

National Aeronautics and Space Administration



# SPINOFF

# 2023



**NASA TECHNOLOGY  
TRANSFER PROGRAM**

National Aeronautics and Space Administration  
Technology Transfer Program  
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## On the cover

This image of the Tarantula Nebula's star-forming region was captured by the James Webb Space Telescope's Near-Infrared Camera two months after it went into operation. Here, the world's most powerful space telescope revealed tens of thousands of young stars that had never been seen before, with the most active region sparkling pale blue.

This image of the Holuhraun Lava Field in Iceland taken by Landsat 8 shows the size of flows and the accompanying smoke plume during an active eruption on September 6, 2014. The false color of the image adapts the infrared, near-infrared, and green light observed by the satellite's Operational Land Imager to observe the size of the plume and amount of sulphur dioxide released by volcanic activity.

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# SPINOFF

## 2023

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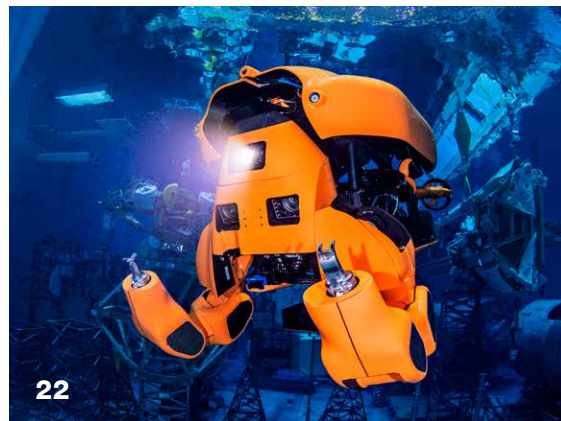
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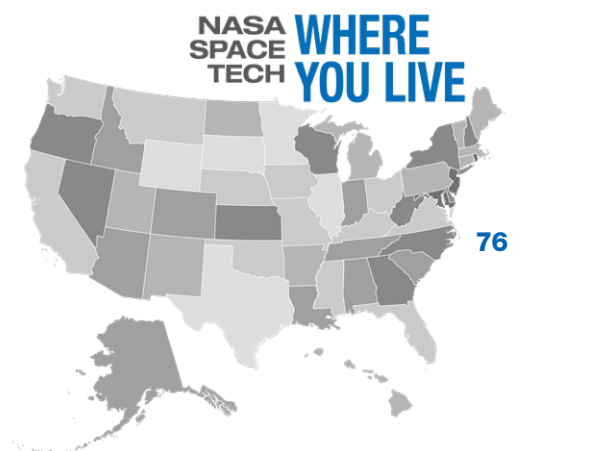
A diagnostic test used to customize cancer treatment and approved by the Food and Drug Administration started with NASA-funded research into a new method for measuring radiation damage astronauts experience in space.

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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.

After an 11-hour journey, moving 4.2 miles away from the Vehicle Assembly Building, the Artemis I stack sits at Kennedy Space Center's Pad 39B awaiting its wet dress rehearsal before launch. During the rehearsal, engineers put the rocket through its paces, running down the launch countdown to the end, without actually launching.

## Introduction

Welcome back!

In this new edition of *Spinoff*, we're celebrating the benefits born from space missions decades in the making. The most advanced space observatory ever built, the James Webb Space Telescope, deployed into space during this past year. It is now revealing stunning views of the universe never seen before (imagery so beautiful, it had to make the cover).

But that isn't the only way the telescope is improving how we see. You can learn more about how one of the most common eye surgeries around the globe has been advanced using technology developed for the telescope's mirrors (page 4).

We're also celebrating 50 years of the Landsat program. With the launch of the program's ninth satellite designed to constantly keep a camera pointed at Earth, the scientific orbiters continue to provide crucial data for farmers, water managers, food manufacturers, and even those just looking for the perfect hiking trail (page 40). Our fleet of satellites, along with NASA software, is also informing powerful tools used to navigate the effects of climate change. Companies are now using all of this to improve climate resilience for wildfires, floods, and extreme weather emergencies (page 30).

Since the birth of NASA, one thing has been clear: the more we create technologies for space, the more ways we can help people here on Earth. We've captured thousands of success stories over the decades and can't wait to share the latest batch. Be sure not to miss out on some of my favorites:

- To assist astronauts working in harsh, remote environments, NASA engineers built robust robots that could work autonomously. Now, many of these engineers have put their knowledge to good use to create an underwater version, dubbed Aquanaut. It's now available to swim offshore to work on oil wells, wind turbines, and even fish farms (page 22).
- When astronauts suit up and perform external repairs on the space station, they are also exposed to space radiation. To help protect them against future health problems, NASA funded research into using certain segments of DNA to estimate the potential damage these spacewalks could have on their bodies. That research is now powering a diagnostic test that helps customize cancer treatments (page 72).
- Besides hosting some of the most beautiful natural wonders our nation has to offer, Yellowstone National Park is also home to lifeforms capable of surviving in extreme environments, making it a perfect place to learn more about what life can do off the planet, too. One such lifeform, discovered during a NASA-funded research expedition, is now the basis of a fungal protein that's ready to be served on your breakfast table in the form of sustainable meat-alternative patties and non-dairy cream cheese (page 34).

In addition to these commercial success stories, we're also featuring companies that used a Jet Propulsion Laboratory-born ventilator to help battle COVID-19 worldwide. Created at the start of the pandemic to assist hospitals and clinics overwhelmed with patients needing life-saving measures, VITAL (short for Ventilator Intervention Technology Accessible Locally) was made by a team of engineers, fueled by a desire to help, in just 37 days. Using different parts than traditional ventilators made it easier to assemble as the world struggled with supply-chain issues (page 26).

Want a sneak peek at the possible future of *Spinoff*? Don't miss the Spinoffs of Tomorrow section, featuring 20 technologies the Technology Transfer program has identified as the next wave of possible success stories (page 85).

Making NASA technology available to the public is our longest-standing mission. There are now thousands of spinoffs at work that boost the economy, create jobs, and improve everyday life. And we aren't stopping anytime soon.



**Jim Reuter**

Associate Administrator  
Space Technology Mission Directorate  
NASA Headquarters



# SPINOFF Capsules

Whether flying through Earth's atmosphere or breaking free of it to explore the solar system, NASA continues to solve problems that once seemed insurmountable. Scientists and engineers tasked with creating novel technologies have also enabled their use on our home planet. Read on to discover the tools – both familiar and surprising – that NASA enables.

In 2018, The USS John P. Murtha rehearsed recovery of the Orion capsule in the Pacific Ocean. When the capsule returns from deep space, the Exploration Ground Systems Recovery Team will work with the U.S. Navy to bring astronauts back to land safely after splashdown.



# Telescope Mirror Tech Improves Eye Surgery



As the James Webb Space Telescope returns some of its first images, such as this near-infrared image of the “Cosmic Cliffs” in the Carina Nebula, eye surgery patients on Earth are benefiting from early research on the telescope’s enormous mirrors. *Credit: NASA*



Johnson & Johnson’s iDesign Refractive Studio, pictured here, takes precise eye measurements that map visual pathways and cornea curvature to help doctors diagnose and plan treatment for eye issues. *Credit: Johnson & Johnson Vision Care Inc.*

## Technology to measure Webb mirrors boosts LASIK eye surgery precision

The James Webb Space Telescope has started to show us some of the first stars in the universe, with its enormous and powerful mirrors capturing bits of light from more than 13 billion years ago.

Meanwhile, technology developed as part of the decades-long effort to build Webb has already improved the vision of millions back on Earth by driving major improvements to LASIK eye surgery.

Part of a process for measuring Webb’s mirrors has been incorporated into Johnson & Johnson Vision Care Inc.’s iDesign Refractive Studio, a device that takes precise eye measurements to map imperfections in visual pathways and cornea curvature. One Johnson & Johnson Inc. (J&J) executive called the resulting information “an optical fingerprint unique to each patient’s eye.”

iDesign Refractive Studio is now available to eye doctors in 47 countries, and the iDesign technology has enabled well over 18 million successful LASIK procedures worldwide, according to J&J.

The technology got its start in the early 2000s, when Albuquerque, New Mexico-based subcontractor WaveFront Sciences worked with NASA to develop a system to measure deviations in Webb’s mirrors as they were being ground and polished to precise specifications (*Spinoff* 2012).

“The mirrors were one of the really critical technologies we needed to develop to enable the observatory,” said Lee Feinberg, optical telescope element manager for Webb at NASA’s Goddard Space Flight Center in Greenbelt, Maryland.

“We had to polish them in such a way that, when they cool down, they become the mirror shape that we want,” he said. “We had to match the curvature of one mirror to the next, which was a very challenging problem.”

WaveFront Sciences incorporated some of the algorithms it developed for the Webb mirrors into a commercial product it called the Complete Ophthalmic Analysis System, which could diagnose eye conditions by mapping the eye.

The technology changed hands several times and was rolled into the iDesign system before J&J Vision, which is headquartered in Santa Ana, California, acquired it in 2017. The company incorporated it into its iDesign Refractive Studio, which won approval from the U.S. Food and Drug Administration in 2018.

Once based on the limited information of a patient’s eyeglasses prescription, LASIK surgery today – guided by the iDesign Refractive Studio – can involve more than 1,200 measurements for individualized vision correction that is also fast and safe.

Kristian Santana, now an electrical engineer at J&J Vision, has worked with this technology from the outset, originally helping to develop the system to measure Webb’s mirrors while working at WaveFront Sciences in the early 2000s.

“NASA was a very good partner,” Santana recalled, noting that the work on the telescope helped the company improve algorithms in the seemingly unrelated eye-mapping system.

Indeed, the space agency’s work often benefits people on Earth. “Ultimately, the investments that NASA made helped the company develop the technology to be useful for other applications – in this case, LASIK eye surgery,” NASA’s Feinberg said. ●

# Feeling Hot, Staying Cool

## NASA-funded technology helps relieve symptoms of menopause



According to the National Institutes of Health, 1.3 million people in the United States begin to experience symptoms of menopause each year, usually characterized by feelings of intense heat known as hot flashes. Menopause can last for years, and the associated temperature swings are uncomfortable at best and debilitating at worst. Because there’s no definitive cure for these biological responses, a textile marketer named Louise Nicholson wanted to help people stay comfortable during this period of their lives. However, she found existing options lacking.

“I did some initial research to find out what was on the market, and there was absolutely nothing apart from nightwear,” Nicholson said.

Exploring high-tech fabrics for regulating temperatures, Nicholson found that these products tended to be cooling fabrics which ignored the cold flashes that often follow hot flashes. Her search soon brought her to a technology called Outlast.

In the 1980s, NASA’s Johnson Space Center in Houston was looking for ways to improve insulation in spacesuit gloves. The center entered into a Small Business Innovation Research contract with the Triangle Research and Development Corporation to explore the use of phase-change materials, which maintain a steady temperature as they change phase from solid to liquid or vice-versa. Based on earlier work it had done with the U.S. Air Force, by embedding phase-change materials into microcapsules inside the material, Triangle was able to demonstrate the effectiveness of a temperature-stabilizing fabric insert for a spacesuit glove. While the technology never went into space, Gateway Technologies (later known as Outlast Technologies) acquired exclusive patent rights from Triangle and soon began marketing it under the name Outlast.

Outlast has been used in numerous products, from desk chairs to underwear (*Spinoff* 1997, 2004, 2009, 2020). Walero, which uses the material in clothes for race car drivers (*Spinoff* 2022), had sold some of its Outlast apparel to people experiencing menopause, but Nicholson noticed that there didn’t seem to be any brands using this technology specifically for menopause.

Founded by Nicholson in 2017, London-based Fifty One Ltd. is named after the average age when people can begin to experience menopause. By bonding Outlast to cellulosic yarn, the company’s clothing maintains the temperature-regulating properties of phase-change materials but retains the look and feel of high-end fabrics.

The initial products, a line of shirts in four styles, were first sold to consumers in the London area via parties, but the company has expanded to e-commerce, selling tops, bottoms, and nightwear directly to individuals around the world. As of 2021, the United States is Fifty One’s second-largest market after the United Kingdom, and the company is looking to obtain a local distributor for the products. In addition, Fifty One has expanded its range of Outlast-based products, including accessories like scarves, facemasks, and turbans. ●



Incorporating a material developed with NASA’s assistance, Fifty One Apparel sells clothing that regulates temperature swings from the symptoms of menopause, such as pajamas (top) and daywear (bottom). *Credit: Fifty One Ltd.*

Spacesuit gloves need to be highly insulated against the extreme temperatures of outer space. NASA funding to explore phase-change materials in this application resulted in a material now found in several products. *Credit: NASA*





# Astronaut Life Support for Earth Families



NASA researchers Neil Yorio and Lisa Ruffe inspect lettuce inside NASA's Biomass Production Chamber at Kennedy Space Center in 1991. For more than 20 years, NASA used the chamber to run experiments on crop growth in support of the Controlled Ecological Life Support System program. *Credit: NASA*



Eden Grow Systems technician Eli Long checks on plants in one of the company's grow towers. *Credit: Eden Grow Systems Inc.*

## Grow towers for crops and seafood will soon drive self-sustaining shelters

Bart Womack likes to be prepared, and he has found no better resource than NASA. After all, an agency preparing for survival in the frozen void of space is ready for anything.

NASA has worked for decades to develop a life-support system that functions as a self-replenishing ecology. At the heart of this work was the Controlled Ecological Life Support System (CELSS) program, which ran for about 25 years, between the late 1970s and early 2000s, at NASA's Kennedy Space Center in Florida. It relied especially on plants, which recycle waste into food and oxygen.

The project's results, published in hundreds of papers over the years, have given rise to the controlled environment agriculture movement (*Spinoff* 2021). But Womack wanted to apply the findings to something closer to NASA's goals – a closed-loop, self-sustaining life-support system that would enable self-reliance for families, homesteaders, and communities.

He founded Houston-based Eden Grow Systems Inc. in 2017 and has since recruited Kennedy's former plant research director, Gary Stutte, as the company's director of research and development.

CELSS scientists experimented with basic technology like LED grow lights, hydroponic and aeroponic growing techniques, and "aquaponics" that would incorporate fish into the system. They also worked out fine details, identifying the best indoor crops and the ideal growing conditions for each and combining them to maximize growth and nutritional value while using minimal energy and recycling resources.

The payoff was substantial, Stutte said. "We were producing yields that far exceeded what was considered feasible."

CELSS also featured automated, user-friendly systems intended for busy astronauts. This emphasis on ease of use and precise "recipes" of lighting, temperature, and nutrients for various crops is central to Eden Grow Systems' approach.

"The biggest secret in the sauce is specific grow profiles for specific plants, which are controlled through our app," said Womack.

The company's ultimate goal, the Genesis System, will be an enclosed habitat that runs on energy from wind, sunlight, and biogas and can indefinitely support a family of four. First, though, the company is marketing parts of the system as they mature. Grow boxes for hobbyists are in the works. And Eden's first products, six-foot towers that can grow various crops and breed fish or shrimp, started shipping in fall of 2021.



Bart Womack, founder and CEO of Eden Grow Systems, trims a plant in one of the company's grow towers. *Credit: Eden Grow Systems Inc.*

The company hopes to start shipping Genesis System habitats at the end of 2022. The U.S. Air Force has expressed interest in uses at military bases. Womack noted that the habitats would be useful at remote outposts or for disaster or famine response, not to mention space applications (he hopes NASA will one day be a customer).

"I see us not as a next-generation farming company but as a life-support company," Womack said. "My vision is that every home on Earth has a life-support system." ●

# Learning to Code with NASA Data



During the Apollo program, hundreds of samples were taken of the lunar surface. Today these rocks are an educational tool, not only to learn about the Moon, but also as a dataset in teaching programming to students. *Credit: NASA*



In this screenshot of Microsoft Learn, an overview of the "Plan a Moon mission by using Python pandas" module references how students will use NASA data to learn how to categorize Moon samples. *Credit: Microsoft Corp.*

## Microsoft uses info and expertise from NASA to build STEM education lessons

Ever since the Apollo program landed on the Moon in the 1960s, NASA has been one of the eminent inspirations for future scientists, and one field of science has seen tremendous growth since then: computer science. This specialty has become one of the most in-demand career fields in the United States, with the Bureau of Labor Statistics projecting another 15% growth in jobs by the year 2029. With help from NASA, one tech company was able to use NASA data to keep inspiring future computer scientists.

Microsoft Corp. of Redmond, Washington, is one of the largest technology companies in the world. Its software is installed on more than 1.5 billion devices, but those devices don't mean anything if no one knows how they work. The Microsoft Learn website began in 2018 as an internet database dedicated to providing documentation for its products and administering the many professional certifications Microsoft provides. In 2020, the company launched an initiative to teach skills needed for these "jobs of tomorrow."

When the company began searching for ways to make inroads with students who were exploring their future career options, the company wanted a way to get them excited about interesting real-world applications of computer science, such as space exploration. This search brought them to NASA.

"Our goal was to cultivate learning by connecting content to something interesting, relevant, and most importantly, inspiring for learners of all ages – whether they are 8, 18, or 80," said Margaret Price, principal strategist at Microsoft. "The topic of space continues to be interesting and inspiring for many early and lifelong learners."

Microsoft reached out to NASA to request help in teaching computer coding by leveraging students' interest in the space program. Under a Space Act Agreement, the Office of Science, Technology, Engineering, and Math (STEM) Engagement at NASA Headquarters in Washington, D.C., provided imagery of items like Moon rocks, as well as sets of data analogous to those used by NASA scientists, such as measurements of mass and size of lunar samples.

"We all agreed we wanted to teach skills related to data science," said Rob LaSalvia, partnership manager in NASA's Office of STEM Engagement. "And we talked about high-profile missions that might connect with the public, such as Artemis."

The new Microsoft Learn modules are based around the Python programming language, with names like "Plan a Moon mission by using Python pandas." Price said the reason they chose Python is because not only is it one of the easiest computer languages to learn, but it's also in wide use among researchers to write programs ranging from data science to artificial intelligence tasks.

"We hope that students use this as a springboard for deeper engagement, both with NASA and with aerospace-related content," LaSalvia said. "We think this project serves as a fantastic introduction to the amazing work that happens in the agency, and we hope students extend that opportunity." ●



Microsoft produces many educational tools for students of all ages. The Learn website lessons include several NASA-inspired courses. *Credit: Microsoft Corp.*



# The Science of the Perfect Cup for Coffee



A phase-change heat exchanger like this one uses a phase-change material (PCM) to help maintain a comfortable temperature in the Orion spacecraft. NASA-funded research into spacesuit material alternatives helped ThermAvant International develop the Burnout thermal mug for coffee. Credit: NASA

## Phase-change material research is behind the design of a temperature-regulating mug

What does the blue freezer pack you throw into your cooler have in common with an astronaut spacesuit? Thermodynamics and phase-change materials (PCM). Just as astronauts need to stay cool when exposed to intense sunlight on a spacewalk, hot drinks need some help staying hot. One of the scientists crunching the PCM data for a NASA-funded research study at the University of Missouri, Dr. Hongbin Ma, kept forgetting about his coffee and was tired of drinking it cold. So his team used the same PCM research to build a mug with better thermal properties – the Burnout Mug – said Ma, CEO of ThermaVant Technologies LLC in Columbia, Missouri.

When space shuttle astronauts worked in space for long hours, their suits weren't able to maintain a consistent, comfortable temperature. The physics of thermodynamics – energy transfer and the effect it has on the physical properties of substances – gets tricky in the extreme temperatures of space. Because of that, a special heating and cooling system is required.

To test designs before fabricating a new suit, technologists use computer simulation. Choosing the right temperature formulas for that virtual test environment was one part of the research. Ma also tested and recommended a PCM that could be used in the suit-cooling system, a modified version of those used in spacecraft.

A thermal control system ensures the cabin environment and machinery of a spacecraft are maintained at the best temperatures, according to Scott Hansen, thermal engineer at NASA's Johnson Space Center in Houston. By including a PCM in that system, it's possible to store excess heat and release it later when extreme cold temperatures can freeze the same technology.

The Apollo lunar rover, space station, Orion capsule, and headlights on the newest spacesuit design all included a PCM.

"Phase-change material heat exchangers are perfectly suited for maintaining a habitable environment. A component temperatures in low lunar orbit. If we didn't include this kind of system in Orion, the crew would get too hot and then too cold," said Hansen.

Some materials can change from liquid to solid and back again, but they need to be safe while maintaining a designated temperature range. Water expands when it freezes and could cause life-threatening rupture in space. Paraffin wax and refrigerants are effective but are toxic to humans, making a leak hazardous. The researchers ultimately recommended a bio-based option for spacesuits.

Michael Merwin, operations director for ThermaVant, said bio-based waxes proved to be the perfect solution for maintaining optimal temperature for coffee as well as astronauts. In this case it was a beeswax-like soy substance.

Released in 2018, the Burnout Mug uses a vacuum seal for insulation with the wax, called HeatZorb, sealed between the inner and outer shells. The wax is formulated to maintain the ideal temperature for a hot drink (coffee or tea) over time. As soon as hot liquid goes in, the wax quickly absorbs excess heat and melts, resulting in a drinkable temperature in just a few moments. As the coffee starts to cool, that stored heat is released back into it.

The company is developing other products that can use the same technology to meet unique needs in the medical field. Two in development are a small insulin container and a donor organ transportation box – both of which require a perfect temperature. ●



Research into PCM options for NASA helped one of the researchers find the best material to use in a mug that maintains the ideal temperature of a hot beverage for hours. ThermaVant International now offers mugs and tumblers. Credit: ThermaVant International LLC

# Flying (Not Quite) Blind



The NASA Quiet SuperSonic Technology Low-Boom Flight Demonstrator, also called the X-59, is designed to prove it's possible to take the loud boom out of supersonic flight. The aircraft design changes the structure of the sound wave, making it more like a thump. This is one step toward removing the overland flight ban for planes traveling faster than the speed of sound. Credit: Lockheed Martin Corporation

## Ultra-high-definition video switcher for supersonic X-plane takes off in commercial aviation

Most pilots would be concerned if their plane didn't have a front window. But Jim Less, NASA test pilot, is looking forward to flying the X-59 Quiet SuperSonic Technology experimental plane. A new External Vision System (XVS) replaces the pilot's direct line of sight, and it can sometimes help pilots spot other aircraft faster than they could through a regular windshield, according to Less.

Two cameras, image-processing software, and a computing system with two processors bring together new and existing technologies to support an augmented reality display that "is going to be almost like looking out the windows," said Less.

The goal of the X-59 is to lower the sound of the sonic boom associated with traveling faster than the speed of sound. If successful, the test flights could lead to the resumption of overland supersonic flight.

The sleek design of the aircraft includes a 38-foot nose that will help diminish the volume of the sonic boom to a thump. But it also means the pilot will sit closer to the middle of the plane without a front-facing windshield.

A critical piece of the innovative technology needed to enable an ultra-high-definition display was developed by Van Nuys, California-based Eon Instrumentation Inc. The DP-25 high-speed DisplayPort switcher delivers the video streams from the processor – linked to both the takeoff and landing and in-flight cameras – to a 4K monitor that has about four times the resolution of traditional high definition.

As part of the XVS pallet, or "brain," that routes the video, NASA specifications required the video switcher to communicate seamlessly with all system components, according to Kemper Kibler, NASA's XVS lead hardware engineer. The agency wanted to eliminate any lag time or disruption to maintain the pilot's visibility, so switching channels could not cause a visible interruption, keeping the display as close to real time as possible.

"We needed the DP-25 to accept video from both XVS computers and route the active video to the monitor," Kibler explained. The minimum requirement for the switch time was 16 milliseconds, but such hardware didn't exist until Eon Instrumentation agreed to take on the challenge.

A longtime agency contractor, Eon was selected to create the part by NASA's Langley Research Center in Hampton, Virginia. Although the agency would only purchase a few units, Jeff Norsen, president of Eon Instrumentation, saw the commercial potential. Even when NASA added a new requirement – to simultaneously send the video to real-time flight recorders for later review – the company was willing to invest its own internal funds to make it work.

In addition to switching between the two feeds in five milliseconds – the speed of a single honeybee wing flap – the device supports multiple recording technologies.

The company now includes the new high-speed DP-25 switcher and two other models built on the same technology, the VMS-22 and VMS-24 switchers, in its inventory. And commercial aviation companies are adding them to their aircraft.

An international helicopter manufacturer is using the switcher to add a 4K video display to a number of its models, making it easier for pilots to see other aircraft in their airspace.

"Eon appreciates working with NASA in order to pioneer breaking-edge technologies made for rugged applications, and we're willing to push boundaries in the avionics and aerospace industries, just as NASA does," said Norsen. ●



With no forward-facing windows, the pilot will rely on a digital display like the one in this rendering of the X-59 cockpit. A custom external vision system includes two cameras that will act as the pilot's eyes. To meet NASA's specifications, the company Eon Instrumentation had to create a DisplayPort switcher/converter capable of instantaneously switching between ultra-high-definition video feeds. With an overlay of important flight information, the pilot will have all the essential information on one display. Credit: Lockheed Martin Corporation



# Cryofuels Come Under Pressure



Landing on a lunar surface is risky, but making the craft as light as possible helps. The mid-sized lander concept in this illustration, which would deliver a rover to the polar regions of the Moon, could benefit from a lightweight carbon composite tank developed by Gloyer-Taylor Laboratories. *Credit: NASA*

## A carbon composite tank developed for NASA enables the move from fossil fuels to cryofuels

Replacing jet fuel with hydrogen would be good for business and the environment. Hydrogen generates no carbon emissions and packs three times the energy per pound of hydrocarbon fuel, but there are some problems. One of the biggest is that current airplane fuel tanks can't safely hold hydrogen. A solution is the carbon-fiber Blended Hybrid Laminate (BHL) cryotank developed by Gloyer-Taylor Laboratories (GTL) Inc. of Tullahoma, Tennessee.

While NASA is testing it to carry liquid oxygen into space, a commercial airline is interested in the fact that the BHL can hold ultra-cold fuels without developing the microcracks that shorten the lifespan of other carbon composite tanks. Hydrogen has one of the lowest boiling points of any element, meaning its liquid form must be kept extremely cold, or it needs to be kept under remarkably high pressure.

That requires a strong tank, usually made of steel or aluminum. Paul Gloyer, president of GTL, said breakthroughs in the use of carbon fiber and resin to wrap tanks have made them lighter than equivalent metal tanks. He wanted them to be even lighter.

A proprietary combination of materials and a manufacturing process developed by the company has produced a new type of carbon composite tank with walls thinner than a business card. Gloyer describes the BHL cryotank as a "stiff balloon." It can withstand repeated cycles of pressurization and thermal changes that occur as the tank is filled and emptied without developing the microcracks that result in dangerous leaks in other carbon tanks. The flexible nature of the material and thin construction mean the tank can hold more fuel per pound of tank mass.

A measurement of the force that leads tanks to crack is called microstrain. Conventional carbon-fiber cryotanks without liners tend to leak at about 3,000-5,000 microstrain. Testing has shown that the BHL tank can withstand more than 20,000 microstrain at cryogenic temperatures, said Gloyer.

Partly funded by multiple Small Business Innovation Research contracts from several NASA field centers including Marshall Space Flight Center in Huntsville, Alabama, the BHL is undergoing assessment for commercial space applications at the center. The BHL technology has the potential to reduce tank mass by 30% to 50% for small spacecraft propulsion systems, according to John Peugeot, a propulsion engineer at Marshall.

One space company is evaluating the new lightweight, high-capacity tank for its commercial lunar lander, according to Gloyer. A significant benefit of using the smaller, lighter tank will be the craft's capacity to carry more technology and science payloads.

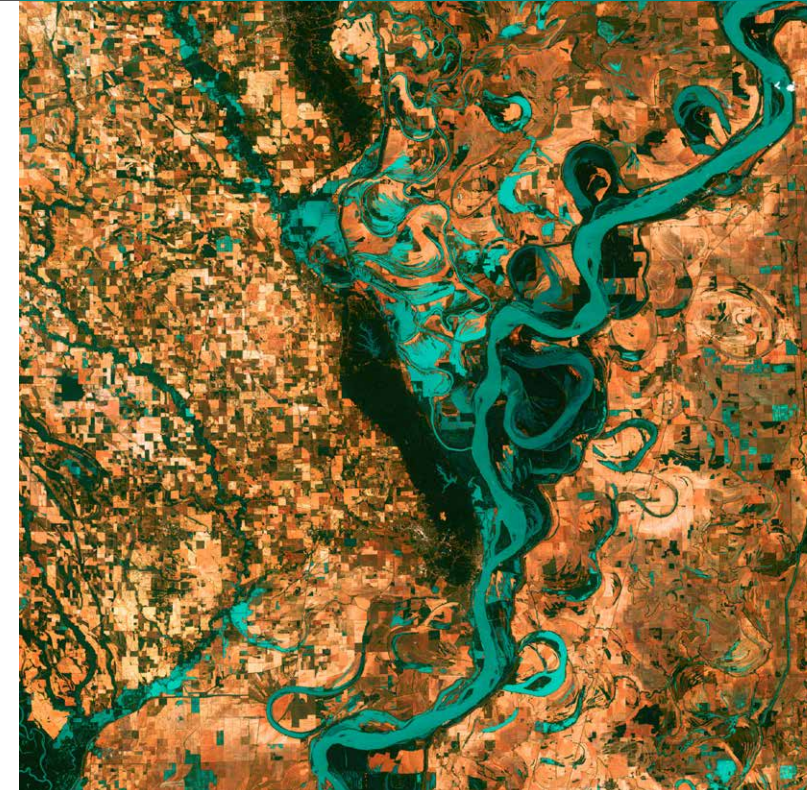
Meanwhile, several aircraft developers are combining the tank with hydrogen fuel cells and an electric engine to provide cleaner, cheaper long-distance air travel. Current cryotanks that fit on a plane are so heavy they can only carry 5% to 6% hydrogen by mass, supporting only short flights, according to GTL. The BHL cryotank, including insulation, can hold 60% to 70% hydrogen by mass.

This extra hydrogen would let a plane fly four times as far as a conventional jet fuel-powered aircraft, cutting operating costs in half and creating a strong economic incentive to switch to hydrogen fuel. Gloyer said the alignment of economic and environmental benefits could result in the rapid adoption of hydrogen fuel, reducing carbon emissions and enhancing prosperity. ●



This unique carbon composite tank developed by Gloyer-Taylor Laboratories with NASA support is lightweight, making it ideal for aviation. And it's designed to hold cryogenic fuels under extreme pressure, so it can be used to hold hydrogen and replace fossil fuels, eliminating greenhouse gas emissions. *Credit: Gloyer-Taylor Laboratories Inc.*

# CubeSats Take a Bus into Space



Trestles CubeSat technology developed by Tyvak Nano-Satellite Systems is used by commercial companies for collecting weather data, Earth imaging, and more. These less-expensive satellites mean businesses and academic institutions no longer need to rely on NASA for pictures of Earth such as this view of the Mississippi River, tributaries, and lakes south of Memphis, Tennessee. *Credit: NASA*

## NASA resources helped develop CubeSat infrastructure that anyone can use

This bus doesn't use wheels to move around, but a CubeSat can't get anywhere without it. In the world of these small, standardized, inexpensive satellites, a "bus" refers to the hardware foundation that provides it with power, communications, thermal stability, and other "services" a payload needs to function. NASA supports the development of this and other technology needed by the agency and the private sector to facilitate activity in low-Earth orbit. Whether enabling data transfer for internet-enabled appliances such as thermostats and refrigerators or tracking weather conditions, CubeSats continue to mature and support everyday services.

These technological wonders are also capable of hosting scientific payloads. What makes CubeSats attractive is that they're small enough to "piggyback on other missions at a reasonable cost," according to Luis Santos, chief engineer with the Small Satellite Project Office at NASA's Goddard Space Flight Center in Greenbelt, Maryland. "Over the years, we've been trying to mature technologies to make CubeSats more capable, so people can do more with them."

Irvine, California-based Tyvak Nano-Satellite Systems Inc., a Terran Orbital corporation, was developing technology called Micro-Avionics Multi-Purpose Platform (MicroAMPP) that could perform various tasks supporting CubeSat functionality. During its development, the company needed to run a flight test for its use in satellites and other vehicles and turned to NASA's Tipping Point funding. In 2016, Tipping Point, which supports technologies that grow commercial space capabilities and benefit future agency missions, funded terrestrial rocket test flights of the technology with the agency's Flight Opportunities program.

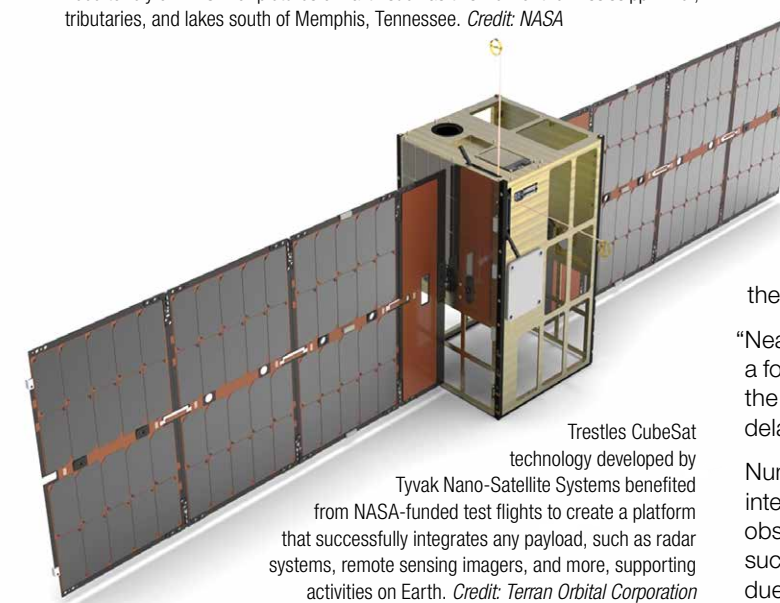
Even though MicroAMPP was never commercialized, the lessons learned included improving the integration of circuit boards and connecting redundant and diverse external sensors. This approach was incorporated into the design and development of Tyvak's Trestles bus systems for CubeSats, according to Marc Bell, CEO of Terran Orbital. Anyone can purchase a Trestles bus and add payloads such as a camera for Earth imaging. The company also offers services to build the satellite, launch it, and manage mission operations.

In the early days of CubeSats, different companies specialized in developing various modular components. The idea was that a bus could be built to integrate with anything developed by another company. But the technology is complicated, so the hardware didn't always work together, and the software necessary to operate a customized system was difficult to write. So companies are adopting a vertical approach, providing full-service hardware, software, and even mission resources.

This kind of all-inclusive support is an evolution that is of interest to NASA for its improvements to cost, schedule, and quality while the mission team can focus more on the payload development, according to Santos.

"Nearly all Tyvak modules are manufactured in-house. This integration methodology acts as a form of risk reduction," said Bell. The approach saves customers time and money, reduces the amount of documentation required to hitch a ride on a rocket, and mitigates potential delays in the supply chain that can disrupt a scheduled launch.

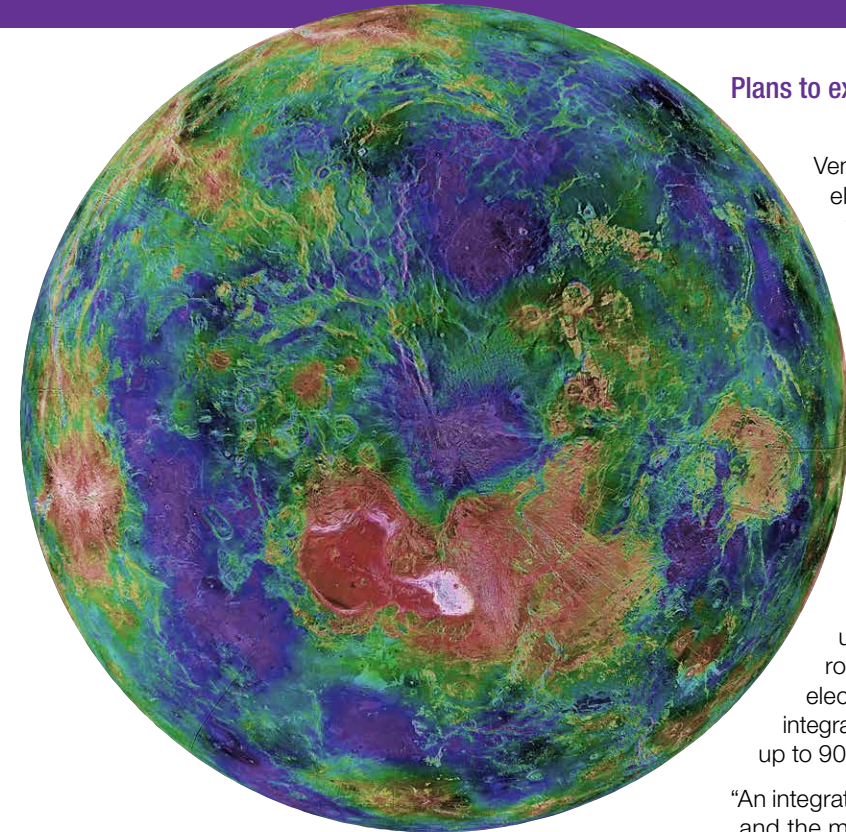
Numerous companies and government organizations use the Trestles technology – now an integral part of the company's offering – for applications like communications activities, Earth observation, and more. Their customers can count on the successful integration of hardware such as radar systems, remote sensing imagers, telescopes, and technology demonstrations due in part to NASA's support of the bus' development, according to Bell. ●



Trestles CubeSat technology developed by Tyvak Nano-Satellite Systems benefited from NASA-funded test flights to create a platform that successfully integrates any payload, such as radar systems, remote sensing imagers, and more, supporting activities on Earth. *Credit: Terran Orbital Corporation*



# Earth's Twin Helps with Extreme Electronics



This composite view of Venus shows the surface of the planet, where temperatures are around 900°F. If future NASA missions to land a craft on the planet are to succeed, electronics must survive the heat. Ozark Integrated Circuits is making some of that technology available on Earth. *Credit: NASA*



Utilizing NASA expertise, SBIR funding, and 3D printing, Ozark Integrated Circuits created a single-board computer module that withstands extreme heat and doesn't require a bulky cooling system. This makes it possible to embed sensors and electronics in geothermal drilling equipment, jet engines, and other Earth applications. *Credit: Ozark Integrated Circuits Inc.*

## Plans to explore Venus give rise to new computer chips for high-heat conditions on Earth

Venus and Earth, often called twins for their comparable size and density, have something else in common – extreme heat. Exploring our closest planetary neighbor will require technology for a corrosive, high-pressure atmosphere and surface temperatures around 900°F. Geothermal engineers tapping heat deep within the earth as a renewable energy source encounter similarly punishing temperatures. Both need compact, rugged electronics to power sensors and collect data without a bulky cooling system. All-in-one, single-board electronics modules that benefited from NASA expertise now offer that capability on this planet.

