National Aeronautics and Space Administration

THE SPARK

TECH TRANSFER, PARTNERSHIPS, AND SBIR/STTR AT GODDARD

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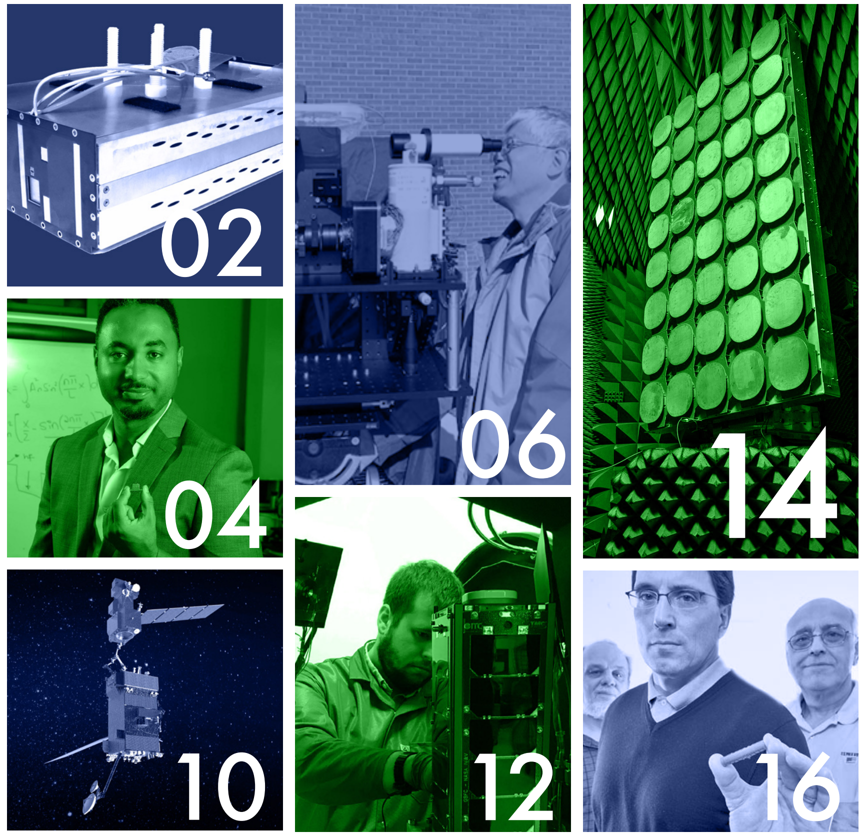

ABOUT THE COVER

The Goddard Space Flight Center was named in honor of Dr. Robert Goddard, a pioneer in rocket development. Dr. Goddard received patents for a multi-stage rocket and liquid propellants in 1914 and published a paper describing how to reach extreme altitudes six years later.

Photo Credit: NASA / GSFC

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OFFICE OF THE CHIEF

In FY22, the Strategic Partnership Office (SPO) received 188 New Technology Reports (NTRs), producing 25 patents, and four license agreements. These numbers aren't just a measure of work productivity; they reflect promising new technologies, ideas, and software solutions to address NASA's mission-critical needs.

Technology development is also critical and much appreciated by private industry. In accordance with the National Aeronautics Space Act of 1959, NASA is charged with providing, "the widest practicable and appropriate dissemination of information," concerning NASA activities. This translates to Goddard innovators helping private industry gain a better understand of NASA's technologies and capabilities.

The dissemination process starts right here. SPO receives hundreds of NTRs each fiscal year. We read and review each one to assess a technology's merits and commercial potential. This issue of *The Spark* magazine focuses on just a few of the recent technologies and software that has been developed in Goddard laboratories to support current and future NASA missions. Without this technology development, exploration of the unknown and the ability to reach new heights of discovery simply wouldn't be possible.

In this issue, you will read about how Manohar Deshpande overcame the problem of dipole antennas jamming on CubeSats when deployed in space. There is also a feature detailing how John Lucas and his team developed the NASA Operational Simulation for Small Satellites (NOS^3). The NOS^3 is a suite of software tools that allows a SmallSat developer to verify and validate all the test flight and ground flight software and component hardware in a spacecraft even before it is built.

You will learn about Goddard's On-orbit Servicing, Assembly, and Manufacturing 1 (OSAM-1) project, a robotic spacecraft equipped with the tools, technologies, and techniques needed to fix and refuel satellites in space autonomously. In the pages that follow, you will find out how Emily Strube developed the Rendezvous and Proximity Operations system, which uses sensors, cameras, software, and guidance controls to maneuver OSAM-1 to within two meters of a satellite.

You will read about the Spaceborne Synthetic Aperture Radar, and the electro hydrodynamic (EHD) modular cartridge pump. You will find out also how Goddard inventors will help astronauts not only land on the Moon but also be able to find water once they are there.

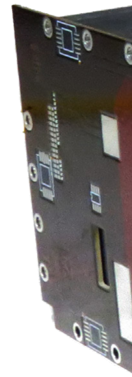
All these articles shine a light on tech transfer and technology development here at Goddard. Many of the technologies you will read about already hold patents and are available for commercial license. After reading this issue, I think you will agree these inventions are well positioned to benefit present and future NASA missions, as well as the needs of the commercial space sector.

