National Aeronautics and Space Administration

THE SPARK

TECH TRANSFER, PARTNERSHIPS, AND SBIR/STTR AT GODDARD

Goddard SmallSat Technologies Power Discovery

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SMALLSAT SOLUTIONS

CONTENTS

ABOUT THE COVER

The combined Landsat 9 Evolved Expendable Launch Vehicle Secondary Payload Adapter (ESPA) Flight System (EFS) will bring multiple CubeSats into space as secondary payloads when Landsat 9 launches, demonstrating the advantages of rideshare. Read more on page 5.

Photo Credit: NASA/Jerry Nagy

OFFICE OF THE CHIEF

From award-winning thermal imagers to flight software programs designed for SmallSat missions, NASA's Goddard Space Flight Center is bursting at the seams with technologies well-suited for your small satellite needs.

This year marks the second time that the Small Satellite Conference is all-virtual, and just like last year, Goddard has committed to strong online participation. Working closely with the team at Goddard's Small Satellite Project Office, the Strategic Partnerships Office (SPO) has coordinated an excellent assortment of presentations and resources for you. Please look at the last page of the magazine for a schedule of events.

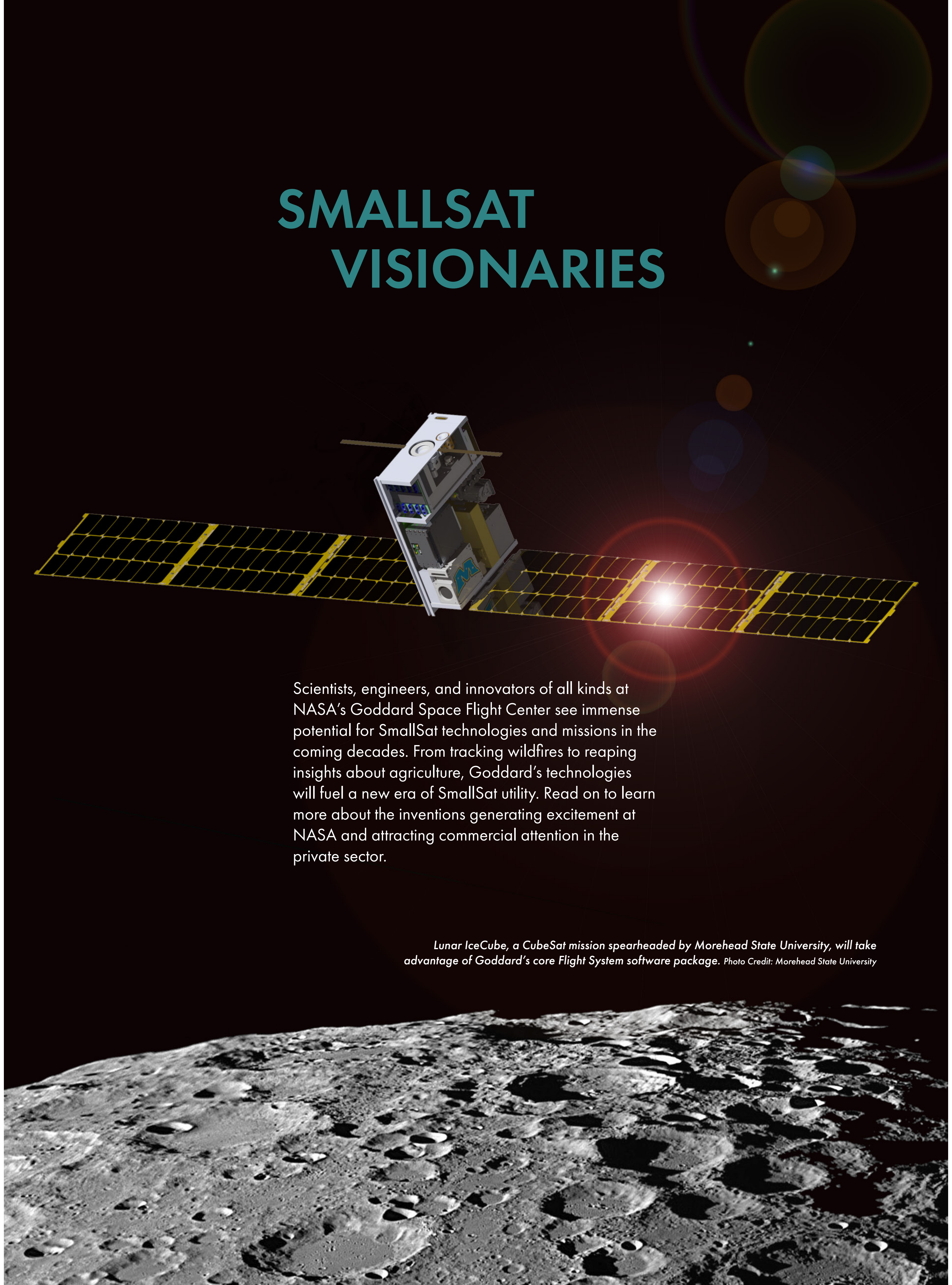
Meanwhile, as Goddard pushes five CubeSat missions ever closer to launch, we're all looking forward to the exciting new capabilities that these platforms will enable. SPO is supporting our innovator community as they develop technologies to launch distributed systems of SmallSats, opening up new science and commercial possibilities for public and private sectors.

Check out some of our most popular SmallSat technologies on page 3, and don't miss a glimpse into the future of SmallSat technology on page 7. As always, SPO is here for you. Flip through the following pages for myriad ways to contact us!

Daryl Mitchell

Darryl R. Mitchell, Chief

Strategic Partnerships Office
NASA's Goddard Space Flight Center



SMALLSAT VISIONARIES

Scientists, engineers, and innovators of all kinds at NASA's Goddard Space Flight Center see immense potential for SmallSat technologies and missions in the coming decades. From tracking wildfires to reaping insights about agriculture, Goddard's technologies will fuel a new era of SmallSat utility. Read on to learn more about the inventions generating excitement at NASA and attracting commercial attention in the private sector.

Lunar IceCube, a CubeSat mission spearheaded by Morehead State University, will take advantage of Goddard's core Flight System software package. Photo Credit: Morehead State University

FIVE GODDARD SMALLSAT TECHNOLOGIES YOU SHOULD KNOW

With hundreds of new technologies reported every year, NASA's Goddard Space Flight Center ranks among the most innovative centers at NASA. Goddard has no shortage of SmallSat technologies available for download or licensing, but with so many options, it might be hard to know what you need. Don't worry: the Strategic Partnerships Office is here to help! We've selected five Goddard innovations to spotlight for their broad applicability to SmallSat missions. If you have questions about these technologies or any others in Goddard's portfolio, please reach out to SPO's technology transfer team: techtransfer@gsfc.nasa.gov.

