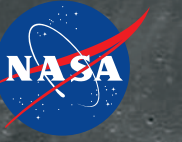


National Aeronautics and Space Administration



SPINOFF

2025



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

www.nasa.gov

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On the cover

Cameras mounted on the Orion spacecraft captured a detailed view of the lunar surface on a close approach to the Moon during the Artemis I mission.

A full moon is seen from Launch Complex 39B at NASA's Kennedy Space Center in Florida as the SLS (Space Launch System) and Orion spacecraft are prepared for a wet dress rehearsal ahead of the Artemis I mission in 2022.

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NASA Technology Transfer Program

NASA Headquarters

Daniel Lockney,
Technology Transfer Program Executive

Spinoff Staff

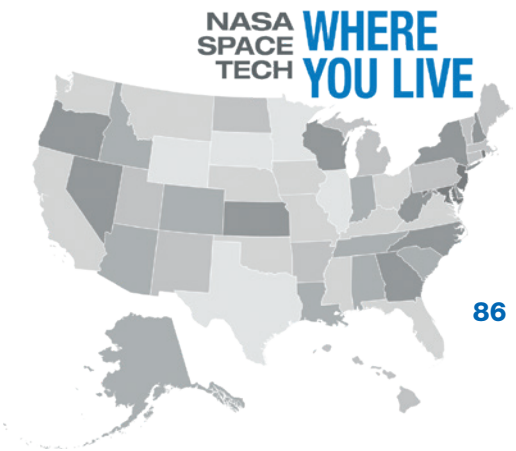
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Spinoff (spin´ôf) -noun.

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.

The Moon passes in front of the Sun with the top of the Washington Monument in silhouette during a partial solar eclipse in Washington on April 8, 2024.

Introduction

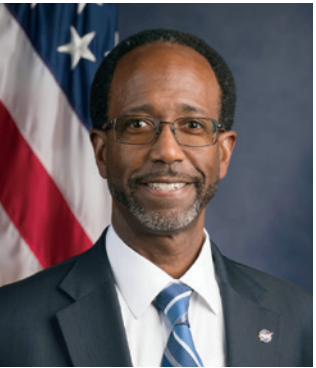
Welcome to Spinoff 2025!

At NASA, we explore the secrets of the universe for the benefit of all — for humanity. The same innovations that make our far-reaching missions possible are improving your daily life in ways you might not even realize.

The heart of NASA's mission is a commitment to ensuring technologies developed for space exploration and discovery have a direct impact here on Earth. We see to it that commercial products or services developed with the help of NASA technology, expertise, or facilities benefit as many people as possible. There are technologies with NASA roots in every hospital and airport. NASA technology is constantly at your fingertips, embedded in your smartphone. I assure you that NASA innovations touch your life in unexpected and profound ways.

This year's edition of our annual Spinoff publication showcases dozens of incredible examples. You'll discover how NASA drives innovation, spans industries, bolsters the economy, and enriches lives. From artificial intelligence developed initially for Mars rovers, now transforming assembly lines, to devices that enable people who can't speak to communicate using only their eyes, there's something here for everyone to get excited about. I encourage you to find a few spinoff examples that resonate with you. I hope they strengthen your understanding of and appreciation for the broader impacts of America's space program.

This year's edition also highlights the treasure trove of untapped, patented NASA inventions ready to be commercialized. These innovations are waiting for creative minds and entrepreneurial spirits to turn them into the spinoffs of tomorrow. Together, we will bring the boundless possibilities of space exploration closer to home. We will continue shaping a brighter, more innovative future — for generations to come.



Clayton Turner
Associate Administrator
Space Technology Mission Directorate
NASA Headquarters



SPINOFF Capsules

Technology spun off from NASA is in your pocket, your car, the office, your home — it's everywhere, including space. NASA technology is increasingly helping private companies make forays into orbit and beyond, whether that means making satellite missions more affordable, improving rocket hardware, or saving space on a commercial lunar lander.

Here are examples of repurposed NASA technology showing up everywhere from your smartphone to the Moon.

The Orion crew module for NASA's Artemis II mission waits inside the Neil Armstrong Operations and Checkout Building at Kennedy Space Center in Florida.

Equalizing Internet Access

Making websites user-friendly for everyone with an easy-to-use plugin

It's hard enough to go online with a smartphone using one hand when you're holding a squirming toddler or dragging a suitcase. Try doing it when you can't see — it can be incredibly difficult. That's partly because devices and programs used to access the internet are often designed for people without disabilities. Equalize Digital Inc. is working to ensure all users have equal access to the web, and NASA is helping.

More than 1 billion people worldwide and 1 in 4 American adults have a disability that could prevent them from interacting with the online world, according to the Georgetown, Texas-based company. Whether due to a permanent condition such as blindness or a temporary disability like blurry vision caused by cataracts, many users have a hard time navigating websites that haven't addressed accessibility issues.

To ensure anyone could access every page of NASA's new website, the agency contracted Equalize Digital to evaluate the site according to accessibility requirements. As part of the project, the company also made improvements to its automated Accessibility Checker plugin, and those changes are now benefiting its other customers.

"Sometimes people don't really know where to start with accessibility, and it can feel overwhelming," said Amber Hinds, CEO of Equalize Digital. "We're trying to create something that helps everyone — small businesses or an individual blogger — find accessibility problems on their website."

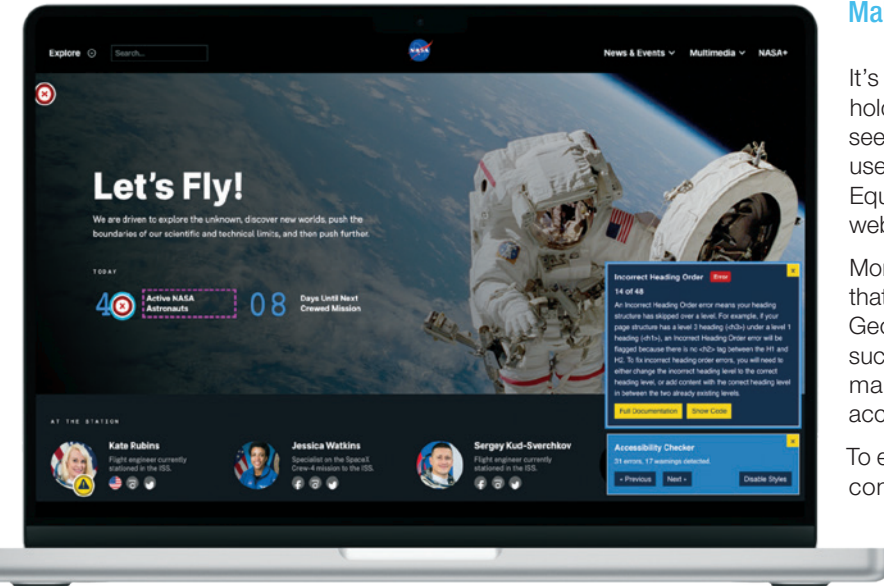
The Accessibility Checker plugin for WordPress tests individual pages or entire sites, automatically updating to generate accessibility compliance reports whenever new content is published. It uses the industry-standard Web Content Accessibility Guidelines to identify noncompliant code. Customers, including businesses and universities, use the plugin to ensure they reach everyone interested in their site's content and avoid potential lawsuits over inaccessibility.

While federal agencies are required to meet minimum accessibility standards, NASA wanted to "push the boundary, to be an example of best practices," said Abby Bowman, agency web modernization lead. The team found that error reports generated by the existing Accessibility Checker were too technical for the writers and editors who prepared the content. So Equalize Digital worked with NASA to create a supplemental highlighting tool that makes the process more user-friendly.

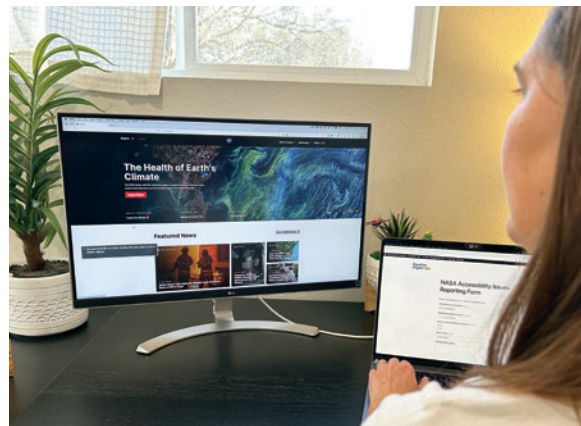
After a writer drafts a new article on the site, but before it goes live, the plugin puts a pink box around any text with a problem — it could be a caption or part of the article. A click on the box calls up an explanation of the issue, how to correct it, and a summary of the relevant accessibility requirements. Over time, users learn the correct content formatting, resulting in fewer errors while also gaining a greater understanding of online accessibility.

The highlighting feature developed for the space agency is now available in the free and paid versions of the Accessibility Checker plugin because NASA wanted to make it widely available. Equalize Digital was happy to meet that requirement, which was in keeping with its corporate ethos. As a Certified B Corporation, it is expected to consider anyone who could be affected by its decisions, from workers to wider society and the environment.

"It's something that appeals to me — to do more than just make money," said Hinds "I want to feel like I'm making a difference in the world. It would have taken us much longer to release this feature if it were not for the support of NASA." ●



To make NASA content accessible for all readers, Equalize Digital created a plugin that highlights issues that could impede readers. This way all users can correct copy before publishing content online. *Credit: NASA*



Amber Hinds, CEO of Equalize Digital, tests the new NASA website using the Apple VoiceOver screen reader. *Credit: Equalize Digital Inc.*

Spraying for Food Safety

Industry benefits from NASA-designed electrostatic spray nozzle

Whether protecting crops from diseases and pests or sanitizing contaminated surfaces, the ability to spray protective chemicals over important resources is key to several industries. Electrostatic Spraying Systems Inc. (ESS) of Watkinsville, Georgia, manufactures electrostatic sprayers and equipment that make this possible. By licensing NASA electrostatic technology, originally made to water plants in space, ESS's improved spray nozzles efficiently use basic laws of electricity to achieve complete coverage on targeted surfaces.

ESS traces its origins to research done at the University of Georgia in the 1970s and '80s. An electrostatic sprayer works by inducing an electric charge onto atomized droplets. Much like an inflated balloon sticking to a wall when it's gained a charge of static electricity, the droplets then stick to targeted surfaces. However, electrostatic sprayers have a sweet spot for the droplet size, one that can be very hard to achieve.

"A 40-micron droplet is small enough to accept an electrostatic charge and yet large enough that it will moisten the surface," said Bruce Whiting, owner of ESS. That's a little smaller than the width of the finest human hair.

NASA's interest in this technology originated with astronauts' need for an easy way to support plant-growth experiments in space. On the International Space Station, watering plants without the help of gravity isn't as easy as using a garden hose on Earth. But with an electrostatic sprayer, the water droplets would stick to the plants with uniform coverage. However, most spraying systems require large sources of water and air to properly aerosolize fluids, breaking them up into the minuscule droplets needed. As both air and water are precious resources in space, NASA needed an easier way to make these incredibly small droplets. Dr. Charles Buhler and Jerry Wang of NASA's Kennedy Space Center in Florida led the efforts to develop this capability, with Dr. Edward Law of the University of Georgia as a consulting expert. Eventually, the NASA team developed a new design by learning from existing technology.

"We used a mister nozzle, which is what you see when waiting in line at Disney World," said Buhler. "Using this, we can get it cheaper, lighter, and also have efficiency at charging and electrospray."