Darryl Mitchell

Darryl R. Mitchell, Chief

Strategic Partnerships Office
NASA's Goddard Space Flight Center

Antenna for CubeSat Platforms



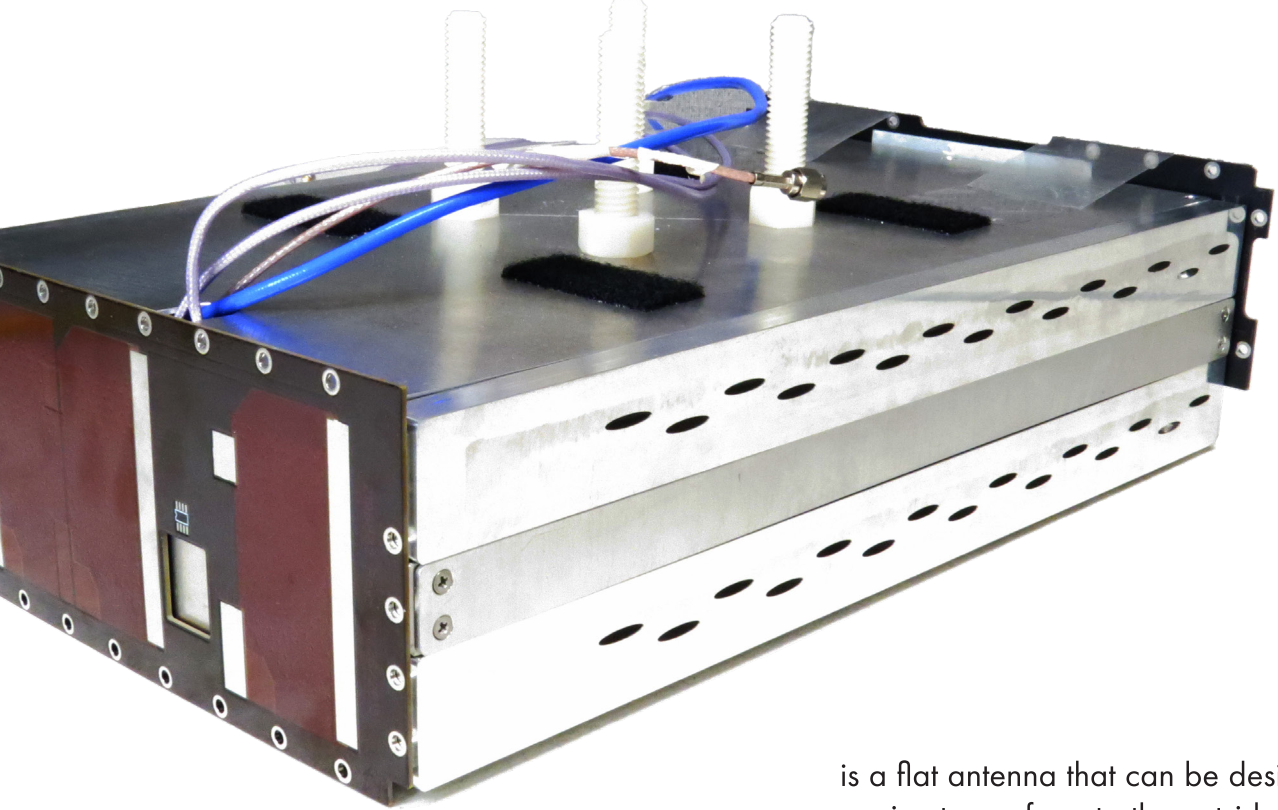
Manohar Deshpande

Manohar Deshpande, Photo Credit: GSFC

In 2011, the spring-loaded deployment mechanism on the Intelsat 28 (formally New Dawn) satellite antenna got caught in the billows of its sun shield and failed to deploy or unfold. That deprived the communications satellite of half of its intended functionality and limited the spacecraft's operational lifespan. When something like this occurs, typically NASA or private industry cannot send a repairman up to fix it.

After a satellite payload is launched into space and enters orbit, its antennas, tucked away during takeoff, need to deploy to be able to fully operate, receive commands, and communicate data back to Earth. As a result, NASA depends upon reliable methods for deploying satellite antennas to reduce the likelihood of mission failure.

"Antenna deployment has been an issue on CubeSats in general," said Luis Santos Soto, chief engineer at NASA Goddard's Small Satellite Project Office. "Antennas actually have a hinge with a spring pushing things in, that could potentially jam during deployment. With CubeSats, most of the time the main issue is with the reliability of the release mechanism. In terms of deploying an antenna, pretty much every single time you have a moving part on a CubeSat or a satellite, something can go wrong."



Manohar Deshpande, an aerospace science and technology engineer at Goddard has developed a patented solution, called Antenna for CubeSat Platforms. The technology uses a simple, lightweight, hollow, rectangular tubed rod with a series of circular or rectangular openings or slots acting as a radio frequency (RF) antenna. Deshpande has been able to use these hollow rectangular tubed rods as a microwave transmission line capable of carrying RF signals, thus creating an antenna capable of receiving and sending data from a CubeSat. The advantage? These antenna rods have no moving parts, and don't have to deploy; they are just secured to various sides outside of the CubeSat.

"As soon as the CubeSat is in orbit, the antenna is ready for use," said Deshpande of the technology, which was funded by NASA Headquarters. "This eliminates the risk of mechanical failure during deployment."

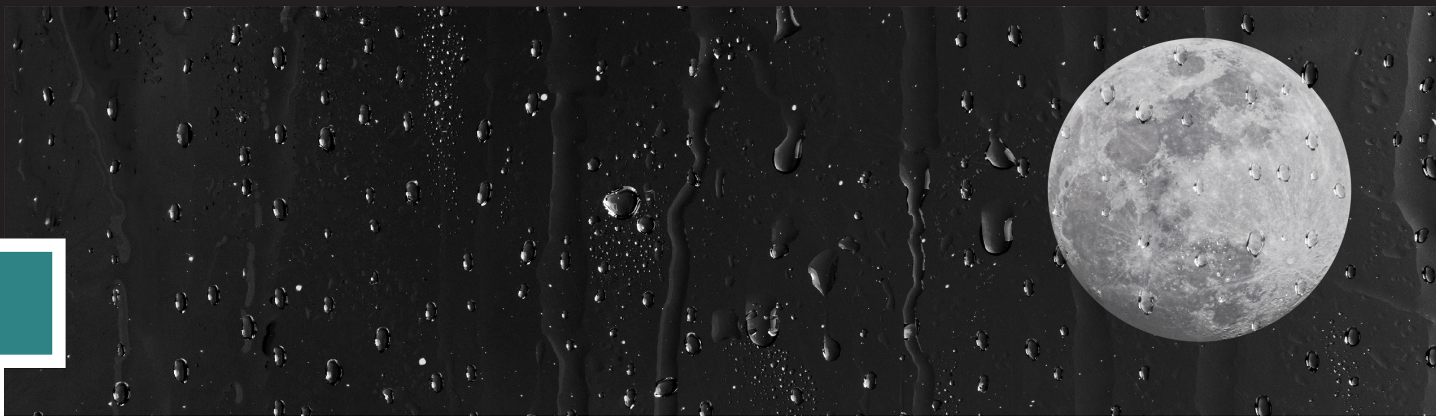
Most satellites use what are known as dipole antennas, which have various antenna wire rods that stick out to send and receive communications. Deshpande's Antenna for CubeSat Platforms in contrast, is a flat antenna that can be designed in any shape or size to conform to the outside of the satellite. The antenna is also lightweight, which is important to launch and get off the ground. It's also inexpensive to produce.

Deshpande said he began working on Antenna for CubeSat Platforms during the time he was assigned to work on the antennas for NASA's Dellingr CubeSat. He recalled, "They asked, if the antenna fails to deploy, how much signal will it lose? That gave me the thought, why risk the antenna anymore by deploying it and why not use the antenna as part of the CubeSat?"