1. MODULAR ARCHITECTURE FOR RESILIENT AND EXTENSIBLE SMALLSATS (MARES)

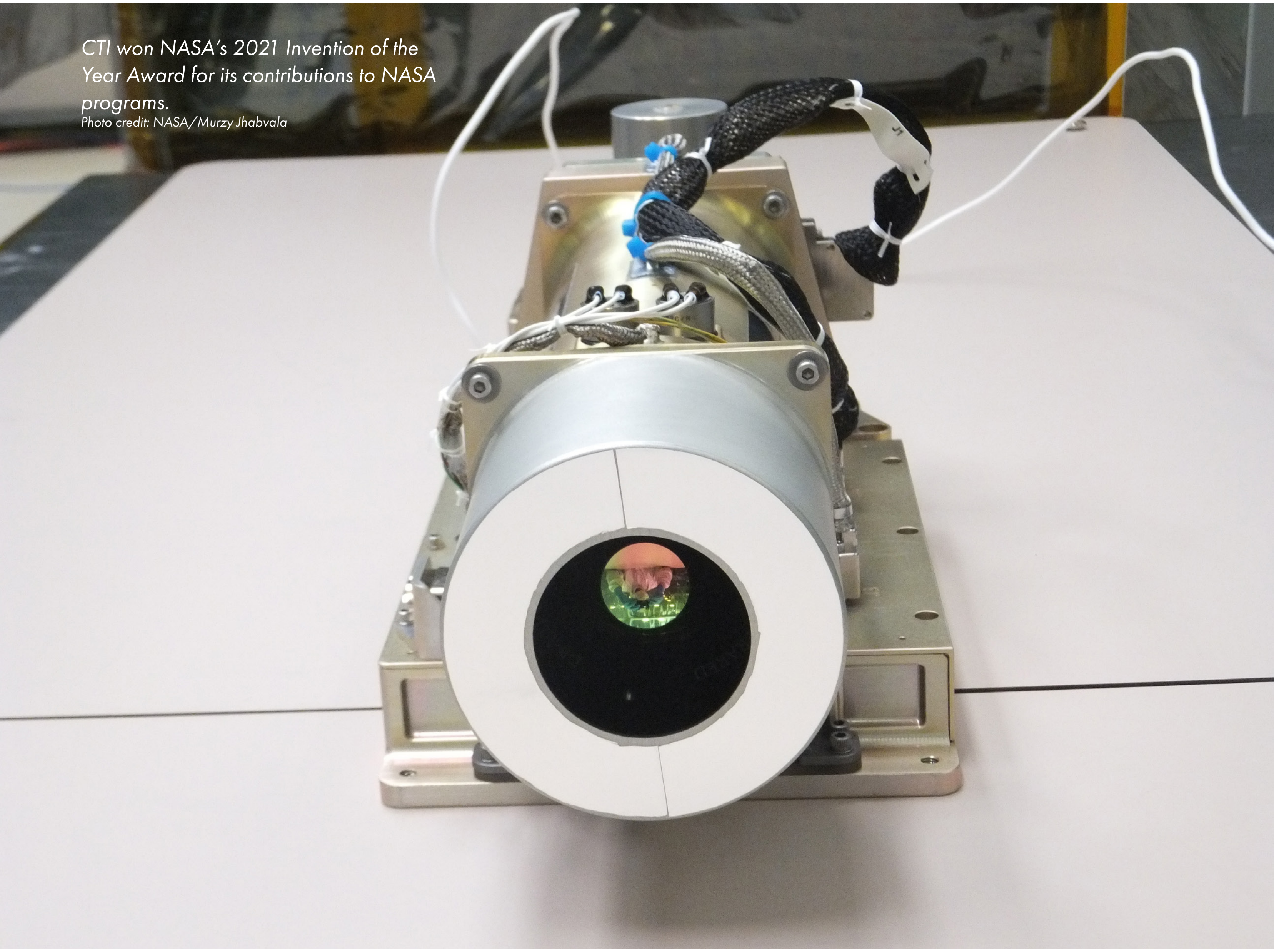
Currently under development at Goddard, MARES is a capabilities-driven design and architecture with an emphasis on reliability, scalability, and high-performance processing. It can apply to SmallSat missions, CubeSat missions, and high-performance instrument processors. The highly integrated architecture reduces mass, volume, and power while still providing the flexibility of a modular system.

2. THE CORE FLIGHT SYSTEM (CFS)

With cFS, software developers at Goddard created a software package that includes the core pieces of code that every mission needs, as well as the artifacts that accompany it, featuring a "layered" approach that allows for the addition of mission-specific code built on top of validated and existing code. The structure includes an operating system abstraction layer that enables cFS to port from operating system to operating system with practically no modifications, a platform abstraction layer that makes it easy to port cFS to new flight computers, and the core Flight Executive layer that includes all the common services NASA missions need to succeed. You can access cFS here: https://github.com/nasa/cFS

3. SPACECUBE

The SpaceCube family of processors has a long legacy at Goddard. These hybrid processors combine radiation-hardened and commercial components, emphasizing a novel architecture that harmonizes the best capabilities of CPUs, DSPs, and FPGAs. Thoroughly flight-tested and ideally sized for CubeSat missions, the reconfigurable SpaceCube processing system saves both time and budget for mission developers. Learn more here: https://technology.nasa.gov/patent/GSC-TOPS-35



CTI won NASA's 2021 Invention of the Year Award for its contributions to NASA programs.
Photo credit: NASA/Murzy Jhabvala

4. CUBESAT COMPATIBLE COMPACT THERMAL IMAGER (CTI)

The award-winning CTI represents the latest advances in infrared detectors. CTI's emerging strained layer superlattice (SLS) infrared detector technology possesses several advantages over other competing infrared technologies. SLS detectors share qualities with quantum well detectors, such as low cost, relative ease of fabrication, and stability; however, they are 10 times more sensitive, can be spectrally tuned, and can operate at much warmer temperatures. This allows the technology to fly on smaller platforms, since it can work with lighter and less power-intensive cooling systems. Find out how to license this technology here: https://technology.nasa.gov/patent/GSC-TOPS-138

5. THE NASA OPERATIONAL SIMULATOR FOR SMALL SATELLITES (NOS^3)

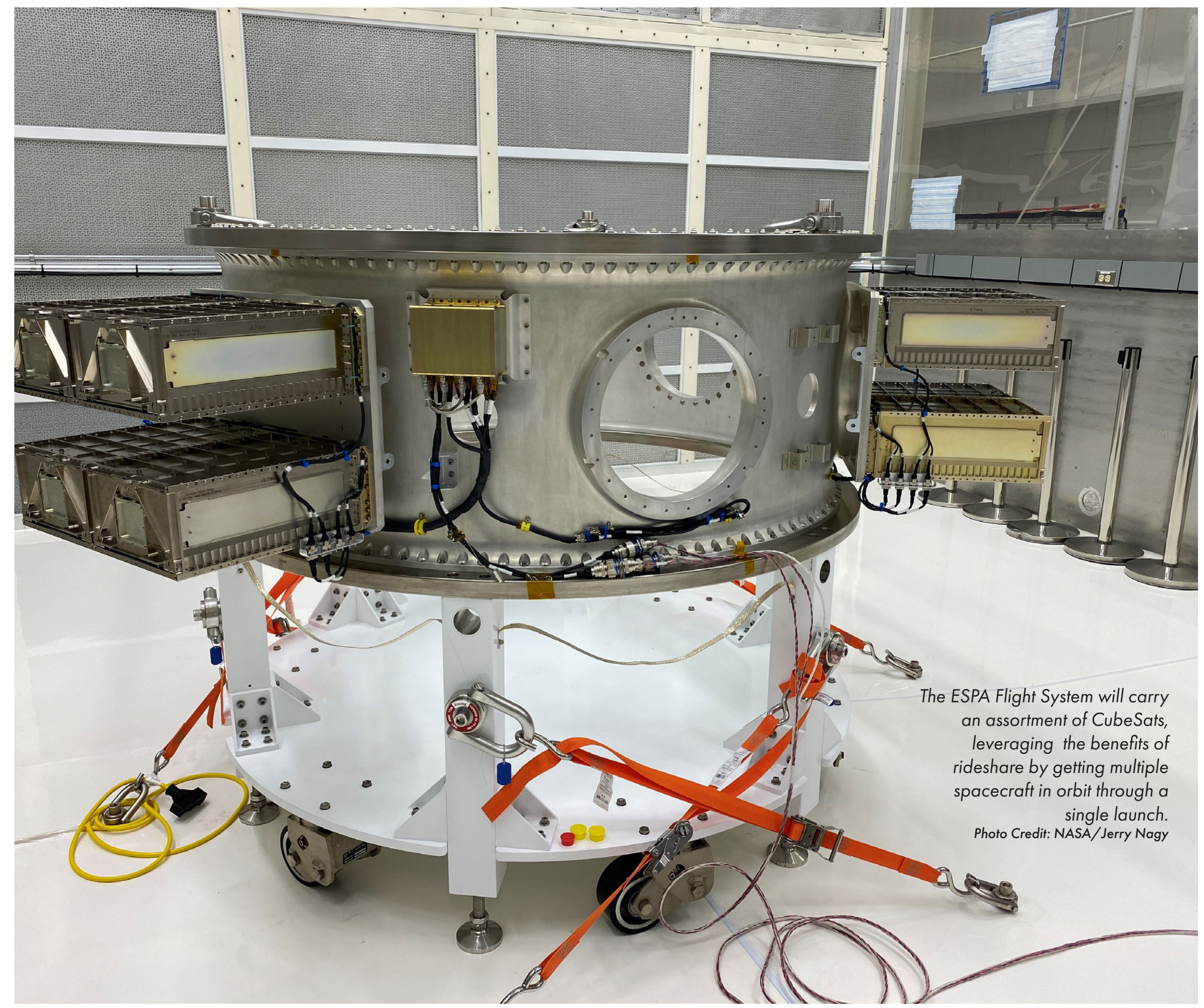
NOS^3 brings several compelling advantages to SmallSat missions. It lessens cost, reduces risk, and allows missions to focus on accomplishing science objectives. Since CubeSat missions move at a fast pace, progress advances more quickly when multiple stages of a mission can happen in parallel. NOS^3 is able to emulate flight hardware, allowing a software-only test environment early in the mission's development and testing phases. Developers don't have to wait for physical hardware to be in place and can perform coding, instrument integration, and software testing while hardware is being acquired. You can find NOS^3 here: https://github.com/nasa/nos3