Buhler said the primary advantage of a mister nozzle is that even though the interior volume of the nozzle is small, the pressure inside never builds up, which makes it perfect for enclosed small spaces like the space station. As the sprayer industry is a tight-knit group, technology transfer professionals at NASA reached out to the companies that could use a nozzle like this on Earth. Because ESS's primary markets include agriculture and food production, the ability to use sprayers in small areas was an important feature. ESS responded to NASA and began discussions to see how well the spray nozzle would work on Earth. ESS later licensed the sprayer design from the agency and incorporated it into the company's Maxcharge product lines.

Today, ESS uses the NASA-designed nozzle to make spraying more affordable while reducing water usage. The Maxcharge sprayers, including the NASA nozzle, are used by customers for sanitization, agriculture, and food safety. Whiting said ESS is appreciative of NASA, as the company is dedicated to sustainability and making life on Earth better and safer, while using less. ●



Astronaut Kayla Barron looks at chile peppers growing in the Advanced Plant Habitat aboard the International Space Station. Determining the best ways to water plants in space resulted in the development of a new electrostatic spray nozzle, now licensed to industry. *Credit: NASA*

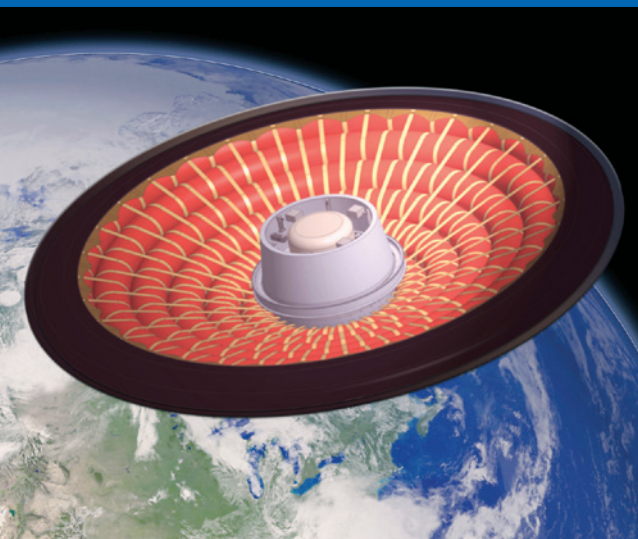


Electrostatic spray nozzles impart a small electric charge to minuscule particles of water, allowing the droplets to stick to surfaces. This array of sprayers, made by Electrostatic Spraying Systems (ESS), is used in food production. *Credit: Electrostatic Spraying Systems Inc.*

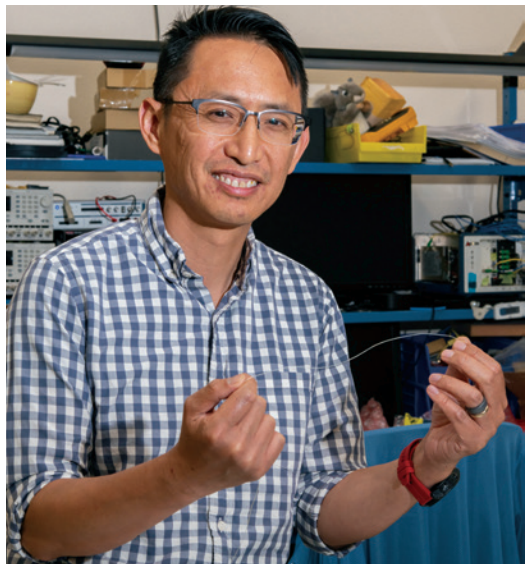


An ESS mister nozzle undergoes testing at Kennedy Space Center. The design was improved through collaboration between the company and NASA. *Credit: NASA*

Giving Sensors Good Optics



To capture temperature data across the entire surface of LOFTID's inflatable heat shield, NASA used flexible fiber-optic sensors woven throughout it. These sensors were enabled by work at Armstrong to improve the technology, now available for industrial customers. *Credit: NASA*



NASA engineer Patrick Chan holds a fiber-optic sensor line. Chan's work to develop these instruments resulted in Sensuron licensing the algorithms that make the sensors function. *Credit: NASA*

Sensuron's RTS125+ system is one of several fiber-optic interrogators produced by the company. Designed for use in aeronautics, it uses algorithms developed by NASA to make measurements along fuselages and wing surfaces. *Credit: Sensuron LLC*



Fiber-optic sensing technology improved by NASA is now available for industry

While screaming toward Earth's surface at 17,000 mph, the inflatable heat shield on NASA's Low-Earth Orbit Flight Test of an Inflatable Decelerator (LOFTID) experiment needed to record as much data as possible. Rather than having individual sensors all along its surface, optical fibers were woven through the heat shield, each connected to a device that could take temperature readings from anywhere along the filament. Such high-fidelity fiber-optic sensing technology took NASA years of work, and now a company the agency collaborated with is making it available to industry.

NASA's Armstrong Flight Research Center in Edwards, California, is known for testing cutting-edge aircraft, and in the 1990s, researchers there wanted to get more data points without adding lots of individual sensors. The engineers turned to fiber optics. Instead of a row of mechanical sensors, each with its own wire bundle for connectivity, multiple fiber-optic sensors could reflect light sent through a thin optical cable, allowing data such as temperature or strain to be read from anywhere along the line.

Allen Parker, an electrical engineer at Armstrong, had seen fiber-optic sensors tested by NASA, but they weren't in any state to fly. "It was a laboratory experiment. It was the size of a large coffee table, and it wasn't very fast," Parker said.

To improve the sensors' capabilities, NASA contracted a company called 4DSP to make improvements to a device called an interrogator, which translates readings from fiber-optic sensors into data that a computer can read. With dedicated processing hardware built by 4DSP, and better mathematical algorithms developed by NASA, the new system could extract data from more sensors more frequently.

"When we first started, we'd push a button and get data 90 seconds later," said Parker. "Today it's 150 samples per second."

These fiber-optic sensors have now become commonplace on NASA projects such as the LOFTID experiment, which marked the first use of a space-rated fiber optic sensor system. 4DSP licensed the algorithms from NASA and started building out a business combining fiber-optic sensors with the company's processors (Spinoff 2012). In 2015, 4DSP spun off its fiber optics business into a new company called Sensuron LLC, headquartered in Austin, Texas.

Primary customers for Sensuron include not only the aviation industry but also manufacturing. These sensors provide distributed temperature measurements in applications like steel production, where temperatures mean the difference between a solid beam and a melted mold.

"If there's a large temperature change along the edges of these molds, they need to detect it to avoid the catastrophic failure that could mean millions of dollars of cleanup," said Justin Braun, who started as a systems engineer at 4DSP and is now Sensuron's CEO.

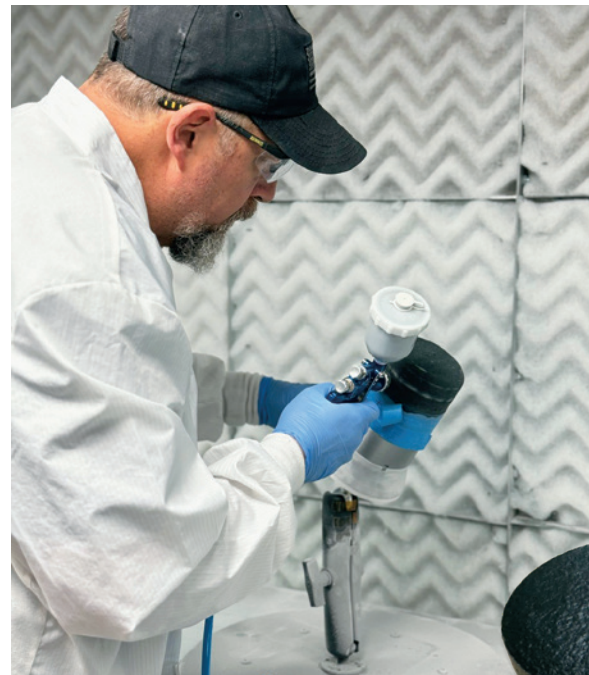
Braun said the new company has sold around 90 units, some to repeat customers. Since splitting from 4DSP, Sensuron has licensed further technologies from NASA, like a shape-sensing algorithm that can find how aircraft wings deform and a much smaller, more powerful laser.

Today, engineers at Sensuron still regularly speak with NASA scientists like Parker's team, and recently Sensuron spun out its own company using the shape-sensing technology for medical purposes. Braun said these new applications couldn't have been found without NASA.

"At NASA, there are a lot of neat things that maybe don't get exposed to the outside world," he said. "And it's good to have a group of people with insights looking at it from a different vantage point and noticing that this could be used in other areas as well." ●



This picture of the underside of the space shuttle Discovery's nosecone shows the thermal protection system (TPS) tiles that Canopy Aerospace now manufactures. *Credit: NASA*



Reusable rockets will allow commercial space companies to lower the cost and increase the frequency of launch services. But they need shielding to survive the heat of reentry, so Canopy Aerospace is manufacturing the proven TPS developed by NASA. *Credit: Canopy Aerospace Inc.*

Launch, Return, Repeat

A NASA thermal protection system enables reuse of commercial spacecraft

The dream of reusable spacecraft became reality when NASA developed the space shuttles to carry the International Space Station into orbit one module at a time. Many of the technologies created for that purpose are considered flight-ready and now could aid the safe return of commercial space vehicles. Canopy Aerospace Inc. is offering one of those technologies — the thermal protection system (TPS).

By participating in NASA's Startup Studio, the Littleton, Colorado-based Canopy learned about a specific TPS called alumina-enhanced thermal barrier (AETB) with a reaction-cured glass coating, usually referred to simply as space shuttle tile.

FedTech, a venture firm that specializes in connecting entrepreneurs with technologies from federal labs, teamed up with NASA's Technology Transfer Expansion (T2X) initiative to introduce entrepreneurs to the agency's technologies ready for commercialization through the Startup Studio. During one-on-one meetings with High Temperature Reusable TPS Program Manager Jay Feldman, senior materials researcher at NASA's Ames Research Center in Silicon Valley, California, Matt Shieh recognized an unmet need.

"The material itself is a flight-proven technology that NASA has already qualified, tested, and flown but has not been commercialized for industry use," said Shieh, who is now CEO of Canopy. Under a Space Act Agreement, Feldman's team is teaching the company how to reproduce the same material NASA used on the underside of the shuttle vehicles.

The shuttle tiles dispersed the heat generated when the spacecraft entered Earth's upper atmosphere at speeds greater than Mach 25. The porous ceramic material was formed into a specific shape and then coated with a black glaze of borosilicate.

"It's essentially a very highly engineered form of sand combined with other ingredients that has this incredible performance, where it can repeatedly withstand thousands of degrees, almost 3,000°F," said Feldman. And the tiles' light weight helps reduce flight costs for a launch vehicle and frees up weight for customer payloads.

With commercial space companies developing flight schedules ranging from daily to weekly, Feldman believes reusable vehicles are the only way to deliver cost-effective launch service. The heritage TPS technology eliminates the time and expense of developing an entirely new system, flight testing it, and then building out the infrastructure for manufacturing.

Another category of TPS is ablative, meaning they disperse heat by shedding layers of material. That single-use approach changes the aerodynamics of the vehicle structure, making it a lot more complicated to use, and requires costly refurbishment, according to Shieh.

