

National Aeronautics and Space Administration



# SPINOFF

# 2024



National Aeronautics and Space Administration  
Technology Transfer Program  
NASA Headquarters  
Washington, DC 20546

[www.nasa.gov](http://www.nasa.gov)

NP-2023-09-3171-HQ



# SPINOFF

## 2024

NASA Technology  
Transfer Program

### On the cover

NASA's Space Launch System (SLS) rocket, capped by the Orion spacecraft, sits on the mobile launcher at Launch Complex 39B at NASA's Kennedy Space Center in Florida prior to the Artemis I mission. Artemis I, which launched in November of 2022, was the first integrated test of the agency's deep space exploration systems: SLS, the Orion spacecraft, and supporting ground systems. It was also the first in a series of increasingly complex missions to the Moon.

Surrounded by wildflowers, NASA's SLS rocket – carried atop the Crawler-Transporter 2 – arrives at Launch Pad 39B at the agency's Kennedy Space Center in Florida.

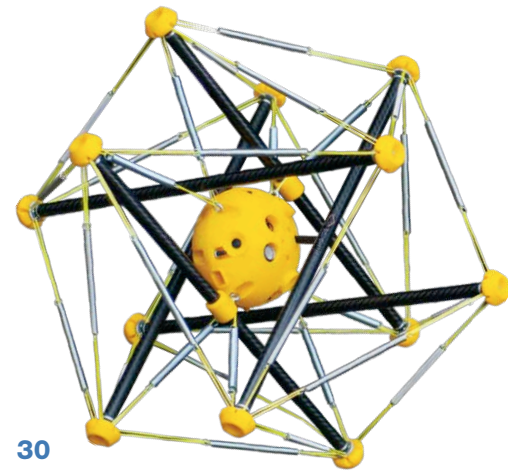
DISCLAIMER: While NASA does not manufacture, market, or sell commercial products, many commercial products are derived from NASA technology. Many NASA-originated technologies are adapted by private industry for use by consumers like you. Spinoff developments highlighted in this publication are based on information provided by individual and private industry users of NASA-originated aerospace technology who acknowledge that such technology contributed wholly or in part to development of the product or process described. NASA cannot accept responsibility or liability for the misinterpretation or misrepresentation of the enclosed information provided by these third-party users. Publication herein does not constitute NASA endorsement of the product or process, nor confirmation of manufacturers' performance claims related to any particular spinoff development.

**NASA Headquarters**  
Daniel Lockney,  
Technology Transfer Program Executive

**Spinoff Staff**  
Ann Harkey, Communications Director  
Mike DiCicco, Managing Editor  
Andrew Wagner, Science Writer  
Margo Pierce, Science Writer  
Jennie Mitchell, Graphic Designer  
Rebecca Carroll, Contributing Writer



# Contents

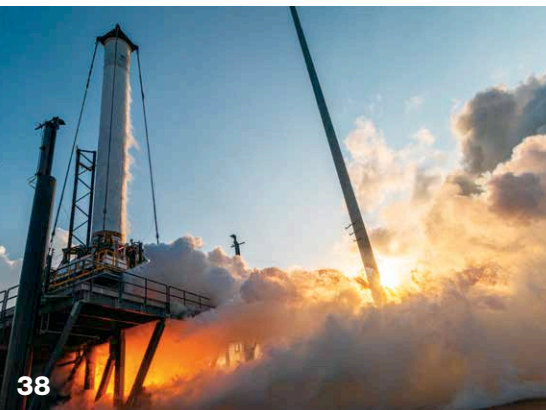


30

- 1 Introduction**
- 3 Spinoff Capsules**
- 29 Spinoff Features**
- 30 Spherical Robots to the Rescue**  
Scouting robots designed for space warn first responders of gas leaks, other dangers
- 33 Satellites 'See' Sea Turtles, Ocean Threats**  
A tracking system in low-Earth orbit locates turtles, boats, birds, oil slicks, and more
- 36 Redefining the 'Rugged' Video Camera**  
A new rocket-riding camera is tough enough for Earth
- 38 Additive Manufacturing Subtracts from Rocket Build Time**  
NASA teamwork on 3D printing and testing engines makes company's launch services more affordable
- 44 'Digital Winglets' for Real-Time Flight Paths**  
NASA-developed routing technology leads to fuel savings and smoother flights
- 46 Next-Level Farming**  
NASA data and expertise helps controlled environment agriculture reach new heights
- 50 Taking the Pulse of Earth**  
Applying AI to Earth data reveals sustainability opportunities for farmers, reforestation, land management
- 53 Ultrasonic Inspections Protect Astronauts, Boat Owners**  
Technology for inspecting Orion heat shield now checks integrity of composite materials in boats
- 56 Oil Drillers, Environmentalists Agree on Small, Sensitive Spectrometer**  
Tiny tool to study water quality gets results anywhere
- 59 Concentrating on Microbes**  
Space station germ testing improves wastewater monitoring
- 62 Rocket Manufacturing Meets Science Friction**  
Additive friction stir deposition builds bigger parts with more alloys



33



38

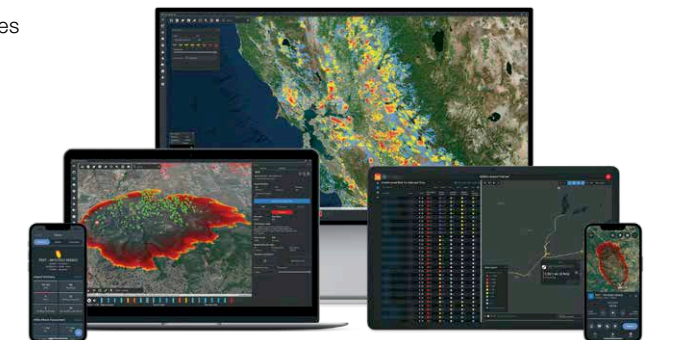
- 66 Cutting the Knee Surgery Cord**  
NASA experts offered early advice on first FDA-cleared wireless arthroscopic camera
- 68 NASA Gives the World a Brake**  
Space agency invention puts a new spin on automotive brake rotors
- 70 Medical-Grade Smartwatch Can Monitor Astronauts, Patients**  
NASA-backed consortium helped develop device for clinical trials, academic research, outpatient monitoring
- 72 Semiconductor Research Leads to Revolution in Dental Care**  
Crystals grown for space electronics lead to profusion of remineralizing toothpastes
- 74 Unfurling Antennas Let Tiny Satellites Do Big Things**  
High-gain antennas for communication and imaging can now ride smaller, cheaper spacecraft
- 76 New Energy Source Powers Subsea Robots Indefinitely**  
Power modules driven by ocean temperatures save money, reduce pollution by living forever
- 80 Where the Wildfires Are**  
Simulation, prediction, and response software helps businesses and communities cope with disaster
- 84 NASA's Moon Shot Launched Commercial Fuel Cell Industry**  
Agency's technology development prepared fuel cells for tomorrow's renewable energy grids
- 86 Webb Telescope Made Simulation Software Better**  
The observatory pushed optical modeling capabilities, driving advances in software used to design medical and augmented reality devices
- 88 Spinoff Technology Across the Nation**
- 91 Technology Transfer Program**
- 92 Technology Transfer Expansion**
- 97 Spinoffs of Tomorrow**



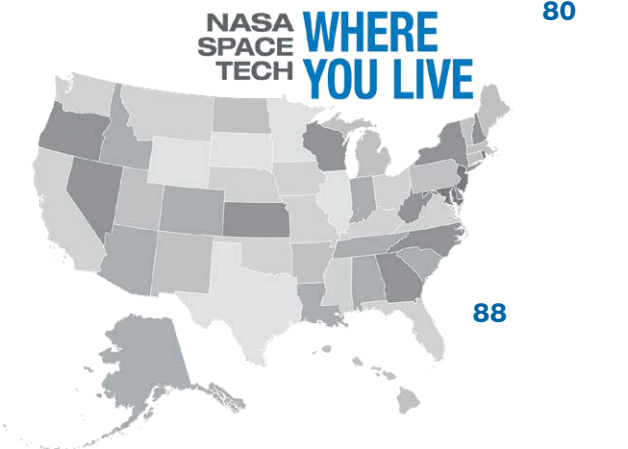
70



76



80



88





## Spinoff (spin'ôf) -noun.

1. A commercialized product or service incorporating NASA technology or expertise that benefits the public. These include products or processes that:

- were designed for NASA use, to NASA specifications, and then commercialized;
- are developed as a result of a NASA-funded agreement or know-how gained during collaboration with NASA;
- are developed through Small Business Innovation Research (SBIR) or Small Business Technology Transfer (STTR) contracts with NASA;

- incorporate NASA technology in their manufacturing process;
- receive significant contributions in design or testing from NASA personnel or facilities;
- are successful entrepreneurial endeavors by former NASA employees whose technical expertise was developed while employed by the agency;
- are commercialized as a result of a NASA patent license or waiver;
- are developed using data or software made available by NASA.

2. NASA's premier annual publication, featuring successfully commercialized NASA technologies.



This high-resolution image, taken on the first day of the Artemis I mission, was captured by a camera on the tip of one of Orion's solar arrays. The spacecraft was 57,000 miles from Earth when the image was captured, as it approached the Moon and distant retrograde orbit.

## Introduction

Welcome to Spinoff 2024!

This latest edition of our annual publication highlights the benefits of NASA's research and development of cutting-edge technologies, from our smallest satellites to the most powerful rocket NASA's ever launched.

As the Orion spacecraft rocketed into space aboard the first full test of the Space Launch System, rugged cameras attached to the rocket withstood the immense heat and raucous vibrations of launch, providing detailed views of booster separation and the spacecraft's full journey into orbit.

While developed initially to help engineers examine the rocket's performance on its voyages, the camera's extreme durability has proven valuable on the ground as well. Before it even launched to space, a commercial version of the camera was helping to see how well airplanes perform on takeoff and monitoring performance of trains (page 36).

In addition, as NASA has been working to monitor climate change, our technologies have been instrumental to mitigating some of its consequences. Data from the Moderate Resolution Imaging Spectroradiometer instruments aboard the Aqua and Terra satellites are helping farmers in rural India check the weather and plan for potential droughts (page 22). Other sources of satellite data keep tabs on Earth's oceans, tracking not only oil slicks left by large vessels but also the migrations of endangered sea turtles back to their nests (page 33).

Here are some more of my favorite spinoffs from this edition:

- In the 1960s, NASA researchers discovered that a method of growing silicon crystals for use in electronics also could produce crystals of the primary mineral in bones and teeth. This technique is now used to produce a type of toothpaste that is popular in Asia and Europe and is now entering the U.S. market (page 72).
- A coating developed in the 1990s for protecting next-generation spaceplanes from the intense temperatures of re-entry by absorbing and radiating heat can now be found in clothing like ski jackets, hunting gear, and sports uniforms, where it helps maintain comfortable temperatures (page 27).
- Robots made using a "tensegrity" design developed with help from NASA can be dropped or rolled into dangerous situations, helping to save lives during wildfires and other disasters (page 30).

NASA is always developing new technologies that could soon find their way into our everyday lives. In the Spinoffs of Tomorrow section, we've identified 20 technologies we think are ready for commercialization and could be featured one day as spinoff success stories (page 97).

At NASA, our discoveries have not only improved our understanding of the cosmos but have led to immeasurable improvements to everyone's life on Earth. It's not merely a side effect but a key part of our mission – one that will continue for decades to come. Ex astris, scientia.



**Dr. Prasun Desai**

Deputy Associate Administrator  
Space Technology Mission Directorate  
NASA Headquarters



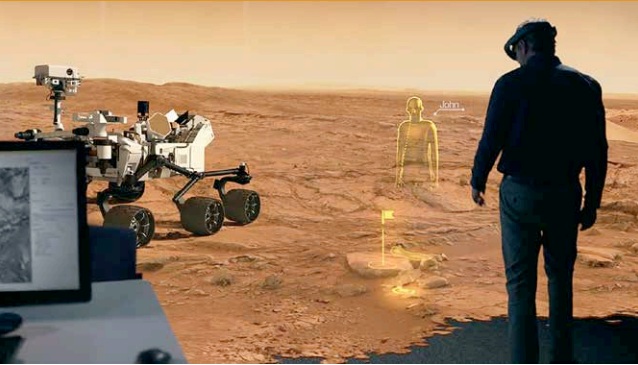
# SPINOFF Capsules

Studying Earth as well as exploring other planets, moons, and asteroids in our solar system presents a wide variety of challenges for NASA scientists and technologists. Many of the solutions they develop and the data generated are used to create resources that improve day-to-day life for everyone. Learn more about these Earth-bound technologies that build on NASA know-how.

NASA's Orion spacecraft for the Artemis I mission is recovered off the coast of Baja California. After launching atop the Space Launch System rocket from the agency's Kennedy Space Center in Florida, Orion spent 25.5 days in space before returning to Earth, completing the Artemis I mission.



# A Virtual World of Data



The Jet Propulsion Laboratory has experimented with virtual and mixed-reality environments as ways to improve data analysis, particularly when it comes to judging the size and distance of geological features as seen from Mars rovers. These experiments were some of the initial tests that inspired the founders of Virtualitics to see how this technology could be used outside JPL. *Credit: NASA*



A researcher examines a data cloud in a virtual world created by Virtualitics software. NASA scientists need to sift through massive amounts of data generated by deep space missions. Efforts at JPL to use virtual reality to assist in this analysis led to the creation of Virtualitics. *Credit: Virtualitics Inc.*



The Virtualitics software also has a desktop mode for analyzing data. Even without a virtual reality headset, the ability to visualize data in 3D space helps scientists get a better grasp on the raw information they receive. *Credit: Virtualitics Inc.*

## NASA developments, experience, and patents lead to a new method of exploring and visualizing data in virtual reality

For almost as long as it's been a concept, NASA has been on the cutting edge of virtual reality (VR) technology. However, the space has seen a renaissance since the bulky headsets of the 1990s. Several high-profile companies now use VR for immersive video games and virtual chat rooms, but to some, this technology has a use beyond entertainment.

NASA's Jet Propulsion Laboratory in Southern California has been trying to improve data visualization for decades. When pictures come back from an alien world, scientists usually survey the environment with a panoramic photo, but this method has limitations. When observing a flat image, judging distances can be difficult.

"Looking at pictures on a screen is a much different experience than walking through a canyon," said Scott Davidoff, manager of the Human Centered Design Group at JPL.

Davidoff began experimenting with VR using image data from the Curiosity rover on Mars. There had been attempts to solve the visual distance issue, like using 3D imagery viewable with red and blue filtered glasses, but nothing made scientists feel like they were really there. Davidoff and his colleagues decided to wrap the panorama around the scientist in a virtual environment. Geologists using VR in this way reported feeling like they were in the real Martian environment. They could ascertain the distance and size of features much more quickly and accurately than they could with a flat display, which sparked another idea. Davidoff thought that if viewing imagery in VR helped, it could be a game changer for more complex "multi-dimensional" data.

"When you look at a network diagram as a system in 3D, it turns out your perception does something different," Davidoff said. "We made a data world where an analyst could look at any science or engineering problem and see patterns and correlations more clearly than they can in a flat version."

At the same time, Ciro Donalek and George Djorgovski at the California Institute of Technology (Caltech) were researching how to use immersive environments for scientific data visualization and collaboration.

The three of them teamed up to create software that uses 3D visualizations to examine relationships between points of data. Much like how viewing a three-dimensional Martian panorama allows for better interpretation, seeing data in virtual space makes spotting correlations easier.

Obtaining an exclusive license from Caltech, which manages JPL, Donalek, Djorgovski, and new CEO Michael Amori founded Virtualitics Inc. of Pasadena, California, in 2016, with Davidoff in an advisory role. To further build out the software, they've incorporated features such as artificial intelligence to point out patterns and relationships in the visualized data.

"We call it intelligent exploration. You're using AI and 3D visualizations to quickly identify drivers and relationships in your data, and drive understanding in ways 2D graphs aren't capable of," Donalek, now CTO of Virtualitics, said. "You can start getting insights from your data right away because it's literally drag and drop."

The software works on both desktop and VR and is compatible with several popular headsets. While the platform is designed for use anywhere there's a significant amount of data, it is currently most often used in banking, retail, and medical research. It can visualize anything from a spreadsheet to a large "data lake" without having to move the data from where it resides. Donalek said the company maintains a relationship with JPL, and many of its 60 employees come from the center or Caltech.

"One of them is from MIT, but we don't hold it against him," Donalek joked. ●

# From Shark Searches to Space Tours



Using a remotely piloted plane that employs technology Aurora Flight Sciences developed for NASA projects, OCEARCH found and tagged its first mature male great white shark. Satellite-tagging George was an important milestone enabling scientists to track the overlapping locations of male and female sharks to find breeding areas. *Credit: Alex Thomas/OCEARCH*



One seat for a human pilot on a small aircraft can be replaced with a system (right seat) that makes it possible to remotely pilot the plane, just like a drone. Aurora Flight Sciences incorporated NASA expertise gained with SBIR contracts to create the optionally piloted aircraft called Centaur. *Credit: Aurora Flight Sciences*

## Experience gained with NASA helps one company engineer a variety of aviation resources

Searching for sharks, even close to shore, means finding moving targets in vast stretches of ocean. Yet OCEARCH overcame those long odds to find and tag its first mature male great white shark off the East Coast, supported by NASA know-how. During a three-week search in 2016, the global nonprofit located a total of five sharks with the help of a plane specially outfitted by Aurora Flight Sciences, a Boeing company.

The twin-engine plane, called Centaur, is a conventional small aircraft retrofitted with an electromechanical device that adds drone technology to automate the control system and fly the plane remotely, with or without a pilot on board. Some of the knowledge required to develop the system, along with the onboard sensors that helped spot and track the sharks, leveraged experience Aurora gained under dozens of NASA Small Business Innovation Research (SBIR) and Small Business Technology Transfer projects.

Aurora's Centaur can execute long-duration flights. One customer conducted air sampling, and a researcher used it as part of a study of variations in Earth's gravity. The robotic plane was able to fly exact flight patterns difficult for humans to replicate, allowing the researcher's sensors to make the very precise measurements.

The Manassas, Virginia-based company has worked with nearly every NASA center on a multitude of SBIR projects. Working with the agency on an experimental airliner concept also expanded the company's access to NASA's aeronautics expertise.

"NASA had a big role in helping create Aurora," said Clint Church, chief engineer for the company. "We learned how to design and build small and large aircraft to meet NASA requirements." In addition to its four U.S. facilities, in 2013 the company established Aurora Swiss Aerospace, a drone engineering team that grew to include commercial aircraft. Aurora now employs nearly 1,000 people worldwide, about 500 of whom are engineers.

Aurora's first sales to commercial companies came from a novel approach to manufacturing lightweight composite parts for drones, developed under a Space Act Agreement (Spinoff 2010). That side of the business continues to grow, expanding into commercial aviation. Gulfstream is now a customer.

The company also offers commercial services, including engineering, rapid prototyping, and flight testing, to a host of aeronautic customers.

In 2022, Virgin Galactic hired Aurora to design and build the next carrier aircraft to take its space tourism vehicles up to launch altitude. This new kind of flight has unique requirements, and Brent Cobleigh, project manager with NASA's Armstrong Flight Research Center in Edwards, California, believes Aurora can create a viable solution.

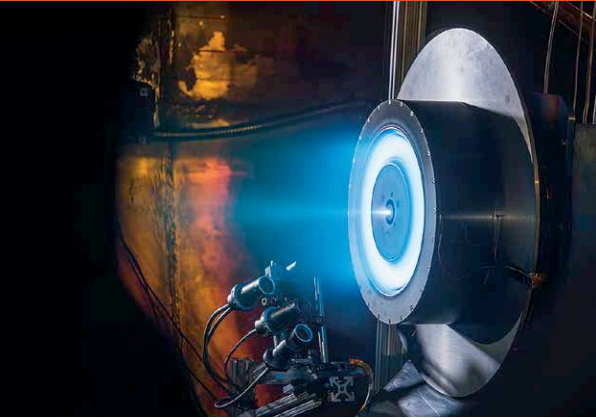
"They learned a lot about our airworthiness process – how to develop an airplane that has a high level of safety and is robust enough to handle disturbances," said Cobleigh.

The company also offers testing services to support commercial customers in their effort to develop and improve flight hardware.

Innovation continues in-house as well. An example is SKIRON-X, an uncrewed vertical takeoff and landing vehicle that is now available for Earth observation. Bridger Aerospace acquired two of these vehicles to augment its current firefighting fleet. Both were flown during the 2023 wildfire season to provide aerial information to support the deployment of resources and inform firefighting strategy. ●



# Ion Thrusters Keep Satellites Going and Going



This Hall-effect thruster, shown being tested at Glenn Research Center, turns electricity and inert gas into force that could propel a spacecraft. Orbion Space Technology was founded to bring the high efficiency of these thrusters to small commercial satellites, and the company sought the center's help to make that a reality. *Credit: NASA*



NASA's Dawn spacecraft used a high-efficiency ion thruster to visit Ceres and Vesta in the asteroid belt. This electric method of propulsion is now being manufactured for small satellites by Orbion Space Technology. *Credit: NASA*



Orbion's Aurora thrusters are small and efficient yet powerful enough to maintain the orbits of small satellites for several years. *Credit: Orbion Space Technology Inc.*

## NASA electric thruster expertise, data keeps commercial satellites on the clock

Much like groceries, satellites have a shelf life.

In low-Earth orbit, satellites are subjected to a miniscule amount of atmospheric drag that, over time, causes them to slow down and decays their orbit. Thrusters are used to boost orbits so the satellites can stay in space. But when they run out of fuel, the drag adds up, and the satellite will eventually re-enter the atmosphere.

While necessary to ensuring these satellites stay up for years, most of these thrusters use chemical propellants, which are heavy and require a lot of storage space. But a company from the Upper Peninsula of Michigan seeks to solve this problem with the help of a technology that NASA has been honing.

Orbion Space Technology of Houghton, Michigan, was founded in 2016 by Brad King and Jason Sommerville, both of whom had prior experience working on projects at or funded by NASA. The two saw a market for ways to make satellites either last longer in orbit or carry more payload than fuel. Meeting this challenge required a thruster that doesn't need much fuel at all.

Hall-effect thrusters, one type of ion thruster technology, use electricity rather than chemical reactions to propel spacecraft. Hall-effect thrusters use the charge of an electric field to accelerate a gaseous propellant, most commonly a noble gas like xenon. NASA has used ion thrusters for a handful of interplanetary missions, such as the Dawn spacecraft that visited Ceres and the Double Asteroid Redirection Test (DART) mission to impact an asteroid. Orbion's founders saw the technology grow from an experimental concept to being regularly used on missions around the solar system, but for the company to make these thrusters viable for satellite operators, they had to turn to the experts.

NASA's Glenn Research Center in Cleveland has had an in-depth role developing ion thrusters for the agency's science missions, designing and evaluating the thrusters for the Dawn and DART missions, as well as working on improving the technology in general. Orbion entered into a Data Usage Agreement with Glenn to receive detailed information about the development of these engines, as well as a non-exclusive evaluation license. One of the reasons Orbion turned to NASA was the agency's advancements in materials research for ion thrusters as well as the cathode heater Glenn developed, which improves electrical efficiency and operating life.

"We started with discussing heaters, but there have been other discussions looking at more aspects that they can utilize," said Timothy Verhey, aerospace scientist in the Electric Propulsion Systems Branch at Glenn. "In many ways we become keepers of knowledge for a lot of companies."

Over the course of the agreement, Orbion's team had many interactions with researchers at Glenn. This included both direct technical assistance and some field trips to the center.

"We've been invited down there to see them build up complex components and take some notes on how they were configuring their systems," said Jason Makela, vice president of engineering at Orbion. "We can also pick up the phone and call someone there, and they'll nerd out."

The end result is that Orbion's thrusters, branded under the name Aurora, are just as capable as the ones NASA builds for deep space missions, with very high delta-v and specific impulse, measurements of how much effort it takes to change velocity, as well as thrust efficiency. Orbion's product is also highly configurable, ensuring it can be tailored to whatever a satellite needs to stay in orbit.

Orbion has sold several of the Aurora thrusters, both to the government and private sector companies. Recently, the company entered into a contract with a large commercial satellite operator to provide ion thrusters for its new constellation of Earth-observing spacecraft. Makela said without the wealth of NASA experience leveraged both inside and outside the company, Orbion wouldn't have been able to get to where it is today.

"It's great to be on a first-name basis with these subject matter experts," Makela said. "We were really able to stand on the shoulders of giants here." ●

# Artificial Eyes Give Pilots a New Worldview



## External vision system for supersonic test plane raises standard for flight camera video quality

Surpassing the speed of sound is noisy. The sonic boom it generates is so loud that supersonic flight over land is prohibited. NASA's X-59 Quiet SuperSonic Technology experimental plane is designed to reduce that boom to a mere thump, but doing so required a streamlined body that eliminated the plane's windshield. Now a technology developed to provide the X-59 pilot with a forward-facing view nearly replicates the acuity of human eyesight for other fast-moving aircraft and spacecraft.

WOLF Advanced Technology USA Inc. in Cleveland was one of the companies NASA contracted to help build the External Vision System (XVS). The project required a new video-processing technology that the company has now added to its product line, called FGX2. This hardware is included in many WOLF products, said Greg Maynard, chief technology officer.

The company already supplied aerospace video capture and display flight hardware, but there was no flight-certified system that had the high definition necessary to supplant an actual windshield. So NASA developed a hybrid system that leveraged WOLF's expertise.

The XVS includes an ultra-high-definition (UHD) camera incorporating commercial, off-the-shelf hardware on top of the X-plane and a standard, flight-certified camera system on the underside. The top camera provides visual quality approaching human sight, with the standard camera underneath acting as a failsafe. But the company needed a new technology to process both data streams simultaneously.

"For the X-59, we had to meet certain specific power, space, and heat-load requirements, and we had to survive at 65,000 feet, 150°F, and minus 30°F," said Steve Williams, XVS software lead with NASA's Langley Research Center in Hampton, Virginia. "It was something that had never been done before in certified flight hardware and software."

Under those harsh conditions, the video cards must continuously fuse the different video feeds into the nearly real-time video display in the cockpit.

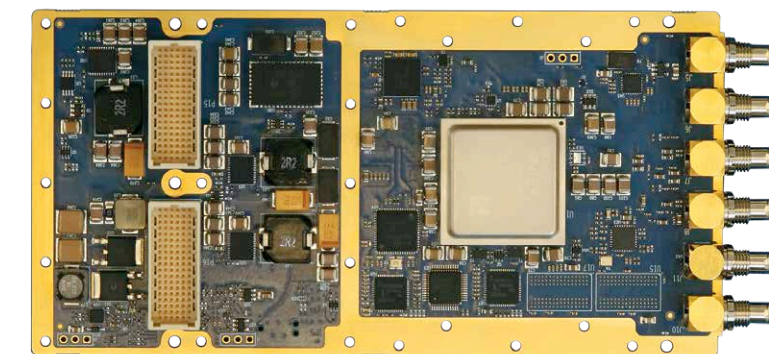
Just presenting the camera image wouldn't be good enough, said Williams. The human eye is more sensitive than any camera, so the vision system replacing it required "a lot of image processing" that had to happen quickly enough that it appeared as a continuous image, "just like you're looking out the window," he said.

The new hardware and software WOLF created for the XVS meets demanding image processing and display requirements, Maynard said. Supersonic commercial flight won't be possible until new aviation rules lift the overland ban, but commercial space companies can now use the WOLF technologies in their vehicles to meet rising demand for UHD resolution. Maynard credits NASA with being ahead of the industry, giving the company a chance to develop the technology early.

Flight-tested by NASA, the hardware now supports other camera systems on aircraft and spacecraft experiencing punishing temperatures and altitudes. The high-data-rate, high-density video capture from multiple cameras can be used for machine vision, synthetic vision, or video processing applications.

"People really want to know the work they're doing is important, and the projects NASA executes are meant to try to improve the world in some way," said Maynard. "It's nice to be able to contribute to something like that." ●

When a plane reaches the speed of sound, it creates a sonic boom so loud that commercial supersonic flight is banned over land. NASA redesigned the traditional airplane shape to reduce the boom to a "thump," relying on video cameras to replace the front windshield. *Credit: Lockheed Martin Corp.*



A new video card developed by WOLF Advanced Technology combines high-definition video with other video feeds to present a near-real-time view for a pilot to use to fly a plane. *Credit: WOLF Advanced Technology USA Inc.*



# Ballooning Business for Shrinking Cameras



A scientific balloon launching from NASA's Columbia Scientific Balloon Facility in Fort Sumner, New Mexico, in 2019. Credit: NASA



The view of a construction site, like this one, can help a developer track construction progress and identify potential climate-resilience planning needs such as flood controls. Urban Sky is able to provide this kind of highly localized Earth-observation photography using technology developed for NASA. Credit: Urban Sky Inc.

## NASA-funded miniaturized technology offers better imagery than a satellite

The stratosphere begins five to nine miles up from Earth's surface. That's where a camera mounted on a zero-pressure balloon takes panoramic pictures of areas as wide as a satellite's field of view but at a higher resolution. The most advanced commercial satellite image resolution is just under 11 inches per pixel. But Urban Sky Inc. pictures have about four-inch resolution, offering eight times the data, according to Jared Leidich, the company's chief technical officer. Thanks to a Small Business Innovation Research (SBIR) award from NASA's Jet Propulsion Laboratory in Southern California, the company can photograph almost any landscape – virtually on demand.

Based in Denver, Urban Sky uses its Microballoon, a scaled-down version of an atmospheric balloon NASA helped perfect, to fly ultra-lightweight sensors. Intended to improve NASA's Fire Influence on Regional to Global Environments and Air Quality program, the SBIR contract funded development of miniaturized color and infrared sensors to capture images and ground-temperature readings of wildfires. Flights could occur during or immediately following a wildfire to provide data essential for predicting downwind air quality impacts.

Olga Kalashnikova, research scientist with JPL, noted that Urban Sky identified agency needs for improved air quality monitoring and modeling data inputs when other solutions were too costly and conflicted with firefighting aircraft.

"NASA recognizes that developing innovative technology for effective mitigation of wildfire risk is essential to reduce the potential for catastrophic losses," she said.

It was necessary to custom design and build everything that's attached to the balloon because the Federal Aviation Administration limits every flight of any two payloads to a maximum total of 12 pounds.

"An off-the-shelf telescope is more than two times heavier than our entire system is allowed to be," said Leidich. "NASA gave us a way to develop new instruments that otherwise wouldn't have been possible."

Thanks to the balloon's small size, it can be driven to any location and launched from the bed of a pickup truck. This makes it possible to strategically place and retrieve the reusable balloon. If conditions are poor for launch, just drive to a different spot.

The color camera the firm miniaturized to meet NASA specifications is already widely used by the company. With over 100 stratospheric flights completed in four years, Urban Sky produced 73 terapixels of Earth imagery covering about 5 million acres – roughly the size of New Jersey. And those images are highly localized. One balloon or a small fleet can collect the data most businesses request for a specific area on a monthly, weekly, or even daily basis.

Insurance companies need to see precise locations to support underwriting and claims adjustment. Oil and gas companies use regular flights to conduct site inspections, including monitoring the return of retired sites back to their original condition. Even though Urban Sky's only experience over wildfires has come from test flights, Denver Water hired the company to assess the sites of former wildfires to evaluate the potential impact of debris runoff. That information helped determine necessary adjustments to the water supply purification systems.

Urban Sky's balloon cameras operate in eight western states (Colorado, Iowa, Kansas, Montana, Nebraska, New Mexico, Texas, and Wyoming). But the miniaturized infrared camera, which enables temperature readings, including from wildfires, recently completed flight-testing and will soon be operating commercial and public-safety flights as Urban Sky completes its expansion into more U.S. locations over the coming year. ●

# Farmers Get Tools from Space



One of IrriWatch's sources of data is the Ecosystem Spaceborne Thermal Radiometer Experiment (ECOSTRESS), seen here undergoing inspection at Kennedy Space Center prior to launch. Built at the Jet Propulsion Laboratory and affixed to the outside of the International Space Station since 2018, ECOSTRESS is the first Earth-imager developed specifically to look at evapotranspiration, a major indicator of plant stress. Credit: NASA

## Service combines data from NASA sensors in orbit to determine current field conditions

Professor and scientist Wim Bastiaanssen founded Dutch company IrriWatch BV in 2019 to put a powerful, space-based tool into the hands of farmers. Unlike many others based on satellite data, his would offer up-to-date information that could help farmers save crops before the point of no return.

"If you tell them what happened in their field 10 days ago, that's too late," said IrriWatch product manager Roula Bachour. "You don't need to tell me I have dry soil if I already see the crop is dead."

As NASA has placed more eyes in the sky, various companies have emerged to turn satellite data into tools for farming. But these typically inform long-term decisions, like adjusting practices from season to season or predicting harvests. Bastiaanssen wanted to help farmers plan each day based on current conditions in their fields.

IrriWatch is one of the only products to combine that timeliness with the ability to calculate evapotranspiration – the amount of water that's evaporating from soil or being "exhaled" by crops, an excellent indicator of plant health. There are several models for extracting this information from thermal images, one of which Bastiaanssen created in the 1990s.

In June of 2023, the company, whose offices remain in Wageningen, Netherlands, merged with Luxembourg-based company Hydrosat, which is launching a constellation of small satellites to supplement existing Earth-imagers, ensuring frequent, high-resolution imagery all over Earth. IrriWatch will retain its name as a Hydrosat product.

For now, IrriWatch pulls its thermal data from three sources. One, the Ecosystem Spaceborne Thermal Radiometer Experiment (ECOSTRESS), is the first Earth-imager developed specifically to observe evapotranspiration. Built at NASA's Jet Propulsion Laboratory in Southern California, ECOSTRESS sits on the outside of the International Space Station. Meanwhile, the Landsat satellites, built by NASA and managed by the U.S. Geological Survey, have observed Earth's surface for 50 years. And the Visible Infrared Imaging Radiometer Suite (VIIRS) comes from a partnership between NASA and the National Oceanic and Atmospheric Administration.

ECOSTRESS boasts more thermal bands than Landsat and higher resolution than VIIRS. And its perch on the space station lets it observe the same places at different times of day, offering a more complete picture than most Earth-observing satellites, whose orbits keep them on the same schedule every day, said Simon Hook, principal investigator for ECOSTRESS at JPL.

Evapotranspiration data helps farmers gauge daily irrigation needs and get the most crops for the least water. But more information can be extrapolated, including the production of dry matter, which helps predict yields, and the amount of water a field is using over time, which helps with water management. By showing plant stress, it can alert farmers to diseases, pests, and other problems.

Not all IrriWatch subscribers are farmers. Water managers from California to India use the service to calculate water use and allocate water. IrriWatch also helps companies that breed seed varieties to monitor the performance of their crops in different parts of the world. Bachour also noted that food processing companies use it to monitor their suppliers' farms and predict how much yield to expect. Still other subscribers are companies with their own agriculture platforms and apps, who incorporate IrriWatch data into their products.

By the time of the merger, IrriWatch, an eight-person operation, had customers in about 60 countries. ●



In February of 2023, IrriWatch founder Wim Bastiaanssen meets with farmers in the Indian state of Madhya Pradesh, who are using IrriWatch to schedule irrigation more efficiently for a variety of crops. Credit: IrriWatch BV



# Commercial Space: NASA Has an App for That



The next space station NASA builds with international partners, the lunar Gateway, will use an agency-developed open-source code to run many of its systems. Commercial space companies are also using the code along with apps developed by Red Canyon to operate planetary landers, satellites, and more. *Credit: NASA*

## Software two decades in the making helps private space companies save time, money

An unexpected technology links the spaceflights of high-altitude balloons, planetary landers, NASA's planned lunar space station, and satellites – core Flight System (cFS). This open-source software framework is similar to a smartphone operating system in that it serves as the foundation for apps developed to perform spaceflight functions. Red Canyon Software Inc. is building those apps to help commercial space companies get into low-Earth orbit and beyond as quickly as possible.

NASA's Goddard Space Flight Center in Greenbelt, Maryland, developed cFS to meet the needs of diverse missions ranging from high-altitude balloons to lunar-orbiting spacecraft. Agency engineers collaborated to identify the most common requirements for NASA flights, according to David McComas, former Software Engineering Division senior flight systems engineer. Now retired, he's still involved with the user groups developing and maintaining cFS code and standards.

Because flight computer platforms vary significantly, the open-source code can be transferred across diverse types of hardware. That means apps don't need a platform-specific interface, so they can be reused for different flight vehicles and missions.

"Companies using cFS can start with less capital for flight software development costs and get to space quicker, achieving a quicker return on investment," said Barry Hamilton, CEO of Denver-based Red Canyon. The space technology company has been able to expand into commercial space, which now accounts for 20% of its business, by using cFS to support entrepreneurs and established companies.

The code provides the foundation for a "highly customizable ecosystem for spacecraft development," according to Hamilton. Red Canyon continues to add to its library of existing apps, called modules, which can be easily modified for multiple projects.

If using a sensor to take pictures, a cFS module will be nearly plug-and-play. Another app might simply read data from a sensor or perform more complex activities such as guidance, navigation, and control.

The company is working on a simulation to verify and validate integration of the program modules with flight hardware. These resources help commercial space companies meet mission software needs more quickly than starting from nothing.

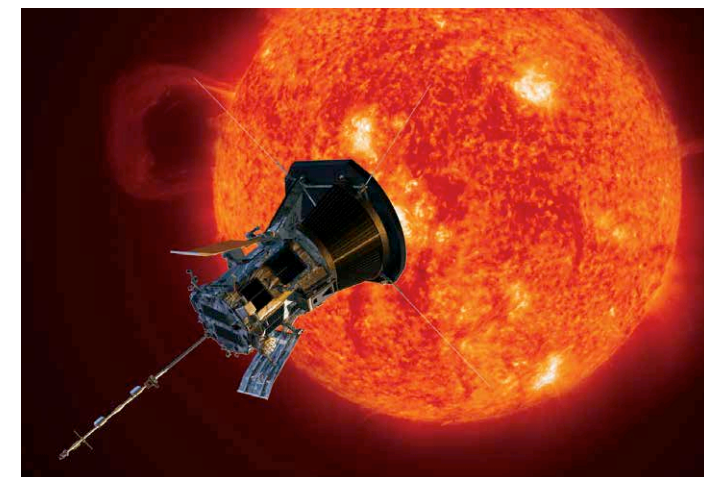
Until now, most aerospace companies developed proprietary flight systems because each mission required custom software – an expensive proposition. NASA invested two decades of expertise and flight heritage to create an exceptionally reliable, stable program for its own use, according to McComas. Making that available not only fulfills the agency mission to share technology, but it also allows users to contribute expertise to improving the program.

"The rapid growth of the aerospace industry is revealing a gap in flight software skills needed by the industry," said McComas. Universities can use cFS to prepare a new generation of software engineers and programmers.

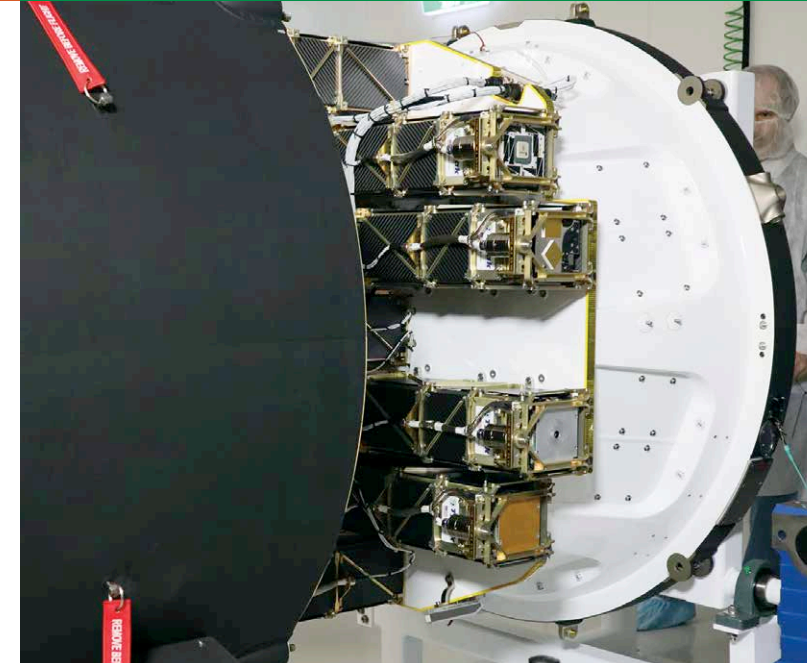
Companies like Red Canyon are creating a corporate culture around cFS technology, making it possible to quickly train employees and work effectively across projects. And software processes can be optimized utilizing automated testing and software that can be used repeatedly.

Red Canyon will support the design, development, assembly, integration, deployment, and ongoing operations for Sidus Space's LizzieSat constellation. The satellites will carry custom scientific experiments into space.

"We can work with customers to develop a very customizable modular system," said Hamilton. "That lets the company focus on the things only they can do, allowing new technology to get to market quicker." ●

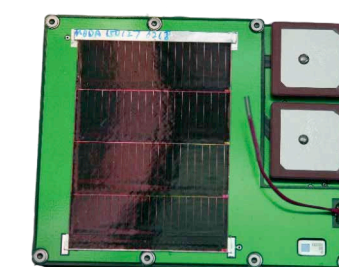
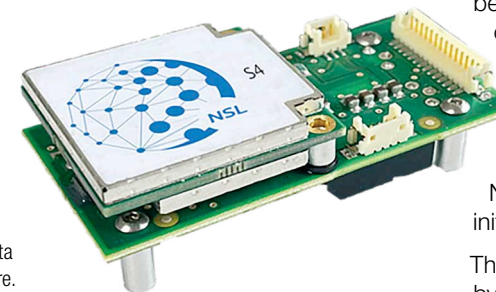


Parker Solar Probe is providing scientists with new information about the Sun, thanks to a complex system of hardware and software. One program that enables some of the satellite functionality, core Flight System software, is an open-source code developed by NASA. *Credit: NASA/Johns Hopkins APL/Steve Gribben*



This picture of the Educational Launch of Nanosatellites 19 mission shows multiple CubeSats encapsulated inside a rocket payload fairing. A flight like this one proved the capability of the NearSpace Launch EyeStar radio before the company made it commercially available. *Credit: NASA*

The EyeStar radio sends data from a small CubeSat to a larger communications satellite constellation in orbit overhead, eliminating the need for the bulkier communications hardware capable of transmitting data through Earth's atmosphere. *Credit: NearSpace Inc.*



The NearSpace Black Box is a self-powered EyeStar radio with GPS technology that can attach to the side of a CubeSat to facilitate satellite-to-satellite communications. Called a "barnacle," the device comes in different sizes to accommodate customer needs. *Credit: NearSpace Inc.*

# Keeping the Connection

## NASA-proven radio enables satellite-to-satellite communication

With about 5,800 satellites orbiting Earth, more data streams than ever are trying to connect with a limited number of ground stations. As more spacecraft join them in orbit – and more of these are small satellites that can't carry powerful, complex transponders – a growing trend is for smaller satellites to set up a data relay, sending those signals to constellations of big communications satellites that transmit them to any location on Earth in a matter of seconds, all day every day.

One device enabling this satellite-to-satellite communication, the EyeStar radio developed by NearSpace Launch Inc., used NASA's CubeSat Launch Initiative (CSLI) to prove a small instrument could deliver big results. The idea of little satellites piggybacking on existing communications constellations to increase the frequency of data transmissions was novel in 2014, when the EyeStar radio was developed, according to Matt Voss, COO of the Upland, Indiana-based company.

"The standard data transmission is about once every eight hours as the satellite passes over a ground station," he said. But that can be less frequent if the signal can't make it through Earth's atmosphere in time or the designated ground station isn't available.

The company has flown over 800 systems and subsystems in low-Earth orbit. Some serve as the primary communication link, while others provide supplemental information like satellite health data or low-resolution images.

EyeStar devices relay signals via more than 66 satellites in the Iridium constellation. These orbit well above most low-Earth orbit satellites, so an EyeStar radio points up instead of down. Even if its satellite tumbles out of control, the EyeStar data can still connect with the constellation.

"Usually you need a very stable satellite to connect to a ground station. But even if the satellite becomes unstable, we can connect and identify whatever the problem is so the spacecraft operator can fix it," said Voss. That connection can prevent a total loss.

Voss' father Hank, cofounder and now chief scientist at NearSpace, led a team that developed the first EyeStar radio at Taylor University and incorporated it into a CubeSat selected by CSLI. The initiative provides flight opportunities for U.S. CubeSat developers, nonprofits, and universities as secondary payloads on commercial or government launches. Norman Phelps, CSLI mission manager at NASA's Kennedy Space Center in Florida, said the initiative selects technologies "based on their scientific, educational, and technology benefits."

The transition to a successful commercial offering included an educational program sponsored by the state of Virginia. A group of 90 satellites carried projects for students, researchers, and others into low-Earth orbit. Voss said several major companies also participated, including General Atomics, Nanoracks, NovaWurks, Nano-Satellite Systems, and others.

Now the company is adding new products such as the EyeStar Black Box. Described as a "barnacle" that attaches to a satellite, the device has its own power source and a GPS antenna and can incorporate sensors to capture things like temperature and particle detection.

The NearSpace technology has been so successful the company now provides radios for other organizations participating in CSLI.

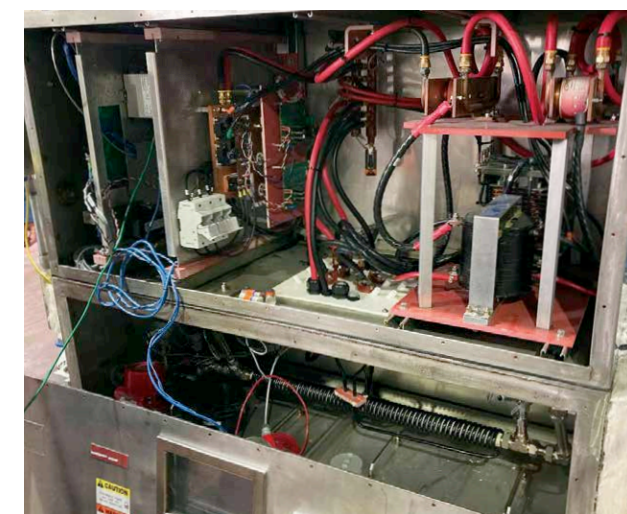
"Because we build systems for a lot of customers using NASA launches or partnering with NASA, we continue to learn from the agency," said Voss. ●



# NASA Ingredients for Industrial Expedience



NASA has explored the possibility of long-term lunar habitation since first setting foot on the Moon. To have a permanent presence on the Moon would require sustaining crew members for months on end. Exploring ways to preserve and make food for these kinds of missions allowed Induction Food Systems to build its industrial induction heating solutions. *Credit: NASA*



The heaters that Induction Food Systems builds are used for more than just food production. This system for processing chemical products is one of many commercial offerings the company makes. *Credit: Induction Food Systems Inc.*

## NASA funding enables large-scale inductive heating for food production

On a mission to the depths of space, astronauts need to pack more than a lunch.