To support missions to the surface of Venus and elsewhere, NASA's Glenn Research Center in Cleveland is developing extreme-temperature integrated circuit technology. Ozark Integrated Circuits Inc. (Ozark IC) of Fayetteville, Arkansas, has built on this work with the help of several NASA Small Business Innovation Research (SBIR) contracts, about half of which came from Glenn. The work helped Ozark IC create a new product line including durable electronic packaging systems.

On a spacecraft or planetary lander, environmental controls to cool electronics take up space and add mass. By removing that cooling requirement, engineers can free up room for more scientific payloads and use less energy. As an alternative to conventional electronics made from silicon, which can only function below about 400°F, Glenn makes integrated circuits with silicon carbide, a semiconductor material that functions in temperatures up to 900°F.

"An integrated and reliable chain of technologies, from the semiconductor to the integrated circuit and the multi-chip board and its physical and electrical connections, is essential," said Philip Neudeck, researcher at Glenn. The work with NASA to achieve this contributed to Ozark IC's understanding of how to better employ high-temperature semiconductor technology and 3D printing techniques to fabricate sensors and create durable packaging for other electronics.

The company recognized an opportunity to support multiple industries on Earth. Here, applications for high-temperature integrated circuits include monitoring and optimizing jet engine performance, underground exploration for drilling well sites, and molten salt nuclear reactors, to name a few. Other electronics in these environments haven't fared well.

Ozark IC collaborated with Glenn to develop the company's eXtreme Nodes – or XNodes – compact, lightweight, rugged electronics that can be used off the shelf or customized for specific needs. Each has one or more integrated functions for extreme environments.

"We can put digital electronics where we haven't been able to before," said Ian Getreu, business development director for Ozark IC. "A piece of equipment that had one sensor can now have 10." Where others would have to put an analog sensor in a hot engine, for example, and connect it to digital electronics away from the heat, an XNode can feed data directly from an extreme environment to computer controls that automatically adjust settings to improve performance.

Founded in 2011 as a one-person company, Ozark IC now employs over 20 people and is developing a new product line based on technology licensed from the agency to introduce even higher-temperature electronics for the commercial sector.

"A lot of the NASA work has been done for Venus," said Getreu, "and we've learned things we can apply to current commercial offerings. Using 3D printing, we can apply things we learned to different materials." ●

# Suspended Solar Panels See the Light



The Skysun Solar Pollinator is designed to be suspended above plants that thrive in partial shade, and it can generate up to two kilowatts of power. The suspended design was validated by Glenn Research Center dynamicists under the Adopt-A-City program. *Credit: Skysun LLC*



NASA developed a spreadsheet program that proved the Skysun suspended solar design would not be susceptible to destructive oscillations at any scale. A larger installation, the solar pergola (artist's rendering pictured) further advances the design by suspending panels above a patio. *Credit: Skysun LLC*



The Ivanpah Solar Electric Generating System is an example of a concentrated solar power plant, which works by having hundreds of reflective panels heating up a central tower. The problem of keeping sunlight directed at the receiver throughout the day brought Jim Clair to request NASA's help in validating the suspended design now used in Skysun solar power systems. *Credit: Cliff Ho/U.S. Department of Energy*

## NASA engineering validated pleasing, practical design

Imagine a bridge twisting and rolling as it's battered by high winds before eventually collapsing into the river below. This happened in 1940, when the Tacoma Narrows Bridge in Washington state shook itself apart on a windy November day. This collapse resulted in huge changes to engineers' approach to suspension cable-based designs – not only in large projects like bridges but in smaller cases as well.

In 2012, Jim Clair was considering investing in renewable energy and came across concentrating solar power. Unlike photovoltaic panels, which make electricity with semiconductors, concentrators work by reflecting large amounts of sunlight onto a small receiver, heating it up immensely. This heat then generates electricity via a steam turbine. To explore this technology, Clair founded Skysun LLC of Cleveland. Because the Sun changes position throughout the day, moving the mirrors to direct the most light at the receiver is vital. Clair thought a suspended cable design would make moving the mirrors easier, but he recalled the warping bridge.

"Every engineer wants to avoid a Tacoma Narrows," Clair said. "Anytime an engineer or physicist sees a tensile-based suspension structure, the first thing they think is, 'We need to make sure this is not going to set up a destructive oscillation.'"

Because his primary education was in economics, not engineering, Clair needed help to determine whether his idea would be safe under high winds. This brought him to the Adopt-A-City program, a collaboration between NASA's Glenn Research Center in Cleveland, the government of Cuyahoga County, and MAGNET, a local business-development nonprofit. Over several years, the program helped companies across Northeast Ohio improve their technologies with NASA expertise.

Paul Bartolotta, a project manager now retired from NASA, oversaw selecting the companies and matching their problems with NASA experts. After seeing how multidisciplinary Clair's project was, he chose Skysun as part of the 2016 Adopt-A-City class.

Trevor Jones, a dynamicist at Glenn, went to Lorain Community College to work with a prototype of the system Clair had set up there. Jones induced vibrations in the cables with hammers and took measurements of the resulting oscillations. Based on all this data, Jones designed a spreadsheet that could accurately model the tensile strength of the design against wind-induced oscillations at any scale. With the dimensions plugged in, the spreadsheet program did the math and proved that Clair's idea would work without shaking apart.

While the company is still pursuing concentration-based solar power, Skysun currently makes installations that use standard photovoltaic panels that can be hung over an area as easily as a hammock. The initial product, Solar Pollinator, is designed to be suspended over plants that thrive in partial shade. Like a concentrator, the panels can track the Sun to maximize exposure.

Skysun has installed multiple Solar Pollinators around the Cleveland area and is preparing to set up its first, larger Solar Pergola system. The pergola generates up to three to five kilowatts of power in places where more permanent solar installations can't be placed, such as rented homes or leased business space. Clair credits NASA's help as instrumental to the designs of both these products.

"We could've just given him the answer, but instead we gave him a spreadsheet program that works on all his installations," Bartolotta said. "He kept plugging along, and I'm proud of him." ●



# Space Program Pumps Up Turbomachinery



A Fastrac engine undergoes testing at Marshall Space Flight Center. The turbopump used in this design was manufactured by Barber-Nichols, which went on to produce similar designs for companies such as SpaceX. Credit: NASA

This turbopump, intended for the SpaceX Merlin engine, is one of many designs manufactured by Barber-Nichols. The company credits work it did on NASA's Fastrac program with enabling better and cheaper methods of building these machines. Credit: Barber-Nichols Inc.



These turbopumps are used in the NewtonThree engine from the first stage of Virgin Orbit's LauncherOne rocket. Produced by Barber-Nichols and similar in design and principle to pumps originally made for NASA, the pumps move liquid fuel into a rocket engine that ignites after being dropped from an airplane. Credit: Virgin Orbit

## NASA helped make turbopump advances still used in aerospace and energy

The turbocharger is well known to car aficionados, but a similar technology is also important to rocket scientists.

To launch satellites and astronauts into space, large rockets rely on liquid-fueled engines. Pumping propellants into these engines requires a lot of power, so this task is typically accomplished by turbopumps – high-speed pumps powered by turbines. Turbopumps are similar in principle and design to the turbocharger, except turbopumps are more complex and can have 20 times more power density than the turbochargers found in a car. But both are examples of turbomachinery, rotating machines that transfer energy into a fluid or vice versa.

In the 1990s, NASA recognized a need to improve costs and reduce development times for a new generation of spaceplanes that could take off from a larger aircraft, launch into suborbital space, and glide safely to the ground. Through the X-34 program, the agency planned to develop a vehicle that would demonstrate these capabilities. To do so, it needed a new engine that could thrust the vehicle to great speeds incredibly quickly, and this required a brand-new turbopump.

NASA's Marshall Space Flight Center in Huntsville, Alabama, contracted with Summa Technology to build the engine, dubbed Fastrac. Barber-Nichols Inc. of Arvada, Colorado, was subcontracted to build the engine's turbopump. Barber-Nichols was no stranger to working with the space agency, but to make this particular pump, the company had to turn to a cutting-edge process.

"It's really hard to machine supersonic turbine blades," said Matt Marsh, Marshall Engine Components Development and Technology Branch chief. "It can be done with milling, but you've got to be really good at it if you're doing something really small and precise."

Instead of milling, Barber-Nichols manufactured the Fastrac turbopump using a process called electrochemical machining, in which material is successively stripped away using high-current electricity passed through an electrolyte. While this was not a new process, applying it to the highly detailed work of building Fastrac's turbopump turbines out of nickel superalloys made the job quicker and much cheaper than other methods while providing the precision and quality required for this turbopump.

Although the X-34 program never got off the ground, Barber-Nichols still produces turbopumps for rocket applications, and the company credits the work on Fastrac with helping to refine the electrochemical machining process.

"What we learned enabled us to have the expertise to design rocket engine turbopumps," said Greg Forsha, senior staff engineer for Barber-Nichols. "One success has led to the next."

Barber-Nichols' turbopumps are found in rockets Virgin Orbit uses to fill a similar role to the X-34 plane the original Fastrac engine was intended for – launching to space from an airplane. Other companies have used these pumps as well, such as SpaceX's Merlin engine, used to launch private satellites into orbit. The work has found uses outside of aerospace as well, supporting exhaust heat energy recovery systems used in cars as well as geothermal power plants. Barber-Nichols' new products are more than just machines, incorporating advances in electronic control systems.

"In the '90s, we just did the mechanical side of things, now we cover all kinds of electronics," said Forsha. "We're a one-stop shop for that entire system." ●

# New Solar Array Design Saves Space



Northrop Grumman's first major customer for its new, NASA-based Compact Telescoping Array (CTA) solar panel design is Airbus, which is using the panels on its new OneSat communication satellites, shown in this artist's rendering. Credit: Airbus Defence and Space Ltd.

## NASA's Compact Telescoping Array will conserve commercial satellite launch costs

Sending astronauts almost 240,000 miles to the Moon was the technical challenge of the day half a century ago. Carrying the cargo necessary to send astronauts 40 million miles to Mars will be no less daunting in the next decades. Total reliance on traditional combustion-based engines would require too much fuel, so NASA is considering scaling up a newer technology, called solar electric propulsion. But this will require massive solar panels.

To address that challenge, several years ago, a team at NASA's Langley Research Center in Hampton, Virginia, started imagining new ways to stow and deploy large, flexible solar arrays.

"If you're really serious about hauling tens of tons of cargo to Mars, you can't do it efficiently with traditional chemical thrusters," said Richard Pappa, who managed the project at Langley. While using solar-powered electric thrusters would dramatically reduce the amount of fuel the craft would have to carry, the amount of space the stowed arrays would occupy in the rocket during launch could be prohibitive.

The team started with the design for the International Space Station's solar arrays. These are supported along a central boom, and the solar blankets fold into a compact bundle. But the boom, made of a foldable lattice structure, is contained in a large, heavy canister, and the solar blankets also require a bulky housing. Instead, the Langley team proposed a central mast that would "telescope," extending by means of a smaller, screw-like mechanism and eliminating the need for a canister.

The packaging efficiency of the resulting design, known as the Compact Telescoping Array (CTA), reduces the volume of a stowed solar array by about a third.

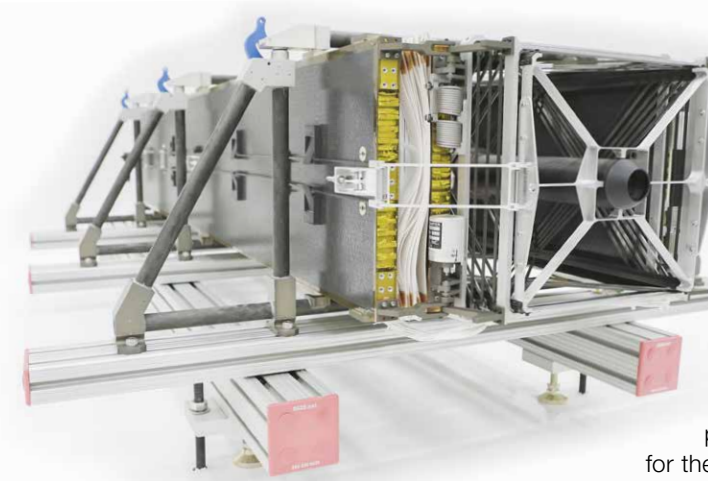
In 2015, the design captured the attention of Orbital ATK Inc., now part of Northrop Grumman Corporation. Langley issued two Small Business Innovation Research (SBIR) contracts to the company Angstrom Designs, with Orbital ATK as the subcontractor, to build and test experimental units, while the Air Force supplied additional SBIR funding.

By 2021, Northrop Grumman found its first CTA customer, with Airbus Defence and Space ordering enough arrays to power its new OneSat communication satellites.

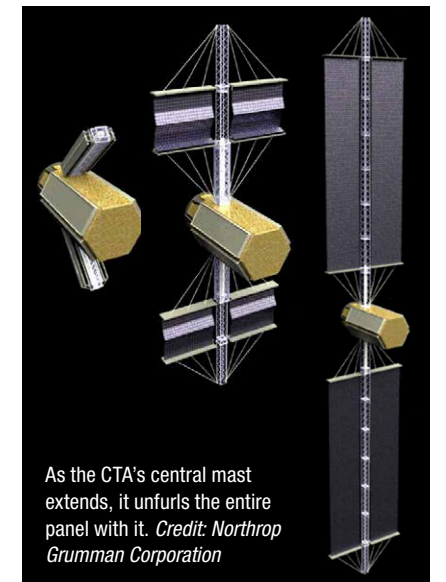
Several of the world's largest satellite communications companies have already commissioned OneSat satellites, including Britain's Inmarsat, Australia's Optus, Japan's JSAT, and the multinational Intelsat.

For all these clients, the compact packaging will save on launch costs by allowing more satellites to be launched at once. "While most launches carry just one or two satellites, the CTA smartly tucks into the satellite bus design, so three satellites can fit on one rocket," said Alan Jones, flexible solar array product director at Northrop Grumman.

Jim Spink, program manager at the Northrop Grumman facility in Goleta, California, where the arrays are produced, said he and Jones saw increasing potential for the CTA as the design progressed. "Now it's become a major product," he said. "That push from NASA and the SBIR funding sparked this innovative class of solar array, which will enable higher-performance spacecraft designs. We're excited to see where it goes next." ●



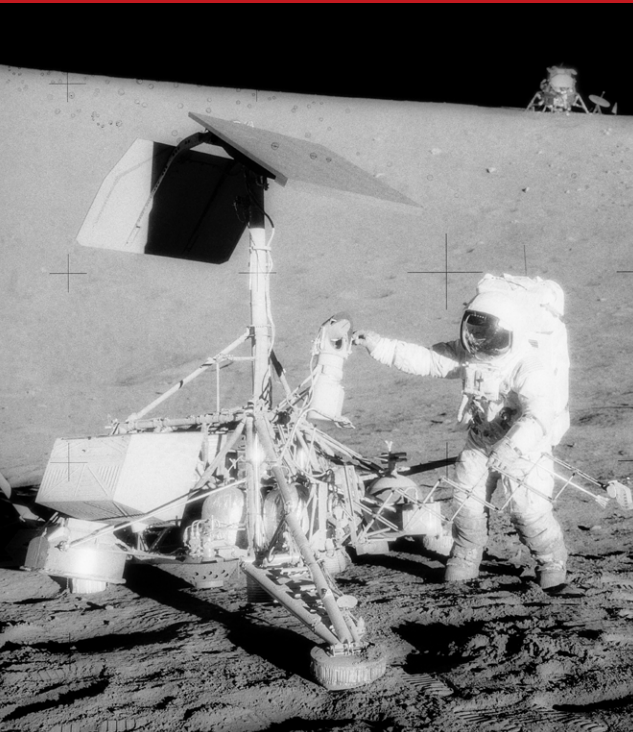
When Northrop Grumman's final version of the CTA is collapsed, the solar blankets and central mast are tightly packed into the smallest possible package. Credit: Northrop Grumman Corporation



As the CTA's central mast extends, it unfurls the entire panel with it. Credit: Northrop Grumman Corporation



# Traveling-Wave Tubes Travel Far



Apollo 12 astronaut Charles Conrad examines the television camera on the Surveyor 3 lunar probe. To have reliable transmissions during the Surveyor program, Hughes Corporation worked to miniaturize traveling-wave tubes, which are used to boost the power of radio signals. *Credit: NASA*



An engineer works on a Voyager spacecraft's high-gain antenna dish. A component necessary to transmitting data on the Voyager 2 spacecraft, the traveling-wave tube, is still functioning over 45 years later. *Credit: NASA*

## Electronic components designed for NASA see use in satellite systems and ground applications

Forty-five years ago, the Voyager 2 spacecraft launched on a mission to visit the outer planets. One vital component of the craft that still works is the key to getting data as it leaves the solar system. But this piece of the now-interstellar spacecraft, the traveling-wave tube (TWT), has also become a necessary component for utilizing microwaves in several applications back on Earth. For example, satellite radio spacecraft use the amplification power of TWTs, and thanks to NASA's help, listeners have coverage over all North America and receive better-sounding audio.

Wherever you see a specialized microwave radio transmitter, there's usually a traveling-wave tube somewhere within. Like the cathode-ray tube in an old television, the traveling-wave tube works due to the movement of electrons in a vacuum tube. A stream of electrons is fired from one end of the tube, which causes movement back and forth between electrodes on either side of the tube. A spiral of wire wraps around the path of the beam, and a radio signal is passed through it. The movement of electrons synchronizes with the radio frequency, boosting the signal. All-in-one traveling-wave tube units that include a power source gain the additional moniker of "amplifier."

In the early 1960s, Hughes Space and Communications Group received contracts from NASA's Jet Propulsion Laboratory in Southern California to build spacecraft for NASA's Surveyor program, which successfully landed five robotic Moon missions before astronauts arrived during Apollo. To maintain communications 238,000 miles from Earth, these landers' transmitters needed massive amounts of amplification, with the additional constraint of having to fit on a small spacecraft. When Surveyor 1 landed on June 2, 1966, it was able to send signals carrying television images of the Moon's surface back to Earth, paving the way for astronauts to land there a few years later.

Throughout the 1970s and 1980s, Hughes supplied the traveling-wave tubes for every deep space mission, working to the exacting standards that NASA set, including the two Voyager spacecraft. Thanks to NASA's need for better ways to transmit data, modern traveling-wave tubes are smaller and able to amplify signals in a wider range of frequencies, such as the Ka band that space telescopes use to send back imagery of distant stars and galaxies.



NASA electronics engineers Dale Force and Rainee Simons with an L3 (now Stellant) traveling-wave tube amplifier (TWT). Today, Stellant is the only company making space-rated TWTAs and has several private sector customers in addition to NASA. *Credit: NASA*

"If it wasn't for NASA, the technology wouldn't be anywhere near how advanced it is today," said Nick Gritti, executive vice president of strategy and business development at Stellant Systems of Torrance, California, a successor company to Hughes.

Today, Stellant Systems is the only company in the United States that makes space-rated traveling-wave tube amplifiers. In late 2021, Stellant sold traveling-wave tubes to SiriusXM for its next generation of satellite radio spacecraft. And machines that provide LASIK eye surgery use these tubes to ensure their beams are properly amplified.

In 2020, the traveling-wave tube amplifier was added to the Space Foundation's Space Technology Hall of Fame. And as of 2022, the TWT on Voyager 2 is still plugging away, transmitting data as it continues to make the journey through interstellar space. ●

# Private Lessons for Private Spaceflight



A SpaceX Dragon capsule carrying four private astronauts booked through Axiom Space docked to the International Space Station in April 2022. To ensure these astronauts would be able to work in zero gravity and be prepared for any eventuality on the space station, Axiom used NASA facilities and know-how to train them. *Credit: NASA*

## NASA facilities, practices, and experience used to train private astronauts

In April 2022, a crew entirely made up of private astronauts journeyed to the International Space Station aboard a SpaceX Dragon capsule. While this was a landmark occasion in the history of both the space station and human spaceflight, the training procedures that allowed these individuals to visit the orbiting lab were developed over decades of experience in historic facilities.

Axiom Space Inc., based in Houston, was founded in 2016 with the goal of furthering private human spaceflight and ultimately establishing a privately operated permanent human presence in space. Shortly after the company's founding, it entered into an agreement with SpaceX to provide launch services for visiting the space station. Axiom's first mission, known as Axiom Mission 1 (Ax-1), launched from Cape Canaveral carrying a crew of four individuals, representing four countries and two different levels of training.

"We have two different classifications: private astronauts and professional astronauts," said Matt Ondler, chief technology officer and director of engineering for Axiom. "Private astronauts are either from countries that don't participate in the space station or they might be from companies that want to further their research objectives and further their potential for commercial manufacturing in orbit."

While Axiom's professionals are former NASA astronauts like Michael López-Alegría and Peggy Whitson, the private astronauts start with little or no training at all. For Ax-1, these included CEOs, former fighter pilots, and an amateur race car driver. As such, these astronauts required instruction to be able to live and work on the space station. To do that, they needed to train with those experienced in it.

In 2008, David Wiedmeyer started working in the Mission Control Center at NASA's Johnson Space Center in Houston as a flight control operator. During his tenure, Wiedmeyer became certified to work in training for astronauts and mission control specialists. Moving to the Office of the Chief Training Officer, he coached new employees on the same systems he worked on when assisting regular operations at the space station. In 2018, Wiedmeyer left NASA and became chief of flight operations and training at Axiom. Like Wiedmeyer, a large contingent of Axiom's employees held positions at NASA before going to the private sector, including Ondler.

"At NASA, we certainly got a lot of opportunities to work on really hard problems and lean forward in terms of technology development," Ondler said. "It's a great training ground for engineers and for folks who are trying to do things in space."

Training for Ax-1 used several facilities at Johnson, from full capsule simulators to mockups of space station modules. Axiom also contracted with KBR, a government services provider that helps train NASA astronauts, which provided Axiom with some of the same training workforce NASA has.

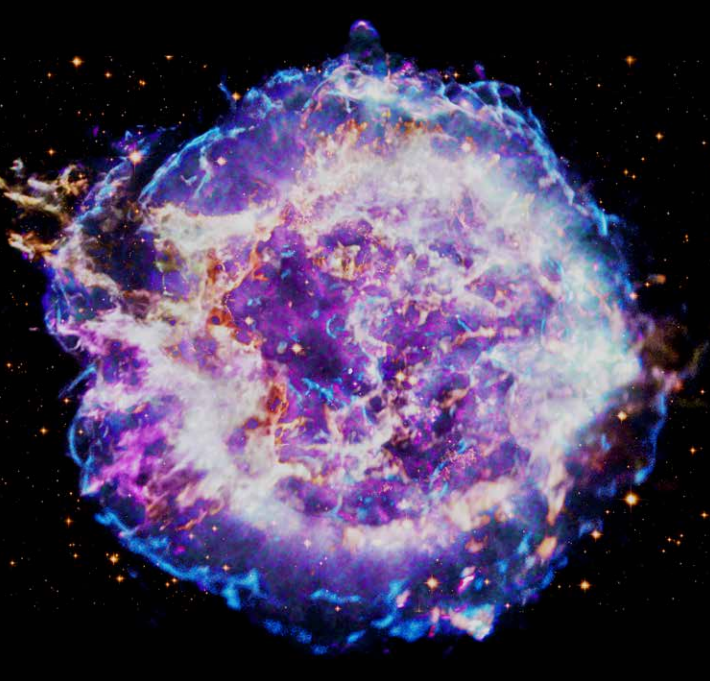
Axiom is slated to make additional trips to the space station with SpaceX, with private astronauts coming from around the world to perform research, conduct outreach, and other activities. During their seven days in orbit, the Ax-1 astronauts conducted biological research into brain function and heart conditions and tested technology for constructing habitats in space, something they wouldn't have been able to do without the proper training. ●



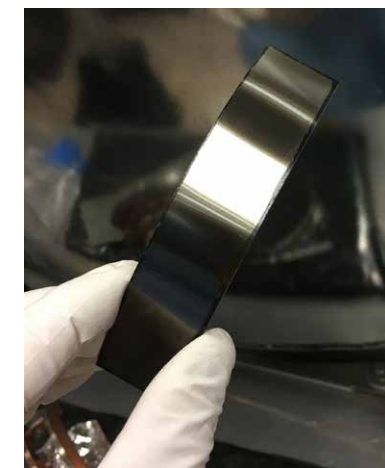
Mark Pathy, one of Axiom Space's private astronauts, trains in a replica of the International Space Station at Johnson Space Center's Vehicle Mockup Facility prior to the launch of Ax-1. *Credit: Axiom Space Inc.*



# Device for Analyzing Deep Space Could Detect Tumors, Air Particles



NASA uses flat microchannel plates in a variety of instruments, including the Chandra X-Ray Observatory's High Resolution Camera, which captured data for this image of the Cassiopeia A supernova remnant. *Credit: NASA/CXC/SAO*



Supported by NASA SBIR funding, Incom has developed curved microchannel plates, like the ones pictured here, which can fit directly onto instruments – such as cameras, spectrometers, air analyzers, nuclear detection devices, and PET scanners – to improve performance and efficiency. *Credit: Incom Inc.*



## A NASA-funded curved microchannel plate is now available for medical uses, air analysis, and nuclear waste detection

An improved version of a device that enables scientists to study the hot matter in remnants of exploded stars and distant galaxy clusters is now available for earthly uses.

NASA-funded curved microchannel plates can perform faster and more accurately than traditional flat microchannel plates, which are used in a variety of space agency instruments, including plasma particle analyzers, mass spectrometers, and the High Resolution Camera of the Chandra X-Ray Observatory, which captures information about the composition of faraway exploded stars.

The incredible detail the Chandra High Resolution Camera can pull from faint sources – akin to an ability to read a newspaper from half a mile away – comes from two 4-inch square microchannel plates that contain tens of millions of tiny tubes that multiply the electrons released when the instrument is struck by X-rays.

“In other words, a microchannel plate can amplify the impact of a single particle or photon, making its detection possible,” explained Nikolaos Paschalidis, chief technologist at NASA’s Heliophysics Science Division at Goddard Space Flight Center in Greenbelt, Maryland.

Because this technology has proven so useful to NASA, the space agency has taken an interest in a specific innovation: curved microchannel plates developed by Incom Inc., a producer of glass and polymer microstructures in Charlton, Massachusetts.

In traditional microchannel plates, the many millions of tubes are arranged in one fixed orientation, parallel to each other, on a flat plane. But nature is three-dimensional, so special optics are required in instruments to fully map natural space.

Incom’s curved microchannel plates – developed with NASA funding from a handful of Small Business Innovation Research contracts between 2015 and 2021 and now available for sale – address this problem with tubes that can be arranged on a cylindrically curved plate.

Curved microchannel plates can be fitted onto instruments more efficiently, enabling them to amplify particles faster and more accurately. They also take up less space and weight, which is critical for both spaceflight and equipment on Earth.

Flat microchannel plates on Earth are used in instruments for analyzing air composition and detecting airborne formaldehyde, for example. They may also be used in PET scanners to detect and analyze tumors, helping doctors determine whether or not to operate.

“Many applications using flat microchannel plates could improve by using curved microchannel plates that fit the natural geometry of the instrumentation better,” said Mark Popecki, a senior research scientist at Incom.

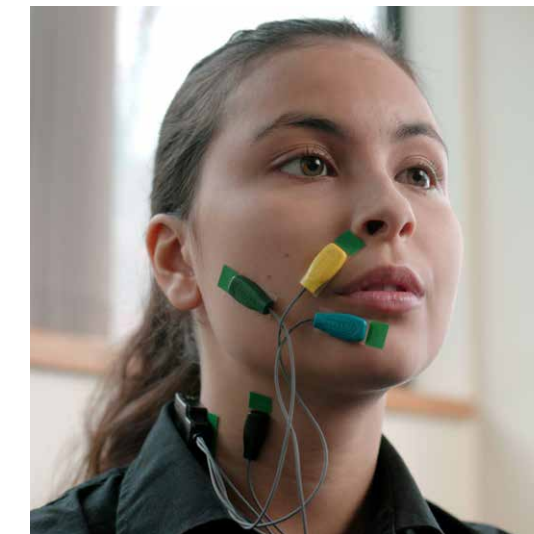
Incom is also working with the Department of Energy to put these microchannel plates in devices that detect nuclear materials that could be associated with nuclear waste, or even nuclear reactors, Popecki said.

NASA’s Paschalidis noted that flat microchannel plates have developed over the past 50 years or so, while curved ones are in their infancy. “There’s room to evolve for improved gain, imaging uniformity, aspect ratios, and geometries,” he said, adding that NASA will continue developing and funding research on this technology. ●

# Electrical Body Signals Help Researchers Restore Movement and More



Trigno Mini sensors are applied to the forearm and hand muscles of professional pianist Rui Urayama to gain understanding of fine motor control strategies. *Credit: Delsys Inc.*



Delsys Trigno Quatro Sensors designed for facial muscles are able to convert electromyographic (EMG) signals from mouthed speech to text. *Credit: Delsys Inc.*

The Delsys Trigno Maize sensor is capable of high-density EMG signal detection to let the operator understand musculature and muscle control in high definition. *Credit: Delsys Inc.*

## Technology for understanding mind-body interface builds on research for space travel

NASA asks hard questions: What’s it like on the Moon? Has there been life on Mars? How did the first stars form? Finding these big answers often means first solving a series of smaller but equally vexing questions.

For example, how does prolonged weightlessness change the way the brain controls muscles? How does the brain control muscles? Before sending humans to Mars, NASA wants to understand the effects the trip will have on astronauts. Now a company that helped the space agency explore these questions is helping others find answers as exciting as any NASA discovery.

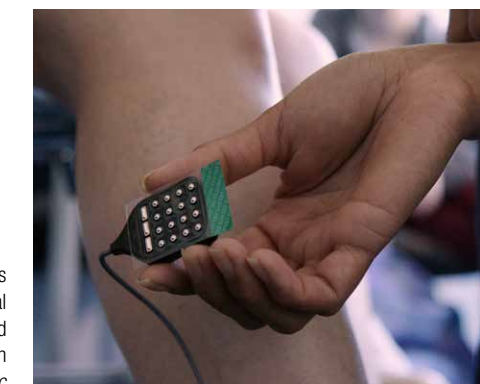
Delsys Inc. of Natick, Massachusetts, was founded in 1993 by Carlo De Luca, founding director of Boston University’s Neuromuscular Research Center (NMRC), to begin commercializing the advanced electromyography (EMG) technology the center was developing. EMG characterizes body movement and motor control by analyzing the electrical signals emitted when motor nerves stimulate muscles.

The NMRC had already worked with NASA by then, with the agency’s Johnson Space Center in Houston funding studies of various spacesuit glove designs’ effects on muscle fatigue, as well as astronauts’ balance and neuromuscular performance before and after space shuttle flights. By 2000, two Small Business Innovation Research (SBIR) contracts from Johnson helped Delsys complete its first commercial EMG system, the MyoMonitor (*Spinoff* 2000).

The early 2000s brought another round of technology development and space shuttle studies, as well as two more SBIR contracts from Johnson. The company used that funding and experience to make cordless sensors that were precise enough to detect individual motor nerve signals from the surface of the skin, overcoming a series of daunting challenges, said Gianluca De Luca, Carlo’s second cousin and the current Delsys president.

Today, most Delsys customers are still academic, commercial, and government research laboratories, and many are developing technologies that would once have been thought impossible. De Luca said several are working to reverse paralysis, including at least one company that has restored movement to paralyzed monkeys. Others are attempting prosthetics that amputees could control much like they would a natural limb. And Delsys is working with several partners to develop technology to let patients speak after having their larynx removed.

Companies making athletic gear, including most major running shoe manufacturers, own Delsys equipment that helps them understand how different designs affect body movement, De Luca said.



As the company has made some of its devices simpler and easier to use, Delsys also has found customers among individual neurosurgeons, physical therapists, athletic trainers, and others who analyze movement or neuromuscular disorders.

While it’s been over 15 years since Delsys last worked with NASA, De Luca said the company, now a global operation, continues to benefit from its long relationship with the space agency, which laid the groundwork for its flagship products. “A lot of our early developments were seeded by the larger research questions that had their inception with the NASA-focused studies.” ●



# SPINOFF Features

From ventilators to robots and satellite imaging to Earthbound bacteria, NASA pursues any means to fulfill its mission to “explore the unknown in air and space, innovate for the benefit of humanity, and inspire the world through discovery.” The following pages reveal how that drive to innovate is both serving exploration and addressing a host of challenges on this planet.

Because the X-59 low-boom supersonic test aircraft has no front window, the eXternal Vision System will be used to give the pilot forward-facing views without compromising the plane's aerodynamic design.





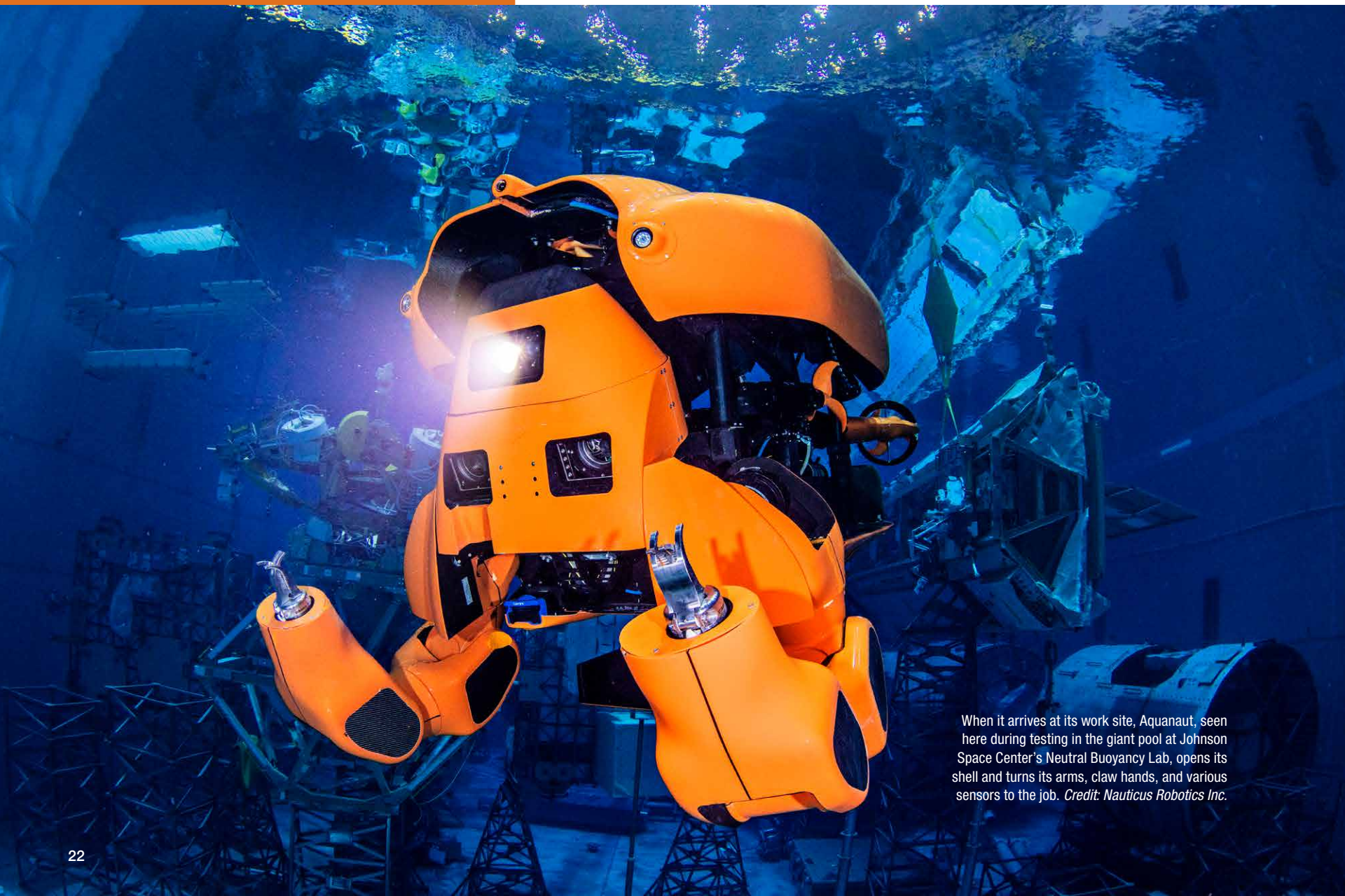
# Space Robotics Take a Deep Dive

## Aquanaut, built on lessons from NASA's robot astronaut, will cut costs for ocean industries

What's the difference between deep space and the deep sea? For a robot, the answer is: not much. Both environments are harsh and demanding, and, more importantly, both are far removed from the machine's operator.

