National Aeronautics and Space Administration

THE SPARK

TECH TRANSFER, PARTNERSHIPS, AND SBIR/STTR AT GODDARD

CONTENTS

ABOUT THE COVER

An artist's rendering of the Pandora Satellite superimposed over the NASA Earth Observatory image. This image of North and South America at night is a composite assembled from data acquired by the Suomi NPP satellite in April and October 2012. Suomi NPP VIIRS data provided courtesy of Chris Elvidge (NOAA National Geophysical Data Center).

Photo Credit: NASA/GSFC/Robert Simmon

OFFICE OF THE CHIEF

Back when I started in 1989, one of the things we at NASA Goddard prided ourselves in was the fact that we could do everything for a mission right here in-house – from planning, engineering, building and testing the hardware, all the way to launch, operations, and decommissioning. When it came to space and space research and science, we were the ones doing it. Goddard had the skills, and we were the agency that industry came to if they had an interest in space.

Obviously, we are still doing those things, but Goddard is no longer the only one. Over time, things have reversed themselves. Now, it is more often the case that resources, money, and new technology development is happening outside of Goddard in universities, commercial industry, non-profits, and other federal agencies.

As SmallSat/CubeSat missions grow bolder and more robust, the small satellite community as a whole needs to develop technologies that enable those audacious goals. To achieve that, we can't have the mentality that Goddard can do it alone. Goddard doesn't have all the answers in-house. Probably the most important thing about this SmallSat Conference is that it provides an opportunity for Goddard to identify partners to work with as we explore space together.

So, it should come as no surprise that Goddard's Strategics Partnership Office (SPO) is always on the lookout to engage with industry and partner with other organizations. One of the interesting things that I discovered over the years is, many times, one achieves a great deal of exciting, unexpected advances when you partner with new organizations that you have never partnered with before.

I would like to encourage those in attendance to visit our NASA Goddard booth in the Juniper Lounge. Our team is available to share Goddard's experience and describe our technologies and solutions for SmallSat efforts. Talk to our folks, learn about what we are experiencing, and what kinds of technologies or solutions we have to offer. Maybe there is a technology that Goddard has that can solve a problem you have or vice versa. It is all about engagement and collaboration and Goddard is here to help.

Goddard is committed to pursuing and becoming a player in the SmallSat/CubeSat community. To help us achieve this goal, we seek partners that can help us stay abreast of technological advances and remain at the forefront as we stretch the boundaries together.

Darryl Mitchell

Darryl R. Mitchell, Chief

Strategic Partnerships Office
NASA's Goddard Space Flight Center

NASA Goddard SmallSats Make Big Splash in FY22

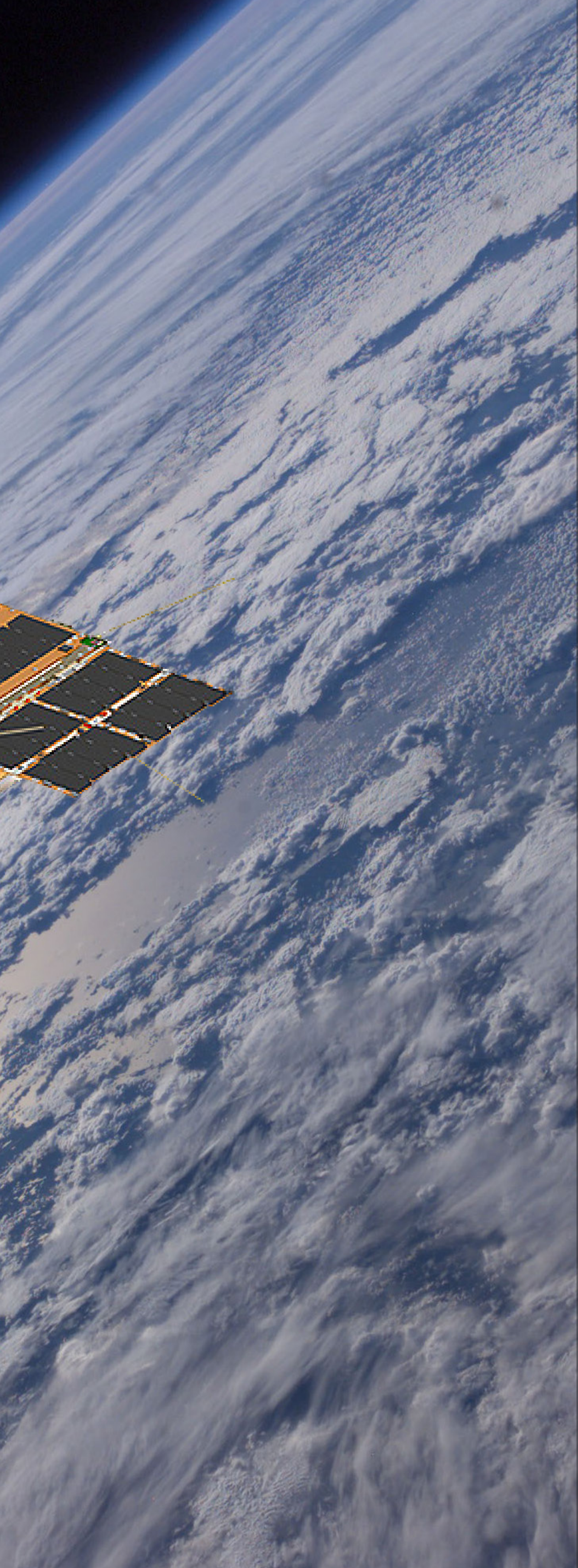
At NASA's Goddard Space Flight Center, scientists and engineers are working to turn big ideas into realities for SmallSat missions by pushing the boundaries of the platform and dreaming up new missions.

As SmallSat missions continue to grow more ambitious, developers at Goddard have explored ways to use this small-sized technology to increase the likelihood of success for future missions. This approach will allow the SmallSat community to abandon past uncertainties in the area of mission confidence and increase the probability of success. In the end, Goddard will achieve more science and expand other operational missions. "We are not thinking of the everyday problems I know we are going to solve," said Christyl Johnson, deputy director for Technology and Research Investment at Goddard. "We are thinking in advance about the next generation of problems that we will need to be able to address. Now it the time to invest in those, so we are ready to implement solutions down the road."

Over the past 20 years, there have been hundreds of SmallSat/CubeSats launched into space with many more missions in the works. While once the goal in the SmallSat community was largely to demonstrate the technology itself and get the mission up in space, today the goals have moved into the realm of expanding our knowledge of earth and space sciences.

"Technology demonstrations used to be the primary objective of early CubeSats," explained Luis Santos Soto, chief engineer in the Small Satellite Project Office at NASA's Goddard Space Flight Center. "Now, with maturing spacecraft bus technologies

Photo Credit: NASA/GSFC



and the payload technologies, people have been able to do compelling science with CubeSats. It is no longer a tech demo platform; you can actually perform important science missions."

"Goddard has been working on SmallSats for over 12 years now," added Santos Soto. "And I think one thing you can say is we're gaining a great deal of experience working on SmallSat and CubeSat missions. We are doing a mix of buying components from the market and developing our own components and that gives us a good perspective on and experience in both developing technologies for CubeSat and working with industry to produce successful CubeSats and SmallSats."