CATCHING A RIDE WITH LANDSAT 9

Flagship Landsat 9 launch will feature CubeSats as secondary payloads

The first Landsat satellite launched in 1972, and since that time, Landsat has become a flagship NASA and U.S. Geological Survey mission that returns stunning images of Earth from space. Landsat satellites have provided Earth insights of forests, crops, freshwater, and other systems that human beings and animals depend on to survive. The Landsat legacy continues this fall, with Landsat 9 scheduled to launch in September 2021. The satellite will carry two instruments – the Operational Land Imager 2 and the Thermal Infrared Sensor 2.

Though this is the ninth Landsat satellite to fly in space, there's a brand new feature to the mission that involves Landsat 9's launch vehicle. Tucked into the launch vehicle is a ring-shaped object with a long



The ESPA Flight System will carry an assortment of CubeSats, leveraging the benefits of rideshare by getting multiple spacecraft in orbit through a single launch.
Photo Credit: NASA/Jerry Nagy

name: the combined Landsat 9 Evolved Expendable Launch Vehicle Secondary Payload Adapter (ESPA) Flight System (EFS). The EFS, developed by the U.S. Space Force Mission Manifest Office, will travel to space inside the fairing with Landsat 9 and enable the simultaneous launch of multiple CubeSats stowed safely away inside. This approach, known as rideshare, maximizes launch vehicle efficiency and takes advantage of cross-organizational collaboration to get multiple satellites into space with a single launch.

Two of these CubeSats are sponsored by the CubeSat Launch Initiative, based out of NASA's Kennedy Space Center. The Colorado Ultraviolet Transit Experiment (CUTE) from the University of Colorado at Boulder will study exoplanet atmospheres, and the Cusp Plasma Energy Detector (CuPID) from Boston University will collect data on interactions between solar wind and Earth's magnetosphere. When Landsat 9's launch vehicle reaches space, the CubeSats will be ejected into orbit.

"'Do no harm'" to the primary mission – that is our top requirement," says Theo Muench, the project manager for Landsat 9 ESPA Flight System. "Anything beyond that is a bonus for NASA, the U.S. Space Force, and ultimately, the taxpayer. That's the mantra for everything we do on the EFS team."

Just like any new pursuit, rideshare has involved a number of challenges. For example, it's been a challenge to ensure the CubeSats pose no hazards to Landsat 9 on assent, as well as align multiple mission schedules to a single launch date. Muench, who has worked at NASA's Goddard Space Flight Center for 21 years, says the EFS team has done a superb job to ensure that Landsat 9 experiences no impact from the rideshare efforts.

Sometimes, that means removing CubeSats from the manifest, a decision that Muench calls "disappointing" but also shows their commitment to the "do no harm" philosophy.

"If there's a problem, it's clear that we can protect the primary mission," Muench says. "We're demonstrating that mass simulator replacement is a practical and effective contingency plan."

Using mass simulators, which mimic the weight and shape of payloads, the EFS team can still meet primary mission timelines even when secondary missions experience delays or setbacks. Since rideshare on this scale is still a relatively new endeavor for NASA, these lessons will inform future rideshare launches.

"EFS is a great demonstration that it's possible to fly secondary payloads on all NASA launch vehicles without impacting the primary payload," Muench says. "We have quite a number of lessons learned from going through this process, but I think it will be useful for future missions to have a road map that explains how you mesh the primary schedule with the secondary payload schedules."

The initial forays into rideshare have yielded promising results, and Muench expects to see more large missions adopt secondary payloads in the coming years.

"It's motivational to know there likely will be more of these rideshare missions," Muench adds. "What the EFS team documents in this process will be valuable for other folks down the road."

"DO NO HARM TO THE PRIMARY MISSION: THAT IS OUR TOP REQUIREMENT."

–THEO MUENCH, PROJECT MANAGER FOR LANDSAT 9 ESPA FLIGHT SYSTEM

BETTER TOGETHER

Distributed SmallSat systems will bring new science abilities at lower cost

Alexa Halford spends her days observing nature with a curious, scientific eye. To her, the universe contains endless questions waiting for answers.

"When you're studying space physics, you're not working in a controlled lab at all," says Halford, deputy principal investigator (PI) for the petitSat mission at NASA's Goddard Space Flight Center. "It's so exciting, because we're seeing small bits and pieces of information while trying to fit it all into the big picture."
"As a pathfinder, GTOSat will demonstrate how CubeSats can be used beyond LEO," Blum says.

Take a natural phenomenon like the aurora borealis, she says. How could anyone ever predict the pathways of pinks and greens snaking their way across the sky? And yet, Halford says, when scientists understand the patterns of solar particles as they flow through Earth's magnetosphere, it's entirely possible to know what the aurora will do.

"Even though we're looking at these incredibly complex systems in nature, we're getting to the point where we understand the physical principles driving them, and that's an amazing feeling," Halford adds.

Scientific discoveries fuel many of NASA's missions, and small satellite missions are no exception. Since CubeSats first developed as university projects more than 20 years ago, the platform has flourished, with CubeSat missions accomplishing bold science objectives that continue to advance our understanding of the universe.

With five CubeSat missions nearing launch and more concepts in the works, Goddard has big plans for these tiny spacecraft. By flying fleets of identical SmallSats, scientists can answer questions that previously weren't feasible to answer with large spacecraft. This approach – known as constellations or distributed systems – provides relatively low-cost networks of sensors that can capture data from multiple vantage points.

These missions are still a few years away, but even now, Goddard scientists can see the exciting opportunities that distributed systems will create.

FLYING IN CONCERT

To understand the promise of distributed systems, it helps to look at Goddard's heritage of constellation missions, says Christa Peters-Lidard, deputy director for Hydrosphere, Biosphere, and Geophysics in Goddard's Earth Sciences Division. Goddard has flown global constellations before, and the 2014 Global Precipitation Measurement (GPM) mission is a great example. GPM is a joint mission with the Japan Aerospace Exploration Agency (JAXA) that features a network of satellites collecting high-quality estimates of Earth's rain and snowfall every 30 minutes. This international endeavor continues to provide key lessons-learned in sensor calibration and data production, both important facets of distributed systems.

"GPM really paved the way for global constellations," Peters-Lidard says, pointing to the mission's ongoing success. GPM's constellation of satellites generate improved measurements of precipitation, reaping numerous societal benefits. With GPM data products, scientists can gain a better understanding of hurricane intensity, flooding, landslides, soil moisture, and climate.

As a flagship mission, GPM has a budget to match – hundreds of millions of dollars supported development, integration, and launch efforts. One reason SmallSat distributed systems hold so much promise, Peters-Lidard says, is because they cost so much less and can reap scientific benefits with nearly the same accuracy and impact as larger spacecraft.