That's why a team of engineers who developed robots at NASA's Johnson Space Center in Houston have decided to apply their expertise to designing a shape-changing submersible robot that promises to dramatically cut costs for a host of maritime industries.

"What NASA really taught us to do is to put together robust software autonomy with a capable hardware morphology and deploy it in a remote setting," said Nic Radford, founder, chairman,



When it arrives at its work site, Aquanaut, seen here during testing in the giant pool at Johnson Space Center's Neutral Buoyancy Lab, opens its shell and turns its arms, claw hands, and various sensors to the job. *Credit: Nauticus Robotics Inc.*

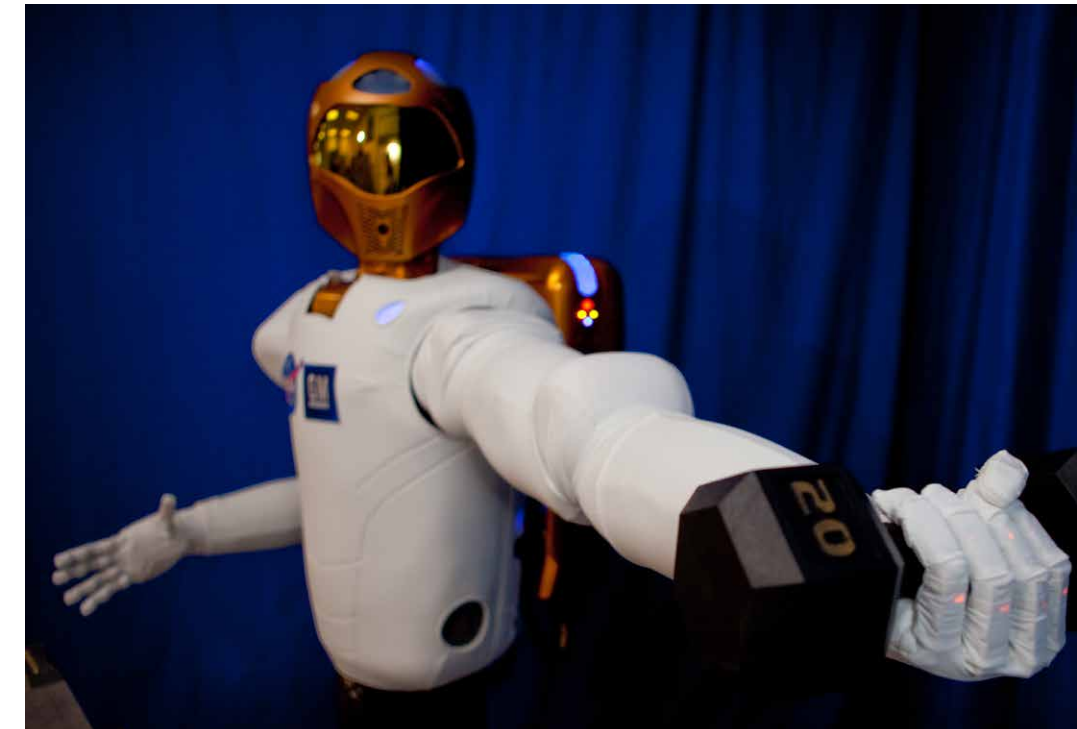
Many of the engineers at Houston's Nauticus Robotics built NASA robots, designed to operate in harsh, remote environments. Now they've applied that knowledge to an underwater robot that can carry out offshore operations with minimal support.

president, and CEO of Houston-based Nauticus Robotics Inc. During his 14 years at Johnson, Radford was, among other roles, the deputy project manager and chief engineer for design and construction of the humanoid space robot Robonaut 2. Now, more than 20 engineers who worked on that project and other NASA robots have joined the 80-person team he's put together at Nauticus.

Whether a robot is working in space or on the ocean floor, the biggest commonality is that the operator is far away, with limited communication and knowledge of the robot's surroundings, he said. "Even if you're putting it on the space station and controlling it from the ground, there's not a high-speed data network. Talking to the space station to control the robot is more akin to using dial-up." So the robot has to be able to sense and understand its environment, navigating obstacles and manipulating objects with minimal operator input.

For Robonaut 2, this meant Radford's team at Johnson had to develop not just advanced robotic hardware like tendon-powered hands, elastic joints, and miniaturized load cells, but also vision systems, force sensors, and infrared sensors to gather information, as well as image-recognition software, control algorithms, and ultra-high-speed joint controllers to process and act on that data.

Built under a partnership between NASA and General Motors (GM), Robonaut 2 was billed as an astronaut assistant and was proven aboard the International Space Station. But it was also a demonstration and testbed for all these advanced robotic systems. NASA is interested in developing robots to carry out dangerous work in space, run "precursor missions" to lay the groundwork for the arrival of human astronauts, and maintain facilities like the planned lunar Gateway station when astronauts aren't around. GM, meanwhile, wanted to explore robotics that could assist



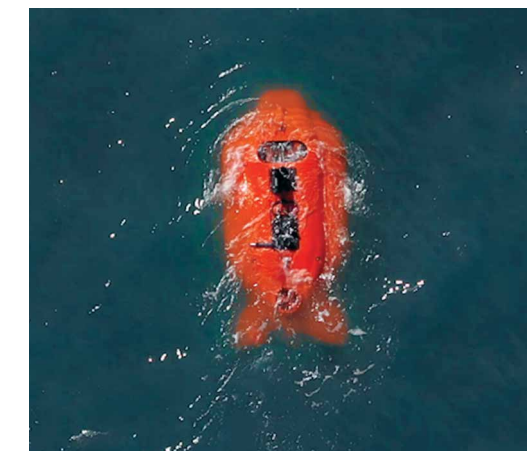
NASA's Robonaut 2, built at Johnson Space Center, became the first android astronaut to go to space in 2011. Now, about two dozen former NASA engineers, many of whom helped build the robot astronaut, have turned their skills to creating underwater robots at Nauticus Robotics. *Credit: NASA*

factory workers. The project resulted in about 50 patents, several of which have already been commercialized in the form of a robotic glove that GM and others are now using in the workplace (*Spinoff* 2022).

### Cutting the Cord

Unlike a robot in space, deep-sea robots that service offshore oil wells or wind turbines, for example, can be connected to an operator with a cable to allow high-speed data transfer and close control. But Radford noted that this comes at the high price of staffing and operating a huge support vessel on the ocean surface, to the tune of about \$100,000 and 70 metric tons of greenhouse gas emissions per day.

Instead, Nauticus is eliminating that cord by enabling its robots to carry out tasks with minimal supervision, which can come from a control center on a distant shore.



While traveling to its destination, Aquanaut resembles a sleek, propeller-powered torpedo. *Credit: Nauticus Robotics Inc.*



Bright orange, fully electric, and about the size of a small sports car, Aquanaut, the company's signature robot, resembles a sleek, propeller-powered torpedo as it motors to its destination. At that point, though, its shell pops open, and the nose flips upward to reveal a suite of cameras and other sensors, now facing front. Two multi-jointed arms swing out, ending in dexterous claw hands that can be fitted with different tools.

When it came time to test the robot in 2019, the team returned to Johnson and dropped it in the giant astronaut training pool in the center's Neutral Buoyancy Lab, where it could swim and try out its systems in full view of operators and cameras.

### A Floating Factotum

Aquanaut is designed to be versatile, and Radford points out that there is no shortage of different jobs for a subsea robot. The best-known industry that would benefit from an underwater robotic worker is offshore oil and gas production, which requires a huge amount of underwater equipment and support structure, all of which need inspection and maintenance. But the fastest-growing is wind power. About 25,000 offshore turbines are planned for operation by 2030, Radford said, and all of them will require servicing and inspection.

With wild fish populations in steep decline, aquaculture – the farming of fish, shrimp, and other seafood – has to grow significantly if there's

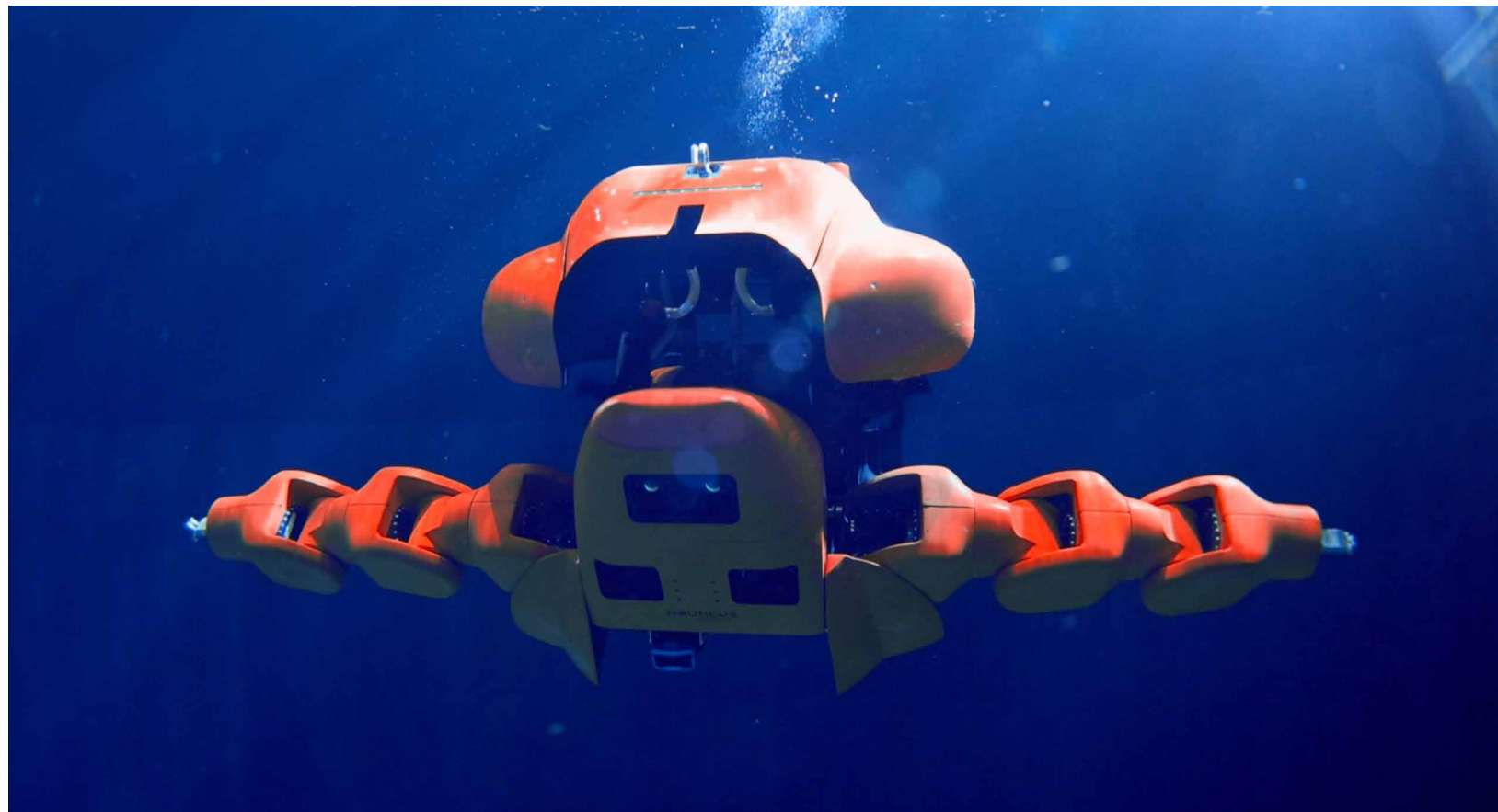
to be enough protein to feed the world, and the nets and cages in those underwater farms need regular cleaning and mooring chain inspections, Radford said.

Other potential jobs include port management, maintaining subsea telecommunication cables, offshore mining of rare materials, and defense applications. "The ocean is interlaced into everything we do, but it's not at the front of people's minds," he said, estimating a total maritime economy of about \$2.5 trillion.

By early 2022, Nauticus had produced two Aquanauts and planned to have 20 more built in the following three years, along with several custom variants. The company primarily plans to

*"Space is amazing because it feels existential...  
But it turns out there are also many real challenges right here beneath the ocean."*

Nic Radford, Nauticus Robotics



Nauticus Robotics' Aquanaut robot can swim to a destination and carry out tasks with minimal supervision, saving money for offshore operations from oil wells and wind turbines to fish farms and more. *Credit: Nauticus Robotics Inc.*



Instead of the huge support vessel and crew that's required to operate underwater robots via cables, the autonomous Aquanaut can be carried to a job site by Nauticus' little Hydronaut boat, which can navigate with or without a crew. *Credit: Nauticus Robotics Inc.*

use them to provide affordable services to ocean industries, rather than selling them. For operations that still require some surface support, or just to transport the robots or other cargo, Nauticus is building an autonomous boat called Hydronaut, which can be operated remotely or navigate on its own. And the company licenses its robotics control software – called toolKITT in a nod to the artificially intelligent car from the 1980s television show *Knight Rider* – to other robotics companies.

By applying space solutions to maritime problems, Radford and his team plan to make the Nauticus name synonymous with ocean robotics, he said. "Space is amazing because it feels existential – it's way out there, and people want to explore it. But it turns out there are also many real challenges right here beneath the ocean, and we could stand to do more innovating in the 'blue economy.'" ●



Nauticus is also commercializing the robotic arm technology – known as Olympic Arm – that it developed while designing and building Aquanaut. *Credit: Nauticus Robotics Inc.*



# NASA's VITAL Contribution to Global Pandemic Relief

**NASA-designed ventilator helps save lives in developing nations**

In 2020, the COVID-19 pandemic forced institutions to lock down, and patients poured into hospitals around the world. But in both the United States and developing nations, one previously little-used piece of medical equipment was suddenly swamped by demand: the ventilator.



To make sure ventilators could be quickly manufactured and administered to those in need during the COVID-19 pandemic, a team of engineers at the Jet Propulsion Laboratory created VITAL, made of off-the-shelf parts. *Credit: NASA*

STARK Industries of Columbus, Ohio, licensed VITAL from NASA and spun off new company Spiritus Medical to distribute the ventilator around the world.

Ventilators are used in hospitals to assist patients with breathing, acting as an external set of lungs to push air down the windpipe and aid the respiratory system. While these machines can save lives, hospitals typically only have a few on-site, and they can only be operated by professionals with specialized training. With a respiratory illness like COVID-19 inundating intensive care units with patients in need of breathing assistance, ventilators were in short supply.

In parts of the world with fewer hospitals and less healthcare infrastructure, the situation was even more dire. In a country like India with a billion people, many of them in rural regions, the ventilator supply was impossible to triage. And 9,000 miles away in Brazil, the disease spread rapidly, infecting millions in the first year.

With such a desperate need for these specialized machines, the engineers at NASA's Jet Propulsion Laboratory in Southern California figured they could use their experience with solving problems and building cutting-edge technology.

"For us, one of the hardest things is to be told that the best thing you can do to help is to just go home. We're engineers. We like to fix things," said Stacey Boland, an engineer at JPL who was part of the team that worked on the ventilator. "And so that kicked off a conversation, and in pretty short order we started brainstorming."

By removing features that weren't necessary for most cases and keeping the design and operating interface simple, the team was able to quickly assemble a ventilator – one that could be manufactured with "off-the-shelf" parts that aren't used in standard

ventilators, eliminating competition for supplies. In less than one month, JPL built a prototype of a working ventilator, dubbed VITAL (Ventilator Intervention Technology Accessible Locally). Soon after, the Food and Drug Administration (FDA) gave emergency authorization to use the device in hospitals. Through the center's Technology Transfer Office, JPL made a cost-free, non-exclusive license available for companies to produce their own versions of VITAL.

"We had a lot of discussions early on about what was the right thing to do, how could we actually get this design out in the world as quickly and effectively as possible," Boland said. "We wanted to make sure that if ventilators were needed anywhere in the world, this technology would be something that could be used to serve that need."

## Ensuring Vitality

Over 100 companies applied for the license globally, and 31 were awarded a license to produce the commercial versions of VITAL. STARK Industries LLC of Columbus, Ohio, was one of eight U.S. companies. As a medical technology firm, STARK had taken a keen interest in VITAL as soon as the company's leadership heard about it.

STARK was founded after Joe Swantack had an idea to build a resistive exercise device. When looking for a heart-rate sensor to pair with the device, Swantack found Dr. Peter Lee, a cardiothoracic surgeon, and together they discovered a wireless cardiac monitor patch. The two joined forces, and in 2016, STARK Industries was formed.



*"This can take care of 80% to 90% of patients who need to go on a ventilator, so those higher-end ones can be reserved for those who absolutely need them."*

*Peter Lee, Spiritus Medical*

Joe Swantack poses with a VITAL ventilator. His company, STARK Industries, was one of the first companies to receive a license from JPL to build a commercial version of VITAL. *Credit: Spiritus Medical Inc.*



Because his device, which builds muscle without weights, had clear benefits for astronauts' exercise needs in zero gravity, Swantack has since worked with NASA personnel several times, and when the coronavirus pandemic began to take hold, the company leadership learned about JPL's invention.

After seeing how useful the machine would be for struggling hospitals, STARK created a subsidiary spinoff called Spiritus Medical Inc. in December 2020, completely devoted to the production and sale of VITAL. Lee said that in the United States sales of the Spiritus ventilator, now renamed the Vitality ventilator, are intended for use as a "stockpile ventilator," to be used in situations when there is an unexpected surge in the need for ventilators that greatly exceeds hospital capacity at the time.

"To use a car analogy, most U.S. hospitals have Cadillacs in their ICUs. This ventilator is a basic Ford. It gets you from point A to point B and doesn't have all the bells and whistles," said Lee.

**Bharat Forge of Pune, India, licensed VITAL to save lives in the country's more rural areas and distribute to places in need around Asia and Africa.**

"This can take care of 80% to 90% of patients who need to go on a ventilator, so those higher-end ones can be reserved for those who absolutely need them."

Spiritus has manufactured and sold over one hundred ventilators abroad and continues to work with international partners to bring its version of VITAL to countries around the world. The company is actively working with partners in several developing countries such as Nigeria and Ghana. Additionally, Spiritus has forged a strong relationship with companies like Bharat Forge Ltd. in Pune, India. As one of the most populous countries in the world, India was heavily affected by the COVID-19 pandemic and suffered from a lack of readily available ventilators. Because of this,

### Forging a New Path

Bharat Forge is the flagship company of the Kalyani Group, a multinational conglomerate whose primary business is in forging and manufacturing metal components, from car parts to military machinery. When India needed ventilators in more rural areas, the Kalyani Center for Technology and Innovation decided to develop and produce one. Its original design worked but would've required additional approvals for international export. As VITAL already had approval from the FDA in the United States, it was a good match for the company's production goals.

Bharat Forge applied for a license from JPL and the soon became one of the international licensees. Jagdish Sherkar, senior manager of the Kalyani Center, said the company's manufacturing and distribution agreement with Spiritus Medical comes from a mutual need to keep the VITAL supply chain going.



The CuraSigna implementation of VITAL is integrated with a service called ICU-on-Cloud, allowing intensive care doctors to keep tabs on all their patients from a tablet. Credit: CuraSigna Systems Pvt. Ltd.

**CuraSigna in Bangalore, India, licensed and integrated NASA's VITAL ventilator design into a medical technology ecosystem for performing "virtual rounds" at intensive care units.**

"We joined hands to serve a greater population residing in Asia, the Middle East, and Africa," said Sherkar. "We had manufacturing strengths, Spiritus has a global reach. During lockdown periods, if one country is shut down, the other could supply the needy."

CuraSigna Systems Pvt. Ltd. in Bangalore, India, also said the country's struggles with a supply of ventilators was its impetus for licensing VITAL. Founded in 2020 during the earliest stages of the global pandemic, the company's founders saw the surges of cases paired with a lack of resources and searched for ways to help.

Srishti Ramasubramaniam and Rama Subramaniam, cofounders of CuraSigna through the Sushil Swabhimani Private Trust, saw that VITAL was licensable, and with the additional help of the Indian Space Research Organization, the company was able to build a new version of VITAL. CuraSigna is integrating its version of VITAL with an entire ecosystem of medical technologies. Dubbed "ICU-on-Cloud," CuraSigna's medical technology is tightly integrated with apps built on the Android mobile operating system. Other devices built on this platform include, but aren't limited to, electrocardiogram heart monitors and intravenous infusion pumps.

"The whole objective is to take the best intensive care doctor to the last patient. Unlike most ventilators, we can take it literally anywhere," said Subramaniam. "And doctors, instead of doing physical rounds, they can use a Samsung Galaxy Fold to do virtual rounds."

CuraSigna is developing other technologies using processes derived from NASA research like air purification systems that use photocatalytic oxidation (Spinoff 2018, 2022). Subramaniam believes both innovations developed at NASA and the way the company's core team worked closely with NASA engineers were instrumental in his company's success.

"We've saved tens of thousands of lives and will probably go on to save more." Subramaniam said. "We can't thank NASA enough."

### Saving Lives from São Paulo

Brazil was another country hit hard by the pandemic, with millions of cases reported in the first year. To Juan Ruben Calbucoy Oliarte, watching the news was terrifying.

"The most dramatic moment was to see images of doctors using plastic bags as a last resort in a desperate attempt to save the lives of their patients," said Oliarte.

As the founder and CEO of Russer, a medical equipment manufacturer based in the city of Indaiatuba in São Paulo state, Oliarte wanted desperately to do something. But his usual business was in urology supplies, not pulmonary care. Russer couldn't produce something on its own.

"Providentially, leafing through the newspaper I found an article reporting that NASA JPL offered the patent and license to manufacture a dedicated pulmonary ventilator for COVID," Oliarte said. "I didn't hesitate for a moment and applied to receive such a valuable contribution."

**After licensing VITAL from NASA, Russer Brasil of Indaiatuba, Brazil, brought it into compliance with the country's local requirements, selling hundreds of units.**

Russer now produces a version of the ventilator called VIDA or VP-VITAL. Brazil's infrastructure presents challenges for building equipment like VITAL. The country has a different electrical system than the United States and rural parts of the nation might not maintain a surplus of ventilator equipment. In order to adapt the machine, the company brought it into compliance with local

standards set by the Brazilian Ministry of Health and worked to ensure VITAL functioned all over the country. Russer has delivered 300 ventilators to hospitals in several regions around Brazil, both in remote places as well as some of the country's larger urban areas.

The JPL team still stays in touch with licensees, answering questions or giving technical advice on how to improve designs. Boland believes worldwide collaborations like this were unprecedented for the center.

"We're used to licensing technology to one or two companies, not 20-something," Boland said. "And the level of effort it took and the amount of support we were able to provide, it was really a privilege to get to work on something like this. I think it's been a very positive experience for all involved."



While Russer's implementation of VITAL may look similar, it's had changes to adapt and bring it into standards for use in Brazil, where medical infrastructure can be inconsistent. Credit: Russer Brasil

*"We've saved tens of thousands of lives and will probably go on to save more. We can't thank NASA enough."*

*Rama Subramaniam, CuraSigna*



# A High-Tech Farmer's Almanac for Everyone

NASA satellite data and climate modeling supports the development of crucial climate-resilience tools

For long-term weather predictions, the Farmer's Almanac was a go-to source after it started publishing in 1818. Its forecasters based their predictions on the tides, alignment of the planets, and other factors, but one variable they didn't have to contend with was the unpredictability of a warming planet.

Today, companies and agencies trying to understand how climate change might alter weather patterns in the years ahead rely on NASA's Earth-observation satellite data, analytics, and climate science to support new approaches to long-term forecasting.

Climate change is leading to stronger, more intense storms, record-breaking droughts, flooding, and more widespread wildfires. By combining data about current conditions and previous weather patterns, much of which is gathered by NASA-built satellites, computer models generate science-based predictions to help everyone from government planners to farmers, schools, and manufacturers prepare for what's to come. These resources are essential for saving lives and limiting property damage.

The first Landsat satellite launched by NASA to observe our planet 50 years ago was the starting point for 77 more Earth-observing satellite missions, which have now amassed petabytes of data. This data is primarily managed by NASA's Ames Research Center in Silicon Valley, California, and Goddard Space Flight Center in Greenbelt, Maryland. NASA has also built tools to apply this mountain of data to climate-related challenges.

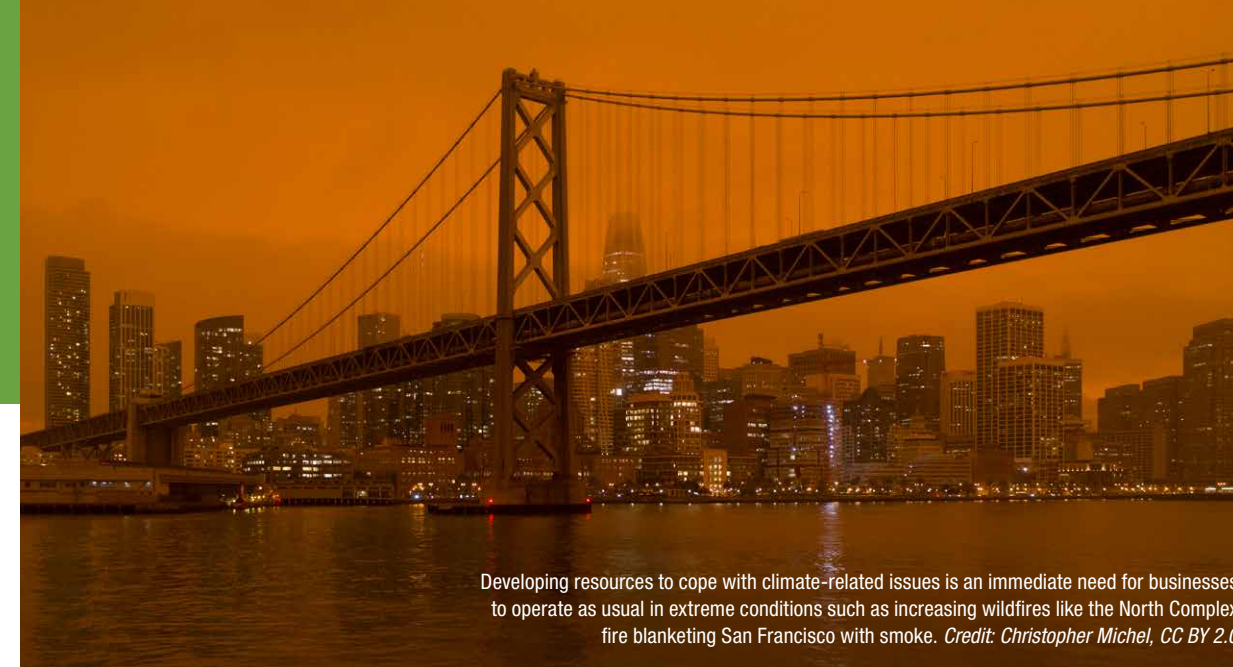
Central to the space agency's effort to make its trove of remote sensing data available and useful to the public is the NASA Earth Exchange (NEX) platform built around 2010. NEX provides the public with software and supercomputing power to analyze and share petabyte-scale datasets, letting everyday users conduct in-depth research.

Private companies now use these resources to bolster climate resilience – the ability to prevent, respond to, withstand, and recover from climate-related disruptions – for themselves, clients, and the public at large. Together, these efforts are turning satellite data into a modern, high-tech Farmer's Almanac.

*“One of the most powerful capabilities we can offer is a continuous global view of our planet.”*

*Dalia Kirschbaum, Goddard Space Flight Center*

Esri's ArcGIS system compiles, analyzes, and displays geographic information system (GIS) data to map and analyze information about locations, such as this image from 2017 showing differences in urbanization and forestry resources between North and South Korea. Mitigation strategies can then be developed for climate-related weather changes and disasters. *Credit: Esri Inc.*



Developing resources to cope with climate-related issues is an immediate need for businesses to operate as usual in extreme conditions such as increasing wildfires like the North Complex fire blanketing San Francisco with smoke. *Credit: Christopher Michel, CC BY 2.0*

## ‘Flying Blind’ into the Future

For half a century, NASA has built constellations of Earth-observing technology. These catalog physical surface changes, temperature fluctuations, greenhouse gases, and much more.

For a long time, though, that data was difficult to access. Before the internet, anyone requesting information needed to know NASA research programs, available datasets, and individual investigators. The time it took to track down that information and submit requests, as well as the expertise to compile datasets, was expensive, even if the data was free. And it often was not. Prior to 2008, for example, Landsat data could be prohibitively expensive.

“When I worked a summer job at Goddard, pulling data meant we had to transfer it from tapes onto a mainframe or workstation,” recalled Beau Legeer, who is now director of imaging and remote sensing for Esri Inc. of Redlands, California. To make that data more accessible, NASA needed a way to extract it from multiple sensors and many different file types, so the agency partnered with the private sector.

In 2010, Esri created the data model for online access to Earth-observation data. NASA-developed algorithms were used to automatically find and compile geographical data from any server. All Earth data correlates to locations, so geography was the best way to organize the information using the geographic information

Partnering with NASA to standardize decades of Earth-observation datasets and move them into the cloud, Redlands, California-based Esri helped give everyone access to climate data. The company develops tools to support businesses building their climate-resilience efforts.

system (GIS). If a researcher needed 40 years' worth of daily high temperatures for Chicago, for the first time, it was easy to collect that data regardless of how and where it was stored.

The agency again partnered with Esri, as well as the U.S. Geological Survey and Amazon Web Services, to move the data to the cloud, making it searchable by anyone. This easy access opened the door to cost-effective, innovative ways to use data.

“One of the most powerful capabilities we can offer is a continuous global view of our planet,” said Dalia Kirschbaum, hydrological sciences lab chief at Goddard. She explained how her team worked with stakeholders including a group in Tajikistan to develop the algorithms to use data for any location around the world to populate an open-source landslide model.

A computer model can identify critical infrastructure, homes, and businesses placed at risk by a changing climate. ArcGIS, the online cloud-based mapping and analysis service Esri developed, supports the landslide program and other climate-modeling efforts at NASA and elsewhere.



Climate-resilience planning relies on science-based projections to envision future environmental conditions. The new normal will include more frequent and more severe events such as floods or wildfires like this one in Dargo, Victoria, Australia. *Credit: fir000c/Flagstaffotos, CC BY-NC*



With these tools, targeted planning and prevention measures for climate-driven challenges become possible. Creating a rain garden might help a school that never had a flood problem before, for example, while changes to construction practices can help weatherproof homes and businesses to protect people and reduce property damage.

“Without the observations of land, precipitation, the atmosphere, and our oceans, we would be flying blind in terms of what trends have been and how we can improve our models for the future,” said Kirschbaum.

In addition to offering free ArcGIS licenses to developing countries, Esri has customers using its data-mapping tools to evaluate climate-related risks at facilities around the world. According to Legeer, construction industry customers, for example, evaluate how to modify a site plan by modeling the impacts of terrain and climate.

A state-of-the-art flood risk modeling tool developed by Brooklyn, New York-based First Street Foundation uses NASA Earth-observation data and open-source analytics to assess flood risk for any U.S. address, making it a valuable resource for property developers, businesses, and homeowners.

## Water, Water Everywhere

Localized flood risk calculations in the United States rely on federal flood maps. They aren't always available, and many are out of date, said Dr. Ed Kearns, chief data officer with First Street Foundation. The Brooklyn, New York-based nonprofit realized that situation made it difficult for homeowners, insurers, real estate agencies, and property developers to obtain accurate risk information about specific addresses.

First Street's goal is to raise awareness about the impacts of climate change and the associated risks. Flooding is the nation's most expensive natural disaster, having cost over \$1 trillion (in inflation-adjusted dollars) since 1980, according to the foundation.

“We're integrating research results from government and open data models and working with commercial and academic partners to assemble the puzzle pieces required to understand climate change,” said Kearns.

Launched in 2020, First Street's Flood Factor program combines multiple data sources such as NASA downscaled climate models, Earth-observation data, topography, and more to predict the impact of rainfall, storm surges, and other potential flooding events.

The program assesses potential impacts of various climate conditions – the once-dry areas that could soon experience flooding or the impact of flooding from an overtopped levee and the likelihood of these events occurring. With this information, property owners can limit damage.

First Street customers like realtor.com, Estatefy, and Redfin integrate Flood Factor into their websites, allowing users to quickly identify risk. With awareness growing about the way extreme storms are shifting flood risk, Kearns said businesses are recognizing the need to make data-driven decisions.

Because climate change poses multiple threats, First Street is developing more risk models. Wildfire modeling is due out in 2022. Along with a forthcoming extreme heat assessment, these services are free to the public.

Extreme floods like this one in Hamburg, Iowa, where the Missouri River broke through two levees and flooded fields, are increasing under the influence of climate change. First Street Foundation created the Flood Factor program to ensure that anyone can see how climate change will alter the 30-year flood prediction for any property in the nation. *Credit: NASA*

A proprietary wildfire prediction model developed by Delos Insurance Solutions of San Francisco combines NASA data and open-source analytics with current climate science to offer property owners accurate risk assessments and the appropriate insurance.

## World on Fire

What happens when the insurance industry tries to assess fire risk using standards developed before climate change intensified wildfires? Higher premiums, according to Shanna McIntyre, chief data officer of Delos Insurance Solutions.

The San Francisco company's custom wildfire modeling program uses “hundreds of parameters” including NASA Earth-observation imagery, datasets like NASA's LANDFIRE, and the most current climate science to calculate risks before pricing insurance policies.

“Artificial intelligence allows us to use far more variables, and the use of more datasets does a much better job of predicting an outcome,” she said. For example, she explained, satellite imagery combined with other datasets help the model “learn” where and how wildfire risk is changing.

The risk for each property is ranked, and the company shares what it learns with the property owner, providing specific steps to reduce the likelihood of losses.

In the last three years, wildfire insurance premiums have risen 400% in many parts of California, according to Delos. But the company has been able to step in when property owners lose their coverage or can no longer afford it. Modeling the risk over time means the company better understands what will happen in a location, avoiding unexpected price hikes that occur under the old method, said McIntyre.

The company, which only operates in California, is scaling up to serve Oregon and Washington state. Delos will eventually offer its program worldwide to calculate growing wildfire risks in places that have never had to deal with them.

## An Ounce of Prevention

Businesses are always managing risk but don't always have access to the latest information, according to Bob Miller, CEO of Tenefit Corporation. International companies frequently operate a global security operation center, or GSOC, which monitors events that threaten business activities, such as hurricanes, volcanic

Wildfires are larger, hotter, and spreading into areas that were previously thought to be at low risk. Delos Insurance Solutions created a new risk assessment program that incorporates climate change factors and hundreds of data points, some provided by NASA, to assess the current and long-term likelihood of fire for property owners in California. *Credit: U.S. Fire Service*

Disaster risk prediction and near-real-time progress reports provided by San Jose, California-based Tenefit let companies mitigate impacts of weather-related disasters in a changing climate with a combination of NASA data, open-source analytics, and other datasets.

eruptions, and other natural disasters. That's why San Jose, California-based Tenefit developed DisasterAWARE Enterprise.

This multi-hazard monitoring system provides early warnings and near-real-time updates as disasters develop. The service also predicts impacts, develops risk assessments, and offers other resources that rely on climate science along with NASA data, analytics, and modeling code.

DisasterAWARE Enterprise is built on the public-serving DisasterAWARE platform developed and owned by the Pacific Disaster Center, which is managed in partnership with the University of Hawaii. A license from the university has allowed Tenefit to extend the platform to meet private-sector needs. Tenefit also helped to scale up the center's smartphone app, Disaster Alert.

In addition to creating the app and providing cloud storage for this vast amount of data, DisasterAWARE Enterprise lets subscribers, such as global distribution companies, track risks to

specific properties. Warnings for manufacturing plants or key suppliers are accessed via a web portal or the Disaster Alert app. A license for the program can feed all of this information directly into any GSOC.

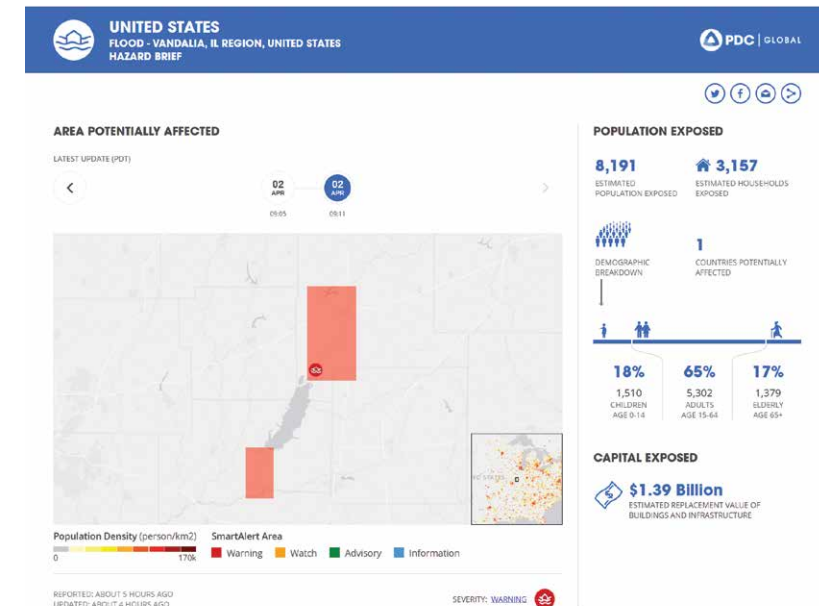
DisasterAWARE uses the landslide prediction tool Kirschbaum's team developed at Goddard and will incorporate a NASA-developed global flood model when it's available in 2022.