While trips to the Moon only needed a few days' worth of meals, a mission to Mars would require years of food supplies that need to be perfectly preserved and ready to eat whenever it's mealtime for astronauts.

"A closed system can be a challenge, because astronauts have limited resources, and they want some variety in the food they can eat," said Grace Douglas, lead scientist for advanced food technology at the Space Food Systems Laboratory at NASA's Johnson Space Center in Houston. "But overall, they have to be able to get the nutrition they need to perform."

In 2008, NASA's Small Business Innovation Research (SBIR) program supported the Advanced Food Technology project to explore technologies that could keep astronauts fed on a long-duration space mission. Among the proposals this project explored for a Moon habitat was a stocked kitchen. Instead of ready-to-eat meals, astronauts could select from a variety of preserved ingredients and assemble their own dishes. This would require kitchen appliances that work in low gravity.

Induction Food Systems Inc. (IFS) of Durham, North Carolina, was one company selected for the project after proposing a food preparation system that, in keeping with its name, relied on the process of induction. Anyone who's walked through an appliance store in the last decade has probably seen an induction cooktop. These use magnetic fields to heat metal pots and pans directly, instead of using a gas flame or a resistive heating element. Induction cooking uses less power than other electrical methods of heating food, making it a desirable option for space, where power is limited.

"The technology is extremely efficient if done correctly," said George Sadler, chief scientist at IFS. "Compared to other elements, it's kind of winner-winner-chicken-dinner."

Throughout the course of the Phase II SBIR, the company consulted with NASA scientists to work out the physics of using induction to make food for astronauts. The process resulted in a new coil design that could put more power more efficiently into the system than the induction heaters found in home kitchen stoves. A secondary development from the program was a method of removing oxygen from food container materials to further preserve the contents, another step to ensuring astronauts eat well.

While the SBIR was largely exploratory in nature and ultimately resulted in no developments used by NASA, it had clear benefits for the company. IFS was able to parlay the NASA experience into building out both of the explored technologies. The company continued to develop them with further funding from the U.S. Department of Agriculture, and soon IFS was able to pivot toward a whole new market.

Today, IFS's primary business is constructing large-scale induction heaters for industrial applications such as food manufacturing. Most industrial heaters use steam heating, which requires enormous amounts of energy, but Sadler said the IFS technology is far more efficient at transforming electricity into heat. Ultimately, Sadler credits the help he received from NASA scientists with getting the company off the ground.

"From building my first inductive heater to all the theoretical calculations I needed to build it at scale, I couldn't have done it without the NASA connection," Sadler said. ●

# Keeping Beds in the Goldilocks Zone



Inspired by NASA and designed by a former NASA contractor, BedJet works by blowing air into a specialized duvet that can maintain a steady temperature under the covers. With two units, the temperature can be controlled individually on each side of the bed. *Credit: BedJet LLC*



BedJet can be controlled wirelessly via a remote or an app available for smartphones. The entire system is an all-in-one unit outside the bed, which the company touts as being safer than other methods of sleep temperature control. Former NASA contractor Mark Aramli credits the safety controls he worked on when developing spacesuits as an inspiration for ensuring BedJet is safe to run all night. *Credit: BedJet LLC*

## NASA experience inspires machine that keeps sleepers comfortable

For Mark Aramli, the bed was a battlefield.

He liked the bed a little cool, while his partner liked to stay warm under the covers. The constant fight over the thermostat meant that in the end, neither of them was particularly satisfied. He'd had enough, and he was going to do something about it using his experience with NASA.

Aramli had worked for NASA contractor Hamilton Sundstrand (now part of RTX Corporation) in its Space Systems division. The company had a contract with NASA's Johnson Space Center in Houston to build and maintain spacesuit components for the agency. In this capacity, Aramli worked on the spacesuit's environmental control systems.

"I thought to myself, how is it that I helped keep astronauts perfectly comfortable in the most hostile environment in the universe, and here I am uncomfortable in my own bed?" Aramli said.

Soon after the thermostat battle, he'd built a prototype on his kitchen table of a machine to address the problem. The device was made from a broken hand dryer and assorted parts ordered from the internet, but he immediately saw results.

Inspired to take his idea further, Aramli founded BedJet of Newport, Rhode Island, in 2013. After an unsuccessful appearance on the TV show "Shark Tank" and several successful crowdfunding campaigns in 2015, the company started shipping finished models.

BedJet works with a cotton sheet that inflates using air pushed by an external machine. This machine has both a fan and a built-in heater, resulting in a temperature-controlling bed cover with no internal electronics. With two BedJet units, the temperature on the left and right sides of the bed can be controlled individually, much like dual-zone climate control in a car. No matter their temperature preferences, people can stay comfortable without fighting over the thermostat.

Today, the company has sold over 180,000 units and has had tens of millions of dollars in sales. Aramli said many of these sales come from not only married couples, but Olympic athletes, menopausal women, and people in chemotherapy who experience temperature swings at night. In addition, because BedJet only pushes air into a sheet that doesn't have any heating elements integrated, the company believes it's far safer than alternative solutions like electric blankets. Aramli credits his experience making equipment for space with ensuring safety and redundancy.



Astronaut John B. Herrington wears a spacesuit aboard the International Space Station in 2002. The pack on his back is full of important life-support equipment, such as an environmental control system to protect against the extreme temperatures of space. Work on this system inspired Aramli to develop the BedJet system. *Credit: NASA*

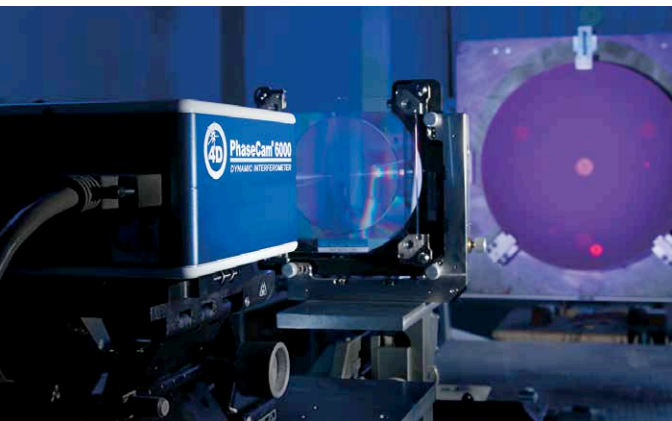
"When we were seeking liability insurance, the inspector said that with BedJet, the biggest hazard is with the outlet it plugs into," Aramli said. "That triple redundancy on safety when it comes to engineering systems at that NASA prime contractor, that was definitely a big role in helping me create a safe product." ●



# Making the Most of Meticulous Measurements



The James Webb Space Telescope captured this image of the Rho Ophiuchi cloud complex. For the telescope to take these stunning images, its mirror needs to be free of imperfections. Equipment built to NASA specifications to test Webb's precision optics went on to test optics of all kinds. Credit: NASA, ESA, CSA, STScI, and K. Pontoppidan (STScI). Image Processing: A. Pagan (STScI)



PhaseCam is one of 4D Technology's commercial products. As a multi-wavelength interferometer, it's capable of measuring optics with an extreme degree of precision. This type of measurement didn't exist in a commercial form until after 4D's work on the Webb telescope. Credit: 4D Technology

## Better space telescope testing makes waves in optics industry

Since the launch of the James Webb Space Telescope, the space observatory has made numerous discoveries about our universe, but it also led to developments in a scientific field that is necessary to science itself.

Metrology is defined as the science of measurement, and it is key to ensuring that scientific tools work. Calibrating equipment is no small feat when working in the smallest fractions of an inch. The mirrors on space telescopes need to be as smooth as possible to focus the light of distant galaxies. Other methods of telescope testing have resulted in leaps before, but Webb's unique folding mirror segments had special requirements that a solid mirror didn't.

"Twenty-five years ago, we realized that our primary goal had to be to develop methodologies and instrumentation that would enable us to do measurements for a cryogenic segmented telescope," said Babak Saif, chief optical metrologist on the Optical Telescope Element of the Webb telescope. "That had never been done before."

NASA's Goddard Space Flight Center in Greenbelt, Maryland, reached out to the private sector for the right technology to make these precision mirror measurements. Soon, a company called 4D Vision was contracted to work on optical testing equipment for Webb.

"NASA actually was 4D's very first customer ever," said Erik Novak, vice president and general manager of 4D. "We were approached because obviously telescope optics are large, and they need to be tested from dozens of meters away. That's where your test system has to be. And the only way to do any of that is with a vibration-immune technique."

The company uses a technique called interferometry, which uses light to make precise measurements. When anything happens to change the path of light that reflects off a tested object, those variations can be detected and used to spot any irregularity in the object's surface. 4D's interferometer was different than others, however. Instead of just noticing slight differences in light from one wavelength, it would use multiple wavelengths of light aimed at the Webb telescope's mirror segments, as well as a reference model of what a perfect surface would look like. These reflected beams would then bounce back to a detector on the machine, and the combination of wavelengths would allow much greater deviations to be measured while not sacrificing any of the system's very high precision. This new method is called multi-wavelength interferometry.

"Multi-wavelength interferometry didn't exist when we started building Webb," said Saif. "It allowed us to test the primary mirror and be able to actually do the measurements and make sure that we can go to a fraction of the wavelength of the light and also get high-precision information out of it."

After a series of mergers and acquisitions, a successor company called 4D Technology, based in Tucson, Arizona, was founded in 2011. Well after the company provided this specialized testing equipment to NASA, Novak said, he saw several potential commercial uses for the technology.

"We serve the optics industry very generally, and what we developed for NASA has been applicable to a lot of that," Novak said.

Today, 4D Technology is a subsidiary of Onto Innovation. The measurement systems developed for Webb have gone on to be used in testing other precision optics, such as lenses for virtual reality headsets or high-end camera equipment. It has also seen use outside of optics, to test contact lenses and advanced semiconductors for computers, and to spot defects on aircraft engines.

"This is a completely brand-new space," Novak said. "The people at NASA are some of the brightest of the brightest, and so just brainstorming ideas and how we might solve them has been very beneficial to us." ●

# Pumping Out State-of-the-Art Design



Decades of NASA rocket engine expertise goes into the turbopump that delivers fuel to a rocket engine, like this one attached to the end of the Space Launch System. Concepts NREC incorporates that know-how into services for commercial rocket companies and any industry that uses pumps, fans, and related machinery. Credit: NASA



Concepts NREC works with companies to design and fabricate hardware for pumps and related system components. When creating custom parts, the company incorporates lessons learned from NASA to achieve the best result. Credit: Concepts NREC LLC

## Engineering expertise gained with NASA improves pump machinery design, analysis

Turbopump machinery is essential for rocket liftoff. Yet few industries employ the precision NASA requires for rockets, so the agency collaborated with private businesses to improve hardware fabrication and system testing through design and analysis. One of these companies, Concepts NREC LLC, is applying those aerospace resources to terrestrial uses through consulting services and software.

The White River Junction, Vermont-based company credits the agency with enhancing software capabilities that have improved the expert services Concepts NREC provides to commercial customers. In the 1990s, NASA taught the company much about rocket engines to modify its engineering analysis software to include the specialized calculations required for rocket engine fuel pumps.

Now called Agile Engineering Design System, the software program combines agency know-how with the company's proprietary code and data. The company's program also includes NASA code, the Generalized Fluid System Simulation program, licensed over two decades ago from NASA's Marshall Space Flight Center in Huntsville, Alabama. It allows customers to design, test, and analyze virtual turbopumps and other machinery as individual parts or mechanical systems (Spinoff 2003, 2016, 2020).

Concepts NREC also capitalized on the knowledge gained during its long NASA collaboration to improve existing engineering consulting and manufacturing services. The company incorporates agency resources to help customers solve problems for pumps, compressors, and turbine parts and the systems that use them.

"NASA improved the state of the art for pump design and the tools people use to design them. A lot of those things have crossed over and benefited other industries," said Mark Anderson, chief technology officer with Concepts NREC. As one of the company's engineers responsible for working with NASA on multiple Small Business Innovation Research (SBIR) contracts for more than 30 years, Anderson appreciates the agency's willingness to share its expertise.

The perfect balance of pressure and temperature is needed throughout a pump system, so all of its parts must work in harmony. The company can review an existing design in the computer environment to find inefficiencies. Then Concepts NREC engineers can redesign parts for better performance, and the manufacturing team can fabricate custom small turbo hardware such as propellers.

Over time, meeting NASA requirements and working with agency technologists has helped the company expand its consulting and manufacturing services. Some customers include United Launch Alliance, other aerospace companies, multiple rocket engine manufacturers, and cryogenic pump and turbine manufacturer Ebara International. Renewable energy and aviation companies and consumer device provider Dyson are also customers.

Matt Marsh, branch chief for Engine Components Development and Technology at Marshall, worked with Concepts NREC and considered the company an SBIR success story.

"There's a point at which a pressurized tank propulsion system just becomes too heavy, and turbopumps are the solution," said Marsh. "There were pieces of software that we needed to design the turbopumps. Through the SBIRs, the company could integrate the software packages and add many special features." ●



# Super Insulation Requires Super Materials



Engineers at Marshall Space Flight Center have experience in testing spacecraft components against extreme temperatures, like the heat shield from the Orion spacecraft. The makers of Super Therm recognized this and reached out to the center for help. *Credit: NASA*

## NASA researchers helped create an insulation coating that blocks heat and sunlight

A summer day can be no picnic.

In addition to the outdoor heat and humidity, the direct sunlight beats indiscriminately on everything. Without proper insulation, a metal-roofed building can quickly feel like an oven.

In the late 1980s, Joseph Pritchett was developing an insulation coating in the U.S. Sun Belt and learned that not all his customers were satisfied with the options available at the time, so he thought he'd develop his own product. He knew NASA had experience in thermal testing, particularly in the realm of ceramics, which have several uses for the agency. Ceramics' heat-resistant properties make them excellent materials for spacecraft re-entry shields, and their durability is perfect for airplane components. However, as Pritchett later discovered, not all ceramic compounds can work in a coating that's applied wet and blended with paint. He had to find the right ceramic, and he thought by infusing paints with both insulating ceramic compounds and tough, resilient polymers, he could devise a coating insulation with the best features of both.

Through the Technology Transfer Office at NASA's Marshall Space Flight Center in Huntsville, Alabama, Pritchett contacted the center's materials lab. The facility had many ways to test heat-resistant materials, such as a thermal vacuum chamber that simulates the extreme temperature swings in space and a thermomechanical analyzer that measures how a sample expands under heating. When he asked researchers there for compounds that could help him, the scientists provided a list of possible ceramics. When none of those worked in a coating, the Marshall engineers widened their search and came back to Pritchett with more ceramic compounds.

Over a period of six years, Pritchett tested every compound on the lists NASA provided, whittling down the potential compounds until he found the perfect insulation. Pritchett founded Superior Products International II Inc. of Shawnee, Kansas, in 1995. The product, dubbed Super Therm, is a composite of both ceramic and polymeric materials. The ceramic acts as the primary heat reflector and heat-blocking insulator, while the polymer is more of a heat- and environmental-resistant binding agent. In 2011, when tested by the Oak Ridge National Lab for a pilot program for cooling low-income housing, it was confirmed that Pritchett's product would work as suggested and save energy when cooling homes.

Pritchett said the engineers at Marshall played a pivotal role in Super Therm's development, as their knowledge was key to finding the right ceramic material. In addition to building

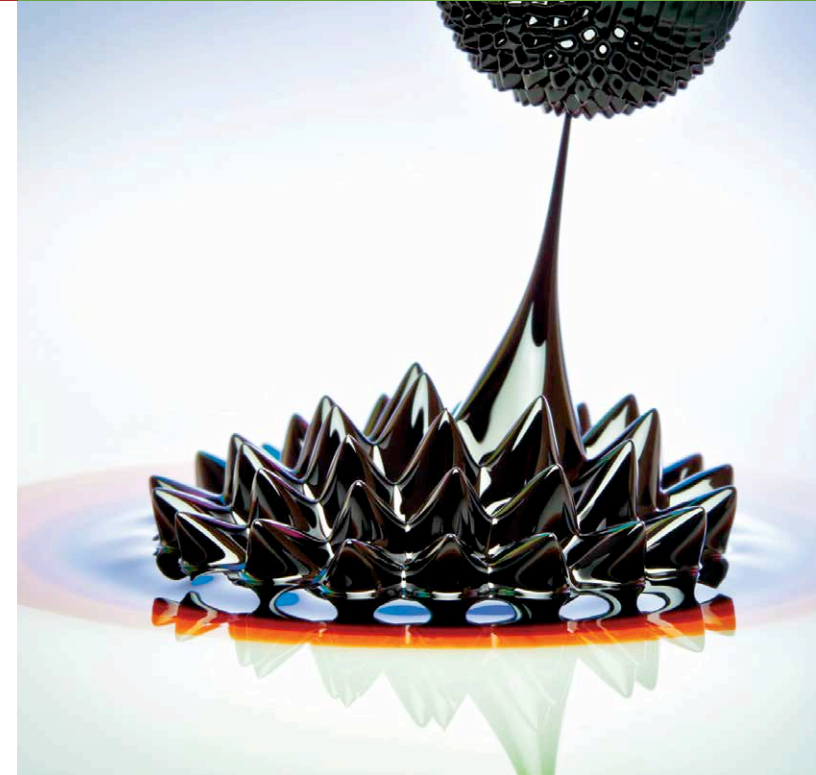
insulation, the material has been used in industrial applications, such as keeping equipment like tanks and pumps cool on oil rigs. Pritchett said other insulation providers have only recently started looking into the same material components to improve their products, but he's grateful Super Therm had the head start.

"It is now a source of accomplishment that I was able to work with NASA to get a start on the study of ceramic compounds when all the others are just now doing it," Pritchett said. "It gives us a 30-year head start on the study of what works and what does not work." ●



The thermal protection system on the outside of the space shuttle included hundreds of ceramic tiles custom made for the orbiter. These reflected heat off the shuttle's outside surface during atmospheric re-entry and were an inspiration for the ceramic ingredients in Super Therm. *Credit: NASA*

# From Magnetic Rocket Fuel to Semiconductors



Ferrofluids – liquids infused with magnetic properties that activate under certain conditions – are sold by the South Korean company MAGRON for use in semiconductor manufacturing, fishing rods, and other consumer products. *Credit: Getty Images*

## A South Korean company offers ferrofluids for a variety of applications

When NASA's Stephen Papell invented the first magnetized liquid in the early 1960s, he was focused on rocket fuel – not semiconductors, speakers, luxury cars, fishing rods, or art.

Those other applications wouldn't come until decades later, when companies like MAGRON, based in Ansan, South Korea, began offering their own line of ferrofluids – the liquid Papell first patented and for which he won multiple NASA awards.

Papell's initial research came in the earliest days of the space program, when NASA engineers weren't sure how liquid fuel would flow to a spacecraft engine in the absence of gravity. Papell – working in Cleveland at NASA's Lewis Research Center, now Glenn Research Center – infused fuel with tiny, coated iron oxide particles that took on magnetic properties under certain conditions, enabling an electromagnet near an engine's turbopump to draw the fuel to it.

That idea didn't fly (in space) because it didn't need to – other methods of ushering fuel to the engine worked better in zero gravity. What remained, however, was the technique for magnetizing liquids – or, technically, creating superparamagnetic liquid, which takes on magnetic properties in the presence of an external magnetic field.

Further experimentation at NASA and elsewhere in the years that followed revealed additional processes for making ferrofluids (Spinoff 1980, 1981, 1993, 2015, 2018) out of various materials, and a variety of new applications.

MAGRON's trade manager Kwon Se-heon said he knew NASA had developed the first ferrofluid decades ago. In designing its own products, the company's developers referred to Korean papers and academic journals with more recent research and findings.

The company's most popular product is a ferrofluid for sealing out gas and dust that is used in the manufacturing of semiconductors, Kwon said. Semiconductors are typically used in electronics and solar cells.

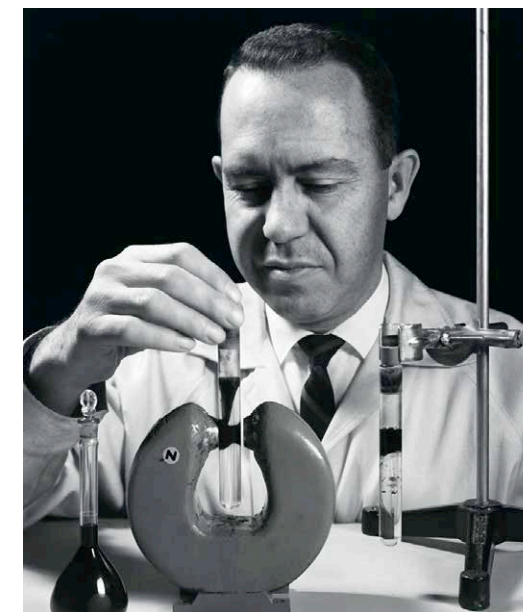
Ferrofluids can create an airtight seal by sticking magnetically to the edges of a gap between moving parts. They are extremely slow to evaporate or degrade and highly resistant to extreme heat and chemicals, so they are long-lasting, even under harsh conditions.

MAGRON also sells ferrofluids for waterproof fishing reels and for art and educational purposes.

Ferrofluids could still one day be useful in space, according to Narayanan Ramachandran, who works on propulsion fluids at NASA's Marshall Space Flight Center in Huntsville, Alabama, and has published research on ferrofluids.

"The sealing properties of ferrofluids – they seal against dust as well as differential pressure – could be used, for instance, in an astronaut visor or in rotating system seals, such as on a rover or even a lab circling the Moon," Ramachandran said.

Back on Earth, researchers are also studying ferrofluids in cancer therapies, developing approaches that could one day change how doctors treat cancer patients. ●



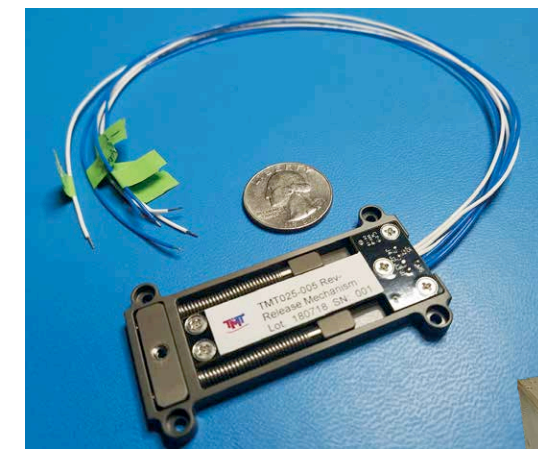
Ferrofluids were first developed at NASA in the 1960s by Stephen Papell, pictured here, at Lewis Research Center, now Glenn Research Center in Cleveland. *Credit: NASA*



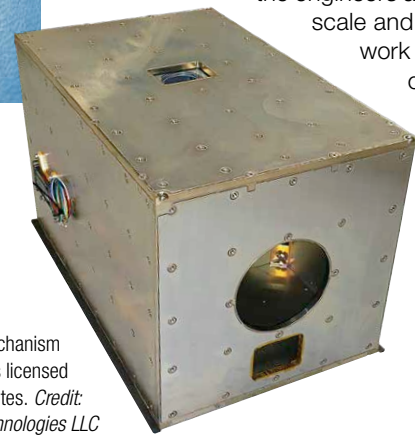
# A Huge Development for Tiny Satellites



The Dellinger CubeSat falls into orbit shortly after its release from the International Space Station in 2017. The antennas on the small satellite were deployed as a test of the Diminutive Assembly for Nanosatellite Deployables (DANY) mechanism, which was later developed into the Gecko Actuator. *Credit: NASA*



The Gecko Actuator built by Thermal Management Technologies (TMT) is extremely compact. This allows CubeSats to fit large attachments like antennas, radiators, or solar panels into the limited payload space aboard rockets. *Credit: Thermal Management Technologies LLC*



This small satellite features a Gecko Actuator release mechanism on the side. Originally developed by NASA, this system was licensed by TMT so it could be used aboard commercial satellites. *Credit: Thermal Management Technologies LLC*

## NASA-developed mechanism improves reliability of small satellites

For satellites to fit into their enclosures on top of a rocket, they often launch folded up into a much smaller size, then unfurl any external equipment once they reach orbit. These parts, such as solar panels and antennas, are known as deployables. While these systems have been refined for large satellites, engineers working on smaller orbiters like CubeSats have had difficulties miniaturizing the mechanisms that release deployables.

One of the most popular solutions has been a thin monofilament rope, similar to fishing line, that secures deployables to the body of the satellite. This line is then burned by a small heating element to release the equipment. However, this process is unreliable, and the exposed nature of the wire causes a high failure rate on these components. Luis Santos, currently the chief engineer of the small satellite office at NASA's Goddard Space Flight Center in Greenbelt, Maryland, saw the issues facing deployables on CubeSats and thought there could be a better solution.

"I just thought, what would be the best way to hold the deployables in place that is repeatable?" Santos said.

He separated the problem into two areas: holding the deployables securely and a movement initiation device. The resulting system combines a nichrome wire and a type of easily molded plastic to initiate the release movement while another mechanism holds and releases the deployable instead of wire alone. The release mechanism became much sturdier and could still be released using the same kind of heating approach, which saves volume and mass in comparison to other mechanisms. Santos named this new method the Diminutive Assembly for Nanosatellite Deployables (DANY).

"Around that time, I had my first son, and his name was Daniel, so I called it a 'Danny' mechanism," Santos joked.

Some prototypes were first tested aboard sounding rockets launched from NASA's Wallops Flight Facility on Wallops Island, Virginia, and later demonstrated on the Dellinger CubeSat mission launched from the space station. The technology proved its worth in space, able to deploy antennas and sensors flawlessly. Soon after, it started to receive interest from the private sector.

"It's a thermal-based actuator, so it kind of fits into our thermal products that we design and develop," said Scott Schick, president of Thermal Management Technologies LLC (TMT) of Logan, Utah, the first company to license DANY for commercial use.

As the company's name implies, its primary business is in providing thermal controls such as radiators for spacecraft and industrial applications. The company was looking for a release mechanism for its deployable radiators, and DANY seemed to be a good fit. While they officially licensed the patent in 2018, the engineers at TMT found the component was not easily reproduced on an industrial scale and needed more development time to be commercially ready. During the work to build out the technology's capabilities, Schick said, they had extensive communications with Santos and his office at Goddard.

TMT's commercial version of DANY is called the Gecko Actuator, owing to the namesake lizard's ability to maintain its grip until release is necessary. In addition to governmental and nongovernmental institutions looking to build CubeSats, several commercial companies have purchased them as well. These use them in applications ranging from Earth-observing satellites to small communications orbiters.

"Anyone who has an antenna could use this, and every spacecraft has an antenna," Schick said. ●

# Connections Made in Air and Space



When astronauts fly aboard the Orion spacecraft during the Artemis II mission, data on their status will be crucial on the ground. DornerWorks' network switch allows information to be quickly routed where it needs to go, whether inside the spacecraft or out. *Credit: NASA*



While designed for the Orion spacecraft, the Ethernet switch created by DornerWorks can be used in many applications that require fast networking, such as self-driving cars. *Credit: DornerWorks Ltd.*

## Industry benefits from networking hardware designed for Orion

Your home internet router has more in common with the Orion spacecraft than you'd think. Both use a standard known as Ethernet to send communications between computer systems. Ethernet is ubiquitous throughout this world, but it has some applications that are out of it.

Many Ethernet connections require a piece of hardware called a switch, which takes one connection and splits it between several computers. These components are necessary in environments such as office buildings or schools, where hundreds of people share an internet connection. Unlike an Ethernet switch on the ground, a switch on the Orion spacecraft needs to be lightweight and hardened against the extremes of space travel, including the stresses of launch aboard NASA's most powerful rocket to date.

"You're not going to be able to find anything on the ground that will fly in space," said Christine Bland, head engineer for Orion electronics at Lockheed Martin, which builds the spacecraft for NASA's Johnson Space Center in Houston. "Orion has to go out and survive deep space and different radiation environments. It's got to pass through the Van Allen belts, get hit with solar winds and galactic radiation ... the design has to encompass all of that."

DornerWorks Ltd. of Grand Rapids, Michigan, was subcontracted to work on the Ethernet switch by another company building the Orion computer systems. The computers aboard Orion make up two distinct systems, one that controls crucial systems like guidance and life support, and another that manages data from all the spacecraft's sensors. The latter includes everything from astronaut video conferences with the ground to views of the Moon from cameras outside the spacecraft. Ensuring this data gets where it needs to go requires speed, something Ethernet connections provide handily.

"It all comes down to performance, networking speed, and the number of connections," said Gregg Wildes, business development director for DornerWorks. "This is human spaceflight – you need that for safety."

Bland and the DornerWorks team worked to ensure the switch will be capable of everything necessary when crewed Artemis missions visit the Moon. The design can take in several telemetry streams and transmit them all back to Earth from the Moon, through all the cosmic radiation between.

"There weren't solutions that were this small and this reliable in those environments," Wildes said. "But now there are."

DornerWorks kept the patent rights to the switch and now sells it to the commercial sector as a product called, aptly, "Space Switch." However, the company largely licenses the design as intellectual property, allowing others to build it themselves. Customers include aircraft manufacturers and the automotive industry. Wildes said most companies use the Space Switch for something called time-sensitive networking, which is required for applications like self-driving cars.

"It's all about, 'Let's get lots of data through very quickly,'" said Wildes. "You'll have a guarantee for how long it'll take to get from point A to point B."

In the future, the company wants to leverage the technology it's built for more applications, especially in the growing commercial space industry. But company leadership credits all the work for the Artemis program with helping the company get off the ground.

"Our work with NASA and the investment NASA put into DornerWorks and helping us get into different markets – it's creating jobs," said Lance Hillbelink, vice president of sales for DornerWorks. "It's a benefit for Michigan." ●



# Synthetic DNA Diagnoses COVID, Cancer



Princeton University undergraduate Kate Sheldon, doing summer work at Firebird Diagnostics, holds a prototype of the Agnostic Life Finder, or ALF, which was developed to seek life on Mars without making Earth-specific assumptions about molecular biology. Credit: Firebird Diagnostics LLC

## NASA-funded molecular research enables better disease detection

At first glance, the search for life beyond Earth might not seem related to human illness. But to biochemist Steven Benner, the connection is clear.

“In diagnostics for infectious disease, you’re looking for alien life inside of a patient,” said Benner, who has spent nearly two decades conducting NASA-funded research on what alien life might look like at the molecular level.

“Of course, we actually know the structures of the genetic molecules in the coronavirus that is causing COVID, for example, so it’s actually a bit easier to build a diagnostics assay to detect COVID than it is to build an agnostic life finder to search for Martian DNA, whose structure would be unknown,” he said.

Benner is the cofounder and CEO of Firebird Diagnostics LLC, based in Alachua, Florida, which sells synthetic DNA and molecule packages to researchers, some of whom are using them to develop tools to detect and treat ailments like cancer, hepatitis, and HIV. The company sold COVID tests during the pandemic and has the technology to test for influenza and respiratory syncytial virus, or RSV, as well.

Benner holds that while some of what we know about biochemistry on Earth is universal, most is almost certainly Earth-specific. For example, Earth-based, natural DNA – the molecules that carry genetic instructions – is composed of four nucleotides that are sometimes described as building blocks. “What if DNA had six or eight different building blocks?” Benner asked.

To answer such basic questions, he and partners went into the lab and made DNA-like molecular systems with six and eight nucleotides, based on research funded in part by NASA’s Astrobiology Program. These systems add to the four building blocks in Earth-based DNA two or four more synthetic nucleotides.

The resulting synthetic or “alien” DNA has structures that are different from natural DNA but are still able to hold and copy genetic information. Most importantly, the platform can support molecular evolution, the fundamental feature of biology – and life.

Mary Voytek, head of the Astrobiology Program at NASA Headquarters in Washington, said Benner’s work has shown NASA that there are alternatives to Earth-based biological molecules. “This helps us understand what else is possible and might be found in life beyond Earth,” she said.

Benner’s molecules can also be evolved to bind to targets important to diseases, such as COVID-19 viruses or breast or liver cancer cells. This initial binding event can be the first step in finding these disease-causing viruses and cells and delivering drugs to them. Because it has more building blocks, the synthetic “alien” DNA has more ways to bind more tightly and selectively than natural DNA. This gives more accurate test results and better therapy targeting, Benner said.

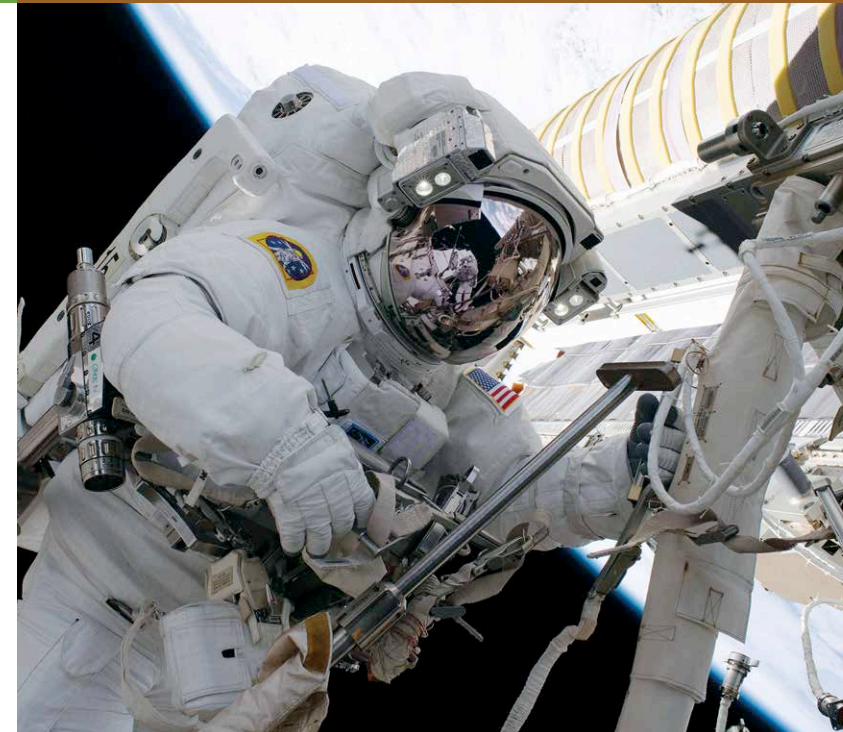
Many diagnostic processes also require a second binding event for detection. Here, the initial binding event attaches to a fluorescent “tag” that has been added to the sample, making the targeted molecule visible. Benner’s synthetic DNA can promote this second binding as well.

Firebird sold COVID tests based on these processes overseas and in the United States under emergency authorization from the Food and Drug Administration (FDA), primarily through its partner GenePath Dx. The company’s other diagnostic capabilities are available only for research purposes because they don’t have FDA approval.

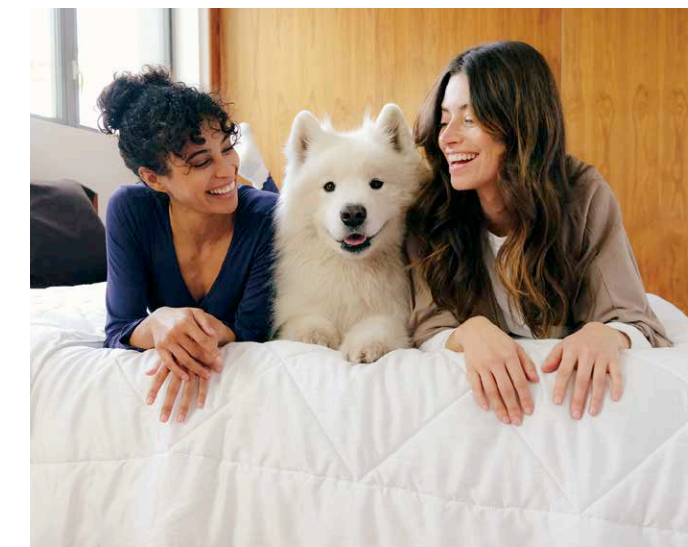
Benner said Firebird sells about \$1 million a year in “alien” DNA. His work with NASA has broadened the search for life on other planets and moons.

Benner said profits from Firebird have helped launch the Agnostic Life Finding Association to seek life on Mars in ways that would not overlook this type of alien molecular biology. ●

# Fixing ‘Thermal Incompatibility’ in the Bedroom



Spacesuits require robust environmental controls to keep astronauts comfortable in the extreme temperatures of space. While phase-change materials didn’t make it into any suit that’s been to space, NASA funding resulted in a textile now used widely in consumer products. Credit: NASA



Slumber Cloud products include bedding and loungewear made with a material known as Outlast, developed in part via a NASA contract intended to improve temperature regulation in spacesuit gloves. Credit: Global Web Horizons LLC

## Temperature-regulating bedding based on NASA-funded research keeps people comfy at bedtime

A good night’s sleep can often be an elusive achievement, but NASA technologies have helped people rest better for decades, from memory foam mattresses to LED lights that help regulate circadian rhythms. Now a material originally tested for spacesuits is keeping the night sweats away.

In the 1980s, NASA’s Johnson Space Center in Houston was exploring ways to improve temperature controls in spacesuits. With temperature swings between extremes of minus 250 to 250°F, astronauts need to have effective air conditioning when working outside their spacecraft. Through a Small Business Innovation Research contract (SBIR), the agency funded Triangle Research and Development Corporation to experiment with using the basic properties of matter to solve this complicated issue.

Phase-change materials take advantage of the fact that substances maintain a steady temperature while turning from liquid to solid or vice-versa. By incorporating these materials into tiny capsules in the textile, called “thermocules,” the company theorized it could make liners that would stay comfortable while external temperatures fluctuated.

Working off prior research it had done into phase-change materials for the U.S. Air Force, Triangle worked with NASA to create a prototype version of the material for spacesuit gloves. While it was never incorporated into anything NASA launched into space, Triangle licensed the material to Gateway Technologies, which was later renamed after this breakout product: Outlast. In the years since, Outlast has been shared with several companies around the world and used in everything from desk chairs to undergarments (Spinoff 1997, 2004, 2009, 2012, 2017, 2021, 2022, 2023).

In 2012, Outlast Technologies was acquired by CoorsTek and the new management wanted to diversify. Instead of licensing the technology to others, the company would produce some products internally, selling them through various direct-to-consumer brands. Global Web Horizons LLC, also known as Slumber Cloud, headquartered in Arvada, Colorado, was founded as a subsidiary of this larger company. Slumber Cloud offers several pieces of bedding that use the phase-change technology, from pillows and bedsheets to entire mattress pads.

“Out of all our product categories, every product uses Outlast today,” said Wily Van Dehy, CEO of Slumber Cloud. “Even our loungewear products have an Outlast treatment to them.”

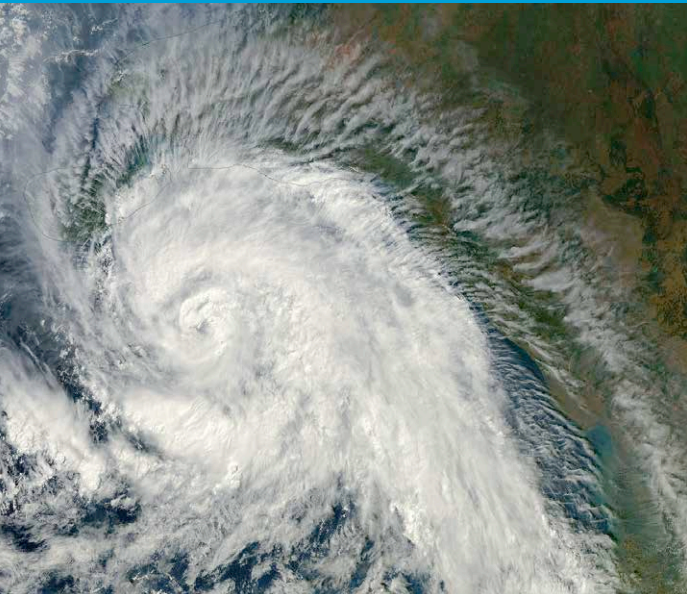
Outlast was spun out of CoorsTek in 2018, once again becoming an independent company headquartered in Germany. Slumber Cloud broke out in the process as well, becoming its own organization in 2019. Slumber Cloud is still based in Arvada, near the headquarters of its former parent company, and Van Dehy said all the firms still maintain a close relationship.

Since it was spun off, Slumber Cloud’s mattress pads and bedsheets have both been given awards by Good Housekeeping magazine, and more than 275,000 people have purchased their products. Van Dehy said the bedding is very popular with young professionals, people going through menopause, and “thermally incompatible” couples. In addition, much of the interest in the product is because of its connection to NASA.

“We like to say, ‘If it works in space, it’ll work in your bedroom.’” ●



# Aqua Solutions for Terra Firma

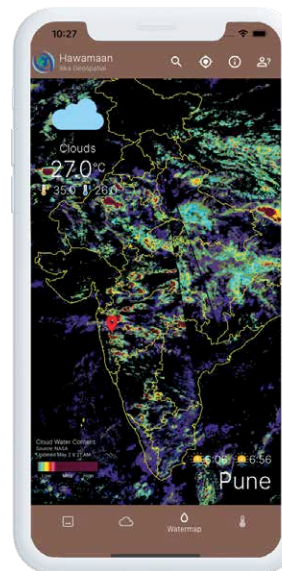


Tropical Cyclone Madi approaches India in 2013, as seen from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument aboard the Aqua spacecraft. Because the satellite's imaging capabilities have a global reach, iilka Geospatial uses data from Aqua and its sister satellite Terra to provide weather forecasting in underserved areas of India. Credit: NASA/GSFC/Jeff Schmaltz/MODIS Land Rapid Response Team



NASA's Aqua and Terra satellites both feature a scientific instrument called MODIS that takes extremely detailed images of Earth's environment. MODIS data is a key part of iilka Geospatial's offerings, as it provides enormous amounts of information relevant to people on the ground, from farmers to CEOs. Credit: NASA

This screenshot of the Hawamaan app shows numerous weather systems over India. Data from the orbiting MODIS instruments allows the app to display forecasts for areas that don't have access to ground-based solutions like Doppler radar. Credit: iilka Geospatial LLC



## NASA satellite imagery supports weather app for farmers in drought-stricken regions of India

Increasingly unpredictable monsoon seasons in India are playing havoc with small farms, to the point that, according to India's National Crime Records Bureau, thousands of the country's farmers commit suicide every year, a crisis that troubled Pankaj Patil.

As someone who grew up in a rural area of the South Asian nation, Patil knew farmland was prone to droughts, and that problem was only getting worse with climate change. These areas were not well served by ground-based weather forecasting technologies like Doppler radar. Having worked with NASA as a graduate student in Florida, he knew the instruments aboard the agency's Aqua and Terra satellites could help.

First launched in 1999 and operated out of NASA's Goddard Space Flight Center in Greenbelt, Maryland, the Moderate Resolution Imaging Spectroradiometer (MODIS) instruments aboard Aqua and Terra produce tremendous amounts of weather data. Using several wavelengths of visible and infrared light to image the entire surface of Earth every one to two days, the satellites paint a detailed picture of our home planet. This includes water levels, vegetation health, and even events like volcanic eruptions, heatwaves, and fires.

"MODIS has numerous products that are used by scientists for research in a variety of disciplines, such as oceanography, ecology, and atmospheric science. This technology is incredible and will open new doors for research across the globe," said Dr. Miguel Román, MODIS science team leader at Leidos, which manages Aqua and Terra for NASA. "It's like having a Swiss army knife for studying the climate from space."

Building off his prior experiences making business cases with NASA technology, Patil cofounded iilka Geospatial LLC of Edison, New Jersey, in 2020. The company uses satellite imagery to help various industries around the globe, from banking to agriculture, learn from the data provided by NASA's Earth Science missions.

One of the first projects undertaken by the company was an app called Hawamaan, which means "weather" in the Hindi language. The application has a specific focus on South Asia, targeting the underserved farmers Patil knew of. Using data from the MODIS instruments, the app can show the availability of water and rainfall trends in the region, simplified from raw satellite data into easy-to-read graphics.

"We needed to get these images in front of these people in the most convenient way possible," Patil said. "So why don't we just write an app that is not only giving the weather forecast, but also giving this additional context where people can look at the numbers?"

Patil said the app is now used by thousands of farmers across the subcontinent. Hawamaan can be downloaded on smartphones and mobile devices that are popular in the region.

While the company started with this app, it is expanding into the larger geospatial intelligence industry. Aqua and Terra are among the data sources included in its Earth Observation Indices program, a curated selection of figures that show the world's ecosystems and the connections between them. These include not only the availability of water for agricultural use but also indices that reflect atmospheric conditions, the recurrence of wildfires, and more. Patil said that even though the company has expanded its offerings, the Hawamaan app is still a priority and will keep being updated for as long as the company is around.

"It will always be supported," Patil said. "We can't forget our roots." ●



Delavie Sciences developed skincare ingredient Bacillus Lysate based on an organism identified and researched by NASA. The ingredient is used as an SPF-boosting additive in sunscreen products. Credit: Getty Images



Bacillus Lysate is also a key ingredient in Delavie Sciences' own line of anti-aging skincare products. Credit: Delavie Sciences LLC

# From Space to Your Face

## Radiation-resistant microbe studied in space leads to fewer wrinkles, less sun damage on Earth

After surviving the cosmic radiation and extreme temperatures of 18 months in space, an organism first identified by NASA decades ago is now improving sunscreens and anti-aging products.

Bacillus Lysate, which doesn't actually contain any live bacteria, is a skincare additive derived from Bacillus pumilus SAFR-032, a bacterium identified by NASA in the late 1990s. Found in a clean room at NASA's Jet Propulsion Laboratory in Southern California, where Mars-bound spacecraft were assembled, the microbe stood out because it had survived intense sanitization efforts by the Biotechnology and Planetary Protection Group, which aims to prevent planetary contamination.