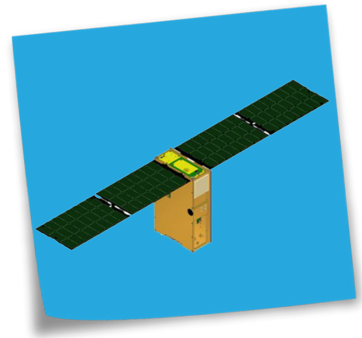
Most of Goddard's attention now is focusing on constellations as part of the Distributed System Missions (DSM). A DSM is a mission that involves multiple spacecraft to achieve one or more common goals. Some DSM instances include constellations, formation flying missions, or fractionated missions.

"I would say that the next big thing for Goddard is to demonstrate these constellations by actually conceiving of, developing, and flying some of these multi-spacecraft missions," describes David Wilcox, chief of the Small Satellite and Special Projects Office at Goddard's Wallops Flight Facility. "Along with everyone else, we are evolving to develop larger and more complicated spacecraft within a constellation network. We have a lot of support from NASA Headquarters and we are helping them forge the path forward with the work that we are doing with SmallSats. I think Goddard's claim to fame is that over the course of the past 10 years,through a lot of trial and error, we have become technical experts on SmallSats within the agency."

(continued on page 4)

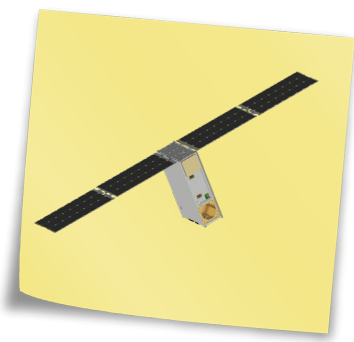
What are some of Goddard's accomplishmenst in SmallSat state-of-the art technologies over the past year? Here is a glimpse of just some of Goddard's latest technologies launched recently or in the near future:

BurstCube



A 6U CubeSat that searches for difficult-to-observe electromagnetic events called gamma ray bursts (GRBs), focusing on short GRBs that are counterparts for gravitational wave sources. BurstCube's primary goal is to detect, localize, and characterize short GRBs (sGRBs). To accomplish this, BurstCube will utilize four cesium iodide detectors sensitive to gamma-rays from 50 keV (kiloelectronvolts) to 1 MeV (mega-electronvolts), which are coupled to arrays of silicon photomultipliers.

Noteworthy Because: BurstCube will increase the sky coverage for sGRBs and may serve as an interim instrument between larger missions.
Status: Completed Critical design review and getting ready for pre-environmental review.
Timeline: Deliver in November 2022 for February 2023 launch.

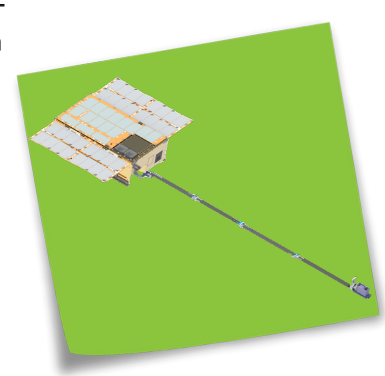


Plasma Enhancements in The Ionosphere-Thermosphere Satellite (petitSat)

The mid- and low-latitude ionosphere is home to a variety of plasma density irregularities, including depletions (bubbles), enhancements (blobs), and small-scale scintillation, which result in the distortion of radio wave propagation. However, recent observations from the Communications/Navigation Outage Forecasting System (C/NOFS) satellite suggest that multiple mechanisms are responsible for forming plasma enhancements, with wave action in the thermosphere as a significant driver of the enhanced densities. petitiSat is a 6U CubeSat designed to examine density irregularities in Earth's ionosphere.

Noteworthy Because: petitSat will help scientists understand how the ionosphere affects long-distance radio communication such as Global Positioning Systems (GPS) and radar signals.
Status: Completed Pre-Ship Review and ready to ship
Timeline: Deliver in July 2022 for an October 2022 launch.

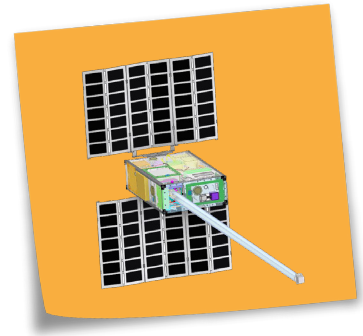
Geosynchronous transfer orbit satellite (GTOSat)



GTOSat is a 6U CubeSat mission with the primary science goal of advancing the quantitative understanding of acceleration and loss of relativistic electrons in Earth's outer radiation belt. From a low inclination GTO (geosynchronous transfer orbit), GTOSat will measure electron spectra and pitch angles of both the seed and the energized electron populations simultaneously, using a compact, high-heritage Relativistic Electron Magnetic Spectrometer, a customized version of the MagEIS- (Magnetic Electron Ion Spectrometer) Medium instruments from NASA's Van Allen Probes mission.

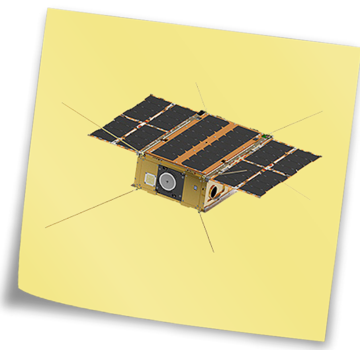
Noteworthy Because: GTOSat will require high radiation tolerance to survive the harsh environment of the radiation belts.
Status: Completed Pre-Ship Review and ready to ship
Timeline: Currently scheduled for launch as a rideshare on a Department of Defense mission; launch date to be determined.

Dione



Dione's primary objective is to quantify how the ionosphere and thermosphere respond to electromagnetic and kinetic energy inputs from the magnetosphere. Just like the ancient Greek goddess Dione that presided over the oracle, Dione the 6U CubeSat will demonstrate a comprehensive sensor package in a low-cost, flexible assembly path for better specification and prediction of Ionosphere-Thermosphere responses to geomagnetic phenomena.

Noteworthy Because: Dione supports NASA's strategic objectives to understand the Sun and its interactions with Earth and the solar system, including space weather. This mission will advance NASA's understanding of the connections that link the Sun, Earth, planetary space environments, and the outer reaches of our solar system.
Status: Completed Critical Design Review with integration and testing later this year.
Timeline: Delivered in April 2022

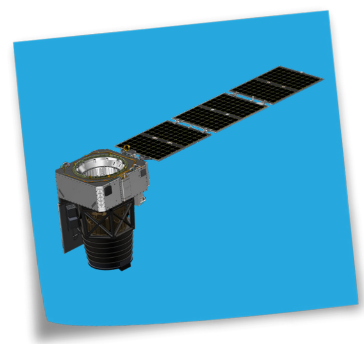


SigNals of Opportunity: P-band Investigation (SNOOPI)

The objective of the SNOOPI mission is to provide an in-space validation of the P-band SoOp (Signal of Opportunity) technique and a prototype instrument. This is a necessary risk-reduction step on the path to a science mission and will verify important assumptions about reflected signal coherence, robustness to the RFI environment, and our ability to capture and process the transmitted signal in space. SNOOPI is designed to demonstrate an innovative instrument that shows promise for measuring root-zone soil moisture and snow water equivalent from space.

Noteworthy Because: SNOOPI will increase scientific understanding of natural phenomena using remote sensing.
Status: Completed pre-environmental review
Timeline: Delivery in July 2022 for an October 2022 launch

Pandora



In the quest for habitable planets beyond our own, Pandora is a NASA-funded mission, which could eventually help decode the atmospheric mysteries of distant worlds in our galaxy. Under NASA's new Pioneers Program —which is intended to do compelling astrophysics science at a lower cost using smaller hardware like SmallSats and Balloon payloads —Pandora will study approximately 20 stars and exoplanets (planets outside of our solar system) to provide precise measurements of exoplanetary atmospheres.