## The New Future

Whether faced with fire, flood, or extreme heat in the United States or other countries, NASA has key data and modeling capabilities to address these global challenges. Long-term monitoring of Earth from space will expand and maintain robust data records.

“We need to understand how things have changed in the past decades so that we can effectively model changes in the future,” said Kirschbaum. NASA and other government environmental data is available at no cost, and the agency is pursuing the use of more open-source analytical tools to enable the easiest access to this high-tech Farmer's Almanac for everyone to use free of charge.

“At NASA and as scientists, our goal is to connect the science to societal impacts, to understand where we can make changes to become more resilient,” said Kirschbaum. ●



Building on NASA Earth-observation satellite data, the Pacific Disaster Center's DisasterAWARE platform automatically generates reports like this one about flood risk in Illinois. With a subscription to Tenefit Corporation's DisasterAWARE Enterprise version, a company now has more than just a weather forecast to assess the level of risk for employees, local facilities, and infrastructure, informing decisions about evacuation and steps to mitigate disruption to business activities. *Credit: Pacific Disaster Center*



# NASA Helps Serve Yellowstone Fungi for Breakfast

An organism found in the park is a sustainable protein on Earth and in space

First, a particular type of microbe evolved in an acidic hot spring. Fast-forward millions of years, when a geomicrobiologist finds this type of microbe in Yellowstone National Park while conducting NASA-funded research on organisms that thrive under extreme conditions.

Now you can buy a protein grown from the organism in grocery stores in the form of vegan breakfast patties and cream cheese. It's also growing in space, where astronauts are studying it as a possible



Hot springs like those in Yellowstone National Park are heated either by shallow bodies of magma or by circulation through faults to hot rocks deep in Earth's crust. Microorganisms like the one in Nature's Fynd's protein have adapted to these extreme environments, where dissolved minerals act as a food source. *Credit: Getty Images*

A microbe found in Yellowstone National Park during NASA-funded research is now the basis of a fungal protein from which Chicago-based Nature's Fynd produces meat-alternative breakfast patties and non-dairy cream cheese.

protein source for long-duration missions. And it's informing a project to introduce sustainable fungal proteins to low- and moderate-income communities around the world.

Mark Kozubal, the researcher who collected and named *Fusarium* strain *flavolapis*, went on to cofound Nature's Fynd, a Chicago-based company that produces the fungal protein in an area of the city once known for meat processing.

The company has since raised more than half a billion dollars from investors.

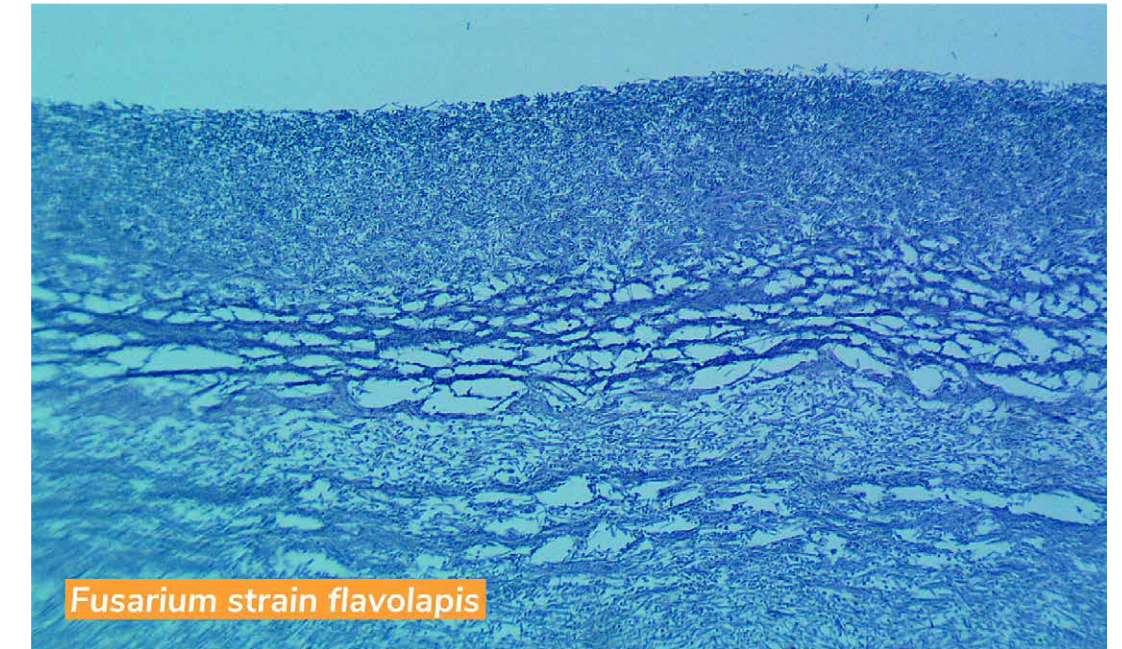
Producing this complete protein, which Nature's Fynd has trademarked as Fy, requires far less water and land than beef, according to the company.

"We're seeing how fragile our food system really is, and under the combined action of climate change and demographic explosion, feeding everyone protein in particular is complicated," said Nature's Fynd CEO and other cofounder, Thomas Jonas.

"That's really what we decided to go after," he said, "so we progressively increased the efficiency of the technology, we enabled better transformation and better yield of protein, and that's what got us here."



Nature's Fynd grows its trademarked meat alternative Fy in trays through a specialized fermentation process. The result is a complete protein with a texture something like chicken. *Credit: Nature's Fynd*



**Fusarium strain flavolapis**

Found in an acidic hot spring, the microbe at the heart of Nature's Fynd's meatless protein prefers a low-pH environment that repels most common bacteria and insects, so pesticides are unnecessary in the fermentation process. *Credit: Nature's Fynd*

## NASA's Interest in Yellowstone

If life exists on other planets or moons, it's not likely to look like life on Earth.

Mars, for example, may have hosted life in the past, but anything living there today would have to survive conditions that are considerably drier, colder, and saltier than our environment. NASA also wants to look for life on Jupiter's moon Europa, where it would need to exist deep under ice.

"In order to understand what life is capable of doing, we look to extreme environments to see what adaptations life has evolved," said Lindsay Hays, deputy program scientist in NASA's Astrobiology Program, explaining the agency's support of research in places like Yellowstone National Park.

"Yellowstone is a truly unique place," she said, describing a deep volcanic environment percolating through ancient and modern cracks and seeps.

"Hot springs in the park have some of the wildest ranges of temperature and pH and other types of conditions," she said. "If you want to understand different adaptations that life has, go look in these hot springs."

That is just what Kozubal did. NASA was funding his work on extremophiles – organisms that thrive in extreme environments – through Montana State University when he isolated *Fusarium* strain *flavolapis*.



### Texture of Chicken, Tastes Like Anything

He and his team initially looked at the microbe as a possible source of biofuel.

They soon discovered that under certain conditions and with the addition of nitrogen, Fusarium strain flavolapis grows into a complete protein, with all the essential amino acids and a chicken-like texture.

Further experimentation revealed the versatility of the Fy protein. It can be ground into convincing breakfast patties, whipped into cream cheese,

or molded into any number food applications, more than a handful of which are under development at Nature's Fynd.

Fy is produced through a proprietary fermentation process that leverages Fusarium strain flavolapis' preference for extreme conditions. The microbe grows in an acidic liquid that is inhospitable to bacteria and other organisms that might contaminate it, rendering pesticides and antibiotics unnecessary.

*"We have this big, complex problem about how we feed everybody, and some of the answers are out there and we just need to use science to figure it out."*

*Thomas Jonas, Nature's Fynd*



The company's meat-alternative breakfast patties and dairy-free "cream cheese" are available in restaurants and grocery stores in some regions. Nature's Fynd is working to expand its presence around the country. *Credit: Nature's Fynd*



Astronaut Jessica Watkins holds a Nature's Fynd bioreactor on the International Space Station. The device successfully produced Fy protein in microgravity, making it a possible food source for long missions. *Credit: NASA*

### Back to Space

To develop a bioreactor to grow the protein in space as a food source for astronauts heading to the Moon or Mars, Nature's Fynd, in partnership with Montana State University, received Phase I and Phase II Small Business Technology Transfer contracts from NASA's Ames Research Center in Silicon Valley, California.

In July, the bioreactor and starter microbe went to the International Space Station with help from a grant from NASA's Established Program to Stimulate Competitive Research awarded to Nature's Fynd and BioServe Space Technologies, a research center out of the University of Colorado.

Leveraging some of the same technology that's currently in space, Nature's Fynd is working to install bioreactors in under-resourced communities in Africa and Asia to generate quality proteins from additional fungal species, with help from a grant from the Bill and Melinda Gates Foundation.

"We have this big, complex problem about how we feed everybody, and some of the answers are out there and we just need to use science to figure it out," Jonas said.

"We feel incredibly excited about what we've done with NASA, the partnerships, the opportunity to contribute even just at our level on these bigger questions," he said. "We deeply love this curiosity about what could be out there." ●



# Giant Batteries Deliver Renewable Energy When It's Needed

## Flow battery company revives NASA research after nearly 50 years



In developing its flow battery, ESS drew from groundbreaking research and development conducted by the space agency more than 40 years ago. Pictured here is a 200-watt demonstration unit of the flow battery NASA built in the 1970s and 1980s. Credit: NASA

Solar power is abundant – when the Sun is shining. Wind power is steady – when the wind is blowing. And a power grid is extremely convenient – until there's an outage.

But creating a steady supply of electricity from intermittent power sources is a challenge.

NASA was focused on this problem more than 45 years ago, when the agency designed a new type of liquid battery during the energy price shocks of the 1970s.

And while engineers continued over the following decades to develop flow batteries, as they're called, the technology has drawn even more attention in recent years, with the urgency of climate change powering a larger-scale transition to renewables like solar and wind.

Wilsonville, Oregon-based ESS Inc. built on NASA's early work as the company developed its own flow batteries using only iron, salt, and water.

Requiring no heavy-metal mining or disposal, the systems are among the safest energy storage solutions available, according to the company. With no corrosive parts, they provide like-new performance after daily use for more than 20 years and necessitate only simple upkeep to go longer. They can easily be scaled up as needed.

NASA's decades-old work on flow batteries, much of which is public-facing and easy to access, provided the ESS team with creative ways of looking at common problems with the technology, said Craig Evans, the company's founder and president.

"It always goes back to research," he said. "If you don't have to reinvent the wheel, you can certainly get things done faster."

### Flow Battery Tech

It's probably fair to say that all flow batteries today owe something to the major push the technology got in the 1970s and '80s, when a NASA team of chemical, electrical, and mechanical engineers

Wilsonville, Oregon-based ESS drew from NASA research to develop an all-natural, nontoxic flow battery that can store energy from wind and sunlight and deliver it when it's needed.

developed an iron-chromium flow battery (*Spinoff* 1985, 2008) at Lewis Research Center – now Glenn Research Center – in Cleveland.

The NASA system, which won agency awards, involved two tanks of liquid electrolyte solutions, one infused with iron chloride and the other with chromium chloride. These electrolytes were pumped through the battery cell, triggering a chemical reaction through a membrane that separated the two solutions inside the battery.

During charge, electrical energy was converted to chemical energy and stored in the electrolyte liquid. To discharge the energy, the process was reversed.

When the ESS team began developing its own flow battery in 2011, the company founders wanted to use iron, the most abundant element on Earth, as NASA had. They found they could pair it with a simple salt solution, which was cheaper to obtain and easier to work with than the chromium mixture NASA had used.

### A Boon for Companies

ESS flow batteries are designed for grids that are increasingly powered by intermittent wind and solar generation. The company's systems store up to 12 hours of energy and discharge it when needed. They have been deployed, for example, by San Diego Gas & Electric in a microgrid designed to provide backup power to critical community facilities, fueled by an on-site solar array.

Additional utilities and developers, including Portland General Electric and Enel Green Power, plan to install ESS systems as well.

They also work at stand-alone businesses and factories – for example, Sycamore International, a commercial facility in Pennsylvania – where they



ESS flow batteries enable a steady supply of electricity from intermittent energy sources, such as wind and solar. They store up to 12 hours of energy and discharge it when needed. They can be built in shipping containers, like the one being installed in the picture here, or larger installations can be housed in a building. Credit: ESS Inc.

help to level out energy captured from rooftop solar panels, for instance. This enables factories to store energy generated by the panels during peak sunshine hours and use it throughout the day.

Such installations can also end up functioning as an alternative to, say, a backup diesel generator that keeps a building operating during power outages or power safety shutoff events, which are increasingly common on the West Coast during wildfire season.

Diesel generators emit harmful pollutants, and they are fire hazards themselves. Another technology, lithium-ion batteries, which are commonly used in electronics, can be scaled up to grid- or microgrid-size installations, but they present fire hazards, are not viable options for storage durations beyond a few hours, and require lithium, which is environmentally problematic.

"The ability to install a technology like ours, which is nonflammable and clean from cradle to grave – that's a huge boon for companies looking to stay up and running during an outage," Evans said.

ESS went public in late 2021 and, in 2022, announced that it would be expanding in Europe, with its two battery products: the Energy

Warehouse, a turn-key battery system built inside a shipping container, and the Energy Center, a larger, utility-scale "battery-in-a-building."

The company expects to ship between 40 and 50 systems in 2022 and said it had additional orders beyond that.

### Lessons from the Past

To increase the amount of energy that can be stored in a liquid flow battery, one simply needs to add more electrolyte solution – an advantage of this technology. To increase the power, one can stack additional battery cells through which the electrolyte is pumped.

But as the electrolyte travels through the system, it loses energy between each battery cell, an inefficiency called shunt losses. NASA worked to mitigate shunt losses in its flow battery system and published research on the issue in 1982. ESS drew from that work to make its own system more efficient.

"NASA's research on shunt losses gave us some good ideas and good ways to model things," Evans said.

Pulling research from the agency's website and libraries, ESS also referred to NASA guidance on handling hydrogen (which results from a side reaction in the ESS system and then is reincorporated back into the system) as well as research on the membrane that separates the electrolyte mixtures.

Thomas Miller, a research engineer at Glenn who worked on the flow battery project as an undergraduate in the late 1970s, recalled that all of the system hardware was custom built, developed through trial and error.

After the flow battery project, which was funded by the U.S. Department of Energy, Miller said some of the knowledge gained went on to inform NASA's work on regenerative fuel cells and other technologies.

Never intended for space, flow batteries are best suited to exactly the sort of terrestrial applications ESS is pursuing, Miller said.

"NASA is funded by taxpayers, so we'll do the research and then turn it over to industry to take it from there," Miller said. "This is a good application of our basic research." ●

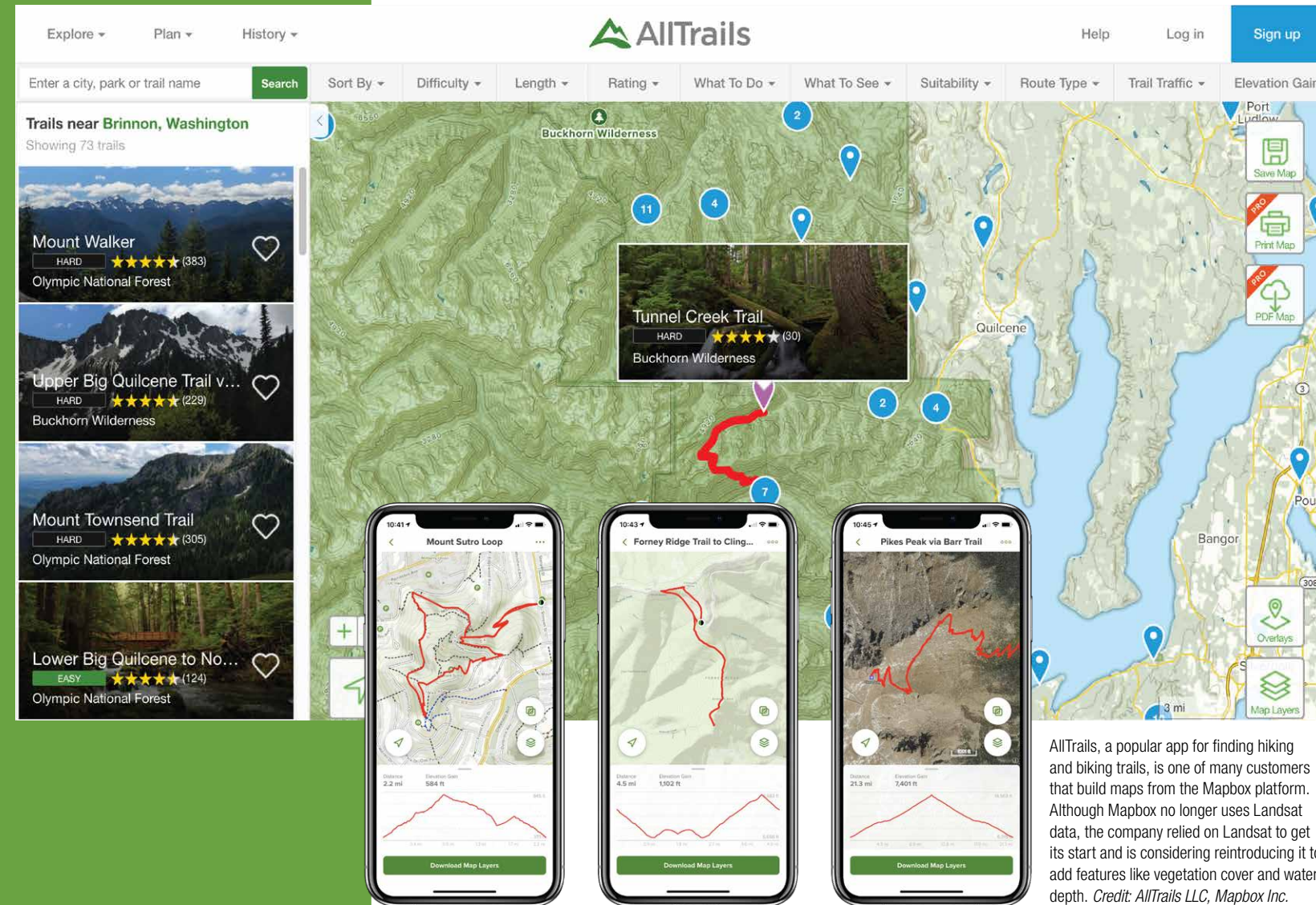


# The View from Space Keeps Getting Better

After 50 years of Landsat, discovery of new commercial and scientific uses is only accelerating

The 30-acre pear orchard in the Sacramento-San Joaquin River Delta has been in Brett Baker's family since the end of the California Gold Rush. After six generations, though, the most precious resource in California is no longer gold – it's water. And most of the state's freshwater can be found in the delta.

Because so much of California now depends on that water, around 2010, the state mandated that all landowners in the delta monitor and report the water they use on their land. What sounded like a simple requirement, however, was not. Equipment to measure water diversion is expensive, and the estuary's twice-daily rise and fall with the tides makes measurements inaccurate, said Baker, adding that the data also is only reported for the previous year, further limiting its usefulness. Meanwhile, the state has calculated



AllTrails, a popular app for finding hiking and biking trails, is one of many customers that build maps from the Mapbox platform. Although Mapbox no longer uses Landsat data, the company relied on Landsat to get its start and is considering reintroducing it to add features like vegetation cover and water depth. Credit: AllTrails LLC, Mapbox Inc.

water consumption in the area using an outdated equation that doesn't reliably account for local weather, groundwater flows, or runoff into the delta. "The utility of that data is minimal, if any," Baker said.

In the last few years, though, accurate, near-real-time measurement of actual water use in the delta has become possible, not with meters on the ground but with satellite instruments in space. The OpenET platform, created by a consortium including NASA, the U.S. Geological Survey (USGS), and several other partners, can calculate the total amount of water transferred from the surface to the atmosphere through evapotranspiration. This is the combined moisture evaporating from soil and transpired, or "exhaled," by plants. Evapotranspiration is a key measure of the water that's actually being removed from a local water system. And it's calculated based on imagery from Landsat and other satellites in low-Earth orbit.

OpenET is only one of the latest practical uses that researchers and businesses continue finding for Landsat imagery, 50 years after the program's first satellite launched.

## A New Standard in Imagery

On July 23, 1972, months before the last Apollo astronauts went to the Moon, NASA launched the Earth Resources Technology Satellite, later renamed Landsat 1, from Vandenberg Air Force Base in California. The world's first space-based land observatory carried two imaging sensors – a television-style camera, initially considered the primary imager, and an experimental multispectral scanner (MSS).

The MSS was conceived by Virginia Norwood, one of the first female engineers at Hughes Aircraft Company. Many involved in the project were initially skeptical of the imager, but its detectors were digital, making its imagery open to precise calibration and computer analysis, and it collected light in specific visible and infrared wavelengths selected for their ability to reveal characteristics like plant health and soil moisture.

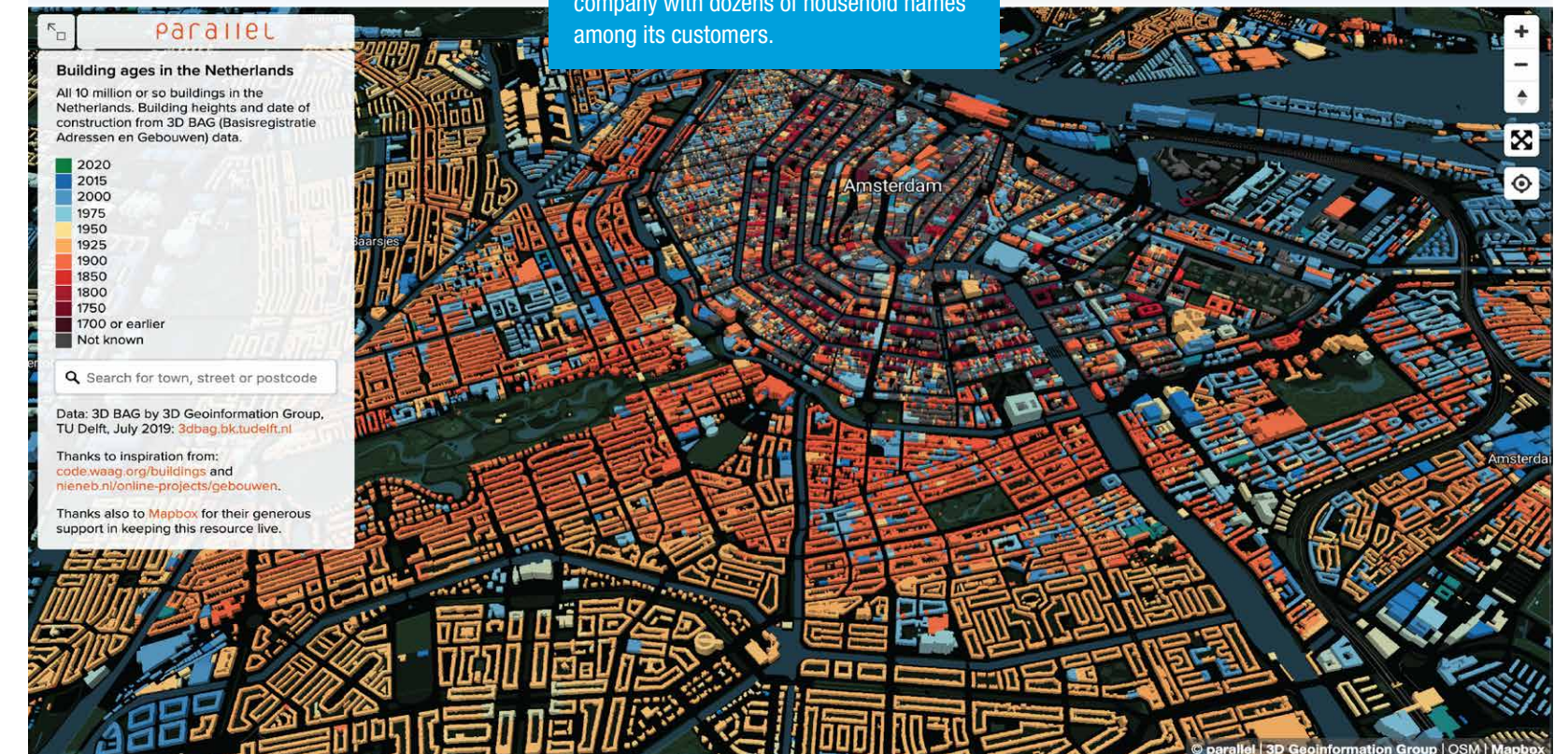


The Earth Resources Technology Satellite, later renamed Landsat 1, the world's first space-based land observatory, launched 50 years ago on July 23, 1972. Credit: NASA

When it started, Mapbox of Washington, D.C., relied on Landsat to build images of the planet. Today, Mapbox, which provides a platform and data for developers to build map-based applications, is a \$1 billion company with dozens of household names among its customers.

"We have an appreciation for NASA essentially starting the Earth-observation industry."

Alistair Miller, Mapbox



This map depicting the ages of buildings in downtown Amsterdam was built with the Mapbox platform, which used Landsat data to get its start. Credit: Parallel Data Intelligence Ltd., Mapbox Inc.



After seeing the first images from orbit, the Landsat team designated the MSS the primary imager, and subsequent Landsat imagers, through Landsat 9, launched in 2021, have all been advances to the basic MSS concept. Norwood became known as “the Mother of Landsat.”

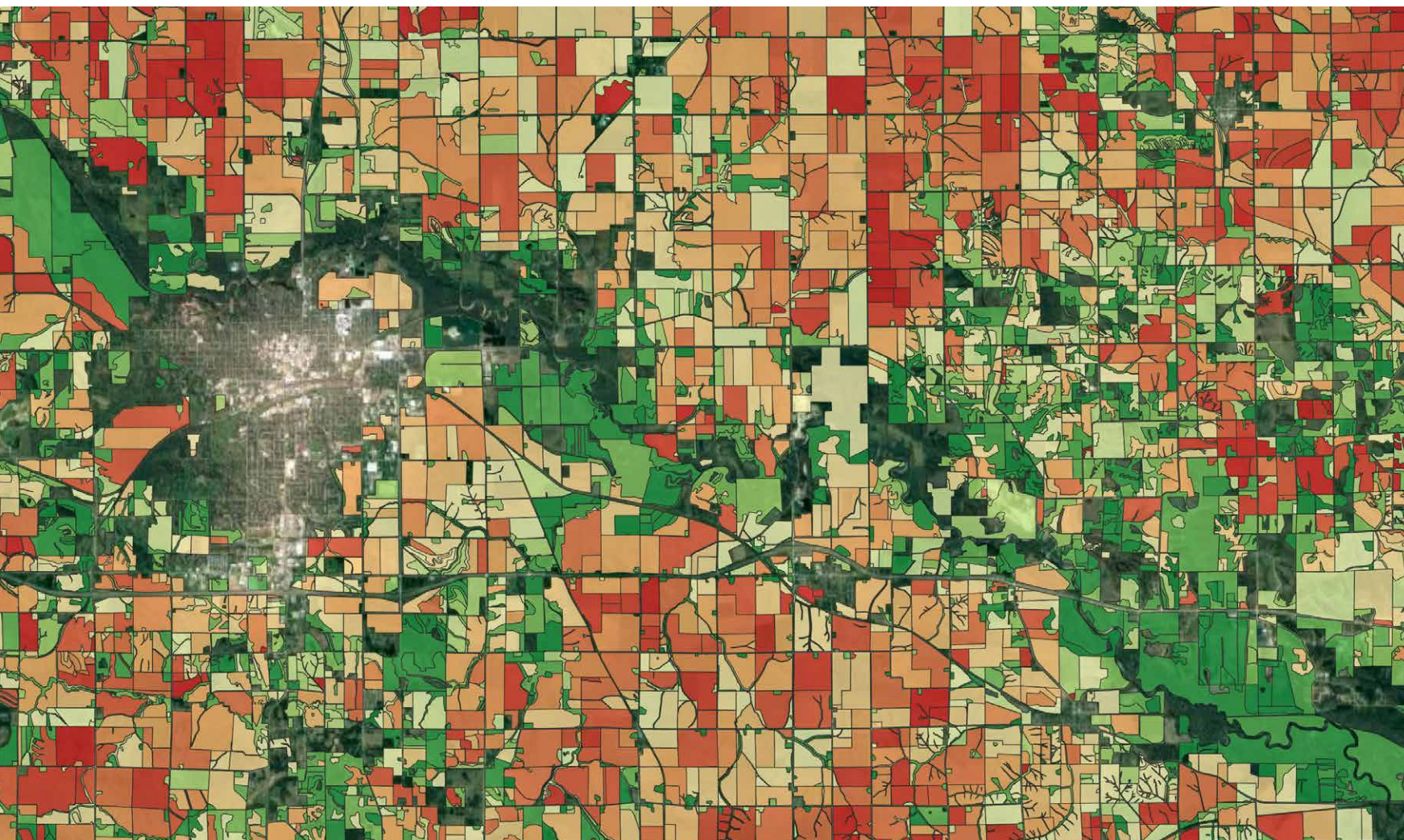
The original satellite exceeded expectations, successfully improving crop-yield predictions, spotting deforestation, monitoring lake and river levels, discovering uncharted islands, and much more. It paved the way for a multitude of other Earth-imaging satellites from NASA, other space agencies, and, later, private companies. Today, even the commercial satellites capturing high-resolution Earth imagery typically rely on Landsat for the precise calibration that makes their data useful for science.

But in a way, the whole concept was far ahead of its time. In the 1970s, before digital displays were common, scientists might print the data in the form of characters on a line printer, contour the characters with a marker, and then stand on ladders to view large-scale Landsat images, recalled Jeff Masek, who recently retired as Landsat project scientist at Goddard Space Flight Center in Greenbelt, Maryland, where NASA’s portion of the program is managed. Distribution meant mailing CDs or tapes. With the advent of high-speed internet and high-performance computing, access to – and applications of – Landsat data exploded in the 2010s. More recently, Masek said, cloud computing has enabled products built using the entire Landsat archive, a dataset most users simply couldn’t have downloaded.

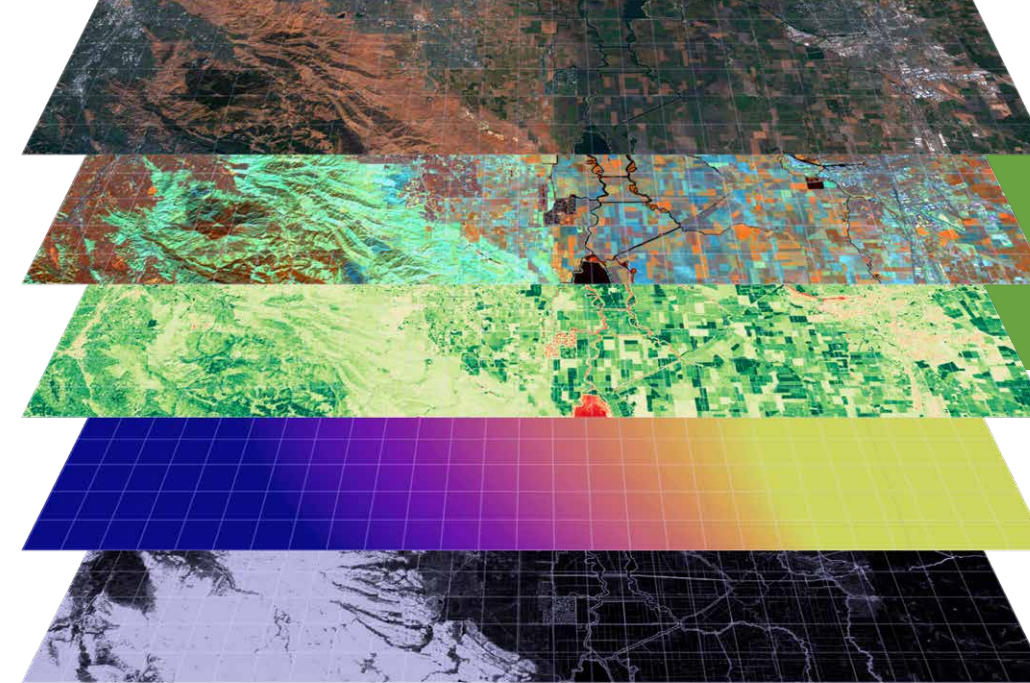
### Landsat Maps a Path for Companies

Maps became one of the most widespread uses for Landsat data, especially after 2008, when the Department of the Interior made all the imagery available free of charge. (Landsat is a joint mission between NASA and the USGS, which owns and distributes the data.)

While driver navigation software usually does not use satellite imagery, applications for hikers, runners, and bikers, for example, rely on it heavily. “For apps like Strava and AllTrails, satellite imagery is a significant enhancement for their users,” said Alistair Miller, who heads imagery products and partnerships for Mapbox Inc., naming two of the company’s prominent customers. Mapbox, based in Washington, D.C., provides a platform and map data that enable



This map created by the company Perennial shows the aggregated soil carbon level for each agricultural field around Marshalltown, Iowa, compared to the regional average, with reds indicating lower carbon content and greens showing more carbon. Perennial uses data from Landsat and other satellites to determine carbon levels. *Credit: Perennial Inc.*



Some of the datasets that go into Perennial’s models to determine soil carbon content include, from top down, visible wavelengths, infrared wavelengths, derived vegetation indices, temperature, and topography. Much of this information comes from the Landsat archive. *Credit: Perennial Inc.*

developers to create customized map-based applications. “Our main purpose is using imagery to enhance the context of the maps our customers create with our platform,” Miller said.

As a small start-up in 2010, he said, the company couldn’t spend millions on proprietary images and instead integrated data from Landsat. The global coverage and regular updates – capturing images of the same areas every 14 days – enabled the company to build huge, cloud-free images of Earth.

The company eventually started purchasing commercial, high-resolution images, and today Mapbox blends these with data from one of Landsat’s direct descendants, NASA’s Moderate Resolution Imaging Spectroradiometer (MODIS) to let users seamlessly zoom in and out of views.

Mapbox now has hundreds of employees and is valued at more than \$1 billion. Among its customers the company counts the Weather Channel, Tableau, ocean cruise companies, and travel planners; automakers like General Motors, Toyota, and BMW; media outlets like CNN, the *New York Times*, and *National Geographic*; and many others.

“We have an appreciation for NASA essentially starting the Earth-observation industry,” Miller said. “If it weren’t for Landsat, we wouldn’t be where we are in terms of understanding our Earth.”

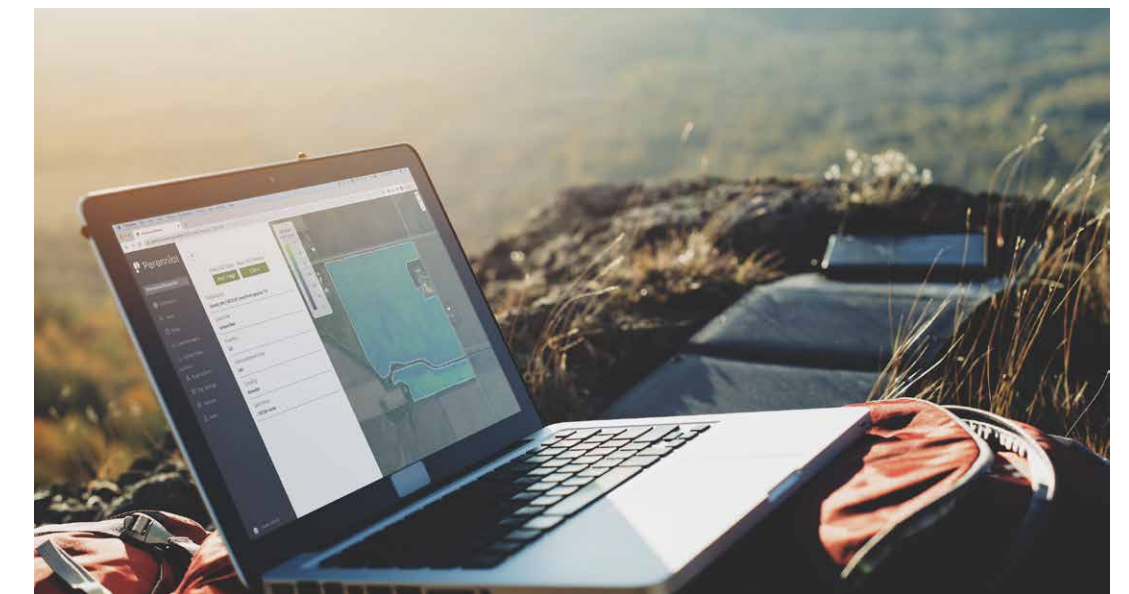
Perennial of Boulder, Colorado, learned how to use data from Landsat and other satellites to determine soil carbon levels. Now the company helps farmers who want to earn carbon credits for changing their practices, food companies that want to reduce their carbon footprints, and many others.

Even in this well-established niche, though, new capabilities continue to emerge. One up-and-coming company, Boulder, Colorado-based Perennial Inc. – formerly Cloud Agronomics – was founded in 2018 to validate sustainable farming practices by measuring carbon stored in the earth. To do this, the company relies on Landsat, as well as the European Space Agency’s Sentinel satellites.