"When you are going to look for life on other planets, it's better you don't take any microbes along with you as hitchhikers," said Kasthuri Venkateswaran, a senior research scientist at JPL, explaining why the space agency goes to such great lengths to sanitize spacecraft. Venkateswaran identified Bacillus pumilus SAFR-032 in 1999.

This microbe did end up making it to space after all, when astronauts, in a highly controlled study, set it outside the International Space Station for 18 months. Then Venkateswaran and his team performed extensive analysis on it, resulting in about 30 publications over two decades. The extremophile – an organism that can thrive under extreme conditions – is resistant to hydrogen peroxide and ultraviolet (UV) and gamma radiation. In fact, it's one of the most resilient microbes known.

The NASA team patented the bacterium, based in part on its potential usefulness in medicine, sunscreens, and research on how to keep clean rooms clean – once Bacillus pumilus SAFR-032 has been cleared out of an area, most everything else has been as well. NASA and the California Institute of Technology, which manages JPL, licensed the organism to Worcester, Massachusetts-based Liberty Biosecurity, a company that had previously been recognized by the space agency for its work on mitigating radiation during long-duration space missions.

Initially thinking Bacillus pumilus SAFR-032 could be incorporated into fabric or possibly coatings to add radiation resistance, the company analyzed Venkateswaran's research and conducted its own, determining that the organism's ability to absorb UVA and UVB radiation could be most valuable in skincare.

"That's what sunscreen blocks, right?" said Kyle Landry, who helped Liberty Biosecurity spin off skincare-focused Delavie Sciences LLC, where he is now president. Delavie Sciences, which is also based in Worcester, developed Bacillus Lysate using an extract of the organism Venkateswaran found at JPL.

"UVB and UVA are linked to skin damage," Landry said. "They're linked to sun damage, sunspots, wrinkles, and other health conditions. So, we thought, let's see if we can enhance sunscreen with the addition of Bacillus Lysate."

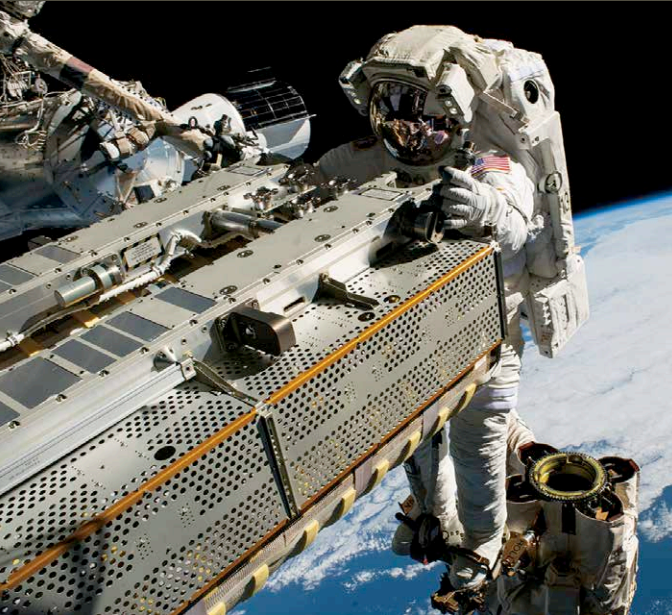
The company registered Bacillus Lysate as an ingredient for use in cosmetics after conducting safety, efficacy, and stability tests. The new ingredient is a Space Foundation "Space Certified" product for skincare. Now Delavie Sciences produces Bacillus Lysate in large quantities and sells it as an SPF-boosting additive for sunscreen products. The company also started its own line of face and eye creams – the Aeonie Age Defying Serum and the Aeonie Eye Refresh.

"We were able to expand on Venkat's research and go from lab to reality," said Landry, referring to NASA's Venkateswaran, who agreed.

"We just do the basic science and apply it to NASA's missions," Venkateswaran said. "Then we have to connect with companies like Delavie Sciences that come forward and do their own research to make something for people on Earth." ●



# Eco-Friendly Bio Breaks



Spacewalks aboard the International Space Station can take several hours to complete, and in the event an astronaut has to use the bathroom, the Maximum Absorbency Garment (MAG) component of the spacesuit can take care of the waste. *Credit: NASA*

## NASA-derived superabsorbent polymer helps relieve hikers, reduce pollution

On the space station, astronauts venture out into space to perform tasks needed to keep the orbiting spacecraft in working order, operations that often take hours on end. But when you gotta go, you gotta go.

It's been pop culture knowledge for decades that astronauts wear "diapers" on spacewalks, but the Maximum Absorbency Garment (MAG) used by astronauts is more than just a diaper, and now a polymer key to the underwear's function is helping to keep campgrounds and parks clean.

During early space missions, astronauts used more mechanical solutions to the problem of bodily necessities, such as tubes attached to the body that collected urine in a bag located on the leg of the spacesuit. But as more and more astronauts were selected, with different body types and genders, NASA needed a better way to ensure that spacewalks would not need to be interrupted when nature called.

Patented in the early 1980s, the MAG uses a highly absorbent polymer compound sandwiched between layers of specialized materials designed to remove moisture and keep the astronauts dry while outside their spacecraft. The sodium polyacrylate polymer absorbs the urine, transforming the liquid into a solidified gel. The waste can then be disposed of much more simply than the complicated collection system of the Apollo days.

The patent for the MAG expired in the 1990s, making it available for wider use. This design and the sodium polyacrylate polymer were used in other commercial products, such as baby and adult diapers, but wearable solutions aren't always the best ones when you're out in the wilderness.

"Sometimes, you need a dignified way to deal with human waste," said Gretchen Thornton, national sales manager at American Innotek Inc., which does business as Cleanwaste.

Headquartered in Oceanside, California, Cleanwaste uses the same polymer utilized in the MAG to give people a more environmentally friendly way to dispose of waste. When it was founded in 1999, the company started by pitching its products to the military but later found a new market in people who like outdoor adventuring, such as kayakers, campers, and hikers – particularly in national parks.

"People are becoming more and more concerned about contaminating the water there. You get up into where there's less oxygen on a mountain and you can bury that all day long, but it never goes away," Thornton said. "The national forests are becoming so crowded that no one can use the provided bathrooms. People are doing it right off the path, and it just ends up being everywhere."

Cleanwaste offers several different products for both kinds of human waste. These products work by using a bag that is filled with the polymer powder to break down the waste into the gel form, in addition to other additives that deodorize it. Poo Powder and Pee Wee are versions of the polymer specialized to their colloquial namesakes, but the Wag Bag is the most popular product, a kit that combines both products into bags that can be attached to an included portable toilet.

"It started more for people hiking up a mountain, but it's becoming more popular for people staying in campers," she said. "A lot of people don't like to deal with black water."

Beyond the outdoors enthusiasts, Thornton said the product has been used in unexpected places like the Burning Man festival, as the temporary city the organizers build in the desert has no plumbing and the portability fits their ethos of leaving no trace. Ultimately, Thornton said that without NASA, the product wouldn't be where it is today.

"The government created this product that so many people use. NASA developed this and opened the door for others to invent with it." ●



Cleanwaste offers several products derived from the same polymer used in the MAG. Poo Powder and Pee Wee are both tailored to their colloquial namesakes. The company also offers a product that is a combination of both. *Credit: American Innotek Inc.*

# Space-Saving Exploration



Astronauts have extraordinarily little personal space while onboard the International Space Station, so the area is designed to use all surfaces – walls, ceiling, and floor – as this image of astronaut Scott Kelly's crew quarters demonstrates. This highly efficient use of space inspired the design of Taxa trailers. *Credit: NASA*

## Space habitat expertise drives recreational vehicle design

Next to a beach, it's raining, so a family of four eats lunch inside their camper. After a hike in a national park, an empty-nester returns to a campground to cook dinner over an open fire and watch the sunset. Because there's more than one way to go camping, Taxa Outdoors Inc. builds trailers designed with a NASA-style approach to human habitats. The Houston-based company creates compact, customizable living spaces to support terrestrial outdoor adventures.

Garrett Finney, CEO of Taxa, said he was "wildly influenced" by his former role as senior architect with the Habitability Design Center at NASA's Johnson Space Center in Houston. The effort to create a human-focused living space on the International Space Station allowed him to develop specialized knowledge about small spaces and related equipment. He later returned to the agency as a consultant to support lunar habitat studies. All the while, he was an avid camper.

Bringing those two interests together to create "mobile human habitats built for adventure," Finney designed the first camper, called the Cricket, for himself (Spinoff 2012). The company has since added three more models – Mantis, Tiger Moth, and Woolly Bear. The one-person enterprise grew to more than 100 employees, adopted a new name – Taxa Outdoors – and continues to follow the original guiding principle.

"The founding idea of the company is that camping is really important. We're giving people a multi-use adventure machine that allows them to be out in the environment," said Finney. To do that, the company employs the three-dimensional approach used in space habitats to meet the most important needs, using every surface in multiple ways. A roof that offers protection and transports cargo also has hooks inside to suspend mesh storage nets or hang retractable sleeping cots for children.

Inspired by the highly efficient use of space in astronaut quarters where all surfaces, such as walls, ceiling, and floor, pull double duty for storage, the Woolly Bear has plenty of compartments and a top-mounted tent. The tailgate serves as a portable kitchen with a built-in awning and space for chairs and other party supplies. The Tiger Moth is a small camper that can comfortably sleep two adults inside. A rooftop tent can accommodate two friends.

For larger groups, there's the Mantis, which can easily accommodate four adults and has more of the comforts of home to make camping with small children or year-round camping easier. The 105-square-foot space has lots of storage along with an indoor kitchen area, built-in shower, air conditioner, furnace, and more. Just as a spacecraft must generate its own power using solar panels and store electricity in batteries on board, this and other Taxa trailers can do the same, eliminating the need for an electrical hookup.

Every model has an off-road version called Overland. Increased ground clearance, all-terrain tires, and other elements improve durability and make it easier to go off the beaten path.

In contrast to the mini-house approach of a large recreational vehicle, Taxa prioritizes efficiency. That doesn't mean "ruthlessly pared down," said Finney, but rather the "most succinct answer" to the complicated challenge of getting individuals and families of all sizes anywhere they want to go.

And the company isn't stopping there. Details about an upcoming product line aren't available yet, but Finney offered a hint: "Not all habitats have wheels." ●



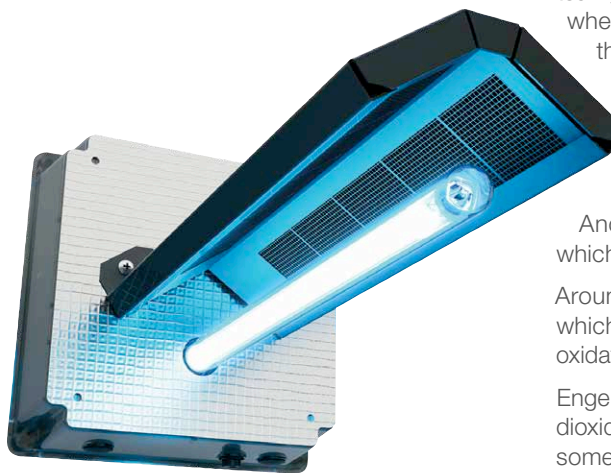
The largest of Taxa's campers, the Mantis can keep a family safely tucked in at night and away from the elements. A bench seat for daytime reading converts into bunk beds, and power for the cooktop stove and reading lights comes from onboard batteries. *Credit: Taxa Outdoors Inc.*



# Air Treatment Systems Break Down Pollutants, Germs



Astronaut Peggy Whitson checks on soybean plants growing in the Advanced Astroculture plant-growth chamber, which went into use on the International Space Station in 2001. The NASA-funded Wisconsin Center of Space Automation and Robotics invented an ethylene scrubber that kept the plants from withering prematurely and became the basis for Fresh-Aire UV's air purifiers. *Credit: NASA*



Fresh-Aire UV's APCO-X, designed for installation in air vents, uses an ultraviolet lamp and activated carbon dipped in a nanoparticle titania suspension to break down organic contaminants in the air through a process known as photocatalytic oxidation. *Credit: Fresh-Aire UV*

## Technology pioneered for space plant-growth chambers cleans indoor air

By 2020, Fresh-Aire UV had been growing its line of air purification products for 20 years, but no product debut had brought the kind of attention that came with an airborne pandemic.

"You always look for ways to bring awareness to the technology. You don't really want it to be a pandemic, but in this case, it was," said Chris Willette, the company's founder and former president.

Among Fresh-Aire's latest technologies was one that began with NASA funding in the 1990s. Known as photocatalytic oxidation (PCO), it became key to helping the Jupiter, Florida-based company's products fight the virus that causes COVID-19.

Fresh-Aire UV adopted PCO 10 years earlier to treat rising indoor levels of volatile organic compounds (VOCs). As buildings have become more airtight to increase efficiency, they trap more pollutants. Meanwhile, increasingly common synthetic building and furniture materials often release VOCs like formaldehyde, acetone, and others. The resulting rise in indoor pollution has accelerated rates of asthma and allergies, and many VOCs are carcinogenic, said Willette.

"Filters address one-third of contaminants in the air – dust and dander," said Aaron Engel, vice president of business development at Fresh-Aire UV. "The other two-thirds, such as microbes and VOCs, pass through a filter like sand through a tennis racket. Our systems address those two-thirds."

PCO was invented to eliminate the organic compound ethylene from plant-growth chambers in space. Without gravity, there's no convection to circulate air, and ethylene, a hormone that accelerates aging and ripening, builds up around plants, causing them to wither prematurely.

The work was pioneered at the Wisconsin Center for Space Automation and Robotics at the University of Wisconsin-Madison, funded by NASA's Marshall Space Flight Center in Huntsville, Alabama. The team, led by Professor Marc Anderson, wanted to use a technique that was then in its infancy. In PCO, when ultraviolet light strikes titanium dioxide, it releases electrons that bond with oxygen and water in the surrounding air, making them reactive. These charged molecules attract organic contaminants, breaking them down into carbon dioxide and water. It turned out to be effective against not just ethylene and VOCs but also bacteria, viruses, and molds.

A number of commercial products have been based on the technology (Spinoff 2002, 2009, 2012, 2013, 2015, 2018, 2022).

Anderson later cofounded a company called Microporous Oxides Science and Technology (MOST), which offers nanoparticle suspensions including the titanium dioxide used in PCO.

Around 2010, Fresh-Aire UV was developing PCO technology when the company came across MOST, which became Fresh-Aire's titanium dioxide supplier, said Willette. Its APCO (adsorptive photocatalytic oxidation) and APCO-X product lines are built around activated carbon dipped in MOST's titania suspension.

Engel said using activated carbon, which captures organic contaminants, in conjunction with the titanium dioxide coating, is what distinguishes Fresh-Aire's PCO technology. PCO reactions have several steps, and some of the intermediate chemical by-products may be harmful, he explained. So the activated carbon holds contaminants in place until they're completely broken down.

Engel said APCO products now account for around half the company's business. These and other Fresh-Aire products saw incredible demand during the pandemic, with the company opening an additional 35,000-square-foot facility to increase production. During that time, the company was acquired by HVAC firm DiversiTech, which helped scale up operations. ●

# Temperature-Regulating Clothing Additive Heats Up



Artilect Systems now incorporates Trizar into the lining of many of its winter apparel items. *Credit: Ali Vagini*

## Materials for coating spaceplanes maintain comfort in outerwear, sports uniforms, jeans

NASA intended its Reusable Launch Vehicle program of the 1990s to demonstrate technologies that would enable hypersonic spaceplanes to make affordable, repeated trips into space. It was never intended to improve the performance of hunting, skiing, and sports gear, but, more than 20 years after its cancellation, that's what's happened.

One of the program's most successful spinoffs has been a substance dubbed Protective Coating for Ceramic Materials, or PCCM, which NASA's Ames Research Center in Silicon Valley, California, invented to protect the spaceplanes' heat shields during atmospheric re-entry. NASA patented the coating, and Wessex Inc. – now known as Emisshield Inc. – licensed it and started developing commercial products.

The material isn't a traditional insulator, and it's not reflective. Instead, it has remarkably high emissivity, meaning it could absorb heat from a heat shield and radiate it away from the spacecraft. Emisshield has adapted PCCM into dozens of formulas now coating industrial equipment around world (Spinoff 2001, 2004, 2011, 2019).

In 2013, Brad Poorman and Jim Hind incorporated Clean Textile Technology LLC, now of North Naples, Florida, and were looking for a niche in high-tech textiles when they learned of PCCM. They approached Emisshield, which agreed to license its technology exclusively to them for use in fabrics in exchange for a share in the brand.

By 2015, Trizar was up and running, with commercial partners turning out a combined 300,000 or so jackets that year (Spinoff 2016). Since then, the company has advanced its technology and worked its way into jeans, sports uniforms, and even face masks. In cold-weather gear, which is most of the company's business, the material emits body heat back to the wearer. Trizar also produces low-emissivity formulas for hot weather.

"During the pandemic, Emisshield was awarded patents around the fibers and fabrics we had developed, and we did a lot of R&D while the factories were shut down," Poorman said.

At first, the emissive ingredients were printed onto fabrics, but the team has now devised ways to incorporate them into thread or yarn before it's turned into cloth. "By getting it into the yarn, we've been able to deliver performance without adding any weight and with much less cost," Poorman said.

Many commercial breakthroughs have come with these developments. A few years ago, Endeavor Athletic started using Trizar in some of its training apparel, and O'Neill put it into skiing and snowboarding jackets. Now customers can find Trizar materials in FORLOH hunting gear, Artilect Studio ski jackets and pants, KJUS jacket liners, Ergonomix apparel for hot and cold weather, Levi's jeans sold in East Asia, and New Balance's basketball and professional lacrosse uniforms.

The company makes its emissive material concentrates in the United States before shipping them to textile mills around the world.

Trizar was growing at about 20% annually until the pandemic hit, and the pace has picked up to 30-40% annual growth since the return to a relative normal, Poorman said. And during the pandemic, Trizar was incorporated into high-end facemasks that sold over 100,000 units.

Poorman said Trizar's popularity with consumers has helped it find new brands and markets. But its origins in the space program also don't hurt, he said, noting that customers know space travel requires extreme temperature management. "Nowadays, everyone's into NASA," he added. ●



The Lockheed Martin X-33 X-plane, shown in this artist's rendering, was intended to demonstrate technology pioneered under NASA's Reusable Launch Vehicle program in the 1990s. The program was cancelled in 2001, but an emissive heat shield coating invented at Ames Research Center under the initiative has since found widespread commercial success as the Emisshield product line. *Credit: NASA*



# SPINOFF Features

As NASA identifies and creates the technologies needed for humans to explore beyond Earth's atmosphere, businesses are transforming those same tools into useful innovations supporting life on this planet. The following pages represent some of the NASA hardware, software, and data that businesses and individuals use daily.

A portion of the Moon looms large just beyond the Orion spacecraft in this image taken on the 20th day of the Artemis I mission. At its closest point, Orion flew within 80 miles of the lunar surface.



# Spherical Robots to the Rescue

Scouting robots designed for space warn first responders of gas leaks, other dangers

Dr. Alice Agogino was researching spherical, skeletal robots that might one day be dropped onto Mars or the Moon to collect information and conduct science experiments, when she realized her NASA-funded technology could have terrestrial benefits as well.

Reading a report on the dangers and high death toll of disaster response, Agogino recognized that her robots, fitted with the right sensors, could gather data at the scenes of fires, crashes, explosions, and other disasters to help first responders assess situational dangers like toxic gas leaks and plan their approach.

“We thought, wow, if we can do this on the Moon, we should be able to do it on planet Earth and save some lives,” said Agogino, who was then director of the Berkeley Emergent Space Tensegrities Lab at the University of California at Berkeley.

She went on to cofound Berkeley, California-based Squishy Robotics Inc. The company makes impact-resistant, customizable robots for public safety, military, and industrial uses.

## ‘The Robot Itself Is the Landing Gear’

Agogino’s robots look like ball-shaped skeletons made of rods and elastic cables. She describes the structure as “a tension network” – if one of these robots is dropped, the impact is distributed across the whole network, dissipating the force, according to the principle of tensegrity.

The term tensegrity – short for tensile (or tensional) integrity – was coined in the 1960s by architect R. Buckminster Fuller, who popularized geodesic domes, which are also tensegrity structures.

For NASA, the ability of tensegrity robots to withstand the impact of a long drop is especially interesting, as is the ability of these structures to collapse into a small package during travel.

Dr. Alice Agogino cofounded Berkeley, California-based Squishy Robotics after realizing spherical robots she was designing with NASA Early Stage Innovations funding to comb planetary and lunar surfaces could help first responders assess disaster scenes on Earth.



Credit: Squishy Robotics Inc.

Squishy Robotics’ tensegrity sensor robots help first responders determine their approach to a disaster scene. Pictured here during a subway attack scenario exercise at the 2021 Unmanned Tactical Application Conference, the robots can detect gas leaks and other hazards. Credit: FLYMOTION LLC

The agency awarded Agogino and her UC Berkeley lab Early Stage Innovations (ESI) funding in 2014 to research tensegrity robot mobility using gas thrusters. The \$500,000, multi-year, proof-of-concept ESI grants aim to accelerate the development of innovative space technologies that have significant potential.

Agogino and her team were designing space exploration probes that could drop from a planetary orbit or a larger spacecraft, survive the drop carrying delicate sensors, and then roll and jump over rough terrain to perform missions and scientific monitoring on the Moon and on other planets.

“Think about the Mars Curiosity and Perseverance rovers,” said Terry Fong, chief roboticist in NASA’s Intelligent Robotics Group at Ames Research Center in Silicon Valley, California.

Fong, who was the NASA-side technical representative for Agogino’s grant, explained that the Mars rovers had to be gently lowered to the planet’s surface with the elaborate Sky Crane system, which was heavy and complicated and used only for the final part of landing on Mars.

“With tensegrity robots, the robot itself is the landing device,” Fong said. “It could survive a fall from very high up and then keep going.”

The tensegrity devices can be folded flat for travel – in fact, that’s how Agogino ships the ones Squishy Robotics sends to customers. Once the robot unfurls, its instruments and sensors are suspended in the center, protected from the impact of a fall or crash.

“So, you save on throwaway mass,” Fong said. “It’s expensive and difficult to launch mass into space, so you want more of it to be used beyond landing, to be used on the surface with scientific instrumentation and other payloads.”

## Informing the Decision to Suit Up

NASA also researched Earth science applications for tensegrity robots, which might be used to monitor, for instance, a glacier that’s about to break off into the ocean.

“That’s the kind of place you just would not want to, or could not, send a person to because it’s very risky,” Fong said. “The whole surface could collapse. With a structure that could survive a drop but still be mobile afterwards, you would have basically a super instrument positioning system.”

On Earth or on other planets, tensegrity robots offer a relatively easy way to place delicate instruments into difficult-to-reach areas. Indeed, that’s the principle behind Squishy Robotics.

Agogino and her team began speaking to fire departments and public safety officials in a process known as customer discovery. “At this point, we’ve interviewed around 300 first responders,” she said. “And it turns out there is a real need with hazardous material emergencies.”



Tensegrity robots can be “squished” down for easy packing and shipping – a feature that’s especially interesting to NASA because there’s not much extra room on spacecraft. Credit: Squishy Robotics Inc.



For these customers, Squishy Robotics now puts miniaturized chemical gas sensors inside the tensegrity robot structure that can be dropped by drone, helicopter, or fixed-wing aircraft, to take readings in an area before firefighters go in. Currently, the company only offers stationary robots, but Agogino and her team are working on mobile models as well.

The data these robots collect can inform firefighters' decisions about whether to wear hazardous material gear, which can add up to an hour of prep time – a delay that's only worthwhile if it's necessary.

### From Firefighting to Preventing Fires

Squishy Robotics has worked with some of the largest fire departments, including Southern Manatee Fire and Rescue in Florida, the Tulsa Fire Department in Oklahoma, and the San Jose Fire Department in California. The company has also established reseller agreements with a number of distributors.

Agogino's tensegrity robots also have military uses, such as helping to defuse bombs, and industrial applications, primarily helping to monitor gas and electric lines.

Wildfire prevention is another emerging area for Squishy Robotics. Tensegrity robots can monitor high-risk areas, help authorities respond to reports, and ensure that smaller fires have been fully extinguished.

"The early detection of wildfires is critical," Agogino said, "because so many of the wildfires that have become raging firestorms could have been prevented if they had been caught early when the fire started."

Agogino is now emeritus, having retired in December 2022 from Berkeley, a move that allows her to spend more time on Squishy Robotics.

NASA's Fong said he was happy to see Agogino was able to spin off the tensegrity robot technology.

"We believe these robots could serve unique purposes for space," he said. "She obviously saw a way to also have a major impact on Earth." ●

*"We thought, wow, if we can do this on the Moon, we should be able to do it on planet Earth and save some lives."*

*Dr. Alice Agogino, Squishy Robotics*

A drone transports one of Squishy Robotics' tensegrity robots as part of an exercise with Southern Manatee Fire and Rescue in Florida. Credit: Southern Manatee Fire and Rescue



# Satellites 'See' Sea Turtles, Ocean Threats

## A tracking system in low-Earth orbit locates turtles, boats, birds, oil slicks, and more



Tracking wildlife such as this endangered green sea turtle is possible due to lightweight transponders. Water temperature, dive depth, and other data collected anywhere on the planet is transmitted to the nearest Argos satellite receiver operated by the French CLS Group. Credit: French National Center for Space Studies

Sea turtles are considered a barometer of ocean health because their well-being depends on the health of their ecosystem, said Sarah Hirsch of the Loggerhead Marinelife Center in Florida.

These days, both are getting sicker. All sea turtle species are considered endangered, but it's difficult to know how to reverse their decline when the first years of their life are spent in the open ocean where it's been virtually impossible to keep track of them.

Until recently, scientists referred to sea turtles' childhood as "the lost years," and the only data collected about this period came from accidental encounters, inadequate for systematic efforts to prevent poaching and premature deaths. But that has begun to change with the aid of technology NASA helped establish decades ago.

Learning about sea turtle habits in the ocean is one way the Loggerhead Marinelife Center located in Juno Beach, Florida, is supporting conservation. Fulfilling that mission requires a combination of NASA-developed technology – sensors and satellites.

Hirsch, senior manager of research and data with the center, said early on, scientists hoped to protect turtles' most heavily traveled corridors by using simple transmitters to identify those invisible places in the oceans. Thanks to miniaturization of technology and improved battery life, Hirsch and her team are able to learn a great deal more by using miniaturized sensors and transmitters to send data to satellites.

"We can now collect data on depth by adding a pressure sensor," she said. "We can look at a turtle's dive profiles to see how much time it's spending at the surface or down at the bottom, either resting or foraging." Details about feeding ground locations, water temperature, and salinity are a few more points of interest.

A transmitter attached to a turtle's back, usually after it receives treatment at the center's veterinary hospital, is designed to last about a year before falling off when the shell sloughs its outer layer. A water sensor recognizes when a turtle is at the surface and automatically transmits stored data to a satellite. Thanks to new trackers that can safely be attached to juvenile turtles, scientists now know that many appear to spend their childhood in the Sargasso Sea, a large, calm, seaweed-laden area in the middle of the Atlantic Ocean.

The Loggerhead Marinelife Center can collect information from transmitters within minutes of a download via a cloud computing service. That's added to a database shared with other conservation organizations. When location information is part of the transmitter settings, the data can automatically update a turtle-tracking map. This lets anyone follow a turtle's path, with the goal of inspiring people to learn about endangered species.

All of this technology, which is now integral to a global effort to reverse the decline of one of the sea's most beloved denizens, came about because of NASA's interest in Earth observation.

Created under a former international partnership with NASA, Argos satellite technology is used for wildlife tracking. Now operated by CLS Group in Ramonville-Saint-Agne, France, the privately operated service tracks location and sensor data for tagged birds, oceangoing ships, stationary marine assets, and more.



### Three Million and Counting

One of NASA's early attempts to learn more about the ocean ecosystem was a collaboration with multiple agencies, called Argos. The Argos technology is made up of tracker tags for Earthbound targets and satellite hardware to send and receive meteorological and oceanographic data. Since the first launch in 1978, the technology has been upgraded several times, and the most recent version launched in 2022.

Argos today is used to track not only sea turtles and other wildlife but also ocean pollution, fishing boats, and other marine vessels, and it transmits distress signals from ships and offshore platforms.

After NASA stepped away from the project in the early 1980s, the French space agency, an original partner, established a public-private partnership called Collecte Localisation Satellites (CLS Group) to manage its end of the project. The U.S. National Oceanic and Atmospheric Administration (NOAA), another original partner, and new collaborators such as the Indian space agency have continued to help develop and fly the technology.

In 2019, CLS Group, headquartered in Ramonville-Saint-Agne, France, became a fully commercial entity, and the company has been expanding the tracking service to meet a growing demand for commercial applications.

"Whilst originally it was used for oceanography applications, Argos expanded into wildlife

monitoring – sea turtles, birds, almost any wildlife animal, really," said Anna Salsac-Jiménez, communications officer for CLS Group.

The transition to the private sector has been remarkably successful, with eight satellites serving users in 100 countries with around 22,000 active wildlife trackers at any given time, as well as transmitters on 5,000 vessels and 7,000 ocean platforms such as oil rigs. Nine hundred employees around the world support over 3 million data transmissions daily.

The location and data collection tags are now attached to numerous animal species, ships, buoys, and more. When the data is received by a terrestrial station, it's processed for CLS Group customers. It can then be organized into spreadsheets, added to maps, or converted into whatever format customers need.

Certified tracking tags use a specific frequency to reduce noise for data transmission, and it's become a plug-and-play system allowing anyone to build a transmitter.

### From Birds to Oil Slicks

CLS Group also works with a number of companies manufacturing tags for various uses.

For animals, the device can be no heavier than 3% of an animal's weight, making bird tagging particularly challenging. One that weighs only



Transponders designed to attach to the shell of a sea turtle are lightweight, so they don't interfere with the animal's ability to swim. The base (left) records and retains sensor data, transmitting the information along with a GPS signal when a turtle surfaces. As the shell sheds layers, the transponder falls off, like this one found in the Florida Keys (right) or can be safely removed from a nesting turtle (center). Any stored data can then be downloaded. Credit: NASA

0.07 ounces might still be too heavy for some birds but work fine for others, providing important migratory pattern information, said Salsac-Jiménez.

"Thanks to the expertise that we have at CLS, we can add land use data once we know where the birds go," she said. A change in a migration path could be explained by land use changes that create an obstacle. Land managers also use that data to modify placement of wind farms to protect important migration corridors.

A different kind of tag is tracking marine pollution. Buoys placed near offshore oil rigs constantly monitor water quality, regularly transmitting data. This is especially important for equipment that isn't frequently inspected. The moment a leak changes the water quality, the company is notified and can send a repair crew to fix the problem.

Drifting buoys using the CLS tags have been used to track the path of oil slicks and "islands" of plastic floating on the sea. The combination of GPS coordinates and knowledge about ocean currents and tides can help cleanup crews start work promptly, mitigating damage to sensitive ecosystems.

Fisheries are also using CLS tags to monitor conditions related to their business activities, including water quality and the location of their catch.

### Locating Trouble

The CLS Vessel Monitoring System is a satellite-based system for monitoring and managing fisheries. In addition to providing verification that small-catch fishing boats are legally operating in the correct area, it can provide a warning when a boat enters a restricted area, and crews can send distress signals if they need help.

Large oceangoing passenger and cargo ships are required to install a ship security-alert system, and one brand, ShipLoc, uses the tagging system. It allows ship owners to meet the maritime requirement while keeping track of their entire fleet. The system even allows the crew to send automatic alert signals ashore when faced with imminent danger.

The growing number of users is increasing the demand for real-time tracking. While current satellites are able to collect and transmit data approximately every 15 minutes, this coverage might not be enough.

To fill this gap, CLS Group created a company called Kinéis to develop and launch a fleet of 23 nanosats to carry Argos payloads. A dedicated constellation will provide nearly real-time service almost anywhere on the planet.

### Evolving Collaborations

Ocean monitoring is a tremendous undertaking encompassing a network of worldwide experts that sometimes overlap, so they depend on each other to manage the workload. One such intersection is occurring with the Surface Water and Ocean Topography (SWOT) satellite developed by NASA and European partners. The satellite, launched in late 2022, observes all of the planet's surface water, measuring ocean features at unprecedented resolution, according to Tahani Amer, program executive for SWOT.

"NASA is protecting our planet by understanding everything from the water cycle to the atmosphere. It's an incredibly challenging job, and we do this in collaboration with all of our international partners," said Amer. Scientists plan to use SWOT data to better understand the global water cycle, providing insight into the roles the oceans play in Earth's ecosystem because, Amer said, "water unites us, and SWOT is water."

CLS Group is one of more than two dozen early adopters that will help NASA prepare the SWOT data for wider distribution. "Our experts are assisting with the processing chain for the ocean



Tracking marine extreme sports participants such as these round-the-world yacht racers docked in Baltimore is easy now, thanks to GPS beacons that transmit location data to Argos satellite instruments. CLS Group operates the system started in 1978 as an international collaboration with NASA support. Credit: Jyothis, CC BY-SA 3.0

data," explained Salsac-Jiménez. "They're also preparing the format of the data and how it's read while SWOT is in orbit."

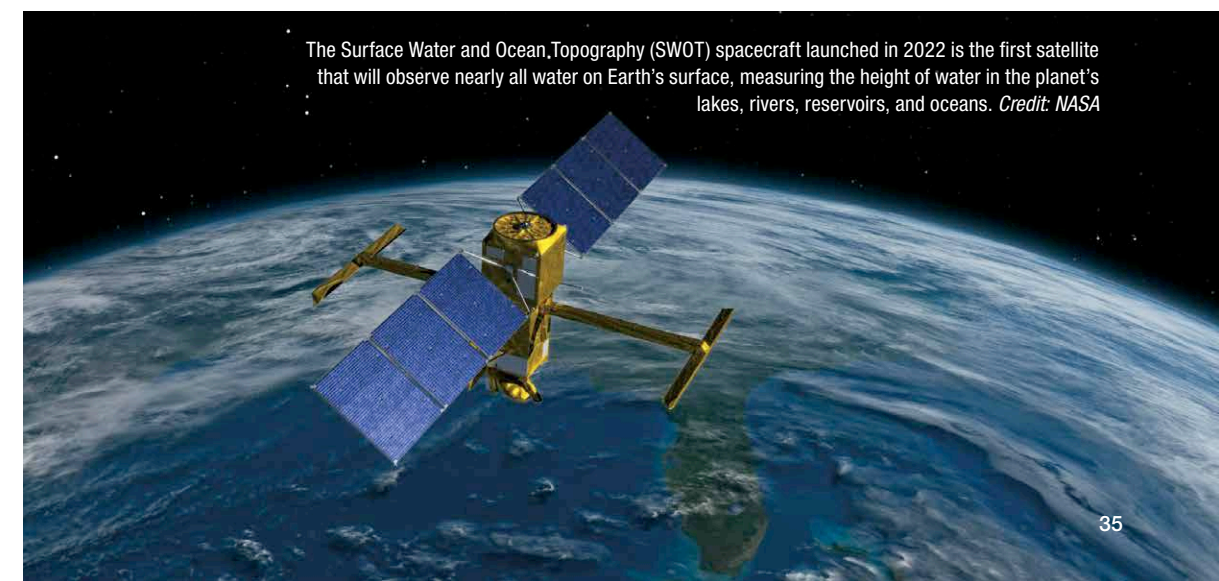
That information will be used to support an important effort for scientists and CLS customers alike – drift models. Drift buoys collect data to validate models that predict how things flow across the ocean. That might be tracking the direction of an oil slick or an ocean garbage patch. When SWOT data is added, the models will be more dependable.

With the expansion of the tracking service into non-maritime industries, from agriculture to crowdsourcing updates about hiking trails, Salsac-Jiménez credits that first collaboration with NASA for making it all possible.

"It started with NASA, NOAA, the French space agency, and everybody else," she said. "Without their collaboration and without their help, Argos wouldn't be where it is today. We wouldn't have the satellites or the payloads in place if it weren't for everybody else's contribution." ●



After a tanker or any other ship leaves port, it can be difficult to pinpoint its location. However, a new fleet of satellites carrying Argos payloads will provide near-real-time tracking for marine assets to ensure cargo and crew safety throughout a voyage. Credit: W. Bulach, CC BY-SA 4.0



The Surface Water and Ocean Topography (SWOT) spacecraft launched in 2022 is the first satellite that will observe nearly all water on Earth's surface, measuring the height of water in the planet's lakes, rivers, reservoirs, and oceans. Credit: NASA



# Redefining the ‘Rugged’ Video Camera

A new rocket-riding camera is tough enough for Earth



NASA's Space Launch System (SLS) rocket carried the Orion spacecraft on the Artemis I flight test in 2022. For the first time, thanks to seven strategically placed Imperx ruggedized video cameras on the exterior of the rocket, technologists watched the launch from the countdown through rocket booster separation from the rocket's vantage point. *Credit: NASA*

Dramatic video of the first flight of the Space Launch System (SLS), from the initial blastoff to rocket-booster separation, gave NASA essential information about the performance of the Artemis I flight. It also proved the capabilities of a new rugged video camera mounted on the exterior of the core rocket stage. The camera, developed using patented NASA hardware and agency expertise, survived the heat of blastoff and the cold of space, and it's now ready for extreme conditions on Earth.

Whether it's mounted to the underside of an airplane to live-stream takeoff and landing for the pilots or added to drilling infrastructure to stream a real-time view of equipment operation, the SPC-S2010 camera is likely the most rugged video camera available.

"It's very rewarding and very advantageous to work with NASA," said Greg Pangburn, CFO of Imperx Inc., the Boca Raton, Florida-based company that built the camera. "We learned a lot of new things that will allow us to offer something to our customer base that we've never had before."

## Too Cold to Handle

After initial testing of off-the-shelf cameras, engineers at NASA's Marshall Space Flight Center in Huntsville, Alabama, found that only one Imperx model, called the Cheetah, performed well on the most difficult challenge for electronics in space – radiation. Jarret Bone, a mechanical engineer working on the SLS camera system, said his team wanted to avoid designing a camera from scratch. Working with an existing camera helped simplify the process by shortening the time needed to perfect the system.

"There just aren't a lot of cameras that can live in space that have the optical requirements for resolution and the image size we needed," said Bone. So the team came up with a design to repackage the Cheetah model, enclosing it in a rugged housing incorporating the necessary electrical and mechanical components.

With an eye toward supporting a commercial camera for future missions, the agency patented the technology. But the need to add a heater presented a problem. When NASA engineers approached Imperx to collaborate, the company readily agreed.

Temperatures around a rocket traveling through space get cold enough to damage electronics. Imperx was happy to collaborate on adding a heater that could be turned on and

A ruggedized video camera that captured footage of the Space Launch System rocket during launch and in the extreme temperatures of space is available in a commercial version, created by Boca Raton, Florida-based Imperx with a NASA license and expertise.



Specifically designed for launch vehicle applications, the Imperx SPC-S2010 camera employs NASA-developed ruggedized housing and internal electronics design. The camera has an internal heater and an integrated LED illumination ring that supports continuous lighting. *Credit: Imperx Inc.*

off as needed, but it soon became apparent to Pangburn that it would be easier and quicker for the company to engineer NASA's requirements into a new camera model.

## 'Built Like a Tank'

Imperx created several versions of a custom camera for the Marshall team to test. The data from every success and failure informed changes, resulting in new models and more testing.

"Environmental testing is expensive, too expensive for us as a small business," said Pangburn. "Because of the extensive testing that NASA requires and their many areas of expertise, we learned a lot of things along the way." Recommendations for non-offgassing materials to eliminate interference with camera performance and changes to conformal coding are just a few tips from NASA being incorporated into numerous Imperx cameras.

A question about screws served as a learning opportunity that, for Bone, illustrates how aerospace expertise can benefit an existing commercial product.

"Imperx builds really elegant cameras – they're small, compact – but they use these tiny, millimeter-sized screws," he said. The company pointed out the housing was "built like a tank," believing that would be enough protection for the existing screws. But NASA's extensive experience building technology to withstand the extreme conditions of launch and spaceflight resulted in another improvement.

The NASA technologists invited the company to view environmental testing. The demonstration of how forceful vibration can effectively "unscrew" bolts gave the company a new definition



A ruggedized video camera designed to withstand the shock, vibration, and extreme temperatures of space could be durable enough to mount to train undercarriages for constant brake monitoring to ensure timely maintenance. *Credit: Tennen-Gas, CC BY-SA 3.0*

for "extreme," according to Pangburn. And it was useful for developing cameras for use in aviation, drilling, and mining.

The second design easily passed the vibration test.

## Adding New Customers

Bone credits the company with the "highly effective" firmware needed to pull the data from the sensor, format it, and transmit it. "That's expertise we didn't have," he said. Keeping the manufacturing cost low to provide an off-the-shelf part that's cheaper than anything the agency could have produced also benefited the project.

Even before the SLS camera launched in December 2022, Imperx was able to develop and offer a commercial version. The SPC-S2010 is a two-megapixel, high-definition camera that incorporates the patented housing, a heater along with a built-in ring light, and three-kilovolt isolation. This isolation protects internal electronics from unstable power sources. Whether that's a power surge or static transmitted by attached equipment, this feature can prevent damage that could be caused, for example, by a lightning strike nearby.

Pangburn said the NASA collaboration is directly tied to an added \$10 million in sales, which is significant for the company. But even more important to Imperx is the opportunity to bring some camera business back to this country. Noting that commercial aviation uses a variety of cameras to improve takeoff and landing safety,

Pangburn said European technology has been meeting that need for years.

"This experience has helped us make a camera that can withstand being mounted on an airplane, which goes from ground level up to 36,000-40,000 feet and then comes back



Seven Imperx ruggedized cameras mounted to the exterior of the SLS rocket were able to capture the Artemis I launch, including a live recording of booster separation and jettison. *Credit: NASA*

down," he said. "It works perfectly during all of those altitude changes, whether it's hot or cold outside, if it's raining or snowing. It's helped our expansion into aviation systems."

## 'If It's Good Enough for NASA'

Bone hopes NASA will be a future customer because "the environmental range on these cameras is insane," he said, noting that one of them survived eight minutes positioned just a few feet from a blasting rocket engine, followed by the frigid space environment.

The video footage from that flight is going to come in handy when talking to potential customers, whether their industry is commercial space, aeronautics, oil and gas, mining, or trains, said Pangburn. "I'm sure the response will be, 'If it's good enough for NASA, I'm sure it's good enough for me.' Because what customers want is a proven concept."

Imperx credits the public-private partnership with giving its small business a big boost.

"NASA engineers are highly educated, motivated, and they're imaginative. They are willing to try things that haven't been tried before," said Pangburn. "We're in the camera business, but there are so many other businesses that can work with NASA and learn from their expertise." ●

*"It's very rewarding and very advantageous to work with NASA."*

*Greg Pangburn, Imperx*



# Additive Manufacturing Subtracts from Rocket Build Time

NASA teamwork on 3D printing and testing engines makes company's launch services more affordable



Speed is everything in rocketry. To get into low-Earth orbit, a spacecraft needs to hit velocities around 17,000 mph. And any company building a commercial rocket must have it designed, built, tested, and flying payloads as fast as possible to begin recouping the astronomical cost of reaching commercial readiness.

For the last decade or more, even as it's been finalizing its own heavy-lift rocket, NASA has also been adding to the nation's launch fleet by helping several commercial space companies reach that finish line. And some of them are accelerating their journey by unconventional means.

Most recently, after about five years of cooperative efforts with NASA, Relativity Space's Terran 1 rocket became the first 3D-printed rocket to reach space during a March 2023 launch. The company aims to use its rockets to offer affordable rides into space for commercial satellites and other payloads.

Under a series of Space Act Agreements, Relativity has worked closely with engineers at NASA's Marshall Space Flight Center in Huntsville, Alabama, on developing rocket engines built with 3D printing, also known as additive manufacturing. And the company has been testing those engines at the agency's Stennis Space Center in Bay St. Louis, Mississippi.

"NASA has certainly helped accelerate the progress we've been making across propulsion, across test and launch infrastructure, and in the flight of our vehicles," said Scott Van Vliet, current advisor and former senior vice president of software engineering, avionics, and additive manufacturing at Relativity, which is based in Long Beach, California. Additive manufacturing, he said, has helped the company speed its development in part by combining the design and build phases.

The Terran 1 rocket was 85% 3D printed by mass, with the body built by Relativity's Stargate printer using what the company calls wire arc additive manufacturing. But printing the engine took some help from NASA.

Relativity Space's Terran 1 rocket sits on the Launch Complex 16 launch pad at Kennedy Space Center. Credit: Trevor Mahlmann

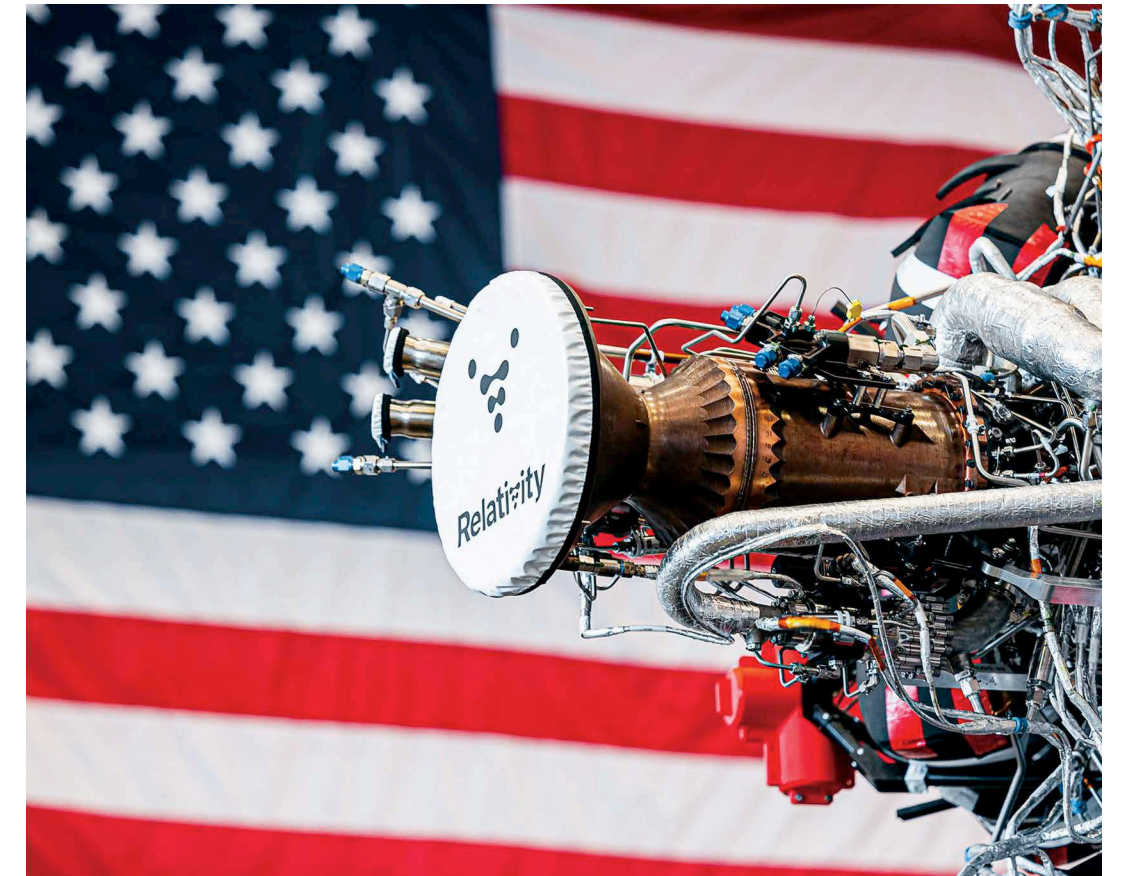
Several Space Act Agreements helped Relativity Space of Long Beach, California, 3D print rocket engines using a NASA-invented alloy, and the company leases agency facilities to test the engines.