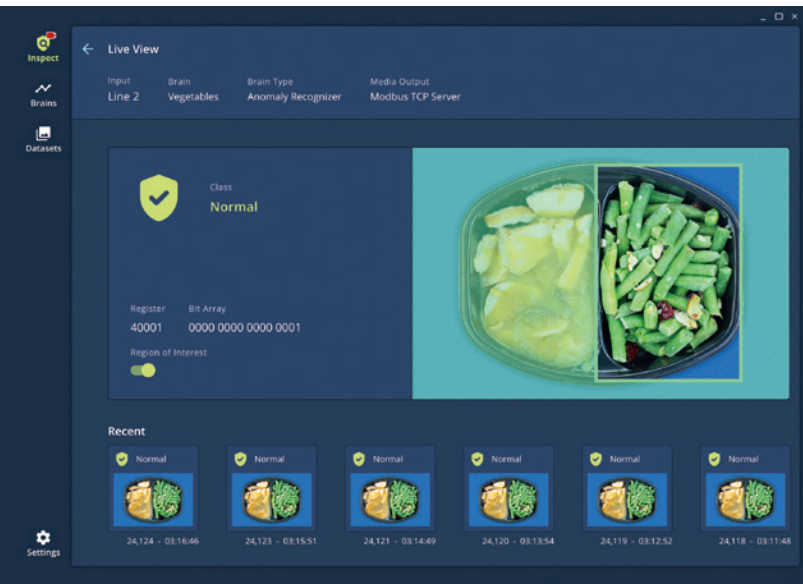
The Canopy tiles are scheduled for testing at the Ames Arc Jet Complex, which replicates the condition of atmospheric reentry.

Working at full capacity, the company can manufacture up to 200 custom pieces per month. This pace likely won't be enough to satisfy the already unmet and growing demand, but the current process is a first step on the way to a new type of manufacturing. While Canopy fills orders, it's also working with NASA to create a 3D-printed material that's comparable to space shuttle tiles but eliminates multiple steps in the current manufacturing process.

"There's a lot of technology that needs to be transitioned out of NASA for the commercial space industry to flourish and get to market. The Technology Transfer program makes that really easy," said Shieh. "Working with NASA has been a really great experience." ●

From Mars Rovers to Factory Assembly Lines

NASA-funded AI technology enabling autonomous rovers and drones now keeps an eye on conveyor belts



European company apetito uses Neurala’s vision inspection software to ensure the quality of its prepared meals, such as green bean portions pictured here. The software evolved from code Neurala was developing more than a decade ago, with NASA funding, for a rover that could independently learn to traverse Martian terrain. *Credit: Neurala Inc.*



When visual inspection systems on an assembly line can process data with their own artificial intelligence, rather than sending it to be processed in the cloud and waiting for a response, the line can move faster and all data is kept secure onsite. *Credit: Getty Images*

Artificial intelligence software designed to learn and analyze Martian terrain is now at the heart of a system to monitor assembly lines on Earth.

The vision inspection software from Neurala Inc., an artificial intelligence company in Boston, works with existing cameras, computers, and even cellphones to monitor the quality of products running along a conveyor belt, for instance.

“Our software can learn very quickly on a processor with a very small footprint, a skill we learned working with NASA,” said Neurala cofounder and CEO Massimiliano Versace. “By doing so, we enable vision inspection with whatever components are already available, deploying in minutes. In our exploration of the market, we realized that the manufacturing space had a precise need for this technology.”

Versace and Neurala began working with NASA more than a decade ago on a project funded through the Small Business Technology Transfer (STTR) program. NASA was interested in “adaptive bio-inspired navigation for planetary exploration,” and Versace and his team had been working on neural network AI software modeled on the human brain.

Focusing on a rover concept that could independently learn to traverse Martian terrain, Neurala went on to win STTR Phase II funding for the project. Additional money from a NASA Center Innovation Fund enabled the Neurala team to adapt its technology to drone navigation and collision avoidance (Spinoff 2018).

In both the rover and the drone applications, the Neurala software could run on a small device on the vehicle itself, eliminating the delay of sending signals to a decision maker in another location.

Onsite computing is an advantage in manufacturing as well, where an assembly line may have a hundred items passing every minute, making visual inspections for quality control difficult.

“If you do the math, you have very little time to understand what you’re looking at,” said Aishwary Jagetia, a senior research scientist and AI specialist at Neurala. “Sometimes you have a few milliseconds, so there is not enough time for you to go from the camera to a cloud somewhere in the world, and then send the result back to the factory. It’s becoming increasingly crucial to bring AI capabilities directly to devices to ensure faster processing and better privacy protection.”

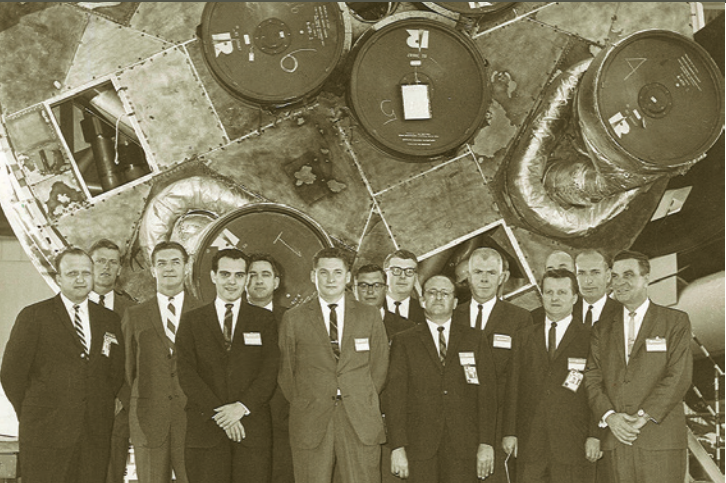
Manufacturers typically don’t want their information online, where they have to pay for storage that might not be secure while production becomes dependent on the strength of the Wi-Fi connection.

Mark Motter, an engineer at NASA’s Langley Research Center in Hampton, Virginia, noted that assembly line quality control at first glance looks like an entirely new direction for the technology.

“But actually, in a dynamic environment you have things flying by you, and that seems somewhat similar to what’s happening here,” Motter said. “Or even with the rover, where we’re trying to recognize things like rocks and cliffs that we don’t want to run into or drive off — that’s not unlike identifying defects in products.”

Motter, who initially suggested Neurala compete for STTR funds after reading about the company in an industry publication, said he’s glad NASA can take some credit for helping to develop this new application. ●

Commercial Sales Flow from NASA Valves



Marotta Controls founder Pat Marotta, far right, poses with members of his company and others in front of the Saturn I main booster in 1963. The company has been making specialized components for NASA since the early days of the space agency, a heritage that’s paying off as private companies move into the space industry. *Credit: Marotta Controls Inc.*



Marotta Controls developed these valves as a subcontractor to NASA’s Commercial Resupply Services and Commercial Crew programs and now sells them to other commercial launchers. Clockwise from top left: The MFV400 electronic pressure regulator is now on a commercial lunar lander. The PRV15B negative pressure relief valve prevents capsules from being crushed on atmospheric reentry. The MV100X is used in small thrusters to adjust spacecraft orientation. And the MV524 controls flows from pressurized tanks. *Credit: Marotta Controls Inc.*

Valves developed for NASA programs meet needs of commercial space, other industries

Founded during World War II, Marotta Controls of Montville, New Jersey, started out designing valves for some of the U.S. military’s first liquid-propellant rockets, making the company an obvious fit when NASA started looking for valve suppliers years later. Marotta components have now been integral to every major rocket and crew vehicle in NASA’s history.

Today, however, there are many more players in space travel, meaning the company’s early leap into space technology is paying off with abundant commercial contracts. “During the Mercury and Apollo days, we were making a handful of those components, whereas now, there are so many spaceflights happening we’re manufacturing thousands per year,” said Brian Ippolitto, senior director of business development for Marotta’s space business unit.

Among the valves Marotta developed for NASA programs and now sells commercially are a pair that trace their lineage to early NASA spacecraft, said Ippolitto. The MV100X and MV524LT were further refined for the Commercial Resupply Services program, through which NASA helped fund the development of several private spacecraft to carry supplies to the International Space Station. Marotta expanded the temperature range for both valves to meet commercial resupply needs. Ippolitto said commercial space companies have now used the MV100X in small thrusters that shift a craft’s orientation in space, while the MV524LT is a higher-flow valve used commercially to control flows from pressurized tanks.

Two valves the company developed for the Commercial Crew Program are also now flying on other commercial spacecraft, Ippolitto said. Under Commercial Crew, NASA helped fund the development of spacecraft to ferry astronauts to and from the space station. As a subcontractor, Marotta created the negative pressure relief valve and the MFV400 electronic pressure regulator. The latter was developed for an in-flight abort system, where it will funnel highly pressurized gases into thrusters that can kick a crew vehicle free of a rocket. This valve now allows a commercial lunar lander to save space with a small, extremely high-pressure fuel tank. And the negative pressure relief valve allows air into a spacecraft during atmospheric reentry, preventing it from collapsing under atmospheric pressure. Ippolitto said other companies are now using it for their own “things that are coming back to Earth and need to not be crushed.”

He said Marotta now has components on every U.S. launch vehicle, with sales to space companies accounting for around a fourth of the company’s revenue.

Jimmy Moore, engineer with the Valves, Actuators, and Ducts Branch at Marshall Space Flight Center in Huntsville, Alabama, said the ultimate goal of the commercial crew and commercial cargo programs is to help companies establish a business model for space travel, with NASA as a customer. “But there’s also the effect of suppliers like Marotta having to push the envelope, and now they’ve got a bigger catalog of offerings,” he said, adding that all these developments benefit the commercial space industry and, ultimately, NASA.

Designing for high pressures and other rigors of space travel has opened other doors for Marotta, Ippolitto said. Customers in petroleum drilling deal with harsh environments, and microchip manufacturers uses high-pressure gases in cleaning and manufacturing processes. Several of these companies buy Marotta products incorporating elements the company developed for space.

“It’s about high temperatures, nasty fluids, demanding applications that can’t fail,” Ippolitto said. “You can’t pick up something at your local big-box store that’s going to have similar quality.” ●

Cloud Software for Above the Clouds



The Double Asteroid Redirection Test required extreme precision in mission planning to achieve its mission of impacting an asteroid. The founders of Continuum Space worked on astrodynamics relating to this mission, which they used to inform their product. *Credit: NASA*



Continuum's platform includes several features for mission planners, such as plotting orbital maneuvers and risk management evaluations. Some of these are built upon software licensed from the Jet Propulsion Laboratory. *Credit: Continuum Space Systems Inc.*



NASA-licensed software enables detailed planning for commercial space

Planning a space mission can be a very involved process. Ensuring orbits are lined up and spacecraft have enough fuel is imperative to the long-term survival of an orbital asset. Continuum Space Systems Inc. of Pasadena, California, produces a cloud-based platform that gives mission planners everything they need to certify that their space resources can accomplish their goals.

“It’s basically a mission in a box,” said Loic Chappaz, cofounder and chief technology officer of Continuum Space Systems. “You have a design, you have navigation, you have a solution.”

Continuum’s story begins at NASA’s Jet Propulsion Laboratory in Southern California. Chappaz started at JPL as an intern working on astrodynamics related to the Double Asteroid Redirection Test. There he met Leon Alkalai, a JPL technical fellow who spent his 30-year career at the center planning deep space missions. After Alkalai retired from NASA, he founded Mandala Space Ventures, a startup that explored several avenues of commercial space development. Chappaz soon became Mandala’s first employee, alongside other former staff from JPL. But to plan their future, Mandala’s leadership needed to start thinking about the act of planning itself.