Perennial is working to enable the emerging markets for carbon credits, through which farmers can get paid for using practices that maximize their land’s storage of carbon, explained David Schurman, cofounder and chief technology officer. These might include reducing soil tillage, planting cover crops during the off season, reducing fertilizer usage, and changing grazing practices. Satellite images can determine not only whether a farm is using these techniques but also the carbon content of the ground. “The amount of carbon in soil is highly correlated to the spectral reflectance of that soil at specific wavelengths,” Schurman explained.

### New Image Analysis Supports New Farming Techniques

Some of the most pressing questions people ask about Earth are about the food it’s producing. Agriculture and adjacent industries like farm equipment manufacturers and grain futures traders are among the heaviest users of Earth-imaging satellite data, which can help assess crop health and predict yields.



Perennial uses data from satellites like Landsat to help farmers monitor the carbon output and carbon sequestration of their operations, helping them access incentives like carbon credits and the business of environmentally conscious buyers. *Credit: Perennial Inc.*



Situated in the river delta that supplies most of California's freshwater, Brett Baker's family pear farm in Sacramento County is required to monitor its water use. It was impossible to get useful data, though, until the release of OpenET, a platform that uses Landsat data to calculate evapotranspiration.



Brett Baker checks a sprinkler on his family's pear farm. Farms like his in California's Sacramento-San Joaquin River Delta have to monitor their water use, but accurate estimates were nearly impossible until the advent of OpenET, a platform that uses Landsat data to determine the total amount of water evaporated and transpired from a given area. *Credit: Environmental Defense Fund*

Jim Kellner, Perennial chief scientist, noted that direct testing can also determine soil's carbon content, but "we're clearly not going to go out into the world and dig holes in every farm," he said. Satellite data, on the other hand, is available for all of Earth's land cover and "allows you to solve the problem at a price people are willing to pay," he said.

In the United States, carbon credit trading registries are managed by nongovernmental organizations, but in Australia, the government manages credits. There, Perennial has found abundant business in the red-meat sector, which is trying to reach carbon neutrality by 2030, said Schurman.

He said the company is also discovering interest among food companies that want to reduce their environmental impact, letting them audit suppliers' carbon footprints and make informed decisions about where to buy food and who to reward with incentives.

Other major Perennial clients are in the fertilizer, farm equipment, and agricultural lending businesses. In the last year, Schurman said, the company has tripled or quadrupled the amount of land it's analyzing for customers, covering hundreds of thousands of acres.

In addition to reducing greenhouse gases, said Kellner, "we want to make lives better for people involved in agriculture. We want to put money in the pocket of the farmer. And we want to reduce chemical inputs and have public health benefits by reducing exposure to things like pesticides."

Landsat provided the scientific-grade images that enabled all this, but Perennial had to figure out how to use that data to determine soil carbon content. While it's not unusual for a company to put in this kind of work, NASA and the

USGS also continually work to create tools and practical applications for Landsat. OpenET, the tool calculating water use at Baker's pear farm, for example, is the product of years of work by scientists at multiple universities and agencies.

"Many of the scientists and software engineers on the OpenET team have been working on these models and approaches for more than a decade," said Forrest Melton, NASA's project scientist for OpenET. The platform uses Landsat data to essentially determine how much energy from the Sun is reflected from Earth's surface, versus how much is absorbed by the surface and the air. The more evapotranspiration that is taking place, the more energy is absorbed, and the cooler the land surface appears in Landsat's thermal infrared imagery, Melton explained.

Baker, who, in addition to his family's Sacramento County pear farm, represents other landowners as an attorney for the Central Delta Water Agency, said the data available from OpenET has finally allowed landowners and regulators in the Sacramento-San Joaquin Delta to reach a consensus and work together. "We're in the most highly contentious place, maybe in the world, when it comes to water use," Baker said. "It's good public policy to start with a measure everyone can agree upon."

### What's Next for Landsat?

Reprocessing and uploading the entire Landsat archive to the cloud was the biggest effort of the last several years at the USGS Earth Resources Observation and Science Center, but Chris Crawford, the USGS Landsat project scientist, said researchers there and at NASA are constantly working to extract more information from Landsat data. The recent development of the ability to calculate surface temperatures, for example, led to the ability to calculate snow and ice melt and measure urban "heat island" effects.

"There's still so much more information to retrieve from Landsat's 50-year, multispectral data record," Crawford said. For instance, he said, the exceptional radiometric quality of Landsat 8 and 9 data might allow scientists to tease out current and historical information about water quality and floating algae blooms. Governments and businesses then find practical uses for each new stream of information. "The same data can be used over and over, so it just keeps adding value," Crawford said.

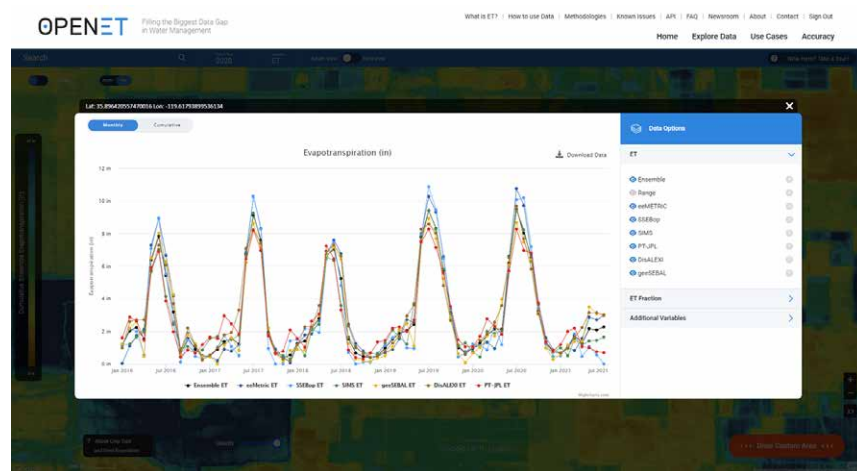
The latest Landsat satellite, Landsat 9, went into orbit in fall of 2021. NASA and the U.S. Geological Survey are already developing options for the next iteration of Landsat, currently known as Landsat Next. *Credit: NASA*



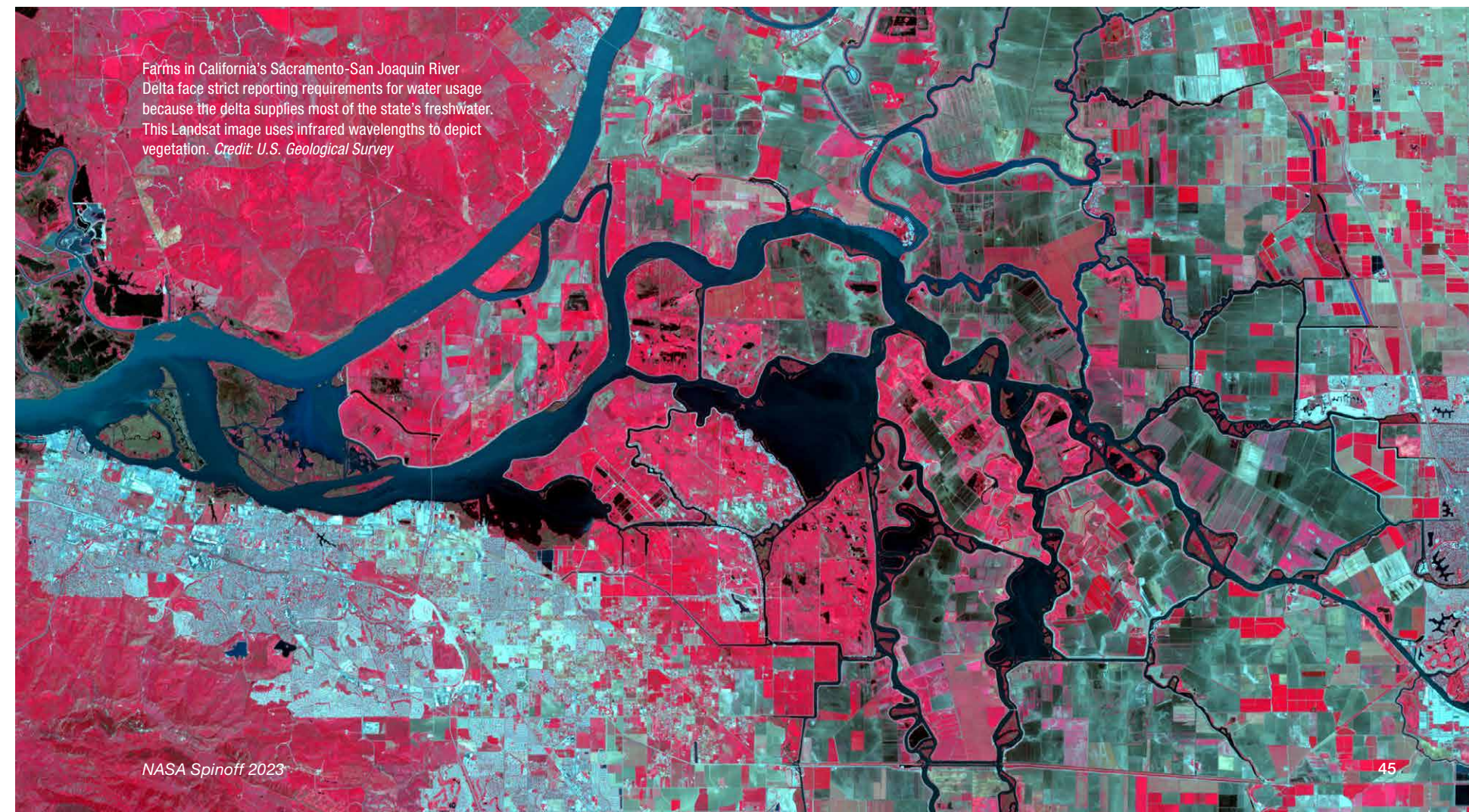
With a data user community that keeps growing, scientists and engineers are already looking forward to the next mission. NASA and the USGS are developing options for the next iteration of Landsat, currently called Landsat Next.

The USGS calculated that worldwide economic benefits of the Landsat program in 2017 alone totaled about \$3.45 billion, with additional downloads from cloud vendors bringing that sum to \$4.18 billion, a substantial return on the government's investment. For example, the total cost for NASA to develop and launch Landsat 9 was about \$700 million.

To the scientists and companies using Landsat data, the program is more personal than a dollar amount. "The analogy I always use is the family photo album," said Masek. "We don't realize how much Earth is changing until we look back through the photos. It's almost a physical record of how Earth looked 50 years ago and how it's changed." ●



A graph derived from the OpenET platform shows the annual fluctuation in evapotranspiration for a field between Fresno and Bakersfield in California. This information, calculated based on Landsat data, lets the landowner accurately report water usage. *Credit: Environmental Defense Fund*

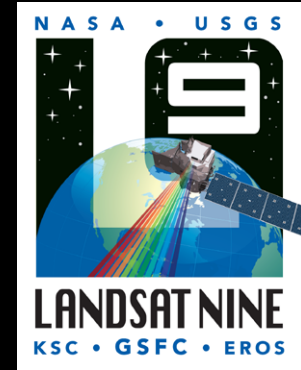


Farms in California's Sacramento-San Joaquin River Delta face strict reporting requirements for water usage because the delta supplies most of the state's freshwater. This Landsat image uses infrared wavelengths to depict vegetation. *Credit: U.S. Geological Survey*



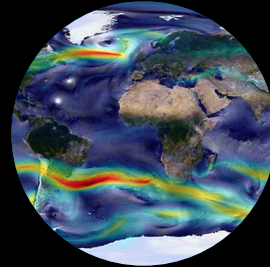
# Landsat Turns 50!

On July 23, 1972, NASA launched the Earth Resources Technology Satellite. Later renamed Landsat 1, this spacecraft was the first scientific orbiter designed to constantly observe Earth's surface and provide up-to-date data on the planet, from farm and forest health to the status of geological and water resources. In the 50 years since, eight more satellites have been built under the Landsat program, and the world has come to rely on the steady stream of Earth data they generate.



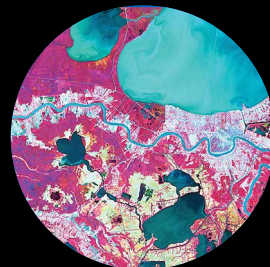
## Cloud Computing Technologies Facilitate Earth Research

Under a Space Act Agreement, NASA partnered with Seattle-based Amazon Web Services to make the agency's climate and Earth science satellite data publicly available on the company's servers. Users can employ high-performance cloud computing to work with massive datasets they never have to download.



## Water Mapping Technology Rebuilds Lives in Arid Regions

Using NASA Landsat and other remote sensing topographical data, New Braunfels, Texas-based Radar Technologies International developed an algorithm-based software that can locate underground water sources, providing water for refugees and other people in drought-stricken regions.



## Earth Images Enable Near-Perfect Crop Predictions

Boston-based start-up TellusLabs developed a crop prediction model that combines data from Landsat and other Earth-imaging satellites with historical data, weather models, and other information. Its first product, Kernel, predicted 2016 U.S. soy crop yields with 99% accuracy.

**Landsat 9**  
launched on September 27, 2021.

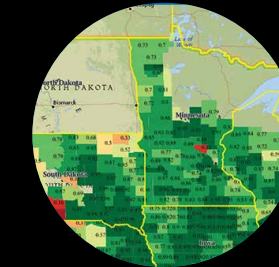
## Satellite Imagery Sheds Light on Agricultural Water Use

Keeping track of how water gets used across millions of acres of cropland is no simple task. Researchers created a program called EEFlux to make it easier. It works with Earth Engine from Mountain View, California-based Google to quickly map evaporation and transpiration, based on infrared images captured by Landsat's Earth-observing satellites.



## Landsat Data Enriches Google Earth

Mountain View, California-based Google has incorporated Landsat data into several products, including a time-lapse capability that animates 40 years' worth of change to any spot on the globe. Google also worked with NASA and the University of Maryland to map global changes in forest cover over many years – the first survey of its kind.



## Algorithms to Detect Clouds Forecast Global Crop Production

In preparation for Landsat 8, NASA put out a call for software to identify cloud cover. State College, Pennsylvania-based Geospatial Data Analysis Corporation, with NASA funding, developed an algorithm that is now used for everything from increasing food security in the developing world to guiding futures trading on Wall Street.



## In the Right Hands, NASA Satellite Data and Analysis Make Earth Better

By making satellite data and imagery available, NASA is contributing to humanitarian and environmental efforts across the globe. This includes locating illegal gold mine operations like Washington, D.C.-based Earthrise Alliance did (with the help of ninth-graders), as did Ethiopia-based Digital Earth Africa. The data was also used by Portland, Oregon-based Mercy Corps to inform farmers in Africa about weather patterns and groundwater sources.

**Landsat 8**  
launched on February 11, 2013,  
and is still going strong.



# An Electronic Traffic Monitor for Airports

## Ground traffic management program saves passengers and airlines time while cutting fuel costs

Charlotte Douglas International Airport served as the first test site for developing the Integrated Arrival, Departure, and Surface (IADS) system. Allowing passengers to wait in the terminal instead of on the plane is one benefit of more-efficient runway scheduling. *Credit: Charlotte Douglas International Airport*

If every commuter drove the same few roads at the same time every day, the traffic would be unbearable. That's exactly what's happening in the skies above the nation, called the national airspace (NAS). Multiple flights from different airlines try to use the most direct flight paths, converging on the same airports. With limited runway space, that causes jumbo-sized traffic congestion. So NASA worked with the Federal Aviation Administration (FAA), commercial airlines, and airports to develop and test a new program to manage airport traffic on the ground – the Integrated Arrival, Departure, and Surface (IADS) system. In 2022, the FAA began incorporating IADS capabilities at 27 of the busiest airports in the country.

“The majority of uncertainty in the NAS can be attributed to surface operations, and in particular, uncertainty related to when a flight will be available to push back from the gate,” said Jeremy Coupe of NASA's Ames Research Center in Silicon Valley, California, who served as the deputy chief engineer for the technology demonstration. So Ames focused on how to improve managing traffic on the ground and scheduling departures.

Ames, which houses the Aviation Systems Division of NASA's Aeronautics Research Mission Directorate (ARMD), is at the forefront of enabling improvements in aeronautics. For decades, ARMD has conducted research and developed innovative technologies to transfer to the entire aviation



Increased air traffic makes it more challenging for airports to manage jumbo-sized traffic with limited space on the ground. So NASA worked with the commercial airlines, airports, and the Federal Aviation Administration to develop a new system to make flight times more predictable. *Credit: Charlotte Douglas International Airport*

Charlotte Douglas International Airport in Charlotte, North Carolina, the second-busiest airport on the East Coast, hosted the IADS system development. Giving passengers time in the terminal to grab a meal or charge their phones is one benefit of efficient takeoff scheduling that means less time spent on the tarmac waiting to take off.

community in support of the ever-growing commercial flight industry. The technology demonstration that resulted in IADS, called Airspace Technology Demonstration 2 (ATD-2), was a six-year effort by NASA Aeronautics to build a completely new software that could help improve airports' data-sharing and traffic movement on the ground, according to Coupe (*Spinoff 2020*).

### Ending Tarmac Gridlock

ATD-2 technology is already helping airline flight managers coordinate plane movement with a commercial software that integrates arrivals, departures, and surface traffic. But managing all activity for all aircraft on the ground requires a sophisticated program.

Just as a traffic officer can prevent gridlock at a busy intersection, IADS is designed to prevent similar traffic tangles. The first test site for the program development was Charlotte Douglas International Airport in Charlotte, North Carolina. It's the second-busiest airport on the East Coast but has only three runways. About 75% of its arrivals and departures are connecting flights.

“Knowing that you're going to get where you need to go when the airline says it's going to deliver you is what people stress about when they're traveling, especially if they're trying to make connections in an airport like Charlotte,” said Lee Davis, communications director for the airport.

Many factors, including weather, influence timeliness, but making ground operations run predictably is fundamental.

Before IADS, one struggle the airport faced was a technology mismatch – the airport's control tower used one software program and ground management used a different one, with no way to integrate them. A phone call was the most common way to notify each other about changes or problems. With approximately 115 aircraft on the ground at any time, a delay in communication could create complications, according to Davis. A plane leaving the gate before an order to delay was received would mean several planes could end up waiting in line at the runway.

To help NASA create a baseline understanding of airport operations, the Charlotte airport provided blueprints of the runways and buildings, procedures, and any information needed to digitize the process of getting planes and their passengers where they need to go on schedule.



Fort Worth, Texas-based American Airlines gave NASA a wealth of information about everything from wait times and crew schedules to ground services. In return, the IADS system helped the airline save hundreds of thousands of gallons of jet fuel, preventing thousands of tons of carbon emissions.

### 'A Million Baby Steps'

For ramp controllers, managing airplane movements involves hundreds of people and thousands of procedures. American Airlines Inc. operates 700 or more flights out of Charlotte a day, so the Fort Worth, Texas-based company was able to provide NASA a wealth of information about everything from passengers, wait times, and crew schedules to ground services and FAA tower communications.

"In the very beginning, it was basically a million baby steps, which included our challenges as ramp controllers. That morphed to including the pilots and the airlines that fly in and out of Charlotte," said Kerry Facer, American's ramp traffic manager. The test demonstration participants provided input about priorities and then feedback on the new program's performance, including the end-user display that shared the data.



The focus of Airspace Technology Demonstration 2 was IADS, a software that coordinates flight schedules between the ramp, tower, terminal, and center control facilities. This visual representation of data helps minimize delays on the ground. Credit: NASA

Departure surface metering tracks and helps coordinate aircraft movement while they're on the ground. Facer explained that seeing the exact location of every plane, even when it was in motion, was revolutionary. The visuals made it easier to coordinate the interrelated activities. The resulting benefits were tremendous.

When flights were assigned an order for takeoff – first, second, or third – the airline could hold each plane at the gate longer, only starting engines when it was time to push back. Taxi time was also shorter because the place in line was set. Takeoffs occurred within minutes of leaving the gate.

During the first four years of ATD-2, it's estimated the airlines at Charlotte Douglas realized a savings of over a million gallons of fuel, almost 11,500 tons of carbon dioxide emissions, and 5,948 hours of engine run time and the related maintenance costs. Savings for flight crew costs were over \$1.3 million, and the value of passenger time saved was approximately \$4.4 million, thanks in part to a 916.4-hour reduction in delays.



Holding airplanes at the gate until just before takeoff allows them to run on power supplied by the airport. American Airlines saved hundreds of thousands of gallons of fuel, as well as maintenance costs and thousands of tons of harmful emissions by only running engines when arriving at and leaving the gate. Credit: NASA

A significant innovation that made it all possible, according to Facer, is the visual display that automatically populated data related to each plane on the surface. If the IADS system identified a delay, the impact for every flight was provided almost immediately. Facer appreciated the opportunity to develop the user interface in particular. "In every situation, NASA is able to come up with a solution or a way to fix the things that need to be fixed," he said.

### Filling the Gaps

The last two years of the technology demonstration tested the program in an airspace with multiple airports at the North Texas Metroplex – Dallas Fort Worth International and Dallas Love Field airports. Dallas-based Southwest Airlines Co. volunteered its flights at Love Field to help demonstrate another feature of IADS, which lets airlines review and revise flight routes, requesting changes to avoid restrictions that can cause delays.

Flights are tracked while in the air, but metering enables more efficient management of the flow of an aircraft through all phases of the flight from departure gate to arrival. Making changes to a flight path also contributes to more efficient operations overall.

"We've got a lot more data on aircraft movement once it's in the air, but we typically have a big gap while it's on the ground," said Rick Dalton, director of airspace and air traffic management for Southwest. Uncertainty leads to inefficiencies.

He estimates the airline will save \$11 million annually because IADS provides data for every aspect of ground movement. In addition to burning less fuel, the savings will come from the ability to predict the ripple effect of events on the ground. With near-real-time data related to on-time departures and delays, Southwest can actively address issues related to connections for crew, customers, and cargo.

Because it's impossible to know in advance when planes will be ready, the airlines must schedule quite a bit of time between departures and arrivals to make sure planes can access the runways. Airlines require an efficient way to stay on top of the state of

Southwest Airlines participated in the second phase of the IADS demonstration at Dallas Love Field airport. The visual display of near-real-time flight data helped the airline deploy staff more efficiently, saving thousands of hours of crew time. Credit: Southwest Airlines Co.

readiness for each flight in order to let the FAA know when each can be scheduled for takeoff. IADS automates this two-way data flow, removing a lot of that uncertainty.

Airlines were able to better manage their fleets. The FAA could facilitate flights better. And passengers could count on reliable flight information. So that more airports will enjoy these benefits, the FAA is integrating IADS capabilities into its existing system and will eventually make it available to some of the busiest airports. All of the airlines credit NASA with making this possible.

"It's critical that NASA stay engaged. They're helping us overcome challenges. It would have taken years longer without their problem-solving expertise," said Dalton. ●

Dallas-based Southwest Airlines tested and provided feedback on the IADS feature that enables airlines to review and revise flight routes and request changes. The opportunity to avoid restrictions that can cause delays contributes to more efficient operation, which translates into cost savings.

*"In every situation, NASA is able to come up with a solution or a way to fix the things that need to be fixed."*

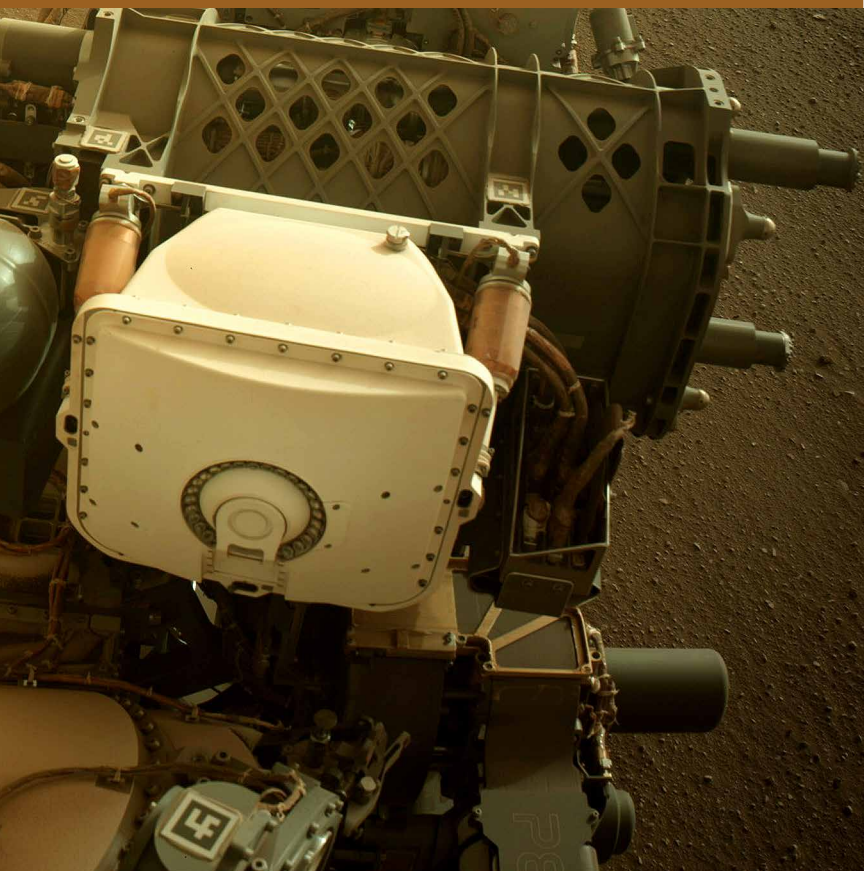
*Kerry Facer, American Airlines*





# Cloning Metal Parts for Space and Earth

Software for modeling metal parts before 3D printing speeds development, cuts costs for NASA and business



NASA rovers benefit from lightweight, durable metal parts fabricated using additive manufacturing. The Planetary Instrument for X-Ray Lithochemistry (PIXL) instrument on the Perseverance rover has several of these parts that have proven they can withstand the harsh conditions on Mars. *Credit: NASA*

Compared to cloning a sheep, copying a metal part should be simple. It's not, though, especially if that part is to be built by a 3D printer.

Additive manufacturing – or 3D printing – can save weight, time, and money and often produce sturdier parts than otherwise possible.

For these reasons, NASA is interested in using the technology to make rover components, ion engines, and other hardware, but the agency needs to know the parts will be reliable. One way to prove them is with software that creates a digital version, or “clone,” of the part to be printed.

It's a complex task. Machines for 3D printing with metal can work in a number of different ways, and factors like power level, laser intensity, and alloy properties affect the final product, often in ways that are hard to predict. So NASA invested in a company that already specialized in creating digital versions of gears and other components. Now DigitalClone for Additive Manufacturing (DC-AM) can perform virtual testing of parts at multiple stages of the process from initial print to final part quality before a single piece of hardware is printed.

NASA's Jet Propulsion Laboratory in Southern California worked with Sentient Science Corp. of Buffalo, New York, to build a modeling program with the help of Small Business Technology Transfer contracts.

## Physics in Real Life

“When you're dealing with expensive alloys or complex shapes, you'd like to have a deeper understanding of what will be happening to the parts during the building process,” said Bryan McEnerney, materials technologist at JPL. Computational material science can minimize the risks connected to printed parts. That could be financial risk, schedule risk, and technical risk, according to McEnerney.

Conventional manufacturing can be time-consuming and expensive and add more mass to a system, but the parts are proven reliable. That's essential when lives of astronauts and billions of dollars of investment are at stake. Additively manufactured parts are still too new to have such a track record of success, making the use of a digital clone important.

“If we model parts, it will save a lot of time and maybe even predict where we might have issues as we're designing them,” explained McEnerney. Modeling brings together the part, its use in real life, and the impact of the conditions it will experience over time.

DC-AM includes three modules for designing and testing a part, which rely on the principles of physics to dependably represent what takes place in any 3D printer. Process modeling takes into account printer parameters, such as power, layer thickness, and laser beam dimension, and their effects on the metal. This contributes to residual stress and distortion predictions for a part. Microstructure modeling predicts the grain structure and porosity necessary to achieve the

A physics-based modeling program partly funded by NASA STTR contracts, called DigitalClone for Additive Manufacturing, tests virtual metal parts before fabrication. Many industries can benefit from the cloud-based software developed by Buffalo, New York-based Sentient Science.

desired properties. Finally, fatigue modeling forecasts the potential damage caused by extended use, such as the onset of cracks, that a part will experience in a specific application.

This approach, called integrated computational materials engineering, yields high-fidelity data that's particularly important for NASA when fabricating unconventional parts, according to McEnerney. “The entire agency often has challenges with certain high-complexity parts, because a lot of what we do is hard.”

## Trial and Error

Makers of additive-manufacturing machines provide some recommended print settings for specific types of metal powder feedstock, according to Jason Rios, senior vice president with Sentient Science. But “there's a lot of uncertainty” when creating a new part, he said. “You have to try to search for that right combination of print parameters to get the part quality that you're looking for.”

Before DC-AM modeling, that meant creating and tracking different settings for various materials before subjecting each part to physical tests. That's an expensive trial-and-error approach. It's been worth the effort, given the opportunity to create more efficient components by using new geometries, but it's not sustainable.

“What's really unique about DigitalClone Additive Manufacturing is the ability to model the process, predict the microstructure, and predict how long the part's going to last in its intended application based on the stresses and the loads it's going to see,” said Rios. While some of these functions are possible with other programs, this combination is the first of its kind.

Thanks to the Amazon Web Services high-performance computing that runs DC-AM, anyone can develop and optimize any part, building and testing it in a virtual environment. When it comes to replacing an existing part design, the program can quickly determine whether the new part is going to meet the design specifications and the intended lifespan for a particular purpose, explained Melissa McReynolds, vice president of automotive operations with Sentient Science.

The company has a number of automobile manufacturers putting the program through its paces to identify how 3D-printed parts might fit into existing and future car designs. The program can be used in any industry that relies on metal parts, and the Japanese company Matsuura Machinery is using DC-AM to provide

quality control for its 3D-part-printing arm. And the company is working with Sentient Science to include the program in a new 3D printer that will monitor parts while they're being created. If a flaw is detected that will result in a defect, the system will automatically cease production, remove the damaged layer, and resume the process.

## 'PhD-Level Expertise'

This new modeling program builds on the success of the first DigitalClone software, also built with NASA's help, which predicts the lifespan of machine components (*Spinoff* 2016). New versions, in addition to DC-AM, support specific industry needs: DC-E for engineering, DC-OM for wind energy, and DC-RM for rail.

Businesses that 3D print parts need to accurately predict how long a part will function so they can create maintenance and replacement schedules without compromising safety. For them and their customers, the expertise NASA contributed to the program adds another level of quality assurance.

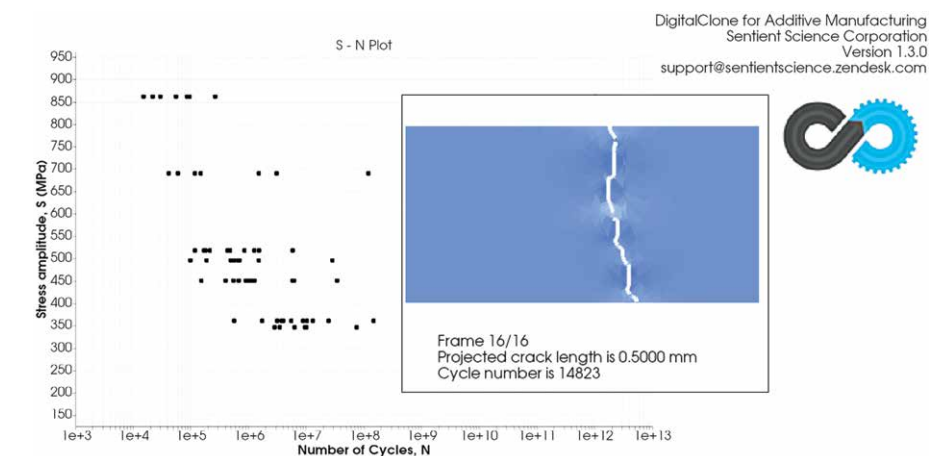
“Through that collaboration with JPL, we were able to include their knowledge in creating a product that allows a customer to do that same type of analysis without having to acquire the PhD-level expertise our team has,” said Rios.

The agency benefits from the significant cost and time reduction compared to conventional physical testing for new component designs, materials, and processes. McEnerney noted that the partnership with Sentient Science has created a new resource for “the greater engineering community.”

“We're looking to continually evolve and hear new voices, to come up with new technologies,” said McEnerney. “By leveraging small businesses, we're going to get a better outcome for the agency and for the country.” ●



This hot-fire test of a 3D-printed rocket engine injector was successful, with post-test inspections revealing the injector remained in such excellent condition and performed so well that it went into acoustic tests. Now engineers can use DC-AM to design, build, and test parts like this in a virtual environment created by Sentient Science. *Credit: NASA*



Testing a 3D-printed part allows the engineer to learn its properties and predict its potential lifespan. A program called DC-AM creates a “digital clone” to identify potential problems such as this fatigue-prediction test result and provide a representative fatigue-cracking pattern. *Credit: Sentient Science Corp.*



# NASA Research Illuminates Medical Uses of Light

Experimentation helped demystify, legitimize, and simplify medical uses for long-known but little-understood light therapy



NASA, the Medical College of Wisconsin, and the University of Alabama at Birmingham Hospital worked together on clinical trials for the use of Quantum Devices' red-light-therapy devices to treat side effects of radiation and chemotherapy in cancer patients preparing for bone marrow transplants. The devices successfully reduced painful oral mucositis sores caused by the cancer treatments. Credit: NASA

Can light help a wound heal faster? Alleviate pain? Prevent loss of eyesight?

Although decades of studies indicate it can – including extensive research funded by NASA – the mounting evidence hasn't always drawn the attention that might be expected for such a striking discovery.

This may be because the science behind it hasn't been well understood. For example, although a Danish physician received a Nobel Prize in 1903 for discovering that exposure to concentrated red light accelerated the healing of sores, he remained reluctant to put it into practice without understanding why it worked.

A larger barrier to acceptance, though, has probably been that it simply sounds unbelievable.

In a 1989 paper about the health benefits of low-powered laser light, biophysicist Tiina Karu noted that the treatment appeared “highly incredible and even mysterious.” What's more, she wrote, its effectiveness against many different ailments only added to doubts by creating the appearance of a proverbial snake-oil panacea.

Karu hypothesized that red light treated many afflictions because it improved overall cell function by stimulating the mitochondria that drive metabolism in animal cells. This would accelerate cell production and relieve oxidative stress, a factor that causes inflammation and symptoms of aging and ultimately contributes to diabetes, cancer, neurodegenerative diseases, and other illnesses.

Today it's thought that red and infrared wavelengths are absorbed by cytochrome C oxidase, a key enzyme in cellular metabolism, and probably by other light-sensitive chemicals, triggering a cascade of effects within the cell.

Karu and others began to suspect that “uniform” laser light probably wasn't necessary for producing beneficial effects, but it was NASA that finally answered that question after the space agency stumbled on it accidentally.

## LEDs for Plants, Then People

In the late 1980s, engineer Ron Ignatius worked at a company that partnered with the Wisconsin Center for Space Automation and Robotics (WCSAR), which was funded by NASA's Marshall Space Flight Center in Huntsville, Alabama. As light-emitting diode (LED) technology entered the commercial market, Ignatius worked with WCSAR to study this new lighting for growing plants in space. In 1989, Ignatius founded Quantum Devices Inc., and Small Business Innovation Research (SBIR) funding from NASA paid the company to complete an LED plant-growth unit that grew potatoes on the space shuttle in 1995.

Multi Radiance Medical of Solon, Ohio, builds light-therapy devices based in part on NASA-funded research. NASA helped with experiments confirming the efficacy of light treatments for certain health applications and proving they could use safe, portable LED technology.



Multi Radiance Medical's line of light-therapy devices, combining LED and super-pulsed laser light, includes products specially designed for use on animals. Credit: Multi Radiance Medical Inc.

But the research had a side effect. The LEDs were red and blue because these are the most efficient light wavelengths for driving photosynthesis, and NASA scientists who spent time working with their hands under the lighting found that abrasions on their hands seemed to heal faster than normal.

This was how NASA stumbled into the world of medical light therapy. The agency saw a possible solution to a longstanding problem of space travel: without gravity, astronauts' muscles and bones atrophy, and any wounds heal slowly, all of which endangers missions.

Ignatius also became interested in possible medical uses for LEDs. When he learned that Harry Whelan, a neurologist at the Medical College of Wisconsin, was investigating medical applications of light, he reached out.

Between 1995 and 2003, a series of eight NASA SBIR contracts, mostly from Marshall, funded experimentation on medical uses of LEDs, carried out between Quantum Devices, the Medical College of Wisconsin, and a few other entities.

Near-infrared laser light had recently been shown to speed healing of wounds – particularly those that were starved for oxygen – by boosting the production of growth-factor proteins, collagen,

*“NASA made it simple, accessible, easy to use, and safe.”*

*Doug Johnson, Multi Radiance Medical*



and blood vessels. But lasers had drawbacks, said Helen Stinson, who oversaw the work as a senior engineer in Marshall's Spacecraft and Vehicle Systems Department. "With lasers, you've got to be careful not to damage surrounding tissue, and they also use a lot of energy and they're expensive," said Stinson.

Besides addressing these issues, LED arrays also can be designed to emit multiple wavelengths, and they can cover a larger area than a laser.