A prototype of the Antenna for CubeSat Platforms was built and has been fully tested at Goddard's Microwave Sensors Lab. Presently, Deshpande is hoping to get additional NASA funding to test it on a future space mission. In the meantime, as a licensed and patented technology, several private companies have expressed interest in the antenna.

"As far as performance is concerned, [the Antenna for CubeSat Platforms] is almost equal in performance and capability as the dipole antenna," said Deshpande. "As far as the function of the antenna is concerned, they are the same."

Water on the Moon



For centuries, astronomers have debated whether water exists on the Moon. As far back as 1645, Dutch astronomer Michael van Langren published the first-known map of the Moon referring to the dark spots as "maria," the Latin word for seas. This put in writing the beginning of a widely held view that there were oceans on the lunar surface. Today astronomers know that these dark spots are not oceans but the remains of volcanic eruptions.

In 2020, NASA's Stratospheric Observatory for Infrared Astronomy (SOFIA) confirmed, for the first time, that water could exist on the sunlit surface of the Moon. This discovery indicates that water may be distributed across the lunar surface, not just in the colder, shadowed places on the dark side. SOFIA is a modified Boeing 747SP aircraft that is used by NASA as an infrared observatory to explore the birth of new stars, planetary nebulas, and supernova remnants, the atmospheres of objects in the solar system, and most recently, the existence of water on the Moon.

Previous observations of the Moon's surface detected some form of hydration, but were unable to distinguish between water and its close chemical relative, hydroxyl (OH). SOFIA detected water molecules (H_2O) in the Clavius Crater, one of the largest craters visible from Earth, located in the Moon's southern hemisphere. Data from this location indicated amounts of water – roughly equivalent to a 12-ounce bottle of water – are trapped in a cubic meter of soil spread across the lunar surface.

"We had indications that H_2O – the familiar water we know – might be present on the sunlit side of the Moon," said Paul Hertz, director of the Astrophysics Division in NASA's Science Mission Directorate. "Now we know it is there. This discovery challenges our understanding of the lunar surface and raises intriguing questions about resources relevant for deep space exploration."

The discovery and presence of large quantities of water on the Moon could prove to be a significant factor in the human habitation phase of NASA's Artemis mission to build a permanent base on the Moon as a stepping-stone to deeper human exploration of Mars and the solar system. The presence of large quantities of water in either liquid, ice, or vapor form in the Moon subsurface would help to offset the prohibitively expensive cost of transporting drinking water to sustain human life and propagate plants.

However, large amounts of water cannot be found on the Moon's surface. You have to look for and find it in the subsurface. Presently, most existing broadband spectrometer technologies cannot distinguish H_2O from OH. The question remains: without extensive and costly excavation to dig into the lunar surface, how can NASA find this water on the Moon? How do we know where to dig?

Dr. Berhanu Bulcha, a research engineer at Goddard, believes he and his team have the answer. Initially funded by Goddard's Internal Research and Development (IRAD) Program, in collaboration with Longwave Photonics through NASA's Small Business Innovation Research (SBIR) program, Bulcha and his team are developing the Terahertz Heterodyne Spectrometer for In Situ Resource Utilization (THSiRU). THSiRU – a scientific instrument used to separate and measure spectral or hidden components of a physical object – will detect the presence of H_2O, OH, and/or HDO (semi heavy water) trapped under the lunar surface of the Moon.

"Molecules like water have their own signature, which provides a unique way of identifying composition and that is what we are doing [with THSiRU], looking for those water signatures," explained Bulcha. "[THSiRU] relies on a heterodyning technique, where a high-powered terahertz [THz] laser source is used to convert the frequency spectrum of the signature and digitizing for reading."

Simply finding water on the Moon is just the first objective. You next need to make sure the water is non-toxic or drinkable. Bulcha said, "Our instrument can be modified easily to allow us to use this same technique to identify the drinkability of the water or tell if the water is contaminated and contains some bad chemicals."

Bulcha and his team are developing the THSiRU as a small, lightweight, energy efficient, hand-held device – the size of a loaf of bread – which astronauts can take with them as they explore and conduct science missions on the surface of the Moon. To use THSiRU, they simply point it toward an area on the surface of the Moon. The device then captures data that can be automatically transmitted to scientists, who then analyze the information to discover the existence of water – either vapor, liquid, or ice – in the subsurface.

"Our goal is when the astronauts go to the Moon, they will take this instrument with them," said Bulcha. "We're doing testing on the prototype in the lab right now, which is leading us to a Technology Readiness Level 5 and 6 [component validation in a relevant environment and prototype demonstration] in the near future. I am optimistic this will be finished and ready for astronauts landing on the Moon in two years."

As NASA plans to return to the Moon, an essential part of the Artemis mission, senior leadership has outlined – through the Moon to Mars mission – how highly critical it is for the agency to develop and demonstrate technologies and operations to live and work on other planetary surfaces for extended periods. Having access to water is essential for meeting this goal.

"Water is a valuable resource, for both scientific purposes and for use by our explorers," said Jacob Bleacher, chief exploration scientist for NASA's Human Exploration and Operations Mission Directorate. "If we can use resources on the Moon, then we can carry less water and more equipment to help enable new scientific discoveries."

Dr. Berhanu Bulcha shows off his terahertz laser technology in his lab at Goddard, Photo Credits: NASA/Michael Giunto

Lunar Landing

Jeffrey Chen -1550nm CASALS lidar rooftop demonstration, Photo Credit: NASA

When Apollo 11 touched down on the Moon on July 20, 1969, it was one of the biggest milestones in human history. Today, we take it for granted that a lunar landing on the Moon is possible. But at the time, nobody had ever done anything even remotely like it. NASA's recent announcement of a return to the Moon brings into focus a pertinent question: How does NASA successfully land a lunar module safely on the Moon?

Children's fairy tales tell us the Moon is made of green cheese, but actually the surface is covered with dead volcanoes, impact craters, and lava flows. Apollo astronauts who visited the Moon have relayed that the crust is a rocky surface covered with regolith, defined as a region of loose unconsolidated rock and dust that sits atop a layer of bedrock. Astronauts have described it as walking on "fine broken glass," which can be hazardous.

As prescribed by NASA's Moon to Mars strategy, a manned Moon landing with a lunar module will involve a series of five stages. The first stage is the initial entry to the Moon, followed by a powered descent to the Moon surface. Next, the lunar module will maneuver to a pre-determined landing site. In the fourth and final stage, the lunar module will divert to accurately identify the site location before finally completing a precise touchdown on a safe landing location.