"Imagine these swarms of CubeSats or SmallSats in different orbital planes," Peters-Lidard says. "From

Photo Credit: NOAA

an Earth science perspective, you want to sense a given location at high resolution with frequent repeats to capture events that happen over the course of a few hours or within a day. These small sensors are becoming as capable as some of our flagship sensors, and this opens up huge possibilities for increasing repeated observations. You gain coverage that you could never get from a single satellite."

This ability will enable many new scientific pursuits, but Peters-Lidard shares one particularly exciting example: wildfire detection with real-time direction. With a distributed system of sensor-wielding CubeSats, NASA could direct assets to focus on the fire, measure smoke, and incorporate incoming data into models to inform evacuation plans.

"In the world of disasters, we typically don't have that sort of flexibility, so the opportunities here are enormous," Peters-Lidard adds.

ONE BECOMES MANY

Several recent developments have brought distributed systems of SmallSats within Goddard's reach. As the SmallSat platform continues improving and becoming streamlined, mission costs have decreased. Meanwhile, Goddard's plethora of successful CubeSat missions have demonstrated the technology's reliability and dynamic nature. Finally, the growth of rideshare means that CubeSats can hitch rides with larger mission launches, significantly reducing the cost of getting to space.

Halford, deputy PI of the petitSat mission, sees many of Goddard's current CubeSat missions as trial runs for future constellations. The petitSat mission will study density irregularities in Earth's ionosphere, and depending on the data yielded by the CubeSat, it could lead to mission concepts that feature distributed systems with multiple petitSats. And why stop at Earth, Halford asks? NASA flew two CubeSats around Mars in 2018, ushering in an era of interplanetary possibilities for tiny spacecraft.

"Once we study these features in Earth's ionosphere, we can see how Mars, Venus, or Mercury compare," Halford notes. "It gets to that fundamental question – what makes us special? Why do we have life? It would be fascinating to find out if we understand what we should see on these other planets."

Cost has played a big role in CubeSat success. In the past decade, reliability of the platform has improved significantly, with multiple missions returning high quality data that has advanced several scientific fields, including physics.

"Dollar for dollar, you're getting a ton of fantastic science," Halford says.

In part, this reliability comes from the miniaturization of radiometers, spectrometers, and other scientific instruments. Goddard engineers also have developed an assortment of small satellite components, such as booms, thermal louvers, and antennas. With each successful CubeSat mission, these new technologies increase scientists' confidence that they can provide years' worth of functionality in the harsh environment of space.

Rideshare also reduces cost by bundling multiple missions together on one launch vehicle. CubeSat missions can split the cost of the ride into space, and depending on their orbit, the only barriers involve coordination and planning to find the right launch.

The Landsat 9 mission, scheduled to launch in September 2021, will travel into space with a collection of CubeSats from NASA's CubeSat Launch Initiative based at NASA's Kennedy Space Center and the U.S. Department of Defense. As rideshare grows and coordination around launches improves, it's likely that secondary payloads will become a regular part of future missions.

THE NEXT 20 YEARS

The SmallSat platform has come a long way since CubeSats first emerged in the late 1990s, but NASA has a few more hurdles to jump before distributed systems of SmallSats take flight. Peters-Lidard and Halford say that continued cost and reliability improvements, better data integration approaches, and strong partnerships with industry will push these missions forward into the future.

"For NASA, it's all about managing cost, risk, and schedule, so when risk is higher, that adds cost," Peters-Lidard says. "The more distributed system missions we do, the better we'll get, and the risks will come down because we'll know what works."

With constellations, Peters-Lidard says, there's a balance to strike between risk and resilience. For a large mission, losing a single spacecraft would be disastrous, but a network of 12 identical spacecraft could lose a unit and still function. It may even provide the opportunity to replace one of the spacecraft

with another SmallSat that could take on a new orbit or carry an updated type of sensor. It's a different mindset, but one that could lead to greater opportunities for innovation.

Another challenge involves the massive amounts of data that a SmallSat constellation would return. It's one thing to simply receive and process data from multiple sensors, but quite another to combine the data with models, machine learning techniques, and other methods to provide usable information to scientists and decision makers.

"It's not reasonable to expect end users to put all that raw data together," Peters-Lidard points out. "It's our role to figure out how these new observations link up with historic data. This is one of Goddard's core areas of expertise – we understand the past to inform the future."

Finally, Halford says, it will take partnerships between government and private industry to build up a robust rideshare network. As endeavors such as the Artemis program increase trips to the Moon, associated launch vehicles could also provide more rideshare opportunities.

In any case, Halford says, it's bound to be an exciting few decades for SmallSat missions.

"Twenty years ago, we weren't even flying these platforms," she adds. "I can only begin to imagine how things will look 20 years from now. If this exponential growth continues, I suspect we'll return 1,000-fold what we put into it."

Photo Credit: NASA

The Global Precipitation Measurement mission paved the way for future global constellations.

ENGINEER SPOTLIGHT: PETER MARQUIS

NASA Aerospace Engineer Peter Marquis is no stranger to CubeSat missions – in fact, he worked on his first CubeSat project as a college student. Since then, he's navigated the SmallSat world in various forms, from the U.S. Naval Research Laboratory in Washington, DC, to Goddard's Wallops Flight Facility in Wallops Island, Virginia.

"There's so much opportunity to do really incredible science in the CubeSat world," says Marquis, who works in the Mechanical Systems Branch at Wallops. "I've been involved with SmallSats in some form or another for about seven years now."

Marquis' SmallSat experience has spanned his early college CubeSat work to studies at the Mission Planning Lab, where engineers spend a week studying the ins and outs of a SmallSat mission to determine feasibility and identify critical development areas. His most recent work, however, has focused on rideshare.

As the size of launch vehicles has increased, NASA and others in the aerospace community have looked for ways to accommodate smaller, secondary payloads on larger mission launches. Additionally, CubeSat and SmallSat missions can hit launch service "bottlenecks" when looking for rides into space. By utilizing more capacity on the launch vehicles, organizations can reap significant cost savings and save valuable mission resources. Due to the compact nature of SmallSat missions, they are well-suited for rideshare, and at Wallops, Marquis is hard at work to qualify rideshare hardware to fly underneath Earth observation satellite Landsat 9. The mission's launch vehicle will be equipped with an ESPA ring, a payload adapter with slots for secondary payloads such as SmallSats or CubeSats.

"We're really looking at how we can fit as many CubeSats as possible without impacting the primary mission in any way," Marquis says. "We consider what kinds of dispensers are available, which will affect what form factors of CubeSat can fit, and then it becomes a logistical game of figuring out which CubeSats are available to fly and when."

At Wallops, Marquis has helped design Mechanical Ground Support Equipment and build and test dispenser plate assemblies. The ESPA ring has six ports, five will have CubeSat dispensers, and the entire structure requires integration and testing in preparation for flight.

"We're aiming to show that we can provide open seats for all kinds of customers to get on board and fly," Marquis says.

CubeSat missions and related endeavors provide early career engineers with fast-paced, multifaceted experiences that enrich their skill set and give them broad perspectives on mission lifecycles. The relatively quick turnaround of mission timelines means that "you get to wear a lot of hats," Marquis explains.

While working on the Landsat 9 rideshare project at Wallops, Marquis says he's accumulated a wealth of knowledge by spending time in the vibration lab, performing crane lifts, and conducting pre- and post-environmental deployment testing. The responsibilities and opportunities that come with these missions come with a lot of challenges and a lot of rewards, he says.

"It's been awesome to see my career progress through all these different missions and look back at all that I've learned in the past seven years," Marquis adds.

ENGINEER SPOTLIGHT: CAITLIN BURTH

As a kid, NASA Aerospace Engineer Caitlin Burth had dreams of becoming a pastry chef, but in high school, a NASA engagement program swayed her in the direction of outer space.

"That experience led me to my first internship opportunity in science and engineering, and after that, I was pretty committed to staying with NASA," Burth explains. "I learned through that internship that I loved hands-on work, and after seeing what my friends in engineering did that summer, I knew I wanted to pursue mechanical engineering."

Burth officially joined NASA as a Pathways intern in 2014 at Goddard, landing a spot at Wallops Flight Facility in 2016 as a full-time employee. During her time with Wallops, Burth has helped with several CubeSat and SmallSat mission proposals, serving as the bus structure subsystem lead and, more recently, turning her attention to instrumentation.