## Saving Time Is Saving Money

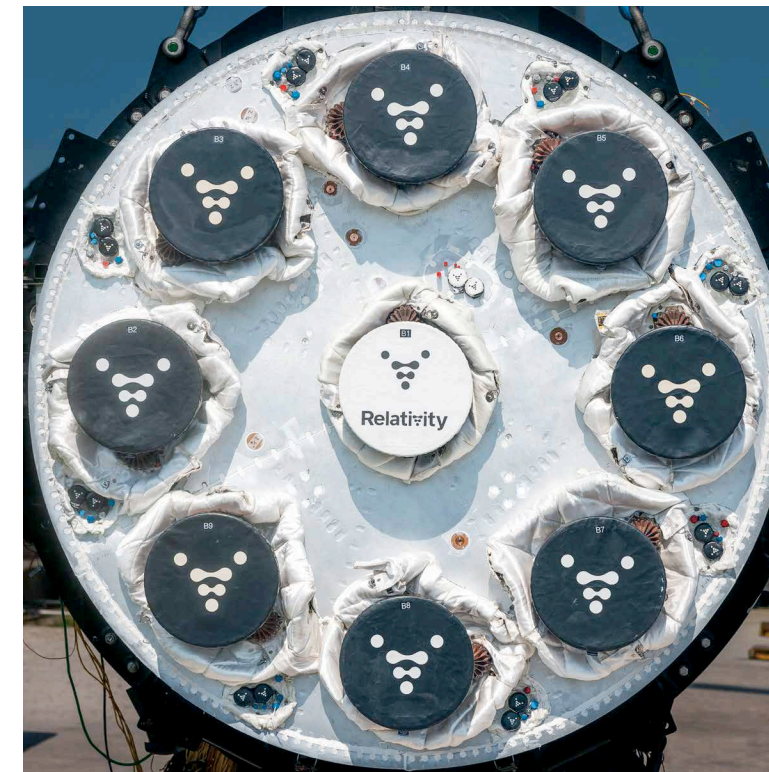
"Compared to other parts of the vehicle, a rocket engine has the longest developmental lead time and comes with the most risk because of the extreme environments and manufacturing challenges," said Paul Gradl, principal engineer of component development at Marshall. "It's operating from cryogenic all the way up through 6,000°F and at very high pressures, pushing the materials to their limits."

Gradl has been leading NASA's research into 3D printing engine components and working directly with Relativity and other companies to get that technology out into the private sector.

Every week, a team of Relativity engineers meets virtually with Gradl and his team to discuss the company's progress and share ideas, said Jake Shearman, senior manager of combustion devices at Relativity. He noted that Marshall



Relativity Space worked with engineers at Marshall Space Flight Center for several years to refine the 3D printing of its Aeon 1 rocket engine, incorporating a copper alloy that NASA had invented. Credit: Relativity Space Inc.



Nine Aeon 1 engines fill out the business end of the first stage of Relativity Space's Terran 1 rocket. The engines were built and tested with help from NASA. Credit: Relativity Space Inc.

*"We are able to reduce the lead time of some of these parts by two to 10 times, and with that comes a huge cost savings."*

*Paul Gradl, Marshall Space Flight Center*





Relativity Space is using its fourth-generation Stargate metal 3D printer to build the body of its rockets. The Terran 1 rocket that launched in March of 2023 was 85% 3D printed by mass, including its body and engines. *Credit: Relativity Space Inc.*

constantly generates new information about 3D printing materials and design, helping the company stay abreast of the state of the art. They also occasionally meet in person to let the NASA engineers take a look at Relativity's latest hardware and offer input, he added.

Gratl also helped the company incorporate a copper-chromium-niobium alloy that NASA invented, known as GRCop-42, which has proven especially adaptable to additive manufacturing.

He noted that NASA has invested millions of tax dollars into this research and wants to do as much as possible to make the resulting data and expertise available to U.S. companies. "It's a huge benefit for NASA and commercial space to infuse these technologies and work collaboratively toward common mission requirements." And Gratl said partnerships like this help the space agency stay on top of the challenges facing the commercial space industry and work on solutions to those challenges.

NASA has been interested in additive manufacturing because it offers the opportunity to produce and test parts faster, in addition to performance benefits. What used to be 200 pieces welded together can now be printed as one or two solid parts. "And with that, I think the biggest advantage is the cost and schedule savings," said Gratl. "We are able to reduce the lead time of some of these parts by two to 10 times, and with that comes a huge cost savings."

Relativity likewise benefits from the ability to produce higher-performance engines, but Van Vliet said the short lead time for producing new parts is also the biggest advantage the company gets from 3D printing because it allows engineers to quickly zero in on optimal designs.

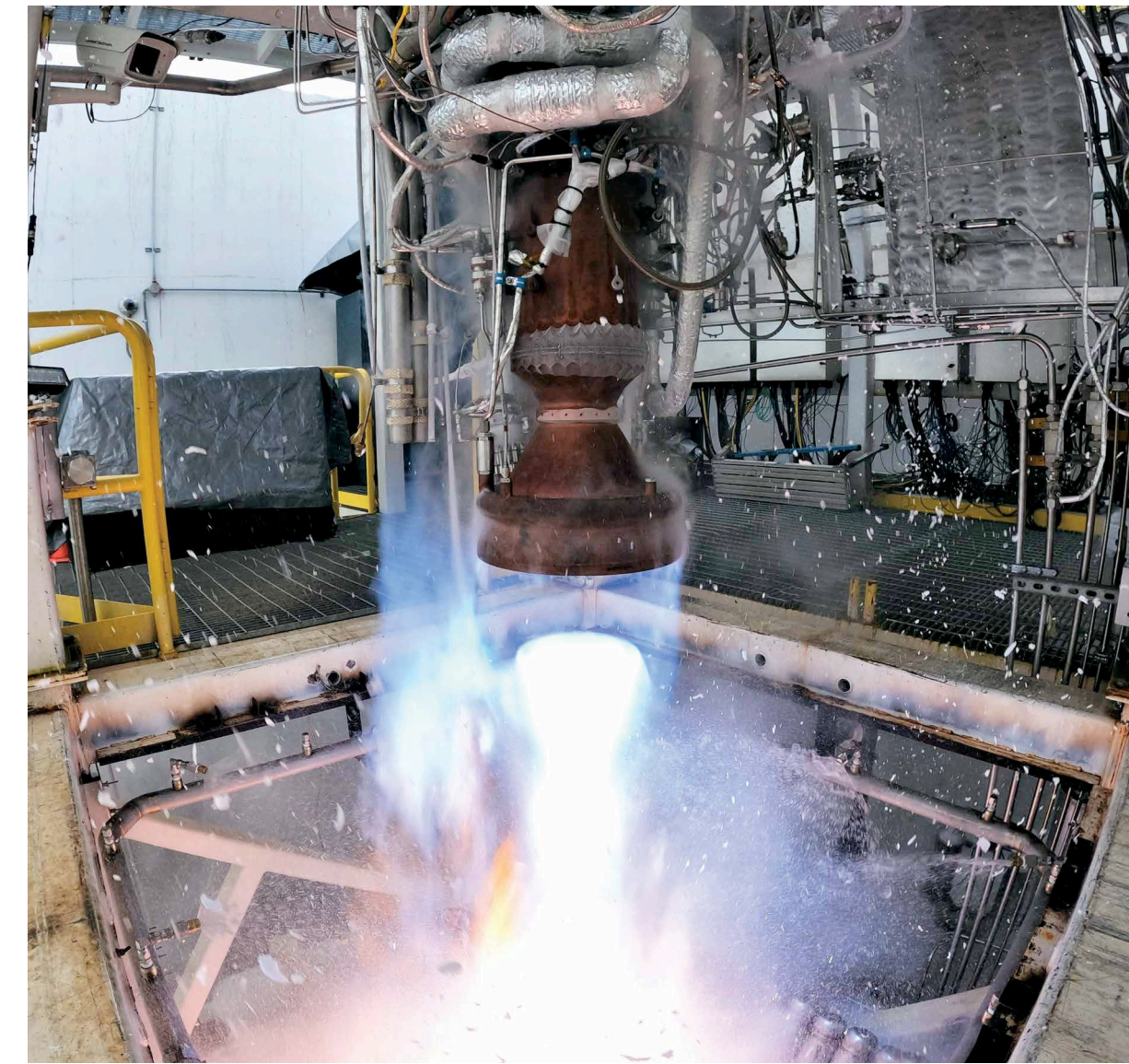
"When you look at a traditional approach to building rockets or engines using traditional systems of casts and molds and dies and tooling to manufacture things, you have to have a decision around the design of the vehicle or the part or component locked in way ahead of time," said Van Vliet. But with a 3D printer, instead of rebuilding the assembly line to make a change, "we can just make changes in CAD, print the part, treat it, and send it back to the test stand."

### Trials by Firing

Those test stands are at Stennis, where Relativity has agreements to use a number of test sites. For example, the company is doing extensive testing in a cell of the center's E Test Complex, which is made to evaluate small engines and high-pressure components.

"Being able to utilize the facilities that NASA's already built at this Stennis facility has put us leaps and bounds ahead," said Clay Walker, Relativity's senior director of test operations.

Shearman agreed. "The E1 test facility has given us the opportunity to get earlier data on our innovative approaches, so we can try new techniques and kind of play in the sandbox without being burdened by the arduous process and longer lead time of building large stand infrastructure." And that's just where the company is testing engines now. "As Relativity has grown and our engines have grown, we've basically just been leapfrogging between all of the test stands," Shearman said.



One of Relativity Space's 3D-printed rocket engines undergoes hot fire testing on Stennis Space Center's E4A test stand. The company leased a number of engine-testing facilities at the center, where it is now building its own test stands. *Credit: Relativity Space Inc.*



Now the company is building its own test complex on 150 acres at Stennis, which is one of NASA's largest field centers, giving it a large buffer area between engine firings and the nearest homes and businesses.

Most of the testing facilities Relativity and others use at Stennis aren't getting a lot of use from NASA, as the space agency's testing needs change, so leasing them out makes sense for everyone, said Duane Armstrong, manager of the Stennis Strategic Business Development Office. He noted that companies also often buy access to other infrastructure and commodities available onsite, such as pressurized propellants or cryogenes. "All of those things lead to a cost-sharing arrangement that's beneficial for everybody. It covers some of our maintenance and operating costs, and it provides quality services for industry."

### Everyone's a Winner

Ultimately, Armstrong said, NASA has a long-term goal of fostering commercial space companies like Relativity, from whom the agency hopes to one day purchase affordable launch services.

"In the end, they're getting better performance and lower costs, which means we can potentially fly our payloads and astronauts safely and at a reduced cost on some of their missions," Gradl agreed. "We help enable this commercial space economy, and then we can take advantage of it and free up some of our resources to do some of the more difficult missions, returning to the Moon and eventually on to Mars."

NASA and the company also hope to learn from each other as they work toward 3D printing Relativity's planned, massive Aeon R engine, said Shearman. The Aeon 1 engine that powered the recent Terran 1 launch was built with an additive manufacturing technique known as powder bed fusion, which works well for small engines but hits limitations as engine size increases, he said. Aeon R is planned to have more than 10 times the thrust of its predecessor.

"As other 3D printing technologies gain in maturity – and NASA has honestly been leading a lot of that – we look forward to figuring out how you scale up in size," said Shearman. "It's something that has not yet been conquered by the aerospace industry for additive technology."

By the time of its launch in March 2023, Relativity had already sold \$1.2 billion in contracts for flights on Terran 1, with customers including OneWeb and Intelsat. The company later announced it would move directly to developing the larger Terran R rocket, with many of those contracts likely transferring to the new rocket.

"From my point of view, additive manufacturing allows us to deliver payload services and launch services at a better price point," said Van Vliet. "And it allows us to integrate the most state-of-the-art technologies because we're able to make design choices along the way." ●

*"We can try new techniques and kind of play in the sandbox without being burdened by the arduous process and longer lead time of building large stand infrastructure."*

Jake Shearman, Relativity Space



The first stage of Relativity Space's Terran 1 rocket undergoes an 88-second hot fire test at Stennis in September of 2022. Credit: Relativity Space Inc.



# 'Digital Winglets' for Real-Time Flight Paths

NASA-developed routing technology leads to fuel savings and smoother flights



Before airplanes even reach the runway, pilots must file a plan to inform air traffic controllers where they're going and the path they are going to take. When planes are in the air, however, that plan often changes. From turbulence causing passenger discomfort and additional fuel use to unexpected weather patterns blocking the original path, pilots have to think on the fly and inform air traffic controllers of any modifications to their routes.

In the past, these changes would have to happen suddenly and without much lead time. But as airplanes have become more digitally connected, the flying machines can take advantage of the additional data they receive, and a NASA-developed technology can help pilots find the best path every time.

NASA has explored methods to improve aircraft efficiency since its inception. Among the agency's most famous contributions are winglets, upturned vertical flanges at the ends of airplane wings that eliminate turbulence at the wingtip and lead to significant savings in fuel (Spinoff 2010). Fuel efficiency is incredibly important to future aircraft development, as not only does it improve the distance a plane can travel and the weight it can carry, but airplane engines release huge amounts of greenhouse gases into the atmosphere. Reducing aircraft fuel use means less carbon dioxide in the air.

David Wing, principal researcher of air traffic management at NASA's Langley Research Center in Hampton, Virginia, develops advanced autonomy systems for aircraft, allowing operators to directly manage flight paths in crowded skies. He noticed that some of the same technology used for safe routing could also be used to optimize routes for flights already in the air. Allowing pilots to identify a better path as soon as it's available could save time and money.

"Air traffic control is there to keep the aircraft safely separated from other aircraft," said Wing. "So the trick is, when you need to change your routing, what route do you ask for, and how much is it going to save you?"

Under Wing's lead, NASA developed Traffic-Aware Strategic Aircrew Requests (TASAR), a piece of software pilots and ground operations teams can use to find better routes in transit. TASAR works by using a genetic algorithm, a kind of machine learning system that finds the optimal answer by pitting hundreds of route changes against each other and seeing which one comes out on top. TASAR takes a map of the area and draws hundreds of lines radiating from the airplane. These lines represent potential routes the plane could take. The software whittles

Alaska Airlines Capt. Bret Peyton looks at route options presented by Traffic Aware Strategic Aircrew Requests (TASAR) during a test of the software at Langley Research Center. The program connects to onboard systems and runs on a tablet called an electronic flight bag. *Credit: David Wing*

Through a NASA licensing agreement, APIJET of Seattle developed the Traffic Aware Strategic Aircrew Requests (TASAR) software into a commercial plane-routing technology that helps airlines save both time and fuel.

down every route it generates, avoiding ones that stray into no-fly zones or dangerous weather systems or get too close to other aircraft until it's found the most efficient route the airplane can take. Then it's up to the pilot whether to take the computer's advice. Information is constantly being updated using sensors on the airplane and connections to ground-based services, which TASAR takes into account.

"The algorithms had been tested and matured already for many years in our autonomy research, so they were in pretty good shape," Wing said. "But what we had to do was to connect this system to a real aircraft, which meant that we needed to be able to access data from the onboard avionics."

On NASA test flights, the software worked perfectly, but for TASAR to break into more flights, commercial planes needed to be able to access large amounts of data. As it turned out, a solution was close at hand.

The company iJET originally built components that could keep planes connected to the latest information available on the ground, which often wasn't available in the sky. After first developing better antennas, the company soon began working on a new integrated computer system for airplanes to take in data and stay connected to ground-based information sources. When looking for a "killer app" for the system, the company discovered TASAR.

"We saw that NASA was getting to the conclusion of this work, and we took a business decision to pick up the baton," said Rob Green, CEO of the company.

After being acquired by another company called Aviation Partners, the Seattle-based company was renamed APIJET LLC in 2018 and became the first company to license TASAR from NASA. APIJET proceeded to tie the software to the



Frontier Airlines was among the first companies to test Digital Winglets for its fleet of aircraft. In testing, the commercial implementation of NASA's TASAR technology provided fuel savings of 2%, which adds up at airline scale. *Credit: Frontier Airlines*

in-flight computer system. The company's version of TASAR is called Digital Winglets, named after the NASA invention that has been saving fuel for decades.

The app runs on electronic flight bags, computer devices approved for use in flight operations by the Federal Aviation Administration, most commonly Apple iPads. Green said there are no plans to integrate it directly into a cockpit instrument panel, because an app can be updated more easily. In testing with Alaska Airlines, Green said the program saved 2% on fuel, working out to approximately 28,000 pounds of fuel per hundred flights.

"Two percent may not sound like much, but little savings can really add up at airline scale," Green said.

Several more airlines have tested the technology since, and Frontier Airlines is field testing for a potential deployment of Digital Winglets across its fleet. APIJET still keeps in touch with the developers at NASA to further research TASAR's benefits and build out its commercial capabilities.

"Everybody that worked on TASAR at NASA should be really proud of the direct impact they are having in fuel savings and carbon reduction," Green said. "It's a lot to get your head wrapped around, but it works." ●



In this screenshot of the APIJET Digital Winglets software based on NASA technology, a route is plotted along navigational waypoints, presenting three options that would save fuel and time based on real-time information. *Credit: APIJET LLC*



# Next-Level Farming

## NASA data and expertise help controlled environment agriculture reach new heights

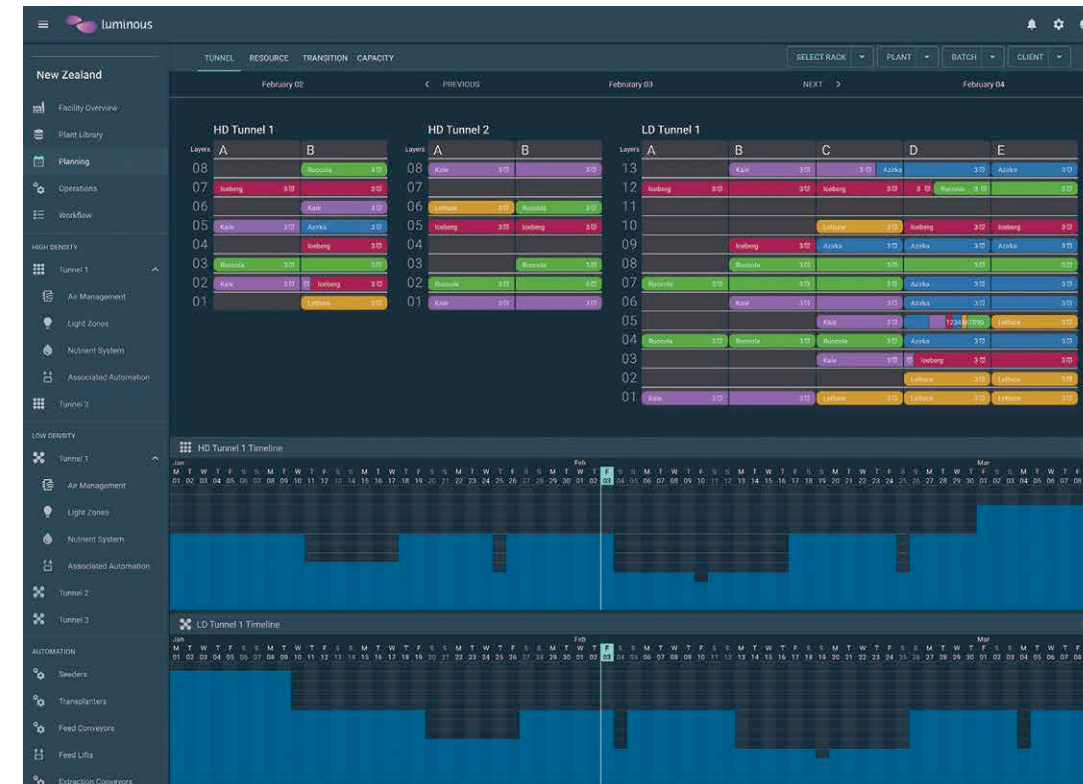
IntraVision Group is using NASA plant-growth research to take vertical farming to new heights. Twenty- and 30-foot towers of hydroponic trays include customized LED lighting, nutrients, water filtration, airflow, and CO<sub>2</sub> levels to meet crop needs. *Credit: IntraVision Group*

It'll be years before astronauts living beyond the reach of regular resupply missions will have to grow some of their own food and medicine, but small-scale farming will be essential for extended lunar exploration and long missions to Mars. NASA has been preparing for that day for decades. Now, using expertise the space agency has developed in closed-environment plant growth, private companies are making indoor farming a major food source on Earth.

Among the largest of these indoor farming operations is the IntraVision Group's GravityFlow closed-environment growth system, which has the potential to produce over a million pounds of produce annually at a single facility.

Beginning in the space program's early days, NASA worked on growing plants without sunlight, open air, or abundant water. Research into bioregenerative life-support systems included growing crops to

Closed-environment plant-growth data and expertise developed by NASA to feed astronauts on long-duration missions helped Oslo, Norway-based IntraVision Group develop complete indoor vertical growing systems and LED lighting to grow food on Earth.



The highly automated controlled environment agriculture (CEA) GravityFlow system developed by IntraVision Group only requires a few people to operate a facility that can grow over 300 tons of food annually. *Credit: IntraVision Group*

produce oxygen and food while recycling waste and carbon dioxide. Decades of effort yielded hundreds of research papers and other resources sharing successful vertical farming conditions, ranging from lighting and oxygen flow to nutrients and “recipes” for producing specific plant varieties, or cultivars (Spinoff 2021).

The task is so complex it required more expertise than the agency had. Describing it as “well beyond the means of NASA programs,” Gioia Massa, life sciences project scientist at NASA's Kennedy Space Center in Florida, said the list of challenges is long.

“NASA's role is in breaking new ground for some of these technologies or approaches, funding the very early-stage development,” she said. “For those things that have terrestrial applications or commercialization potential, industry picks up those.”

### Space Crop Production

Starting in 2003, IntraVision's technology development was informed by NASA data and staff expertise as the two organizations researched and tested plant growth technology at the University of Guelph's Controlled Environment Systems Research Facility in Toronto, Canada. As a long-term sponsor of the program, IntraVision benefited from these projects, conducted in conjunction with NASA researchers.

As part of a 20-year informal partnership with the university, the agency supported the creation of the Guelph Blue Box chamber system, which is now the university's primary plant-growth chamber. The collaboration included a NASA research fellowship during which Tom Graham, now a faculty member at the university, conducted red-light plant-growth experiments.

In addition to informal information exchanges, such as sharing results from a particular experiment, findings are also published or presented at conferences. Massa said her team relies heavily on other scientists for data related to space crop production.

“The University of Guelph is probably the primary group working on those types of challenges. The data they're collecting and their publications are really helping meet NASA's needs for understanding different biological or technological solutions,” she said. Businesses are filling other gaps.

Photobiology – controlling living organisms with light – is a primary focus for Oslo, Norway-based IntraVision. Since working with LEDs in 2004, the company expanded into creating complete controlled environment agriculture (CEA) systems. A customer can have an entire farm designed by the company or purchase individual components for a plant-growth system.

The 20- to 30-foot-tall vertical shelving system is called GravityFlow. It includes the Raptor sensor kits, Maestro light controllers, and a facility management software called Luminous. The company's LED lighting systems emit wavelengths selected through plant experiments.

“We say plants have light sensors, so they're able to detect UV rays, and blue, green, red light in the visual spectrum, as well as infrared light,” said Per Aage Lysaa, CEO of the company. “The spectrum a plant detects will then kick off a chemical process, which directly controls morphology and primary and secondary metabolite processes.” This changes the flavor, nutrient content, color, and even size of the plant. To optimize all this, IntraVision developed multispectral LED lighting that can be automatically preprogrammed for different growth chamber needs.

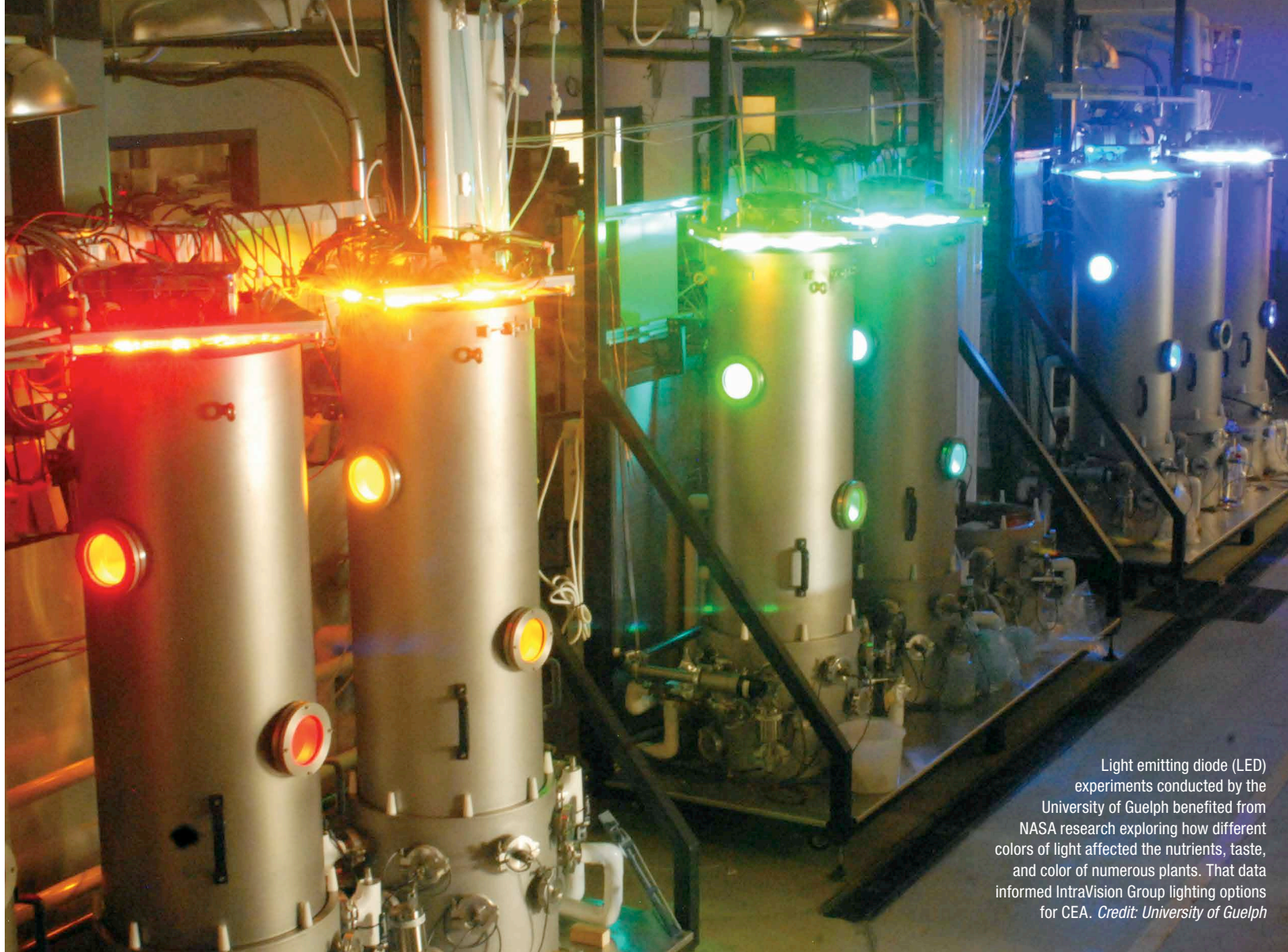
### Safer Lettuce

The company incorporates various lighting options and other technologies into its CEA platform for scalable vertical farms. The computer-controlled GravityFlow system generates any light spectrum and regulates the hydroponic nutrient flow, temperature, air speed, carbon dioxide levels, and relative humidity.



A variety of romaine lettuce shows how the plant responds to white, red, and blue light. Each had a different nutrient content and flavor, showing that the quality and kind of light matters. *Credit: University of Guelph*





Light emitting diode (LED) experiments conducted by the University of Guelph benefited from NASA research exploring how different colors of light affected the nutrients, taste, and color of numerous plants. That data informed IntraVision Group lighting options for CEA. Credit: University of Guelph

A variety of sensors collect data while custom software uses that information to control growth. A library of data is automatically generated and added to a larger plant database, which uses machine learning to continually improve the systems.

Following a small pilot farm in Toronto, Canada, in 2017, the first full-scale growth system was built by Vision Greens in Canada in 2020. A new highly automated farm, the first in the United States, started production in New Jersey and will produce between 300 and 450 tons of produce annually while requiring only a handful of staff.

In addition to optimizing growing conditions, the automation allows growers to trace a crop from

seed to plant to produce, and to the grocery store or restaurant, improving food safety, according to Lysaa. The system provides life cycle documentation that demonstrates that the produce is uncontaminated.

“The system will always know which plant is where, so you can check for the optimum conditions,” he said. “We have planning tools and alarms to prevent problems. And we eliminate the sources of bacteria, such as the E. coli found in romaine lettuce in the United States that killed several people.”

Approximately 55% of all lettuce consumed in this country comes from California. Once harvested, it’s shipped over 2,000 miles to

*“The system will always know which plant is where, so you can check for the optimum conditions.”*

*Aage Lysaa, IntraVision*

processing plants in the Midwest or on the East Coast. Bacteria can be transferred to the plants at any time – from a bird overhead, or the surface of a shipping container. CEA eliminates those sources of possible contamination.

High-quality, high-volume production makes it possible to transition from selling the small quantities of produce most commercial vertical farms produce to a commodity-level volume that competes in price with traditional, subsidized agriculture. And CEA uses up to 95% less water, requires no pesticides, and grows more food on a fraction of the land, making it a sustainable alternative.

### Medicine and More

Thanks in part to NASA-funded research, IntraVision has built on LED research to produce light fixtures that generate 75% light and only 25% heat. The company also expanded into LEDs with specific ultraviolet wavelengths. These control the morphology in flowering plants, including many used for medicinal purposes.

“We picked roughly 10 of the important Chinese, Middle Eastern, and other traditional medicinal plants to cultivate,” said Lysaa. The company’s effort to develop new CEA cultivars builds on research performed for customers on the indoor cultivation of cannabis. This involves using different light spectrums to optimize the plants’ growth and production of bioactive molecules.

One customer, Plant Form, uses the IntraVision growth system to grow a biosimilar form of Herceptin, a drug that breast cancer patients take following an operation. The company uses genetically modified tobacco plants to generate a biological form of the drug. Herceptin costs approximately \$35,000 annually per patient. A plant-based version will cost considerably less.

Other successful biotech cultivars are food extracts such as mint oil. The mint in toothpaste and chewing gum is from plants that used to grow in the United States until it became too expensive. The mint is now produced in Sri Lanka, Vietnam, and China, whose populations are forcing more land into food-crop production. Recognizing that mint could easily become a CEA crop, IntraVision has the technology to make that transition.

### Feeding Astronauts and Other Humans

As human populations grow, the resources needed to provide food are diminishing. Hotter and more extensive wildfires scorching arable land, increased coastal and river flooding, and groundwater contamination by chemical fertilizers and pesticides all limit what traditional farms can produce. CEA technology offers a different kind of farming for future generations, just as it will feed astronauts.

“As we grow in space, we have similar challenges that indoor agriculture has on Earth,” said Massa. NASA’s efforts to support improvements

in commercial products for plant growth provide off-the-shelf technologies that save time and money.

“NASA does the things that are hard, the things that don’t have a quick return on investment, and industry is going to do the things that will have a much faster return on investment,” said Massa. “Some of the things we’ve worked on are things that now have terrestrial uses, like the use of LEDs to grow plants. Now, that’s really something.” ●

*“As we grow in space, we have similar challenges that indoor agriculture has on Earth.”*

*Gioia Massa, NASA*



The first growth test of crops in the Advanced Plant Habitat aboard the International Space Station yielded great results. Arabidopsis seeds – small flowering plants related to cabbage and mustard – grew well, building on more than 40 years of plant-growth research. Credit: NASA



# Taking the Pulse of Earth

## Applying AI to Earth data reveals sustainable options for farming, reforestation, land management

Volcanic eruptions, floods, and tornados can all dramatically change the surface of Earth to the point where alterations can be seen from space. Some modifications driven by human intervention, such as mining and deforestation, are also visible in satellite imagery. For the past 50 years, NASA's Landsat satellites have recorded our planet's changing surface. Now maps from a company called terraPulse Inc. help academic institutions, nongovernmental organizations, and businesses see, understand, and manage those changes.

By combining historical and current data from multiple NASA and European satellites, the North Potomac, Maryland-based company applies artificial intelligence (AI) to create meaningful maps. This application of NASA's massive volume of data enables the private sector to make data-driven ecological decisions, according to Joe Sexton, chief scientist with terraPulse.

NASA satellite data and imagery combined with artificial intelligence developed by terraPulse enables customers of the North Potomac, Maryland-based company to monitor changes to Earth's surface now and over the past 40 years.

"We take the pulse of the planet," he said. "We're able to see the entire surface of Earth through nearly 40 years of change. Many societies have risen and failed often because they couldn't see they were outstripping and misusing their natural resources. This new ability is humanity's best shot at global sustainability."

### Practical Data

"One of NASA's most important missions is studying our home planet," said Dr. Kathrine Calvin, the agency's chief scientist and senior climate advisor, explaining that NASA's many Earth-observing satellites have instrumentation to collect a variety of information. That data includes imagery, atmospheric measurements, and more, creating a comprehensive view of our ever-changing world (Spinoff 2022).

All of this has helped make NASA a global leader in understanding Earth science and climate change. Extensive collaborative efforts with international space agencies, academic institutions, researchers, and others identify gaps in data and plan future initiatives. The resulting data is available free to anyone who wants it.

"We do generate a very large volume of data, and we're starting to move it to the cloud," said Calvin. Analyzing and organizing datasets and presenting it in useful formats is another ongoing effort. Using sea-level rise as an example, Calvin explained that satellites measure the height and shrinkage of massive ice sheets and the rate of sea-level rise over time.

The data helps scientists understand changes to the environment and the processes driving them, all of which can provide practical information to local decision makers for infrastructure planning and disaster preparedness.

At NASA's Goddard Space Flight Center in Greenbelt, Maryland, which manages many of the agency's satellite missions, Sexton was hired in 2009 as a postdoctoral scientist on a project to create the world's first high-resolution map of changes to global forest cover. It proved formative to his work.



Whether a municipality wants to evaluate land for conservation, or a developer wants to find parcels with the best views, terraPulse can map for that. This image of the Lake Artemisia subdivision in Maryland created by the company delineates parcels, existing structures, and tree cover. Credit: terraPulse Inc.

### Planting Trees, Preventing Fires

Geospatial data – information about phenomena, objects, or events on Earth's surface – is a rapidly growing industry.

"This new combination of satellite imagery, artificial intelligence, and the cloud gives us the ability to develop faster and produce pertinent data products supporting an entirely new industry built on location intelligence," Sexton said.

Funds from a number of private and public sector supporters, including NASA-funded grants, built the world's first global map of forests at Landsat resolution. The use of AI and machine learning allowed the team Sexton later worked with at the University of Maryland to complete the project in 2013. TerraPulse formed in 2014 to offer ecosystem monitoring and analysis at local and global scales. What started as support for academic and scientific research is expanding to include numerous business interests.

A pine seedling company needed to identify timber clearings across the southeastern United States to reach out to potential reforestation customers. A biomass energy company needed to verify that suppliers were reforesting after harvesting wood for their mills. Supplementing on-the-ground observations saves staff hours and the expensive process of evaluating those observations.

However, mapping biomass – the mix of vegetation on the ground such as trees, bushes, and grasses – can be tricky. It's essential that the historical data for the exact same geography is collected over years. "We can go back anywhere in the world because terraPulse's algorithms and data are consistent backward through time," said Sexton.

That same comprehensive view also makes it possible to look at any fires that occurred in the satellite record.

Fire changes landscapes, so it's essential to use the correct imagery when modeling fire risk. Wildfire forecasting is critical to public safety and disaster planning. But more industries are also looking to satellite data to plan for resilience to climate change by monitoring worldwide facilities, identifying manageable risk factors, and more (Spinoff 2021).

*"Earth observation tells us what our planet looks like now ... and how it's changed."*

*Dr. Kathrin Calvin, NASA Headquarters*

This natural-color image of mountains of central Pennsylvania taken by Landsat 8 shows the colors of changing leaves and the unique topography of the region. Thanks to more than 50 years of planetary observation from low-Earth orbit, it's possible to see natural changes and those engineered by humans. Credit: NASA



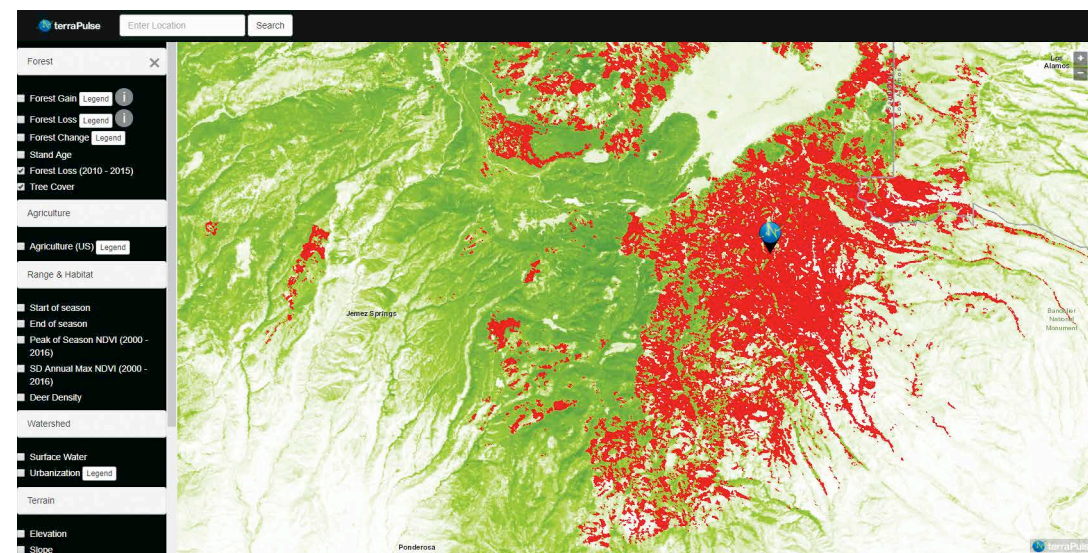
## Valuing Carbon Credits

Land brokers, insurance companies, investors, and developers are taking a more sustainable view of land use and turning to companies like terraPulse to get better information about a geographic area. For a resort, the best views can determine the value of cabin rentals. Others might need to know what natural resources are nearby.

Risk-assessment strategies are a primary focus, according to Sexton. "It helps the client when we take their data, apply our AI, and provide them a regional map that shows changes and conditions specific to their needs," he said. That might be looking at flood history to add preventive measures.

Agriculture customers also need information, whether for a family farm or multiple holdings across several states. Farmers can monitor characteristics of the land and nearby wildlife habitat to inform changes to planting. Cattle ranchers track vegetation health indices during the growing season to influence range-management choices.

A new service called terraView is an online platform for monitoring tree cover, deforestation, and other indices. At 32-foot spatial resolution starting in 2017 using the European Space Agency's Sentinel-2 data, and at 98-foot spatial resolution back to 1984 using Landsat, this service detects and monitors forest change globally at the highest resolution available on a global scale.



In 2022 wildfires in New Mexico burned over 1,000 acres. This map of the northern part of the state created by terraPulse shows the tree loss (red) that occurred from 2010 to 2015 against the remaining tree canopy (green). Historic data pulled from satellites makes it possible to track changes like these. Credit: terraPulse Inc.

For carbon-market customers, this kind of mapping helps set the value of forested areas left in a natural state. To offset fossil-fuel emissions, a company can buy "carbon credits" – one credit equals one ton of carbon dioxide or the equivalent amount of another greenhouse gas. Buying credits equal to the emissions produced will, in theory, reduce or sequester the same amount of greenhouse gas. The money can be used for reforestation efforts or to pay individuals to maintain undeveloped land.

A challenge for the landowner is identifying how much carbon a geographic area can sequester, which is what drives its credit value. For companies purchasing those credits, monitoring the land is a way to ensure the carbon offset is maintained.

## 'Seeing Around Corners'

"What remote sensing provides is information for the times and places you can't access for yourself. That includes the other side of the planet," Sexton said.

These measurements taken from space are still undergoing significant research and development. NASA Earth Science is funding several initiatives to



Photographed by satellite instruments, damage caused by volcanic eruptions and other natural disasters can be easy to see. But terraPulse uses expertise in geographic information systems and proprietary algorithms to map changes, including ecosystem restoration, that take place over many years. Credit: U.S. Geological Survey

use remote sensing to expand our understanding of the impact of land cover change, including a terraPulse effort to use FitBits to track the health of wild deer and assess the impact of habitat change. This work is of particular interest to Sexton, who trained as an ecologist. He said this kind of information is essential to maintaining healthy forests for wildlife.

"Earth observation tells us what our planet looks like now. We provide that information to people in near-real time in many cases, so they can respond to the world and how it's changed around them," said Calvin.

Sexton calls the ability to access that information about places individuals can't get to "seeing around corners." He appreciates the contribution NASA has made toward "democratizing" access.

"Any person with access to a computer and the internet is able to see anywhere in the world at a higher resolution than ever before," he said. ●

*"This new ability is humanity's best shot at sustainability."*

Joe Sexton, terraPulse

# Ultrasonic Inspections Protect Astronauts, Boat Owners

## Technology for inspecting Orion heat shield now checks integrity of composite materials in boats

Shipbuilders didn't have the option of fiberglass when the nonprofit American Bureau of Shipping (ABS) was established 160 years ago to help safeguard life and property on the seas. Fortunately, technology to help better ensure the safety of ocean vessels has also come a long way in that time, in part because people have become a spacefaring species.

ABS Group of Companies Inc. of Spring, Texas, an ABS subsidiary that provides risk management solutions and extends marine technical services to smaller vessels like yachts and fishing boats, has

After NASA funded Aerospace Corporation's development of an ultrasonic scanner that could detect defects inside the Orion spacecraft's heat shield, ABS Group of Spring, Texas, adopted it for inspecting composite materials in boat hulls.

now taken a technology developed to inspect the heat shield on NASA's Orion spacecraft and is offering it for evaluating seacraft hulls made with advanced composite materials.

Ships longer than 175 feet or so require the strength of a metal hull. Because metal conducts sound easily, these can be inspected using traditional ultrasonic scanning, which sends high-frequency sound into the material and detects damage by spotting irregularities in the echoes returned to the device. Smaller vessels can save weight with composite hulls, often made of layers of fiberglass, epoxy resin, or carbon fiber, but these materials absorb and dampen sound, making them much harder to evaluate with ultrasonic technology.

"We looked at industries that were already more advanced in their ability to detect defects in nonmetallic materials, and the aerospace industry is really leading that sector," said Nick Obando, director of asset integrity management at ABS Group.

The weight savings provided by composite materials, as well as reliable inspections to ensure safety, are among the very highest priorities for NASA and other spacecraft designers.

So when the space agency chose a new construction method for the Orion module's heat shield, its engineers needed an inspection technique that could help guarantee its integrity. They ended up turning to the nonprofit R&D company Aerospace Corporation to create a new ultrasonic technology for examining composites – one that would also turn out to fit the needs of ABS Group and its smaller, lighter clientele.



Technicians at Kennedy Space Center finish applying blocks of Avcoat, a lightweight epoxy resin, to the heat shield for the Orion crew module. To examine the blocks' bond to the shield, NASA turned to Aerospace Corporation to develop an ultrasonic sensor that could spot defects in or under the material despite its resistance to sound. Credit: NASA



## From Space to the Seas

Orion is the spacecraft that will carry astronauts to the Moon and back in the coming years under NASA's Artemis missions. Its heat shield will protect it on its return, as it streaks through Earth's atmosphere generating temperatures up to 5,000°F. The shield was originally to be made by injecting Avcoat, a lightweight epoxy resin previously used for the Apollo capsule's heat shield, into the cells of a honeycomb structure. However, when a test shield was built, cracks formed at some seams, so NASA and contractor Lockheed Martin decided to adhere blocks of Avcoat directly to the shield's base.

"In doing so, they created a situation where that bond line now became critical," said William Prosser, technical fellow for nondestructive evaluation in the NASA Engineering and Safety Center at the agency's Langley Research Center

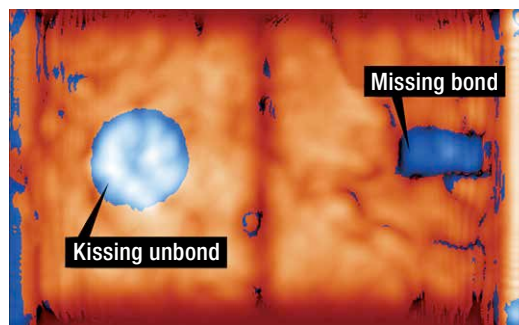
in Hampton, Virginia. "And they didn't have a good way to test it because the strength of the bond was greater than the strength of the Avcoat material, so they couldn't do pull tests on them like they did with shuttle tiles."