To ensure safety, NASA will rely on advanced navigation lidar – or light remote sensing – to carefully guide the spacecraft as it descends to the surface. NASA also will employ high-resolution 3D imaging through advanced swath-mapping lidar technology to provide highly accurate global elevation data of the proposed landing site.

"[Ensuring a safe lunar landing] is very challenging," said Dr. Jan-Peter Muller, professor at University College London, who in 2020 was commissioned by NASA's Jet Propulsion Laboratory to create a 3D model and image of Aristarchus, a crater on the Moon that was originally selected as the landing site of the cancelled Apollo 18 mission. "NASA needs better quality maps, models, and imagery of the Moon surface to minimize the risks and maximize the safety of astronauts."

A team of Goddard engineers and research scientists are working to solve that problem. Dr. Guangning Yang, Dr. Jeffery Chen, Dr. Mark Stephen, and Dr. Hui Li are now developing the Concurrent Artificially-intelligent Spectrometry and Adaptive Lidar System (CASALS). This technology uses multiple wavelengths, advanced lidar, and laser technology to rapidly and ac-

1st row from left to right: Jeffrey Chen, Hui Li, Guangning Yang; 2nd row left to right: Wei Lu and Zoran Kahric, Photo Credit: NASA

curately map a landing site on the Moon or planetary surface the size of 100 meters by 100 meters.

"The new technology [CASALS] will provide more measurements, use less power, is smaller, and more efficient than any of the existing [lidar] technology," said Chen. "But to accomplish this we needed to create a breakthrough technology. Existing lidar technology scans a beam mechanically, but that is unreliable and also too slow. We developed a smart laser system that can scan one single beam very fast over a given area. By fine tuning the laser wavelength and using something called 'optical grating,' we can change the angle of the laser beam to allow us to scan the beam faster and wider over a given area."

Chen said another advantage of CASALS over present lidar scanning technology is that it can both measure and calculate distance as the lunar module is descending, as well as map the desired landing area on the Moon. In addition, CASALS can begin taking mapping measurements of the lunar surface from a distance of two kilometers (or 1.2 miles) from the surface. Present technology can only map the landing site from about one half kilometer away.

"The key to the CASALS technology is to make it super-efficient because a satellite has only so much available power," noted Chen. "The Moon landing lidar is power hungry. Our lidar uses only about 80 watts and therefore is more efficient."

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Work to date has focused on maturing the lidar components and demonstrating the performance required for space. The CASALS lidar has already been demonstrated in various rooftop tests at Goddard.

CASALS was supported originally by NASA's Radical Innovative Initiative (RI2) Internal Research and Development (IRAD) program. It is presently supported by an Instrument Incubator Program (IIP-19) and several IRAD projects and has three patent applications with the U.S. Patent and Trademark Office. The technology is presently in a Technology Readiness Level 5 or 6 (component validation and prototype demonstration in a relevant environment). The goal, Chen said, is to have CASALS developed and ready for Artemis III, the first crewed Moon landing targeted for 2025.

"NASA [leadership] is very excited about the CASALS technology, and we have gotten a lot of support from them," said Chen. "To have it ready for the Moon landing, we are working on having an airborne demonstration over the next year."

CASALS was originally designed and received funding from three other NASA projects before being targeted for the Moon landing mission. Engineers first designed CASALS for Earth Science mapping applications such as ICE-Sat-2, NASA's satellite mission for measuring ice sheet elevation and ice thickness. It also was designed to map the lunar surface of the Moon on NASA's Lunar Orbiter Laser Altimeter (LOLA). LOLA's mission was to survey the lunar landscape from an orbiting spacecraft. In addition, it was going to be used for asteroid mapping. Now, the CASALS technology is being extended for Moon landing.

"Up to now, our architecture [for the Moon to Mars mission] has focused on initial human landing capabilities of putting two humans on the surface of the Moon, and eventually expanding that to four, for extensive periods of time," said Cathy Koerner, NASA's deputy associate administrator for the Exploration Systems Development Mission Directorate. "That is going to require us to infuse new technologies [like CASALS] and develop infrastructure that will eventually help us to establish more capabilities on the lunar surface."

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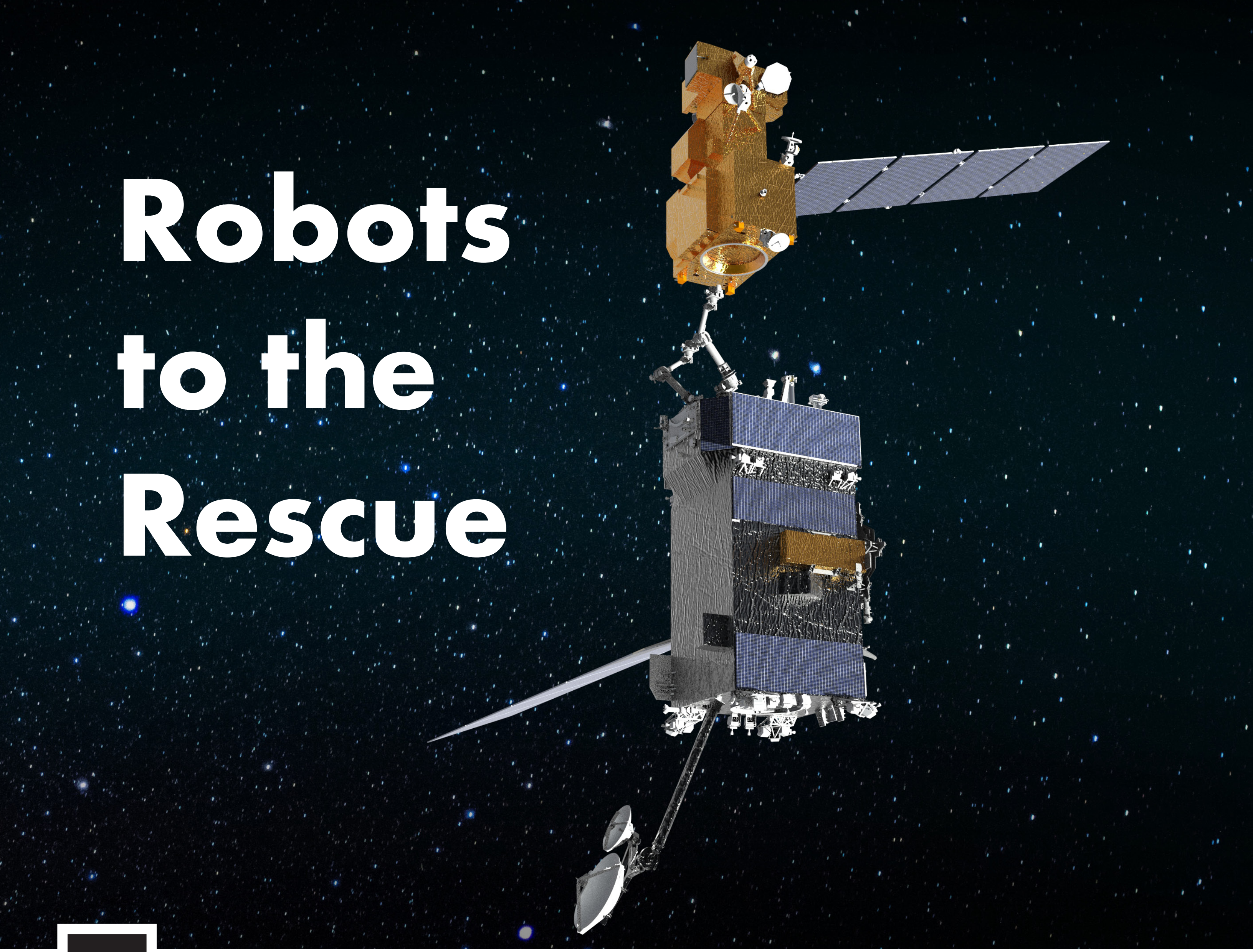
Robots to the Rescue