“We developed several mission concepts, with analysis and simulation design, but we were confronted with the problem of not having the right tools, software, or workflows that were adapted to all the new space activities,” said Chappaz.

Because the staff had decades of combined experience at JPL, they knew the center had the building blocks for the software they needed. After licensing several pieces of software from JPL, the company began building planning systems that were highly adaptable to any space mission it could come up with. Mandala eventually became more of a venture firm that incubated space-related startups rather than a space company itself. However, because Mandala had invested considerably in developing mission-planning tools, further development could be performed by a new company, and Continuum was fully spun off from Mandala in 2021.

Based on the Amazon Web Services cloud platform, Continuum’s tools are designed to take a space mission from concept to completion. There are three different components to the “mission in a box” — design, build and test, and mission operations. The base of these tools are several pieces of software developed at NASA. These include the General Mission Analysis Tool for high-level plotting of missions; a method of planning observations called Spacecraft, Planet, Instrument, C-matrix, and Events (SPICE); and the Mission Analysis, Operations, and Navigation Toolkit Environment (MONTE), which enables accurate assessment of spacecraft positions from millions of miles away.

“When you measure position, there’s some error there that can be found with basic calculus,” said Bill Taber, who leads MONTE development at JPL. “What our software does is turn that error into a more accurate estimate of where the spacecraft is.”

As of 2024, several space startups have begun planning missions with Continuum’s software, as well as established operators of satellite constellations. Chappaz believes Continuum only got to where it is today by licensing NASA technology.

“The vision was always to transfer some of that technology into the marketplace. Do we think we’re smart enough to do it from scratch? Maybe not,” Chappaz said. “This is really core to what we can provide to other people to enable the blossoming space revolution.” ●

Controlled Propulsion for Gentle Landings



The controlled descent of the Mars Curiosity rover included the use of propulsion rockets pointing to the surface to allow a gentle landing. The engine, shown firing in this illustration of Perseverance and the sky crane landing system relied on a pyrovalve that released the rocket fuel. *Credit: NASA/JPL-Caltech*



As the sky crane descended toward Mars at approximately 200 mph, eight engines fired to produce a counterthrust to reduce its speed to about 1.7 mph before lowering the rover to the surface. Eaton developed a custom pyrovalve to ensure the fuel was released at just the right moment. *Credit: NASA/JPL-Caltech*

A valve designed for NASA rover landings enables aerospace companies to fly safely

The Curiosity and Perseverance Mars rovers continue to provide a wealth of information about the Red Planet and its history. But if the sky crane landing systems that gently lowered them to the surface had run out of fuel a mile up, none of that would have happened. A successful descent managed by eight powerful engines depended on a small part created by Eaton Corp. It ensured the fuel didn’t leak from tanks during months traveling through space and then flowed freely to execute a gentle landing. That valve is now used on commercial space vehicles.

Working under contract to NASA’s Jet Propulsion Laboratory in Southern California, the company developed a new one-time-use pyrovalve to sit between the hydrazine fuel tanks and the controlled-descent engines. The zero-leak valve was the largest ever made of its type at the time, and at three-fourths of an inch, it now enables commercial rocket-stage separation in space.

Engines producing about 750 pounds of thrust each for Martian surface landing required more fuel than a conventional valve could deliver, said Carl Guernsey, propulsion subsystem chief engineer for the Mars Sample Laboratory mission, which delivered the Curiosity rover. The absolute seal was to ensure adequate fuel for landing because the parachute would not guarantee a soft touchdown.

“With the engines pointing down, we throttle up and increase the thrust, so we slow down,” said Guernsey. “At a certain altitude above the surface, you hold at a constant velocity to collect more sensor data, and then proceed with the rest of the descent.” With only seconds for sensor data to identify the landing area and direct any last-minute diversion maneuvers, landing could only occur with fuel available at the right time.

That required a reliable pyrovalve — a Y-shaped pipe with a pair of leak-proof solid metal barriers that prevent propellant flow until the valve is employed in the descent. The valve contains a pyrotechnic charge that’s fired to activate a piston called a flying ram, which shears off the barriers, carrying them to the bottom of the valve and allowing fuel to flow.

To build the valve, NASA turned to a company that had provided the space program with reliable gas regulators since the 1950s (Spinoff 2019). Through a series of mergers, by 2021, the original company, called Conax Florida, had become part of Eaton based in Orchard Park, New York.

But a problem arose during flight qualification testing. Sometimes the ram didn’t stay wedged in place, posing a risk that it could float back up and block the flow of hydrazine. While the new design worked well in every other way, this issue had the potential to disrupt the launch schedule.

The solution the team came up with was simple — magnets at the bottom of the valve. This ensured the ram was held in place. It worked well enough to fly again on the Perseverance mission.

“When you are up against the wall and have to get something done, you can come up with some great ideas,” said Mosher. The built-to-order pyrovalve created by Eaton now ensures reliable rocket stage separation on commercial rockets. ●

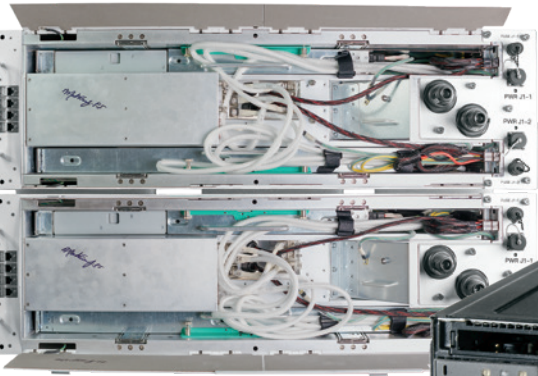
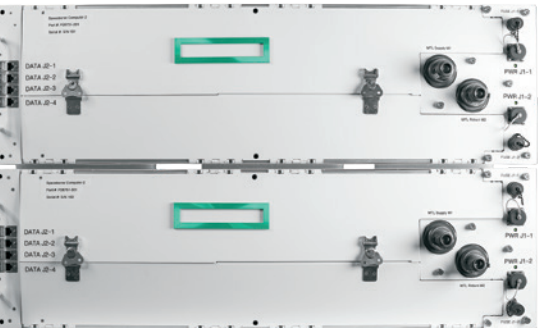


This one-time-use pyrovalve sat between the hydrazine fuel tank and the controlled-descent engines on the sky crane for the Curiosity and Perseverance Mars rovers. The zero-leak valve developed by Eaton also ensured no fuel was lost on the long flight to Mars. *Credit: Eaton Corp.*

Cutting-Edge Computing Goes Spaceborne



Following the success of the Spaceborne Computer missions, the company OrbitsEdge decided to use the Hewlett Packard Enterprise (HPE) Edgeline 8000 in one of its SatFrame satellite models. Credit: OrbitsEdge Inc.



Spaceborne Computer 2, currently on the International Space Station, comprises a ProLiant DL360 server and an Edgeline 4000 server, both from HPE. Credit: Hewlett Packard Enterprise Co.

The Edgeline 8000 is designed to perform in harsh environments on Earth. At least one company now plans to send the server into orbit. Credit: Hewlett Packard Enterprise Co.



Spaceborne Computer missions demonstrate faster, easier protection against space radiation

When Hewlett Packard Enterprise Co. (HPE) sent an unmodified high-performance computer to the International Space Station in 2017, no computer expert thought it would last a week. Over a year-and-a-half later, Spaceborne Computer-1 returned home, having operated successfully for its entire mission.

“No one in the aerospace industry thought this was going to work,” said Mark Fernandez, now principal investigator for Spaceborne Computer-2 at Spring, Texas-based HPE. “The longest publicly stated life expectancy for Spaceborne-1 was four days, because we did nothing to the hardware at all.”

Unaltered, off-the-shelf computers don’t last long in space due to radiation that the atmosphere protects us from on Earth. When high-energy particles or photons strike microchips, they can alter the voltage in nearby transistors, corrupting data, changing the computer’s behavior, and eventually destroying its electronics.

The solution has been radiation hardening: a commercial computer’s electronics are mounted on insulating boards instead of conventional semiconductors and shielded in a protective layer, in a lengthy process that Fernandez said “takes 10 years and millions of dollars.”

As a result, radiation-hardened computers “are usually several generations behind the current state of the art,” said Rupak Biswas, director of exploration technology at NASA’s Ames Research Center in California’s Silicon Valley, who proposed the first Spaceborne Computer mission. Meanwhile, he said, as NASA sends astronauts farther from Earth, increasing the lag time for transmissions, the agency will want more computing power aboard its spacecraft. “So the idea was, what if we take one of our latest-generation processors, put it in space, see what radiation does to it, and use software to correct those errors, as opposed to depending on the hardware?”

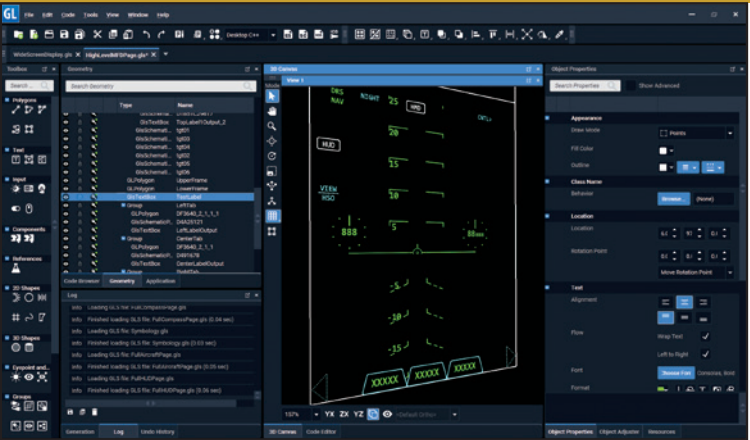
NASA reached out to Silicon Graphics International, a company that had built supercomputers for Ames, where Fernandez was one of the chief technology officers. HPE acquired SGI not long after. By then Fernandez was already developing software that would monitor all of a computer’s components and slow it down incrementally when any behavior fell outside normal operating parameters, avoiding damage.

When the approach worked, it wasn’t just HPE and NASA who were pleased. “Hearing Mark say this thing worked great, when there had been no small consensus that it was nothing more than a fire hazard, was very encouraging to us, that this would be something we could do,” said Rick Ward, founder and chief technology officer of OrbitsEdge Inc. The recent startup was making its own plans to put cutting-edge computers in space without traditional radiation hardening.

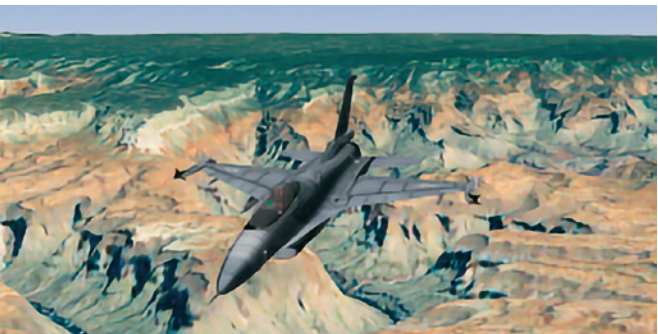
Following HPE’s success, OrbitsEdge is making HPE’s Edgeline system the heart of one of its SatFrame satellites. Developed while Spaceborne Computer-1 was on the space station, Edgeline is a rugged system intended to provide processing power in the field and is now on the station as Spaceborne Computer-2. OrbitsEdge has signed an agreement to use the Edgeline 8000 in its 1,000-watt satellite, which will likely be developed after one or two smaller versions, and the company has already purchased several units for development.