The Engineering and Safety Center maintains networks of experts that extend beyond NASA and happen to include Shant Kenderian, director of Aerospace Corporation's Materials Processing Department and the company's Nondestructive Evaluation Laboratory.

When Prosser reached out to Kenderian in 2015, Aerospace Corporation was already dabbling with a technology that had potential to solve the problem. Recent hire Toby Case had brought along advanced scanning technology he had developed as a graduate student, and the team demonstrated it could perform a simple spot check on a heat shield sample. "But to do a big scan on a production scale, that's a completely different level of robustness," Kenderian said.

What followed were two years of refining the focusing and signal-processing techniques, and even the hardware, until a user could hand-scan a large area of composite materials and get a clear image of any damage or defects beneath the surface. "All these signal processing tricks or steps that we applied, every step enhanced the signal more and more until it became clear," Kenderian said. "That level of development all happened under the funding from NASA."

NASA and Lockheed Martin engineers were also involved in the effort, especially when the time came to test and



A raw ultrasonic scan of a block of Avcoat, the epoxy resin on the Orion spacecraft's heat shield, yields little useful information (top). Extensive signal processing that Aerospace Corporation developed for NASA, however, is able to detect defects like a missing bond and a "kissing unbond" – a spot where the surfaces meet but aren't bonded to each other (bottom). *Credit: NASA*

validate the technology. "And then we had to actually translate that into a system that could be used on the actual flight hardware at Kennedy Space Center by the inspectors," said Prosser. "And that was another significant activity."

Aerospace Corporation received a patent on the technique in late 2019, and it wasn't long before ABS Group came calling, licensing the technology in early 2021 and turning it out as a commercial service the following year. "So as far as I know, we're first to bring a true ability to evaluate through the thickness of these nonmetallic composites for the maritime industry," said Obando.

*"As far as I know, we're first to bring a true ability to evaluate through the thickness of these nonmetallic composites for the maritime industry."*

*Nick Obando, ABS Group*



One potential market for composite material inspection is in offshore platforms, where damaged composite pressure vessels can pose a hazard and composite materials could better repair pipes and topside structures if there's a way to test their integrity. *Credit: Getty Images*



One market ABS Group is targeting for its ultrasonic scanning technology for composite materials is the boat repair industry, where it can assess damages or defects that can't be seen on the surface. *Credit: Getty Images*

## Sounding Out Markets

He said the company is targeting three main types of users: manufacturers and retailers, both of which can use the technology for quality assurance, and repair shops that need to assess damage or defects. "It's trying to protect all of the parties involved, with better assurance about the integrity of the asset during fabrication and post-fabrication," said Obando. The manufacturer or reseller can better guarantee quality, and customers can have more faith in their purchase. He also noted insurers might have a use for these thorough inspections.

But he said the company is still working to determine other niches it can fill in the boating industry and beyond. "We're excited about the

technology," Obando said. "So now it's really about translating that excitement to our clients to say, 'Hey, we think this could help you, can you help show where there's a use case for this in this industry that's really underserved?'"

One future market with potential is offshore platforms, where composite materials could be preferable for repairs to pipes and topside structures if there's a way to test their integrity, Obando said.

Offshore platforms are also major users of composite pressure vessels. These high-pressure storage tanks are lightweight but difficult to assess for damage – and dangerous if they fail. "The main cause of failure in those is a disbond or

delamination between the layers," Obando said – exactly the kind of defect the new technology is designed to spot.

Meanwhile, Kenderian said his group has been approached by automotive and petrochemical companies interested in the technology.

"I think it may generate interest for a lot of composite materials that are covered by a more complicated material, like foams and cork. We don't know yet," he added. But he said the technology will have to keep evolving. "I really think there's a conspiracy where, the more we advance our technology, they start to design things on the edge of our capabilities, always," he laughed. ●



# Oil Drillers, Environmentalists Agree on Small, Sensitive Spectrometer

**Tiny tool to study water quality gets results anywhere**

At a mere 93 million miles from the Sun, Earth really shouldn't have as much water as it does. No one knows how it all got here. Max Coleman of NASA's Jet Propulsion Laboratory in Southern California subscribes to the theory that a significant amount of water arrived on comets that bombarded the planet close to 4 billion years ago. To look for evidence, he wants to examine water from as many locations around the solar system as possible.



Nicholas Ward, a researcher with the Department of Energy's Pacific Northwest National Laboratory, uses an OKSI-developed capillary absorption spectrometer for field measurements of methane in coastal wetlands of Washington state in June of 2021. Credit: Jason Kriesel

NASA STTR funding and an agency scientist helped a company develop a small spectrometer capable of measuring trace gases and isotope ratios. Now Guiding Photonics of Torrance, California, offers the spectrometer to petroleum companies, conservationists, and others.

Specifically, he would need to discover the ratios of different isotopes within those water samples. These are slightly different versions of the water molecule, and the proportions in which they're present can tell researchers a lot about a water sample's history.

A former geochemical researcher for the oil and gas industry, Coleman also knew isotope ratios would hold valuable information for offshore drilling operations, environmental researchers, and others here on Earth.

In 2012, NASA sent a tunable laser spectrometer to analyze isotopes on Mars aboard the Curiosity rover. There, the instrument analyzed hydrogen, carbon, and oxygen isotopes in the atmosphere and in gases released from samples the rover acquired.

Now a smaller, simpler commercial version is available to analyze Earth environments.

## Draw Down the Volume

Isotopes are atoms of the same element that have different numbers of neutrons, giving them different weights, although they're chemically identical. These atoms can combine with others to form molecules that are also identical except for their weight. The ratio of heavy to light molecules in a sample depends on processes it underwent in the past, from evaporation and condensation to biological metabolism. But counting the molecules in a sample and identifying their ratios is no easy task.

Groundbreaking though it was, Curiosity's instrument has to fill a gas sample cell that's almost a quart in volume to get an accurate reading, which makes it bulky and, for certain applications, useless. Now, following years of work with JPL, as well as the Department of Energy and the National Oceanic and Atmospheric Administration (NOAA), a company called Guiding Photonics LLC of Torrance, California, has produced a laser spectrometer that has similar accuracy but requires a sample volume of less than a quarter teaspoon.

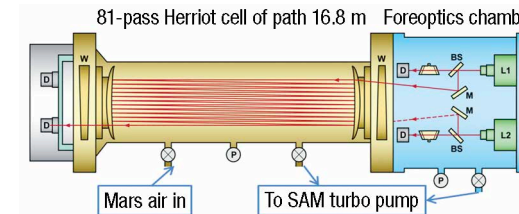
Guiding Photonics, which produces commercial fiber optics and sensors, recently spun off from OKSI, formerly known as OptoKnowledge Systems Inc., a research and development company with a long history of working with NASA. Starting in 2014, OKSI received two Small Business Technology Transfer (STTR) contracts through JPL to develop a laser spectrometer for sensing trace gases and isotopes.

Like the version on Curiosity, the spectrometer directs laser light through a gas sample. Molecules in that sample vibrate and rotate at different frequencies depending on which isotopes of which element are present, causing them to absorb different wavelengths of light. By observing how much certain wavelengths are absorbed, the device can identify molecules and their isotopes.

While the version on Mars bounces that laser light back and forth more than 80 times through a cylindrical cell to maximize absorption, the prototype OKSI built with STTR funding instead sent the laser through a long, thin optical fiber with a hollow, reflectively coated core. The design, which the company calls a capillary absorption spectrometer, requires only a tiny gas sample to fill the fiber, while its length still provides plenty of opportunity for laser photons to be absorbed by the sample molecules. The fiber cable can also be coiled to produce a compact device.

A team at a Department of Energy lab first put forward the concept, and the device OKSI built with NASA STTR funding proved it worked. In addition to funding, the company also used previous NASA research to build its first capillary absorption spectrometer. "They did a lot of pioneering work – simple things like, what part of the molecular fingerprint of methane we should target," said Jason Kriesel, lead scientist at OKSI and president of Guiding Photonics. "When they put together that system for the Curiosity rover, they did a lot of basic research that we can build on."

Coleman got involved in the 2014 project when he realized it was "really up my street," he said, and when that funding ran out, he and OKSI collaborated on a project with NOAA. Researchers there were interested in using such a device to test methane from deep-sea vents, and a Space Act Agreement let JPL help OKSI build on its earlier prototype under grants from NOAA.

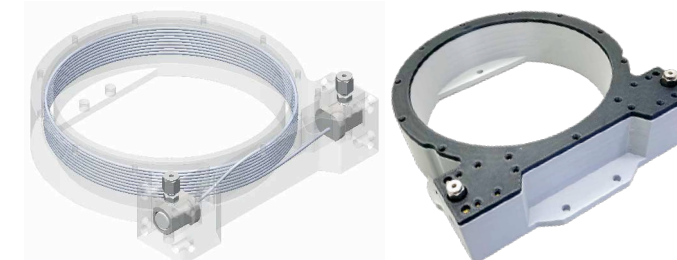


The Tunable Laser Spectrometer on NASA's Curiosity Mars rover bounces a laser 81 times through a chamber filled with sample gas. This measures absorption of varying laser wavelengths to determine not only concentrations of different gases but also their isotope ratios, which give clues about the sample's history. Funding and expertise from NASA have helped a company develop a much smaller commercial version of the technology. Credit: NASA

Using the spectrometer underwater required gases to be extracted from a water sample. This has always been accomplished with a membrane, which both throws off isotope counts and requires a bulky device, said Kriesel. Instead, Coleman came up with the novel solution of incorporating a small, depressurized chamber at the intake to the fiber-optic sample cell. The low pressure causes gases to bubble out from the water, making them available for testing.

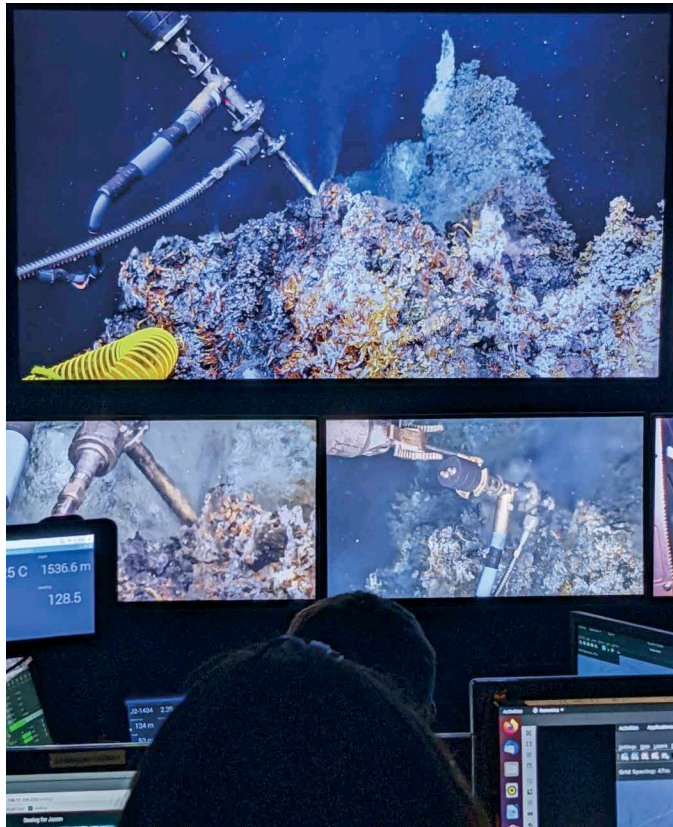
"This degassing approach wasn't used before because it would be difficult to fill up a normal cell with the small amount of gas you get from it," said Kriesel. "But since you have this small hollow-fiber cell, you can get away with this new method."

Guiding Photonics released its Omega fiber-optic gas cell for laser spectroscopy in 2021, available with or without accompanying sensors and degassing chamber.



Guiding Photonics' compact Omega gas cell is a long, hollow, coiled optical fiber. It requires only a tiny gas sample to fill it, but the fiber's length of 15 feet or more still offers plenty of opportunity for a tunable laser beam to be absorbed by molecules in the sample. Credit: Guiding Photonics LLC





### Striking Oil, Preserving the Environment

Most of the early commercial interest in the technology has come from the offshore oil and gas industry, where at least one major supplier has already bought multiple systems and others are showing interest, Kriesel said. He noted that offshore oil and gas drillers have a few reasons to look at, for example, methane isotopes. Methane might indicate an underground oil deposit, or it might be coming from a decaying whale carcass – isotopes can reveal the difference. Characterizing methane content of the water in an area before drilling also informs environmental impact statements, and it allows later testing during operations to reveal any leaks, helping with facility maintenance and minimizing environmental damage.

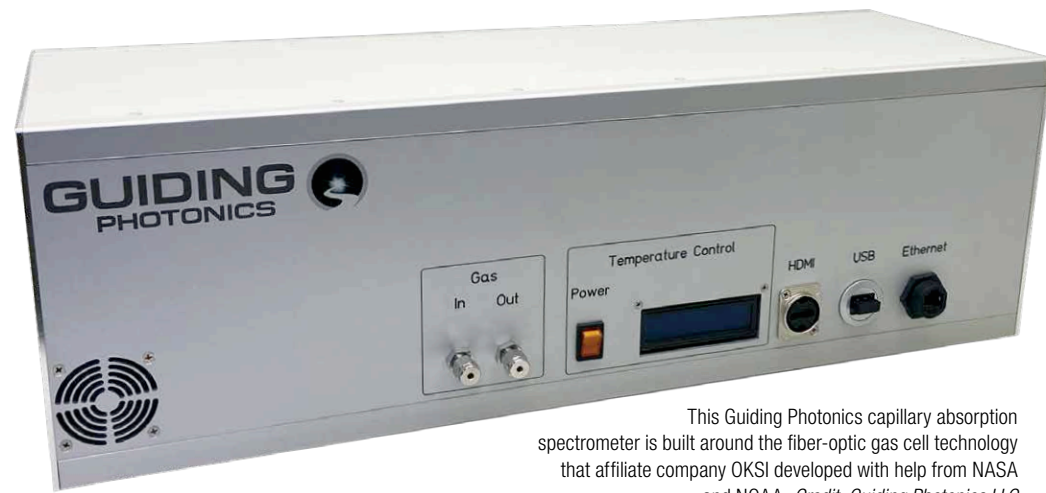
Normally, Kriesel said, the driller would have to send the samples to a lab and await results, which would direct the next round of sample collection. Instead, getting immediate results lets the user characterize an entire area in one attempt. “This technology gives them the ability to measure in the field and make decisions in real time, in terms of what they want to study further, which can save them a lot of money,” he said.

Other pilot projects have used the new capillary absorption spectrometer to look for methane in coastal wetlands – which would help climate researchers understand sources and sinks of greenhouse gases – and to monitor emissions from prescribed forest burns using a drone. Being small helps the device fit on a drone, where it can measure carbon dioxide-to-carbon monoxide ratios, imparting valuable information about the fire below.

OKSI is now working under SBIR funding from NASA’s Goddard Space Flight Center in Greenbelt, Maryland, to develop an instrument that could support Coleman’s search for the origins of water on Earth. Kriesel said he expects the project – adapting the technology to examine water isotopes on the Moon – to also result in a commercial water isotope analyzer from Guiding Photonics.

“For my interest in water,” said Coleman, “this could become a very small instrument that could take advantage of other NASA missions to go here, there, and everywhere, studying water around the solar system.” ●

Operators with the National Oceanic and Atmospheric Administration (NOAA) watch from a control room as a remotely operated vehicle measures methane concentration and isotope ratios at an underwater volcano off the coast of Oregon in July of 2022. It was the first deep-water test of the capillary absorption spectrometer developed by Optoknowledge Systems Inc. (OKSI) with funding from NOAA and NASA and now commercialized by Guiding Photonics. Credit: Andrew Fahrland



This Guiding Photonics capillary absorption spectrometer is built around the fiber-optic gas cell technology that affiliate company OKSI developed with help from NASA and NOAA. Credit: Guiding Photonics LLC

*“This could become a very small instrument that could take advantage of other NASA missions to go here, there, and everywhere, studying water around the solar system.”*

*Max Coleman, Jet Propulsion Laboratory*

# Concentrating on Microbes

## Space station germ testing improves wastewater monitoring



NASA astronaut Megan McArthur collects microbial samples from surfaces inside the space station to study the microbes associated with closed habitation and predict those that may pose a threat to crew health. Credit: NASA

Tracking the spread of COVID-19 through communities provided essential data for public-health officials and individuals to make informed decisions during the pandemic. One method that proved useful was collecting, concentrating, and testing municipal wastewater for the presence of the virus that caused the illness. As this testing ramped up, a technology developed for NASA to identify pathogens inside spacecraft saved time and produced dependable results on Earth.

SBIR requirements and funding for testing water and air on the space station helped InnovaPrep of Drexel, Missouri, improve its commercial kits for testing water and air quality on Earth.

Several Small Business Innovation Research (SBIR) contracts awarded a few years earlier helped InnovaPrep LLC of Drexel, Missouri, improve its existing bioconcentration process and apply it to automated testing for viruses, bacteria, and other pathogens in the air and water and on surfaces in the International Space Station. In addition to using a new filter material, improving the process, and modifying it for space, the company developed new fabrication steps to semi-automate production processes. Prior to the SBIR work, the company hand-built the disposable filter, called a pipette, producing about 200 a week. Now the output is 12,000 per week with a system that can easily scale up to meet increased demand.

The improved production came just in time. InnovaPrep could easily fill the orders from public-health departments, commercial laboratories, and researchers as COVID-19 monitoring efforts were put in place. Andy Page, chief technology officer with InnovaPrep, credits NASA with the company’s ability to advance its AirPrep and FluidPrep product lines.

“We had a lot of good interaction with NASA scientists who provided a lot of good insight. That collaboration is super-valuable,” he said. “The SBIR program allows you to discover things that you’re not going to be able to easily discover without that funding.”

### Preventing Super Bugs

Pathogens, including some bacteria and viruses, can become more harmful in zero gravity, so keeping a spacecraft safe for astronauts requires vigilance. But sample collection and testing are time-consuming tasks. NASA’s Jet Propulsion Laboratory in Southern California led the effort to make it more efficient using automation, with Kasthuri “Venkat” Venkateswaran, senior research scientist at JPL, working with InnovaPrep to modify its sample-concentration technology for space.



Concentrating the microbes in gallons of water down to a few ounces for testing could be a time-consuming task. But the specialized InnovaPrep filtration system called CP Select, which benefited from NASA expertise, can quickly do just that on Earth. Credit: InnovaPrep LLC



One option to enable faster results is a polymerase chain reaction (PCR) test. PCR rapidly amplifies small segments of genetic material – DNA or RNA – by making many copies. This creates a larger sample for genetic testing, making it easier to identify the type of bacteria or virus present. Targeting specific molecular fragments of viruses or bacteria is preferable in space instead of growing a live culture, a process frequently used on Earth.

“If you are growing microbes in space, that means even one cell will become billions of cells. One cell will not do any harm to human health, but growing that one cell in a closed system is dangerous,” said Venkateswaran. Tiny microbes are difficult to find, so NASA did some research to find out what was living on the space station.

One study required astronauts to wipe surfaces with sterile cloths before sending them to Earth. Once in the lab, the cloths were rinsed in a large



After the cloths used to wipe down the space station arrived on Earth, they were rinsed in the water jar seen here with an orange lid to remove microbes. That liquid was then concentrated into this vial (inset) for testing by InnovaPrep's CP Select system. *Credit: NASA*

amount of water, the resulting liquid was filtered, and the microbes were concentrated into a small amount of liquid for testing. The SBIR technology was meant to concentrate viruses and bacteria, reducing the time and cost required to get results.

### 72 Tiny Straws

InnovaPrep used its previous pipette structure for the SBIR work, but NASA's demanding filtration requirements compelled the company to look for a new material. Testing showed the best option was a hollow-fiber material made of what looks like 72 tiny straws, which make up part of the filter inside the pipette. A better filter means more viral and bacterial cells are captured per sample.

The company then automated the application of glue that holds the filters in place. This improved the performance and reliability of the device while serving as a first step toward improved production.

NASA requirements also prompted InnovaPrep to advance the quality of a foaming liquid that removes the trapped microbes from the filter.

To concentrate a sample in preparation for analysis – including PCR testing – a pipette containing the filter captures molecules and microbes suspended in a water sample. The next step, called wet foam elution, pushes the foaming liquid into the pipette, across the inner surface of the filter to recover the organisms or contaminants from a liquid sample. This pushes them down into a vial, ready for testing.

NASA's application required modifications to the process to function in zero gravity, along with a longer shelf life for the elution fluid. The liquid canisters were modified to dispense the liquid in space and sit for a year or more before being used. With some work, InnovaPrep met all of NASA's requirements.

“Wet foam elution is the backbone of our company. It's used in all our products,” said Ann Packingham, marketing and distribution director for InnovaPrep. “NASA really helped us improve the formulation and build a better canister. We were able to improve our shelf life by four to six months.”

### Rover Dry Wash

The bioconcentration system created for zero gravity hasn't been used on the space station yet, but companies on Earth are saving time and money with the technology upgrades. One advantage of the water and air monitoring equipment InnovaPrep offers is that it's simple to use. Unlike growing cultures in a lab, no special training is required.

It's not just tracking a pandemic that requires the concentration and testing of pathogens. Recreational facilities use InnovaPrep technology to monitor water quality in swimming pools. Hospitals use it to screen indoor spaces to keep them as sterile as possible. Water from cooling towers and municipal water systems is regularly tested for legionella bacteria, which can cause a severe form of pneumonia.

A major U.S. brewer concentrates its finished beer to look for spoilage organisms as part of the quality-control process. Pharmaceutical companies do the same, concentrating ingredients to identify spoilage organisms and other contaminants – the kits can also concentrate inorganic particulate matter. Businesses producing consumer goods such as dishwashing soap and lotions also look for contaminants that can cause discoloration or unpleasant smells in the products.

Farmers test irrigation water for pathogens, and food manufacturers monitor produce and equipment rinses to eliminate food-borne diseases. The InnovaPrep FluidPrep concentrator now used by businesses is so efficient, in fact, that JPL developed a series of cleanroom protocols using the commercial device.

When NASA sends hardware to other planetary bodies, technologists try to make sure it's as clean as possible. The intent is to remove microscopic hitchhikers from Earth to limit opportunities for contamination. Cleanroom staffers use a three-foot square piece of sterile cloth to wipe down large surfaces, removing as much biomatter as possible.



Wiping down the hardware of the Perseverance rover is one step in NASA's Planetary Protection strategy to limit the number of Earth microbes going to Mars. The Jet Propulsion Laboratory cleanroom, one of the cleanest places on the planet, developed procedures using InnovaPrep technology to check for any microbes left on the surface before flight. *Credit: NASA*

“If you increase the surface area to collect, then obviously you increase the liquid you use. And you have to do cumbersome filtering,” said Venkateswaran. “All the material must be DNA-free, so we asked InnovaPrep to come up with a product that is more sterile than what they had. They developed the technology to ensure their products are free of biomolecules.”

The published research verifying the efficacy of the cleanroom procedures helped InnovaPrep add new customers that require a sterile environment. But InnovaPrep's biggest customer base is still wastewater surveillance. When the prevalence of COVID-19 drops, it's necessary to test a greater volume of wastewater to understand what variants and levels of virus are present.

This makes technology to concentrate the relevant genetic material all the more essential. “It's very, very difficult to detect really low concentrations of microbes that could be present in a cleanroom or in large volumes of wastewater,” said Page. With the company's current products, it now takes less than 10 minutes to filter about a quart of liquid and end up with less than a quarter of a teaspoon containing the microbes, he said. “That gives us over a thousand times higher concentration.” ●

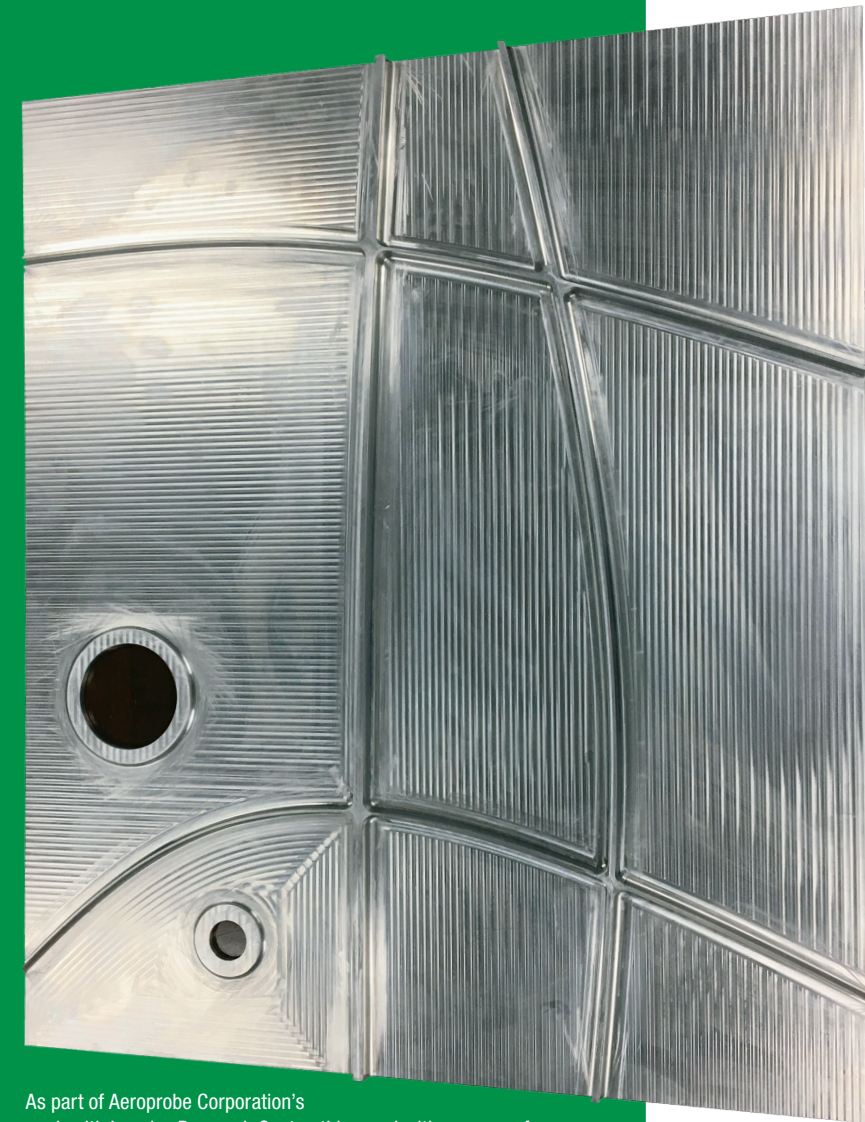
*“The SBIR program allows you to discover things that you're not going to be able to easily discover without that funding.”*

*Andy Page, InnovaPrep*



# Rocket Manufacturing Meets Science Friction

## Additive friction stir deposition builds bigger parts with more alloys



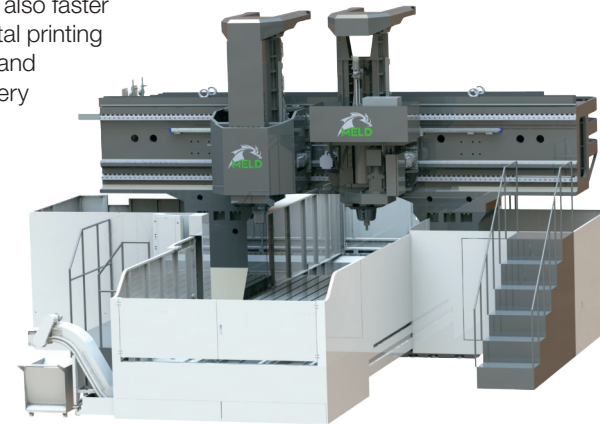
As part of Aeroprobe Corporation's work with Langley Research Center, this panel with an array of stiffeners was created with the help of additive friction stir deposition. Airplane bodies typically wrap a fatigue-resistant "skin" material over high-strength stiffeners, but NASA is interested in combining these two elements in a single piece. *Credit: NASA*

When Chase Cox and his team of engineers won NASA funding in 2014 to try a new 3D printing method by building metal parts for the Orion spacecraft, the project seemed like a long shot. The aluminum-alloy test objects, at a few cubic feet and well over 100 pounds, were outsized for any metal 3D printing process of the day, let alone one that was still in development and had never been used for aluminum.

"For what we were trying, it was at a scale that, at the time, seemed like science fiction at best," said Cox, now vice president at MELD Manufacturing Corporation of Christiansburg, Virginia, the company that spun off from that effort. "It was a small team with a really big idea."

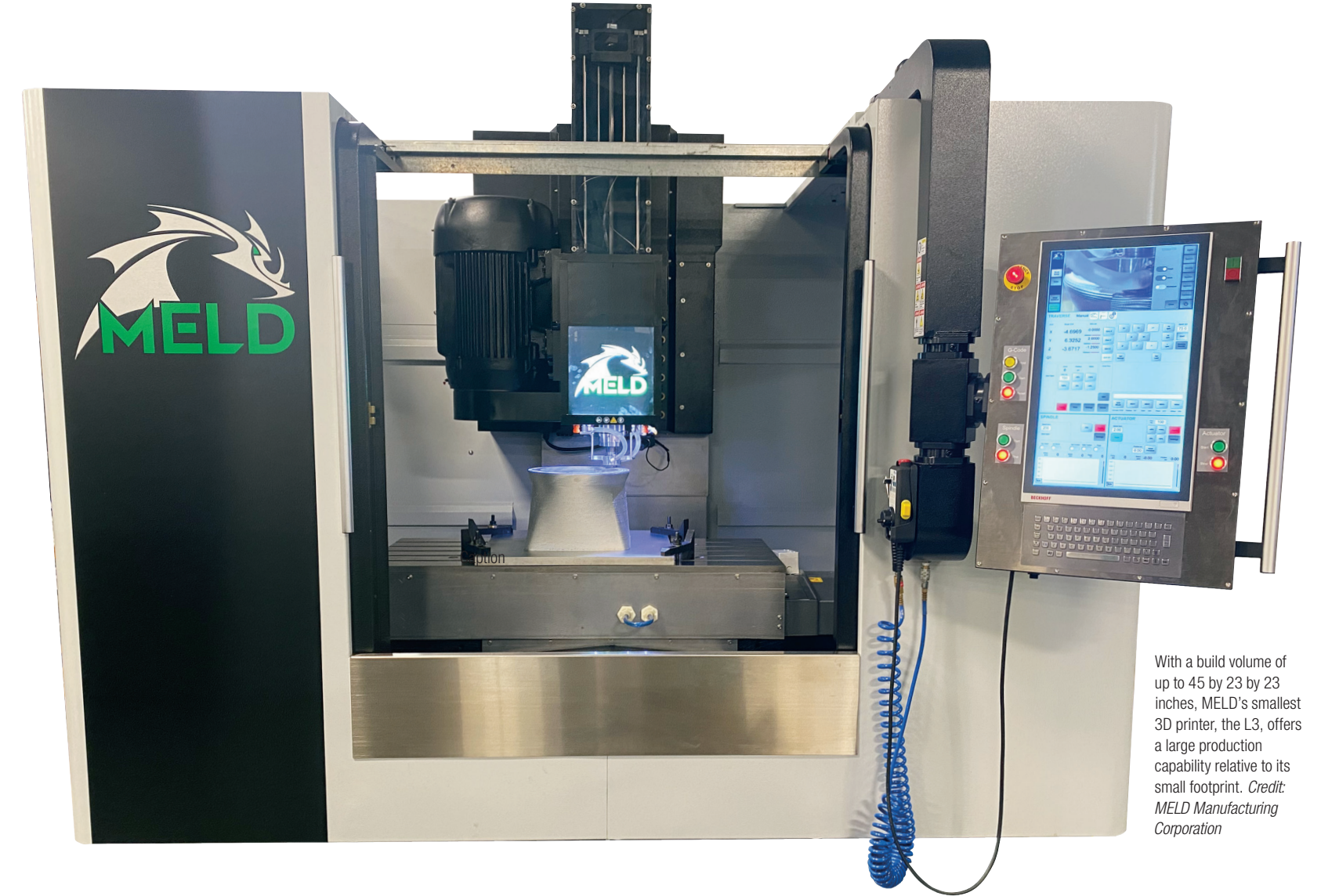
Now that big idea is the basis for what is planned to be the world's largest 3D metal printer, capable of producing entire tank hulls and other components of up to 20 by 30 by 12 feet for the U.S. Army, one of MELD's many new customers.

The technology the team tried out under NASA funding and has since commercialized, known as additive friction stir deposition, is the only metal 3D printing technique that doesn't melt the metal feedstock material. This gives it several advantages over the competition: It can work with metals and alloys that other 3D printers cannot. It can work in open air on a factory floor. It can build objects whose composition gradually changes from one end to another. It's also faster than other metal printing technologies, and it can create very large objects.



The 3P0 is MELD's largest 3D printer, incorporating both additive and subtractive manufacturing machines with an immense build space of 380 cubic feet. *Credit: MELD Manufacturing Corporation*

SBIR funding from NASA helped prove a new metal 3D printing technique. Now MELD Manufacturing of Christiansburg, Virginia, sells 3D printers that can make huge parts with alloys that defy other additive manufacturing technologies.



With a build volume of up to 45 by 23 by 23 inches, MELD's smallest 3D printer, the L3, offers a large production capability relative to its small footprint. *Credit: MELD Manufacturing Corporation*

MELD is now working with universities and major manufacturers around the world, and PhD students write dissertations on the technology. But when NASA awarded Cox's team some of its first funding, "there weren't a lot of people coming to us asking questions," he said. "It was hard to get people to pay attention."

### Printing Up Parts

At the time, the team was part of Aeroprobe Corporation, primarily a producer of airflow-measurement and avionics instruments, and had pioneered the new additive manufacturing technology internally. The NASA funding came in the form of Phase I and II Small Business Innovation Research (SBIR) contracts from the agency's Langley Research Center in Hampton, Virginia.

NASA was already exploring 3D printing as a way to cut weight and eliminate points of failure on rocket engines or to manufacture tools and other objects in space. But additive friction stir deposition presented the first chance to consider 3D printing rocket bodies and pressure vessels, which are usually made of aluminum alloys unsuited for additive manufacturing.

Aluminum lends itself to spacecraft and aircraft for a number of reasons. "With the right choices, we can get an aluminum alloy that's lightweight and has got a good balance of strength and ductility and good corrosion resistance," said Marcia Domack, who helped oversee the SBIR contracts as a senior engineer in the Advanced Materials and Processing Branch at Langley

before her recent retirement. "And some of those aluminum alloys that are not weldable tend to have higher strength."

The agency was already using a similar technology, known as friction stir welding, to join the pieces of rocket bodies. Invented in the early 1990s and improved by NASA (Spinoff 2001, 2008), friction stir welding uses a rapidly rotating pin tool to generate heat by friction, softening or "plasticizing" metals to allow them to be joined without melting them. Additive friction stir deposition similarly uses a hollow spinning printhead tool to plasticize metal feedstock so it can be deposited in a thin layer. Objects are built in multiple layers.



Unlike other metal additive manufacturing methods, it doesn't have to start with a metal powder. Since it therefore doesn't present dust hazards or require a vacuum, it can be used in open air on a factory floor and isn't limited by the size of a vacuum chamber.

It can be used with powders, however, to create what are known as functionally graded parts. "You can start with one material and add small amounts of another material and keep changing that ratio to create a grade in the component you're building," said Domack. One interest both Langley and industry have in graded materials is for building airplane bodies, which are typically made by riveting a fatigue-resistant skin onto high-strength stiffeners, she said. "One of our goals is a manufacturing process that would let you go from the skin-type material to the stiffener-type material in one piece." This would create a stronger structure while eliminating the weight of the rivets.

The work with Langley also demonstrated that the technology could recycle titanium scraps, which could save manufacturers a lot of money. Companies that use titanium often cut and mill a block of the expensive metal down to the desired shape, generating a pile of scrap metal that gets thrown out, Domack said. Aeroprobe and Langley found they could hot-press titanium chips into a feed rod and print with it, she said. The team also proved the technology's ability to print from feedstock made by pressing wires together.

But Domack said much of the initial work was "a lot of development of the parameters – how fast do you rotate? How hot do you have to get?"

"We demonstrated the ability to print in open air using high-strength aluminum alloys that couldn't be printed with other methods," said Cox. It's the kind of work that's now a significant part of the company's business.

### Technology MELDs with Several Industries

In 2018, MELD Manufacturing spun off to sell its printing machines and offer 3D printing services, although it remained a subsidiary of Aeroprobe. And at the start of 2023, the 3D-printing-as-a-service business spun off into another new Aeroprobe subsidiary, MELD Printworks.

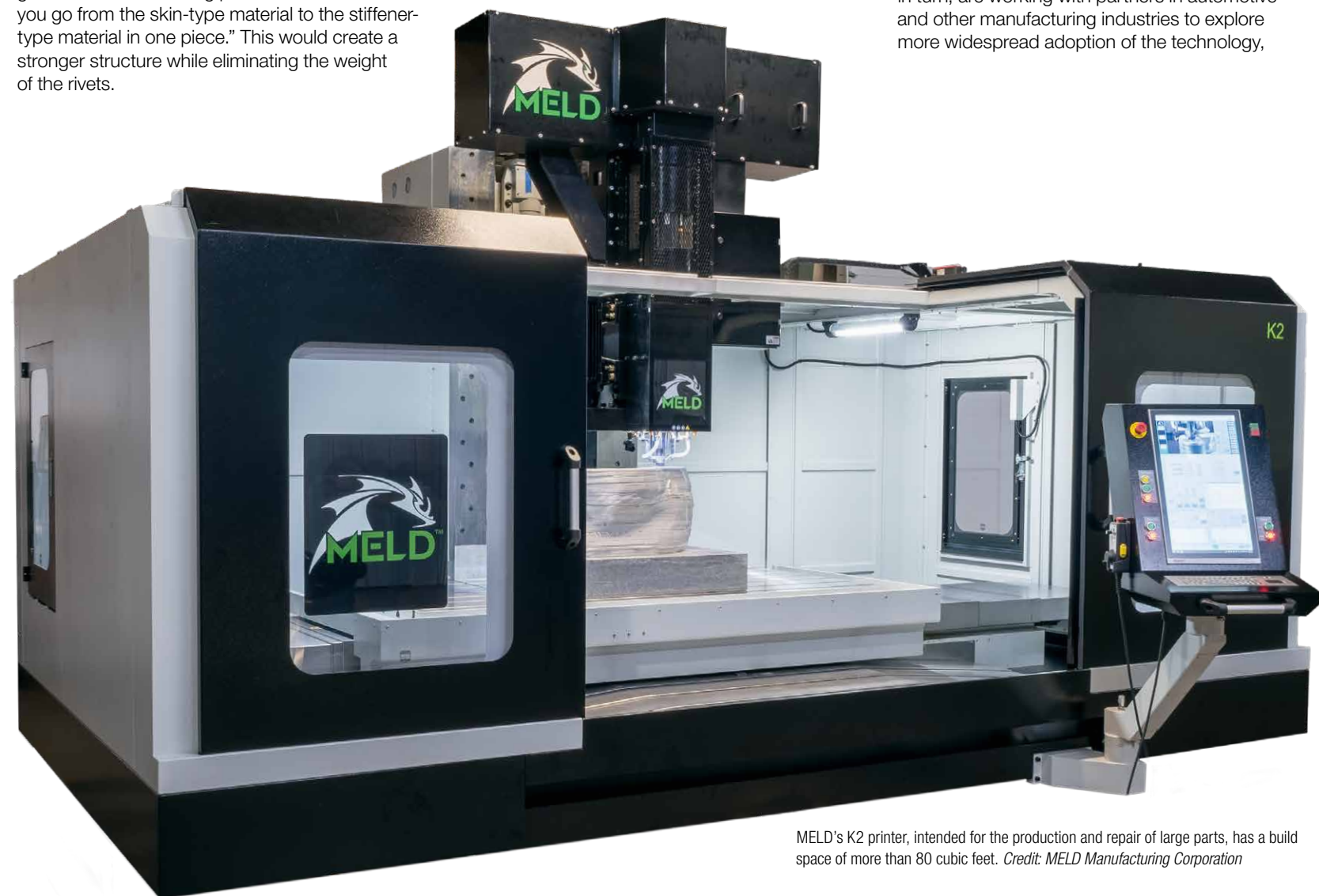
Cox said most major aerospace companies have already purchased MELD machines, as have a number of universities. Several of the universities, in turn, are working with partners in automotive and other manufacturing industries to explore more widespread adoption of the technology,

he said, adding that commercial airplane makers are also showing interest. Federal government customers include the military and the Department of Energy.

MELD is also licensing the technology to larger manufacturing companies so they can build their own 3D printers, Cox said.

So far, most of the interest is in applications that require low numbers of large parts, as this is where the biggest savings can be realized. "Some of these really high-cost parts have lead times of two years," Cox said, noting that reducing that time to months with a MELD printer saves a significant amount of money.

In the two years before MELD Printworks spun off, the number of employees at MELD Manufacturing expanded from the single digits to about 40, he said. "We've got a team of people from all over the country, and they're all excited at the chance to have an impact on a technology that has so much to offer." ●

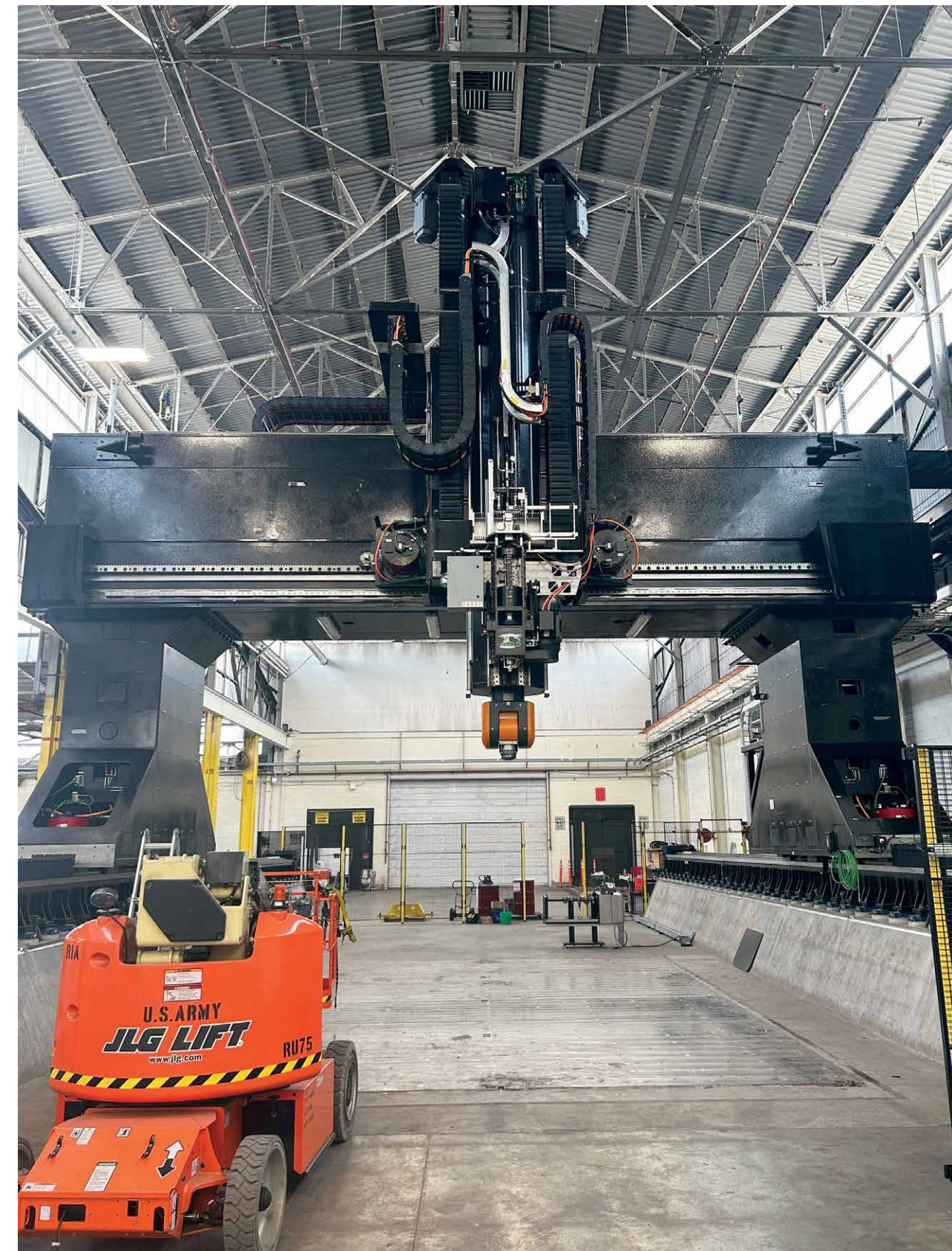


MELD's K2 printer, intended for the production and repair of large parts, has a build space of more than 80 cubic feet. Credit: MELD Manufacturing Corporation

*"For what we were trying, it was at a scale that, at the time, seemed like science fiction at best."*

Chase Cox, MELD Manufacturing Corporation

This huge 3D printer from MELD Manufacturing is being commissioned by the U.S. Army at Rock Island Arsenal in Illinois for the Army's Jointless Hull Program, which will create single-piece hulls for combat vehicles. Credit: Rock Island Arsenal, Joint Manufacturing Technology Center





# Cutting the Knee Surgery Cord

## NASA experts offered early advice on first FDA-cleared wireless arthroscopic camera

Years ago, Eugene Malinskiy saw a physician assistant trip over the cords of an arthroscopic camera during a medical procedure. He recalls the story when people ask why he and his brother cofounded Lazurite Holdings LLC, a medical device company in Cleveland.

The assistant fell to the floor, pulled cables off the patient, and needed to be wheeled out of the operating room. The procedure had to be postponed.

Malinskiy and his brother, Ilya Malinskiy, went on to develop the first Food and Drug Administration (FDA)-cleared wireless arthroscopic camera, a project that got an early boost from engineers at NASA's Glenn Research Center in Cleveland, which advised on technical specifications.