Artist rendering of OSAM-1 space vehicle (bottom) grappling Landsat 7 (top) during the autonomous rendezvous and docking phase of the servicing mission. Photo Credit: NASA

According to the United Nations Office for Outer Space Affairs, there are currently 8,261 satellites orbiting the Earth. Together they play a critical role in communication, navigation, remote sensing, atmospheric monitoring, universal observations, and other tasks. They were all launched with the understanding that, if anything breaks, there is almost no way of fixing it. In some cases, the satellite just runs out of fuel. When either of those things happen, the satellite can become space junk, adding to the ever-increasing stream of debris encircling the Earth. But there's hope that robots can help to stem this flow.

So far, most repairs and construction that have been made to satellites in space have relied exclusively on astronauts. That was the case with the fixes on the Hubble Space Telescope and the construction of the International Space Station. But sending people into space each time a satellite breaks down or runs out of gas is extremely expensive and impractical; that's why there's a push to develop robots that can do the job.

"What we would really like to do," said Dr. Glen Henshaw, head of the robotics and machine learning section of the U.S. Naval Research Laboratory, "is have some way of having a robotic mechanic sent up in space that can fix satellites when they break."

Goddard's On-orbit Servicing, Assembly, and Manufacturing 1 (OSAM-1) project is developing the answer. Much like a service 'tow truck' when a car breaks down, the OSAM-1 space vehicle is a robotic spacecraft equipped with the tools, technologies, and techniques needed to fix a satellite in space. During its mission, the

OSAM-1 servicer will autonomously rendezvous with, grasp, repair, and refuel a satellite in orbit.

"When you buy a car and it gets a flat tire or it runs out of gas, what do you do?" asked OSAM-1 Deputy Project Manager Emily Strube. "You go to the gas station and get more fuel, or you go to the repair shop, and you get your tire fixed. With a satellite, what they usually do is leave it on the side of the road and they go buy another one. So, OSAM-1 moves to the paradigm of trying to fix what is already up there in space."

Strube said some of the critical issues of repairing or refueling a satellite in space are working out how to locate, capture, and then connect with it as needed to service it. With the exception of the International Space Station, Strube defined most satellites and spacecraft as non-cooperative, which she said are satellites that are not naturally designed to communicate and dock with other satellites in orbit.

As SPO's Inventor of the Month in December of 2022, Strube designed the autonomous Rendezvous and Proximity Operations (RPO) system, which uses sensors, cameras, software, and guidance controls to help maneuver OSAM-1 to within two meters of a satellite.

"To fix a spacecraft you have to get here," explained Strube. "So, what RPO is all about is: how to bring two satellites close together. To repair it, you have to be very close together. That is what makes RPO as important to the servicing task as the robots and tools."

Strube said the OSAM-1 RPO sensor suite – which lives on the top of the OSAM-1 space vehicle – and supporting software is unique. To find and dock with a non-cooperative satellite, this RPO system contains visible and infrared cameras and a 3-D scanning lidar. The system also contains 2-D and 3-D natural feature image recognition software applications that compute relative position and orientation between the two vehicles. Then additional guidance, navigation, and control software autonomously pilots the servicing vehicle to the client. This RPO technology is a patented technology that is available for licensing to private industry. The RPO system, which is in varying stages of flight fabrication and testing, will be flown on OSAM-1.

The first test for OSAM-1 and its RPO system is going to be the refueling of Landsat 7. Launched in 1999, the satellite, which has observed everything from melting glaciers in Greenland, to the extent of deforestation in Papua, New Guinea, ran out of fuel in 2017 and is now slowly degrading. In the near future, NASA plans to launch OSAM-1 with its RPO system and refuel Landsat 7 to demonstrate the capability of servicing legacy satellites, which were never designed to be refueled or fixed in space.

"So, in a nutshell, OSAM-1 is the tow truck used to refuel Landsat 7," said Strube. "But it needs a system to know where the satellite is located and then navigate the tow truck to exactly where the disabled spacecraft is. With this [RPO] system, using visible and infrared cameras, and laser ranging, we have all the information to tell us exactly where Landsat 7 is. Then we can move on to the reason that we are there, which is changing the 'flat tire' or refueling the vehicle."

If the refueling of Landsat 7 is successful, Strube believes this could eventually lead to the development of better and cheaper satellites that could be serviced in space. This could even enable a new wave of in-orbit construction, with armies of robots building satellites, space stations, and even Mars-bound spaceships in space.

"What I really love about [OSAM-1 and RPO] is we are not only developing technology for other folks in industry to use, but we also are showing that we can rethink how we use satellites," said Strube. "It is no more one and done; we don't have to throw away a satellite just because it broke; those days are gone. That is kind of the underlying message and RPO is one of the things [at Goddard] we do that makes it happen."

Inventor (far left) giving a tour of the Robotic Operations Center at Goddard where the OSAM-1 project is testing engineering models of the RPO and other systems necessary to perform the planned servicing on Landsat 7. Photo Credit: NASA

Simulation Tool Helps Increase SmallSat Reliability

SmallSats can be very complex systems, harnessing many components within multiple subsystems that must mesh together perfectly for the spacecraft to operate for years. If it breaks down in space, there is no prospect for repair. Considering the cost and time involved in designing and building a SmallSat, every developer must answer a critical question: Will what they've designed on the drawing board – before they have any of the physical hardware components – actually work?