### Light Treatments Prove Themselves

Through experimentation, the researchers showed that high-intensity red and near-infrared LEDs significantly accelerated the healing of oxygen-deprived wounds in rats and also sped the growth and proliferation of skin, bone, and muscle cell cultures from mice and rats. The team supplied LED devices to U.S. Navy crews for treatment of training injuries. These produced more than a 40% greater improvement in musculoskeletal injuries and a 50% faster healing time for lacerations, compared to control groups.

Around that time, Whelan and colleagues showed that irradiation with Quantum Devices' red LED arrays prevented methanol from causing blindness in rats, leading them to suggest light therapy as a treatment for retinal ailments from glaucoma to age-related macular degeneration.

With additional military funding, Quantum Devices advanced this technology as the handheld WARP 10 – for Warfighter Accelerated Recovery by Photobiomodulation – to treat pain, inflammation, and minor injuries in military personnel. The U.S. Food and Drug Administration (FDA) cleared its use for the temporary relief of minor muscle and joint pain, arthritis, and muscle spasms. The company commercialized the device (*Spinoff* 2005) and followed it in 2007 with the larger and more advanced WARP 75 (*Spinoff* 2008).

Quantum Devices' partnership with NASA and the Medical College of Wisconsin, along with the University of Alabama at Birmingham, culminated with a clinical trial using the WARP 75 to successfully treat acute sores that form in patients' mucus membranes following powerful doses of radiation and chemotherapy that prepare them for bone marrow transplants.

### An Industry Emerges

Two years after Ignatius' death in 2011, Quantum Devices left the field of medical LEDs, and NASA didn't end up using the technology in space. By then, however, the NASA-funded research had given rise to a growing multitude of companies commercializing the technique.

Not all those devices, however, are equal, said Robin Schumacher, who handled marketing for Quantum Devices during the WARP years. "The WARP is still leaps and bounds better technology than 99% of what's on the market today," said Schumacher, noting that the devices used advanced construction to efficiently produce intense, evenly distributed irradiance at specific wavelengths without dangerous heat.

And the NASA-initiated research not only advanced scientists' understanding of different wavelengths' ability to penetrate the body and elicit cellular responses but also included some of the first experimentation on optimizing doses with different intensity levels and treatment times, said Schumacher.

*"With lasers, you've got to be careful not to damage surrounding tissue, and they also use a lot of energy and they're expensive."*

*Helen Stinson,  
Marshall Space Flight Center*

Many of Multi Radiance Medical's customers are athletic trainers, physicians, physical therapists, and chiropractors who use light therapy in their practices. The technology's applications are primarily for relief from pain, inflammation, and stiffness.

*Credit: Getty Images*

Devices that aren't built on this knowledge "are just light bulbs," she said.

After Ignatius' death, Schumacher started working at Multi Radiance Medical Inc. of Solon, Ohio, which produces light-therapy devices for physical therapy, sports medicine, veterinary applications, and more. The company was founded in 2006 and has incorporated many of the findings from NASA and partners.

Multi Radiance devices now combine simultaneous super-pulsed laser and LED light, said Doug Johnson, the company's senior vice president of clinical and scientific affairs, explaining that the rapid laser pulses create an acoustic effect on tissue that increases LED light penetration.

Before NASA's involvement, light-therapy devices were entirely laser-based, making them unsafe for home use, said Johnson. "So it was only available at clinics. NASA made it simple, accessible, easy to use, and safe."

### Smaller Devices, Bigger Reach

Multi Radiance started out making large, stationary devices for clinics, but as the company began following the WARP example with handheld, cordless devices around 2010, it was able to move into both the home market and veterinary applications. "If you're treating a horse in a barn, you can't have cords and plug in a console," Johnson pointed out. Some of the company's veterinary devices also use blue light for treating infections and other antibacterial applications, which the FDA still hasn't cleared for use on people.

The company's business is now evenly split between home devices and the stationary units still used by physicians, athletic trainers, physical therapists, and chiropractors. The devices vary by coverage area, power level, and wavelength combination, and some add electrical stimulation or magnetic fields to increase light absorption. Human applications are primarily for relief from pain, inflammation, and stiffness.

Multi Radiance now has almost 50 employees and sells tens of thousands of devices each year in 32 countries, said Johnson.



Different Multi Radiance Medical light-therapy products are intended for use by athletes, trainers, and doctors, as well as pet owners. The devices are based in part on research that NASA funded in the 1990s and early 2000s. *Credit: Multi Radiance Medical Inc.*

He credited NASA with advancing and popularizing the field by taking a chance on a possible treatment for inhibited healing and atrophy in space. "It wasn't until NASA took a hard look and said it might work that you started seeing commercial development," Johnson said. "They went after something no one could treat and found something so simple and easy it's incredible."

Now Multi Radiance is expanding its consumer line, with a second-generation home device planned for release in 2022.

As the science becomes better understood, Johnson said, the company also hopes to advance more specific medical applications. For example, Multi Radiance has patented an LED-arrayed eyepatch for treating disorders like diabetic macular edema, as well as a device for reducing symptoms of fibromyalgia. Both are in clinical trials.

"But even as the biological effects of light become clearer," Johnson said, "it's hard to say what mechanisms of action are at work. Light works on so many different conditions it's hard to identify just one underlying mechanism, but we're getting closer." ●



The late Quantum Devices founder Ron Ignatius holds what he referred to as a "photon cannon," capable of delivering a full watt of energy from LEDs alone. Marshall Space Flight Center partnered with Quantum Devices and others to explore the health benefits of certain light wavelengths and prove they could be effectively delivered by LEDs, giving rise to a light-therapy industry. *Credit: NASA*



# Weather Forecasters Adopt NASA's 'Occult' Science

**Radio occultation, pioneered by NASA for other planets, offers cheaper, better Earth weather data**

Halfway through 2020, there was almost no aspect of modern life that hadn't been affected by the COVID-19 pandemic, and weather forecasts were no exception. Weather agencies rely in part on data from atmospheric sensors on commercial aircraft, most of which were grounded. So Vienna, Virginia-based Spire Global Inc. offered weather agencies atmospheric data its constellation of small satellites was collecting by a technique, relatively new to weather forecasters, called radio occultation. The European Centre for Medium-Range Weather Forecasts accepted the offer.



Having used radio occultation to profile the atmospheres of the rest of the solar system's planets, NASA now plans to use the technique to detect and analyze heavy rainfall on Earth, especially over oceans, where data is sparse. Credit: Getty Images

"They assimilated it into their models and found that our radio occultation data was able to make up for the lack of in-situ data from airplanes," said Vu Nguyen, radio occultation orbit scientist at Spire.

This method of atmospheric sounding wasn't entirely new to weather scientists, though not much radio occultation data had been available previously. But it was already ancient history to researchers at NASA's Jet Propulsion Laboratory in Southern California, where the technique was pioneered and first used to gather data on the Martian atmosphere from the Mariner spacecraft in the 1960s.

Only now, however, is the technique poised to improve accuracy and reduce costs of atmospheric modeling for weather forecasts, with further implications for other Earth sciences. Accurate weather prediction helps protect lives, health, and property and has significant benefits for industries such as agriculture, energy, construction, and transportation. Weather and atmospheric data is also foundational to understanding and predicting long-term trends in climate change.

Radio occultation is the observation of changes to a radio signal from a spacecraft as it passes behind a planetary body. As the signal's path to a distant observer moves closer to the planetary surface, it passes through – or is "occulted" by – the planet's atmosphere, which bends the signal. The degree of this refraction, as well as other effects on the signal, reveal information about the atmosphere's temperature, pressure, and moisture.

After sounding the Martian atmosphere, JPL scientists used the technique to characterize the atmospheres of the rest of the solar system's planets and a few of their moons. But observing Earth with radio occultation would be trickier. For one thing, both the transmitter and receiver have to be off the planet being observed. To take readings from other planets, the receiver could sit on Earth. But to observe our own atmosphere, the receiver would have to be in space, and receivers of the day were large and heavy. A bigger challenge was that, for the data to add to existing knowledge of Earth's atmosphere, a large number of signals and receivers would be needed.

In the 1980s, a NASA scientist and future founder of GeoOptics proposed repurposing a technique NASA had pioneered for learning about other planets' atmospheres to sound Earth's atmosphere. Now the Pasadena, California company offers atmospheric data to improve weather forecasts.

## GPS Guides Radio Occultation Home

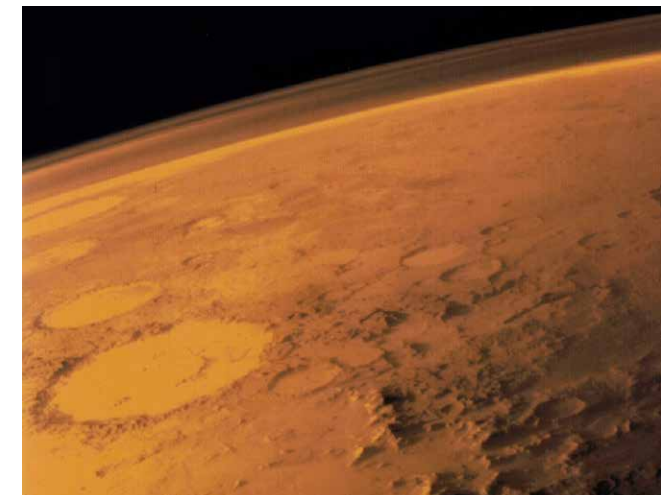
By the late 1980s, though, these problems were resolving themselves. Advances in computing power produced smaller receivers, and a multitude of new space-based radio transmitters were being placed in Earth orbit as the U.S. Air Force launched the first GPS satellites. In 1988, JPL scientist Thomas Yunck wrote the first proposal for using GPS signals to gather radio occultation data for Earth weather and climate observations.

The technique offered clear advantages over the technology that still dominates atmospheric observation from space. The signals are not blocked by clouds, and because they pass horizontally through the atmosphere at a series of different altitudes, they can produce more accurate, detailed vertical profiles of the air than any other satellite technology. Because they aren't subject to drift or bias, they can be used to calibrate other types of sensors. And GPS radio receivers were already smaller and cheaper than the instruments on traditional weather satellites, such as passive infrared and microwave sounders.

Yunck's proposal caught the attention of researchers at the University Corporation for Atmospheric Research (UCAR), who successfully lobbied their sponsoring organization, the National Science Foundation, to fund a demonstration of the concept. The GPS/MET instrument, adapted by UCAR and partners from an existing JPL receiver, was placed on NASA's Microlab 1 minisatellite and launched in 1995. JPL helped modify the receiver's software and analyze the experiment's results, which, although limited, resoundingly proved the feasibility of the approach.

*"What NASA did was take a complex system and put the pieces in place to let science happen at a very low cost, without always knowing what we were solving."*

*Thomas Meehan, Jet Propulsion Laboratory*

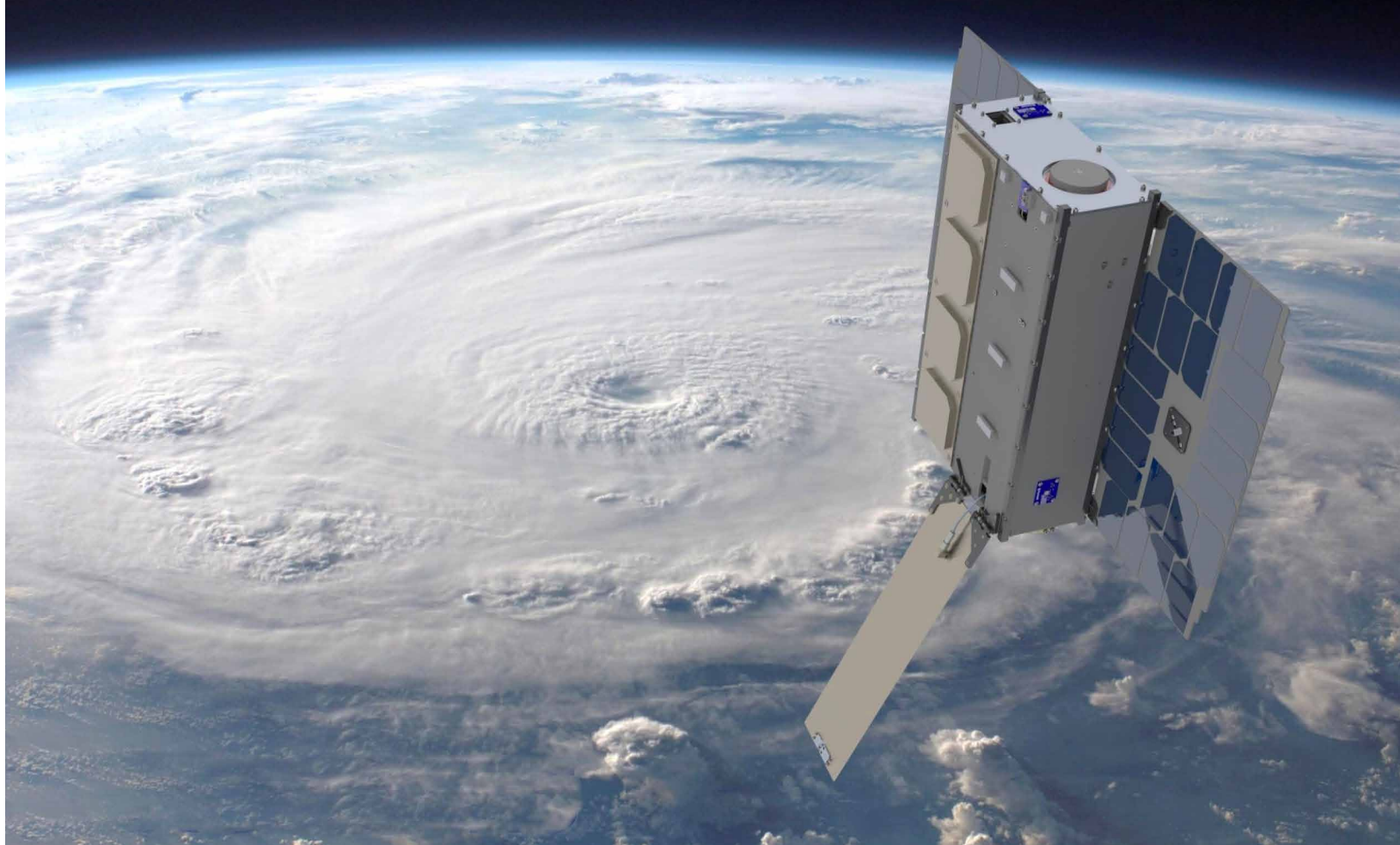


NASA's Jet Propulsion Laboratory pioneered radio occultation in the 1960s, with the help of Stanford University, to gain the first information about Mars' thin atmosphere by analyzing signals from the Mariner IV space probe after they had passed through the Martian air. Credit: NASA

NASA then sponsored five more demonstrations mounted on satellites already scheduled for launch, testing more capable receivers and laying the groundwork for the first constellation of radio occultation satellites. COSMIC-1 (Constellation Observing System for Meteorology, Ionosphere, and Climate), a group of six small satellites launched in 2006, was funded by the Taiwanese space agency, spearheaded by UCAR, and supported by NASA, the National Oceanic and Atmospheric Administration (NOAA), and others. Over the next 14 years, COSMIC-1 produced millions of atmospheric profiles, and most major weather agencies started working these into their models.

By the time COSMIC-2 launched in 2019, a few companies had already put the first commercial radio occultation satellites into orbit. Although the commercial market for this data was barely emerging, there were clear incentives for companies to enter the field. The advent of CubeSats and other small satellites had helped reduce the cost of putting radio occultation equipment into space to a fraction of the cost of legacy weather-observation systems.





One of GeoOptics' CICERO (Community Initiative for Cellular Earth Remote Observation) satellites is depicted in low-Earth orbit. Advantages of radio occultation include an ability to see through clouds and high vertical resolution, meaning it can distinguish the altitudes of phenomena it observes. *Credit: GeoOptics Inc.*

### An Industry Emerges

"With a tiny, \$40,000 instrument, you can get results 10 to 20 times more accurate than with traditional instruments costing tens or hundreds of millions of dollars," said Yunck, who in 2006 founded the company GeoOptics Inc. of Pasadena, California, to advance commercial radio occultation.

GeoOptics' CICERO (Community Initiative for Cellular Earth Remote Observation) constellation, launched between 2018 and 2022, now comprises four satellites, all equipped with a receiver that JPL engineers modified specifically for the project.

Rob Kursinski, a former colleague of Yunck's, also worked on radio occultation and other GPS-based projects at JPL for decades before he cofounded PlanetIQ Inc. of Golden, Colorado, in 2015 to commercialize the technology. PlanetIQ started collecting radio occultation data in 2021 after its first satellite failed in orbit a year earlier. The

company now has two operational satellites, with plans to expand to a constellation of 20 in the next few years. Kursinski said PlanetIQ will emphasize getting the most out of each of its spacecraft, with a higher number of atmospheric profiles per day reducing the cost per profile, and with a high signal-to-noise ratio enabling readings from the lowest mile or so of the atmosphere, which has proven challenging with radio occultation.

Spire currently has by far the most radio occultation satellites in orbit, with about 40 of its 100-plus Low Earth Multi-Use Receiver (LEMUR) satellites using the technique to collect atmospheric data. Nguyen, radio occultation scientist with the company, noted that the data, while inexpensive to acquire, can have an outsized impact on the accuracy of weather forecasts, especially when it's gathered from areas where there's a shortage of information from other sources, like over oceans where weather balloons are scarce.

Having used radio occultation to gather information about other planets' atmospheres, a former NASA scientist founded PlanetIQ in Golden, Colorado, to put the technique to use for Earth, commercializing atmospheric data for weather forecasting and other applications.

Spire is now the first vendor to sell radio occultation data to NASA. Through the agency's Commercial Smallsat Data Acquisition program, NASA first validated the company's data and now purchases it and makes it available to authorized researchers.

All three companies are expanding capabilities to use signals not only from the United States' GPS constellation but also from the European, Russian, and Chinese global navigation satellite systems (GNSS), multiplying the number of atmospheric soundings a given satellite can make.

Spire Global of Vienna, Virginia, was founded to inexpensively collect large, valuable datasets with a constellation of CubeSats in orbit. Dozens of the company's satellites now use a technique NASA invented to sound the atmosphere for weather and climate data.

NOAA started purchasing commercial radio occultation data in 2021, from Spire and GeoOptics, and doubled its order in 2022. Both companies also sell the data to the European Organization for the Exploitation of Meteorological Satellites. And GeoOptics picked up an early commercial customer with the new weather services start-up Climavision.

While the market for selling weather data to private customers remains "embryonic," Yunck said, a few commercial weather services are emerging and purchasing raw data, while companies like his are developing the ability to turn their own data into informational products for sale to many industries. "A third of the world's industry uses weather data," he said. "They want to know what's going to happen next week, next month – how the climate's going to change in the next 10 years."

### Divining the Future of Occultation Arts

Today, radio occultation still accounts for just a sliver of the data most weather agencies use, but Kursinski said he expects it to become the dominant source of weather data before long. Even a handful of the soundings can dramatically improve forecast accuracy because they provide precise information with high vertical resolution on temperature, pressure, and water vapor, in clear and cloudy conditions, well beyond other space-based methods, he said. "You can also use that to correct biases in other observations and reduce the uncertainty you assign to that data, which makes everyone else's data more accurate and useful."

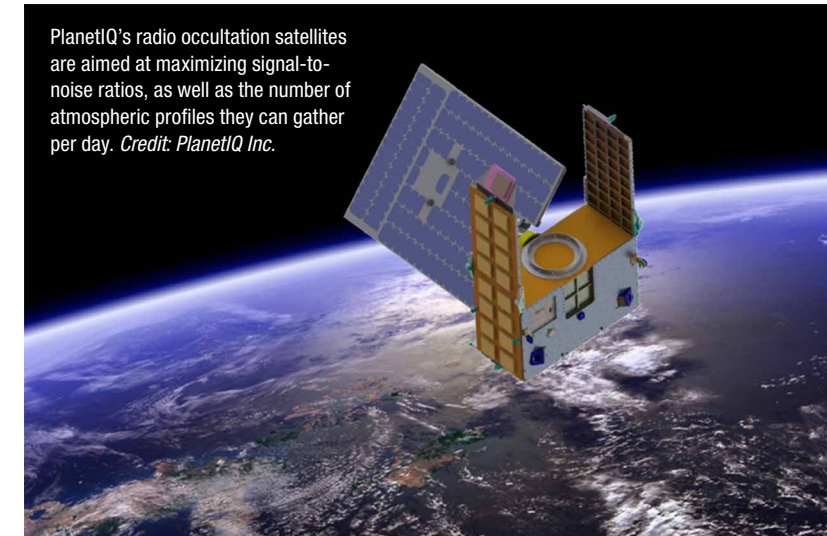
"The impact on weather forecasting is astonishing," said Yunck. "When radio occultation is available in large numbers, it will raise forecasting accuracy to new levels." He noted that this will include long-term predictions of climate change. "It's a vital new addition to a growing armada of space observatories rapidly improving our understanding of the planet. That's why I got into it."

All the companies also noted that radio occultation will improve climate studies because it's the easiest way to collect accurate temperature readings from the upper atmosphere.

Additional possibilities for Earth science stem from the fact that the same receivers on the same satellites can use GNSS signals for more than just radio occultation. All three companies are working on using techniques that NASA helped pioneer to analyze satellite navigation signals reflected from Earth's surface for applications like determining soil moisture and wind speeds over oceans. Spire is using the reflected signals to map sea ice, while GeoOptics is mapping the planet's gravity field with the help of GNSS signals.

The companies also use the same equipment to map activity in the planet's ionosphere, where electrons affect and can interfere with communications and navigation, selling this data to the Air Force and others.

Another longtime colleague of Yunck and Kursinski's who is still at JPL, Thomas Meehan, a flight software engineer, said NASA is now working to use radio occultation to detect and analyze heavy rainfall, especially over oceans, where data is sparse, and to improve



PlanetIQ's radio occultation satellites are aimed at maximizing signal-to-noise ratios, as well as the number of atmospheric profiles they can gather per day. *Credit: PlanetIQ Inc.*

Meehan pointed out that JPL's work over the last 40 years, building the highly accurate receivers and complex positioning software that let satellites and ground stations process and correct navigation signals, laid the foundation for all this work and more. "What NASA did was take a complex system and put the pieces in place to let science happen at a very low cost, without always knowing what we were solving," Meehan said. "It was all for potential applications, and NASA understood that. To me, it's just a massive success story." ●



Spire Global currently has the most radio occultation satellites in orbit, having outfitted 40 of its Low Earth Multi-Use Receiver (LEMUR) satellites with radio receivers capable of the technique. *Credit: Spire Global Inc.*



# With NASA's Help, the Moon Becomes a Commercial Destination

First of many commercial landers are headed to the Moon, paving the way for future missions



Intuitive Machines' Nova-C lander, shown in this artist's rendering, uses a liquid methane propulsion system, one of a handful of similarities between this commercial lunar lander and the experimental Morpheus lander that several of the company's engineers helped build when they worked for NASA. Credit: Intuitive Machines LLC

Almost a decade ago, a group of engineers left NASA to start the company Intuitive Machines LLC, but it wasn't until recently that the team found a true home for its business – on the Moon. Now they are working to bring along as many customers as they can for the ride.

"An actual destination of the Moon was something we couldn't resist," said Dr. Tim Crain, company cofounder and chief technology officer. "It's what most of us had dreamed about – what brought us to NASA to begin with."

On the Houston-based company's first trip to the Moon under NASA's Commercial Lunar Payload Services (CLPS) initiative, its Nova-C lunar lander will carry both experimental NASA technologies and several other payloads from commercial customers. The International Lunar Observatory Association, for example, bought a ticket for a pair of cameras that will precede the organization's flagship project – a space observatory on the Moon. Other commercial cargo includes a camera system designed by Embry-Riddle Aeronautical University students, a time capsule containing data from a million customers, and Columbia Sportswear's newest reflective insulation for testing in the harsh lunar environment.

But NASA will be this mission's biggest customer, sending science and technology payloads to pave the way for future lunar activities, such as demonstrations of new landing navigation technology, cameras to see how lunar dust interacts with engine plumes, and a device to determine how much interference radio antennas will experience on the Moon.

Former NASA engineers at Houston-based Intuitive Machines created a lunar lander by using their experience building a NASA lander. The Nova-C will carry commercial and NASA payloads to the Moon under the Commercial Lunar Payload Services initiative.

This is the first of three landers Intuitive Machines will send to the Moon under NASA's CLPS initiative. More than a dozen other companies have also been selected as part of the CLPS vendor pool, and all have the chance to compete for lunar delivery services via task orders. Among the first task orders awarded is also a lander built by the company Astrobotic (*Spinoff 2022*).

With CLPS, NASA is harnessing private investments and revenues to rapidly demonstrate and deploy technology on the Moon that will support the arrival of astronauts during the



Between 2010 and 2014, Project Morpheus at Johnson Space Center developed a vertical-landing test vehicle to try out landing navigation technology and nontoxic liquid methane propulsion. Now several of the engineers who worked on the project have applied some of that technical knowledge to one of the first commercial lunar landers, Intuitive Machines' Nova-C lander. Credit: NASA

agency's upcoming Artemis missions. To the extent that NASA can help build a commercial lunar economy, it will further lower the costs of future lunar deliveries.

"We're trying to establish a cadence of going to the lunar surface and make it so that, while we're a customer, we're not the primary customer," said Darryl Gaines, former CLPS deputy manager at NASA's Johnson Space Center in Houston. "These companies will be using their assets, developing their landers, finding customers, integrating payloads, and coordinating with launch providers. It's their mission, and our objective is to support them."

Funding lunar delivery task orders is only one of many ways NASA has supported the first stages of a commercial lunar economy. The agency's influence began with the lander's design, which is based on the Morpheus lander, a test vehicle the company's core team of engineers worked on during their time at Johnson. Morpheus was a rocket-powered vertical takeoff and landing vehicle built to test what was, in 2010, a new autonomous landing system and a new, nontoxic propulsion system fueled by liquid methane and oxygen. NASA has never powered a spacecraft with methane, but one advantage of the technology is that both methane and oxygen can, in theory, be produced in space from resources found on planetary bodies.



One of Intuitive Machines' commercial partners is Columbia Sportsweat, which will test the ability of its new Omni-Heat Infinity thermal-reflective technology to protect parts of the first Nova-C lander to touch down on the Moon. Credit: Intuitive Machines LLC

Nova-C uses a similar methane and oxygen propulsion system. Crain noted that the company also built the flight software with the open-source core Flight System platform created at NASA's Goddard Space Flight Center in Greenbelt,

Maryland, and designed the craft with the help of Johnson's open-source Trick Simulation Environment software.

Then, when it came time to test the lander, Intuitive Machines borrowed fuel tanks from the retired Morpheus vehicle – the pandemic and an anomaly had delayed delivery of the company's own tanks – as well as a landscape of tiles simulating the lunar surface, which NASA had created for testing its own landing systems.

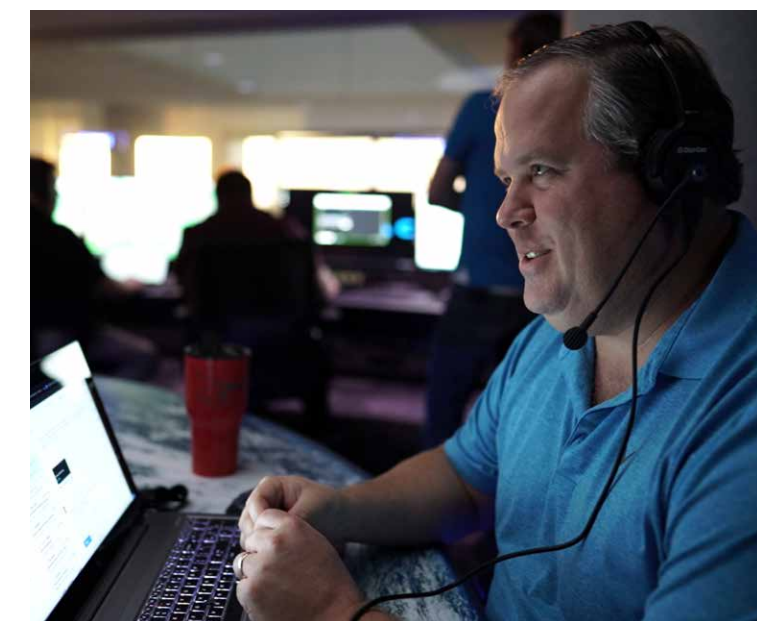
A NASA Tipping Point contract funded development of the

company's Micro-Nova, a small, rocket-powered "hopper" that will ride to the Moon's south pole on Intuitive Machines' second CLPS flight.

That mission will also carry a NASA ice-mining experiment, to help determine the availability of water to support a sustained human presence, as well as the first of five cislunar relay satellites that Intuitive Machines plans to put in orbit around the Moon. The satellites will enable the high data-transmission rates necessary to support complex commercial and civil operations on and around the Moon, and they'll communicate with Earth, at least in part, via space communication ground stations Intuitive Machines has established around the globe.

Crain said being involved in NASA's CLPS initiative "is exciting because so many more people are going to be able to get involved, with small and large companies participating meaningfully. Greater participation will open up new ideas and concepts."

After the company's founding, Intuitive Machines completed a series of projects for other industries, but since getting selected for CLPS in 2018, Crain said, "We've pivoted our whole company to being a lunar transportation and infrastructure services provider. That is a crazy thing to even say exists." ●



Dr. Tim Crain, Intuitive Machines cofounder and chief technology officer, helps run test flights of the Nova-C lander at the company's mission control center in Houston. Credit: Intuitive Machines LLC



# Shuttle-Analysis Software Improves Airplane, Turbine Safety

**Crack-growth software that started with shuttle program has become global standard**

Nothing is ever perfect, but the farther one is from the safety of solid ground, the more dangerous small imperfections can become. The airline industry and the country got a reminder of this hard truth in the late 1980s.

In April of 1988, cracks in the fuselage on an Aloha Airlines flight caused the plane's roof to rip off about 20 minutes into a short flight from Hilo to Honolulu in Hawaii. A flight attendant was ejected and never found, but pilots managed an emergency landing at a Maui airport without further casualties. The following year, a United Airlines flight crashed while attempting an emergency landing at an airport in Sioux City, Iowa, killing 112 of the 296 people on board. Investigation determined that a crack in the fan disk of one of the plane's tail-mounted engines had caused the fan rotor to fracture, releasing pieces of metal that sliced through lines for all three of the plane's independent hydraulic control systems.

Many other planes in the airlines' fleets were found to have cracks similar to those in the Aloha Airlines fuselage, which had previously been deemed insignificant. Congress held hearings and called on the Federal Aviation Administration (FAA), NASA, and other agencies to take action.

One result was the airplane industry's adoption of "damage-tolerant" design philosophy, the idea that a structure should be able to function safely despite cracks and other damage until they can be detected and repaired. It's an approach NASA had taken since the early days of the Space Shuttle Program.

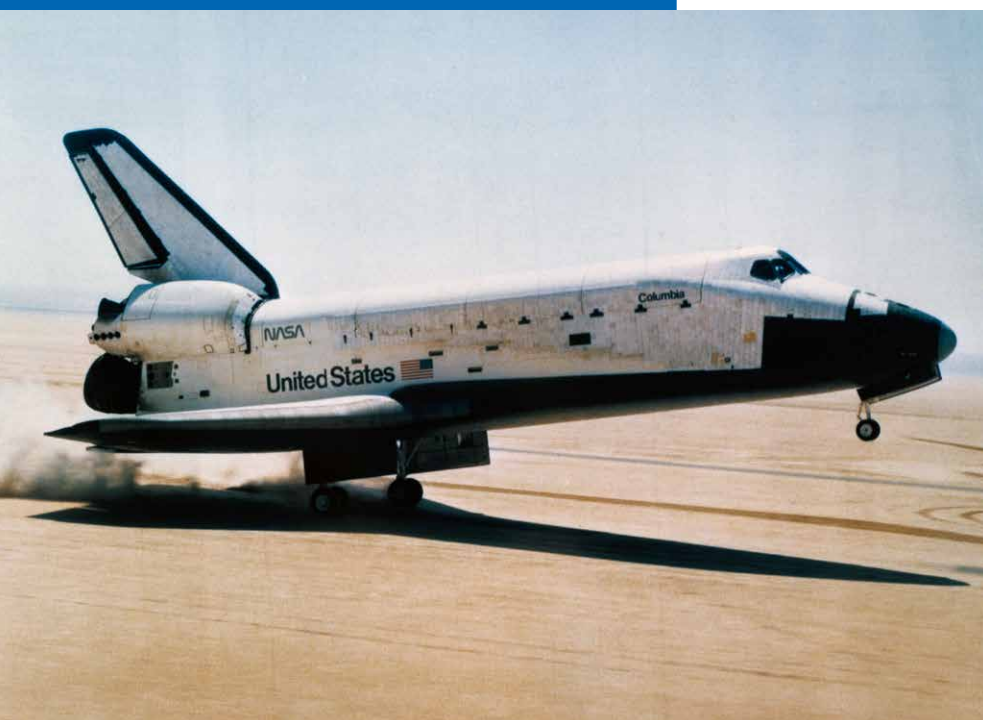
This was how an obscure software the space agency had been developing and using for a decade began its rise to become the worldwide standard for fracture mechanics, helping to prevent such accidents from recurring and eventually spreading to the commercial space and even energy industries.

Today, airplane manufacturers assume that as soon as a plane rolls off the assembly line, it may already have cracks and flaws somewhere. The question is what sorts of fractures could eventually cause a failure. Before production even begins, that question has been answered by the plane's designers with the help of sophisticated fracture-mechanics analysis software.

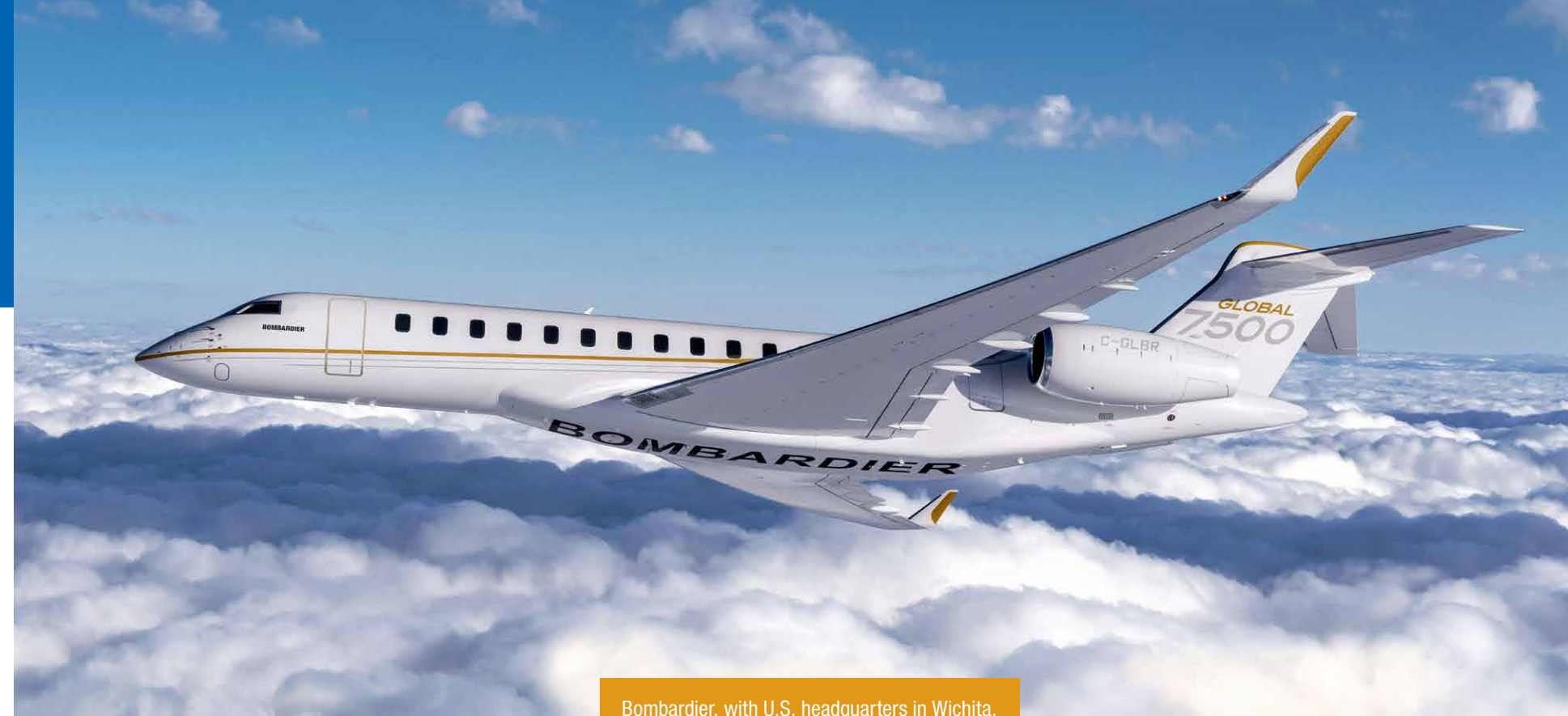
For business jet manufacturer Bombardier Inc., as for many of the world's largest producers of aircraft, that software is NASGRO, born under NASA's Space Shuttle Program. "We use it in our day-to-day design, production, and support of our planes," said Pascal Lortie, structural engineer at the Canadian company, which has its U.S. headquarters in Wichita, Kansas.