Lazurite's ArthroFree Wireless Camera System incorporated aerospace-grade lithium-ion batteries after developers consulted with NASA engineers. Credit: Lazurite Holdings LLC

The first FDA-cleared wireless arthroscopic camera – for knee surgeries and other orthopedic procedures – got early support from NASA through the Adopt a City program, which enabled agency engineers to consult with companies like Cleveland-based Lazurite, the device manufacturer.

## Cutting the Cord

For orthopedic surgeons probing patients' knees and other joints, the case for a wireless arthroscopic camera is strong.

In the operating room, cords are a tripping hazard; they can overheat and burn patients; and they are cumbersome and difficult for doctors to move around. Critically, the technology required for a wireless device has been mature and reliable for years.

To get rid of the cords, the Malinskiy brothers needed a power source and a wireless communication technology. They drew up design plans to fit those innovations into an economical and ergonomic package – “something that would be comfortable and not too heavy to hold for long periods,” Ilya Malinskiy explained.

They had a few technical questions, but otherwise things were going well – surprisingly well, considering their limited experience in the world of medical devices. Was there something they weren't seeing?

That's where they were in 2016 when they met with NASA engineers through the Adopt a City program, which ran from 2012 to 2016. The program enabled Glenn engineers and experts to consult with local businesses on a pro bono basis via a Space Act Agreement with the city of Cleveland.

## Don't Go on the Internet

It turned out that the first wireless arthroscopic camera wasn't entirely unlike CubeSats – tiny satellites that often orbit Earth in clusters.

“We had a lot of the same issues,” Ilya Malinskiy said. “We both have very small devices that need to be reliably powered without a lot of weight.”

Thomas Miller, an electrical engineer in the Photovoltaic and Electrochemical Systems



The case is strong for getting rid of extra cords in an operating room setting, where they are a tripping hazard, can overheat and burn patients, and are cumbersome and difficult for doctors to move around. Credit: Lazurite Holdings LLC

## 'This Will Work'

The Lazurite team also consulted with NASA engineers on their plan to use the ultra-wideband protocol – radio technology that enables encrypted transfer of a high-definition signal – and on the processors and chips they planned to use in the device's central processing unit.

“The electrical engineers at NASA looked at our design and said, ‘Maybe use this one instead,’ or, ‘That's a really good idea.’ They were saying ‘You may want to make a few changes, but this will work,’” Ilya Malinskiy said.

The company took the feedback to investors, he said. “Being able to say we had very skilled engineers from NASA take a look and say we should keep going was very, very useful.”

In 2022, Lazurite's ArthroFree Wireless Camera System became the first FDA-cleared wireless camera system for minimally invasive surgery. The device has been used in scores of surgeries, and the company has raised tens of millions of dollars.

“It doesn't always work out this way,” NASA's Miller said. “Sometimes we must give companies bad news to prevent them from dumping more money into a project that won't work. Lazurite had a good design, so it worked out great for them.” ●

Branch at Glenn, said the Malinskiys were using the same-sized lithium-ion battery found in devices on the space station and in spacesuits, in addition to satellites.

Miller thought through the particular use scenarios of the device. “You don't want the battery to fail. You don't want a thermal runaway,” he said. “You want the system to be safe during fabrication, during routine charging. You have heat considerations in a device that needs to be sterilized.”

Ultimately, the NASA engineers connected the Lazurite team with several high-fidelity aerospace lithium-ion battery vendors.

“You don't want to get batteries that went through a third party or aren't up to snuff,” said Miller. “We recommended not going on the internet and buying cells from an unknown vendor.”

Overall, he said Lazurite's early camera design was great. “They did a lot of upfront work, and they were just trying to make it better and more efficient, using the best batteries available,” Miller said.



# NASA Gives the World a Brake

## Space agency invention puts a new spin on automotive brake rotors

Just as NASA needs to reduce mass on a spacecraft so it can escape Earth's gravity, automotive manufacturers work to reduce weight to improve vehicle performance. In the case of brake rotors, lighter is better for a vehicle's acceleration, reliable stopping, and even gas mileage. Orbis Brakes Inc. licensed a NASA-patented technology to accomplish that and more. This revolutionary brake disc design is at least 42% lighter than conventional cast iron rotors, with performance comparable to much more expensive carbon-ceramic brakes.

During the pandemic shutdown, Jonathan Lee, structural materials engineer at NASA's Marshall Space Flight Center in Huntsville, Alabama, got to thinking about disc brakes. His skills as a mechanical designer backed with material science training are usually focused on his dual roles as the structural materials engineer for the Space Launch System and a microgravity material scientist for the space station. Interested in supporting NASA's other mission to advance technology to improve life on Earth, he was looking for an innovative way to design a better automobile disc brake.

"NASA's willingness to help companies be more successful, using all of their expertise and the goodwill that extends, is really amazing," said Chance Claxton, co-CEO of Santa Rosa, California-based Orbis Brakes.

### The Periodic Wave

Reducing the mass of its wheels means a vehicle will use less energy to brake and accelerate. Conventional brake discs are heavy because they consist of two metal plates cooled by air circulating between them. The design is inefficient because it's the outside surfaces that are heated by friction with the brake pads, but the air cooling takes place on the inside surfaces, where the plates face each other. Lee wanted to directly cool the hot surfaces instead, allowing one of the heavy discs to be eliminated from each of a vehicle's four rotors. His design proved to have additional benefits as well.

He started with a single disc with a series of small fins around the central hub. As they spin, these draw in air and push it across the surface of the disc, where the brake pads make contact, cooling the rotor, as well as the brake pads and calipers. He then added several long depressions around the braking surfaces, radiating from the center to create the regular, periodic pattern that gives the new Orbis technology its PeriodicWave brand name.

The NextWave disc brake by Orbis Brakes of Santa Rosa, California, replaces existing disc rotors in high-performance cars thanks to exclusive licenses for NASA patents.

The spinning fins and the centrifugal force of the wheel push air into the depressions, causing a turbulent airflow that draws away heat. "When the air flings out, it goes across the brake caliper and cools it – no conventional rotor is capable of doing something crazy like that. It's huge," said Lee.

These trenches in the braking surfaces also increase the available surface for air cooling by more than 30% and further reduce the weight of the disc. And they increase friction in the same way that scoring concrete makes steps safer to walk on – the brake pads are less likely to slip, which makes braking more reliable.

The troughs draw away more than just heat, too. Water and road debris getting between the pad and rotor are equally problematic, so the trenches provide a place for the air vortex to push any

substance out of the way. A small hole machined at the end of each one creates an opening through which unwanted material can escape. "And it also just looks cool," said Lee.

A second periodic wave is cut along the outer edge of the disc. By replacing the conventional circular design with an undulating pattern, the new rotor has still more surface area that will come into contact with the cool air flowing over it. This additional heat dissipation will occur no matter which periodic wave pattern is used, making it possible to create funky designs and add personality to what is usually a boring car part.

Finally, a thin layer of black coating applied to surfaces that don't come into contact with the brake pads, like the inside of the troughs, can help the rotor to radiate additional heat. This unique three-part cooling system – convection powered by airflow, conduction of heat across the metal rotor, and radiation from dark-coated surfaces – has never been implemented effectively on any conventional disc brake rotor before, Lee said.

### Eco-Friendly Brakes

Unlike conventional brakes that can overheat and potentially fail, this new brake design can dramatically improve dependability. It also may offer a mechanical solution to a serious environmental pollutant – toxic nanoparticles.

"When brake pads exceed a certain critical temperature, depending on their materials, they can emit a 10,000-fold increase in toxic nanoparticulates," said Marcus Hays, co-CEO of Orbis Brakes. Because the toxic dust hovers right at street height, the impact on human health is more harmful than exhaust emissions, according to an Oxford University study. So the company is currently testing its EcoWave brake design to ensure it will not create that kind of emission, according to Hays.

In the meantime, Orbis is offering the NextWave rotor as an after-market disc brake for high-performance cars like the Ford Mustang and some Tesla models.

Electric cars can be about 25% heavier than internal combustion-engine vehicles, and they have excellent speed, acceleration, and torque. Owners tend to drive them like sports cars, according to Hays, so the company is offering an alternative to the factory-installed brakes, which aren't designed for that kind of handling. NextWave will enable faster stops and better direction changes, in addition to a different kind of cool factor: "This extraordinary functional



Early adopters of the Orbis Brakes NextWave disc brake for high-performance cars include the personal vehicles of race car drivers who provide the company feedback about performance. The input will inform the design of future brakes for electric cars, gas combustion-engine vehicles, and everyday drivers. *Credit: Orbis Brakes Inc.*

configuration also has an incredibly novel appearance – there's nothing like it in the history of disc brakes," said Claxton.

### 'Mind-Blowingly Powerful'

As the company gets feedback from early adopters, it will be preparing two more lines: LightWave will combine the NextWave rotor with a lightweight caliper, and CarbonWave will be exclusively for electric vehicles.

All of these models weigh approximately half what conventional rotors weigh, while drastically improving the braking performance. All the brakes will be manufactured in the United States. In addition to the potential for reduction of toxic nanoparticles, the carbon footprint for every type of periodic wave disc brake will be much smaller than conventional brakes.

Calling NASA's Technology Transfer program "instrumental to American competitiveness," Hays described the company's relationship with NASA as "mind-blowingly powerful."

"It is absolutely going to catapult our business and gives us a credibility and validity for everything we do," he said. "NASA gives us a foundation to go out into the world and negotiate and have the respect of our peers right out of the gate. That would not be the usual case for an early-stage company." ●



The periodic wave design of the Orbis Brakes NextWave disc brake reduces the overall weight by about 40% while increasing surface area and incorporating more efficient cooling to prevent overheating, and it reduces the release of brake pad particulate matter into the environment. *Credit: Orbis Brakes Inc.*



Materials used in space must survive extreme temperatures, as demonstrated by this static test of a booster engine for the Space Launch System. NASA's materials experience helped Orbis Brakes create a new, lighter, affordable disc brake system for cars and trucks. *Credit: Northrop Grumman Corp.*



# Medical-Grade Smartwatch Can Monitor Astronauts, Patients

**NASA-backed consortium helped develop device for clinical trials, academic research, outpatient monitoring**

Life for astronauts on the International Space Station has been, for the most part, less taxing than it was in the space shuttle days, when missions often included many goals and milestones compressed into a short period of time. That won't be the case, however, for the first astronauts to journey to the surface of the Moon during the Artemis program, said Alexandra Whitmire, a NASA scientist whose job concerns astronaut well-being and performance.

"Artemis missions will be very ambitious, with crews having to conduct many tasks, sometimes across extended work hours or overnight shifts," she said. "Their schedules will likely be disruptive to sleep patterns, similar to what we experienced in the shuttle days." As a science manager for the Human Factors and Behavioral Performance element of NASA's Human Research Program, Whitmire is looking for the best ways to monitor and support astronauts' sleep to help ensure their safety and performance. And hers is just one of five elements in the Human Research Program at NASA's Johnson Space Center in Houston. Others have concerns like astronauts' exercise and medical needs and guarding their health against hazards of the space environment, such as radiation.

Most of the program's efforts could benefit from a wearable device capable of measuring and providing feedback on astronauts' physiology in a variety of ways. That's why, in 2020, Whitmire found herself presented with the latest work from medical wearable technology company Empatica Inc. of Cambridge, Massachusetts. With help from NASA and an eye toward the agency's needs, the company had developed a smartwatch that packed five sensors into a small, comfortable, attractive design, which is now commercially available as the EmbracePlus.

Development of the device's prototype was funded in part by a grant from the Translational Research Institute for Space Health (TRISH), a research consortium that looks for ways to reduce risks to astronauts on long missions. TRISH is funded by Johnson and Baylor College of Medicine.

## Combining Electronic Brains and Beauty

Empatica had previously commercialized a science-grade smartwatch known as the E4, mainly for use in academic research and clinical studies, as well as a smartwatch for detecting epileptic seizures to alert caregivers, called the Embrace2, which was designed to be attractive and comfortable for daily use. For the EmbracePlus, the company wanted to combine the pleasing look and feel of the Embrace2 with the capabilities of the E4. These included an accelerometer to detect movement, a temperature sensor, an infrared sensor that monitors cardiac and respiratory activity, and another that detects electrical activity in the skin, which correlates to nervous system activity. The EmbracePlus also adds a gyroscope for more refined movement detection.

The EmbracePlus automatically and continuously collects data and streams it via Bluetooth to its companion app as part of the Empatica Health Monitoring Platform. *Credit: Empatica Inc.*

Empatica of Cambridge, Massachusetts, developed its EmbracePlus wearable device with funding from a NASA-backed research consortium. The smartwatch can monitor astronauts' physiology, but it's also being used in clinical trials and to observe outpatients.

"EmbracePlus combines the beautiful design of Embrace2 with the data-collection capabilities of the E4, so it's a medical device with a consumer look and feel, which can be easily worn in everyday life," said Simone Tognetti, chief technology officer at Empatica.

The development carried out with the help of TRISH funding included evaluating different sensors for detecting heart rate and oxygen flow, running trials on critical features, integrating all the components and design elements, determining the most comfortable form factor, and choosing a display, among other work.

"The funding allowed us to implement important engineering features, such as placing the electrodermal activity sensors on a comfortable, removable strap," said Tognetti, referring to the sensors for electrical activity in the skin. "This was the result of much R&D into the manufacturing, electrical connection, and signal-quality implications of various constructions."

The Human Research Program's need for a device to be used by astronauts in space and even in studies on the ground also shaped the watches. Whitmire noted that a small, lightweight, comfortable design is essential to the space program. "You really need a device that is not obtrusive, that is not burdensome, so it's not causing a stressor in and of itself," she said.

Tognetti said NASA also required the technology to be energy-efficient, easy to use, and robust enough to work in the harsh space environment. "We have customizable hardware modes to optimize data collection with battery life, a built-in memory that can store up to 55 days' worth of data in case of low connectivity, and a low-power display that also helps with troubleshooting," he said. Meanwhile, the device automatically and continuously collects data and streams it via Bluetooth to its companion app, which pushes it to the cloud. "All the user needs to do is make sure the device is charged and connected," he said, noting that the app will also remind users of even these steps.



Developed with funding from a NASA-backed consortium, the EmbracePlus combines medical-grade capabilities and precision with the look, feel, and comfort of a consumer product. *Credit: Empatica Inc.*

## Researchers Embrace New Wearable

EmbracePlus went into mass production in 2021. It's already been cleared by the U.S. Food and Drug Administration as a key component of the Empatica Health Monitoring Platform. Tognetti described it as a platform where machine learning algorithms can analyze simultaneous data streams from different types of sensors to detect and monitor various aspects of health. Empatica's software development kit also lets sensor data be combined in new ways to identify different conditions. For example, during the COVID-19 pandemic, the company developed an algorithm to detect a respiratory infection before symptoms presented.

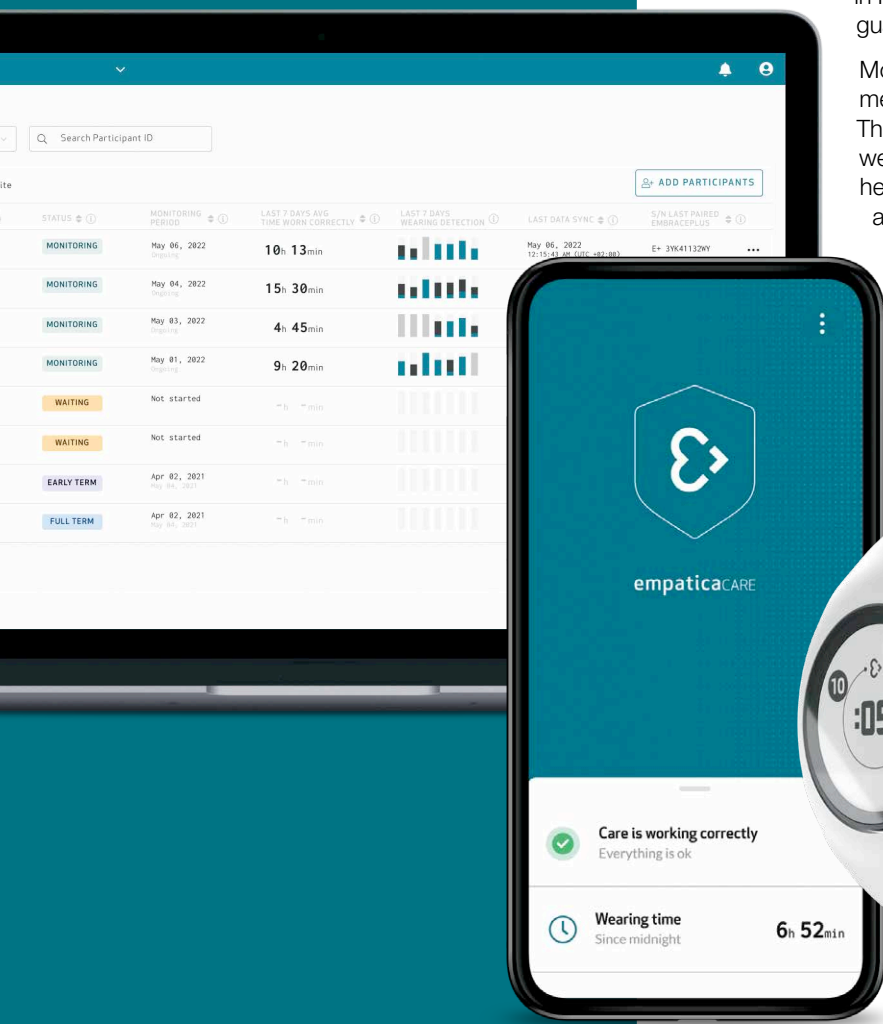
"The wearable is already being used in large-scale clinical trials and in academic research," said Tognetti, noting that customers include some of the largest pharmaceutical companies and major research projects around the world. Among the latter are two European Union-funded initiatives – the Sleep Revolution project, which seeks to use machine learning to diagnose and treat sleep apnea, and the TIMESPAN project, which is looking at the intersection of attention deficit hyperactivity disorder and conditions like diabetes and cardiovascular disease, with the hope of optimizing and personalizing treatments.

For research and clinical trials, he said, "being able to get gold-standard measurements from participants' homes or their offices without relying 100% on self-reporting, or on weekly site visits that provide only snapshot metrics, means more high-quality data and a much lower participant burden."

In the future, Tognetti said, the company also wants the Empatica Health Monitoring Platform, including the EmbracePlus, to be "the go-to tool" for monitoring patient health outside of clinics.

Back at Johnson Space Center, Whitmire said the EmbracePlus is one of the devices under consideration for measuring vital signs and sleep-wake activity in spaceflight and ground research. It's the device's accelerometer, which can be used to identify sleep-wake cycles, that mostly interests her group, but she noted that some of the other sensors could be of interest to other elements of the Human Research Program. The wrist-worn device astronauts have been using to collect data is going out of production, and she said the EmbracePlus could address some of the limitations of the previous device, including comfort and connectivity, especially given that the other device doesn't stream data in real time.

For monitoring sleep, Whitmire said she thinks a device like the EmbracePlus could also find applications outside the medical field. She noted that trucking, railway, and other industries have fatigue-management systems that rely largely on self-reporting. "There's established research that shows we underestimate the effects of sleep deprivation on our performance," she said. "I see these kinds of devices and, yes, they're important for research, but in an applied setting, their ability to provide objective feedback has the potential to improve safety across many industries and to promote taking care of people who work extended hours or overnight shifts." ●





# Semiconductor Research Leads to Revolution in Dental Care

## Crystals grown for space electronics lead to profusion of remineralizing toothpastes



Sangi's first hydroxyapatite-based toothpaste, Apadent, hit the market in 1980 with this packaging design. Credit: Sangi Co. Ltd.

The casual observer is unlikely to find much in common between teeth and electronics. Early in NASA's history, though, a space agency researcher spotted one similarity that has led to a whole new family of toothpastes.

Toothpaste based on the mineral hydroxyapatite is only beginning to find a market in the United States after spreading across much of Asia and Europe during the last 40 years. But the unlikely story behind this unique approach to toothpaste, which is said to repair teeth by remineralizing them, began here, in the 1960s in an electronics lab at a short-lived NASA field center in Cambridge, Massachusetts.

At that time, Bernard Rubin was a senior scientist working on semiconductor technology at NASA's Electronics Research Center, which sat across the street from the Massachusetts Institute of Technology from 1964 until it closed just six years later. He was working to grow structurally and chemically perfect crystals for use in semiconductors – essential components of computers and other electronic devices – and he found that he could produce higher-quality crystals by growing them in a silica gel rather than in water or other media.

There was precedent for this method of crystal growth but not for the insight it inspired in Rubin and his colleagues. They became aware, he wrote in a 1970 article in the journal *Nature*, of a "similarity between the physical chemical mechanisms of our gel diffusion system and the process of calcium phosphate crystallization during bone formation." Hydroxyapatite is the form of calcium phosphate that lends its hardness to bones and teeth, where it also crystallizes in a gelatinous medium that was not well understood at the time.

Some years later, Rubin told representatives of the first company to produce hydroxyapatite toothpaste that this realization was inspired by his team's knowledge that bone loss is one of the most serious physical effects astronauts experience during a prolonged stay in zero gravity.

When he and another NASA scientist filed for a patent around the idea, though, they pitched it for tooth repair, as hydroxyapatite is the main mineral ingredient in both bone and dental enamel. The idea they patented was a method for using gel to grow crystals of brushite – a precursor to hydroxyapatite – and then capping them in place on the damaged surface of a tooth, where they would convert to hydroxyapatite and repair the tooth.

Tokyo-based Sangi Co. acquired a NASA patent for repairing teeth by growing hydroxyapatite crystals, leading the company to develop the first hydroxyapatite-based remineralizing toothpastes in the 1980s. Hundreds of other companies have followed suit.



This building in Cambridge, Massachusetts, now the John A. Volpe National Transportation Systems Center, housed NASA's short-lived Electronics Research Center from 1964 to 1970. That's where research into crystals for electronics led to an idea for repairing teeth with hydroxyapatite crystals. Credit: Daderot, CCO

By repairing teeth using their own natural ingredient, and even imitating the tooth's gel-based crystal-growth process, Rubin's proposed method was an early example in the emerging field of biomimetics, the imitation of biology to solve biological problems.

By the time the patent was granted in 1972, the Electronics Research Lab was no more, and Rubin had transferred to NASA Headquarters in Washington to manage remote sensing and data acquisition programs.

### 'The Same Substance as Our Teeth'

Two years later, on the other side of the world, Shuji Sakuma founded Sangi Co. Ltd. in Tokyo as a trading company dealing in wine, machinery, intellectual property, and more. Early on, as he searched for business ideas, Sakuma came across a compilation of available NASA patents. Rubin's patent caught his eye.

Sakuma mentioned the technology to one of Sangi's original investors and directors, who happened to be a dentist with connections in the dental academic world. In November of 1974, Sakuma sent this dentist and a professor from Nippon Dental University to meet Rubin and colleagues. Sakuma's wife and current president of Sangi, Roslyn Hayman, describes the trip in a history she recently compiled, writing that the two envoys spent a full day with Rubin at a NASA facility and were impressed enough with his discovery that Sakuma decided to acquire the patent.

According to Sakuma, this is when Rubin cited astronaut bone loss as an inspiration for his insight.



Monocrystalline silicon ingots like these are grown in labs. A NASA researcher growing crystals for electronics in the 1960s noticed a similarity with the way crystals form in teeth and bones and patented a method for growing hydroxyapatite crystals to repair teeth. Credit: Getty Images

The dental professor then spent the next decade trying to implement the idea outlined in the brief, two-page patent but never achieved the desired results. Meanwhile, Sakuma grew impatient and proposed skipping the intermediate step of forming hydroxyapatite in the mouth from brushite crystals and instead simply infusing a toothpaste with hydroxyapatite. "On the basis of the NASA patent that his company had acquired, Sakuma proposed creating 'a toothpaste containing the same substance as our teeth' that could actually restore teeth," Hayman writes. He enlisted the help of another dental university specialist to work out the technical details and test the resulting toothpaste's effectiveness.

By the late 1970s, Sakuma had found a manufacturer, and clinical trials were underway. Sangi launched its first toothpaste, Apadent, in Japan in 1980, followed by Apagard in 1985.

### From East, Back West

Japan has been slow to adopt fluoride treatment, so there was interest in finding an alternative, Sakuma said in an interview. "Given the situation, our product was carried on the wind."

However, it took years to get government approval to make any medical claims about the products, so they were initially – and successfully – marketed as beauty products for whitening teeth. After Sakuma "begged, borrowed, and mortgaged everything" to fund his first advertising campaign, featuring people identifying each other by the whiteness of their teeth, the company sold what it had expected to be a year's supply in three weeks, Hayman said in an interview. Hydroxyapatite toothpaste was in business.

It wasn't until 1993 that the Japanese government recognized hydroxyapatite as an anti-cavity agent. According to the company, studies over the last 40 years have also found that by restoring the enamel surface, hydroxyapatite improves tooth whiteness and gloss, protects against plaque attachment and erosion, and prevents hypersensitivity, and it's also been shown to help remove oral bacteria and eliminate bad breath.

Different markets have embraced it for different reasons. The Japanese government still doesn't recognize it for sensitivity prevention, but this is its biggest selling point in much of Europe, Hayman said. Because hydroxyapatite is safe to swallow, it has also been successful in children's products.



Sangi now makes a children's variety of Apadent, among other variations. Credit: Sangi Co. Ltd.

Following its success in Japan, Sangi's first international toothpaste sales were in Russia, followed by Canada and China. These are still the company's biggest markets outside its home country. Sangi also makes toothpastes that a number of other companies sell under their own names, such as Yakult's popular Apacoat S.E.

The company now exports to 25 countries, has a subsidiary in Germany, and employs more than 100 people. Since its founding, Sangi has sold more than 160 million tubes of its hydroxyapatite toothpaste.

In the United States, the Food and Drug Administration (FDA) doesn't allow cavity-fighting claims for toothpastes that don't have fluoride, preventing Sangi from entering the U.S. market until now. However, the FDA recently approved an anti-sensitivity product the company developed based on hydroxyapatite.

By now, hundreds of other companies make hydroxyapatite toothpaste. Most of them followed Sangi's lead, and Sangi followed NASA's Rubin. "Sakuma could never have conceived of his idea without Rubin's revolutionary insight," reads Hayman's company history. "We believe that we owe it all to the NASA patent." ●



# Unfurling Antennas Let Tiny Satellites Do Big Things

**High-gain antennas for communication and imaging can now ride smaller, cheaper spacecraft**

As NASA's Artemis missions build out infrastructure on and around the Moon in the coming years, CubeSats and other small satellites will likely play an important role in a communications network that will enable not only conversation with mission control but also navigation, direct scientific observations, and more, all enabled by an internet-like "LunaNet." These little satellites are cheap to launch and can form constellations for relaying signals reliably. But their small size makes it hard for them to carry antennas large enough to communicate across vast distances.

Now, a solution that was invented at NASA's Jet Propulsion Laboratory in Southern California is already drastically reducing the cost of putting antennas for sensing and communications into Earth orbit. Satellite builders now have the option of using small, collapsible dish antennas made by Tendeg LLC of Louisville, Colorado, which developed them with funding and cooperation from NASA, along with the patented technology developed at JPL.

In 2014, JPL set out to build a high-gain, high-frequency antenna that could collapse into a canister only about four by six inches in size, with the goal of allowing a CubeSat to communicate with Earth from as far away as Martian orbit. The resulting Ka-Band Parabolic Deployable Antenna (KaPDA) had curved, folding ribs and a reflector dish of gold-coated metal mesh. A small motor extended the antenna's central hub, which unfolded the rest of the structure by a series of catches, hinges, and springs.

Part of the challenge was that the antenna needed to handle higher frequencies than prior CubeSat antennas, said Jonathan Sauder, who was a KaPDA team member at JPL. Higher frequencies transmit data at a much higher rate. KaPDA was to transmit in the Ka-band, microwave frequencies that would allow data rates 10,000 times those of even "high-performing" CubeSat antennas of the day. But these tiny waves require a much more perfect reflecting surface, said Sauder. "If you're doing communication in the Ka-band, you need 0.3 millimeters of surface accuracy in order to focus the beam."

The project exceeded expectations. At less than 20 inches across, KaPDA was smaller and performed better than anticipated. JPL patented the overall antenna design and tried it out in Earth orbit on a little satellite called RainCube, which went into orbit in the summer of 2018 and used radar to track heavy storms.

## Meeting Industry Needs

From 2015 through 2020, Tendeg, whose founders had worked on deployable satellite instruments since the 1990s, received a series of Small Business Innovation Research (SBIR) contracts from JPL to develop a follow-up to RainCube. This design maintained Ka-band surface accuracy and the ability to deploy from a CubeSat but expanded the aperture to 40 inches and used a new deployment mechanism.

A contract to develop a NASA antenna, along with an agency license, SBIR funding, and a former NASA chief engineer, all helped Tendeg of Louisville, Colorado, develop high-performance antennas that collapse to fit into small satellites.

Throughout this time, Tendeg also won several other SBIR contracts from JPL to work on adapting metal mesh for Ka-band reflectors and to design small, deployable antennas and precise, deployable boom and hinge systems. The work led to a 2021 contract from JPL to build a 63-inch Ka-band reflector for a mission called INCUS, short for Investigation of Collective Updrafts.

The INCUS project led to a flight contract with a commercial company that's already using the resulting antenna to collect Earth imagery with the synthetic aperture radar technique, which can penetrate clouds and darkness. That antenna has become one of Tendeg's commercial products, known as KaTENna, which can be up to 11 feet across. At that size, though, it needs a satellite a little larger than a CubeSat.

As rideshares into orbit have become cheaper in the last few years, CubeSat popularity has fallen off in favor of slightly larger, less restrictive small satellites, said Gregg Freebury, Tendeg president and CEO. "One thing we've seen is, customers have come back and said, what we really need is a larger aperture because we need more gain," Freebury said. "And then the other thing is, they often wanted these to be steerable so they would be able to track a ground station on Earth or perhaps track another satellite."

To meet that second need, Tendeg secured an exclusive license to the KaPDA technology and redesigned it while incorporating many of the same elements as well as a gimbal, which gives the antenna a hemisphere of pointing motion. The resulting KaPDA Gimbal antenna has become one of the company's most popular products, Freebury said. "Most of our growth right now is around this gimbal antenna system."

He noted that all the company's antenna designs, including a couple it hasn't quite commercialized yet, benefit from both NASA SBIR funding and the KaPDA license. "Anytime we incorporate any of the KaPDA patent elements or some of the non-patented but technology-transferred elements, we pay royalties," Freebury said. "We're picking up a lot of steam on this, so we're writing

more checks and bigger checks to Caltech every quarter now." (Caltech, or the California Institute of Technology, manages JPL and owns patents the lab generates.)

"This gimbal approach and its compactness could not happen without KaPDA," said Mark Thomson, who is now Tendeg's chief technology officer but conceived and oversaw KaPDA development during the 10 years he was a chief engineer at JPL. "It's not pretty what you have to do to stow a gimbaled 70-centimeter antenna if its dish doesn't fold up like this."

## 'You Just Can't Match It'

Only a couple of years after Tendeg was selected to build the INCUS antenna and licensed KaPDA, sales on the first two resulting commercial products are rolling in. A version of KaPDA Gimbal is already going up on the first satellites of one company's planned communication constellation, Freebury said, noting that each of these satellites needs two or three of the antennas, and the company plans on a constellation of up to 200. "They're operating at even higher frequencies, in the QV band," he said. "So the combination they needed, of a higher-frequency deployable reflector and very precise pointing capability, no one else is able to do."

Thomson noted that the KaPDA Gimbal offers an advantage even to makers of larger satellites. "Because it does fit a microsatellite, we can fold it up like a switchblade on the side of a larger spacecraft and really make a huge difference on size, weight, and power for gimbaled antennas using this design," he said. "You just can't match it with any other approach and have mechanical steering in two directions."

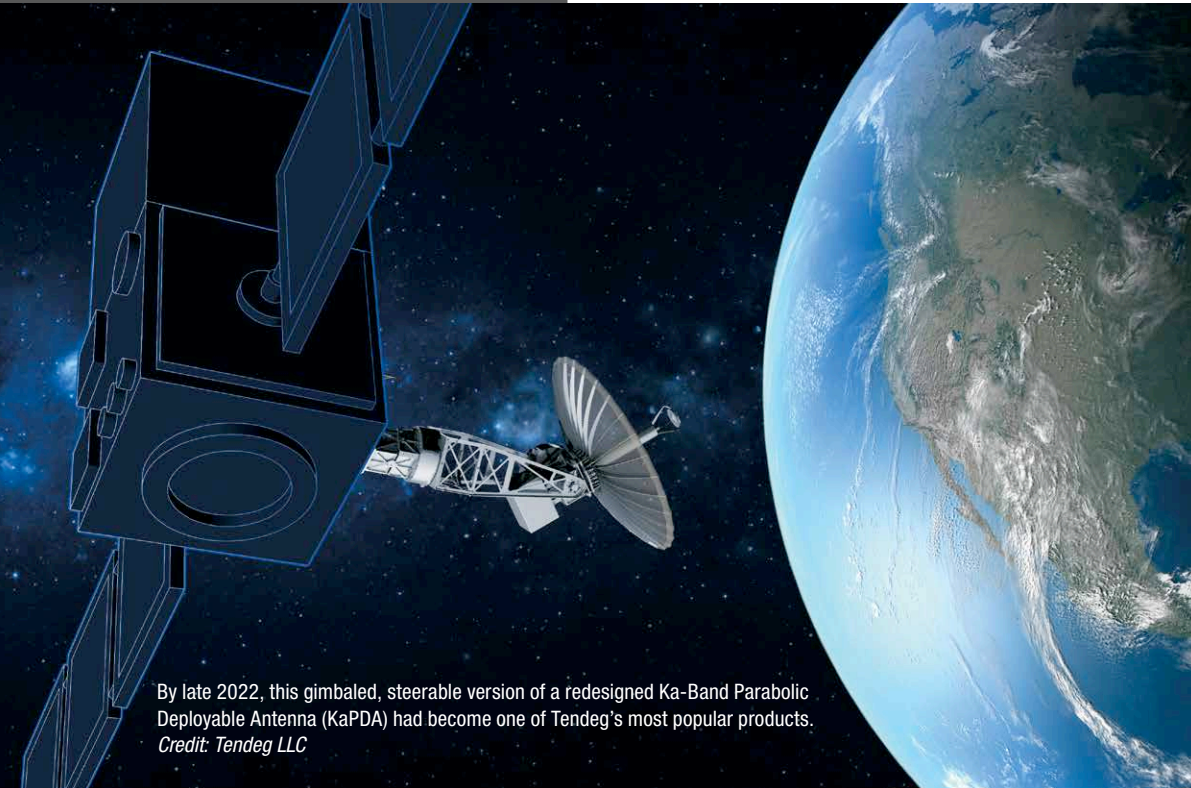


The Jet Propulsion Laboratory developed KaPDA to enable high-speed communication with small satellites in deep space. Tendeg licensed the design and incorporated aspects of it into the company's antennas. *Credit: NASA*

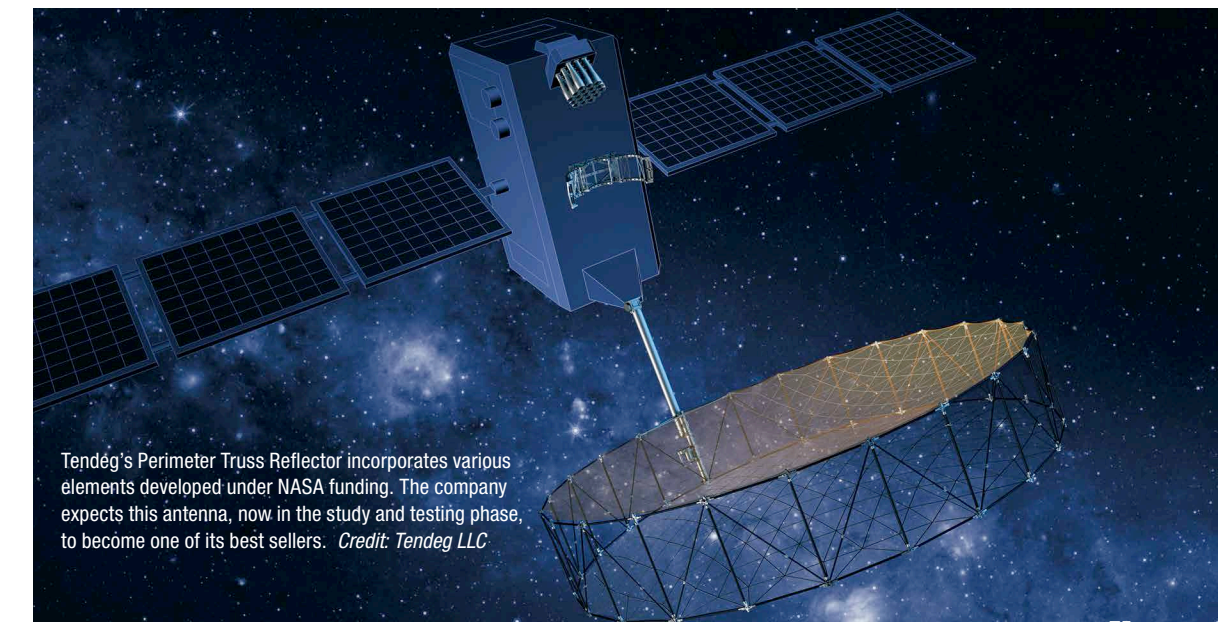
Two other commercial customers are also under contract to buy KaPDA Gimbal antennas, and it and the KaTENna both have multiple customers who are federal defense contractors. In April of 2023, Lockheed Martin announced that Tendeg would be its new strategic supplier for deployable antennas.

The company has already grown to 90 employees and announced in October of 2023 that it would expand into a new 100,000-square-foot facility and planned to add up to 451 new jobs over the following eight years.

Freebury said all of the burgeoning company's products were only made possible through its work with the space agency. "Especially the SBIR funding is pretty much what allowed us to do all the R&D that's led to all of our antenna architectures," he said. ●



By late 2022, this gimbaled, steerable version of a redesigned Ka-Band Parabolic Deployable Antenna (KaPDA) had become one of Tendeg's most popular products. *Credit: Tendeg LLC*



Tendeg's Perimeter Truss Reflector incorporates various elements developed under NASA funding. The company expects this antenna, now in the study and testing phase, to become one of its best sellers. *Credit: Tendeg LLC*



# New Energy Source Powers Subsea Robots Indefinitely

Power modules driven by ocean temperatures save money, reduce pollution by living forever

When it comes to mapping new territory, NASA's record swamps Lewis and Clark's. And the space agency doesn't only chart other stars and planets – a vantage point from space also allows a great view of Earth. Now a recent NASA invention could allow robots to map our planet's entire seafloor, helping to unlock valuable resources while protecting marine habitats. While the aquatic sonar devices for such an operation are not new, they've been severely hampered by batteries that leave them dead in the water.

Seatrec of Vista, California, licenses technology its founder developed at NASA. Its modules generate energy to power robotic ocean floats when material inside them melts and expands as they rise into warmer waters.

After earning his doctorate in ocean sciences, Yi Chao took a job at JPL to dedicate himself to ocean studies. His choice might seem counterintuitive, but the space agency has made the study of Earth – including its oceans and icecaps – a major priority, launching dozens of satellites with hundreds of sensors to measure sea levels, temperatures, salinity and much more.

"I spent the first 15 years or so at JPL studying the ocean from space," said Chao, including a career highlight as project scientist for the Aquarius satellite mission that measured the salinity of ocean water. One challenge of the mission was to calibrate the satellite's instrument against direct measurements of salt content from sensors that Chao and his team had to distribute across the oceans. While the satellite effortlessly whipped around Earth many times a day gathering readings, those oceanic distances remained stubbornly vast for researchers crossing them by boat.

"We went out to sea for 30 days," he said. "We deployed – and we asked our colleagues in universities to deploy – all kind of robotic platforms to collect data in the middle of the Atlantic Ocean, not only near the surface but also below the surface, so we can calibrate and interpret what we're measuring from space."

Based on technology created at NASA's Jet Propulsion Laboratory in Southern California and licensed from the California Institute of Technology, Seatrec Inc. of Vista, California, now offers the first energy source for subsea robots that is powered entirely by its environment, allowing devices to work in the open ocean indefinitely, without any intervention.



NASA's Aquarius instrument aboard the joint U.S. and Argentinian Satélite de Aplicaciones Científicas mapped the surface salinity of Earth's oceans between 2011 and 2014. To calibrate the instrument, a team from NASA's Jet Propulsion Laboratory, including project scientist Yi Chao, had to distribute robotic floats across oceans. The experience helped inspire Chao's invention of an inexhaustible power source for ocean floats and sensors. Credit: NASA



From left, Michael Zedelmaier and Miles Mallinger, both of Seatrec, and Capt. Todd Black of Fish Heads La fishing charters, deploy a float with one of the company's SL1 power modules in the Gulf of Mexico before the 2022 hurricane season to collect data that could improve hurricane predictions. Credit: Seatrec Inc.

The experience showed him how difficult it remains to access many of the world's open oceans, which may lie more than a week from the nearest major ports, and it taught him about the robots that monitor conditions there. Their most limiting factor, he learned, is energy, especially for underwater sensors that can't rely on the renewable energy that's available at the surface from the Sun, wind, and waves. All subsea robots are currently battery operated, and when the battery dies, the owner can either leave the sensor to become pollution or charge the battery on a ship. In the open ocean, that ship costs around \$50,000 a day and burns tons of diesel fuel.

"I really had an opportunity to know the challenges of underwater robotics, and especially energy, and settled on this particular bottleneck that I want to address," Chao said.

## Robots Rise Up

He recruited two JPL colleagues, and they set out to build a different kind of power source for subsea robots, with funding first from JPL and then from a JPL contract with the Navy, which was also interested.

To generate power, they settled on phase-change materials, substances that transition between phases – usually between solid and liquid – at certain desirable temperatures. NASA often uses phase-change materials to blunt temperature extremes in space, but Chao's team wanted to generate power by taking advantage of the change in volume that accompanies a change in phase. Most substances, with the exceptions of water and metals, expand when they melt and contract when they freeze.

"We use the kinetic energy from that volume expansion to spin the motor and then turn the mechanical energy into electricity, and now you can recharge your battery," Chao said. It's an old concept and basically the way a steam engine works, using water's expansion into steam to turn a motor. But the solid-to-liquid transition creates only about a 10% expansion. The challenge, therefore, is to make the most of the small amount of energy it generates. "So every component has to be super-efficient," Chao said. "That's why people have tried this and didn't think it's enough energy to convert. We are the first to go through the process end to end and pick the highest-efficiency components, and eventually we can generate a sufficient amount of energy for an underwater robot."



The robots cause the material's temperature to change simply by rising and falling through the ocean, something they typically have to do anyway, surfacing to determine their position via GPS and transmit the data they've collected to satellites. The team selected a common industry-grade paraffin-family material with a melting point around 50°F, right between the typical deep ocean temperature of about 40°F and surface temperature around 70°F. But that material can be swapped for one with a higher or lower melting point depending on the environment.

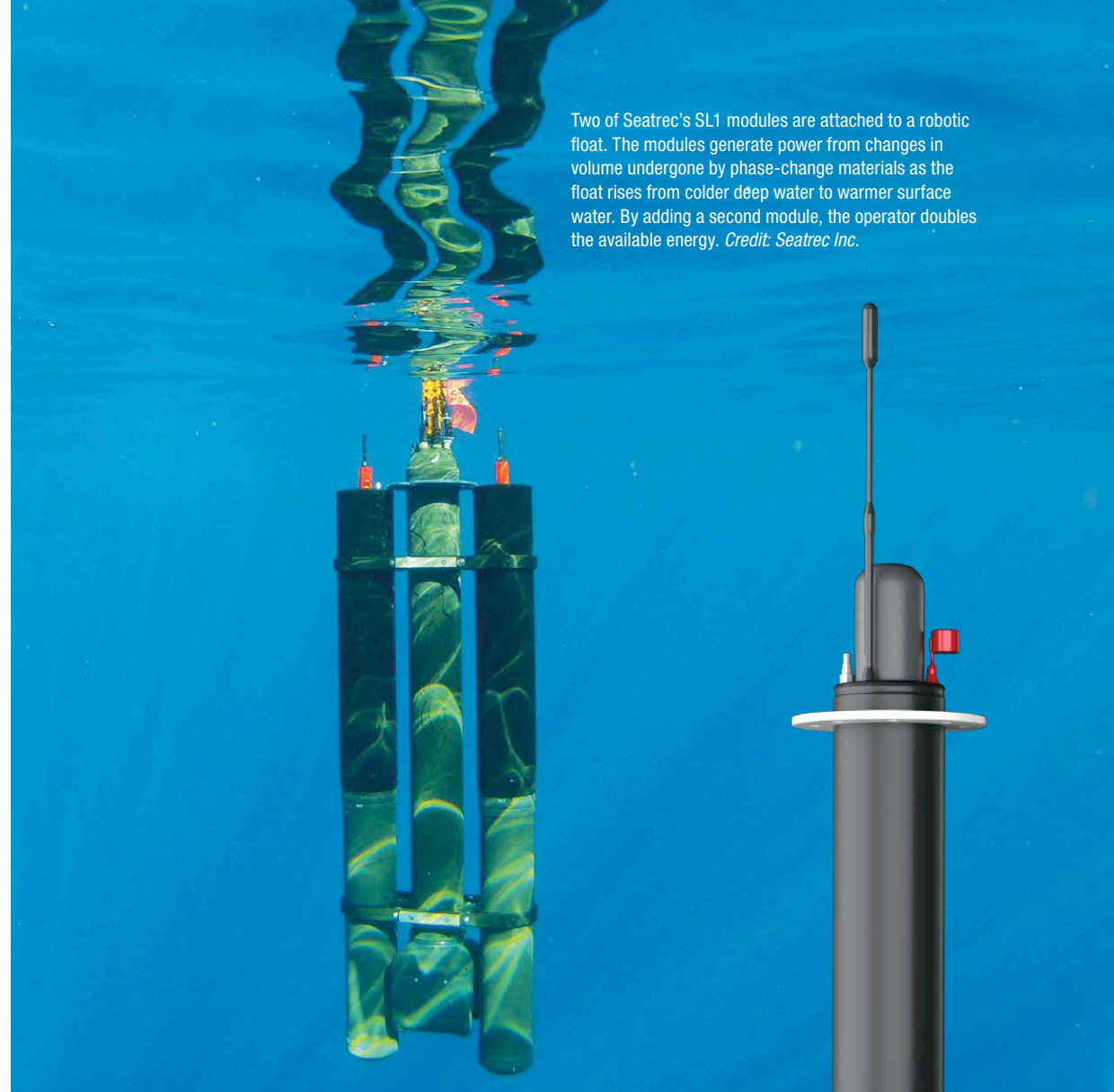
At JPL, the team built and demonstrated a prototype float in 2011, followed by an underwater glider that operated on the same principle but could also move horizontally. Over the next few years, Chao worked on exclusively licensing the invention from the California Institute of Technology, which manages JPL, and founding Seatrec.