In 2020, Burth worked on the proposal for a Goddard SmallSat mission called Dorado. If funded, the Dorado mission will feature a SmallSat equipped with a UV instrument that can observe binary neutron star mergers. Burth's role involved the design of the telescope housing and structure.

"Working on SmallSat missions is one of my favorite things I get to do at Wallops," Burth says.

SmallSat missions have several advantages from an engineering perspective, Burth adds. They have relatively short life cycles of four to five years, which means the technology used can stay current. SmallSats can utilize technologies at the forefront of advancements, and they offer more flexibility than larger missions.

As an early career engineer, Burth says that SmallSat missions give team members an opportunity to see the entire spectrum of a flight project and provide critical training and experience to both engineers and scientists. From her own time at Wallops, she says she's gained valuable insight into the nuts and bolts of a mission from beginning to end.

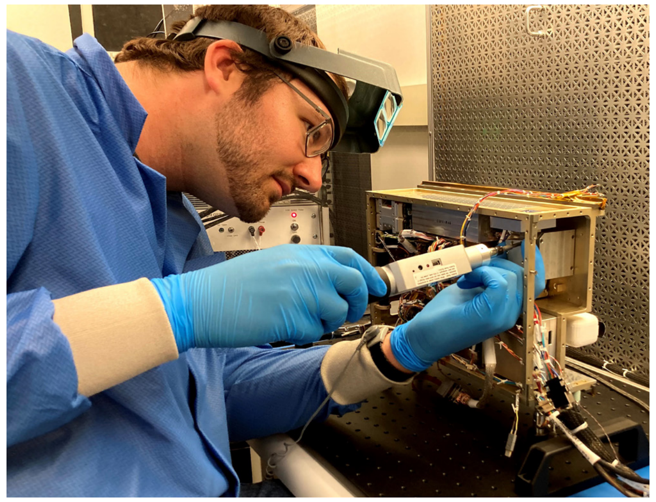
She describes a moment in her first few months at Wallops when she participated in thermal vacuum (TVAC) testing for the IceCube mission, a CubeSat that flew in 2016.

"It was such a cool experience to be fresh out of college and jump right into helping integrate and test this small satellite," Burth says. "I really appreciated being a small part of this bigger picture."

Burth says another aspect of SmallSat work that interests her is the platform's ability to generate technology for larger missions. She saw firsthand the development and design of a new solar panel deployment system that featured 3D printing and worked successfully on the IceCube spacecraft. Now, she says, the technology is being used on balloon missions and other larger platforms with only minor modifications.

"It's always a great thing when you can iterate the design relatively quickly and influence missions outside of the SmallSat arena," Burth says.

ENGINEER SPOTLIGHT: DAKOTAH RUSLEY



Goddard Electrical Engineer Dakotah Rusley remembers the first time he saw CubeSat hardware in the lab after spending more than a year working with 3D, computer-aided design (CAD) models.

"I'd worked closely with these spacecraft designs for months and months, but to see them in person was really cool," Rusley says. "Somehow it's really different to see something real and right in front of you that isn't just pixels on the screen."

Rusley joined Goddard as a Pathways intern in 2017 and started working for the center fulltime at the beginning of 2019. As a college student at the South Dakota School of Mines and Technology, Rusley gained an early start on SmallSat work by organizing a CubeSat team that focused on building the necessary infrastructure to support a CubeSat mission.

This initial focus on CubeSats helped Rusley acquaint himself with engineering and design processes that NASA uses in missions. He quickly saw the benefits SmallSat experience could provide, especially for students from smaller schools with fewer resources.

"The SmallSat platform creates opportunities to get your feet wet in the NASA spacecraft world," Rusley says. When Rusley attended the Small Satellite Conference in Utah as an undergraduate student, he knew he wanted to work with SmallSats. The supportive and collaborative SmallSat community made an impression on him, and from that moment on, he focused his efforts on the world of small satellites.

At Goddard, Rusley has jumped into the CubeSat fray, serving as the integration and test lead for five Goddard CubeSat missions. Additionally, he's pitched in with several Internal Research and Development proposals, working on early-stage technology development. From actuator systems designed for CubeSats to a CubeSat mission designed to "hop" on the lunar surface, Rusley has crammed a diverse array of engineering projects into his handful of years with Goddard.

CubeSat missions have relatively quick paces and small team sizes, which gives early-career engineers opportunities to gain a breadth of experience in the first few years of their professional life.

"The key to success on missions like this is gaining a deep understanding of the whole system," Rusley says. "I'm an electrical engineer by trade, but I understand the mechanical system, how the software is written, and the ACS [attitude control system] requirements. An engineer's role on a larger mission tends to be highly specialized and focused on one task, but with CubeSats, one or two people can understand the whole spacecraft."

Rusley sees a bright future for CubeSats, especially at Goddard, where science takes the spotlight. CubeSats still serve important roles as educational tools, but the platform has advanced to the point where it can return valuable scientific data. Not only are CubeSats proving grounds for technology, but they also hold promise for science missions in their own right.

"We're at the point where we're talking about constellations of CubeSats replacing flagship missions," Rusley shares. "Goddard has a big part to play in changing the traditional view of what CubeSats can accomplish."

SMALLSAT TECHNOLOGIES

NASA's Goddard Space Flight Center brings years of expertise in small satellite technology development and mission planning to the SmallSat community. Through NASA's Technology Transfer Program, members of the public can license patented technologies for their own use, saving valuable time and resources. Instead of starting from scratch, companies can incorporate Goddard technologies into their mission design, freeing up resources for other parts of the mission. Below, please find a list of featured technologies. To learn more about these licensing opportunities, or if you have questions about specific technology needs, please contact Goddard's Strategic Partnerships Office at techtransfer@gsfc.nasa.gov.

OPTICAL COMMUNICATION

CARBON NANOTUBE POLYMER COMPOSITE MIRRORS FOR CUBESAT TELESCOPES GSC-18378-1
Goddard has developed a compact, lightweight, cost-efficient ultraviolet-visible-infrared telescope, covering the 0.3 μm to 2.5 μm spectral range, based on a fast, reflective optics design and an optical coupling interface appropriate for COTS spectrometers, commensurate with a 2U-3U CubeSat volume.
Patent Pending

HIGH VOLTAGE, HIGH SLEW RATE PULSE DRIVER ELECTRONICS FOR CAPACITIVE ELECTRO-OPTIC DEVICES GSC-18398-1
High voltage pulsed electronics for solid state, remote sensing laser applications are a specialized filed with limited commercial options. This new high voltage driver design is suitable for the SmallSat platform, with multiple future mission capabilities via in situ, fast response and high precision high voltage modulation and adjustable pulse width.
Patent Pending

OPTIMETRIC MEASUREMENTS OVER COHERENT FREE SPACE OPTICAL COMMUNICATION GSC-17781-1
Through utilizing coherent optical communication to combine optimetric measurements over an optical carrier, one can accurately measure Doppler and absolute ranging. This process works through a looping and synchronizing iteration, measuring frame, bit, and phase change values using a phase detector and clock data recovery apparatus. The technique improves free space optical communications.
Patent Number: 10,148,352

ON-DEMAND, DYNAMIC RECONFIGURABLE BROADCAST TECHNOLOGY FOR SPACE LASER COMMUNICATION GSC-17922-1
The mirror system can address likely obstacles in space optical communications. Through using miniature adjustable mirrors and programmed phase delays to diffract a single communication beam, numerous diffracted beams can be sent to other satellites in various directions for communication and tracking.
Patent Pending

STEERING MIRROR ASSISTED LASER FINE POINTING GSC-17782-1
The system more finely points lasers so as to improve the precision of space optical communications and ranging. Through linking a laser beam mirror steering mechanism and associated closed loop control, any residual error in pointing to a desired target is reduced dramatically.
Patent Number: 10,228,465