"What you don't want to happen," said Luis Santos Soto, chief engineer of the Small Satellite Project Office at Goddard, "is to put all your components together to complete the SmallSat only to find there is a problem. Although having no issues during I&T [Integration and Testing] is incredibly difficult to achieve, the risk can be considerably reduced from the software standpoint if we have a digital equivalent for the system to enable early software development."

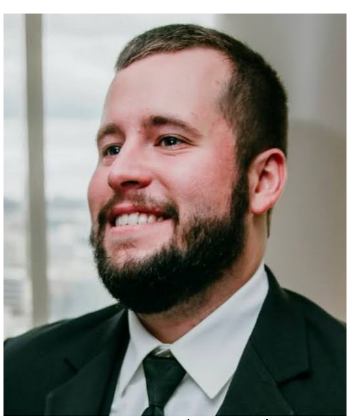


Photo Credit: NASA

John Lucas, deputy lead of the Jon McBride Software Testing and Research (JSTAR) team, mission systems engineer for the [Geostationary Transfer Orbit Satellite] (GTOSat) mission and computer engineer at Goddard's Katherine Johnson IV&V Facility has the answer. He and his JSTAR team have developed the NASA Operational Simulation for Small Satellites (NOS^3), which is a suite of software tools that allows a SmallSat developer to verify and validate all the test flight and ground flight software and component hardware in the spacecraft before it is built and assembled. NOS^3 is a Goddard technology that holds several patents and is available commercially for licensure.

"What NOS^3 allows you to have is a spacecraft in your laptop," said Lucas. "Instead of having the full physical SmallSat or without having to actually build an entire spacecraft, you can run and simulate your entire spacecraft, including orbital dynamics, ground and flight software as it fits in space, just on any old laptop that is laying around. NOS^3 is just another tool in your toolbox to really do your design and testing of the spacecraft."

NOS^3 was born seven years ago out of NASA's Simulation to Flight (STF-1) CubeSat mission. Under NASA's CubeSat Launch Initiative, Goddard teamed with West Virginia University to build and launch the STF-1 spacecraft. The main goal of the mission was to fully demonstrate the Operation Simulation technologies in the NOS^3. All the needed software development, mission operations/training, verification and validation, test procedure development, and software check-out systems grew from a background of developing simulations on the James Webb Space Telescope, the Global Precipitation Measurement mission, the Juno spacecraft mission to Jupiter, and the Deep Space Climate Observatory.

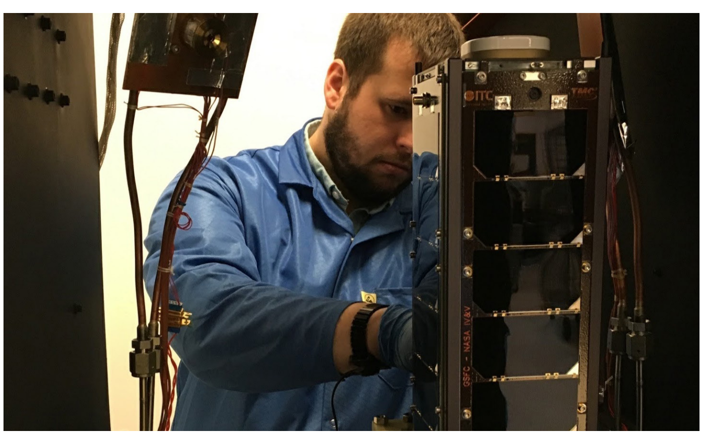
"NOS^3 is really an augmentation for your development flow," said Lucas. "We've built spacecraft before and we've had this kind of technology and simulation capability, but NOS^3 really allows us to expedite the development process. Now, we don't have to [physically] break things to see their response on the spacecraft."

"The other beauty of NOS³ is you can actually have the hardware in the loop as well," added Santos Soto. "You can start with all the software simulation and everything that can be done on your laptop. But eventually, when you get all of your components, you can potentially plug them into the NOS³ system as well. So, you can have a combination of real hardware and simulation software talking to everything on the NOS³."

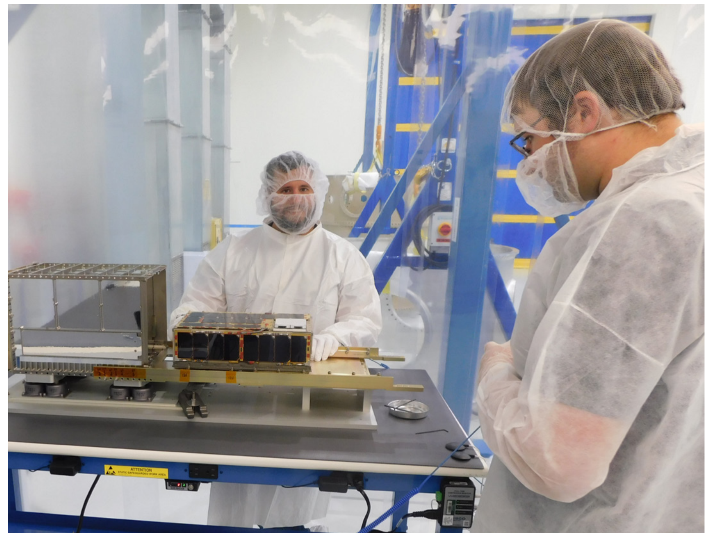
One of the other advantages of NOS³ was during the COVID-19 pandemic, when commercial off-the-shelf parts for satellites were delayed due to production and shipping issues, and developers had to wait months for products. Using NOS³, satellite developers could simulate components until they arrived.

"The really nice thing about NOS³ is it has allowed NASA to continue satellite development during the pandemic," stressed Lucas. "That was extremely critical during COVID because we did not get a single component delivered on time due to the nature of the world. NOS³ allowed us to basically start doing all the coding for both the flight and ground software, as well as run the spacecraft simulation for the developers at all of the NASA centers so they could continue to do SmallSat development and build spacecrafts."

NOS³ also saves time and money. "Now, you don't have to wait until the hardware components show up to start coding," said Santos Soto. "When they arrive, all you have to do is test the developed software with the actual components and there are no unforeseen issues."