HPE said a number of other commercial space companies are also considering its software-hardened systems for use in space. Meanwhile, the company is working with NASA to provide the first commercial high-powered computing in space by opening up Spaceborne Computer-2 to do work for paying customers, a service it hopes to offer shortly. ●

From Cockpit Controls to Dashboard Data



This screenshot of DiSTI’s GL Studio software shows how it can be used to create user interfaces for aircraft. Capabilities the company developed for NASA led to features in the commercial product. Credit: DiSTI Corp.



NASA’s WorldWind is a virtual globe program that produces a visualization of Earth’s surface. DiSTI helped NASA’s Ames Research Center develop a WorldWind-based flight simulator with GL Studio, which in turn made the company’s software compatible with the Java programming language. Credit: NASA



Since 2020, the interfaces on the infotainment and instrument cluster displays on Hyundai car models have been produced with DiSTI’s GL Studio software. The ability to run on this sort of integrated hardware can be traced back to requirements for NASA. Credit: Hyundai Motor America

NASA feedback enables better display systems for aircraft, more

In the early days of computers, interfaces were paper printouts or blinking lights, but as the technology matured, the graphical user interface (GUI) quickly became the standard.

As more and more everyday products become computerized, their embedded systems need straightforward, reliable ways of generating interfaces. DiSTI Corp. of Orlando, Florida, is one company that provides software that forms the backbone of computer graphical interfaces, and several of its features trace a lineage to NASA requirements.

In the early 1990s, digital multi-function display screens were starting to become standard on aircraft, and the modern “glass cockpit” was beginning to take shape. Founded in 1994, one of DiSTI’s first projects involved making digital instruments for the U.S. Navy and Air Force, including a digital interface for the F-16 fighter jet.

“We had a couple of Small Business Innovation Research contracts with the Department of Defense,” said Chris Giordano, vice president of user experience technology at DiSTI. “One was to have our GUI tool generate code that could fly on real aircraft hardware.”

This GUI tool soon became GL Studio, named after the OpenGL code that enables easy graphics generation. By the 2000s, GL Studio was commercial off-the-shelf software, so when several NASA missions needed interfaces for reading crucial information, DiSTI’s GL Studio software helped them get there. Several NASA programs use GL Studio, including a tool that helps spacecraft recovery helicopters during the Artemis splashdown process.

“We started working with GL Studio as far back as 2009. We chose it for its real-time graphical flexible interface,” said Jeffrey Fox, chief engineer of the Rapid Prototyping Lab at NASA’s Johnson Space Center in Houston. “Using this software and its customizations allows this helicopter to get closer to a spacecraft than ever before.”

GL Studio has several features that originate from various NASA needs. In 2007, when the flight simulator developers at NASA’s Ames Research Center in Silicon Valley, California, wished to integrate GL Studio with the agency’s WorldWind virtual globe, they asked DiSTI to write interface software that would work with WorldWind’s Java environment.

“We presented it at the Java One conference in San Francisco. Everybody went nuts because it was a full 3D cockpit done in Java,” said Giordano. “I would say that was the first time NASA directly influenced the direction of our tools.”

The ability to export Java-based interfaces was soon built into GL Studio, where it now generates the interface on Rohde & Schwarz TV broadcasting equipment.

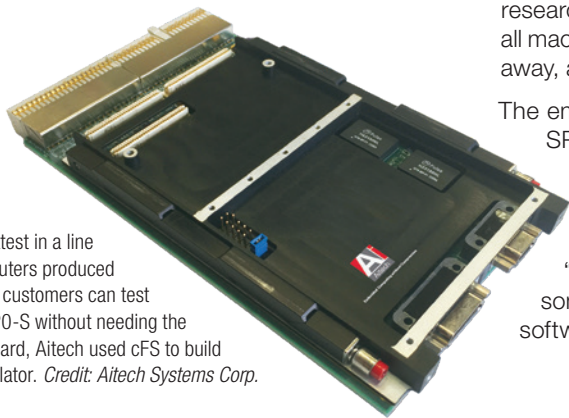
Another case where NASA’s needs resulted in new features arose during the development of the Orion spacecraft’s computer interfaces. To render the graphics on Orion’s screens, NASA wished to use OpenGL rendering in software, which GL Studio did not support at the time. Dedicated graphics rendering chips weren’t hardened against radiation, so the computers aboard Orion needed software that could generate graphics without a chip.

The company followed NASA’s request, and while Orion’s screens ultimately used a different tool, the software graphics rendering feature is a vital part of the commercial releases of GL Studio. Many automotive infotainment systems, instrument clusters, and heads-up displays run on embedded hardware to keep costs low by eliminating the need for custom graphics processing chips. Since 2010, GL Studio has powered the infotainment systems on Jaguar and Land Rover models, and since 2020, it has run the interfaces of Hyundai and Kia cars as well. ●

Hard(ware) to the Core



Most of the robotic missions operated by Goddard Space Flight Center, such as the Core Observatory of the Global Precipitation Measurement mission use the core Flight System (cFS) as a software framework to build upon and manage base systems. This versatility makes it a popular choice to run systems on commercial spacecraft as well. *Credit: NASA*



The SP0-S is the latest in a line of spacecraft computers produced by Aitech. So customers can test software on the SP0-S without needing the physical circuit board, Aitech used cFS to build an emulator. *Credit: Aitech Systems Corp.*

NASA-developed open-source software forms basis of spacecraft emulator

At the heart of every satellite is a computer designed to control it and communicate with operators on Earth. Effectively the spacecraft’s nerve center, the command and data handling system is essential to a satellite. But running that system requires a framework to build upon, something NASA provides the public openly.

The core Flight System (cFS) is an open-source software framework that allows spacecraft to have a common starting point, without having to code all the base functions from scratch. Managed out of NASA’s Goddard Space Flight Center in Greenbelt, Maryland, cFS covers all the basics that a spacecraft’s computer needs to operate.

“It allows applications to communicate and be managed on the spacecraft,” said Jay Bugenhagen, the former program manager for cFS. “Missions typically would add their own customized applications, such as navigation, guidance, and control, but the main core functions are provided by cFS.”

With its open-source availability, cFS has become a standard for running software aboard satellites. Bugenhagen said virtually all satellite missions run by Goddard use cFS, and organizations like the ESA (the European Space Agency) and members of the commercial space industry are frequent users.

As a manufacturer of computer hardware for spacecraft, Aitech Systems Corp. of Chatsworth, California, incorporates cFS into its SP0 brand of single-board computers, though users can elect to use another software. There are hundreds of components that can be plugged into an SP0 to fit any mission and hundreds of permutations of software to control them, so for its latest model, the SP0-S, Aitech explored a new way to ensure compatibility with all that hardware and software. Spacecraft makers would usually need the computer in hand to know exactly how the programs would run, but Aitech turned to a process called emulation.

Emulation recreates the hardware environment inside another computer. While it’s not a direct one-to-one replica, it’s close enough to simulate how the computer will perform in flight. Aitech partnered with Embedded Flight Systems Inc. to build an emulator that could replicate the SP0 hardware, any components that might be used with it, and the accompanying software. And to mirror SP0, cFS forms a key part of the emulator, taking care of the basic software functions, just as it’s used in space missions.

“That’s what this whole system is built on top of. Now no matter what software you run, it might be a bit different on the SP0-S, but it’ll run,” said Ralph Grundler, director of space research and development at Aitech. “Back in the olden days with the first satellites, it was all machine language written right on the processor. Now we’re a couple of levels abstracted away, and you can emulate it without needing any hardware.”

The emulator helped design the SP0-S, but now it’s become a product itself. Aitech’s SP0 computer boards are a popular choice for companies that need assets in space, and the emulator has been used by companies like space technology outfit Red Canyon to test software that will be deployed in orbit. Grundler said NASA’s work on cFS has been indispensable for the commercial space industry.

“Think about every time NASA’s flown something — that means they’ve learned something. They’ve put that into cFS,” said Grundler. “That’s why this core Flight System software is so critical to anybody who wants to start their own space company.” ●

NASA and Education Make Quite the Pear



A-PUFFER is a robot designed by NASA, one of many used as an example of agency technologies in lessons produced as part of the Pear Deck Learning Suite. *Credit: NASA /JPL-Caltech*



Robots Inspired by Nature		
	LEMUR	Can scale rock walls, gripping with hundreds of tiny fish hooks in each of its 16 fingers. Uses artificial intelligence (AI) to find its way around obstacles.
	SpiderBot	A micro robot designed to chart the terrain on other planets and explore smaller bodies, such as comets, asteroids, or the Moon.
	A-PUFFER	Foldable robots that could scout regions on the Moon and gain intel about locations that may be difficult for astronauts to investigate on foot.
	SPARROW	Would be propelled by steam and hop across the icy terrains, like those found on Jupiter's moon Europa and Saturn's moon Enceladus.
	Geckobot	A gripping system inspired by the tiny hairs on the bottom of geckos' feet allows this robot to cling to vertical walls and other surfaces.
	BRUIE	Designed for underwater exploration in extraterrestrial, icy waters, this robot uses its two wheels to roll on the underside of the ice covering bodies of water.
	RoboSimian	An ape-like robot that could respond to disaster scenarios too dangerous for humans.

This interactive science lesson instructing students to design a robotic insect is one of many that Pear Deck produced with help from NASA experts. *Credit: Limnex Inc.*

NASA partnership makes interactive educational resources for teachers nationwide

Few things capture a child’s imagination like space exploration. According to a 2018 study by Harris Insights and Analytics, “astronaut” is one of the most popular answers kids give to the enduring question, “What do you want to be when you grow up?” For all those children who could go on to make those dreams a reality, a solid education in science, technology, engineering, and math (STEM) starts early. Now NASA is lending expertise to bolster one company’s lesson plans.

Pear Deck is a subsidiary of the educational technology firm GoGuardian. The El Segundo, California-based company specializes in building interactive experiences as part of the Pear Deck Learning suite that teachers can use to build and enhance their lessons. Aimed squarely at K-12 educators, lessons for students of all ages and reading levels are available. The cornerstone of Pear Deck’s technology is an extension for Google Slides and Microsoft PowerPoint Online. More than just pre-written slideshows, the browser plugin allows students to interact with the presentations and answer question prompts on their own devices, no hand-raising required.

“It’s a tool that fosters collaborative learning experiences for students, promoting active learning and ensuring an equitable environment in the classroom,” said Amardeep Sahni, director of product management for Pear Deck. “Every student’s voice is heard.”

Befitting the “pear” name, the company’s online marketplace is called the Content Orchard, where teachers can find standards-aligned lessons that fit curricula for several subjects, such as math, English language arts, and science. To further fill out the Orchard’s offerings, the company sought assistance from NASA. The space agency’s Office of STEM Engagement has a long history of educational outreach, not only helping create teaching materials directly, but also working with major technology firms like Microsoft to make other lessons. Knowing this, Pear Deck reached out to NASA about collaborating.

“We have an open call for partnerships,” said Rob LaSalvia, partnerships manager at the Office of STEM Engagement. “Pear Deck responded, and we started discussing what we could do together.”

Working with NASA Headquarters in Washington through an ongoing partnership, Pear Deck has created several lessons based on the agency’s programs, with NASA providing input, alongside images and data from the archives. These lessons aren’t strictly confined to scientific themes but also explore the wider concept of “STEAM,” adding “art” to the list of STEM subjects.

