Rideshare and Access to Space

This year the S3VI partnered with the Small Payload Ride Share Association (www.sprsa.org) to co-sponsor and host the 20th Annual Small Payload Rideshare Symposium held in June 2018. This symposium features plenary and panel discussions on topics such as:

- Space traffic management
- Rideshare user's perspectives
- Development of operationally responsive spacecraft
- Hosted payload opportunities
- Small launcher systems
- Swarms and constellations launch and operations

Overall the symposium focuses on concepts and technologies to enable the small payload community to meet future launch needs and test new capabilities in a cost-effective manner.

NASA SMALL SPACECRAFT ACTIVITIES (PAST, PRESENT, PLANNED)

Ames Research Center (ARC), Goddard Space Flight Center (GSFC), the Jet Propulsion Laboratory (JPL), and Marshall Space Flight Center (MSFC), have in the past or are currently engaged with small spacecraft programs. The following tables provide a partial listing of those missions by center. NASA also has a number of programs soliciting or allowing the use of small spacecraft for science, exploration, and technology demonstration missions.

Jet Propulsion Laboratory

Table 1: JPL Small Spacecraft Missions 2015-2019

Mission	Launch Date	Objective
GEO-CAPE ROIC In-Flight Performance Experiment (GRIFEX)	January 31, 2015	JPL-developed all digital in-pixel high frame rate Read-Out Integrated Circuit (ROIC)
Arcsecond Space Telescope Enabling Research in Astrophysics (ASTERIA)	August 14, 2017	Technology demonstration of astrophysical measurements using a CubeSat
Integrated Solar Array & Reflectarray Antenna (ISARA)	November 12, 2017	High bandwidth Ka-band CubeSat communications
Mars Cube One (MARCO)	May 2018 (with Insight)	Communications-relay (first time CubeSats will fly in deep space)
Radar In A CubeSat (RAINCUBE)	May 20, 2018	Enable Ka-band precipitation radar technologies
Radiometer Assessment Using Vertically Aligned Nanotubes (RAVAN)	November 11, 2016	New technology for detecting slight changes in Earth's energy budget at the top of the atmosphere
Near Earth Asteroid Scout (NEAScout)	Late 2019	Perform reconnaissance of an asteroid using a CubeSat and solar sail propulsion
Lunar Flashlight	Late 2019	Will map the lunar south pole for volatiles and demonstrate several technological firsts

Table 2: NASA GSFC Small Spacecraft Missions 2017-2018

Mission	Launch Date	Objective
IceCube	April 18, 2017	Space validation of a submillimeter wave radiometer for ice cloud remote sensing
Dellingr	August 14, 2017	Data collection on the sun's influence on Earth's upper atmosphere using a suite of miniaturized instruments
Compact Radiation Belt Explorer (CeREs)	May 30, 2018	Measure radiation belt energization and loss electron spectra, and microbursts

Table 3: NASA ARC Small Spacecraft Missions 2015-2019

Mission	Launch Date	Objective
Edison Demonstration of Small spacecraft Networks (EDSN)	November 13, 2015 (lost in launch vehicle failure)	In space communication; data cross-link
Nodes	December 6, 2015	Communications relay and negotiated control
NanoSatellite Launch Adapter System (NLAS)	Multiple launches through industry	Modular platform with configurable sequencing to deploy multiple secondary spacecraft
Technology Educational Satellite (TechEdSat) 4, 5, 6	2015, 2016, 2017	Exobrake and iridium modem utilization
E. coli AntiMicrobial Satellite (EcAMSat)	November 12, 2017	Demonstrate *E. coli* antimicrobial resistance
Technology Educational Satellite (TechEdSat) 7, 8, 9	Multiple launch dates planned in 2018	Exobrake passive deorbit system demonstration

Mission	Launch Date	Objective
CubeSat Handling of Multisystem Precision Time Transfer (CHOMPTT)	May 2018	Precision timing
BioSentinel	Late 2019	Use of organisms as biosentinels
Pathfinder Technology Demonstrator (PTD)	Late 2019	Electrolyzed water as fuel for a small thruster.
AztechSat-1	CLSI in 2019, 2020, or 2021	Technology demonstration using constellation Globalstar for satellite phone and low-speed data communications.