### Occupying Earth's Final Frontier

The company now sells its first power module for diving floats, called SL1, to research labs, universities, government researchers, and the military. But Chao envisions a much larger market in the near future, starting with efforts to map the 80% of the seafloor that remains uncharted today. The military is interested in seafloor mapping, he said, especially for submarine navigation, but so are companies that drill for oil and gas or build wind farms offshore, as well as communications companies laying transoceanic internet cables and environmental conservation groups that want to learn more about the locations of marine habitats.

Mapping all that seafloor by ship would cost billions of dollars and require a fleet of hundreds of huge, global-class vessels, Chao said, noting that only about a dozen such ships are actually available for this sort of work. Mapping the ocean floor from the surface also requires high-powered sonar to cut through noise in the upper ocean, whereas a float can dive down to 500 meters or deeper to map the seafloor with much less energy and little disturbance to marine wildlife. "So we are enabling mapping the ocean floor from a subsea platform for the first time," Chao said.

Other markets include companies managing offshore operations, from oil wells and wind turbines to fish farms, which need underwater sensors to monitor conditions and equipment.



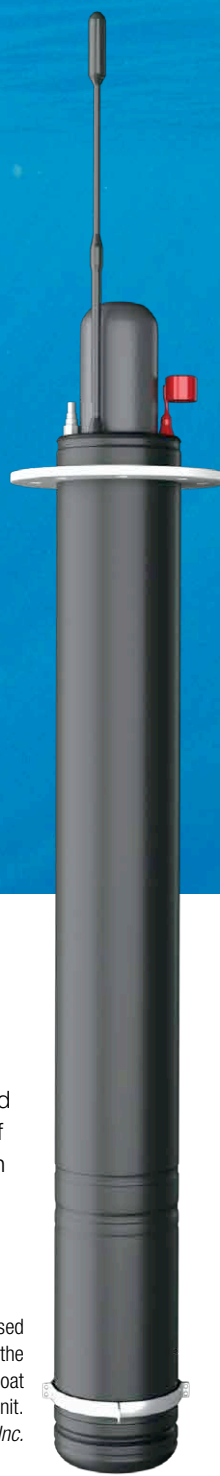
Two of Seatrec's SL1 modules are attached to a robotic float. The modules generate power from changes in volume undergone by phase-change materials as the float rises from colder deep water to warmer surface water. By adding a second module, the operator doubles the available energy. *Credit: Seatrec Inc.*

And anyone laying cables or mining for rare Earth elements on the seafloor needs to assess the local environment and wildlife.

Weather and climate studies will be another important application, especially improving hurricane predictions, whose accuracy and timeliness save lives and property. It's the water temperature 30 or 50 meters deep that will ultimately fuel or starve a tropical storm, Chao said, but it's not monitored in real time because current underwater sensors only surface every 10 days or so to conserve their batteries. "Many hurricane forecasters and oceanographers believe that's the last missing piece of information we need to increase the accuracy of storm intensity prediction."

And he said the company is working on a project to outfit floats with underwater microphones to quantify sound in the ocean. These would help cargo ships avoid whale strikes and are also of interest to both conservation groups and the Navy.

In February of 2023, Seatrec released its second-generation float product, the InfiniTE, which integrates a robotic float and an SL1 power module in one unit. *Credit: Seatrec Inc.*



"Once you have energy underwater, there's a variety of use cases you can think about," Chao said. In all, he said, there are already about 4,000 robotic sensors floating in oceans around the world, 1,000 of which expire every year due to dead batteries. With an SL1 power source, he said, they could not only operate indefinitely but could also transmit data much more often because surfacing would generate more energy than it would expend.

Seatrec plans to commercialize a system to power underwater gliders using the same solid-to-liquid phase-change technology. In the future, the company hopes to develop a power station that would cycle a liquid-to-gas phase-change material through ocean depths, creating an order of magnitude more energy, which could recharge more power-hungry robots at sea. And Seatrec has a grant from the Navy to deploy a power

station on the Arctic ice, taking advantage of the difference between water temperatures and the much colder air above the ice.

As the company continues to refine the technology, Chao said, it can be applied to various temperature ranges and applications. "Anywhere you have a temperature difference, we can turn that into electricity." ●

Seatrec hopes its technology will help save lives and property by multiplying the data available to make hurricane predictions. For example, ocean temperatures 30 to 50 meters deep are what starve a tropical storm or feed its growth into a hurricane like Hurricane Florence of 2018, seen here from the International Space Station. But any data collected at those depths is currently available only intermittently. *Credit: NASA*





# Where the Wildfires Are

Simulation, prediction, and response software helps businesses and communities cope with disaster



In 2022, nearly 100 large wildland fires burned in the U.S. West. Almost two dozen of those burned in Washington and Oregon alone, filling the air with smoke. Plumes from the fires often could easily be seen from space. *Credit: NASA*

"This is a fire planet as much as it's a water planet, so we need to be able to use fire as our friend and thrive," said Jessica McCarty, branch chief of Biospheric Sciences at NASA's Ames Research Center in Silicon Valley, California. Part of the space agency's job is to help monitor and understand our home planet, including natural disasters. In the case of wildfires, this means developing technology and gathering data to help wildland fire management agencies predict and put out fires.

As the agency tries to "solve the impossible problem of catastrophic wildfires" by providing resources to improve mitigation and community response, McCarty said the combination of data and technology is helping firefighters. Businesses are also benefiting, with help from Technosylva Inc., a company that combines fire science and NASA data to create fire simulation and forecast software.

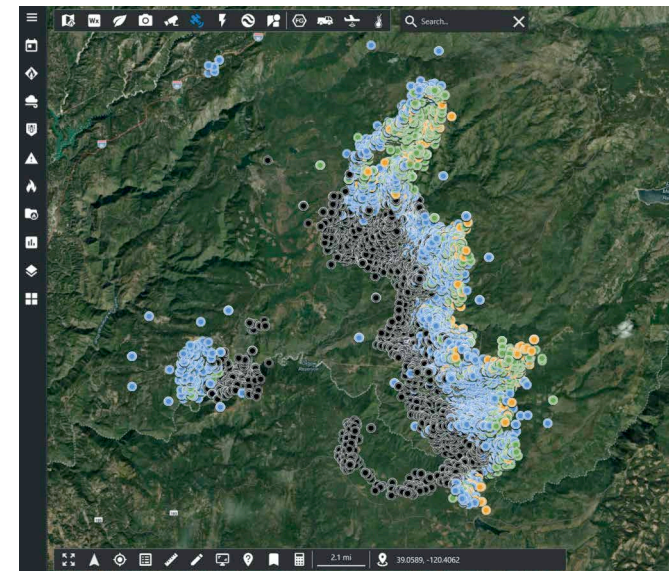
Globally, as much as 90% of all wildfires start with a human ignition source, said McCarty. This is just one example of the sort of knowledge that helps predict and prevent wildfires, a challenge that NASA and industry are undertaking together.

Joaquin Ramirez, president of San Diego-based Technosylva, said the company has been working to understand wildfires since 1997 by combining science, data, and technology. It begins with the numerous elements that influence a fire. From the natural world, that includes the interaction of terrain, vegetation, soil moisture, weather, climate, and more. Human influences include alterations to the natural landscape such as housing developments, wetland elimination, dams, and power generation and distribution.

Technosylva developed software that combines these factors with data from NASA and other sources to model fires, predict their spread and potential impacts, and provide up-to-date information for crews fighting wildfires. "We need technologies that bridge the gap between scientists and the user community, because that community has to address those problems every day, everywhere, all at once," said Ramirez.

The company, which started in Spain, now has more than 90 staff members in 11 countries, collaborating with research institutions to access the most current scientific findings and provide operational tools.

San Diego-based Technosylva's wildfire monitoring service employs NASA Earth-observation data along with other wildfire resources, artificial intelligence, and machine learning to predict, monitor, and support post-fire recovery.



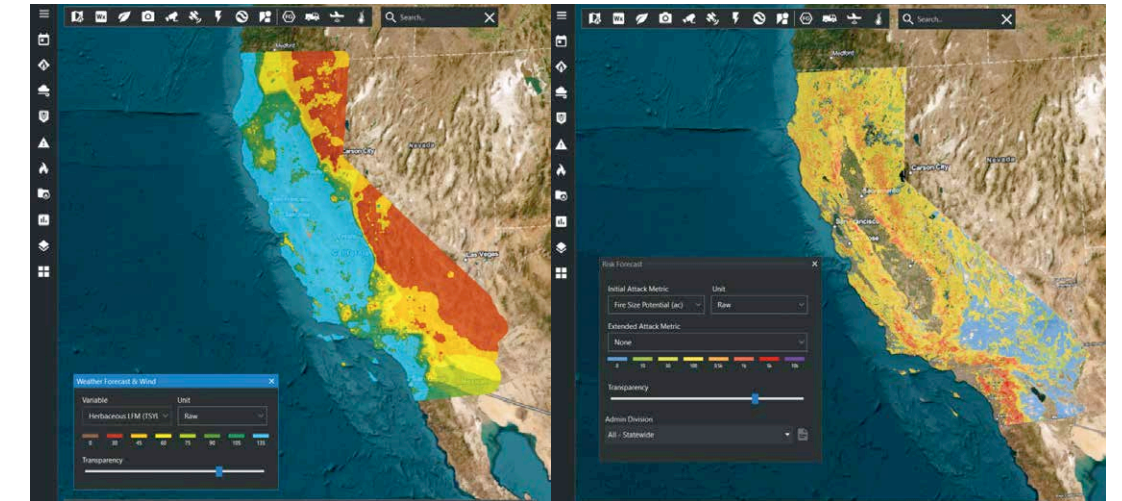
Satellite imagery helps Technosylva's Wildfire Analyst software identify areas previously burned by wildfire to eliminate those areas without fuel like leaves or grasses (black circles) and pinpoint areas with different types of available fuel (colored circles). *Credit: Technosylva Inc.*

## Not Waiting on Heroes

The view from space provides a different perspective on natural disasters like wildfires and the conditions that affect them. Sensors on Earth-observation satellites and the International Space Station not only capture that view but can turn it into quantifiable data, measuring soil moisture, vegetation health, and other factors. NASA compiles this information into datasets for anyone to use.

"For vegetation condition or what is sometimes referred to as 'fuels,' this information helps to assess and predict risk for human and animal communities, vulnerable populations, infrastructure, and economies," said McCarty. This might mean a power company that wants to prevent fires evaluating above-ground powerlines standing in migration corridors. A bird flying into power lines can cause sparks that ignite grass and leaves below, so removing that fuel could be helpful.

San Diego Gas & Electric, a Technosylva customer, created a wildfire climate adaptation department to better understand and mitigate the effect climate change is having on current infrastructure and future operations. Utilities in other states are learning how to deal with wildfires in areas that never experienced them, and others are facing increased fire intensity. Pacific Gas & Electric, Southern California Edison, Pacific Power in Oregon, Xcel Energy in Colorado,

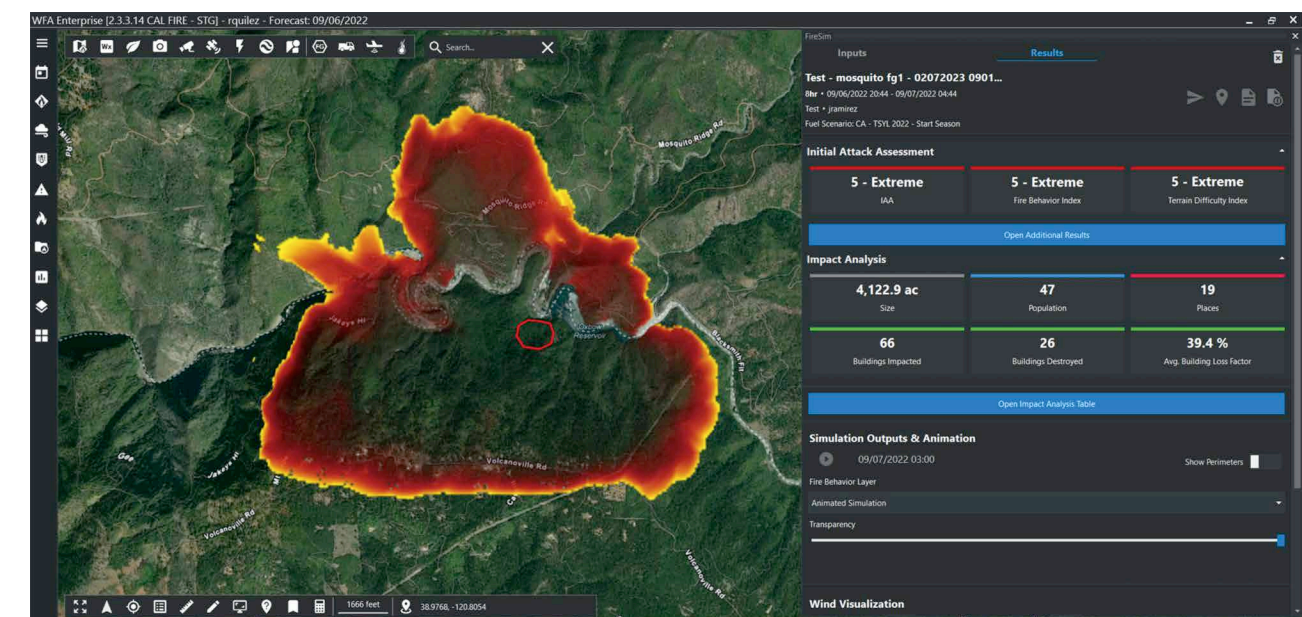


A recent discovery that soil moisture can impact wildfire predictions dramatically improved the accuracy of Technosylva's FireCast service. Here, with the addition of soil moisture data – wet areas in blues and greens, the driest areas shown in reds and oranges – significantly reduced (left) the area originally predicted to be at risk of a serious fire denoted in color (right), enabling the placement of resources where they were eventually needed. *Credit: Technosylva Inc.*

and Rocky Mountain Power in Utah are all using Technosylva products to make these adjustments.

Government agencies in the Netherlands, Northern Ireland, and Italy haven't had to deal with wildfires as intense as those in the western U.S. But the risk and frequency of wildland fires is increasing in those places. Technosylva is working with them on mitigation and planning to enhance public-safety preparations.

"In many places we hear 'thank you' for firefighters as heroes. But they don't need to be heroes – they are usually underpaid and die at the end of the movie," said Ramirez. "We need to build more resilient landscapes, which will create safer communities." That happens, he said, by educating the public and businesses about their environment. Technosylva helps community leaders do that by using simulations to identify high-risk areas and how to reduce that risk.



In addition to NASA satellite data, Technosylva's FireSim uses topography, weather, and other data to generate computer models for fire spread over five days to help communities evacuate safely. *Credit: Technosylva Inc.*

"To understand fire, we need to understand our landscape in relation to atmospheric conditions."

Joaquin Ramirez,  
Technosylva

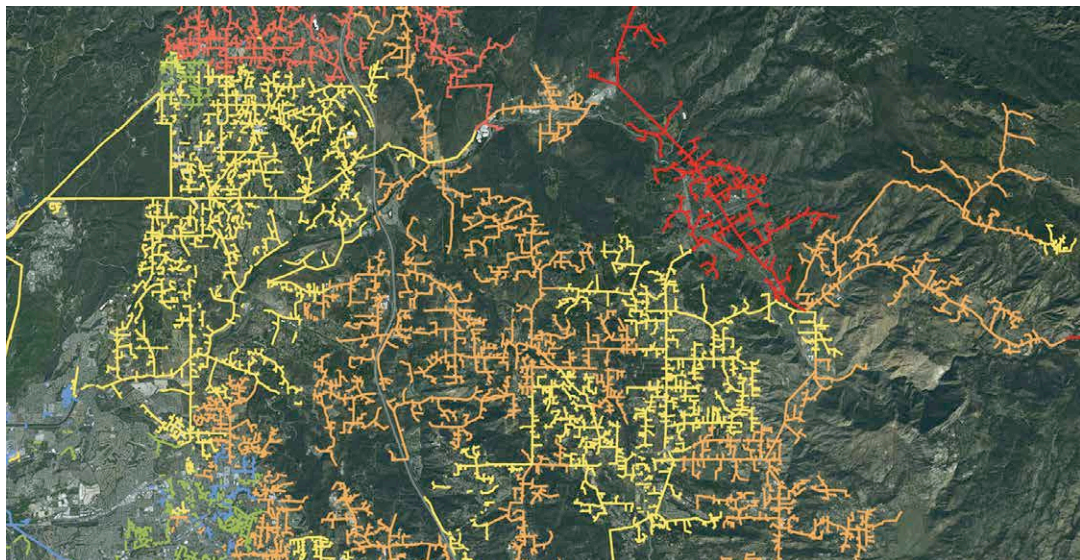


## A Backward View

Technosylva's Wildfire Analyst software employs artificial intelligence and machine learning to combine multiple data sources and run half a billion of wildfire-spread simulations every day. The software can evaluate wildfire risk in real time, whether for an active fire or in forecasts that use short-term conditions to find at-risk areas. Historical data, including conditions for previous fires, "teaches" the program what conditions will lead to increased risk.

FireSim, one of Wildfire Analyst's core applications, uses this data to simulate wildfire behavior. Some of the data comes from the NASA-built Landsat satellites that have supplied the longest record of Earth's surface. NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) and Visible Infrared Imaging Radiometer Suite (VIIRS) instruments provide weather information and the health status of vegetation. The agency's Global Ecosystem Dynamics Investigation (GEDI) high-resolution lidar imager mounted on the space station generates global information about forest changes. And the Land Information System (LIS) provides soil moisture content

The complex modeling the software generates based on this data is proven and quick. When predictions – not guesses – are needed in the



Utility companies are using Technosylva's services to prepare for wildfires by identifying vegetation that needs to be removed and monitoring energy infrastructure during a fire. A map like this one reveals where power should be cut for safety (in red) and the areas that could be next (orange). Credit: Technosylva Inc.

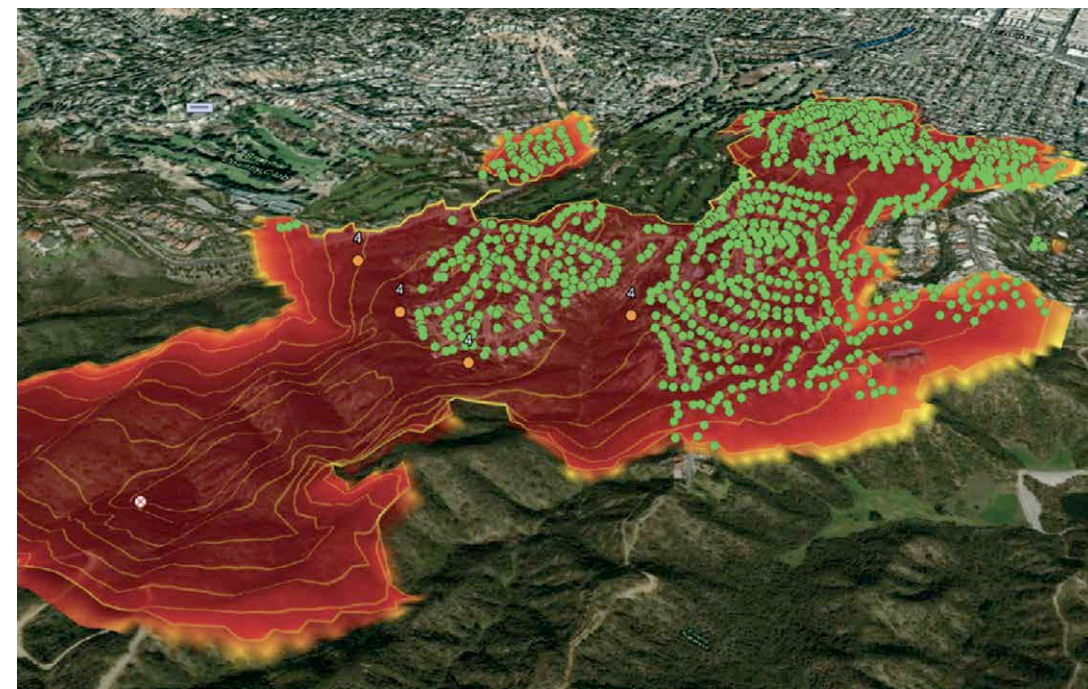
midst of a blaze, it takes about 10 seconds for Technosylva software to complete a simulation with an impact analysis for buildings, infrastructure, and populations, in addition to an assessment of the complexity of the fire, said Ramirez.

The simulations help response teams to perform consequence analysis and make operational decisions. Changes to weather such as humidity, wind direction and speed, and precipitation are automatically added, keeping first responders prepared.

During fire season, the California Department of Forestry and Fire Protection uses Technosylva's FireCast application to predict and analyze the likelihood and timing of a fire outbreak over a five-day period. The current and near-term forecasts look at existing fires and other hot spots once or twice daily, taking into account human population, buildings, and critical infrastructure that might be impacted. The results contribute to public alerts and the placement of emergency responders and equipment.

The timing of a power shutoff for public safety is also difficult for power companies. Losing power makes an emergency situation more difficult for everyone. But waiting too long can result in the loss of infrastructure, property, and lives. Access to real-time data is critical to such decisions.

When a wildfire is burning, streams of data come in from drones, planes, field cameras, and satellites, among other sources. Technosylva's Tactical Analyst and fiResponse platforms for incident management automatically combine and share all of that information.



Knowing where a fire is and what infrastructure is in its path is essential for extinguishing the blaze. Technosylva's fiResponse uses satellite imagery and more to show which homes, businesses, roads, and more (colored dots) are within the environment of a wildfire. Credit: Technosylva Inc.

"In Chile we supported efforts to fight the 2017 Las Máquinas fires that burned about 600,000 acres in two days. Multiple fires were spread out and so large that the only way to view the perimeter was from space," said Ramirez. Satellite data helped identify new and extinguished hot spots and contributed to ongoing simulations that guided containment efforts.

Teams on the ground can't always see through the smoke to locate each other, but Technosylva's incident tools track the locations of people and resources to continually update all participants.

## Behind the Headlines

Technosylva conducts ongoing research and development to improve and refine these tools. As wildfires increase in frequency and intensity due to climate change, it's essential to keep learning about their characteristics. For example,

Ramirez noted the recent discovery that dead leaves on the ground absorb moisture from the soil. The models needed related data.

Satellite data provides information about vegetation density and assesses changes in plant health that can increase fire risk, such as an increase in dropped leaves. "This is critical because when you want to know if a fire will start, you need to know the amount of water in the vegetation," said Ramirez. "If the ground is wet when the sun is shining, leaves won't dry out as quickly as previously thought."

In January 2023, right before fire season began, the company added the soil moisture content in California to its calculations. The new simulations dropped the estimated risk of fire by 40%. It proved to be accurate and is adding to our understanding of the dynamics of the fire season in wet years.

Having collaborated with Technosylva staff before joining NASA, McCarty is familiar with the company's approach. "We need to be able to not just grudgingly live with fire. Technosylva is using data fusion, integrating multiple data sources from climate, weather, landscapes, and human infrastructure to come up with a full picture of what fire risk may be," she said.

Ramirez attributes the models' credibility to easy access to high-quality, publicly available NASA data.

"There's a huge demand for wildfire support right now in business," he said. "But to understand fire, we need to understand our landscape in relation to atmospheric conditions. The Landsat program was absolutely the first step to understand our world." Ramirez also credits MODIS and VIIRS for providing a global view.

"Wildfire science would not have advanced without all this openly available data. The eyes in the sky are the best ally we have," he said. ●

*"We need to be able to use fire as our friend and thrive."*

Jessica McCarty, NASA



The web-based wildfire prediction, monitoring, and resource management service provided by Technosylva employs NASA data to help businesses, municipalities, and local communities deal with wildfires. The company manages over 20,000 incidents annually worldwide. Credit: Technosylva Inc.



# NASA's Moon Shot Launched Commercial Fuel Cell Industry

Agency's technology development prepared fuel cells for tomorrow's renewable energy grids

When NASA started investing in fuel cell technology in the 1960s, the rest of the world was still content to be powered by fossil fuels. The simple imperative that drove NASA to explore new ways to generate and store energy was the crushing cost of launching mass into space: somewhere on the order of \$10,000 per pound.

Fuel cells were first pioneered in preparation for NASA's Apollo missions. The group that developed these and subsequent NASA fuel cells, now called HyAxiom, manufactures commercial fuel cells at the same facility in South Windsor, Connecticut.

"NASA's interest in fuel cells had nothing to do with alternative energy – we didn't have any alternative," said John Scott, NASA's principal technologist for power and energy storage. "We had to make them work in order to fly the mission."

NASA's earliest crewed spacecraft relied on batteries for onboard power. Energy requirements for the long round trip to the Moon, however, would have necessitated more batteries than could feasibly be launched.

NASA's Johnson Space Center in Houston, then called the Manned Spacecraft Center, stepped up to solve the problem. Engineers there considered fuel cells a potential solution because they had higher specific energy than batteries of the day, meaning they could, at least theoretically, provide more energy per pound over the course of a long mission. However, although the fuel cell concept had existed for more than a century, it had never been put to practical use.

NASA awarded funding to General Electric, Allis-Chalmers Energy, and an arm of Pratt & Whitney to develop fuel cell prototypes, and General Electric was contracted to deliver fuel cells for the Gemini spacecraft, flown in preparation for the Apollo Moon shot.

For Apollo's fuel cells, NASA selected the Pratt & Whitney group, which became UTC Power, supplier of fuel cells for all the space shuttles and the seat of NASA fuel cell development for the next decades. With the space agency funding and shaping its fuel cell development, UTC eventually branched out into commercial fuel cells. After the Space Shuttle Program ended in 2011, the company changed hands a couple of times and is now known as HyAxiom Inc., a subsidiary of the South Korean Doosan Group.

Now HyAxiom, which still produces fuel cells in the same manufacturing plant in South Windsor, Connecticut, that produced them for NASA, is experiencing a renaissance as alternative energy is increasingly seen as the way of the future.

## Different Fuel Cells, Same Basics

Unlike a battery, which only stores energy, a fuel cell generates electricity and heat when hydrogen and oxygen bond through an electrolyte. The by-product of this reaction is better than harmless – it's water. This is the environmental advantage that makes fuel cells attractive today.

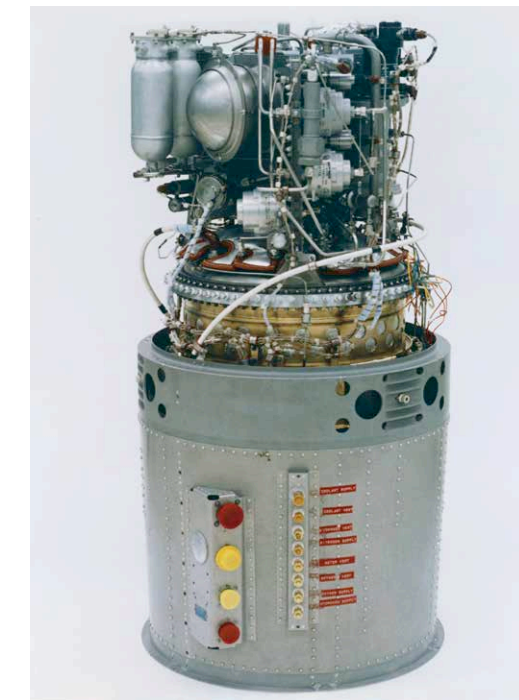
While the Gemini fuel cell was based on a proton-exchange membrane (PEM), the cells UTC Power produced for Apollo and the space shuttle were alkaline fuel cells. Alkaline cells are extremely mass-efficient but have been too fussy for commercial applications. Much of the underlying technology, though, is similar across different types of fuel cells.

HyAxiom, a subsidiary of the Korean Doosan Group, supplied 114 fuel cells for the Daesan Hydrogen Fuel Cell Power Plant in Seosan, South Korea. The world's largest by-product fuel cell power plant, it runs entirely on waste hydrogen from petrochemical facilities to produce enough energy to power 160,000 homes in the area. *Credit: HyAxiom Inc.*

Not only is the basic chemistry the same, but so are the fundamentals of "what might be called the 'balance-of-plant' – which manages the reactant flow into the fuel cell stack and gets product water and the heat out," said Scott, noting that this hadn't been considered in practical terms until NASA started pursuing the technology.

During the shuttle program, the space agency funded improvements that, for example, doubled space shuttle fuel cells' life from 2,500 to 5,000 hours.

UTC Power released its first commercial product, a 200-kilowatt phosphoric acid fuel cell, in the mid-1990s. The company chose to commercialize cells with a phosphoric acid electrolyte in part because of their long lifespan, relatively common materials, and tolerance for impurities, said Sridhar Kanuri, HyAxiom's chief technology officer. They can also run on natural gas or liquid petroleum gas, with a reformer at the front end of the cell converting the gas to hydrogen to feed what is still a hydrogen fuel cell. About 10 years later, the company put out 440-kilowatt versions with better efficiency and twice the lifespan, Kanuri said. This is still the product line HyAxiom manufactures today.



This is the fuel cell design Pratt & Whitney created for the Apollo missions. It was only the world's second practical fuel cell design, the first having been invented by General Electric for NASA's Gemini missions, which were preparation for the Apollo Moon shot. *Credit: NASA*

"The models they built for these products we use today had a lot of the electrochemistry understanding from the space program," said Kanuri. "So the knowledge that they gained got transferred down to these other products."

Production ramped up following the company's acquisition by Doosan in 2014, partly because that transaction opened up the burgeoning Korean market, and HyAxiom now produces around 120 units per year.

## Higher Efficiency, Falling Costs

In the United States, these fuel cells can now be found powering Whole Foods, Stop & Shop, and ShopRite locations. They also power a Coca-Cola bottling plant not far from HyAxiom's facilities. The University of Connecticut and Rochester Institute of Technology use the company's fuel cells, as do CBS Studios in California and the new World Trade Center in New York. San Diego Gas and Electric uses the cells in its electrical grid. "So these fuel cells are sprinkled all over the East and West coasts," Kanuri said.

The Korean market, meanwhile, is primarily in utilities. "They put up tens of megawatts of these fuel cells at a given site," said Kanuri. "In that configuration, we put anywhere between 10 and 125 fuel cell power plants in one location."

The South Korean government offers incentives for fuel cell use, but the technology also has its own incentives, he said. While natural gas power generation on a typical electrical grid operates around 35% efficiency, HyAxiom fuel cells operate at 43% efficiency, so they already have an advantage, depending how close they're located to end users. But the real trick is to make use of the heat they generate as a by-product. Korean utilities often include district heating grids, which can pull heat from fuel cells, bringing their efficiency close to 70%. And with clever engineering, even higher efficiency is possible. For instance, Kanuri said, the Mohegan Sun casino in Connecticut managed to extract close to 90% efficiency from its HyAxiom fuel cells by integrating them tightly into its heating systems, using the heat to warm water and even sidewalks.

With governments around the world starting to invest heavily in fuel cell technologies, and with companies competing to meet increased demand, Kanuri said, the price of fuel cells should plunge. "If we can take the latest technology into mass production, I think that is where the costs are going to come down dramatically," he said. "We are producing fuel cells today in the hundreds of



HyAxiom's 440-kilowatt phosphoric acid fuel cell is now its flagship product, and it still builds on technical know-how developed under the Apollo and space shuttle programs. *Credit: HyAxiom Inc.*

megawatts. If we can go to gigawatt-scale fuel cells, then you can beat out the grid with regard to cost."

The U.S. government plans to use fuel cells to store energy from renewable sources. Electricity from solar panels or wind turbines would electrolyze water into clean hydrogen and oxygen, with the stored hydrogen then powering fuel cells when there's no sun or wind.

HyAxiom has modified its technology to run on this clean hydrogen and has already installed 50 megawatts of these fuel cells at a petrochemical complex to generate power from hydrogen that otherwise would have been vented.

HyAxiom's predecessor, UTC Power, also helped various companies develop PEM fuel cells for vehicles. UTC acquired PEM fuel cell patents decades ago from General Electric, which had cut its teeth making PEM cells for Gemini. UTC worked on fuel cell technology with Ford, Toyota, Hyundai, Nissan, and BMW. "They did development programs with us, where we transferred knowledge and made prototypes for them," Kanuri said. Now at least three of those companies have fuel cell-powered vehicles in limited production.

Scott said there isn't a commercial fuel cell today that doesn't owe some debt to NASA's early exploration of the technology. "All these companies trace their intellectual property heritage, their corporate heritage, even the generations of personnel to those three companies NASA funded back in the early '60s," he said. ●



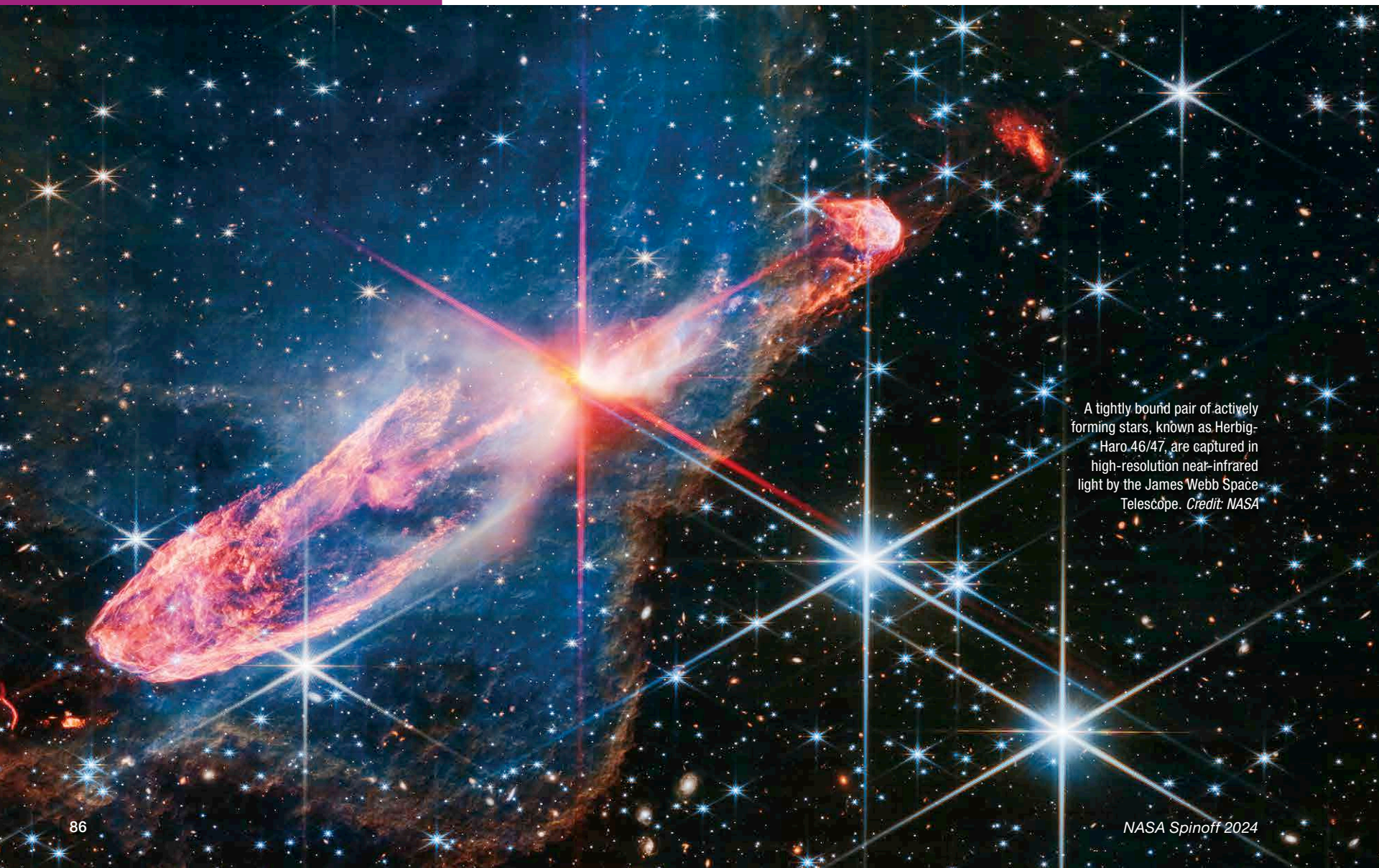
# Webb Telescope Made Simulation Software Better

The observatory pushed optical modeling capabilities, driving advances in software used to design medical and augmented reality devices

The James Webb Space Telescope's stunning images showing previously unseen corners of the universe are possible because of the telescope's 21-foot segmented mirror that had to unfurl on its own after launch and assemble itself in space.

Plenty of testing went into the materials, design, and process over the decades it took to develop the largest telescope in space, but the whole project was just too large to test on the ground, at scale, at minus 400°F and other space-like conditions.

Instead, engineers relied more than ever before on software to simulate how the telescope would behave under wide-ranging space conditions, work that has helped advance the whole field of integrated modeling.



A tightly bound pair of actively forming stars, known as Herbig-Haro 46/47, are captured in high-resolution near-infrared light by the James Webb Space Telescope. Credit: NASA

Webb Telescope developers relied heavily on simulation software, helping to advance the whole field of integrated modeling, including OpticStudio, a suite that was used to develop the observatory and is now sold by Canonsburg, Pennsylvania-based Ansys.

"We pushed everything, all the simulation, just as hard as it would go," said Erin Elliott, an optical engineer at Ansys Inc., the company that makes Ansys Zemax OpticStudio, one of a handful of design software suites that were used to develop hardware and software for the Webb telescope.

Simulation technology has improved dramatically over the last two decades as a result of increases in computing power and new ways of accessing offsite computing power as a cloud service. But additional improvements trace back directly to the Webb telescope development.

Elliott used OpticStudio to support the Webb telescope while working for NASA contractors, beginning in the early 2000s, before starting work in 2015 for Zemax, which was bought in 2021 by Ansys Inc., which is headquartered in Canonsburg, Pennsylvania.

In the early days, Elliott said, Zemax tweaked its software for the Webb telescope effort. "They made some specific changes for us at the time that had to do with handling the coordinate systems of the segments," she said, referring to the 18 hexagonal segments that make up the telescope's primary mirror.

Elliott also recalled talking to Zemax leadership numerous times about the need for the software to communicate better with other Microsoft Windows programs. The company introduced an API, or application programming interface, for OpticStudio, which enables the suite to work with other programs and allows for further customization, as well. There were plenty of reasons to add that technology, but Webb telescope demands were likely significant among them, Elliott said.

Joseph Howard, an optical engineer at Goddard Space Flight Center in Greenbelt, Maryland, where Webb was built, said NASA's use of several modeling packages also helped drive innovation in the field. "It's important to have multiple software companies out there that can help you not only for cross-checking the modeling, but also because they make each other better by having this competition," he said.

In addition to improvements made to OpticStudio during Webb telescope development, Ansys in 2021 introduced the Structural, Thermal, Analysis, and Results (STAR) module, which benefited from knowledge Elliott gained working on the NASA project.

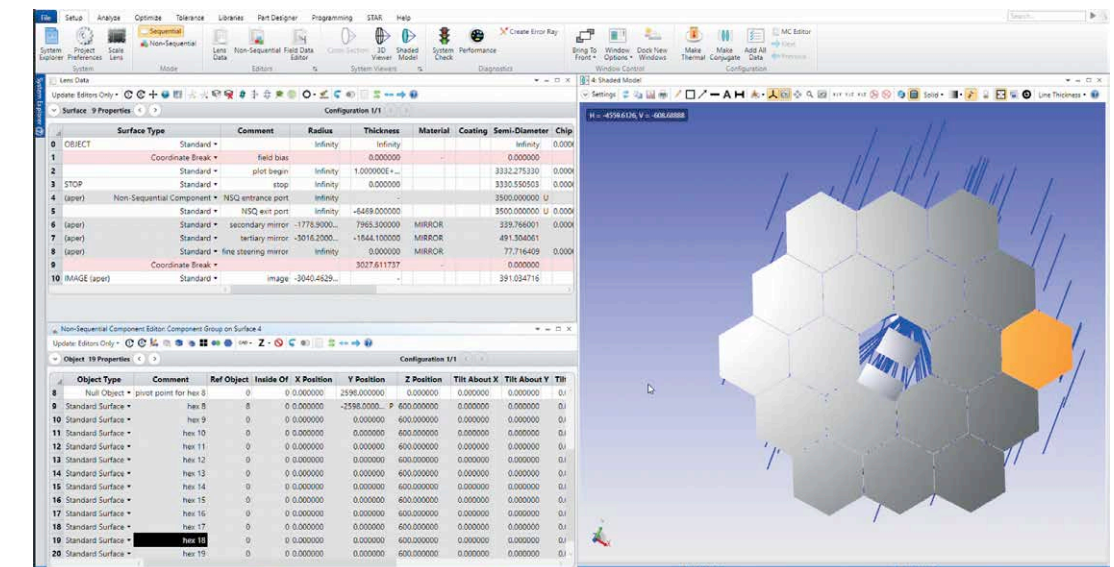
When a mirror or lens changes shape due to temperature swings, the optics move. Much of the OpticStudio modeling for the Webb telescope was done in smaller pieces – engineers would run a thermal simulation on its own and add that data to the next optical model, generating more data for the next run.

The STAR module incorporates structural and thermal analyses from other simulation software directly into OpticStudio optical models – an efficiency that is useful to telescope and aerospace designs, but also increasingly important for autonomous vehicles, cell phone lenses, and other optics that have to work in tough environments, Elliott said.

Future telescopes and other spacecraft are likely to involve elements of the Webb telescope design. More will travel in segments that must self-assemble in space, and development of the increasingly complicated robotics and optics will rely on modeling software.

*"The next great observatory will be even more dependent on modeling software."*

Joseph Howard, Goddard Space Flight Center



The Ansys Zemax OpticStudio software package, pictured here in a demo of James Webb Space Telescope mirror modeling, was equipped with new capabilities and features as a result of being used in the observatory's development. Credit: Ansys Inc.

"When we built James Webb, we knew that we couldn't fully test it on the ground prior to flight, so we depended a whole lot upon modeling and doing analysis to get it ready for flight," NASA's Howard said. "The next great observatory will be even more dependent on modeling software."

Meanwhile, designers of more earthly technologies are already seeing the benefits of an improved OpticStudio, which has been used to design precision endoscopes, a thermal imager to detect COVID-19 exposures in a crowd, augmented reality displays and headsets, a laser thruster technology for nanosatellites, and, of course, more telescopes.

Elliott noted that, in addition to technology spinoffs, the Webb telescope project trained the next cohort of telescope and optical device builders – those who will be designing and using the telescope's technological spinoffs.

"The people who built the Hubble Space Telescope were leading the Webb telescope," she said. "And now the younger engineers who were cutting our teeth on this project and learning from it are becoming the group of people who will build the next structures."