*"We use it in our day-to-day design, production, and support of our planes."*

*Pascal Lortie, Bombardier*



Space shuttle Columbia touches down after the first shuttle mission on April 14, 1981. The world's first reusable spacecraft and the first combination of launch vehicle, aircraft, and spacecraft, the space shuttle presented new challenges to NASA engineers. To ensure safety throughout repeated cycles of high stress, they created the fracture-mechanics and fatigue crack-growth software now known as NASGRO. *Credit: NASA*



Bombardier, with U.S. headquarters in Wichita, Kansas, is one of many aircraft manufacturers that license NASA's fracture-mechanics software to design planes with optimal strength and weight and write repairs and maintenance schedules, ensuring their safety.

Not only did Bombardier use NASGRO software to design its new Global 7500 long-range business jet, but the company also required all the companies that supplied parts for the plane to analyze those components with NASGRO. *Credit: Bombardier Inc.*

## NASGRO Moves Beyond NASA

Following the high-profile airline incidents, it became clear that NASA's fracture-mechanics software was the best tool available for assessing the risks posed by actual or possible cracks. In fact, Joachim Beek, who was already working on NASGRO at the time at NASA's Johnson Space Center in Houston, recalled one engineer running a NASGRO analysis using what was known about the faulty fan disk in the Sioux City crash and arriving at a probable failure on almost exactly the flight that ended in disaster. "That was eye-opening to me," said Beek, who is now Johnson's team lead for fracture control and for the software's continued development.

Developing that capability, however, had been a monumental task. NASGRO employs an extensive database of material properties and formulas for solving for crack growth based on a component's shape, the amount of force applied to it, how that force is distributed, and different possible shapes and orientations of cracking. In practice, for example to determine aircraft maintenance and retirement schedules, engineers use NASGRO to calculate a component's potential for fracturing under repeated stress cycles. They start with the largest hypothetical crack an inspection could miss and calculate the smallest number of cycles

in which that crack could grow enough to cause a failure. Then they usually divide that number by a safety factor (NASA divides by four) to be safe.

Ultimately, as aircraft manufacturers came to rely on the software, the space agency decided it needed help supporting the program. In 2000, NASA initiated a Space Act Agreement with Southwest Research Institute (SwRI), a nonprofit research and development organization, to manage NASGRO and license it to industry.

The software's inventors hadn't originally imagined it as an industry tool, though. They were only trying to solve novel problems presented by the world's first reusable spacecraft. Any spacecraft undergoes immense stress, especially during launch and

atmospheric reentry, and nothing had ever been designed to survive those ordeals more than once. Not only was a space shuttle supposed to last for 100 missions, but it was the first combination of launch vehicle, aircraft, and spacecraft, and it comprised a huge number of complicated, critical structures made with materials that had vastly different fracture properties.

Leading the effort at Johnson to digitally analyze all these factors was Royce Forman, who had started working on crack-



NASGRO software relies on a huge database of material properties, created through extensive testing of physical materials, such as these fracture test specimens. *Credit: NASA*



business who was doing research back when the science was just being discovered,” said Craig McClung, who now helps manage NASGRO as a program director at SwRI. “When he came to NASA, he had a vision for developing software to do these kinds of things, and he kept chasing that vision over many, many years.”

As a result of Forman’s tenacity and NASA’s buy-in, McClung said, by the time the software that began around 1980 as NASA/FLAGRO was renamed NASGRO and introduced to industry, it was well ahead of any comparable program.

In 2003, it was one of two programs named NASA Software of the Year and also won an R&D 100 award.

“It’s easier to win the race when you start off ahead,” McClung said, noting that it was also easier for other players to join the NASGRO effort than to start their own software from scratch.

### Competitors Cooperate to Ensure Safety

Major manufacturers across four continents have indeed joined team NASGRO. Under the Space Act Agreement, while Beek and other expert users across all of NASA’s field centers, as well as the FAA and the European Space Agency, continually contribute to the program’s annual updates, more than 20 companies also provide input through the NASGRO Consortium that McClung manages at SwRI.

“We can share our needs and experiences at the annual meetings and influence the software’s development, and that’s a huge advantage,” said Lortie. In each update cycle, he said, the institute consolidates hundreds of requests and suggestions from consortium participants and puts priorities to a vote to determine the next changes to be made to the software.

Lortie estimated Bombardier has about 100 employees using NASGRO for everything from designing planes with optimized strength and weight to creating repairs for in-service damage and writing maintenance schedules for new aircraft. He said the company once had its own fracture-mechanics software but eventually decided it was spending too much time and money updating it and keeping up with the field’s latest science and technology. Instead, NASGRO’s cooperative model “is much more efficient than everyone having their own software and trying to find their own solutions to common problems,” he said, adding, “We’re encouraged knowing it’s used by so many people around the world in different industries, and having NASA and Southwest’s expertise behind it.”



The scorched SpaceX Crew Dragon Endeavour capsule is lifted out of the Gulf of Mexico after safely carrying NASA astronauts Robert Behnken and Douglas Hurley from the International Space Station back through Earth’s atmosphere in 2020. To ensure the capsule’s safety and durability under stresses like liftoff and atmospheric reentry, SpaceX engineers used NASGRO software to predict the behavior of any possible cracks or damage to the structure. NASA invented NASGRO to evaluate the world’s first reusable spacecraft, the space shuttle. Credit: NASA

The cooperative approach also pools resources, with licensing and consortium participation fees covering a substantial portion of the cost of constant updates and improvements that are driven by and benefit all participants.

Bombardier first used NASGRO to design and support its narrow-body CSeries airliner, which is now the Airbus A220, and more recently, its Global 7500 long-range business jet. Not only was the software run “probably 10,000 times” to design the Global 7500 “from nose to tail,” Lortie said, but Bombardier required all the companies across four continents that supplied parts for the plane to analyze those components with NASGRO.

Among the other airplane manufacturers that participate in the consortium are Boeing, Airbus, the Brazilian Embraer, the Japanese Mitsubishi Heavy Industries, and more. Some of the world’s largest helicopter producers, including Sikorsky and the Italian aerospace and defense company Leonardo, are also participants, as are most of the largest spacecraft manufacturers including SpaceX, United Launch Alliance, Blue Origin, and Sierra Nevada Corporation.

Nearly a thousand other companies also license the software without participating in the consortium. And not all NASGRO users are in the business of flight.

### More Reliable Power to the People

One of the consortium’s longest-running participants is German energy giant Siemens Energy, which uses NASGRO primarily to design utility- and industrial-scale gas turbines that are responsible for 16% of the world’s energy production.

Around the time of the consortium’s formation, Siemens was considering developing its own fracture-mechanics software, said Phillip Gravett, who now manages turbine mechanical integrity at the company’s U.S. headquarters in Orlando, Florida. The software didn’t meet all his department’s needs at the time, but the cooperative model offered chances to expand its capabilities. “The consortium has been a two-way street,” he said. “We were able to take advantage of the extensive capabilities already in NASGRO but also promote some unique developments for gas turbines that may also benefit other users.”

For example, the NASGRO team developed several models to evaluate gas turbine parts that endure temperatures ranging from minus 40°F to over 3,000°F. “With the equipment we produce being 10 times more powerful than aircraft engines, and with spinning components weighing upwards of 200 tons, the safety NASGRO helps us achieve is of utmost importance to us,” Gravett said.

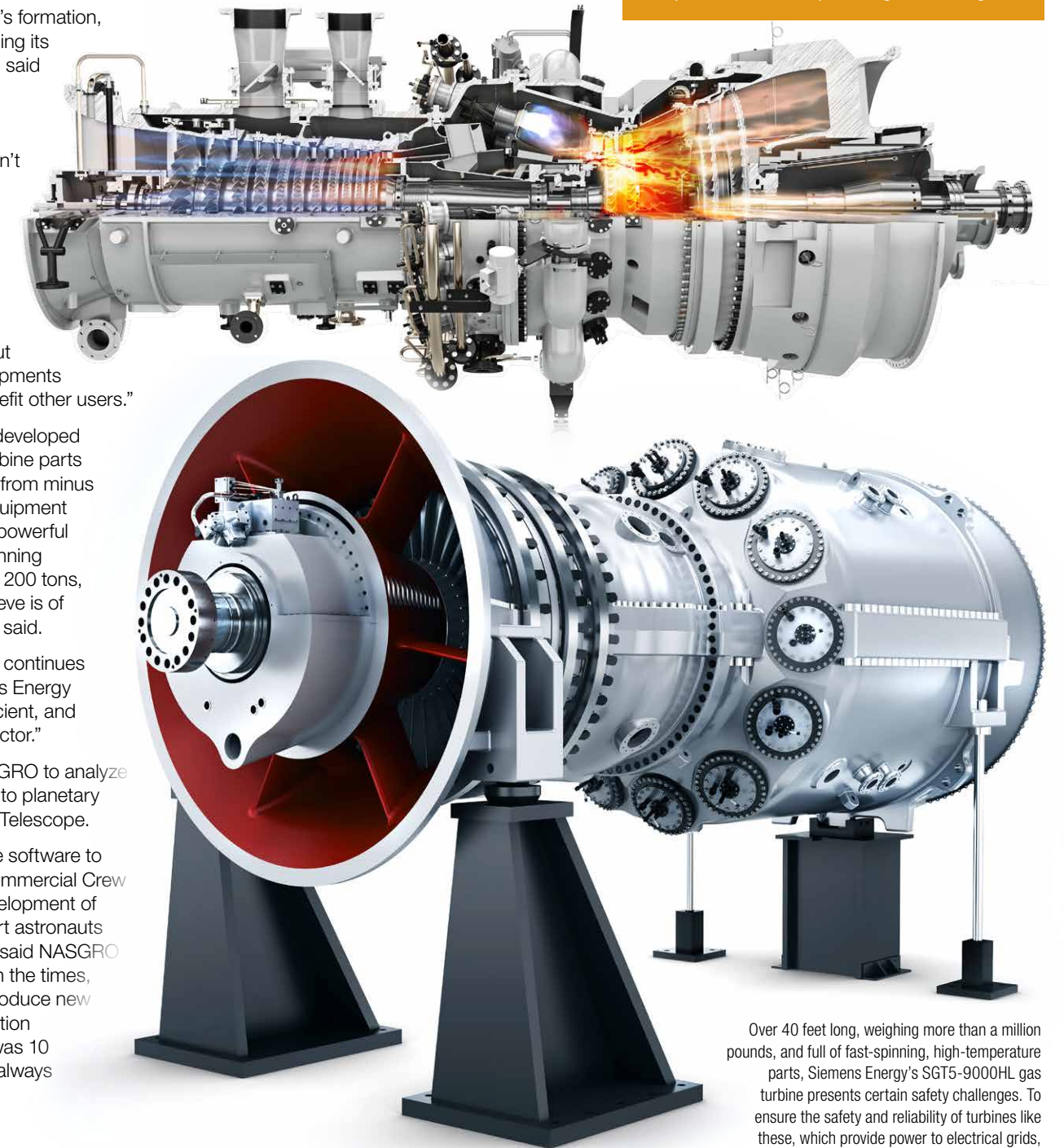
After 20 years, he said, “NASGRO continues as one of the design tools Siemens Energy uses to create more powerful, efficient, and reliable products for the energy sector.”

NASA, meanwhile, has used NASGRO to analyze spacecraft from the space station to planetary rovers to the James Webb Space Telescope.

At Johnson, Beek is now using the software to oversee fracture control for the Commercial Crew Program, which manages the development of commercial spacecraft to transport astronauts to and from the space station. He said NASGRO has had to continually change with the times, as companies and NASA alike introduce new spacecraft materials and construction methods. “It’s not the same as it was 10 or 20 years ago,” he said. “You’re always playing catch-up.”

But McClung said he’s confident NASGRO won’t fall behind anytime soon, thanks to continual support from industry. “If you look at our total budgets, they have grown every year for 20 years, so it’s still accelerating.”

Siemens Energy, whose U.S. headquarters is in Orlando, Florida, licenses NASA’s fracture-mechanics software and helped modify it for gas turbine manufacturers. Siemens uses the program to design safe, huge, high-temperature turbines powering electrical grids.



Over 40 feet long, weighing more than a million pounds, and full of fast-spinning, high-temperature parts, Siemens Energy’s SGT5-9000HL gas turbine presents certain safety challenges. To ensure the safety and reliability of turbines like these, which provide power to electrical grids, the company uses NASGRO fracture-mechanics software invented by NASA. Credit: Siemens Energy



# FINDER Finds Its Way into Rescuers' Toolkits

**NASA-designed technology helps find trapped individuals in the wake of disaster**

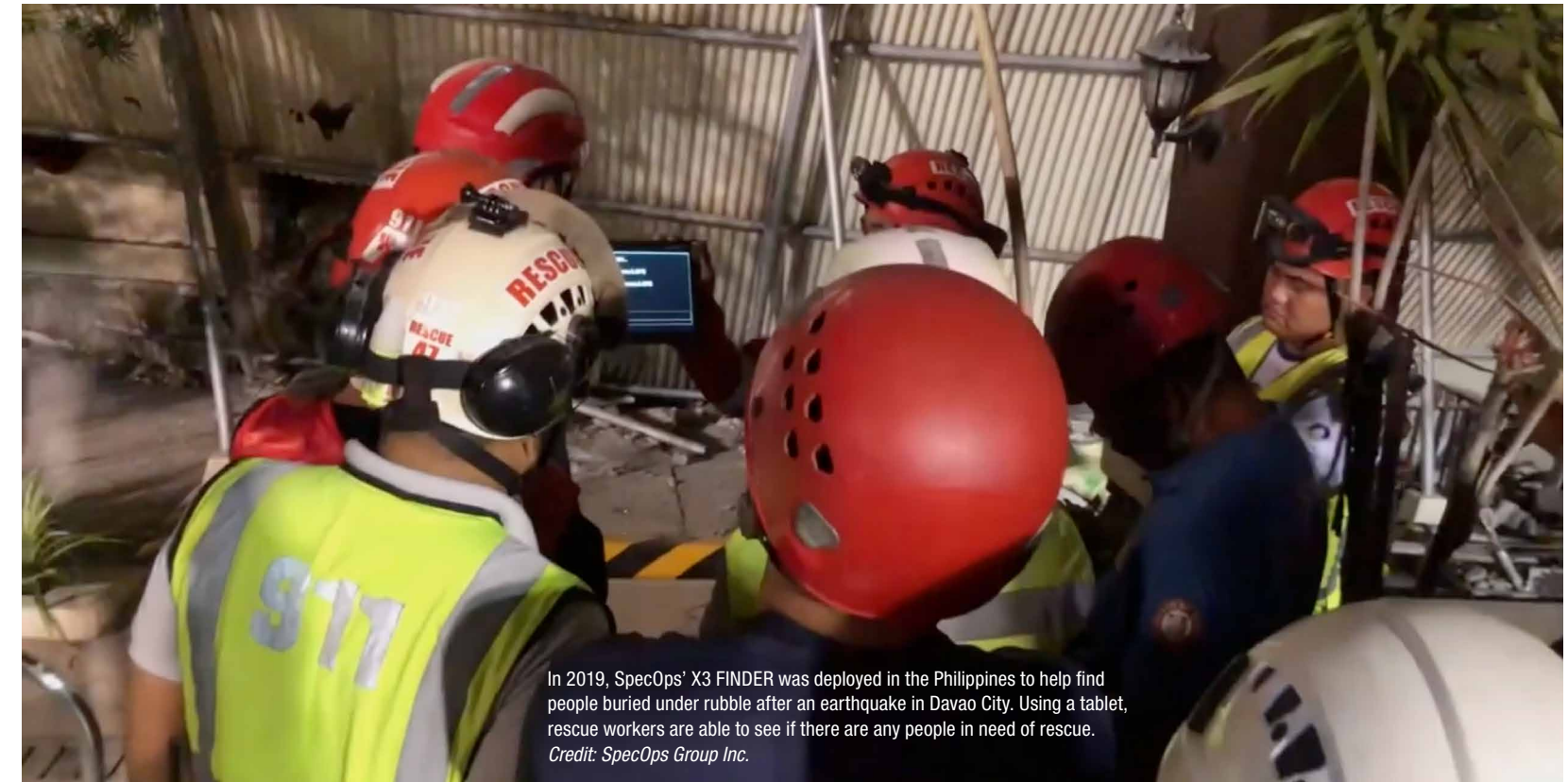
After a natural disaster, time is of the essence to find and rescue missing people. In collapsed buildings, survivors could be trapped under enormous piles of rubble. Even with the assistance of specialized teams or trained dogs, it can take days to find people, and by then, responders might be too late. With NASA's help, the Department of Homeland Security (DHS) was able to produce designs and prototypes for a tool that could detect people trapped under several feet of rubble, one that's now being used for several public safety applications.

In 2010, the Federal Emergency Management Agency (FEMA) Urban Search and Rescue Task Force teams provided humanitarian aid after a devastating earthquake in Haiti, where hundreds of people were trapped under fallen buildings in the country's capital of Port-au-Prince. Incidents like this were the catalyst for a request to the DHS Science and Technology Directorate for a technology that would add to the search and rescue toolbox for first responders to locate people trapped under rubble in similar disasters.

The request soon came to managers at NASA's Jet Propulsion Laboratory in Southern California. Homeland Security had seen that JPL had previously collaborated with the military on remote sensing technology to try and measure heartbeats from a distance, and the department thought that work might help with the tool request. The project was dubbed Finding Individuals for Disaster Emergency Response (FINDER), and a team was assembled at JPL to design a prototype, funded by DHS.



During the Department of Homeland Security's (DHS) Shaken Fury exercise in 2019, rescue teams from several countries tested X3 FINDER for use in finding people trapped after disasters such as floods and earthquakes. *Credit: SpecOps Group Inc.*



In 2019, SpecOps' X3 FINDER was deployed in the Philippines to help find people buried under rubble after an earthquake in Davao City. Using a tablet, rescue workers are able to see if there are any people in need of rescue. *Credit: SpecOps Group Inc.*

SpecOps Group of Sarasota, Florida, licensed a technology NASA developed to find people buried under dense material or rubble after a natural disaster and is now selling a version to public safety departments around the world.

## Don't Skip a Beat

FINDER works by using microwave radar to detect minuscule motions of the body caused by processes innate to living things, such as heartbeats or respiration. While these tiny movements are hard to see with the human eye, the wavelengths used by microwave radar can penetrate deep through mountains of dirt and rubble.

"Your body moves a millimeter when your heart beats. Because the rubble itself isn't moving, we can separate those motions out. Then, we look to see if the motion shows both heartbeats and respiration," said Jim Lux, who was task manager on the FINDER prototypes.

FINDER can distinguish between movements made by people and machinery, and even between people and animals – an important distinction in the rapid-paced search-and-rescue environment.

The prototypes were built into a Pelican case, a brand of ruggedized container typically used to transport high-end gear and equipment. First responder teams have other equipment in Pelican cases, so they know how to pack and repair them.

"Search and rescue is all about logistics," Lux said. "If you make a weird box and the handle breaks off, that's a problem for them. Build it into something they're used to, and they know exactly what to do."

The initial FINDER wasn't without its limitations. It couldn't accurately determine how many individuals were buried, and it couldn't see very far past certain materials, such as solid metal walls, but the concept proved to have merits.

"The NASA culture is to try and make things perfect," Lux said. "We were told by the DHS undersecretary, 'You're going to want to make it perfect, but I would rather have something that is an 80% solution, because during the years of making it perfect, people will die. If you give us something that's not quite perfect, we can save lives in the meantime, and we can work on it more later.'"

After the initial prototype showed promise, SpecOps Group Inc. of Sarasota, Florida, was one of two companies that received licenses to build commercial versions of FINDER. Founded by Adrian Garulay and Tom Coulter in 2015, SpecOps is dedicated to equipping public safety and military organizations with tools to protect people. The company's leadership is made up of former military and government officials, who saw the benefits in a technical partnership with NASA.



The company constructed additional prototypes with the help of the designers at NASA and continued to work with Lux and JPL to get manufacturing going. SpecOps saw several scenarios the technology could be used for, such as searching for people buried under snow after an avalanche.

“The way they look for people in avalanches right now is by sticking long poles in and seeing if they hit you. It’s a really tedious process,” Lux said. “With FINDER, you can put the sensor on a long rope and drag it along the surface, looking for the heartbeats under the snow.”

After FINDER was completed, Lux moved on to other projects at NASA, but SpecOps kept working at it. X3 FINDER, the latest variant, has differences from the original NASA-designed version. Housed in a bright-red case, X3 FINDER is much lighter than the prototypes, weighing in at only 13 pounds, and is more capable, able to conduct a full scan in under 30 seconds, compared to the 90 the original took. An advanced model of the X3 FINDER called FINDER MK4 is even lighter and interfaces to iOS and Android phones.

### FINDER Gets Found

Of the two companies that partnered in the program, SpecOps is the only company still producing a FINDER derivative.

Long after its initial request for a new tool, FEMA deployed X3 FINDER in the Bahamas after Hurricane Dorian in 2019, assisting in recovery after the Category 5 storm.

All of SpecOps’ sales have been to local or national government authorities. One of the company’s most notable non-military sales is to the fire and rescue department in Orange County, California. SpecOps has also taken FINDER international. In addition to having sales offices in Singapore and Sweden, it’s sold the product to public safety departments in countries such as the United Kingdom, France, Norway, Saudi Arabia, and the Philippines.

Garulay said the initial sales from FINDER are funding additional detection devices intended for police use, such as Cyclops ID, a handheld



An emergency responder in Mexico City carries an X3 FINDER while responding to a 7.1 magnitude earthquake. Credit: SpecOps Group Inc.



The MK4 version of X3 FINDER is noticeably smaller than previous iterations and is compatible with both iOS and Android devices. Credit: SpecOps Group Inc.

device that detects movement through walls via Doppler radar and can locate subjects in three seconds.

“Same principle, just in a different form,” Garulay said.

Across the world, FINDER devices are being kept in reserve and demonstrating their usefulness in the meantime. Both Garulay and Lux think this collaboration between NASA and private industry will save hundreds of lives.

“It’s rewarding to work with these licensees. They’re the ones in touch with the users, learning about how they work or any issues they may have,” Lux said. “They can take a concept that has a lot of warts and work on it a lot easier than NASA can.” ●



To test the prototype version of FINDER, several NASA engineers, including Jim Lux (second from the left), worked alongside DHS at the Virginia Task Force 1 Training Facility in Lorton, Virginia, to test how far the device could see into rubble. Credit: Department of Homeland Security/John Price

*“Your body moves a millimeter when your heart beats. Because the rubble itself isn’t moving, we can separate those motions out. Then, we look to see if the motion shows both heartbeats and respiration.”*

*Jim Lux, Jet Propulsion Laboratory*



# Space Radiation Research Fights Cancer on Earth

Research into a novel method for detecting molecular damage in astronaut DNA led to a new cancer test

Astronauts who spend six months in space are exposed to roughly the same amount of radiation as 1,000 chest X-rays. Having multiple kinds of radiation bombard their bodies puts them at risk for cancer, central nervous system damage, bone loss, and some cardiovascular diseases. No one is certain about the exact level of risk, so it's not surprising that NASA funded research into a new method for measuring radiation damage to humans. Two decades later, fundamental science supports a diagnostic test to improve cancer treatment on Earth, called the OncoMate MSI Dx Analysis System.



A spacewalk can be fun, as this image of NASA astronaut Jessica Meir shows. But it's also hard on an astronaut's body, with little protection against the constant exposure to space radiation that could lead to future health problems. Now discoveries made as a result of radiation research conducted for NASA are helping doctors customize cancer treatment. Credit: NASA

NASA-funded research found that certain segments of DNA can be used to measure the radiation damage astronauts experience while in space. Fitchburg, Wisconsin-based Promega used the technique to create OncoMate MSI Dx Analysis System, a diagnostic test that helps customize cancer treatment.

Dosimeters measure radiation exposure, and astronauts wear them in space to have an estimate of the amount an individual is exposed to. But dosimeters can't measure the impact of that radiation on the body, according to Honglu Wu. A senior scientist at NASA's Johnson Space Center in Houston, Wu specializes in biodosimetry, which identifies levels of physiological, chemical, and biological changes caused by radiation exposure.

"The radiation type is different in space from what people are exposed to on Earth, and we have limited knowledge about the risks, especially for long-term space missions to the Moon and Mars," he said. "We want to have some biodosimetry information or some reliable biomarkers to predict that risk."

A biomarker is a biological molecule found in the body that indicates whether a process is occurring normally. One way scientists can see changes is by comparing samples of an astronaut's DNA taken before leaving and after returning to Earth. Those provide some information, but it's still not enough.

"Using cancer as an example, by the time you detect the markers for cancer, it's already too late. We want to be able to determine the risk sooner so we can take some countermeasure actions earlier or limit flight time," said Wu.

*"Research projects like the one that NASA funded... lead to unexpected things."*

Annette Burkhouse, Promega



Identifying the type of a cancer tumor can help doctors choose the best treatment. OncoMate MSI Dx Analysis System, developed by Promega, uses the results of NASA-funded research to find changes in DNA like those shown in this illustration to begin the diagnostic process. Credit: Promega Corp.

## A Different Kind of Satellite

A 2002 research study funded by NASA's Office of Biological and Physical Research explored the possibility that specific sections of DNA, called microsatellites, might accurately record radiation damage over time.

While some microsatellites can mutate and lead to disease, other microsatellites can mutate without harmful effect to a person. The latter are also more susceptible to radiation damage. This means they can accumulate radiation damage and be used to identify an individual's cumulative exposure level, making them the first place to look, according to Jeff Bacher, senior scientist with Fitchburg, Wisconsin-based Promega Corporation.

He led the NASA-funded study at the Brookhaven National Laboratory, which consisted of exposing human cells and mice to measure effects of radiation. "The goal was to develop a method to measure a personalized radiation exposure using microsatellites as the indicator, or marker. Was there a one-to-one relationship between the radiation exposure our samples received and the detectable damage?" said Bacher.

Using microsatellites as biomarkers in testing is nothing new. They're more commonly used in forensic testing and even kinship analysis, such as paternity testing. Early work by the team identified microsatellites that could be used to screen cancer tumors, leading to the eventual launch of a product for clinical research.

Under the NASA study, researchers needed more sensitive indicators, leading to the discovery that certain groups of long mononucleotide repeats (LMRs), a type of microsatellite, were their best option.

The research showed that as the dose of radiation went up, the mutation frequencies in these parts of DNA also went up.

Because of the NASA research, that set of LMRs helped the team develop the Food and Drug Administration (FDA)-approved test OncoMate.



### Searching a Genetic Haystack

Trying to search a human genome for evidence of molecular damage can be akin to looking for a needle in a haystack. But looking for a known biomarker makes it possible to zero in on a reliable indicator of trouble. For cancer, a molecular disease, identifying the genetic mutations in a tumor is critical for choosing the best drugs for treatment.

Using the knowledge they gained from the NASA study, the research team developed a method to measure the number of changes made to microsatellites during DNA replication, when cells divide. Cancer cells with a significant number of changes, a condition called microsatellite instability (MSI)-high, can indicate a genetic defect that could be caused by Lynch syndrome and other conditions. Finding that needle in the genomic haystack is the first step in a diagnosis.

A hereditary condition, Lynch syndrome is a gene mutation that increases the risk of colon, endometrial, stomach, ovarian, and other cancers. An estimated 1 in 279 people have Lynch syndrome, but most are unaware, according to

Bacher. In 2021, the FDA cleared OncoMate MSI as a test to determine MSI status in colorectal cancer tumors. This preliminary test can identify the need for Lynch syndrome screening and a diagnosis, making it possible to monitor and find some of the most treatable forms of cancer.

“The work Dr. Bacher did under NASA funding is now helping improve the way that we can detect MSI tumors,” said Annette Burkhouse, medical affairs officer for Promega. “With that improved detection, we can better help physicians and patients make good decisions about treatment options. That’s where the broadest impact is.”

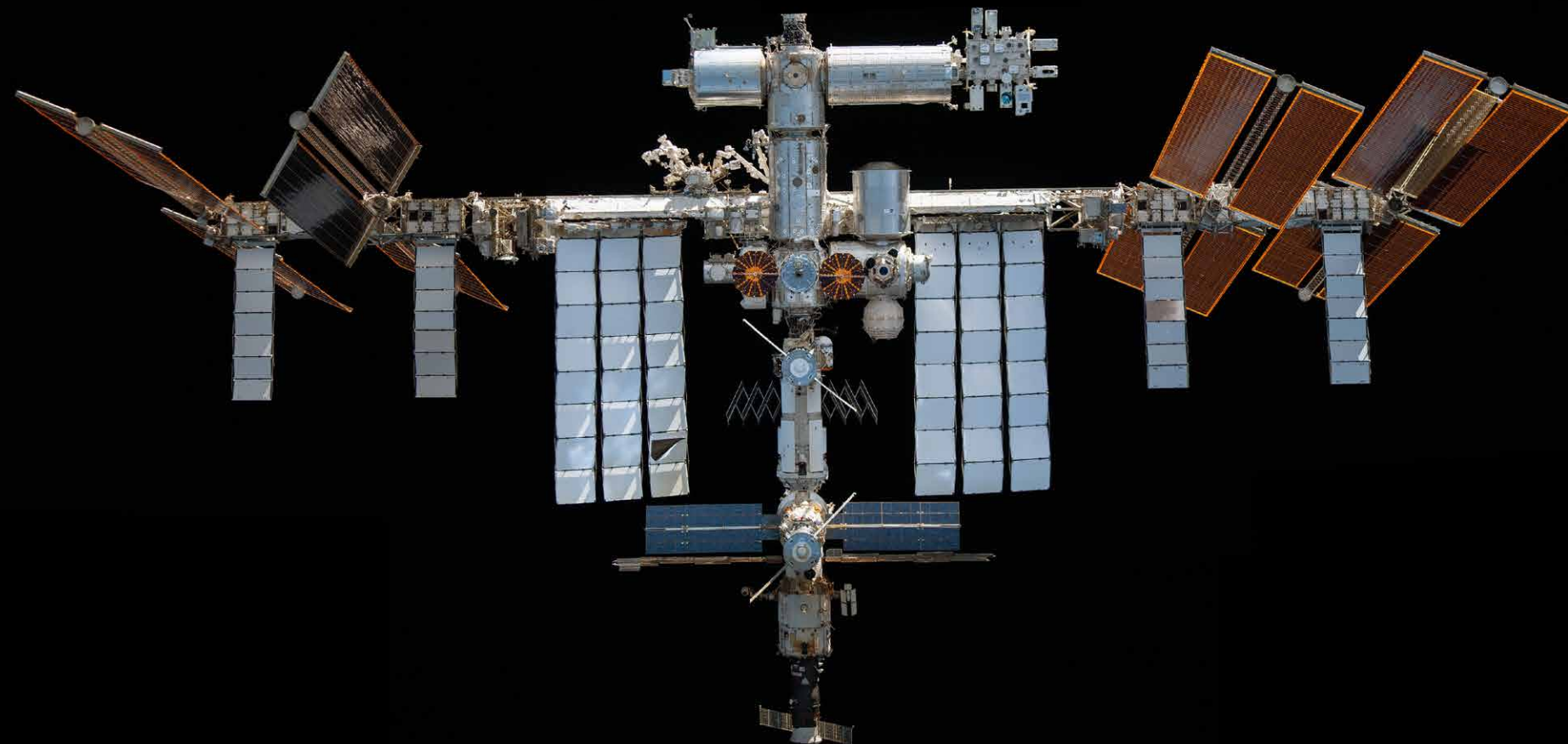
Looking at the molecular makeup of cancer cells makes it possible for doctors to choose the treatments known to reduce that specific type of tumor. One example of this involves the MSI test developed by Promega for use in research studies. Using MSI analysis technology, a 2015 study at Johns Hopkins’ cancer center found that MSI-high tumors responded well to new immunotherapy drugs. The company is now working with the FDA to expand the use of OncoMate as a companion diagnostic test. Once a type of cancer is identified, OncoMate will be used to determine if it will respond well to immune oncology drugs, according to Burkhouse.

Other countries are already using OncoMate in other ways. In Europe, the test is used to diagnose MSI-high for any tumor found in the body. Promega is supporting nine research studies around the world to identify other ways in which the test might prove beneficial. Burkhouse credits future discoveries, in part, to NASA’s support of scientific research.

“Research projects like the one that NASA funded with Promega years ago lead to unexpected things.” ●

*“The radiation type is different in space, and we have limited knowledge about the risks.”*

*Honglu Wu, Johnson Space Center*



## International Space Station Spinoffs

The space station is a technological wonder in its own right – sustaining human life in space for over 20 years. But its construction, upgrades, and maintenance have spurred a wealth of innovation that is also beneficial on the planet it serves.



### Improved Osteoporosis Treatments

To help mitigate bone loss caused by long stays on the space station, NASA worked with a company to test new osteoporosis treatments on mice in microgravity. The result? A new bone treatment drug for earthbound patients.



### Home Fitness Equipment

NASA, looking for ways to help astronauts retain muscle mass in microgravity, teamed up with an entrepreneur with the idea for a weightless weight trainer. After testing on the space station, a popular home gym system was born.



### Water Filtration

With early NASA funding and testing on the space station, a company incorporated nature’s water-filtering proteins into membranes. Now companies and researchers are trying them out for many applications, from wastewater treatment to dialysis.



### Robotic Glove

NASA and General Motors cooperated to build Robonaut 2, which went to the space station. The work led to a suite of robotic glove patents, now commercialized for industrial workplaces to help reduce strain injuries.



### Safer Batteries

Experience developing battery-testing methods to ensure safety on the shuttle and the space station is now used to reduce the risk of fire and explosion in lithium-ion batteries for appliances and electronics here on Earth.



### Indoor Farming

The need to grow food in space pushed NASA to develop indoor agriculture techniques. Thanks to the agency’s research, private companies are building on NASA’s vertical farm structure, plant-growth “recipes,” and environmental-control data to create indoor farms.



### Circadian Rhythm Lamps

NASA-funded lighting research for both growing plants in space and normalizing astronauts’ sleep cycles in orbit is now helping to make products that regulate circadian rhythms, decontaminate rooms, and even boost indoor farming yields.



### Fine Motor Skills App

How does leaving and returning to gravity impact fine motor skills? An app to test astronaut performance helps NASA learn more, and now it helps users measure their abilities via an app released by the agency.