Internally Funded Missions

- Scintillation Prediction Observations Research Task (SPORT) – Marshall Space Flight Center. Awarded a CSLI launch in 2019, 2020, or 2021.
- Shields-1 – NASA Langley Research Center. Awarded a launch on ELaNa XIX, Rocket Lab 4 – May 30, 2018.
- ALBus – NASA Glenn Research Center. Awarded a launch on ELaNa XX.

SOLICITATIONS for SMALL SPACECRAFT

The following is a list of active or planned solicitations for small spacecraft organized by mission directorate. The NASA centers also have internally funded missions and projects that are not listed here.

Solicitations by Mission Directorate

Table 4: NASA Small Spacecraft-Related Solicitations by Mission Directorate

Mission Directorate	Title	Response Date
Science Mission Directorate	ROSES-18 Amendment 8: New Opportunity - Astrophysics Science Small spacecraft Studies	July 13, 2018
	In-space Validation of Earth Science Technologies	March 26, 2018
	Draft Small Innovative Missions for Planetary Exploration (SIMPLEx)	March 14, 2018
	Request for Information: Possible NASA Astrophysics Small Spacecraft	November 30, 2017
	Advanced Component Technology (ACT)	June 19, 2017
Space Technology Mission Directorate (STMD)	SpaceTech – REDDI-2018 Appendix F1: Tech Flights – NASA Flight Opportunities	June 8, 2018
	NASA SBIR and STTR 2018 Program Solicitations – Chapter 9. Research Topics for SBIR and STTR: Focus Area 21: Small Spacecraft Technologies	March 9, 2018
	Request for Information - Suborbital Flight Testing and Flight Experiments with CubeSat Payloads	November 21, 2017
	NASA Flight Opportunities (FO): Technology Advancement Utilizing Suborbital Flight Opportunities	November 17, 2017
	Small spacecraft Technology Partnerships (STP)	September 25, 2017
	SpaceTech-REDDI-2017 Appendix F1(A): NASA Flight Opportunities	June 02, 2017
	Space Technology Announcement of Collaborative Opportunity (ACO)	May 31, 2017

Mission Directorate	Title	Response Date
	Utilizing Public-Private Partnerships to Advance Tipping Point Technologies	May 30, 2018
	Flight and Payload Integration Services	March 16, 2018
	Small spacecraft Parts On Orbit Now (SPOON) Database Request for Information (RFI)	On-going
Human Exploration and Operations Mission Directorate (HEOMD)	Announcement of CubeSat Launch Initiative	November 21, 2017

Small Launchers

The global space industry is experiencing a robust growth period as evidenced by approximately $1B in space investments just during the first quarter of 2018.[1] Included in this wave are emerging small launchers. Approximately 30 active systems are currently in development or quickly becoming operational.[2] Taken together with existing rideshare providers (SpaceX, Orbital ATK, ULA), and associated rideshare mission aggregators (TriSept, Xtenti, Spaceflight Services, Tyvak, etc.), the US is experiencing increasing domestic launch capacity. In addition, international providers (PSLV, ESA/Vega, Soyuz, etc.) are also available to the small spacecraft community, increasing global capacity further.

The S3VI is working to develop aides for mission designers to increase awareness of these launch service providers and related opportunities, as well as to provide tools and information supporting mission/launch development. This capability is planned for initial roll out starting in 2019.

Table 5: Emerging Small Launchers

Organization	Vehicle Name	Country	Latest Launch Date	2016 Status
Aphelion Orbitals	Helios	USA	2021	
ARCA Space Corporation	Haas 2CA	USA	Q3 2018	Active
Bagaveev Corporation	Bagaveev	USA		Active
bspace	Volant	USA	2018	Active
Celestia Aerospace	Sagitarius Space Arrow CM	Spain	2016	Active
Cloud IX	Unknown	USA		
CONAE	Tronador II	Argentina	2020	Active
CubeCab	Cab-3A	USA	2019	Active
Departamento de Ciencia e Tecnologia Aeroespacial	VLM-1	Brazil	2019	Watch
ESA	Space Rider	Europe	2020	
Gilmour Space Technologies	Eris	Australia/ Singapore	Q4 2020	Watch
Heliaq Advanced Engineering	Austral Launch Vehicle	Australia		Watch
Interorbital Systems	NEPTUNE N1	USA		Active
ISRO	PSLV Light	India	Q1 2019	
LandSpace	LandSpace-1	China	Q4 2017	Active
LEO Launcher	Chariot	USA	Q4 2018	
Lin Industrial	Taimyr-1A	Russia	Q1 2020	Active
Linkspace Aerospace Technology Group	NewLine-1	China	2020	
One Space Technology	OS-M1	China	2018	Watch
Orbex	Proprietary	United		