Noteworthy Because: As NASA moves toward an era of atmospheric characterization, Pandora focuses on trying to understand how stellar activity affects our measurements of exoplanet atmospheres, which will lay the groundwork for future exoplanet missions aiming to find planets with Earth-like atmospheres. Pandora is also a Secondary Payload Adapter (ESPA) Evolved Expendable Launch Vehicle (EELV) adapter for launching standard secondary payloads. The use of ESPA ring technology reduces launch costs for the primary mission and enables secondary and even tertiary missions with minimal impact to the original mission.
Status: Team is working towards their Preliminary Design Review
Timeline: Late 2024-early 2025

For more information about SmallSat missions, please visit, https://smallsat.wff.nasa.gov/missions/

PARTNERING with Goddard Can Take Your Company to Higher Orbits

When researchers at the Smithsonian Astrophysical Observatory (SAO) needed a state-of-the-art coating on the optics used in their solar-laboratory experiments, they turned to NASA Goddard, a leader in space-optics. Performed under a Space Act Agreement (SAA) between Goddard and SAO, the unique coating provided by Goddard's thin-film coating facility allowed SAO's mirror to reflect light over a wide range of wavelengths. Having this improved optic dramatically increased the efficiency of SAO's experiments, allowing researchers at SAO and other institutions around the world to rapidly acquire the atomic data needed to develop more accurate models of the solar atmosphere.

As a not-for-profit organization, the Cambridge, Massachusetts-based SAO was not in a financial position to develop its own coating capabilities. After learning about Goddard's thin-film coating capabilities from articles in scientific journals, SAO researchers contacted their counterparts in Goddard's Optics Branch. The Technology Transfer Office (TTO) at Goddard developed a Space Act Agreement with SAO, with the center providing the optic and SAO reimbursing Goddard for the thin-film coating services. Being able to access Goddard's facilities saved SAO significant time and money.

"Goddard was the only place in the country that does that kind of coating," said Dr. Larry D. Gardner, a physicist at the SAO. "We could have tried to make do with a commercial coating, but they're significantly less efficient. If we weren't able to access Goddard's facilities, it would have taken us four times as long to get the data we need. It has a big impact on our ability to do the experiments."

> *"Goddard was the only place in the country that does that kind of coating"*

Like SAO, thousands of businesses over the years have benefited from partnerships with Goddard. Goddard's Strategic Partnerships Office (SPO) connects NASA's world-class technologies, capabilities, and expertise with industry, academia, and other government agencies. Goddard technologies can provide the foundation for a new business, add products to a company's portfolio, or complement and enhance existing products.

"When industry is designing a new technology for the first time, you do not know if it is going to work or not or just how much of an improvement it is going to make," said Christyl Johnson, Deputy Director for Technology and Research Investment at Goddard. "Strategic partnerships are a big thing I believe in. That is the role of government, to help private industry invest in those things to take technology to the next level, whereby they can demonstrate the capability to develop it even further."

When it comes to partnering, SPO partners with industry, non-profits, academia and other government agencies.

"Typically," said Viva Miller, senior technology manager at Goddard. "A SPO partnership is an external collaboration with industry or another federal agency to develop a technology further, but it could also be a collaboration to provide some form of subject matter expertise another organization needs. What happens in a SPO partnership can literally be anything. For example, right now we have a partnership with the National Security Agency (NSA) that involves the use of Goddard Subject Matter Expert support.

"Or it can be a situation where an organization like SAO that may not have the kinds of facilities that we have at Goddard. So, we can form a partnership whereby another organization can utilize our facilities to further develop technologies."

So, if you are an attendee at this year's SmallSat Conference and want to establish a partnership with SPO, what do you do and how does it work?

"It can work any way that you can think of, we are very accessible," stressed Miller stressed. "Contact our office, or interact directly with the engineers who are actually working on the technology. Or it could be a situation where we approach industry and let them know that it seems like they are an organization that specializes in something that we are interested in and where we can help."

Another way SPO partners with industry is through licensure. Many of the technologies developed for SmallSats at Goddard have received patents and can be licensed by interested companies. SPO can work as a matchmaker, helping to connect companies with technologies that are a good match for their business niche.

Many companies find it cost-effective to license SmallSat technologies from Goddard instead of "reinventing the wheel" and creating their own version.

"There are a lot of different ways that licensing can go, but what happens typically with licensing is we have a technology that has been developed and subsequently patented, and what we can do is license out this patented technology," Miller said. "Once a licensee has obtained a license for a particular NASA patent, we grant them the right to commercially use, make, or sell the NASA invention for a specified period [of time]. Goddard may get a percentage of the profit from a sale depending on the terms of the license."

Five Ways to Work with Goddard's Strategic Partnership Office

Helen Keller once said, "Alone we can do so little; together we can do so much." There are many ways industry work with Goddard's SPO and take advantage of the technology resources available to you, but the following list of options is a great place to start.

1 **License Goddard technology.** If you think patented or patent-pending SmallSat technologies found in this magazine or on our website, http://partnerships.gsfc.nasa.gov, meet your technology needs, contact SPO to learn more and begin the licensing process. First, get in touch with a Goddard technology manager to troubleshoot your requirements and agree on a suitable technology to fit your requirements. Then, fill out an application through NASA's Automated Technology Licensing Application System (ATLAS). After submitting your application in ATLAS, a staff member from Goddard's SPO will get in touch for next steps.

2 **Apply for Startup NASA.** Startup companies can take advantage of additional benefits by participating in our Startup NASA initiative. NASA waives up front licensing fees for participants, removing some of the barriers encountered by tech entrepreneurs looking to secure intellectual property rights. Learn more about this opportunity by contacting the Strategic Partnerships Office at techtransfer@gsfc.nasa.gov.

3 **Check out our online software catalog.** Goddard has 143 programs available online to fulfill your software needs, free of charge. Categories include business systems and project management, environmental science, and data and image processing. To request NASA software, go to https://software.nasa.gov/ and select the "Software Catalog" button to begin the process. Some codes and mobile apps offer direct download, while others require a completed request form for processing through Goddard's Software Release Authority.

4 **Explore Space Act Agreements.** Established in 1958, the National Aeronautics and Space Act allows NASA to form Space Act Agreements (SAAs) with various partners to make progress on shared goals. SAAs facilitate advancements in numerous industries.—For example, in 2016, Virginia Electric and Power Company signed an SAA with Goddard to allow researchers to study the effect of Geomagnetically Induced Currents (GICs) on the U.S. power grid. SAAs can play a role in license agreements by allowing Goddard scientists to support technology transfer, if it doesn't interfere with their job responsibilities. This arrangement also permits partners to reimburse Goddard for its time.

5 **Leverage your Small Business Innovation Research or Small Business Technology Transfer (SBIR/ STTR) award.** Companies with SBIR/STTR awards or government contracts can utilize Goddard technology to enhance their research objectives. Your contracting officer or contracting officer representative can assist you in adding new technology to your list of Government Supplied Equipment.

To learn more about the **Strategic Partnerships Office**, please visit https://partnerships.gsfc.nasa.gov.To connect with a technology manager, please email techtransfer@gsfc.nasa.gov.