SPACECUBE

SPACECUBE DEMONSTRATION PLATFORM GSC-15953-1
This fault-tolerant framework allows for recovery from radiation upsets. It is reconfigurable from the ground while in orbit. It can be used to produce fault tolerance technologies and serves as a generic data processing solution for space-based applications.
Patent Number: 8,484,509

SPACECUBE V2.0 FLIGHT CARD MECHANICAL SYSTEM GSC-17868-1
TSpaceCube V2.0 is a family of high-performance reconfigurable systems designed for spaceflight applications requiring on-board processing. The SpaceCube V2.0 Flight Card Mechanical System is inherently adaptable and configurable for various configurations.
Patent Number: 10,681,837

SPACECUBE V2.0 PROCESSOR CARD, ENGINEERING MODEL GSC-16673-1
SpaceCube is a cross-cutting, in-flight reconfigurable Field Programmable Gate Array (FPGA) based on-board hybrid science data processing system. The goal of the SpaceCube program is to provide 10 to 100 times improvements in on-board computing power while lowering relative power consumption and cost.
Patent Number: 9,705,320

SPACECUBE V2.0 PROCESSOR WITH DDR2 MEMORY UPGRADE GSC-17983-1
The improved version of the card assembly extends the life and design of the processor and provides even greater memory throughput to support the next generation of instruments.
Patent Number: 10,667,398

SPACECUBE V3.0 FLIGHT PROCESSOR CARD GSC-18136-1
SpaceCube V3.0 features the radiation-tolerant multi-core T2080 processor and the radiation-tolerant Kintex UltraScale FPGA. The SpaceCube V3.0 Flight Processor Card meets the industry standards in lightweight systems specifications.
Patent Pending

SPACECUBE V3.0 MINI PROCESSOR CARD GSC-18356-1
The SpaceCube v3.0 Mini is a high-performance, spaceflight processor card that is 9 cm by 9 cm and designed to fit easily in a 1U CubeSat form factor system. Because the Mini is designed with high-reliability components and fault-mitigation techniques, it is capable of operating in harsher environments and supporting higher-class missions than commercially available market options.
Patent Pending

SPACECUBE V3.0 RADHARD MONITOR GSC-18417-1
The SpaceCube v3.0 RadHard Monitor is an FPGA IP that is responsible for providing monitoring to the SpaceCube v3.0 processor card for single-event upsets and other faults.
Patent Pending

OTHER HARDWARE

ACTIVE POINTING AND TRACKING DESIGN TO CORRECT YAW AND PITCH RANGE ERROR IN LASER SATELLITE-TO-SATELLITE TRACKING (SST) GSC-17923-1
By using a programmable phase mirror, a communication laser beam from the master satellite can be dynamically diffracted into multiple narrow beams, and each diffracted beam tracks a separate receiving satellite to broadcast information.
Patent Pending

AIRBORNE POWER SUPPLY UNIT (APSU) – BUCK CONVERTER DECK GSC-17998-1
APSU is a programmable DC/DC converter that can supply multiple constant voltages or constant current outputs in a small enclosure, enabling power conditioning from a single battery bus to multiple airborne experiments with differing requirements.
Patent Pending

A BROADBAND, COMPACT LOW-POWER MICROWAVE RADIOMETER DOWN CONVERTER FOR SMALL SATELLITE APPLICATIONS GSC-18098-1
The system includes a fundamental local oscillator source composed of a broadband tunable frequency synthesizer as well as a crystal oscillator. The synthesizer employs a harmonic doubler to expand frequency coverage.
Patent Number: 10,659,094

CUBESAT COMPATIBLE HIGH RESOLUTION THERMAL INFRARED IMAGER GSC-17113-1
The thermal infrared imager has high quantum efficiency, broad spectral response, and ease of fabrication. It is small and compact, making it ideal for the CubeSat platform.
Patent Number: 10,306,155

CUBESAT FORM FACTOR THERMAL CONTROL LOUVERS GSC-17034-1
The thermal control louvers use passive thermal control to improve the internal thermal stability of small spacecraft, creating a difference of several watts in dissipated heat between open and closed louvers. The modular design can be produced in large quantities and swapped into various sized plates to tailor the thermal control to each spacecraft's needs.
Patent Number: 9,862,507

DELLINGR 6U CUBESAT GSC-17152-1
The Dellingr CubeSat design is more reliable than previous CubeSat designs. It is cost effective and more robust in terms of volume and power than older designs.
Patent Number: 9,938,023

DEPLOYABLE BOOM FOR CUBESATS GSC-17579-1
The deployable boom for CubeSats is a rigid boom over 50 centimeters in length when deployed that houses a three-axis magnetometer. It is stowed on one side of the CubeSat with a double hinge system.
Patent Pending

DEPLOYABLE SYSTEM FOR CUBESAT ELECTRIC FIELD INSTRUMENT (CEFI) GSC-18120-1
CEFI is a 3-axis electric field instrument with six rigid booms packaged into a less than 1.5U CubeSat volume.
Patent Pending

DIRECTION OF ARRIVAL ESTIMATION SIGNAL OF OPPORTUNITY RECEIVER GSC-18190-1
This transceiver technology for small satellite and CubeSat platforms enables maximization of antenna gain in a specific direction to receive desired signals and suppress signals from other directions.
Patent Pending

EFFICIENT RADIATION SHIELDING THROUGH DIRECT METAL LASER SINTERING GSC-17193-1
The electronic component shielding innovation will facilitate the introduction of state-of-the-art electronics, increasing performance while decreasing hardware complexity, volume, and power and saving mass by enabling use of lightweight spacecraft structural materials. For small satellites, the technology could lead to longer missions by extending the lives of critical components.
Patent Number: 10,255,382

GRAPHENE FIELD EFFECT TRANSISTORS FOR RADIATION DETECTION (GFET-RS) GSC-17279-1
Unlike conventional charge-sensing detectors, the GFET-RS utilizes the sensitive dependence of graphene conductance on local change of the electric field, which can be induced by interaction of radiation with the underlying absorber substrate. This technology provides low power consumption and high sensitivity radiation sensors for the commercial space industry and government agencies.
Patent Number: 9,508,885

ION CONTROL SYSTEM GSC-17976-1
The electric propulsion system is suitable for small satellite attitude control, precision orbit control, constellation formation management, and extended low-thrust maneuvers.
Patent Number: 10,581,345

LHR-CUBE: LASER HETERODYNE RADIOMETER CUBESAT GSC-16966-1
This concept measures atmospheric methane and carbon dioxide from within a 6U CubeSat spacecraft. LHR-Cube will provide a small, lightweight, low-cost, fast turnaround platform for limb measurements that will help constrain the vertical distributions of atmospheric gas by providing measurements with differing vertical sensitivity.
Patent Pending

MAGNETIC SHAPE MEMORY ACTUATOR GSC-17551-1
The push-pull type actuator utilizes a magnetic shape memory alloy. The actuator has nanometer precision and self-position sensing, enabling reliable actuation with applications ranging from precise optical instrument pointing to simple locking mechanisms.
Patent Number: 10,581,345

MICROSCALE ELECTRO HYDRODYNAMIC (EHD) MODULAR CARTRIDGE PUMP GSC-17220-1
This innovation incorporates a simplistic design that reduces the number of components required to make an assembly by up to 90 percent over previous iterations, ensuring a solid, reliable electrical connection to the electrodes that form the pumping sections. Its modular design allows for flexibility in incorporating the pump cartridge into various assemblies and applications.
Patent Number: 10,461,621