One of the NASA-inspired lessons instructs students to draw and design a robotic insect, working through the factors that would help it explore extraterrestrial environments, teaching students about arthropod biology and engineering at the same time. NASA technology experts were consulted on the agency’s projects and concepts that could tie into the prompt, such as animal-inspired robots designed by the Jet Propulsion Laboratory to explore the moons of our solar system, like the Autonomous Pop-Up Flat Folding Explorer Robot (A-PUFFER) and the Steam Propelled Autonomous Retrieval Robot for Ocean Worlds (SPARROW).

Today, these NASA lessons are among the most popular offerings in the Orchard. More recent lessons produced in conjunction with the space agency include modules based around Mars exploration for younger students, as well as one that combines art and science using the NASA-produced First Woman graphic novel as a springboard. Sahni credits the NASA partnerships with shoring up the content available to teachers, allowing them to educate future space explorers today. ●

Intelligent Processing at the Edge



While imagery taken from orbit can be important to humans on the ground, cloud cover can obscure important surface features. Ubotica's platform was tested on the International Space Station to sort out photos with excessive cloud cover. *Credit: NASA*

Ubotica's system is designed to interface with common enterprise computer components like those found in the Hewlett Packard Enterprise Spaceborne Computer-2, enabling further development of these computers for space applications. *Credit: Ubotica Technologies Ltd.*



This image of California's Salton Sea taken by astronauts aboard the space station shows an algal bloom, which could be harmful to wildlife in the area. Identifying and monitoring these from orbit requires clear imagery, which can be provided by machine learning models sorting through photos. *Credit: NASA*

Faster space computing improves disaster response time

Earth observation enables enormous benefits for people on the ground. From weather forecasting to disaster monitoring, lives can be saved through timely processing of satellite data. However, that timeliness can be difficult to achieve.

"Satellites are just data collectors. They don't know what they're looking at. They just gather data, and then when they get over a ground station they downlink all of it," said Brian Quinn, chief strategy officer of Dublin-based Ubotica Technologies Ltd., which has offices in Cleveland. "It takes post-processing, which could be days later, to say, 'Hey, there was a fire. Hey, there was a harmful algal bloom.'"

Founded in 2017, Ubotica sought to eliminate that time gap. The company's line of CogniSAT platforms are components for satellites that allow some processing to occur in orbit before data is sent to ground. Processing data at the point of capture is called edge computing, and it's a growing industry not only in space, but in all fields where sensors are in remote or inaccessible environments. The CogniSAT system primarily acts as a companion processor to enable edge computing on an orbiting satellite. The processors are optimized for machine learning, running specialized algorithms called "models" to learn which data points are useful.

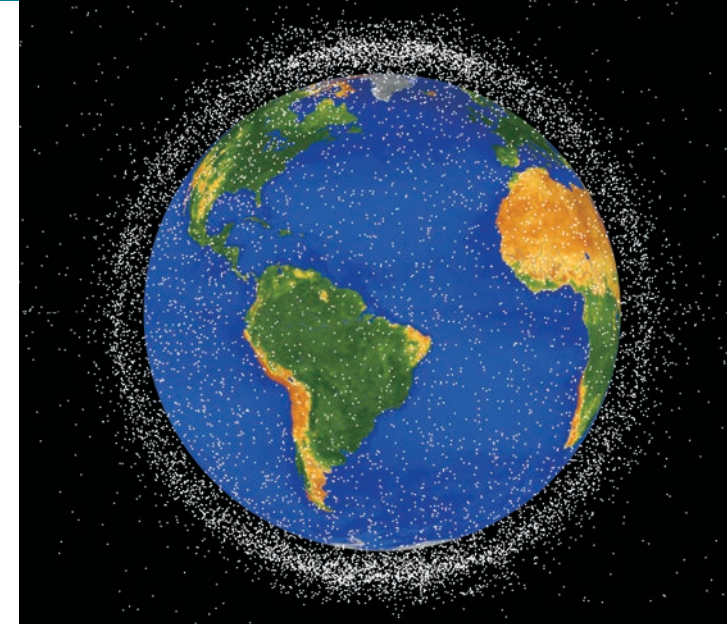
Ubotica partnered with NASA's Jet Propulsion Laboratory in Southern California to send a CogniSAT platform to the International Space Station in 2022, integrated with the Hewlett Packard Enterprise Spaceborne Computer-2 (page 12). The mission was twofold, testing NASA models that could process data collected by Earth-facing cameras, and also testing how well the platform would work without Earth's atmosphere to protect it from radiation. Ubotica protected its unit against radiation with a combination of hardware, such as circuits that resist surges in current, and software, such as a memory checker to detect data corruption caused by radiation.

"The models we worked on with Ubotica fell into two categories — segmentation and classification," said Emily Dunkel, a data scientist at JPL involved with the collaboration. "I would send them a JPL model and they would adapt it to their processor, then we'd send it up to the computer aboard the International Space Station."

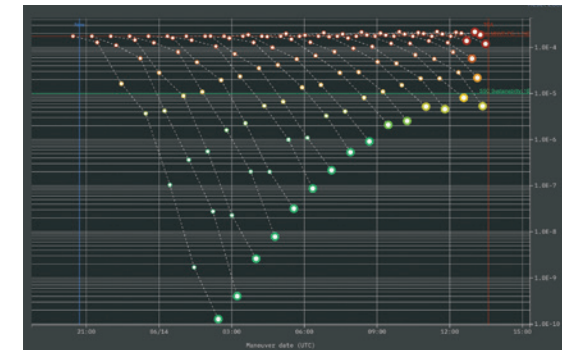
The models run on the space station were simple but effective. Developed both by Ubotica and NASA, they primarily were tasked with sorting out images that would not be useful, such as images full of cloud cover. As the models learned, they could successfully sort out images with more complex cloud cover. In 2023, Ubotica's platform returned to Earth alongside the Spaceborne Computer-2 and was examined to see how it fared after months in space.

"We got the hardware back, and it was still fully functional," said Léonie Buckley, senior engineer at Ubotica. "This was the first time that we demonstrated our platforms' robustness in space, and we did not observe any adverse radiation effects."

The Spaceborne Computer-2 provided spaceflight validation for the Qualcomm Snapdragon 855 and Intel Myriad X, primary processors that are frequently used in commercial computers, enabling the deployment of CogniSAT platforms in satellites, and Quinn credits NASA with helping Ubotica prove its platform works in space. In the time since the NASA collaboration, Ubotica has sold its platform to operators of Earth-observation and communications constellations, as well as launched its own satellite to further test and showcase the hardware. ●



Tens of thousands of human-made objects orbit Earth. To ensure vital space-based infrastructure is safe from collisions with debris, Kayhan's software helps give awareness to satellite operators. *Credit: NASA*



A graph shows potential orbital maneuvers generated by Kayhan's Pathfinder software. Satellites have to make these movements to not only keep from falling into the atmosphere, but to avoid collisions with other satellites or orbiting hazardous objects. *Credit: Kayhan Space Corp.*



Space traffic coordination system helps make sure satellites stay in their lane

As of 2024, there are more than 45,000 human-made objects orbiting Earth, and these are just the ones we can track. With so many crowded orbits, and hundreds more satellites being launched every year, close approaches are inevitable. And with the increasing importance of satellites to modern infrastructure, it's imperative these approaches don't result in any collisions that would disrupt the important tasks being performed or cause debris that could impair other spacecraft.

Right now, the U.S. Space Force tracks these orbital objects for the government, and NASA's Conjunction Assessment Risk Analysis program evaluates close-approach risks and alerts mission managers of any potentially hazardous situations. Because of the growing number of commercial satellites, including several large constellations, the Department of Commerce is building a system to predict close approaches for all operators, the Traffic Coordination System for Space (TraCSS). Assessing the risk of these close approaches falls to the satellite operator. Due to the highly specialized analysis involved, many rely on private companies to ensure the safe operation of their satellites.

For these companies, receiving thousands of conjunction alerts and determining which are of main concern is an increasingly difficult job.

"A lot of them are low-risk, but for a human to be able to go through all those alerts and be able to positively identify the high-risk events is just not possible," said Siamak Hesar, CEO of the company Kayhan Space Corp. Based in Broomfield, Colorado, Kayhan grew out of the need for situational awareness in the increasingly crowded low-Earth orbit.

Hesar used to work at SpaceNav, a company founded by a former NASA contractor that assisted NASA in making orbital safety assessments for such missions as the Global Precipitation Measurement mission's Core Observatory and Orbiting Carbon Observatory-2, as well as several CubeSats launched from the International Space Station (ISS).

"We had to figure out the best way for the CubeSats to be deployed, so we did a lot of analysis to figure out the safest direction was for them to get deployed below the ISS," Hesar said. "As I was seeing Starlink going up, and OneWeb was planning to launch 1,000 satellites, I quickly realized, we are doing all this work manually. We were not set to scale the capabilities to keep these assets safe in orbit."

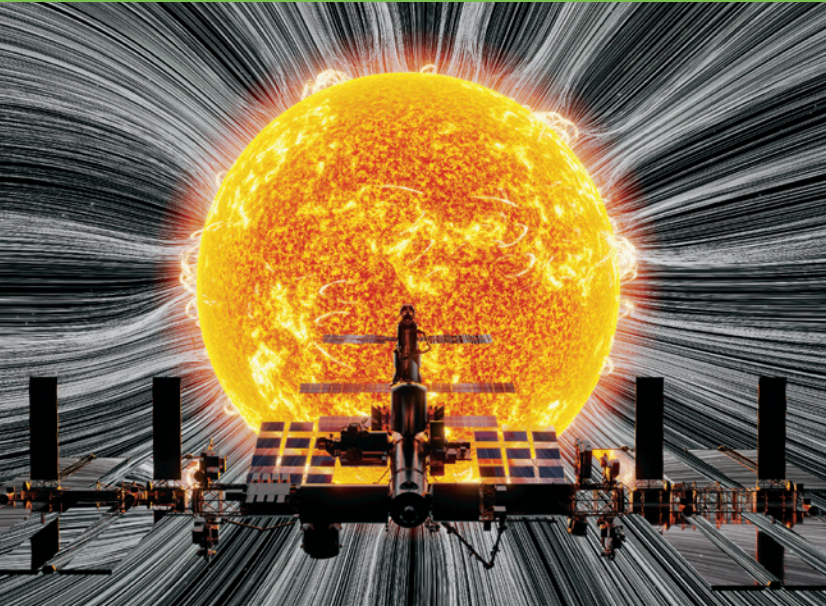
In the absence of telescopes or radars to keep track of objects, Kayhan's Pathfinder system aggregates data of known orbits, and cross references them. When multiple data sources show a close approach, Pathfinder automatically flags an alert for operators to evaluate mitigating the potential collision.

Today, several former NASA personnel and contractors work at Kayhan Space, and the company's software supports more than 30 satellite constellation operators. Hesar credits his work with NASA with developing his skills in the relatively new field of space situational awareness, and with showing him the need for increased safety in private spaceflight.