Q&A

with **MICHAEL** JOHNSON

DISTRIBUTED SYSTEM MISSIONS OFFERS SMALLSATS A CRITICAL ROLE IN FUTURE SPACEFLIGHTS

SmallSats are cost effective, schedule efficient, and agile. As Goddard looks to the future of SmallSat missions and begins to plan to use them for science exploration, these tiny satellites are a perfect match for what is known as Distributed Systems Mission (DSM).

The Spark magazine caught up with Michael Johnson to learn more about DSM, and how and why this system will be used by Goddard in conjunction with future SmallSat missions.

Michael Johnson is the Chief Technologist in NASA/Goddard's Engineering and Technology Directorate. His passion to "expand the possible" is encapsulated by Albert Einstein's thought: "Your imagination is your preview of life's coming attractions." Johnson holds a master's degree in electrical engineering and computer science from the Massachusetts Institute of Technology. He has worked at NASA for 29 years.

What is DSM and how is Goddard planning to use it?

When we collaborate intelligently, our outcomes are typically significantly better than we operate as "lone rangers." This principle need not be limited to humans or even to terrestrial scenarios. It can and should also be applied to spaceflight missions by coordinating assets to achieve an objective.

A DSM implements this behavior. It autonomously combines components, systems, instruments, data, models, and even other missions into a unified whole to enable timely actions and objectives from the fusion of the resultant knowledge. The "fleet," with nodes or assets residing anywhere—in space, on or beneath a surface, on water, ... —can increase the spatial, temporal, and spectral resolution and diversity of measurements and deliver science and exploration outcomes much more significant than an individual asset could. These distributed missions can be implemented by a range of architectures—from a few to thousands of nodes in an intelligent constellation with loose levels of attitude and position control and knowledge to nodes controlled with precision sufficient to implement virtual telescopes.

An impactful DSM characteristic is its ability to autonomously augment a fleet with additional assets that can contribute toward mission objectives. An Open Architecture enables fleet membership to be agile, dynamic, and opportunistic, again mimicking human intelligent teaming behavior. This characteristic can cooperatively bring additional national, international, academic, and industry resources to the mission.

While we take such behaviors for granted in many terrestrial environments, we often think it a strange or a stretch to attach them to spaceflight systems. But advancements in spaceflight technologies and capabilities are lowering barriers between transformational visions and reality. Tension in the stretch is being relaxed.

How are SmallSats to be used in the DSM?

DSM assets should be whatever and reside wherever is required to accomplish mission objectives. The characteristics of SmallSats that make them attractive in a broad range of mission contexts are aligned with characteristics that add impact to DSM. Specifically, the lower cost of many SmallSats, CubeSats in particular, increase the pool of spacecraft developers, enabling a broader community to contribute to these architectures. Their size is aligned with the disaggregated approach many DSM will implement. And frequent launch opportunities facilitate mission architecture agility.

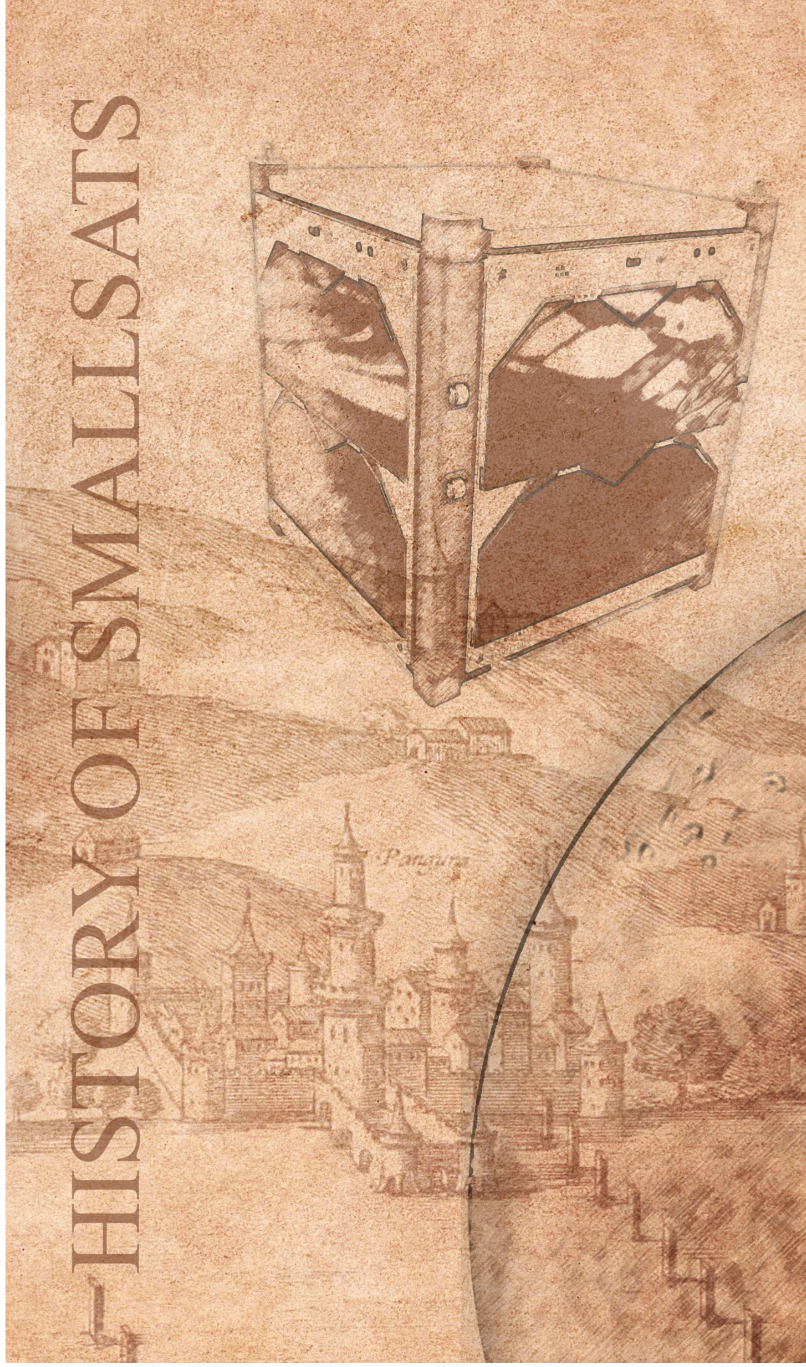
Does the DSM architecture have application to educational and commercial sectors?

DSM architectures have application to educational and commercial sectors. The systems integrated into the architecture can have varying levels of complexity. This allows organizations to deliver systems consistent with their strengths and capabilities. This diversity can yield levels of mission robustness and agility at costs not typically associated with traditional mission architectures.

How can institutions partner with Goddard is developing this architecture?

We realize the aerospace sector is evolving rapidly, with institutions beyond NASA industry increasingly delivering impactful capabilities and executing critical spaceflight roles. This landscape offers potential for collaborative outcomes that exceed those an institution could achieve separately. We are eager to explore and fully realize this potential. The Goddard Strategic Partnership Office can help begin partnership discussions. (See page 6)

SmallSats Enable NASA's Continued Journey Through Space



A new era in satellite technology is upon us. Call it a revolution in the industry, but engineers and scientists at NASA Goddard are today at the forefront of utilizing SmallSats and CubeSats to achieve compelling science at a lower price point.