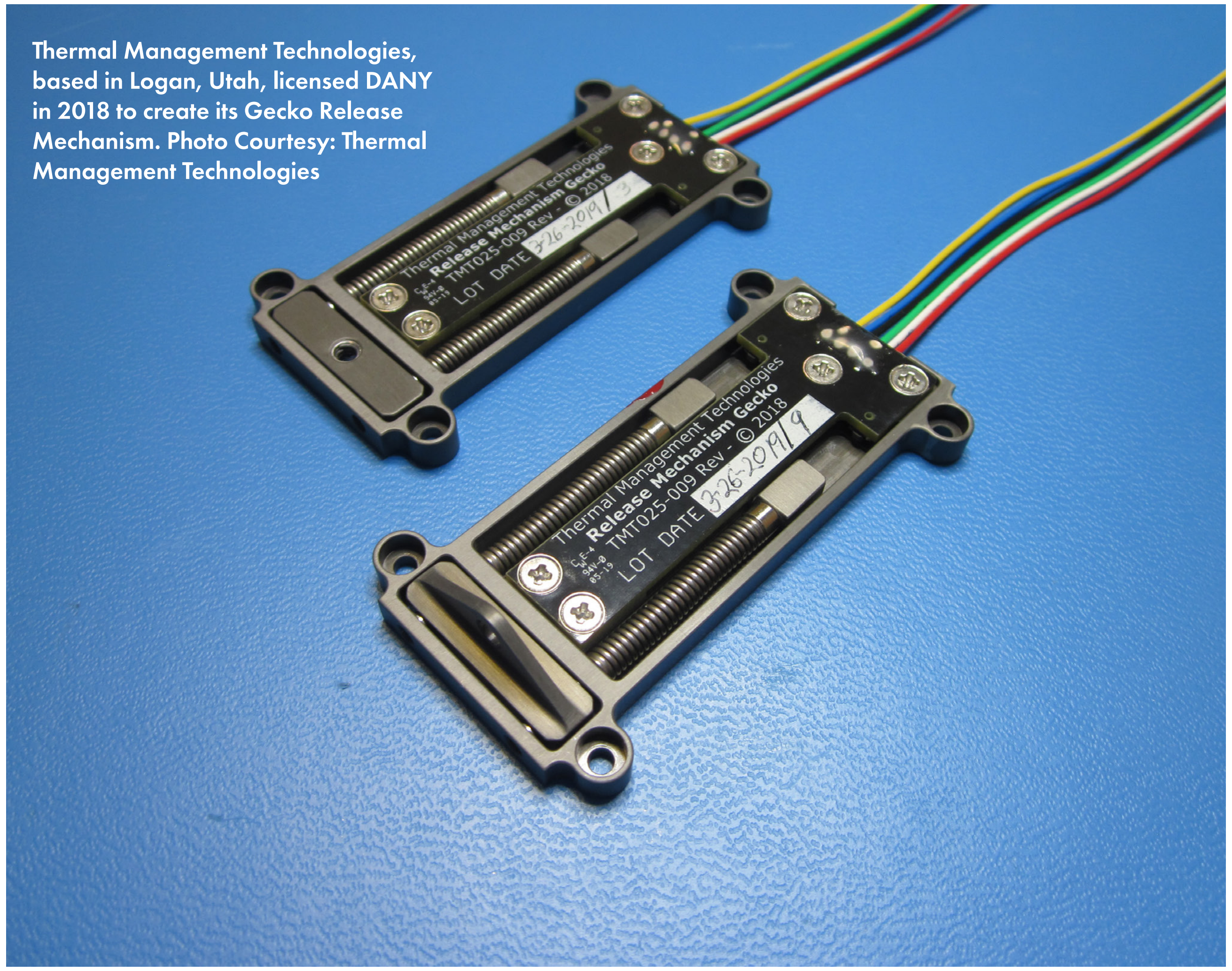
MINIATURE RELEASE MECHANISM OR DIMINUTIVE ASSEMBLY FOR NANOSATELLITE DEPLOYABLES (DANY) GSC-16900-1
NASA's DANY technology uses spring-loaded metal pins, a reliable burn-through mechanism, efficient bracketing, and a circuit board to reliably stow and release deployables on command. Using DANY, stowed deployables are securely fastened using the spring-loaded locking pins.
Patent Number: 9,546,008

MINIATURIZED ASTROMETRIC ALIGNMENT SENSOR GSC-17963-1
The technology advances satellite capabilities for astrophysical measurements, which are necessary for formation flying, relative navigation, and virtual telescope capabilities. The Miniaturized Astrometric Alignment Sensor makes it possible to measure a spacecraft's altitude and orientation with respect to known stellar objects.
Patent Number: 10,657,371

MODULAR ARCHITECTURE FOR A RESILIENT EXTENSIBLE SMALLSAT (MARES) COMMAND AND DATA HANDLING (C&DH) HARDWARE GSC-18435-1
The MARES C&DH hardware evolves a number of previous design concepts that involve the development of a C&DH design within less than a 1U CubeSat form factor using a combination of robust, radiation-tolerant components and COTS components.
Patent Pending

NOVEL ANTENNA CONCEPT FOR CUBESAT PLATFORMS GSC-17864-1
By integrating the antenna into the structure of a CubeSat, the need for extruding antennas, packaging considerations, and a deployment mechanism are eliminated. The resulting antenna has reduced weight and volume, as well as increased dependability.
Patent Number: 10,361,472

OCCULTER FOR CUBESAT CORONAGRAPH GSC-17246-1
This technology is designed to minimize noise from the coronagraph that can interfere with data collection and analysis. It has applications in solar research and photography where the goal is to image a dim object near a bright one.
Patent Number: 9,921,099



Thermal Management Technologies, based in Logan, Utah, licensed DANY in 2018 to create its Gecko Release Mechanism. Photo Courtesy: Thermal Management Technologies

A PROTOTYPE MINIATURIZED MULTI-FREQUENCY GPS RECEIVER
GSC-18426-1
This GPS receiver design is extensible to support processing of Global Navigation Satellite Systems (GNSS) signals. It is based on a commercial Field Programmable Gate Array (FPGA) development board and a custom ASIC-based GPS/GNSS radio frequency down-conversion and digitizing card.
Patent Pending

RADIATION HARDENED 10BASE-T ETHERNET PHYSICAL INTERFACE GSC-16902-1
This Ethernet solution combines a custom circuit and a front-end field programmable gate array (FPGA) design to implement an Ethernet Physical Interface (PHY) in compliance with IEEE 802.3. The custom circuit uses available radiation-hardened parts and handles the electrical interface between standard differential Ethernet signals and the digital signal levels in the FPGA.
Patent Number: 9,680,527

THE ROLE OF SMALLSATS IN SCIENTIFIC EXPLORATION AND COMMERCIALIZATION OF SPACE GSC-18311-1
A highlight of investments made by NASA to date, specifically a study in developing and prototyping a SmallSat platform with standard interfaces, along with several example mission concept scenarios in Earth and space science applications.
Patent Number: 10,604,280

SATELLITE LASER COMMUNICATION NETWORK WAVELENGTH PLAN IMPLEMENTED WITH MULTI-CHROIC FILTERS GSC-18235-1
This innovation implements satellite laser communication networks by supporting both relay satellites and user satellites.
Patent Pending

SELF-REGULATING CURRENT CIRCUIT GSC-18108-1
This technology utilizes a switching regulator to provide high-efficiency power conversion. The Self-Regulating Current Circuit simplifies the deployment of a circuit as circuit resistance associated with wire and interfaces are negated due to the self-regulating circuit. The entire circuit can be miniaturized and can still provide relatively high constant current needed for nickel chrome based deployment devices.
Patent Pending

SILICON OXIDE COATED ALUMINIZED POLYIMIDE FILM RADIATOR COATING GSC-18217-1
This technology uses all the exposed surfaces on the six sides of a CubeSat as radiators. All the internal components are thermally coupled to the radiators. The technology lowers power demand and eliminates the need for voluminous heat regulation.
Patent Pending

SMALLSAT ATTITUDE CONTROL AND ENERGY STORAGE GSC-17252-1
By replacing reaction wheel ensembles with reaction spheres, this technology reduces the overall size and net power consumption of conventional three-axis attitude control systems.
Patent Number: 10,053,242

SMALLSAT COMMON ELECTRONICS BOARD (SCEB) COMPLEMENT BOARD DESIGN: MEMORY CARD GSC-17902-1
The innovation is a miniaturized memory board that has up to 96 GB of NAND Flash memory along with either a radiation tolerant FPGA or a set of three commercial FPGAs. The memory board is designed to interface with the standard subsystems of Goddard's Modular SmallSat Architecture (GMSA).
Patent Pending