John Lucas, Photo Credit: NASA



John Lucas in the lab, Photo Credit: NASA

Flight and Ground Software Components That Interact with NOS³

NOS³ is an open-source software that integrates with a variety of key flight and ground software tools, as well as hardware simulation platforms such as:

- NASA Operational Simulator of Small Satellites (NOS) is the core technology for NOS³ that provides the connectivity between the flight software and the simulated hardware components.
- NASA's Core Flight System (cFS) is a reusable flight software framework that is used as the base system for flight software.
- Simulated hardware components serve as a virtual hardware model that connect to the NOS engine and provide the hardware input and output to the flight software.
- Oracle VirtualBox and Vagrant allows a computer to set up the virtual machinery necessary to run the applications associated with the NOS³ suite.
- COSMOS (Open Source Managed Operating System) is a ground system software used to provide command and control of the flight software.
- OIPP (Orbit Inview and Power Prediction) is a planning tool developed by members of the NASA IV&V team that allows the ground station to know when the satellite will be in view, as well as when the satellite will be in direct sunlight. This allows the IV&V team to plan power usage and communication times.
- 42 is a NASA developed visualization and simulation tool used for spacecraft attitude and orbital dynamics. 42 provides magnetic field and positional data inputs to the magnetometer and GPS simulators.

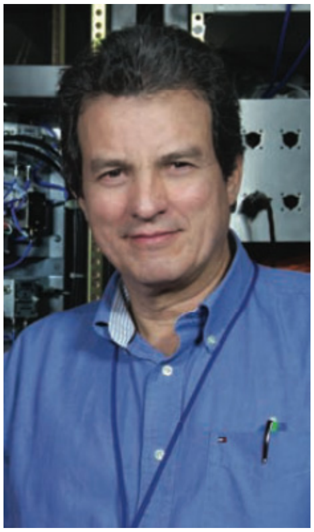
Discovering What Lurks Beneath the Surface

NASA is one step closer to discovering what lies up to 32 feet – or roughly the length of a three-story building – beneath the surface of the Moon, Mars, or other bodies in the solar system. Presently, NASA instruments and conventional radar systems can probe one or two feet beneath the surface of a planet but can't detect what lies deeper.

Working together, Goddard Earth and Planetary scientists, and a team of Goddard engineers and scientists have developed and fully tested a new type of Spaceborne Synthetic Aperture Radar (SAR) System. This new SAR is capable of taking high resolution images and measurement readings of things, such as ice deposits, lava flows, caves, natural resources, and fluvial or river channels, that lie buried below the surface of not only other planets and the Moon, but regions right here on Earth. Mapping and chronicling these otherwise hidden features could potentially help NASA scientists locate regions hospitable to life and potential sources of water on other planets.

Overcoming the limitations of a conventional SAR system, this Spaceborne SAR architecture can achieve a vast number of planetary and Earth survey goals. These include the measurement of ecosystem structure, surface and subsurface topography, subsurface stratigraphy or rock layers, soil compaction and freeze-thaw cycles, ice sheet composition, glacier depth, and surface water, among many others. The technology holds three patents, one for the spaceborne digital beamforming SAR instrument concept, another for a digital beamforming single-pass interferometry technique, and a third for the power reduction of the radar instrument using a Frequency Division Multiplexing hardware and technique.

"This is the future of radar," said Rafael Rincon, the project's lead electrical engineer. "Conventional SAR has been proven and flown and it works really well. This Spaceborne SAR is the next generation of radar and it has a lot more user flexibility. So, this gives us the opportunity to tailor the radar to mission needs, not to tailor the mission to what the radar can do anymore."



Rafael Rincon, Photo Credit: NASA

Conventional SAR is a form of radar that uses the motion of a radar antenna over a given area to create either two or three-dimensional images of the surface. Mounted on an aircraft or spacecraft, SAR uses successive radio waves over a targeted area, and the echo of each pulse is received and recorded. The pulsed waveforms are transmitted using a single antenna, which directs the energy to a fixed location on the surface. The phase history of the waveforms are then used to create very high spatial resolution images.

By contrast, utilizing advanced and innovative radar techniques not possible with conventional radar instruments, such as software defined waveforms, digital beamforming, and reconfigurable hardware, the Spaceborne SAR provides a much more flexible and capable instrument. Along with Rincon's team, other members of the Spaceborne SAR development team include Goddard bio-research Earth scientists Lola Fatoyinbo, Jon Ranson, and Lynn Carter,

Dr. Jon Ranson (Left), Lola Fatoyinbo (Center) and Lynn Carter (Right), Photo Credit: NASA

previously at Goddard, and now an assistant professor of Planetary Sciences at the University of Arizona in Tempe, Arizona.

"We started out to improve SAR by reducing the size, weight, and power of lower frequency radar," explained Ranson of the technology that this year was named First Runner Up for NASA's prestigious Invention of the Year Award. "And we came up with the concept of a so called 'smart panel' cutting edge design, which is a compact panel that requires less power, is lightweight, and is made of composite materials. This modular multi-panel approach then allows for the customization of the instrument architecture for specific flight missions."

What makes the Spaceborne SAR truly innovative and unique, added Ranson, "is the radar waveforms are software defined or focused as opposed to hardware defined and can be steered [or directed] from the spaceship without any moving parts. This means we can reconfigure and shape the radar beam to put the energy [or imagery] wherever we want. This enables selectable incidence angles, imaging on both sides of the tract, as well as nadir [position directly below]. This also allows for an increase in the measurement swath area without degrading the measurement resolution."

So far, Spaceborne SAR has been focused solely on applications here on Earth. To get a feel for how this technology works for sequence-system mapping on other planets, it was tested by taking measurements and images of forest and wetland locations in the U.S., the Bahamas, and Costa Rica.

"We hope the next journey [iteration] for this technology is to the Moon and Mars, where we are going to try and launch these longer wavelength Spaceborne SAR Systems, which will be known as Spaceborne Exploration Synthetic Aperture Radar (SESAR) Systems for planetary exploration," said Rincon. "On Mars we know we can scrape a little bit of the soil off and see ice, but with SESAR technology we can go several meters into the subsurface and see what is there. Commercially, there are other applications that people may want to use SAR for, whether it is for agriculture, urban studies, or looking at subsurface features. That can all be done with this technology and be reconfigured for different applications as necessary. So, that is the real value, I believe, in this technology."

SAR's "smart panel" in Goddard's anechoic chamber, Photo Credit: GSFC

Goddard's EHD Modular Pump Cools Things Down

Technologists Jeffrey Didion (center),Matt Showalter (left), and Mario Martins (right)
Photo Credit: NASA

Up in space, it's hard to keep your cool, especially if you're a high-powered electronic device. Much of the electronic hardware found in contemporary satellites and spacecraft generate considerable heat. Goddard-developed instruments in satellites and spacecraft normally function properly at a set operating temperature, which can range from room temperature down to cryogenic temperatures.

"Anything that is consuming power in space to do its job—it could be instruments, the propulsion system, or batteries—gets translated into heat," said Luis Santos Soto, chief engineer of Goddard's Small Satellite Project Office. "Those components can get very hot, and all have a certain temperature range to operate. So, if they get too hot, the components will not operate correctly or could even breakdown."