"This is a unique opportunity," explained Luis Santos Soto, chief engineer of the Small Satellite Project Office at NASA's Goddard Space Flight Center. "With CubeSats, we have the opportunity to demonstrate some technologies up in space that might not have been considered on a more expensive mission with a smaller risk tolerance posture.

"It is just a perfect storm for technology maturation and increased access to space. So, you are enabling cheaper and faster access to space, and at the same time you are making them more capable by developing new technologies or miniaturizing technologies to be able to fit within SmallSats."

As technical advancements have made it possible to reduce the size of many satellites, it would be useful to look back at the history of SmallSats and how we arrived at its current state. In the beginning, almost everything was a "small" satellite.

When the Soviet Union successfully launched Sputnik 1 on October 4, 1957, it was by today's standards a small satellite. Resembling a beach ball, the world's first artificial satellite weighed only 83.6 kilograms or 183 pounds. It took only 98 minutes for the satellite to orbit Earth along its elliptical path.

Almost four months later, under the direction of renowned scientists Dr. Wernher von Braun and Dr. James Van Allen, the United States successfully launched Explorer 1. Weighing only 30.66 pounds —18 of which contained science gear such as cosmic ray detectors, temperature sensors, and a microphone to pick up the sounds of micrometeorites—the satellite was 80 inches long and about 6 inches in diameter. Perhaps, a perfect definition of a SmallSat.

As launch vehicles and satellite technology expanded in the late 50s and very early 60s, so did their size. The desire back then was to build bigger, more capable satellites with almost perfect reliability. Many of those early satellite technology pioneers, including von Braun and Van Allen would probably have a hard time envisioning the move toward building smaller satellites again today. But the miniaturization of electronics now means it's possible to build small satellites equipped with the desired capabilities both faster and with smaller budgets. As such, the community is evolving to welcome the industry back to an earlier age of smaller satellites.

"As recently as 35 years ago, the idea of building tiny spacecraft 'again' would have been unheard of," says David Wilcox, chief of the Small Satellite and Special Projects Office at Goddard's Wallops Flight Facility. "We're almost coming back around to where we started in terms of the size and volume."

In the Beginning

Advanced rocket technology made its first appearance in the United States after the conclusion of World War II when the V-2 rockets captured from the Germans were transported to the White Sands Missile Range in New Mexico to study. Engineers, scientists, and students could not help but be amazed by this new-fangled futuristic technology the Germans had developed.

"My friends and I watched the rockets' vapor trails rise in the sky and immediately became interested in the new program," wrote R. Gilbert (Gil) Moore, a rocket propulsion engineer, whose 60-plus year career includes serving as general manager of the Astromet Division at the Thiokol Corporation, senior research scientist at Utah State University's Space Dynamics Lab, and an instructor at the Astronautics department of the United States Air Force Academy.

An early advocate and pioneer of SmallSats, Moore became so excited about what he witnessed, that he decided to become a satellite engineer and was able to get a part-time job paying 65 cents an hour at the New Mexico University's Physical Science Laboratory.

Following Explorer 1, spacecraft design was constrained by launch vehicle payload mass and on-board computer processing performance ceilings. The U.S. launched a large number of small satellites throughout the 1960s to obtain space environment data, test flight various technologies, and provide communications. But, as expectations for satellites grew, launch vehicle payload capacity to low-Earth orbit steadily increased.

"Microsatellites, nanosatellites and picosatellites were essentially replaced by heavier, much more capable spacecraft over time," wrote Siegfried W. Janson in his abstract paper, 25 Years of Small Satellites. "This trend resulted in the 'Small Satellite Doldrums.' Technology and economics ultimately reversed that trend starting in 1987."

Interestingly, Janson wrote, it was the advent of two SmallSat Conferences in 1987—the first one sponsored by the American Institute of Aeronautics and Astronautics and the Defense Advance Research Agency (DARPA) and the second, the Utah State University SmallSat Conference, whereby a large number of technical papers on the subject were presented by experts that piqued the interest in SmallSats in the industry.

To get SmallSat development off the ground so to speak, engineers and scientists stressed the need for cheaper and more responsive launches. But it was two professors in the early 1990s—Jordi Puig-Suari of California Polytechnic State University, San Luis Obispo, and Bob Twiggs of Stanford University, who came up with a solution. When promoting student education projects, they developed the concept of what became known as CubeSat – a class of miniaturized satellites that are approximately four inches long, have a volume of about one quart and weigh about 3 pounds, and often using commerical-off-the shelf (COTS) components for their electronics and structure - this new class of satellites enabled regular, safe access to launch vehicles into space.

When looking at designs for this new small satellite, Twiggs went to a local department store comparing boxes. What he went home with was a clear acrylic Beanie Baby box that eventually became the design model for a CubeSat.

"They restarted the small satellite idea with what are known as CubeSats and their claim to fame is that they standardized the size of small satellites," Wilcox explained. "Thanks to Pugi-Suari and Twiggs, we now categorize almost everything by a unit of 'U,' which represents a cube that is 10 centimeters on a side. Right now, Goddard is building five 6U CubeSats, which are roughly the size of two loaves of bread side by side. We're preparing to do real cutting edge science with these missions when they deliver later this year."

In 1999, when Twiggs first proposed CubeSats, small satellites were seen primarily as an educational tool.

Santo Soto notes that what has given SmallSats a big boost over the past two decades is the significant enhancement in capabilities for the bus – the main body and structural component of the satellite in which the payload and all scientific instruments are held – and instrument technologies. These technologies include power generation and distribution, processing capabilities, guidance, navigation and control, and communications.

"Those are all a good combination of things to help enable compelling science missions," Santo Soto said. "As you are making your spacecraft bus smaller, you are allowing more space. At the same time, you are making your instrumentation technology smaller, so now you can increase the science capability of the small spacecraft even further. Improvements in these areas enable new missions, which then can be flown for easier and cheaper access to space."

HISTORY OF SMALLSATS

THE NEXT *SMALL* BIG THING

Image Credit: NASA/GSFC

History has given Napoleon Bonaparte credit for that well-known quote, "A picture is worth one thousand words." But in the satellite world, a single picture requires the same amount of data storage as ten thousand to ten million words.

If you go back to 1987 and the beginning of the Small-Sat Revolution, charge coupled device imagers for small satellites typically had less than 500,000 pixels, resulting in poor quality satellite imagery and extremely slow download speed. Back then, one to ten megabytes of random access memory storage was typical for small satellites. What made matters worse was, if the power switched off, all the data was lost.

The problem the SmallSat industry faced from the beginning in making satellites smaller was what to do with large amounts of data. Transmitting 16 gigabytes of information using a one-megabit per second downlink could take 35 hours.

To show just how much technology has changed over the past 35 years, on-board data storage has grown by several orders of magnitude. Today, small satellites use mass-produced integrated circuits or complementary metal oxide semiconductor to create inexpensive multi-megapixel cameras with 10-megapixel (commercially off the shelf imagers with image and compression techniques that enable a ten to 100-fold reduction in data storage with little loss in image quality.

When it comes to technology advancement and where SmallSats are going in the near to distant future, the question the industry is constantly facing is: What is the next big thing and what should the community invest in?

Goddard's flagship technology-development program called the Internal Research and Development Program (IRAD), helps to answer these challenging questions. IRAD funds risk-reduction activities for mission and instrument opportunities, advanced concept development, and long-range, high-impact activities.