"I graduated from the University of Colorado in Boulder, one of the leading institutions when it comes to astrodynamics. But space situational awareness and collision avoidance was not really in our curriculum," Hesar said. "Even though it's a very important topic, all the knowledge in the field is gained by people actually doing it." ●

The black mark in this space shuttle window was made by a piece of space debris. As more essential infrastructure is placed into low-Earth orbit, avoiding these strikes becomes both more important and more difficult. Kayhan's software enables space companies to have awareness when there's a probable close approach. *Credit: NASA*

Using AI to Predict the Sky



The Frontier Development Lab (FDL) is a partnership between NASA and several commercial firms in the artificial intelligence field. A focus of the partnership one year was applying machine learning technologies to heliophysics, the study of the physics of the Sun and its influence on the solar system. *Credit: FDL.ai*



While auroras are a beautiful sight on Earth, the solar activity that causes them can wreak havoc with space-based infrastructure like satellites. Using artificial intelligence to predict these disruptive solar events was a focus of KX's work with FDL. *Credit: NASA*

NASA partnership to explore AI in space bolsters analytics software used in finance, manufacturing, and industry

Data analytics is a multibillion-dollar industry, and the growing field of artificial intelligence (AI) is in high demand everywhere. AI generally means that computers learn from massive amounts of data and apply it to help solve problems. KX Systems, a division of FD Technologies plc., is a technology company that offers database management and analytics software for customers that need to make decisions quickly. While KX started in 1993, the AI-driven part of its business has grown considerably. And the company credits work done with NASA for accelerating some of its capabilities.

"Working with NASA has been so important, because it lets us get years ahead of the curve," said Robert Hill, head of space solutions at the United Kingdom-based company, which has offices in New York City. "Working with NASA exposed us to a group of scientists that's very different from our daily work."

The Frontier Development Lab (FDL) is an ongoing partnership between NASA and commercial AI firms to apply advanced machine learning to problems that matter to the space program and beyond. Since 2016, FDL has applied AI on behalf of NASA in planetary defense, heliophysics, Earth science, medicine, and lunar exploration.

"We're interested in the big problems, grand challenges, and the application of AI in those sorts of situations," said James Parr, CEO of Trillium Technologies, which manages the FDL partnership for NASA. "Sometimes you have a cool new AI method, but it's hard to imagine what the applications could be. At FDL, we can prove an application, and then suddenly everyone can see how it would be really useful for the space program."

KX participated in the FDL partnership between 2017 and 2019. The company's flagship data analytics software is called kdb+, and it's typically used in the financial industry to keep track of rapid shifts in market trends, but the company is also exploring how it can be used in space. Working at NASA's Ames Research Center in Silicon Valley, California, KX partnered with FDL and NASA scientists to apply the capabilities of kdb+ to searching for exoplanets and predicting space weather, areas which could be improved with AI models.

In the summer of 2024, people across North America were amazed when they could see auroras in their hometowns, but the same solar activity that makes auroras could cause disruptions to satellites that are essential to systems on Earth. One question FDL worked to answer was whether kdb+ could forecast this kind of space weather to predict when GPS satellites might experience signal interruption due to the Sun. By importing several datasets monitoring the ionosphere, solar activity, and Earth's magnetic field, then applying machine learning algorithms to them, FDL researchers were able to predict disruptive events up to 24 hours in advance. While this was a scientific application of AI, Hill says some of this development work has made it back into the company's commercial offerings, as there are similarities between AI models developed to find patterns in satellite signal losses and ones that predict maintenance needs for industrial manufacturing equipment.

"It was taking those datasets and looking for anomalies. We use that same process for advanced manufacturing clients," Hill said. "That's not all because of our work with NASA, but at FDL, you're working with some of the brightest people. It's probably R&D we wouldn't have done or even thought of doing if we hadn't had the chance to do it with them." ●

Bringing Hybrid Power to the Rescue



Parallel Flight Technologies' Firefly aircraft is designed to run for 100 minutes while fully loaded, allowing the aircraft to perform agricultural surveys as well as assist in the aftermath of natural disasters. *Credit: Parallel Flight Technologies Inc.*



NASA's Glenn Research Center has pursued hybrid powertrain aircraft for years, through projects such as the Electrified Powertrain Flight Demonstration. Funding from Glenn resulted in Parallel Flight's initial test bed for the company's hybrid motor. *Credit: NASA*

NASA-funded hybrid power system makes drones more capable in disasters

In industries all over the country, remotely piloted aircraft have become a common sight. However, most of these drones have a weakness: they can't carry more than a few pounds without major trade-offs in flight time. This limitation is inherent to the energy capacity of the batteries that power these vehicles, but a technology explored by NASA has been adapted to mitigate these drawbacks and enable more capable aircraft.

Living in California, Joshua Resnick had seen his fair share of wildfires. As he watched low-flying helicopters skim along the tops of burning trees just to monitor firefighting efforts, it gave him an idea.

"You look at some of those helicopter missions, and you realize it's a waste of labor and equipment, and it's all to do a small mission where a person has to go into a really dangerous situation," said Bobby Hultner, a friend of Resnick's. "If you had a drone that could lift 50 pounds and fly for longer than 10 minutes, it doesn't need to be a helicopter, it can be a \$500,000 solution instead of a \$25 million solution."

Soon after, Resnick, Hultner, and friend David Adams cofounded Parallel Flight Technologies Inc. of La Selva Beach, California. Parallel Flight's name comes from the company's chosen method of increasing a drone's capabilities, the parallel hybrid motor. Much like the drivetrain of a hybrid car, it combines a gasoline-powered engine with an electric motor. Unlike a serial hybrid, which uses the gas engine to run a generator that then drives electric motors, a parallel hybrid can switch between the two power sources, playing to each other's strengths. Compared to using batteries alone, Hultner said, hybrid engines give the aircraft more cargo capacity and the ability to stay in the air for 40% longer. When the Parallel Flight team saw that NASA's Small Business Innovation Research (SBIR) program was looking for alternative energy and transportation proposals, they decided to apply.

In 2019, Parallel Flight received Phase I SBIR funding from NASA's Glenn Research Center in Cleveland to test the concepts behind the company's hybrid system and build a test bed for the engines. An important part of the SBIR was ensuring that the hybrid engines could fail safely. Rotorcraft can have several rotors on multiple arms, and a failure on one or more rotors could cause the drone to fall out of the sky. In that event, it was important to ensure the hybrid system could keep working to bring the aircraft down safely.

"If an engine dies on one arm, every single arm has its own engine, and the other arms can help take over in the event of a failure," said Hultner, now director of software and controls at Parallel Flight. "The SBIR allowed us to test that functionality and prove we were able to fly through that and other engine-out events."

While the NASA SBIR funding wasn't continued past the first phase, Parallel Flight received additional funding from the National Science Foundation, the U.S. Department of Agriculture, and National Security Innovation Capital to further build the capabilities of its drone. Soon the company's commercial hybrid rotorcraft, now called Firefly, was in the air. In 2024, Parallel Flight made the first domestic sale of the Firefly platform to an industrial drone operator that uses these aerial systems to perform agricultural spraying, transport medical supplies, provide aid after natural disasters, and fight wildfires. ●



The Firefly aircraft can carry up to 100 pounds of cargo or equipment, including cameras and tools for fighting fires. *Credit: Parallel Flight Technologies Inc.*

NASA ‘RAMPT’ Up 3D Printed Engine Size



Tyler Blumenthal, sales manager at RPM Innovations, stands with a 3D printed rocket engine nozzle, freshly printed using the technique the company refined with NASA for large-scale metal 3D printing. At about five feet across and six-and-a-half feet tall, this is a 65% scale model of the nozzle from the RS-25 engines that were the space shuttle main engines and now power the SLS's (Space Launch System) core stage. *Credit: RPM Innovations Inc.*



Under the Rapid Analysis and Manufacturing Propulsion Technology program, RPM Innovations and NASA 3D printed different classes of rocket engine thrust chambers to mature the novel technologies associated with each. Seen here are the printed engines capable of 2,500, 7,000, and 40,000 pounds of thrust. *Credit: NASA*

Initiative advances, validates technology for 3D printing big, complex parts

Additive manufacturing, better known as 3D printing, has become an important tool for many industries, and NASA has been central to adapting it for one of the most demanding applications — rocket engines.

“Engines are challenging to move from development into production, and they take a lot of resources to develop, so there are tremendous opportunities to speed up the design and the manufacturing process and improve performance,” said Paul Gradl, principal engineer at NASA’s Marshall Space Flight Center in Huntsville, Alabama, who’s leading the agency’s efforts at 3D printing engines. “And if we can develop these technologies for the most extreme environments, temperatures, and pressures, they can be used for applications that are less severe.”

NASA’s largest effort on this front has been the Rapid Analysis and Manufacturing Propulsion Technology (RAMPT) project, funded by the Game Changing Development program and led by Marshall. Beginning in 2017, RAMPT printed a combustion chamber from a NASA-invented copper alloy and a nozzle from a NASA-invented iron-nickel alloy, fused the two, and wrapped them in carbon fiber to maintain their strength while significantly dropping their weight.

To 3D print a large nozzle, the team explored a new technique called laser powder directed energy deposition, which seemed promising for large-scale printing but needed considerable refinement. NASA turned to RPM Innovations (RPMI) of Rapid City, South Dakota. Gradl’s team and RPMI honed NASA’s powdered alloy, NASA HR-1, and the printing process itself to enable production of large, intricate parts. A demonstrator nozzle five feet across and almost six feet tall was printed. Its walls, already thin, were filled with tiny cooling channels, making them extremely intricate and challenging, said Gradl. A subscale version of the nozzle was hot fire tested and accumulated over 200 starts, proving its reusability.

“With RAMPT, we reduced the overall thrust chamber weight by about 40%. That’s huge because in the last 20 years, we’ve been chasing after marginal differences of 1 or 2%,” Gradl said, adding that production time and costs were cut by at least two-thirds. These 3D printed thrust chambers were named NASA’s 2024 Invention of the Year.

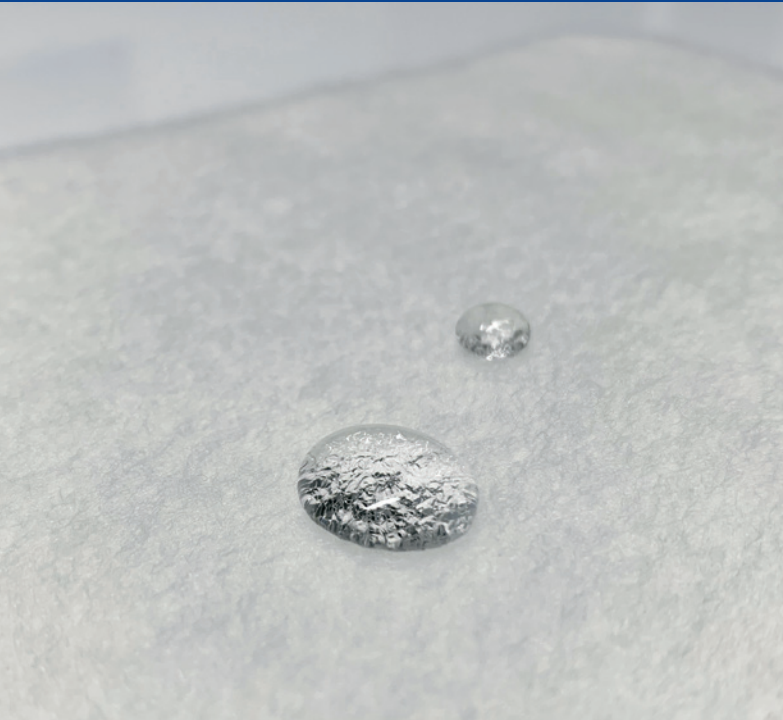
A follow-on program used RPMI machines to produce even lighter nozzles from an aluminum alloy engineered by the company Elementum 3D (see page 52).

Nick Wald, general manager at RPMI, said the project not only helped the company refine its large-scale printing but also proved its technology for the harsh conditions in space. “What NASA has done is take a lot of that up-front risk in printing these parts, and then they actually test them to validate them,” said Wald. “That becomes data your space companies can pick up, and they don’t need to go figure out if this is real.”