For many years, NASA has been searching for ways to overcome extreme heat to improve the performance and reliability of electronics in its satellites, planetary robots, and manned platforms, including the International Space Station. As with all space hardware, the optimal solution uses little electric power, is lightweight, and has few moving parts, which could create noise and vibrations.

A promising answer to this problem is NASA's electro hydrodynamic (EHD) modular cartridge pump. Designed by Goddard Engineers Jeffrey Didion, Mario Martins, Matthew Showalter, and

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This image shows the Defense Department's experiment pallet, STP-H5, hanging at the end of Canada's robotic arm during installation on the outside of the International Space Station. The EHD pump technology flew on the STP-H5 mission as part of a Goddard bundle of experiments in 2017. Photo Credit: NASA

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> It's a similar system where you are simply pumping a liquid through the system to control the temperature.

Franklin Robinson, the EHD modular cartridge pump uses electric fields to move a dielectric fluid coolant in a thermal loop to dissipate heat generated by electrical components. Aside from being lightweight, the pump consumes very little power to operate and has few key components and no moving parts, which increase its simplicity and robustness.

"The EHD operates no differently than the radiator in your car," explained Jeffrey Didion, senior thermal technologist and manager at Goddard's Mission Support Directorate Nanotechnology Facility. "It's a similar system where you are simply pumping a liquid through the system to control the temperature; the liquid acquires the heat which is then radiated to space at some remote point in the system. So, you go from hot to cold."

Another advantage of the pump is its modular design. That means the various pumping sections that house the high voltage and ground electrodes, along with spacers that act as both an insulator and flow channel for the dielectric fluid, can be easily and simply connected electronically through commercially available pin and jack assemblies.

"So, it is not a mechanical pump that has lifetime issues," said Didion of the EHD technology, which received a U.S. Patent [# 10,461,621]. "It is easily controlled and can be a smart system, or in other words, how much fluid you pump though the EHD will allow you to maintain the temperature that you want to achieve. Or, you can increase its [cooling] capacity by simply sending it greater voltage. And you don't need a big power system to make it run. That is the idea of this pump."

Santos Soto notes that the EHD pump may have SmallSat applications in the future, as the technology continues to develop and advance. Didion adds that the team continues to develop the technology from what he terms a "single-phase system to a two-phase system," and is also working on trying to get the EHD pump to a Technology Readiness Level 6, which is a fully functional prototype or representational model.

"We are moving forward with development," Didion said. "We had an initial breakthrough with the cartridge pump in the single-phase system and that was significant. The two-phase system we are working on has the potential to be even more impactful. There is an experiment scheduled on the International Space Station in a couple of years. At that point, the EHD will be considered ready for infusion into that project."

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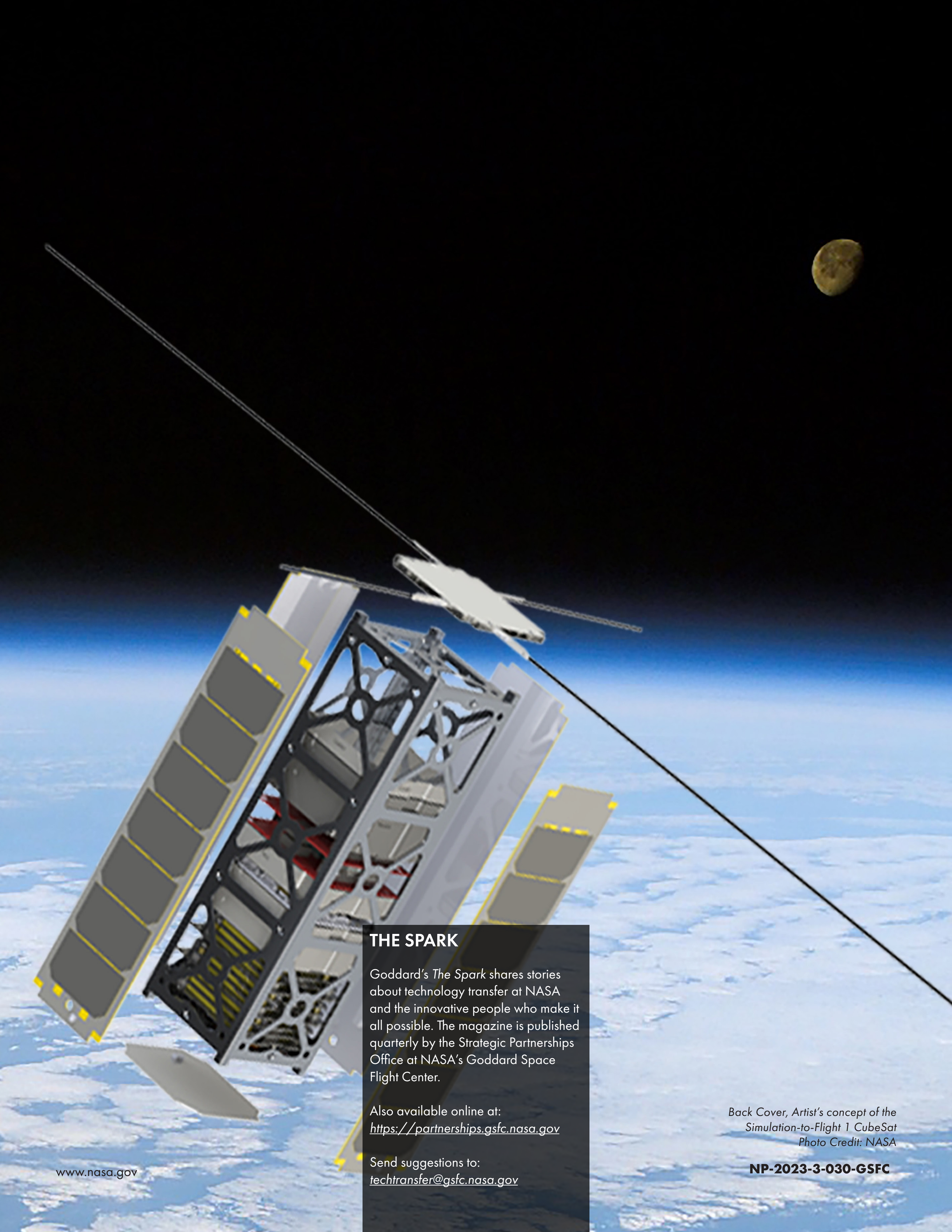

THE SPARK

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Back Cover, Artist's concept of the Simulation-to-Flight 1 CubeSat
Photo Credit: NASA

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