TOOL FOR CUBESAT/SMALLSAT DESIGN SEMICONDUCTOR PART SELECTION WITH REGARD TO RADIATION EFFECTS GSC-17197-1
Small spacecraft built with commercial-off-the-shelf (COTS) components carry a high risk in terms of radiation and reliability. A tool that provides tailorable guidelines for part selection based on mission architecture and existing data helps to increase the life of the spacecraft.
Patent Pending

A TWO-WAY MICROWAVE POWER DIVIDER USING MICROSTRIP TRANSMISSION LINES GSC-17888-1
The power divider has matched impedances via Klopfenstein tapered transmission lines to provide ultra-bandwidth functionality with low losses and a small physical footprint.
Patent Number: 10,370,127

ULTRA COMPACT STAR SCANNER GSC-17887-1
This innovative approach fuses the rapid advancements in miniaturized high-speed electronics with the ultra-compact freeform optical design from NASA efforts to create the next generation of stellar scanner instruments.
Patent Pending

WALLOPS FLIGHT FACILITY 6U ADVANCED CUBESAT EJECTOR (ACE) GSC-16795-1
The ejector system interfaces to the launch vehicle and functions to protect the primary payload from the nanosatellite, constrain the nanosatellite during launch, and perform a guided ejection afterwards.
Patent Number: 9,434,486

SOFTWARE

THE CORE FLIGHT SYSTEM (CFS)
The cFS is a flight software framework with a layered architecture that builds on best practices from previous missions and works in tandem with mission-specific applications.

THE NASA OPERATIONAL SIMULATOR FOR SMALL SATELLITES (NOS^3)
NOS^3 is a suite of tools that caters specifically to small satellite missions and helps shorten development timelines.

CONFERENCE HIGHLIGHTS

AUGUST 9TH

10 - 11AM MT — NASA INTERNSHIPS
SHAWNTA BALL
NASA internships provide opportunities for students to contribute to short term work on specific NASA projects.

11 - 12PM MT — SMALLSATS @ GODDARD: TODAY, TOMORROW, AND BEYOND
DAVE WILCOX
NASA's Dave Wilcox shares the latest SmallSat missions and activities taking place at Goddard.

1 - 2PM MT — ADVANTAGES OF TEAMING WITH NASA'S GODDARD SPACE FLIGHT CENTER ON SMALL SATELLITE PROJECTS
SCOTT SCHAIRE
Goddard offers unsurpassed science collaboration, comprehensive integration and test facilities, experienced engineering, mission planning tailored for small satellites, and more.

AUGUST 10TH

10 - 11AM MT — NASA PARTNERSHIPS
DIANE FRAZIER
Learn more about the advantages of partnering with NASA from the NASA Partnerships Office.

1 - 2PM MT — CUBESAT CORE TEAM: 5 CUBESATS, SINGLE TEAM, CHALLENGES AND LESSONS LEARNED
JOHN VALLIANT
This presentation will describe five Goddard CubeSat missions, currently in I&T and design phases, the challenges of balancing a core support team across the portfolio, and how the design and build phases were managed before and during the COVID-19 pandemic.

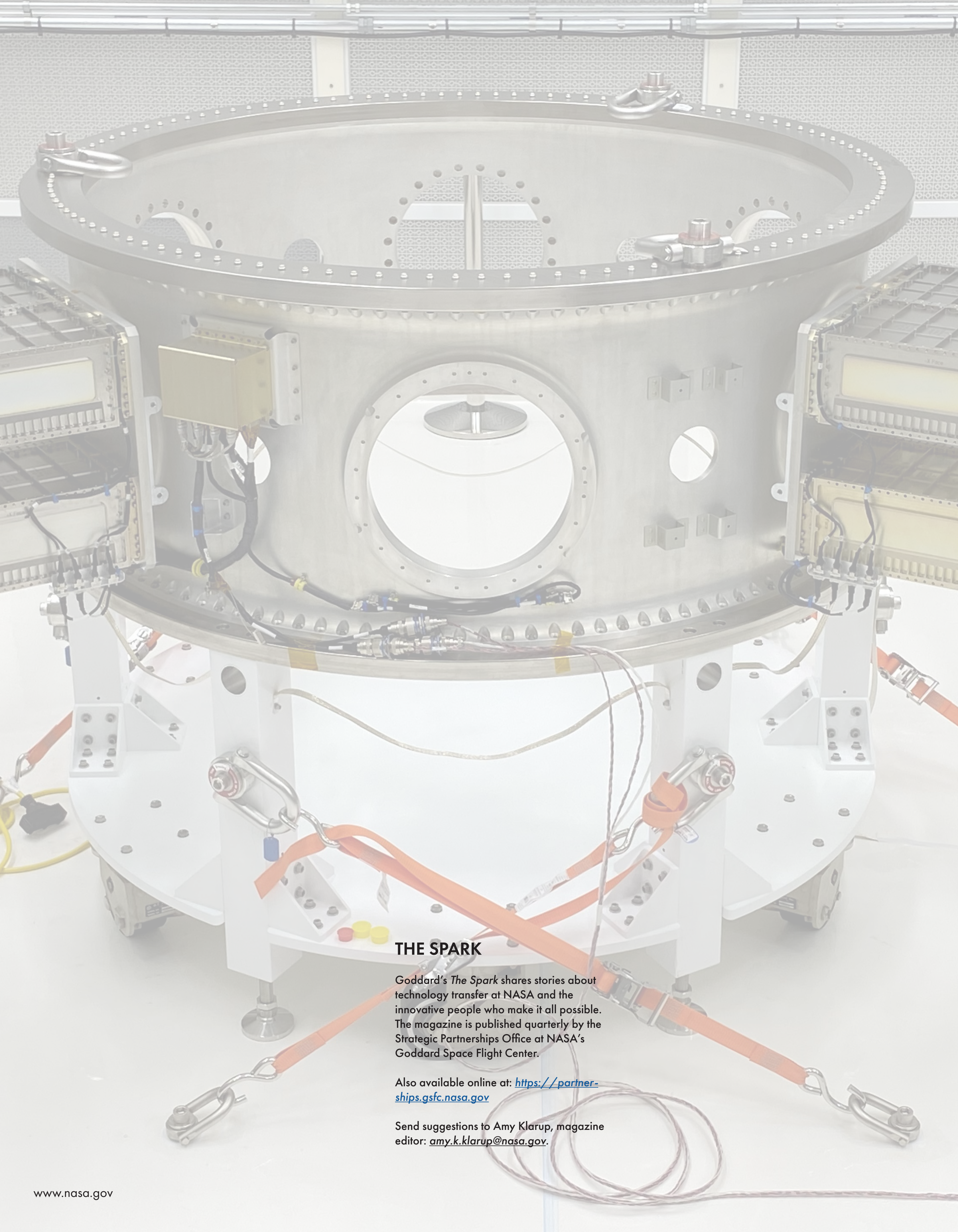
2 - 3PM MT — NASA GODDARD OFFICE HOURS
Do you have questions related to Goddard SmallSat projects, missions, or capabilities? Have your questions answered by Goddard SmallSat subject matter experts during live office hours.

AUGUST 11TH

10 - 11AM MT — NASA GODDARD WALLOPS FLIGHT FACILITY STUDENT FLIGHT OPPORTUNITIES
JOYCE WINTERTON
Learn how Goddard Suborbital Platforms are used for student research and launches, including RockOn, RockSat-C, RockSat-S, HASP, and USIP, and how these experiences build the skills and knowledge needed for CubeSats and small satellites.

1 - 2PM MT — NAVIGATING SMA AND ELECTRONIC PARTS IN NASA SMALLSAT SCIENCE MISSIONS
JESSE LEITNER
This presentation will describe the details within the NASA Science Mission Directorate's (SMD) new Class D Mission Assurance Requirements document, which will soon be used to characterize the Safety and Mission Assurance expectations for upcoming SMD Announcements of Opportunity covering most NASA SmallSat science missions.

2 - 3PM MT — NASA GODDARD OFFICE HOURS
Do you have questions related to Goddard SmallSat projects, missions, or capabilities? Have your questions answered by Goddard SmallSat subject matter experts during live office hours.



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

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