The purpose of IRAD is to develop strategic technical capabilities that enable science, technology and engineering efforts for future Agency missions. The advances in science and technology expected through this program will shine a light on opportunities for technical risk reduction and/or increased cost effectiveness and initiate potentially transformational solutions. IRAD provides the SmallSat community with a glimpse at the future.

IRAD provides the SmallSat community with a peek at the future.

"One of the things I am responsible for is putting together a portfolio of technology investments," said Christyl Johnson, deputy director for Technology and Research Investment at NASA's Goddard Space Flight Center. "These are the kinds of technologies that are leading edge. They are going to enable future missions. They will not just make small incremental change in the way that we do things, but will take the next big leap, leading to revolutionary changes in the way that we are doing things.

"Today at Goddard we are only scratching the surface of what SmallSats can do and I am excited to see what the next few years bring."

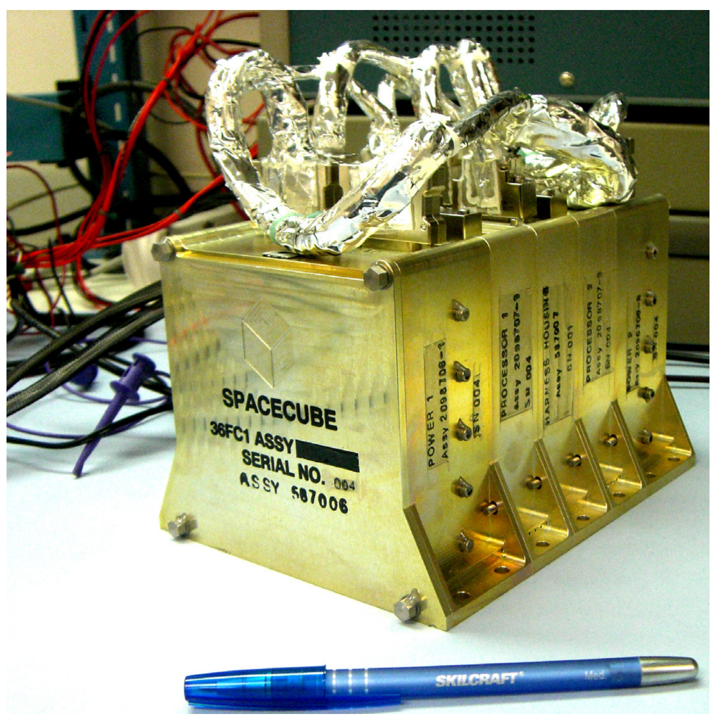
Largly due an explosion in commercial activity, David Wilcox, chief of Small Satellite and Special Projects Office at Goddard's Wallops Flight Facility, believes that most of the activity surrounding SmallSat today, deal with constellations.

"One of the big shifts that has happened recently is that advances have now made it possible to use multiple small spacecraft or a 'constellation,'" said Wilcox. "They can be in the SmallSat/CubeSat [size] range or slightly larger than we are currently building to conduct the same level of science that we would normally implement on a much larger, more expensive satellite."

Goddard is actively working on constellations as part of the Distributed Systems Missions (DSM) effort. DSM involves multiple assets such as satellites, rovers, and ground observatories to achieve the mission goals.

"That is the next big focus at Goddard going forward," Wilcox added. "Let's say you are monitoring weather or wildfires. You could have a mission of a dozen 12U sized spacecraft that all have the same instruments on board. If you plan your orbits right and space them out in a 'string of pearls' fashion, you can set up a small network of monitoring stations, where there is always a spacecraft observing your science objective.

"But you could also design a mission with multiple spacecraft whereby each spacecraft performs an entirely different measurement, or they might work together to collect measurements. Advancements in fine pointing and formation flying allow us to conceive of almost anything with the right combination of spacecraft and onboard capabilities—all this at a fraction of the cost of large observatories."



SpaceCube is assembled. Photo Credit: NASA/GSFC

(continued on page 16)

To expand SmallSat constellation and DSM capabilities into the future, below is a preview of just some of the new FY22 IRAD state-of-the art technologies Goddard is currently developing:

SpaceCube Intelligent Multi-Purpose System (IMPS)

New and innovative constellation CubeSat mission concepts demand modern capabilities such as artificial intelligence and autonomy, coordination, fault mitigation, and robotic servicing —all of which require vastly more processing resources than legacy systems are currently capable of providing. Enabling these domains within a scalable, configurable processing architecture is advantageous because it also allows for the flexibility to address varying mission roles, such as a command and data-handling system, a high-performance application processor extension, a guidance and navigation solution, or an instrument/sensor interface. NASA's IMPS for enabling remote sensing, communication, and navigation in mission architectures allows mission developers to mix-and-match 1U (10 cm × 10 cm) CubeSat payloads configured for mission-specific needs.

Noteworthy Because:
IMPS is reconfigurable and reusable to meet future science and defense needs for several mission types. This architecture design is advantageous for instruments that can be repurposed to varying science aims without significant changes to the electronics processing cards.

Formation of Control of SmallSat Constellations

This project seeks to develop methods for orbit visualization, selection, and analysis for SmallSat formation flying missions in a multi-body regime by creating a common set of computational tools for use by scientists and engineers. These methods and tools will facilitate the mission design process and help identify propellant efficient formations and control strategies, thereby enabling future formation missions, such as constellations, starshades, and servicing.

Noteworthy Because:
It will develop analytical tools for selecting viable orbits, formations, and control algorithms and also will allow scientists to study how spacecraft configuration parameters, such as relative position/velocity, orbit, epoch, affects the evolution of constellation formation. This will assist in developing strategies to identify advantageous orbits for formation flight and initialize SmallSat spacecraft constellations. This framework will better enable scientists and engineers to visualize SmallSat constellations mission management.

Gallium Nitride-Based Cubesat-Sized Power System (GaN LVPC)

Many flagship missions at Goddard adopt a similar power distribution architecture for avionics and electronics. Typically, these systems are independent units that receive power from the spacecraft bus and provide electromagnetic interference filtering and isolated power for distribution to other circuit-card assemblies across the system requiring lower voltages, commonly referred to as the low-voltage power converter (LVPC).

The objective of GaN LVPC is to develop a scalable architecture using GaN High-Electron Mobility Transistor (HEMT) modules to construct highly reliable and highly efficient power systems. This architecture design will allow for both isolated and point-of-load converter modules to be designed independently of specific mission power requirements and support a wide range of use cases.

Noteworthy Because:
Many CubeSat missions are severely cost-constrained, therefore will forgo the radiation-hardness assurance provided by the standard DC-DC (direct current-to direct current) brick approach and prioritize cost savings by using all commercial components. This design practice also affects miniaturized instrument payloads, especially when the instruments used in the CubeSat mission are repurposed for independent use as part of a rover or larger mission sub-experiment. Using GaN modules is advantageous because GaN HEMTs provide comparatively higher efficiencies with lower volumes, mass, and cost when compared to conventional Silicon MOSFETs (metal–oxide–semiconductor field-effect transistors) found in rad-hard DC-DC converters.

CubeSat Data Recorder for High-Throughput Instruments

The objective of this project is to develop a miniaturized, CubeSat-sized, high-reliability solid-state data recorder (SSDR) design for CubeSat and SmallSat applications or instrument electronic boxes in varying harsh radiation environment orbits. The SSDR design will also be scalable to allow increased memory density and throughput by insertion of more SSDR card assemblies to the system. Additionally, the design will focus on supporting high-throughput data rates proposed by many upcoming sensors and detectors on NASA missions.