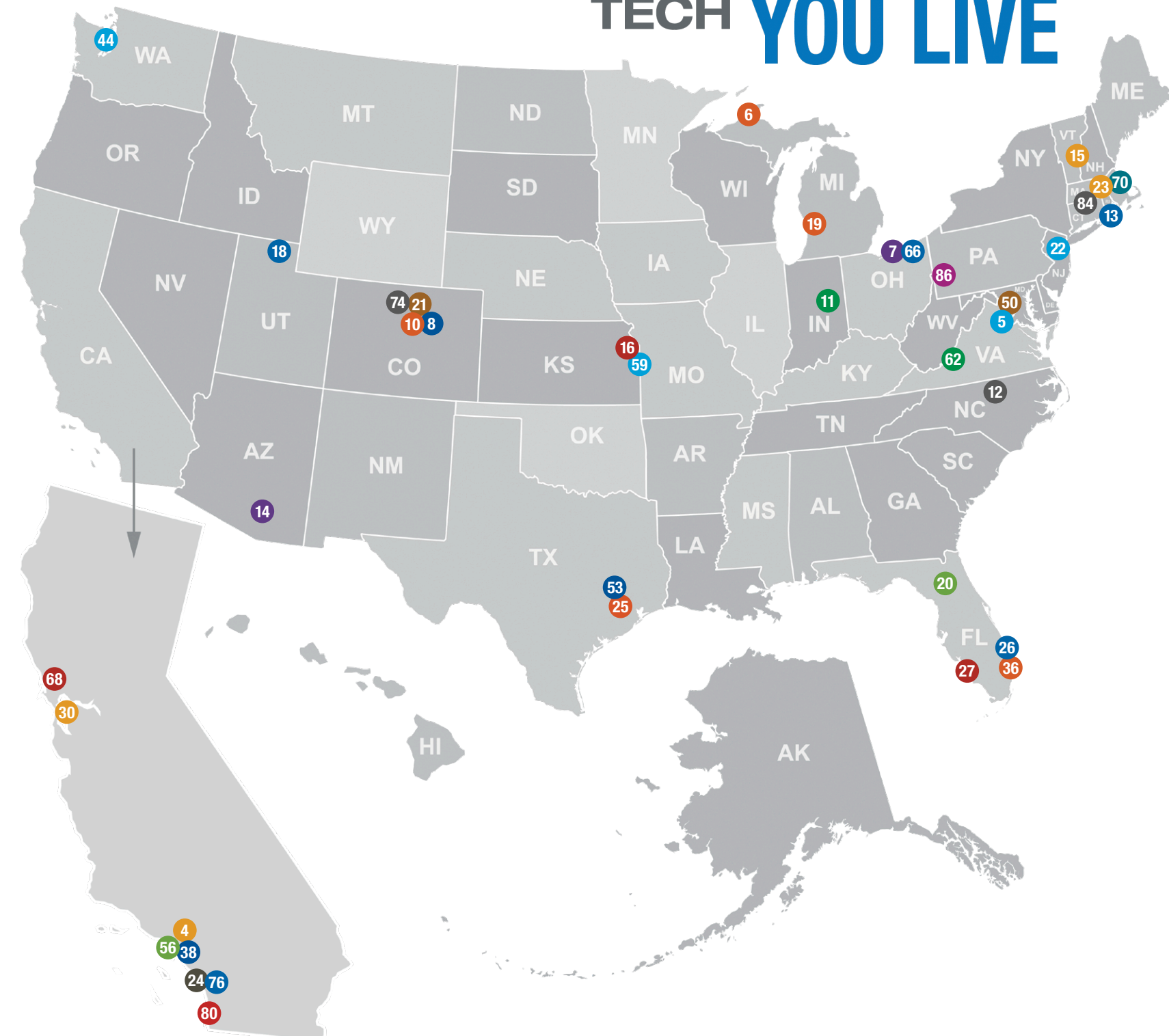
Elliott maintains that the project "was worth it alone for training this huge cohort of young engineers and releasing them into high-tech fields." ●



## Spinoff Technology Across the Nation

Page	Article	Technology	Company, Location
4	A Virtual World of Data	Virtual reality data visualization	Virtualitics, Pasadena, CA
5	From Shark Searches to Space Tours	Aviation engineering and manufacturing services	Aurora Flight Sciences, Manassas, VA
6	Ion Thrusters Keep Satellites Going and Going	Electric thrusters	Orbion Space Technology, Houghton, MI
7	Artificial Eyes Give Pilots a New Worldview	Video cards	WOLF Advanced Technology USA, Cleveland, OH
8	Ballooning Business for Shrinking Cameras	Miniaturized sensors	Urban Sky, Denver, CO
9	Farmers Get Tools from Space	Satellite data service for agriculture	IrriWatch, Wageningen, Netherlands
10	Commercial Space: NASA Has an App for That	Flight system software	Red Canyon Software, Denver, CO
11	Keeping the Connection	Satellite communications radios	NearSpace Launch, Upland, IN
12	NASA Ingredients for Industrial Expedience	Industrial induction heaters	Induction Food Systems, Durham, NC
13	Keeping Beds in the Goldilocks Zone	Bed cooling system	BedJet, Newport, RI
14	Making the Most of Meticulous Measurements	Industrial interferometers	4D Vision, Tucson, AZ
15	Pumping Out State-of-the-Art Design	Technology and software services	Concepts NREC, White River Junction, VT
16	Super Insulation Requires Super Materials	Building insulation coating	Superior Products International II, Shawnee, KS
17	From Magnetic Rocket Fuel to Semiconductors	Ferrofluids	MAGRON, Ansan, South Korea
18	A Huge Development for Tiny Satellites	CubeSat deployable release mechanism	Thermal Management Technologies, Logan, UT
19	Connections Made in Air and Space	Ethernet network switch	DornerWorks, Grand Rapids, MI
20	Synthetic DNA Diagnoses COVID, Cancer	Synthetic DNA for disease diagnostics	Firebird Diagnostics, Alachua, FL
21	Fixing 'Thermal Incompatibility' in the Bedroom	Temperature-stable bedding	Slumber Cloud, Arvada, CO
22	Aqua Solutions for Terra Firma	Weather app and geospatial data	ilika Geospatial, Edison, NJ
23	From Space to Your Face	Skincare additive	Delavie Sciences, Worcester, MA
24	Eco-Friendly Bio Breaks	Portable waste solution	Cleanwaste, Oceanside, CA
25	Space-Saving Exploration	Camping trailers	Taxa Outdoors, Houston, TX
26	Air Treatment Systems Break Down Pollutants, Germs	Air scrubber to break down organic contaminants	Fresh-Aire UV, Jupiter, FL
27	Temperature-Regulating Clothing Additive Heats Up	Temperature-regulating fabrics	Trizar Technology, North Naples, FL
30	Spherical Robots to the Rescue	Spherical robots for disaster response	Squishy Robotics, Berkeley, CA
33	Satellites 'See' Sea Turtles, Ocean Threats	Low-Earth orbit tracking tag	CLS Group, Ramonville-Saint-Agne, France
36	Redefining the 'Rugged' Video Camera	Ruggedized video camera, software	Imperx, Boca Raton, FL
38	Additive Manufacturing Subtracts from Rocket Build Time	Terran 3D-printed rockets	Relativity Space, Long Beach, CA
44	'Digital Winglets' for Real-Time Flight Paths	Plane routing software	APIJET, Seattle, WA
46	Next-Level Farming	Controlled environment agriculture technology	IntraVision Group, Oslo, Norway
50	Taking the Pulse of Earth	Earth observation using artificial intelligence	terraPulse, North Potomac, MD
53	Ultrasonic Inspections Protect Astronauts, Boat Owners	Ultrasonic scanner to inspect composite materials	ABS Group, Spring, TX
56	Oil Drillers, Environmentalists Agree on Small, Sensitive Spectrometer	Capillary absorption spectrometer	Guiding Photonics, Torrance, CA
59	Concentrating on Microbes	Bioconcentration technology	InnovaPrep, Drexel, MO
62	Rocket Manufacturing Meets Science Friction	Low-temperature metal 3D printing	MELD Manufacturing, Christiansburg, VA
66	Cutting the Knee Surgery Cord	Wireless arthroscopic camera	Lazurite Holdings, Cleveland, OH
68	NASA Gives the World a Brake	Automobile disc brakes	Orbis Brakes, Santa Rosa, CA
70	Medical-Grade Smartwatch Can Monitor Astronauts, Patients	Medical-grade smartwatch	Empatica, Cambridge, MA
72	Semiconductor Research Leads to Revolution in Dental Care	Medical hydroxyapatite toothpaste	Sangi, Tokyo, Japan
74	Unfurling Antennas Let Tiny Satellites Do Big Things	High-performance collapsible space antennas	Tendeg, Louisville, CO
76	New Energy Source Powers Subsea Robots Indefinitely	Module to indefinitely power robotic floats	Seatrec, Vista, CA
80	Where the Wildfires Are	Wildfire risk mapping service	Technosylva, San Diego, CA
84	NASA's Moon Shot Launched Commercial Fuel Cell Industry	Fuel cells for buildings and utilities	HyAxiom, South Windsor, CT
86	Webb Telescope Made Simulation Software Better	Simulation software	Ansys, Canonsburg, PA

# NASA SPACE TECH WHERE YOU LIVE





# Technology Transfer Program

Countless details go into space travel whether that's transporting astronauts to and from the space station, returning to the Moon, or launching a satellite into orbit around Mars. Ensuring the success of everything NASA does, down to the last detail, is what drives innovative engineer and technologists throughout the agency. And the Technology Transfer program is equally committed to finding new ways to move those inventions out into the world for much wider use.

Guests watch the launch of NASA's Space Launch System (SLS) rocket carrying the Orion spacecraft on the Artemis I flight test from Operations and Support Building II at NASA's Kennedy Space Center in Florida. Artemis I was the first integrated flight test of the agency's deep space exploration systems: the Orion spacecraft, SLS, and ground systems.



# Technology Transfer Expansion

NASA wants your entrepreneurial effort to succeed – here's how the agency helps



In 2021, students from the Daytona Beach, Florida, campus of Embry-Riddle Aeronautical University joined representatives from Kennedy Space Center's Technology Transfer Office for a Tech Talk Day. Embry-Riddle is part of the Technology Transfer University (T2U) network. *Credit: NASA*

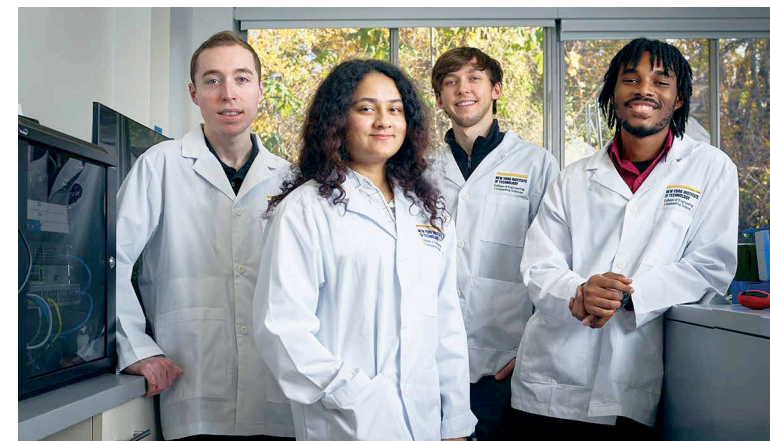
Bringing NASA technology down to Earth means getting innovations out of the lab and into the companies that can commercialize them. Nested under NASA's Technology Transfer program, Technology Transfer Expansion (T2X) initiatives are designed to accelerate the commercialization of NASA-patented technologies through strategic partnerships, outreach, and training opportunities to support an entrepreneurial workforce, minimize the risks associated with innovation, and ultimately boost the economy through new and improved products and services built from space tech.

T2X engages entrepreneurial and investment communities, local and state government, academia, and others who share a common interest in solving the challenges of tomorrow, today.

## NASA in the Classroom

Taking a technology from paper to an early-phase prototype can be a daunting and expensive task. To help eliminate that potential barrier for commercially viable but unrealized NASA patents, T2X started a pilot prototyping project with the New York Institute of Technology (NYIT) to develop working prototypes

Students in the school's STEM fields, from computer science to mechanical, electrical, and computer engineering, get the opportunity to learn about and work with selected NASA-developed technologies. Combined with a patent license, the resulting prototypes can then help a company improve its likelihood of startup success.



New York Institute of Technology students Robert Doxey, Hibah Agha, Robert Maksimowicz, and Lincoln Dover formed the first team to build technology prototypes based on existing NASA patents. Their backgrounds include computer science, as well as mechanical, electrical, and computer engineering. *Credit: NASA*

Now in its third year, the initiative will soon have students creating prototypes focused on assistive technologies. These include products, equipment, and systems that enhance learning, working, and daily living for people with disabilities.

Augmenting human senses, providing better prosthetics, and making buildings and services easier to access are just a few of the ways innovation for space exploration is making an impact on our home planet.

But prototyping isn't the only way NASA has entered the classroom.

By introducing students to space technology through Technology Transfer University (T2U), the agency is educating tomorrow's industry leaders about the benefits of using these tools in commercial applications. Educators build lesson plans around these NASA technologies, such as developing business plans, to give students a taste of launching their own startups.



Dover and Maksimowicz collaborate to model NASA's c-gauge technology. C-gauge measures cord tension in parachutes, sails, and weather balloons. *Credit: NASA*



Agha performs testing on NASA's upper body robotic exoskeleton, a soft, wearable robotic garment designed to control the shoulder and elbow. It was originally developed to provide motor rehabilitation for patients with neurological impairments, such as brain injury or stroke. *Credit: NASA*



In 2022, participants in the first Hillsborough Community College Patentthon learned how to develop new business ideas using NASA patented technologies. Based in Tampa, Florida, the event connected educational, entrepreneurial, and STEM-focused organizations with maker communities to accelerate innovation. *Credit: NASA*

Over 50 universities now participate, and some educators at those institutions are reaching out to potential participants through the new T2U Innovation webinar series. These virtual events feature firsthand accounts of experiences and best practices from distinguished instructors at colleges and universities around the country.

These instructors have valuable perspectives about the educational benefits of working with NASA-developed technology and an understanding of the entrepreneurial value of leveraging related patents to start tech-based companies.

## Starting Up Climate Tech

In addition to addressing disabilities and other problems faced by individuals and small groups, NASA also works with entrepreneurs, small businesses, and startups to address challenges that impact all populations on Earth – human, animal, plant, and more. NASA technologies are already being utilized for better water conservation, improved renewable energy storage, and even toxic chemical cleanup. But there is much more emerging technology available.

To pair entrepreneurs with selected inventions, the agency offers an annual Startup Studio powered by FedTech – an organization that specializes in connecting entrepreneurs with technologies from federal labs such as NASA.

This year, the focus of the NASA Startup Studio is on climate-related technology, exploring the commercial potential of six eco-focused patents through the lens of new venture

creation. Following an introductory boot camp, entrepreneurs begin a three-month effort, conducting research through customer discovery, creating market plans, developing pitch decks, and learning from advisors.

Previous studios have helped launch new companies that moved NASA technologies into the private sector.

## Back to the Lab

T2X isn't just reaching out to future industry leaders. By offering commercialization boot camps for NASA innovators, the program equips scientists, engineers, and researchers with practical skills for bringing out the commercial potential of their inventions.

Through a mix of virtual and hands-on sessions, NASA employees can explore their work through the eyes of an entrepreneur and understand it in the context of the startup and investment communities. This leads to more informed invention disclosures, with focused applications beyond space exploration. Better disclosures make patents easier for companies to understand and utilize, shortening the pipeline to commercialization.

As we venture to the Moon, Mars, and beyond, T2X will continue to train innovators and entrepreneurs to harness emerging science and engineering resources, multiplying the impact of NASA investments back to state and local economies. This impact will be visible in new job creation, increased revenue generation, and the development of innovative products and services. ●



# Will the next spinoff be yours?

Our technology is ready for you at [technology.nasa.gov](https://technology.nasa.gov)

Our portfolio includes:

- More than 1,100 patented technologies
- Hundreds of innovations now in the public domain
- More than 700 software codes

Whether you're looking to start a new company using NASA technology, enhance an existing product, or create a new product line, you can gain a competitive edge in the marketplace by putting NASA technology to work for you.



Aerospace



Communications



Electrical



Environment



Medicine/Biotech



IT/Software



Instrumentation



Manufacturing



Materials/  
Coatings



Mechanical/  
Fluid Systems



Optics



Power Generation



Propulsion



Robotics



Sensors

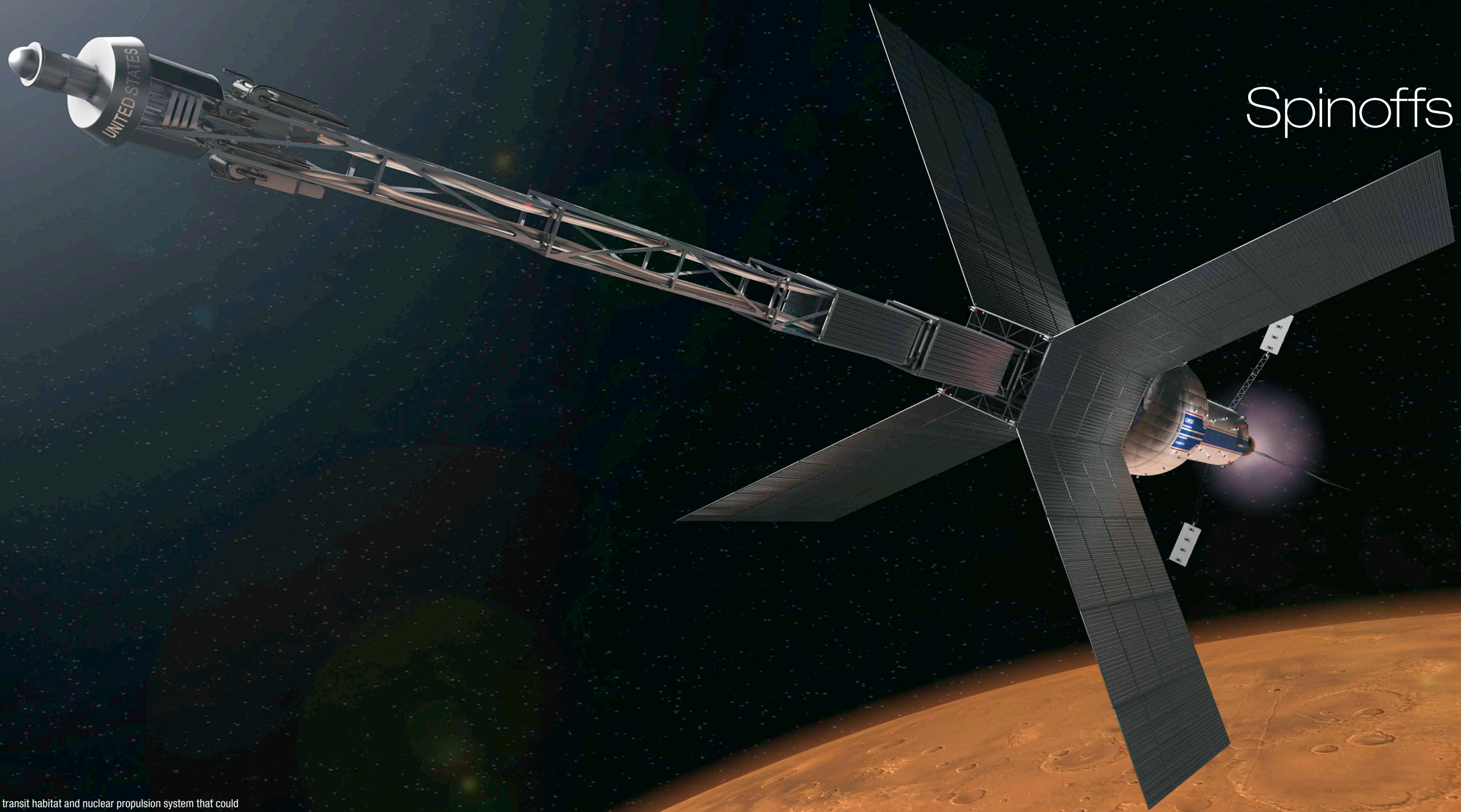
The Atacama Rover Astrobiology Drilling Studies project, carried out in the Mars-like conditions of the Atacama Desert in Chile, developed tools and techniques to look for signs of life on the Red Planet and other worlds.



NASA TECHNOLOGY  
TRANSFER PROGRAM

BRINGING NASA TECHNOLOGY DOWN TO EARTH





# Spinoffs of Tomorrow

NASA maintains a patent portfolio with more than 1,100 technologies and a software catalog with hundreds of codes, making many of the aeronautic and aerospace technologies that are solving problems for the agency available to anyone.

The following are 20 examples from all 10 NASA field centers. Each is ready to find a new home on Earth.

To learn more about – and get started licensing – these or any other NASA resources, please visit [technology.nasa.gov](https://technology.nasa.gov).

Illustration of a Mars transit habitat and nuclear propulsion system that could one day take astronauts to Mars. NASA is already inventing the technology to enable missions to the Red Planet, which will also find uses here at home.



## Rapid Nucleic Acid Isolation Method

**Smaller, simpler sample-preparation system for analysis of gene expression**

Sample preparation is a common bottleneck in genetic analysis and carries risk of RNA contamination and degradation during processing. Ames Research Center has developed a novel assay methodology and suite of devices to isolate nucleic acids and prepare samples for reverse transcriptase quantitative polymerase chain reaction analysis that solves the problem of contamination and degradation. This invention enables end-to-end processing of a biological sample for gene expression analysis from raw tissue to data.



### Benefits

- Reduces or eliminates contamination concerns
- Cost-effective, battery-powered, fast and easy to operate
- Portable, stowable at room temperature, and disposable

### Applications

- Medical diagnostics
- Commercial and academic research
- Food-quality testing
- Disease or microbial monitoring in remote areas



### Benefits

- Decreases cost and complexity of wing design
- Enables active wing control to manage flutter on existing aircraft
- Can be applied to aircraft in any Mach regime

### Applications

- Aircraft wing design
- Active aircraft wing control
- Rotorcraft blades

## Quick Method for Predicting Transonic Flutter

**Resolving transonic aerodynamics with data modeling**

Aircraft moving near the speed of sound experience wing flutter. Engineers have relied on experimental or computational methods to understand flutter, requiring tens of hours of simulation on a costly supercomputer. Ames Research Center has developed a novel closed-form solution to model flutter aerodynamics for aircraft wings. The closed-form solution matches, in near-real time, complex supercomputer simulations at a fraction of cost and time required by traditional methods.

## Streamlined Liquid Level Sensing

**Fiber optics offer extraordinary accuracy monitoring tanks**

Innovators at Armstrong Flight Research Center developed a highly accurate method for measuring liquid levels and other tank-gauging applications using optical fibers. Unlike current liquid level gauges, Armstrong's method provides precise, accurate measurements at quarter-inch intervals. Originally designed to monitor a rocket's cryogenic fuel levels, this technology can be used in many tank-gauging applications.

### Benefits

- Precise down to a quarter-inch
- Simple, requiring just one fiber-optic strand and one metallic wire
- Robust: can be used in corrosive or toxic liquids and is not susceptible to electromagnetic interference

### Applications

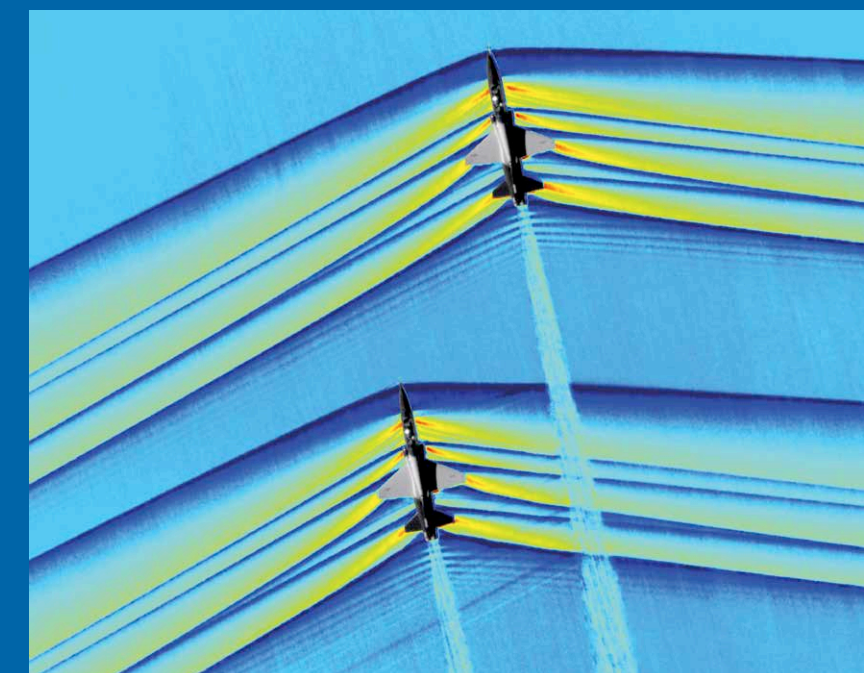
- Cryogenic liquids
- Food products
- Grain storage
- Oil and natural gas



## System to Capture Shockwave Images

**High-speed Schlieren imaging technology**

Innovators at NASA's Armstrong Flight Research Center have developed a novel system for capturing images of shockwaves created by supersonic aircraft. The Background Oriented Schlieren Using Celestial Objects technology uses a celestial object, such as the Sun, as a background to secure measurable shockwave images of full-scale aircraft. The patented image-processing technology captures hundreds of observations with each shockwave and also has potential uses for visualizing air density gradients in the construction and renewable energy industries.



### Benefits

- Works with existing commercial hardware, no need for complicated equipment or setup
- Works anywhere
- Uses optical filters to efficiently capture fine details with high resolution

### Applications

- Study of shockwaves and vortices around supersonic aircraft and helicopter rotors
- Wind turbines
- Large structures



## Contaminant-Free Steel

Superior steel alloys for high-performance applications

Innovators at Glenn Research Center devised a method for creating ultra-pure steel alloys free from ceramic particle contamination. These ultra-high-quality steels can make bearings, gears, or any other machine components. Conventional steel alloys contain small amounts of hard particle contaminants that cause weak points, making mechanical components vulnerable to failure. Glenn's process for creating steel alloys has proven nearly perfect, with the potential for significantly better performance, especially in high-stress applications.



### Benefits

- Produces extremely clean parts capable of long life under high mechanical stress
- Proven: modeled after processes NASA uses to generate ultra-pure nickel-titanium alloys
- Flexible: useful in production of various steel alloys

### Applications

- Bearings and gears
- Helicopters, tooling and cutting, medical equipment
- Nuclear power plants and oil and gas drilling



### Benefits

- Performance: high discharge rates, lightweight and robust, energy density more than double lithium-ion batteries
- Safety: high damage tolerance and no fire risks
- Sustainability: enables electrification, is amenable to recycling, and is made with environmentally friendly materials and processes

### Applications

- Aviation
- Automotive
- Military and defense

## Solid-State Lithium-Sulfur Battery

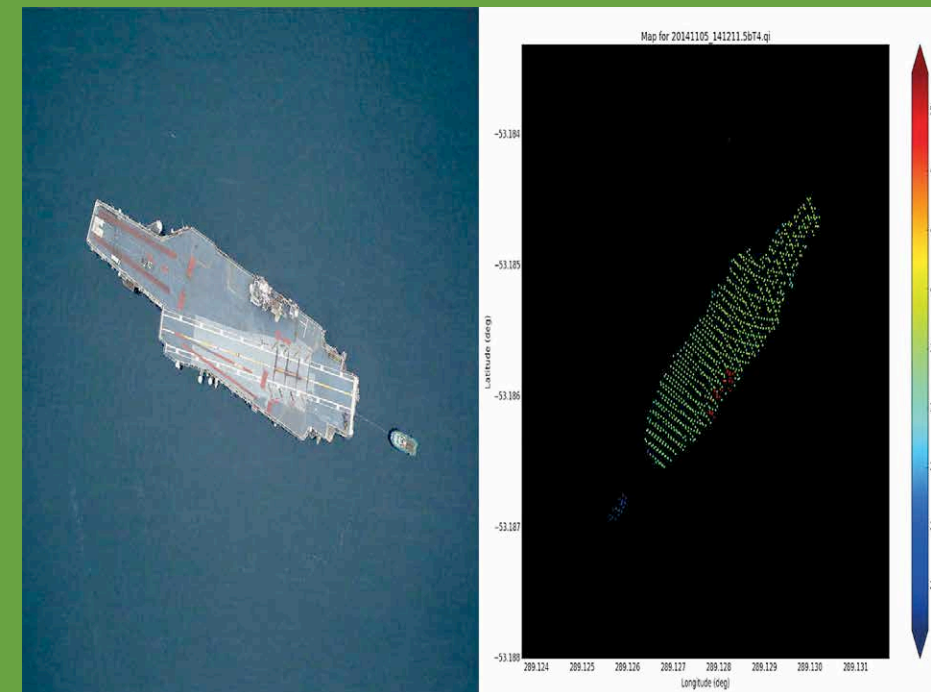
New battery paradigm for energy density, power, reliability, and safety

Developed at Glenn, Langley, and Ames research centers, the Solid-State Architecture Batteries for Enhanced Rechargeability and Safety (SABERS) technology portfolio includes advanced material, manufacturing, and design innovations. The primary target is electric aviation propulsion, yet SABERS will benefit other applications. In large vehicles or small devices, SABERS can set new benchmarks in energy density and power, along with safety and reliability. Uses environmentally friendly, sustainable materials and manufacturing methods. Available for license as a portfolio or as individual technologies.

## Kodiak 3D Lidar

Provides low-cost, reliable 3D images in nearly any lighting conditions

Goddard Space Flight Center developed a 3D lidar system combining a scanning lidar with a long-range telescope for spaceflight ranging. The technology includes microelectromechanical beam steering, high-performance reconfigurable computing, and an in-depth understanding of systems-level integration. It's designed to meet the challenges of high-orbit satellite servicing and planetary science missions, including harsh environments, long mission durations, and a need for long-range, high-speed, accurate measurements. Conventional systems suffer from high costs and questionable reliability.



### Benefits

- Lower cost, higher performance and reliability
- Reconfigurable
- Capable of long-range 3D imaging in nearly any lighting condition

### Applications

- Space detection and ranging
- Proximity laser ranging
- Autonomous vehicles

## Non-Scanning 3D Imager

High-resolution, real-time, three-dimensional imaging with a single-lens system

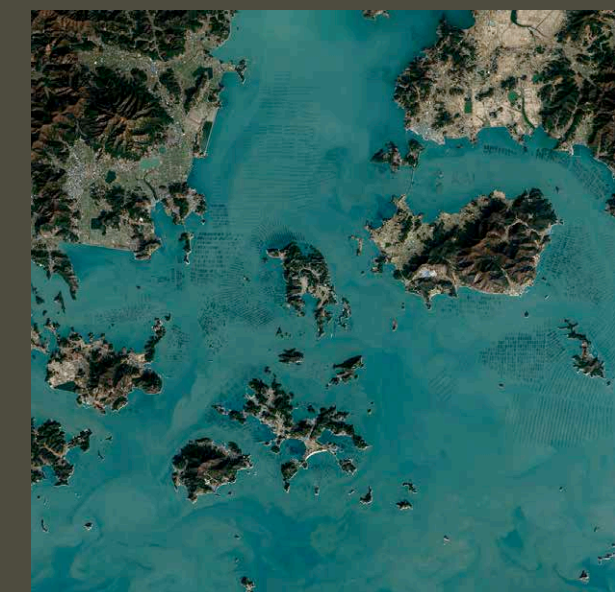
This innovation is a method and instrument to generate a topographic profile of an object, surface, or landscape. It overcomes the shortcomings of typical methods like scanning lidar, diffraction grating, and flash lidar. Goddard Space Flight Center's 3D imager uses a simple lens system to instantaneously generate a one-dimensional or two-dimensional array of optical spots to illuminate an object, surface, or image to generate a topographic profile. The system produces real-time three-dimensional images at television frame rates or higher.

### Benefits

- Simple design does not require scanning or moving parts
- Greatly improved system efficiency and reduced crosstalk between pixels

### Applications

- Remote sensing
- Machine vision
- Robotic vision





## High-Performance, Lightweight, Simple Heat Exchanger

**A key technology for thermoelectric generators, other energy-recovery systems**

Researchers at the Jet Propulsion Laboratory developed a heat exchanger that addresses problems with metal-based systems, such as high thermal expansion and high density. JPL's innovation has a lightweight, high-heat-flux design, offers a low coefficient of thermal expansion, and reduces the pressure drop during heat transfer. It can handle gases up to 1,200°F. This technology has undergone successful preliminary testing and meets the requirements of high-temperature, high-specific-power thermoelectric generators and other energy recovery systems.



### Benefits

- High-performing, lightweight, and easy to manufacture
- Robust, with low coefficient of thermal expansion and good structural strength
- Easy to reconfigure into other designs using similar materials

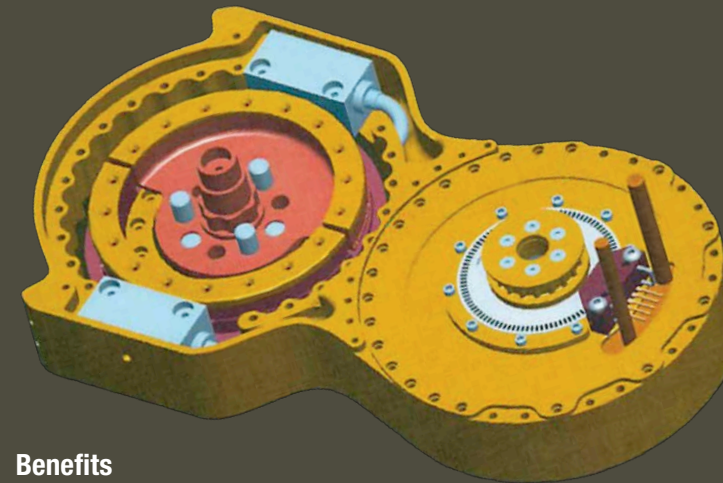
### Applications

- Thermoelectric generators
- Thermal energy recovery in industrial processes and exhaust energy recovery in vehicles
- Hypersonic engine and aircraft cooling

## Split-Ring Torque Sensor

**An optical device for measuring position, velocity, and torque**

Innovators at Johnson Space Center, together with Oceaneering and the Florida Institute for Human and Machine Cognition, have developed a device that uses optical sensors to measure the position, velocity, and torque of a rotating system such as an actuator, motor, crankshaft, or rotor. The sensor was created for NASA's X1 robotic exoskeleton, a wearable exercise machine. It uses two optical sensors and a single, custom-designed split ring rather than a standard dual-ring system.



### Benefits

- Smaller and lighter than similar technologies
- Highly accurate position and displacement measurement
- Adaptable to various configurations with different devices or sensors

### Applications

- Robotics and prosthetics
- Aerospace, defense, and automotive
- Industrial tools and machinery

## Foot Pedal Controller

**Novel system to control movement of an object in three dimensions using foot pedals**

Johnson Space Center has developed a system that lets operators control the movement of spacecraft, aircraft, or watercraft using only foot pedals. This design leaves the hands free for operation of other equipment. The foot pedal controller integrates six articulating mechanisms and motion sensors and provides continuous positional feedback to the operator. Motion control is enabled by three control motions for each foot, with one foot controlling movement through space and the other controlling rotation.



### Benefits

- Hands-free and accessible for individuals with hand/arm disabilities
- Intuitive control movements mimic natural human movements
- Ergonomic design reduces fatigue

### Applications

- Aircraft, spacecraft, and watercraft control
- Video gaming and flight simulation
- Robotics mobility

## Biomarker Sensor Arrays for Microfluidics

**For multicolor imaging and processing of single-molecule life signatures**

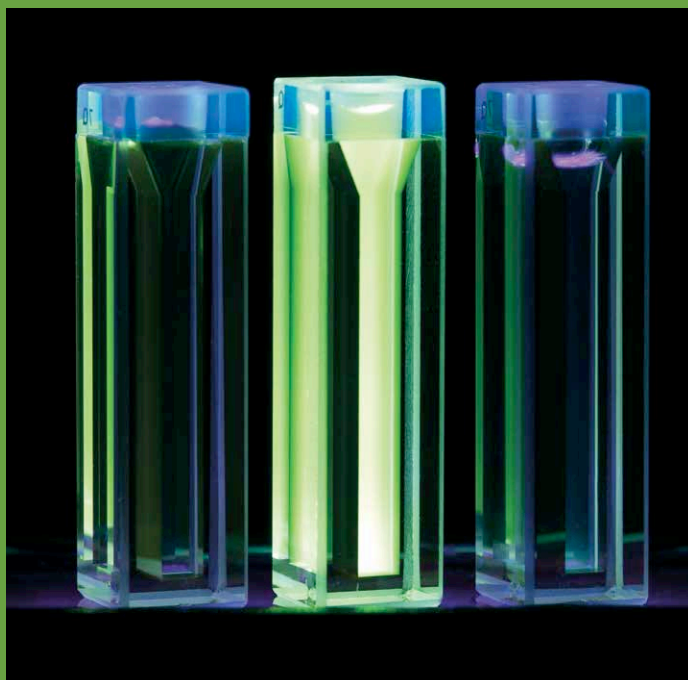
The Jet Propulsion Laboratory offers a way to manufacture biomarker sensor arrays with nanoscale resolution and active regions on the order of 1 micron, by applying nanolithographic direct-write techniques to the fabrication of silane chemistry sensors on a transparent substrate. The technology enables extremely fine patterns of detectors suitable for multicolor imaging of single-molecule samples at resolutions far below the diffraction limit. The sensors' tiny size allows for rapid screening for hundreds of functionalities in one microfluidics chip.

### Benefits

- Fast and efficient
- High resolution at 1 micron or less
- Can apply patterns using a wide range of previously incompatible materials in various pH environments

### Applications

- Life sciences: medical diagnostics, pharmaceutical research, biotechnology
- Security: detection of toxins and bioweapons
- Agriculture: processing and analysis of soil samples
- Chemistry, electronics, and petroleum





## Cryogenic Flux Capacitor

Device for solid-state storage and distribution of cryogenic fluids

Kennedy Space Center seeks partners interested in the commercial application of this new technology that exploits a unique attribute of nano-porous materials – aerogel in this case – to store liquefied gases in a molecular surface-adsorbed state. Currently, highly pressurized gases are stored in vessels with thick walls, requiring constant pressurization and complex storage systems to limit boil-off. The cryogenic flux capacitor addresses these issues and lets cryogenic liquids be quickly converted to gas when the need arises.

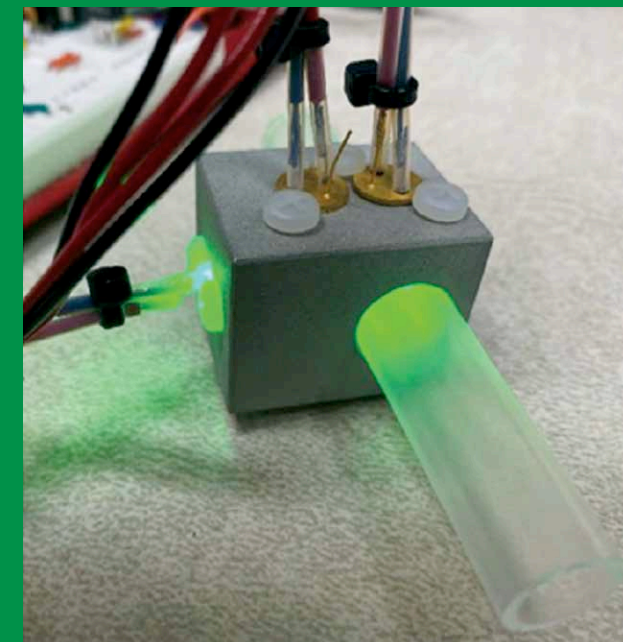


### Benefits

- Compact and lightweight
- Low to moderate storage pressures
- Fast charge-up times and on-demand, fast discharges

### Applications

- Spacecraft and aircraft
- Fuel cells
- Medical



### Benefits

- Easy to adopt: based on commercial components and established techniques
- More reliable, less prone to voltage drift and contamination
- Compact: can be miniaturized to roughly one cubic inch

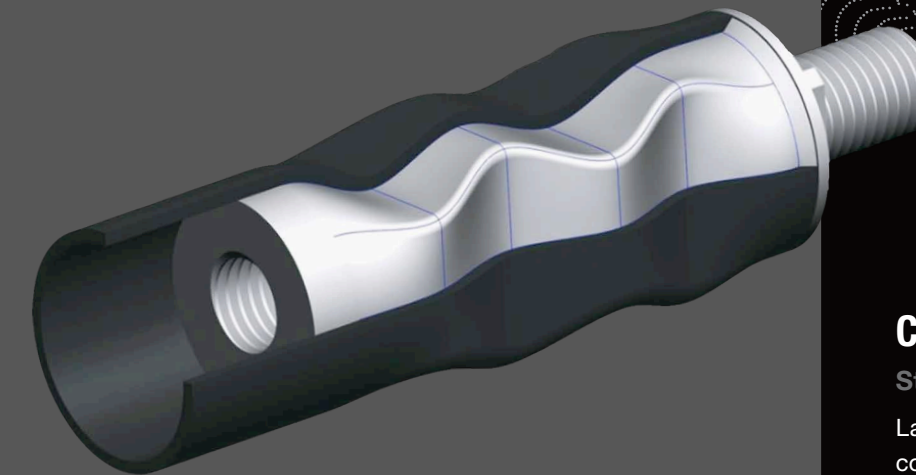
### Applications

- Aerospace: waste or fuel management
- Industrial: food and beverage processing, pharmaceutical production, medical devices
- Wastewater processing: from municipal treatment plants to chemical toilets

## Liquid Solution Concentration Sensor

Light-scattering approach precisely measures concentrations

Innovators at Kennedy Space Center have developed a new optical sensor for measuring concentration in a liquid solution. The sensor was designed to measure the pretreat solution concentration in the space station's waste management system. Using established methodologies and commercial components, the sensor uses the light passed through and scattered by the solution to precisely measure its concentration. It can be adapted to solutions across various industries.



### Benefits

- Increased structural integrity
- Can be formulated to fit a variety of joint shapes
- Corrosion resistant, lightweight, and electrically insulated

### Applications

- Aerospace and automotive
- Outdoor structures
- Sporting goods

## Composite Joint Connector

Structural joint with multi-axis load-carrying capacity

Langley Research Center has developed a composite joint connector that is more structurally efficient than joints currently on the market. Traditionally, composite joints can bear heavy loads along their length but tend to fail when stress is applied along multiple axes. This joint is designed to minimize stress concentrations, leading to overall increased structural efficiency compared to traditional joints.

## High-Atomic-Number Fabric Coatings

Improved durability using a low-atomic-number metal tie-down layer

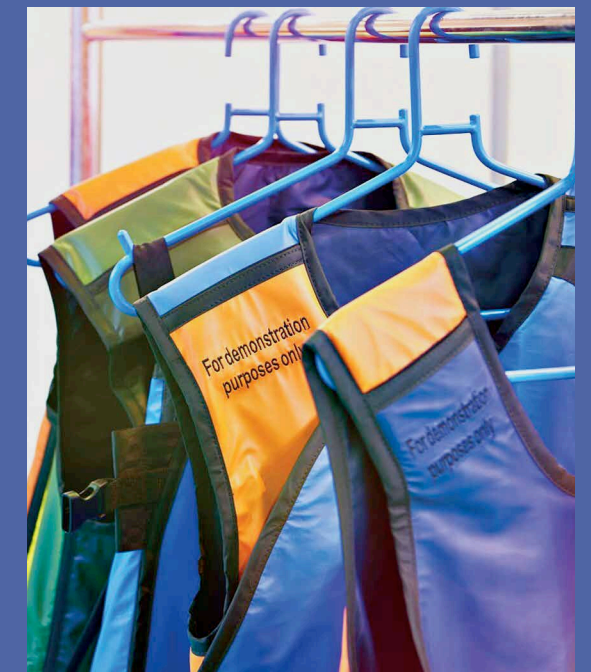
Langley Research Center developed an innovation to improve adhesion and durability of high-atomic-number metal coatings on oxygen- or hydroxyl-rich surfaces. This approach is useful for building radiation shields via the Z-grading method, the process of layering metal materials with different atomic numbers to provide radiation protection from protons, electrons, and x-rays. This invention enables Z-graded coatings to be applied to lower-cost, lighter substrates like glass-fiber fabrics while maintaining durability and flexibility.

### Benefits

- Promotes adhesion without increasing weight
- High-atomic-number metals can be sprayed on inexpensive materials, and low-atomic-number metal tie-down can be applied via thermal spray
- Significantly increases durability and flexibility of Z-shielding coatings

### Applications

- Medical: radiation-protection clothing
- Building materials: radiation shielding for walls and ceilings
- Electronics: electromagnetic interference and radio frequency shielding





# Marshall

## Tension Element Damping with Hydraulics

Disruptive modal coupling damps large-structure vibrations using small-footprint devices

Marshall Space Flight Center engineers developed a new approach to mitigating vibrations in tall structures like wind turbines or towers. Tension element damping uses disruptive modal coupling between two structures, each with their own vibrational behavior, to provide vibration damping for one or both of them. Line tension is provided by hydraulic, pneumatic, or magnetic means. Compared to conventional spring dampers, these devices are simple, lightweight, and very effective, and they have a smaller footprint.

### Benefits

- Smaller, more reliable, and more effective than previous damping methods
- Adaptable: responds to changing vibration amplitudes
- Adjustable: damping can be tuned in two dimensions

### Applications

- Energy: wind turbines, solar arrays, liquid natural gas platforms
- Commercial space mobile launchers
- Towers



# Stennis

## Remote Sensing Toolkit

Online portal offers easy access to NASA Earth-observation data

NASA's Technology Transfer program created an online resource to promote wider use of the agency's freely available remote sensing data and the software to work with it. Through its constellation of Earth-observation satellites, NASA collects petabytes of data each year. The Remote Sensing Toolkit lets users find, analyze, and use the most relevant data for their projects. The toolkit's simple system quickly identifies relevant sources based on user input.



### Benefits

- Free and easy to use
- Centralized online repository with unified file formats
- Includes data from more than 20 satellites and missions

### Applications

- Precision agriculture and crop forecasting
- Conservation and resource management
- Natural disaster planning and response

## High Flow-Differential Cleaning

Cleans complex 3D-printed parts in minutes

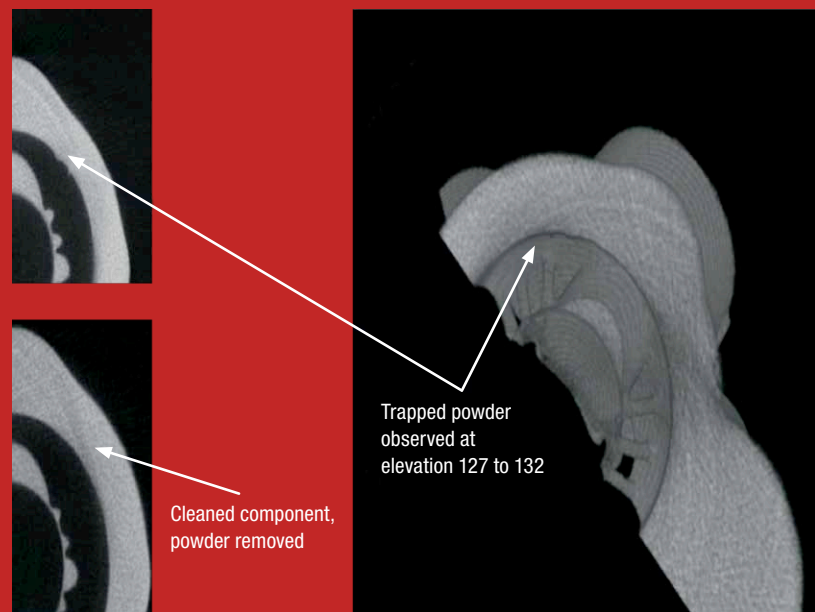
Powder-based additive manufacturing typically requires post-fabrication cleaning to remove residual powder from the surface and crevices of the part, which becomes increasingly challenging with part complexity. Current methods have significant drawbacks. Marshall Space Flight Center developed technology that uses a large volume of pressurized air in a cleaning chamber, with the high flow resulting in a decrease in pressure as it passes through smaller component orifices, which removes remnant powder from the part.

### Benefits

- Takes seconds or minutes instead of hours or days
- Effective cleaning
- Works on complex parts with small channels and passageways

### Applications

- Powder-based additive manufacturing, including direct metal laser sintering, electron beam melting, selective heat sintering, selective laser melting, and selective laser sintering
- Post-processing of complex additively manufactured parts



## Cryogenic Butterfly Cam Valve

No-leak valve performs in broad range of temperatures

In typical butterfly valves, the disc must create a tight seal with the seat when it hits 90 degrees. If additional torque is added, the disc will rotate further, reopening the valve. These valves also fail liquid nitrogen leakage tests. Researchers at Stennis Space Center have created a butterfly valve that allows additional rotation of the shaft so the disc can slide toward the valve body until it seals tightly, preventing leaks regardless of temperature changes.

### Benefits

- Improves performance over a wide range of temperatures
- Zero leakage
- Simple design

### Applications

- Aerospace
- Natural gas
- Cryogenic plants