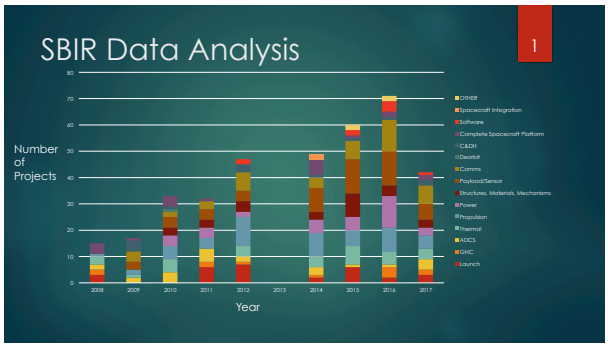
Organization	Vehicle Name	Country	Latest Launch Date	2016 Status
		Kingdom		
Orbital Access	Orbital 500R	United Kingdom	2020	Active
PLD Space	Arion 2	Spain	3Q 2021	Active
Rocket Lab	Electron	USA/New Zealand	2017	Active
Rocketcrafters	Intrepid-1	USA	Q1 2019	Active
RocketStar	Star-Lord	USA	2018	Evolution
Scorpius Space Launch Company	Demi-Sprite	USA		Active
Skyora	Skyora XL	UK/Ukraine		
SpaceLS	Prometheus-1	United Kingdom	Q4 2017	Active
Stofiel Aerospace	Boreas	USA		Watch
Stratolaunch	Pegasus XL	USA		Watch
Tranquility Aerospace	Devon Two	United Kingdom		Active
VALT Enterprises	VALT	USA		Active
Vector Space Systems	Vector-R	USA	2018	Active
Virgin Orbit	LauncherOne	USA	H1 2018	Active
zero2infinity	Bloostar	Spain	2017	Active

NASA's HEOMD also sponsors the CubeSat Launch Initiative (CSLI) <https://www.nasa.gov/directorates/heo/home/CubeSats_initiative> which provides free launch services to qualified CubeSat developers. Developers are typically educational or university led. However, industrial missions are not supported. Selected teams are mapped to an upcoming launch opportunity. The teams then begin to work with the mission integration team to prepare their CubeSat for launch.

Small Business Innovative Research (SBIR)

Another significant source of funding and support is the Small Business Innovative Research (SBIR) program. A large fraction of current small spacecraft related companies can trace their early beginnings to the SBIR program, and we are now starting to see some consolidation and consolidation of and investment into these small companies. Table 6 shows the types of SBIR small spacecraft projects funded by technical area or subsystem over time. [Note, 2017 is only a partial listing of awards.]

Table 6: Summary of SBIR-Funded Small Spacecraft Projects by Year and Subsystem



CONCLUSION

All of NASA's space flight Mission Directorates (SMD, STMD, HEOMD) have significant, active programs in small spacecraft. This trend is expected to continue as these systems become more and more capable and find wider acceptance as instrument or technology development platforms. However, there are areas that still need to be addressed and improved such as mission reliability and small spacecraft launch that will continue to attract the attention of program managers and scientists.

To that and related goals, the S3VI will continue to support the development and growth of small spacecraft capabilities and adoption through the creation and exchange of information and studies among the various small spacecraft and launch stakeholder communities. Particular plans continuing into 2018 include the continued expansion of information available in the SSBK, along with S3VI-hosted workshops and technical exchanges that foster new and existing relationships with other government agencies,

universities, and industry to promote collaboration and information sharing. The S3VI will continue to provide a policy coordination function to provide information on such topics as security, information assurance, and orbital debris, along with reliability and access to space for small spacecraft. Consolidation of information on NASA investments in small spacecraft missions, subsystem and instrument development is a goal for 2018.

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- Langley Research Center: Stephen Horan

References

1. Sheetz, M. (2018, April 10). *Investors pour nearly $1 billion into space companies in Q1*. Retrieved from URL https://www.cnbc.com/2018/04/10/space-angels-q1-report-small-rockets-backed-by-silicon-valleys-money.html

2. Niederstrasser, C. and Frick, W. (2017, August 4). *Small Launch Vehicles, A 2017 State of the Industry Survey*. Retrieved from URL: https://digitalcommons.usu.edu/smallsat/2017/all2017/238/