Noteworthy Because:
The SSDR design will be able to meet the needs of a variety of upcoming NASA science mission proposals. It also has potential to benefit the commercial industry and other government agencies that have a need for a high-reliability, miniaturized form factor data recorders that can be paired with high-performance science data processors, such as the SpaceCube v3.0 Mini.

Technology managers with the Goddard Technology Transfer Office are always available to answer questions or help move projects forward. For more information, please email techtransfer@gsfc.nasa.gov or call 301-286-5810.

To find out more about IRAD, please visit
https://www.nasa.gov/content/internal-research-development-program-irad.

Engineer Spotlight

Important innovations are on the horizon for SmallSats. Young engineers are the future and will play a key role in inventing and developing SmallSat technologies of the 21st century. We reached out to a few of our young engineers to find out who they are, discover why they think SmallSats are important, and why they decided to join NASA's Goddard Space Flight Center.

Julie Cox

Julie Cox began aerospace work while attending Northwest Nazarene University. There, she earned degrees in mechanical and agricultural engineering. She also worked as a research assistant for an automated agricultural vehicle in 2017 and a 3U CubeSat in 2018. Cox then went on to work as a mechanical engineer contractor for Goddard's SmallSat division, where she worked on design, integration, and testing. She then converted to a government NASA employee in 2022.

Cox continues to work on SmallSats at Goddard, as well as in mechanical packaging, with a special interest in Internal Research & Development. When not in the lab, Julie can be found volunteering at the local Humane Rescue Alliance or out hiking with her own dog, Lando.

Why did you choose to work at NASA Goddard?

After I graduated college, working in aerospace really wasn't on my mind. I assumed the industry was too hard to get in and NASA seemed too elusive. Without a job offer, I decided to move out east from the west coast. On the drive over, my resume got pinged by an aerospace contracting company looking for CubeSat engineers. After a quick interview at an eastern Oregon gas station, a final interview was set up for once I got to D.C. It wasn't until they sent me the location that I realized the contract was for NASA. The project and location were a great fit, and after meeting the team, I felt that my skills and attitude would be complimentary. Fast forward a couple years, I officially made the switch to from a contractor to a NASA employee and I'm excited for what new Goddard projects await!

What do you enjoy most about working on SmallSat technologies?

I've most enjoyed seeing these missions become real. I've gone from seeing the unfinished Computer-Aided Design (CAD) models to a functioning and finished spacecraft. Come fall, we'll (hopefully) see our CubeSats launch and start to see data collection. Getting such a well-rounded overview of a full mission life cycle and having hands-on work in various areas is a great opportunity.

What have you learned most from working on SmallSats at Goddard?

Saying I've learned a lot is an understatement. Our Goddard SmallSat teams are pretty small, so instead of having lots of seasoned engineers working on certain specific parts, we have a couple core people doing most of it. As a mechanical engineer, I've done everything traditionally mechanical—design, analysis, and integration—but I've also been included in project management, electrical work, and some software. Having a small part in a lot of disciplines is something unique to the SmallSat teams—not a lot of other early career engineers can get such an overview of all the moving parts of a mission and have hands on experience putting it together. I've learned how missions and Goddard work and what my strengths are in the process.

Why do SmallSats matter? Why should industry people pay attention to this subject?

SmallSats bring quicker and cheaper science to space. For a science team that has a great idea but not the funding or extended time frame to put their instrument on a larger mission, that same team could get their payload in orbit in a few years for much less cost and red tape. Think of petitSat—it has two science payloads and a tech demo; all designed, integrated, and tested within a few years. In contrast, if a team wanted to get similar science on a mission like PACE (Plankton, Aerosol, Cloud, ocean Ecosystem) or LISA (Laser Interferometer Space Antenna), they could be queued up for years or decades with much stricter requirements. Of course, larger missions have larger lifecycles in orbit and other highlights, but if a team only needed a few months of data collection for cheap, SmallSats are the way to go.

I think the industry is paying more and more attention to SmallSats. The more I work on SmallSats, the more I see new companies coming out with parts and systems designed for SmallSats, or new ideas coming from universities or NASA branches. Everyone wants to learn more about space, and SmallSats are helping to make it accessible.

What work experience/training/education prepared you for your role?

My introduction to CubeSats happened in college, where I was on an undergrad 3U CubeSat team, RFTSat (Radio Frequency Tag Satellite). On RFTSat, I worked with three other students and a professor taking RFTSat from concept to launch in about two years. While my education helped give me technical knowledge, my work on RFTSat was invaluable. On the team, I learned the NASA lingo and procedures, going from critical design review to launch. Coming into Goddard understanding the environment, style, and loads of acronyms that come with SmallSats put me ahead to start diving into the work.

Seth Abramczyk

After several high school and college NASA design competitions and an internship at NASA's Johnson Space Center in Houston, TX, Seth Abramczyk began his career at Goddard in 2018 in the Pathways program with the Facilities Management Division. He then joined the Thermal Engineering Branch in 2019, where he primarily worked on thermal analysis for the Roman Space Telescope.

Abramczyk started working on CubeSats in 2020 and is now the lead thermal engineer for the SNoOPI (of Opportunity P-band Investigation and Dione missions. Along with assisting on several of the other CubeSat missions in the Goddard portfolio, Seth continues to support the Roman Space Telescope.

Why did you choose to work at NASA?

I always loved space and aviation as a kid, so it was natural that I also always wanted to work for NASA. I grew up in Houston and I dragged my parents to Space Center Houston (at Johnson's visitor center) all the time, so NASA always felt close to home. I eventually did a few outreach programs in high school and college as well as an internship at Johnson.

I applied to the Pathways program at every NASA center that I could, and I was lucky enough to be accepted at Goddard. I didn't know much about Goddard before I started Pathways, but I immediately loved the atmosphere and the types of missions that were being worked on. I also loved Goddard's location, being just a few miles from D.C. and Baltimore.

What do you enjoy most about working on SmallSats technologies?

As an early career, I truly appreciate working on CubeSats because they give me a sense of ownership and responsibility over the thermal design of an entire spacecraft. Furthermore, I enjoy the fast pace and short project lifecycle because it allows me to experience and get involved with every phase of the mission in a relatively short period of time.

What have you learned most from working on SmallSats at Goddard?

I can honestly say that I learned just as much, if not more, in the first two months of working on CubeSats than I had in the previous six months of working on larger missions. One of the lessons I've learned is how the increased risk tolerance for CubeSats flows down to technical and programmatic decisions made during design, analysis, and testing. Finding the middle ground between guidelines and norms based mainly on heritage from larger missions and the fast-paced and higher risk CubeSats can sometimes be a challenge.

Why do CubeSats matter? Why should industry people pay attention to this subject?

CubeSats are a great way to quickly test out new and developing technologies in the space environment. Because of the quick turnaround time you can make incremental changes to your payload and perfect the design before moving to larger and more complex missions.

That said, CubeSats are becoming increasingly capable and can provide great science in their own right. The recent success of Jet Propulsion Laboratory's MarCO (Mars Cube One) that went to Mars with the Insight lander and the upcoming CAPSTONE (Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment) testing the NRHO (Near-Rectilinear Halo Orbit) used by Gateway around the Moon, show the huge potential of CubeSats.

What experiences prepared you for your role?

On the technical side, the most important classes I took in college for my job were heat transfer, thermodynamics, and computer-aided design. I use knowledge and skills from those classes every day when doing thermal design and analysis, and it's of course an essential part of my job.