To learn more, visit:

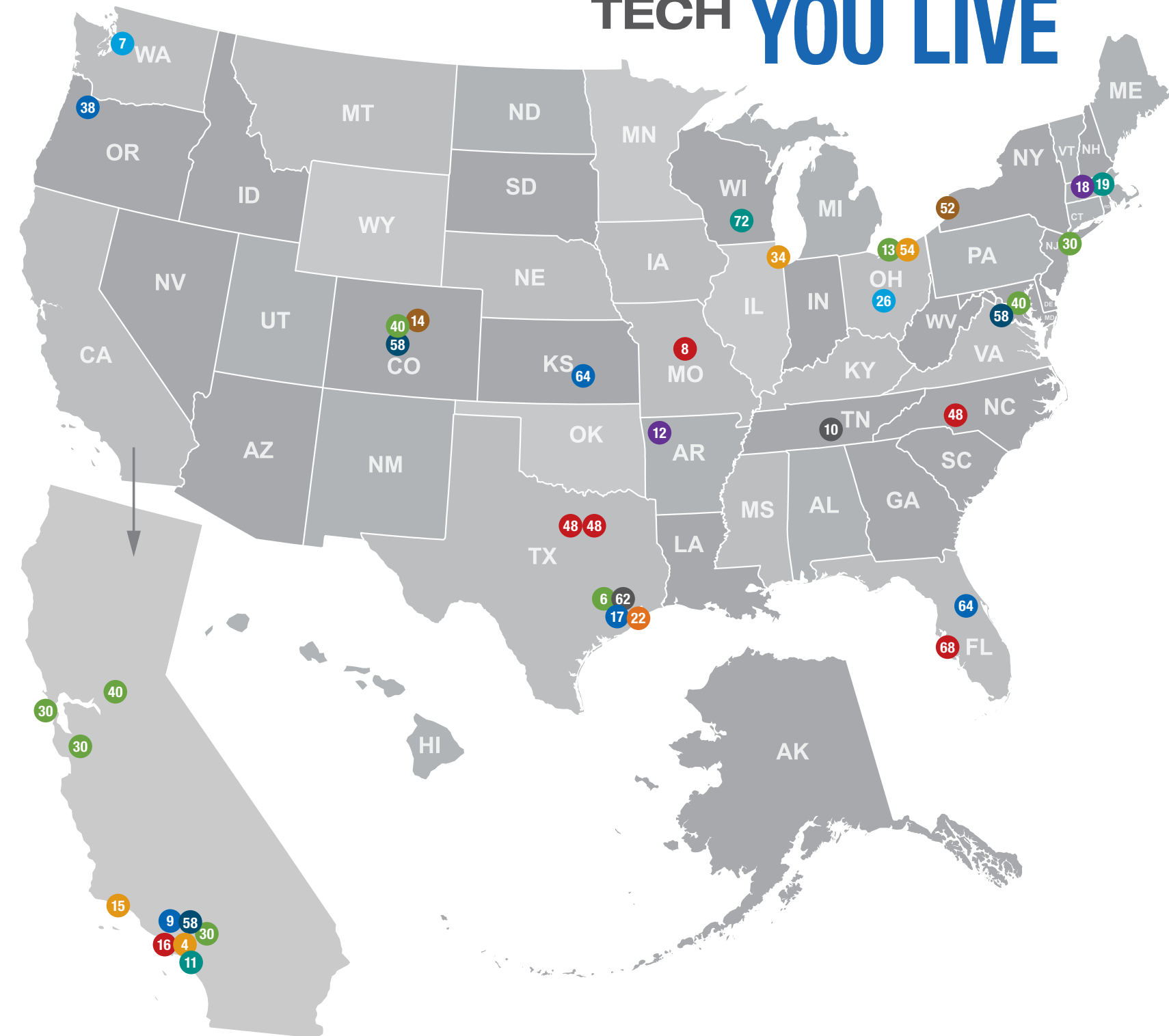
[spinoff.nasa.gov/ISS-Spinoffs-2023](https://spinoff.nasa.gov/ISS-Spinoffs-2023)



## Spinoff Technology Across the Nation

4	Telescope Mirror Tech Improves Eye Surgery	System for guiding LASIK eye surgery	Johnson & Johnson, Santa Ana, CA
5	Feeling Hot, Staying Cool	Temperature-controlling clothing for menopause	Fifty One, London, England
6	Astronaut Life Support for Earth Families	Aeroponic tower for growing crops, seafood	Eden Grow Systems, Houston, TX
7	Learning to Code with NASA Data	Data for computer science/programming lessons	Microsoft, Redmond, WA
8	The Science of the Perfect Cup for Coffee	Phase-change material mug	ThermAvant Technology, Columbia, MO
9	Flying (Not Quite) Blind	Avionics video switcher with simultaneous recording	Eon Instrumentation, Van Nuys, CA
10	Cryofuels Come Under Pressure	Ultra-lightweight carbon composite cryofuel tank	Gloyer-Taylor Laboratories, Tullahoma, TN
11	Cubesats Take a Bus into Space	Small satellite hardware platform	Tyvak Nano-Satellite Systems, Irvine, CA
12	Earth's Twin Helps with Extreme Electronics	Single-board computer module for extreme heat	Ozark Integrated Circuits, Fayetteville, AR
13	Suspended Solar Panels See the Light	Suspended solar panel installations	Skysun, Cleveland, OH
14	Space Program Pumps Up Turbomachinery	Turbopump machinery	Barber-Nichols, Arvada, CO
15	New Solar Array Design Saves Space	Solar array design for compact stowage	Northrop Grumman, Goleta, CA
16	Traveling-Wave Tubes Travel Far	Traveling-wave tube amplifier	Stellant Systems, Torrance, CA
17	Private Lessons for Private Spaceflight	Private astronaut training	Axiom Space, Houston, TX
18	Device for Analyzing Deep Space Could Detect Tumors ...	Curved microchannel plates	Incom, Charlton, MA
19	Electrical Body Signals Help Researchers Restore Movement ...	Wireless sensors to map motor nerve activity	Delsys, Natick, MA
22	Space Robotics Take a Deep Dive	Aquanaut autonomous underwater robot	Nauticus Robotics, Houston, TX
26	NASA's VITAL Contribution to Global Pandemic Relief	Low-cost respiratory ventilators	Bharat Forge, Pune, India
			CuraSigna Systems, Bangalore, India
			Russer Brasil, Indaiatuba, Brazil
			STARK Industries, Columbus, OH
30	A High-Tech Farmer's Almanac for Everyone	Open-source modeling and Earth-observation data and imagery	Esri, Redlands, CA
			First Street Foundation, Brooklyn, NY
			Delos Insurance Solutions, San Francisco, CA
			Tenefit Corporation, San Jose, CA
34	NASA Helps Serve Yellowstone Fungi for Breakfast	Fy meat-alternative protein	Nature's Fynd, Chicago, IL
38	Giant Batteries Deliver Renewable Energy When It's Needed	Flow battery	ESS, Wilsonville, OR
40	The View from Space Keeps Getting Better	Landsat Earth-imaging data and data-analysis tools	Perennial, Boulder, CO
			Baker Family Farm, Sacramento County, CA
			Mapbox, Washington, DC
48	An Electronic Traffic Monitor for Airports	Airport ground traffic management system	Charlotte Douglas International Airport, Charlotte, NC
			Southwest Airlines, Dallas, TX
			American Airlines, Fort Worth, TX
52	Cloning Metal Parts for Space and Earth	Additive-manufacturing modeling software	Sentient Science, Buffalo, NY
54	NASA Research Illuminates Medical Uses of Light	LED-based medical light-therapy devices	Multi Radiance Medical, Solon, OH
58	Weather Forecasters Adopt NASA's 'Occult' Science	Atmospheric sounding technique for better weather forecasting	GeoOptics, Pasadena, CA
			PlanetIQ, Golden, CO
			Spire Global, Vienna, VA
62	With NASA's Help, the Moon Becomes a Commercial Destination	Commercial lunar lander	Intuitive Machines, Houston, TX
64	Shuttle-Analysis Software Improves Airplane, Turbine Safety	Fracture-mechanics software	Siemens Energy, Orlando, FL
			Bombardier, Wichita, KS
68	FINDER Finds Its Way into Rescuers' Toolkits	Microwave radar for search and recovery operations	SpecOps Group, Sarasota, FL
72	Space Radiation Research Fights Cancer on Earth	Diagnostic test to customize cancer treatment	Promega, Fitchburg, WI

## NASA SPACE TECH WHERE YOU LIVE







NASA astronaut Mark Vande Hei looks at Earth from the International Space Station's Cupola module.

# Technology Transfer Program

Before and after high-profile launches, spectacular landings, and amazing pictures sent back from space, NASA's tenacious inventors do the work that makes those successes possible. And the Technology Transfer program is equally driven to move those inventions out into the world for much wider use. What follows are a few of the ways the program helps students, entrepreneurs, small business owners, and others find NASA technology they can make their own to improve life on Earth.



# NASA Transfers In-House Technology

## Call to Action

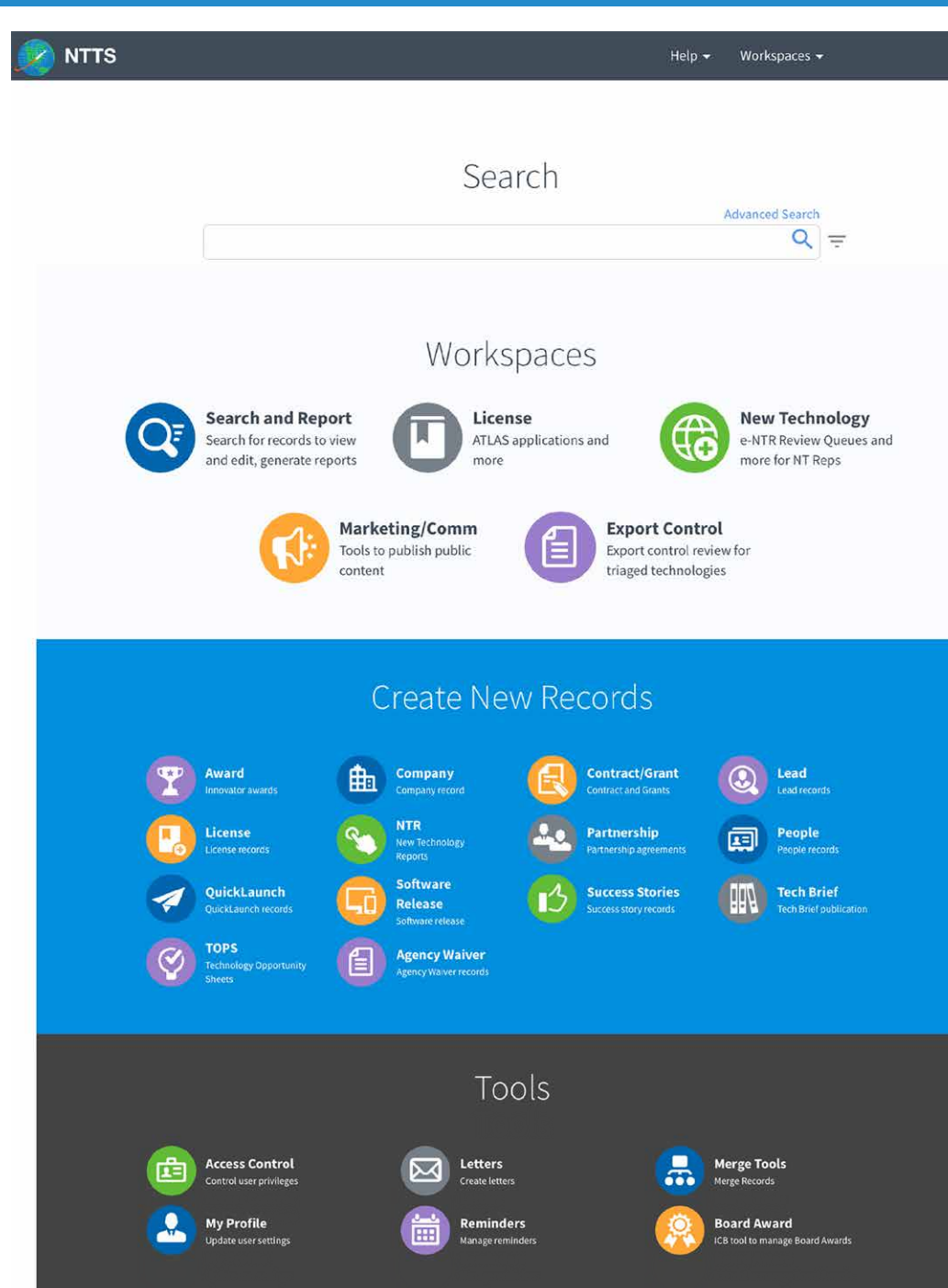
Since the very birth of NASA in 1958, the space agency was tasked with an important mission that would continuously transform the entire nation for the better: “Provide for the widest practicable and appropriate dissemination of information” about its activities.

This call to action meant that, not only did NASA have to find ways to help humanity achieve things never done before in space, but it also had to make the technology created along the way available to do the same here on Earth.

Fast-forward six decades, and NASA-born technologies had already found their way to ubiquitous status with spinoffs such as shock-absorbing memory foam, drag-reducing airplane winglets, and even fortified baby formula with brain-boosting ingredients.

Despite these successes, the NASA Technology Transfer program (T2) still wanted to increase the rate of commercial products “hitting the shelves” and improving lives. That meant going digital.

The interface for the NASA Technology Transfer System (NTTS) allows users to navigate from workspace to workspace seamlessly.



## Backbone of Technology Transfer

The pipeline of NASA technology to commercial products once started with paper invention disclosures. NASA innovators submitted these if they developed a new tool, system, or software while completing mission work such as building rockets, launching satellites, or operating the most advanced space telescope ever built. The T2 team then patented these technologies and licensed them to companies, start-ups, entrepreneurs, academics, and other government agencies.

Unfortunately, this paperwork-heavy process could be tedious, time-consuming, and inefficient. Remembering its call to action, T2 created its own software tool called the NASA Technology Transfer System (NTTS) to streamline a months-long activity to one that took a matter of days.

NTTS facilitates the entire T2 process and activities, including the reporting of new technologies, protecting intellectual properties, and commercializing technologies through various technology licenses, software releases, partnerships, and success stories.

“We quickly realized our in-house software developers had created a game-changer for the world of federal tech transfer,” said Dan Lockney, NASA Technology Transfer program executive. “NASA was one of the first agencies tasked with transferring technologies to the public, and now, all federal agencies are required by law to do so. But no one could do it as fast or as efficiently as we could. And that’s all thanks to the powerhouse that is NTTS. Inventors can disclose tech directly into it, it hosts our patent portfolio website, it’s our software release tool, it provides our reporting information, it allows us to share success stories and even guides licensees through the online licensing application process with the click of a button. It is the very backbone of our work. And we recognize the importance of sharing it.”

## Tech Transfer Transfers Tech

The success of the patented NTTS software tool in addressing NASA’s technology transfer requirements led to interest from other U.S. federal agencies and research labs with similar goals and objectives.

“The success of transferring NTTS to external organizations isn’t just attributed to following software development best practices. Understanding the complexity of technology transfer processes allows our team to quickly

understand our stakeholders’ requirements and offer the pros and cons of implementing certain software features,” said Tek Okimura, NTTS technical lead.

This commitment to providing a customizable NTTS software platform for other interested government agencies earned the NTTS team one of the most prestigious NASA awards: Government Invention of the Year.

## Award-Winning Success

Each year, through its Inventions and Contributions Board, NASA recognizes the ingenuity, determination, and efforts that its engineers, scientists, and innovators put into tackling the difficult technology challenges across NASA and beyond. Because NTTS was transferred 11 times via software usage agreements to other agencies, NASA named the platform Government Invention of the Year for 2022.

Flexibility was a key factor in the successful transfer of the program. Because NTTS was created from piecing together the needs of 10 NASA centers, future improvements and changes needed to be easy to implement, lending to the ability to customize the platform for other tech transfer programs.

“As the NTTS ecosystem expands in complexity, we want the flexibility to accommodate feature additions without adding more complications,” said Anh Trinh, NTTS software architect. “Using Service-Oriented Architecture along with microservices and modular architectural design best practices, we are able to design and implement a core T2 platform that can support rapid development, testing, and deployment.”

“Scalability through reusability” was also a core mantra for the team. As tech transfer needs advanced, so did NTTS.

“We took many lessons learned and best practices from NTTS to design and implement the next-generation technology transfer system for other federal agencies,” said Peter Tran, NTTS project manager. “Using a tailored, agile, and iterative software development approach, we collaboratively designed and implemented the improved platform with our colleagues to meet their expectations.”

In 2021, T2 executed 211 new license agreements, breaking NASA’s record for the most licenses ever completed in one year. T2’s continued effort and dedication to streamlining processes, both internal and external, are paving the way to another record-breaking year. Even more products and services that protect the planet, create jobs, and boost the economy can be anticipated from this rapid increase in transfer. ●



The software experts that make up the NTTS team include (from left to right) Takeshi “Tek” Okimura, Vu Tran, Anh “Alan” Trinh, Peter Tran, Dustin Cai, Jonathan Maluf, Ron Instrella, and Jairom Camarillo.







# Will the next spinoff be yours?

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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.



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Instrumentation



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Materials/  
Coatings



Mechanical/  
Fluid Systems



Optics



Power Generation



Propulsion



Robotics



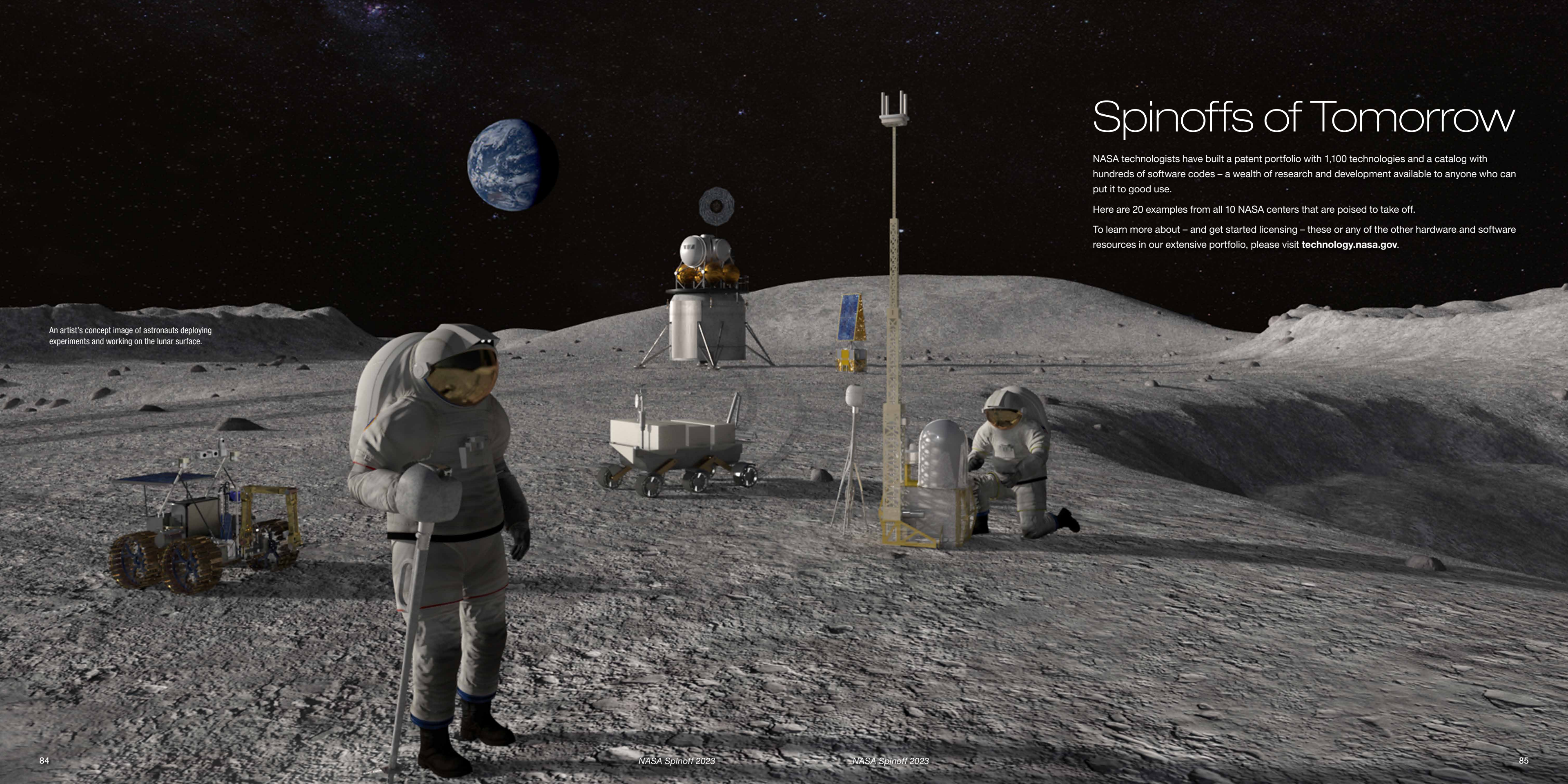
Sensors



**NASA TECHNOLOGY  
TRANSFER PROGRAM**

BRINGING NASA TECHNOLOGY DOWN TO EARTH





An artist's concept image of astronauts deploying experiments and working on the lunar surface.

# Spinoffs of Tomorrow

NASA technologists have built a patent portfolio with 1,100 technologies and a catalog with hundreds of software codes – a wealth of research and development available to anyone who can put it to good use.

Here are 20 examples from all 10 NASA centers that are poised to take off.

To learn more about – and get started licensing – these or any of the other hardware and software resources in our extensive portfolio, please visit [technology.nasa.gov](https://technology.nasa.gov).



# Ames

## Fluid Lensing System

**Sensing technologies for seeing through waves to explore ocean worlds**

Few remote sensing technologies can capture images of underwater objects well due to surface wave and light distortion. This means the ability to accurately assess shallow marine ecosystems, like coral reefs, is severely impaired. To combat this, innovators at Ames Research Center developed a technology capable of seeing clearly through ocean waves in 3D. The technology removes optical distortions to enhance otherwise underpowered optical systems.



### Benefits

- Tested in several different environments
- Exploits surface waves as magnifying optical lensing elements
- Addresses wave distortion challenges posed by aquatic remote sensing

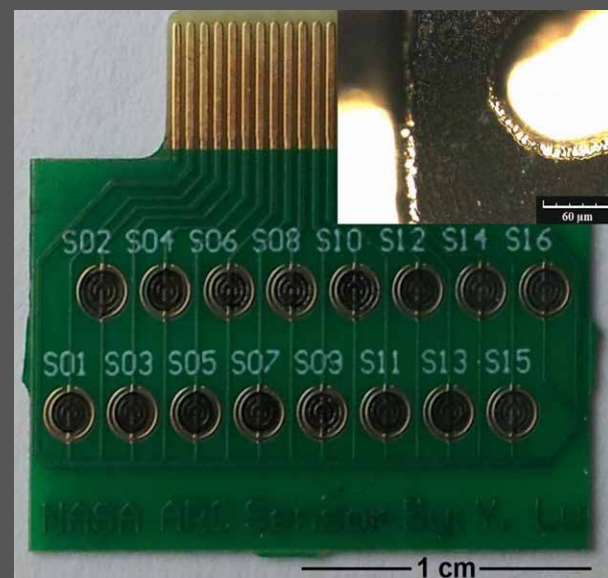
### Applications

- Marine debris recovery efforts
- Remote sensing applications
- Submerged camera imaging

## Room-Temperature Oxygen Sensors

**Small, low-cost, low-power oxygen sensors**

Oxygen ( $O_2$ ) sensors are used in a wide array of applications, from emissions control in the automotive industry to monitoring  $O_2$  levels in controlled environments such as spacecraft. However, traditional oxygen sensors have some drawbacks. They often require high temperatures to operate while consuming a lot of power to function. To help solve these issues, innovators at Ames Research Center developed novel low-power oxygen sensors made of a hybrid material capable of detecting  $O_2$  gas at room temperature.



### Benefits

- Low-cost and easily manufactured
- Fast response and recovery times
- Easily integrated into wearable devices

### Applications

- Chemical sensing
- Medical applications
- Automotive emissions control

# Armstrong

## Ground Collision Avoidance System

**Improved ground collision avoidance for all classes of aircraft**

Researchers at Armstrong Flight Research Center have dramatically improved upon existing ground collision avoidance technology for aircraft. NASA's system leverages leading-edge fighter safety technology, adapting it for public transportation as an advanced warning system app. It offers better terrain mapping, enhanced vehicle performance modeling, multi-directional avoidance techniques, more efficient data-handling methods, and user-friendly warning systems. The system has been incorporated into an app for tablets and smartphones that can be used by pilots in the cockpit.



### Benefits

- Can be used with a variety of aircraft
- Triggers alarms only in the event of an impending collision, reducing the risk of false alarms
- Improved terrain mapping

### Applications

- General aviation
- Military aircraft
- Remotely piloted aircraft

## New Wing Design

**Improved design to reduce drag**

Innovators at Armstrong Flight Research Center have created a new wing design that dramatically increases aircraft efficiency by reducing drag. Known as the Preliminary Research Aerodynamic Design to Lower Drag (PRANDTL-D) wing, this design addresses integrated bending moments and lift to achieve a 12% drag reduction. The design also helps shed structural weight to increase aircraft efficiency by eliminating the vertical tail.

### Benefits

- Improves fuel efficiency by allowing aircraft to fly faster
- Requires no vertical stabilizers, reducing production costs
- Optimizes aircraft performance

### Applications

- Mid-sized commercial aircraft
- Remotely piloted aircraft

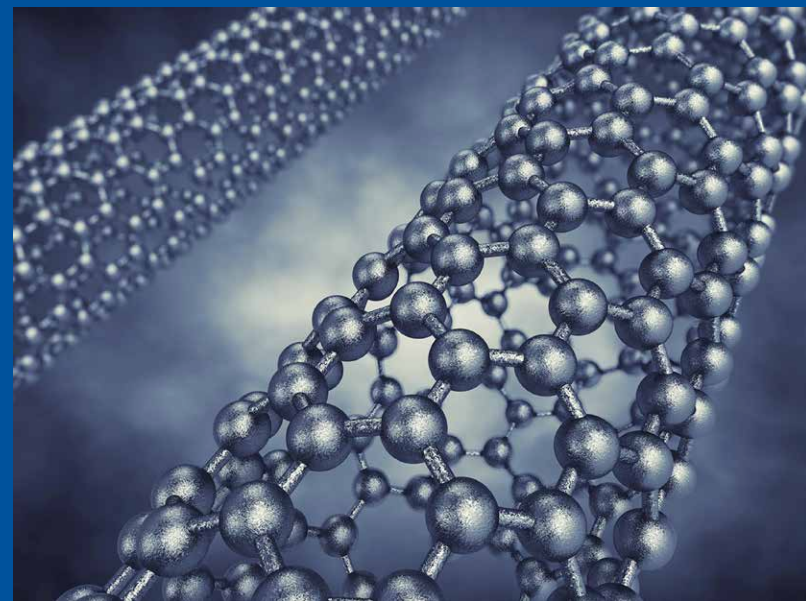




## Microsensor Fabrication Process

### Low-cost sensors fabricated using nanostructures

Because chemical sensors are routinely used in space missions, NASA researchers are always developing smaller, stronger, more cost-effective sensors. Innovators at Glenn Research Center have developed a method of making microsensors in batches using nanostructures as templates. Existing nanostructures have excellent potential for use in sensor systems but lack certain advantages, like the ability to work in high temperatures. This technique enables the unique properties of nanostructures, such as larger surface areas for sensing, to be combined with more durable materials like metal.



#### Benefits

- Enables the simple fabrication of robust, customizable, highly reliable sensors
- Can be installed in a wide range of locations
- Successfully demonstrated as a low-power, compact methane gas sensor

#### Applications

- System monitoring
- Fabrication
- Fire and gas detection

## High-Powered GPS Receiver

### GPS navigation system built for high-Earth orbits

Until now, Global Positioning System (GPS) receivers, while providing accurate navigation, have been limited to low-Earth orbit missions. This innovative new receiver technology developed by researchers at Goddard Space Flight Center is enabling a leap forward for GPS technology. The Navigator receiver is an autonomous, real-time, fully spaceflight-qualified GPS receiver with exceptional capabilities for fast signal acquisition and weak signal tracking. These features enable the use of GPS navigation in high-Earth orbit, geostationary orbit, and other high-altitude applications.

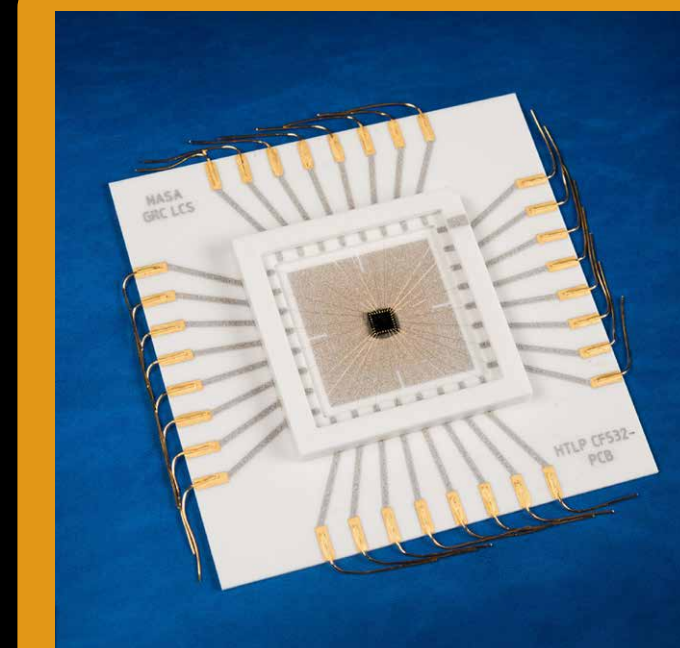


#### Benefits

- Acquires signals faster
- Enables GPS in high-Earth orbit
- Operates autonomously

#### Applications

- High-altitude spacecraft
- Low-Earth-orbit spacecraft



#### Benefits

- Operates at the broad temperature range of minus 150°F to over 930°F
- Offers customizable digital and analog circuitry
- Enables intelligent electronics to operate directly in harsh environments

#### Applications

- Oil and gas
- Power generation
- Environmental monitoring

## Integrated Circuit Chips

### Robust circuits for extreme environments

Working in harsh, high-heat environments often requires robust tools and sensors to get the job done safely. High-temperature electronics, such as system-monitoring equipment, often use circuit chips made primarily from silicon carbide. But previous versions could not withstand more than a few hours of 900°F temperatures before failing. Innovators at Glenn Research Center have developed a new generation of silicon carbide and mixed-signal integrated circuits able to withstand over 1,000 hours of continuous operation at that temperature.

## Robotic Satellite Servicing

### Robotic tools for capturing, servicing, de-orbiting satellites

How do you repair or refuel a satellite already in Earth's orbit? Engineers at Goddard Space Flight Center have come up with a solution using a combination of lidar and robotics. This method begins with the optical seeking and ranging of a target satellite using lidar. Once the target is located, the spacecraft deploys a robotic grapple arm or berthing pins to provide a secure attachment to the satellite. Robotic arms perform servicing autonomously, executing either a pre-programmed sequence of instructions or a sequence generated by artificial intelligence support aboard the robot.



#### Benefits

- Increased satellite lifetime
- Lowered costs due to decreased satellite turnover rates
- Decreased satellite insurance rates

#### Applications

- Robotics
- Communications
- Earth remote sensing



### Collaborative Augmented Reality System

System combines computer-aided design, augmented reality

Researchers at the Jet Propulsion Laboratory have developed a system that allows users to view and edit computer-aided design (CAD) models of structures, such as boats and cars, in an augmented reality space. Using equipment such as a headset, the 3D CAD model is rendered in the augmented reality space at true scale, a feature that has been unsuccessful in previous systems. The user can then edit the model using a virtual toolbox.



**Benefits**

- Provides immersive experience for users
- Displays CAD models in true scale

**Applications**

- Automotive design
- Marine craft design
- CAD modeling

### Upper-Body Robotic Exoskeleton

Lightweight garment for arm, shoulder injury rehabilitation

Patients recovering from side effects of stroke or traumatic brain injuries often need intensive rehabilitation to strengthen the damaged parts of the body. To help these patients, innovators at Johnson Space Center have developed a wearable, robotic exoskeleton designed to control the shoulder and elbow. To reduce strain, it helps position the limb in specific orientations while assisting it through desired motions. The portable design allows patients to rehabilitate practically anywhere, including at home. The technology also has applications in human performance augmentation, including in future spacesuit designs.



**Benefits**

- Portable for use outside clinic, enabling task-oriented therapy
- Soft design distributes loads around torso to eliminate pressure points
- Multiple control modes

**Applications**

- Upper-limb motor rehabilitation
- Upper-limb assistance with daily tasks
- Human performance augmentation



### Collision-Prevention Device for Miniature Drones

Lightweight system detects obstacles for high-speed micro air vehicles

Miniature “micro air vehicles” (MAVs) are a challenging type of drones for high-speed autonomous flight because their power and size restrictions limit obstacle-detection and trajectory-planning devices that can weigh them down. To combat this, researchers at the Jet Propulsion Laboratory have created a lightweight device that can detect obstacles in a cluttered environment. The technology generates a real-world scene using a suite of range sensors mounted to the drone and calculates a new flight path to avoid collision.

**Benefits**

- Lightweight
- Low power

**Applications**

- Remotely piloted aircraft
- Micro air vehicles

### Human-Powered Ventilator

Portable, manual technology to stabilize respiratory distress

Originally created for space missions, the human-powered ventilator has been reengineered by innovators at Johnson Space Center to help COVID-19 patients in areas where traditional ventilators are in short supply. The technology utilizes hand-pump motions to help stabilize respiratory distress in a patient without requiring electricity. By using an arm-pumping motion to operate the accordion-like ventilator, operators need minimal training. The ventilator is made of portable and inexpensive parts and is easy to assemble.



**Benefits**

- Inexpensive and easy to manufacture
- Requires little training
- Portable and easy to store

**Applications**

- Any location which may lack electricity
- Any confined military or commercial vehicle
- Relief of supply-chain challenges for ventilators



## Miniaturized Electro spray System

Efficient, precise electrostatic sprayer

Made by innovators at Kennedy Space Center to precisely water in-space aeroponic crops, NASA's electro sprayer utilizes a technique where droplets are electrically charged to increase adhesion power. The droplets stick to the target more effectively than traditional air-powered sprayers used to paint vehicles, coat industrial materials, disperse disinfectants, and apply chemicals such as pesticides. The technology also uses far less liquid and only requires small, off-the-shelf batteries to work.

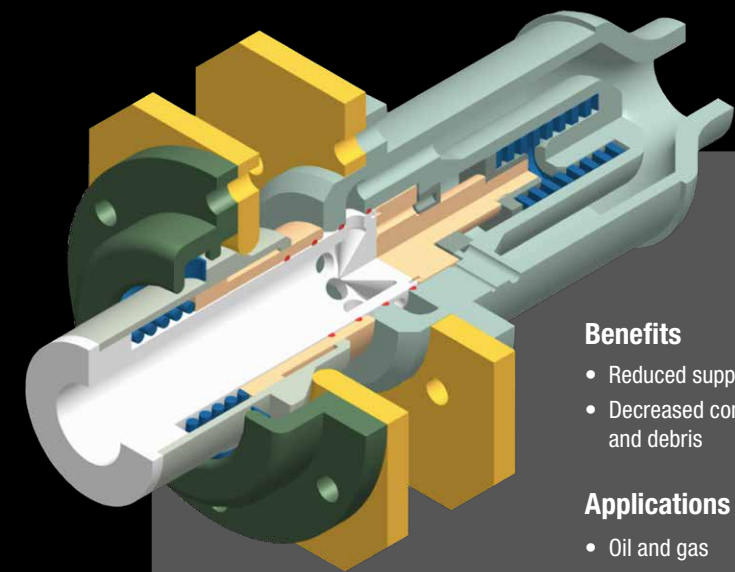


### Benefits

- Provides approximately 90% coverage efficiency
- Small size enables handheld devices
- No air assistance required

### Applications

- Agricultural
- Industrial coatings
- Medical devices



### Benefits

- Reduced support structure weight
- Decreased contamination from dirt and debris

### Applications

- Oil and gas
- Satellites
- Remotely piloted vehicles

## Quick Disconnect Device

Self-aligning, self-healing system for pneumatics, cryogenics

Researchers needed a device that helped them connect high-pressure fluid lines, such as fuel and pneumatics, to vehicles that could also be quickly disconnected in case of emergencies. However, these fluid lines required heavy support structures because of the pressure of the fluid being pumped into the vehicles. So researchers at Kennedy Space Center developed a device that uses a unique seal arrangement and flow path to ensure low separation force regardless of line pressure. The device is also self-aligning and self-healing, preventing contamination from dust, dirt, and debris.

## Sensory Metallic Materials

Shape memory alloy particles improve nondestructive evaluations

To enhance nondestructive evaluation (NDE) of a structure, researchers at Langley Research Center developed a metallic material that can be embedded into structural alloys. Current NDE tools, which can be costly, labor-intensive, and time-consuming, often miss small flaws in certain materials and structures. This innovation embeds shape memory alloy particles into the structural material that react to strain in a way that is easily detected using acoustic or magnetic tools.



### Benefits

- Increased structural reliability
- Increased intervals of component replacement
- Ability to detect damage at its earliest stage

### Applications

- Aerospace vehicles
- Aircraft
- Construction

## Wind Event Warning System

Doppler lidar alerts to protect wind turbines, aircraft

Unexpected wind gusts, microbursts, or storms can cause serious damage to wind turbines and aircraft. To stay on guard, innovators at Langley Research Center have developed an early warning system using Doppler lidar that can predict wind events up to 10 minutes away. This is often enough time to take measures to prevent damage, such as rolling aircraft into hangars or ramping down wind turbine rotors so they don't exceed maximum speed limits.

### Benefits

- Allows time to ramp up or down an alternative power source
- Provides long-range wind measurements in clear air, critical for airports

### Applications

- Offshore wind energy
- Airports



Image credit: Pixabay/Erich Westendarp



# Marshall

## Integral Tuned Mass Absorber for Turbine Blades

Additive manufacturing enables novel turbine blade, blisk designs

Researchers at Marshall Space Flight Center needed a way to greatly reduce the vibration produced by turbine blades in rocket engines. Vibration, left unmitigated, can potentially cause engine damage and even failure. Using additive-manufacturing methods, such as laser metal sintering, they were able to integrate tuned-mass vibration absorbers inside the actual blades, reducing up to 50% of the vibration.



### Benefits

- Will not lock up or introduce debris
- Inexpensive
- Reliable

### Applications

- Rocket engine turbopumps
- Jet engines
- Gas turbines for power generation

# Stennis

## Floating Piston Valve

Novel approach to low-maintenance, actuator-less valves

Innovators at Stennis Space Center have developed a simple valve that works in extremely high pressures. The valve consists of a piston floating in a medium to control flow. The piston is balanced within the flow whether the valve is open or closed. The only force on the piston is that which the operator chooses to put on it. This eliminates a conventional actuator (replaced by one or two simple solenoid valves) as well as actuator adjustments. It also eliminates the valve stem, stem seals, and most flow-induced thrust forces and ensures consistent seating force regardless of the pressure drop. The design also reduces downtime and maintenance costs while increasing reliability and valve seat life.



### Benefits

- Reduced maintenance
- Reduced size and cost
- Withstands high pressure

### Applications

- Power plants
- Chemical refineries
- Pharmaceutical manufacturing



### Benefits

- Prevents damage to heavy objects during assembly
- Increases user efficiency
- Enables a neutral load during operation

### Applications

- Construction
- Industrial machinery
- Marine shipbuilding

## Soft-Mate Lifting Device

Device enables gentle crane placements, decreases damage

Innovators at Marshall Space Flight Center developed a below-the-hook lifting device that provides initial, gentle contact between mating connections while using a crane. While structure-testing the Space Launch System, the overhead cranes were too rough to connect parts without damage. In response, the soft-mate lifting device was created to incorporate an adjustable pneumatic soft spring into the lift rigging of a crane to let it maintain a neutral load while connections are assembled or disassembled.

## Cryogenic Butterfly Cam Valve

No-leak valve performs in broad range of temperatures

Current butterfly valves have disadvantages. The disc has to create a tight seal with the seat around it exactly when the disc hits 90 degrees. If additional torque is added, the disc will rotate past 90 degrees, and the valve will open again, allowing fluid to flow through. These valves also fail leakage tests when it comes to liquid nitrogen. To combat this, researchers at Stennis Space Center have created the cryogenic butterfly cam. The design 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