In addition, the myriad other experiences I had outside of the classroom were just as impactful to help me prepare for my role. I participated in diverse extracurricular experiences, ranging from Boy Scouts to NASA educational outreach programs and internships to being a swim teacher. These experiences all taught me responsibility, teamwork, leadership, and organizational skills and were all invaluable when working on a diverse and fast-paced project like a CubeSat.

Nickalas Cason

Nickalas Cason began his professional career as a summer intern at NASA's Langley Research Center working on a SmallSat with other interns and experienced engineers. Afterwards, he worked as a system administrator for Old Dominion University WHERE until the fall of 2018, when he was picked up by NASA's Wallops Flight Facility, part of Goddard, in the Regional IT Services and Solutions branch as part of the Pathways program.

Cason finished his degree and was converted to a permanent employee in early 2020. In early 2021, he transitioned to Goddard as a member of the Components and Hardware Systems branch assigned to work in the SmallSats Development Lab.

Why did you choose to work at NASA?

I chose to work at NASA because I want to help shape the future of space exploration.

What do you enjoy most about working on SmallSats technologies?

Being on the cutting edge. SmallSats allow the use of the latest and greatest from industry, enabling high performance with a small form factor.

What have you learned most from working on SmallSats at Goddard?

Testing thoroughly and often is the best way to understand the status of a rapidly developing product.

Why do SmallSats matter? Why should industry people pay attention to this subject?

SmallSats drastically lower the barrier to entry for space. With lower costs, development time, and physical footprint, putting a satellite into space is no longer limited to large corporations or state entities. Ignoring SmallSats means not being a part of the rapidly growing market of low-cost space exploration.

What work experiences prepared you for your role?

I've been a computing hobbyist my whole life, experimenting with hardware and software. My previous experience as a system administrator has also come in handy for managing the Linux configurations for some of the missions I'm a part of. Additionally, my previous experience on a SmallSat mission as an intern at Langley has been invaluable. I've also taken some courses offered at various training programs at NASA, including classes on hardware description language), field-programmable gate array, hardware applications, and foundations of aerospace.

Photo Credit: NASA/GSFC

SmallSat Conference *Happy to be Live Event Again*

When the first SmallSat Conference took place back in 1987, only a small group of engineers and scientists in the industry expressed interest in reducing the size of satellites. Originally called the Utah State University (USU) Small Satellite Conference, the idea of small satellites did not seem especially useful with the technology available at the time.

"The small satellite concept was ludicrous to people, wrote Kristen Redd Wilkinson in her abstract paper, From the Perspective of the Pioneers: The Small Sat Revolution. "SmallSats were thought of as toys, with no relevant value. Everyone thought they required too much ground support for communications and couldn't perform useful missions."

As attendees of that first conference soon realized, noted Wilkinson, "The advantages of small satellites are not only that they are cheaper, faster to build, and more tolerant of failure, but also that they represent new ways of achieving objectives."

What led to this change in thinking was the miniaturization of electronics, small budgets, and ultimately, the need for faster completion time. SmallSats officially transitioned from hobbyist projects to performing important missions.

By the end of that first conference, Dr. Frank J. Redd, who chaired the conference, got up at the end of the meeting and asked all the attendees, "Is this something that we should do again? Is this worthwhile?" Everybody raised their hand to signify yes, they would love to do this again. The rest is history.

"Back then there were about 50 attendees," said Dr. Pat Patterson, conference chair and the director of Advanced Concepts at USU's Space Dynamics Laboratory. "Now,35 years later, we are expecting to have between 3,500 or 4,000 people here on the campus of USU and upwards of approximately 1,500 different private and government organizations from about 45 different countries from around the world, in addition to 240 different exhibiter booths."

Out of this World

With a good proportion section of commercial and government engineers and scientists, researchers, academics, program managers, sponsors, executives, and students in attendance, Patterson defined the conference as a technical meeting, which will focus on everything ranging from new technologies, propulsion systems, attitude control, structural vibration, communications, power systems, and more.

"This year, we chose a theme called Small Satellites Out of this World," says Patterson, who has chaired the conference for the past 22 years. "The reason why we chose that is because, over the past several decades, we have seen a lot of technology advancements in the small satellite industry and what we really wanted to focus on are those advancements, what three-to five specific technical areas does the SmallSat community as a whole need to advance, and where does money need to be spent so future missions can be successful."

"The SmallSat Conference is like an annual reunion where everybody in the community comes together," observed David Wilcox, chief of the Small Satellite and Special Projects Office at NASA Goddard's Wallops

Flight Facility. "Goddard is primarily a science center, which is to say, we are trying to push the envelope in regard to what world-class science can be done on these very small platforms. We also use the forum to explain what technologies and capabilities we have been developing and see if there are people who are potentially interested in partnering with us."

NASA's Goddard Represents

NASA Goddard will have no less than 20 scheduled speakers at various technical sessions throughout the conference, in addition to other speakers taking part in numerous side meetings, which convene during breaks and between events.

"We are thrilled about that; NASA Goddard always has a great turnout," said Patterson. "The SmallSat community is still a relatively small community, but it is a pretty collaborative group and growing super-fast."

"It is really great to be at the 36th Annual SmallSat Conference," said Christyl Johnson, deputy director for Technology and Research Investment at Goddard. "With so much activity in the SmallSat arena, it's even more important than ever collaborate with members of the SmallSat community in pursuit of our shared technology goals.

"Goddard is always seeking to partner with industry to share our technology advancements and to continue to develop the SmallSat platform. The SmallSat Satellite Project Office and the Strategic Partnership Office are two resources within Goddard that can help attendees license NASA technologies, learn more about our missions, and find ways we can work together."

Happy to Be Live Again

So, when Patterson talks about the SmallSat Conference being out of this world, the big change from over the past two years is that it is has returned to a live and in-person event again. This gives everybody the opportunity to interact and share as much information as possible.

"Even though I believe we did the best that we could last year in terms of virtually sharing content with the community," Patterson says, "it just isn't the same when you can't hear somebody's talk, when you can think up a couple of questions, or something you would like to talk to them about [later]."

"Another opportunity of being at conference," added Wilcox, "is that almost all of the [commercial] companies that build hardware are there in attendance showing off their products. With the conference being live again, it gives us the opportunity to go talk and engage with them."

Patterson estimates that about 15% to 20% of the attendees at this year's conference will be students and their professors doing front end research. Given the SmallSat conference's origins on a university campus, student teams gain valuable experience working on relevant SmallSat projects.

"A lot of these students walk away at the end of the conference with a job offer," says Patterson. "So, this is a great opportunity for them to speak to the people in the SmallSat community and really understand the technology and show what they have learned and gained with hands-on experience. We're really high on students here at the conference and we will aways keep that for the future."

For many, the SmallSat conference has become an annual event that helps bind the community together, as attendees have the opportunity to forge new connections and catch up with those they know well but perhaps haven't seen in a while, Patterson says. "As it grew and got larger, I began to call them a family. I've had dozens of people over the years tell me they are going not to a SmallSat Conference but to a SmallSat family reunion to see old friends and colleagues."

THE SPARK

Goddard's *The Spark* shares stories about technology transfer at NASA and the innovative people who make it all possible. The magazine is published quarterly by the Strategic Partnerships Office at NASA's Goddard Space Flight Center.

Also available online at:
https://partnerships.gsfc.nasa.gov

Send suggestions to:
techtransfer@gsfc.nasa.gov

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