Now, about 90% of the company’s service business — that is, printing parts for others — is in the aerospace field. Wald noted that RPMI is the world’s largest user of the NASA HR-1 alloy. But the company also sells printers to customers in several fields, including energy, mining, and oil and gas.

Tyler Blumenthal, RPMI’s sales manager, noted that NASA is also building a public database of various 3D printed materials’ properties, to the benefit of the entire field. “They’ve developed all this data, and everyone has access to it, so now there’s additional knowledge on how to adopt and use the technology across applications,” he said. “It has benefited all of industry.” ●

Innovation Comes Out of the Wool Work



Water droplets on top of Lanaco filter material. Its wool construction naturally keeps out moisture and particulates, which was what interested NASA for use in space firefighting equipment. *Credit: Lanaco Ltd.*

NASA takes wool filters where no sheep has gone before

For millennia, sheep’s wool has been key to major leaps in technology. From the invention of the spinning wheel to the dawn of computer-controlled looms, refining wool into textiles has led to revolutions in industry. Today, wool itself is leading the charge, with some assistance from NASA.

In the enclosed environment of a spacecraft, a fire is among the worst-case scenarios. Astronauts spend days training to put out a fire quickly and effectively. However, extinguishing a fire doesn’t eliminate the consequences that remain afterward, like hazardous gases and microscopic particulates that could be dangerous to breathe. Compared to the International Space Station, where a module can be sealed off and astronauts can take shelter elsewhere on the station, Artemis astronauts in the much smaller Orion spacecraft would have to spend hours in the environment where fire once raged.

Looking for a good option to extend the life of the Orion spacecraft’s emergency firefighting masks, NASA contractor Amentum Holdings Inc. explored several filtration media. Lanaco Ltd., based in Auckland, New Zealand, was the company Amentum entrusted to make an attachment that would augment the existing filter in the firefighting masks astronauts currently wear (Spinoff 2020).

“Twelve years ago, we came across some interesting technology. It’s called sheep’s wool,” said Nick Davenport, founder and managing director of Lanaco. “We’ve done a lot of science to understand how a natural fiber like this could perform in industrial applications.”

Founded in 2012, the company initially focused on filters for industrial protection like spraying paint or sandblasting. Davenport said the company used a two-pronged approach to develop its “Helix” product — constructing a filter medium out of wool that was effective and also breeding sheep that would produce better wool at the source. Meeting NASA specifications, Lanaco developed a version of the filter that would function perfectly in conditions that would come after a fire in space, for example, making it resistant to the moisture that lingers after the use of fire suppression equipment. Davenport said wool was very effective for this, because it has several properties that equal or exceed the performance of synthetic fibers.

“Wool is naturally fire-resistant, it’s naturally bacteriostatic, and it handles moisture exceptionally well. And when it’s built into our filter, it has hydrophobic performance, so you can’t ask for anything better,” Davenport said.

Lanaco’s work has previously resulted in firefighting masks on Earth, but since then, the company’s NASA-derived wool filters have been used in several industrial applications, particularly since the COVID-19 pandemic highlighted a global need for masks.

Today, Lanaco’s filters can be found in industrial respirator masks that protect people from inhaling particulates anywhere from home DIY projects to dusty workplaces.

Lanaco products are also cleaning the air in filtration systems at home and on the go, and are now being tested for many other devices. Because the NASA work produced a wool filter that’s effective at removing particulates in high-moisture environments, it’s perfect for medical devices that have to contend with the particles and moisture present in exhaled breath and the humidified air of hospitals. ●

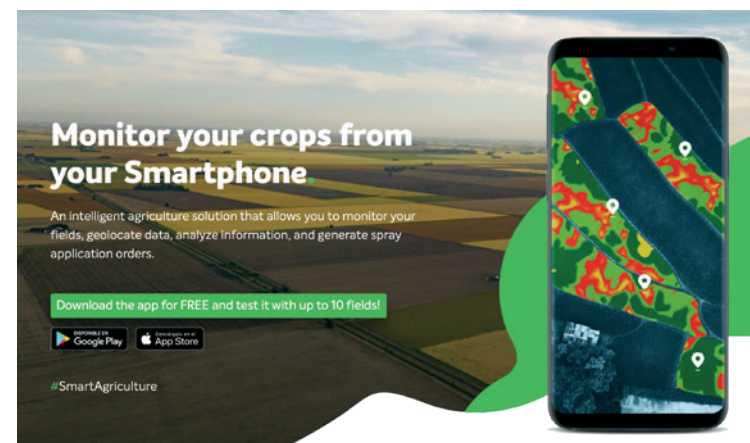


Aboard the International Space Station, astronauts have to wear special masks to fight fires. But to use these masks on the much smaller Orion spacecraft required long-lasting filters, and NASA worked with Lanaco to develop them. *Credit: NASA*

View from the Sky Helps Predict Crop Yields



NASA satellite imagery provides information that can help farmers predict crop yields. The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument on NASA's Terra spacecraft captured this image northwest of Buenos Aires, Argentina, in 2015, after days of torrential rains. *Credit: NASA*



SIMA's app helps farmers document and track what they've planted, what machinery was required, weather conditions, and what weeds, pests, or disease they encountered and the treatments they administered. *Credit: SIMA Software Corp.*

NASA Harvest brings satellite data, crop prediction function to farming app

When SIMA began working with NASA Harvest in 2020, the Argentinian agricultural technology company had already been gathering crop data for years.

SIMA, or Sistema Integrado de Monitoreo Agrícola, sells a data collection tool that helps farmers track and digitize the situations in their own fields.

The collaboration with NASA Harvest, the space agency's agriculture consortium led by researchers at the University of Maryland, brought crop-yield prediction capability to the company's app through a feature called SIMA Harvest.

"It's a sought-after feature because in agriculture it's very important to know how much a crop is going to yield by the end of the season," said SIMA CEO Andres Yerkovich. "Having an algorithm that has more precision than a human estimation is very useful."

SIMA's main app, available for download on Apple and Android devices, gathers data from farmers in their own fields documenting what they've planted, what machinery was required, weather conditions, and what weeds, pests, or disease they encountered and the treatments they administered.

"The idea is to standardize all of this information in a way that is comparable between different users doing the same task in several locations and also for these data to be comparable over time, from one year to the next," Yerkovich said.

Headquartered in Rosario, Argentina, SIMA's strong relationships with farmers throughout Latin America and its extensive, high-quality field data made the company a good fit for collaboration with NASA Harvest.

"We brought expertise in Earth-observation data and machine learning methods to track crop conditions throughout the growing season," said Ritvik Sahajpal, a professor in the University of Maryland's Geographical Sciences Department and a NASA Harvest developer who worked with SIMA.

Sahajpal noted that SIMA's strengths worked well with those of NASA Harvest. "Where we brought in expertise in applying machine learning models to Earth-observation data, they contributed knowledge on local agro-meteorological conditions and their impacts on crop growth."

The science development was led by NASA Harvest researchers, who wrote a paper and gave a presentation on the project.

Yerkovich noted that SIMA's data, which the company calls "ground truth," complemented the information NASA Harvest drew from satellite images.

"Of course, satellite images are among NASA's primary assets, and they do a great job getting information from the crops and the fields from space," Yerkovich said. "But there are certain variables that you cannot observe from the sky, and that's where SIMA comes in, because our data comes directly from users standing in the field."

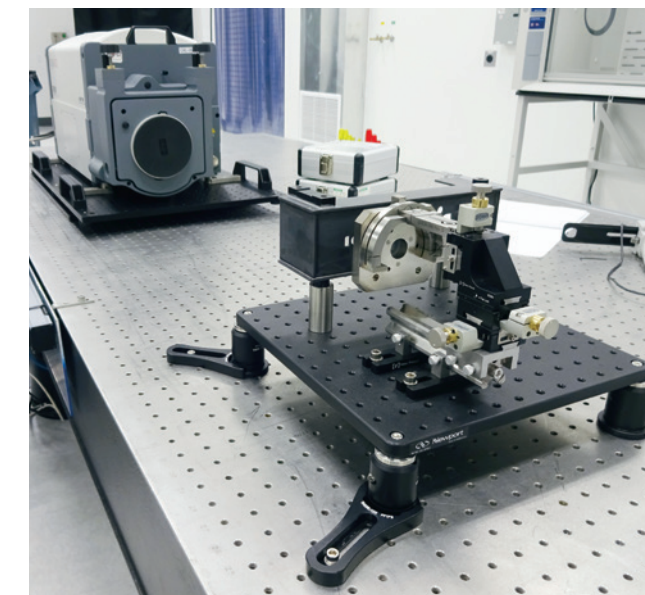
For SIMA, which was founded in 2013 and now has offices throughout South America and in Mexico, the collaboration "was a big opportunity," Yerkovich said.

Working with NASA and the University of Maryland served as an acknowledgement of the company's achievement, he said. "We were very enthusiastic about developing those relationships and the product itself." ●

Tweaking Analysis Tools to Give SAGE Advice



Robert Damadeo of Langley Research Center, co-principal investigator for the Stratospheric Aerosol and Gas Experiment (SAGE) IV satellite, holds a model of the proposed little CubeSat's bus beside a model of the far larger and more expensive SAGE III instrument, which is currently mounted outside the International Space Station. *Credit: NASA*



In this benchtop testing setup, Quartus Engineering carries out risk mitigation testing on the original SAGE IV optical assembly demonstration unit. *Credit: Quartus Engineering Incorporated*

Sound predictive simulations can significantly cut development costs

While designing the telescope for a proposed NASA satellite, Quartus Engineering Incorporated spent extra time and money to intentionally build additional optical assemblies that would perform poorly under conditions like launch vibrations and the temperature fluctuations of space. The investment could pay off handsomely for both the company and NASA.

"The additional work we're doing is not to validate the design itself," explained Alexander Halterman, director of technical program development at the San Diego-based company. "It is to validate the tools and methods that are used to analyze the design, and therefore have higher confidence in future designs."

The idea was to build assemblies that would be stressed and deform under harsh conditions and then ensure the company's design analyses could correctly predict that behavior, fine-tuning those tools when their predictions were off. With confidence in proven analysis methods, engineers can more rapidly develop reliable systems that don't need to be aggressively tested, adjusted, and rebuilt.

"The reason people don't do this is because it costs a lot of money," said Halterman. "But if we can cut out a design cycle that costs a few million dollars for multiple programs, this pays for itself in spades."

The initial investment came from Small Business Innovation Research (SBIR) contracts from NASA's Langley Research Center in Hampton, Virginia, funding the company to fine-tune its analyses as it designed the telescope for the proposed Stratospheric Aerosol and Gas Experiment (SAGE) IV satellite. The SAGE program observes the ozone layer and stratospheric aerosols — particles from volcanos and large fires that affect the chemistry and energy balance of the upper atmosphere. This is accomplished with a technique called solar occultation. Instruments in orbit observe sunrises and sunsets from space, extracting information by comparing sunlight passing through Earth's atmosphere to sunlight above the atmosphere.

The Stratospheric Aerosol Measurement experiment demonstrated the technique in the early 1970s. SAGE instruments helped characterize a hole in the ozone layer in the 1980s, leading to a global ban on chlorofluorocarbons, and have been monitoring its recovery. SAGE IV would be smaller and cost significantly less than its predecessors, but it's currently not funded for flight, said Robert Damadeo, who, as co-principal investigator for SAGE IV, oversaw Quartus' SBIR work.

"It's all about having a high-fidelity model that you can trust so when you build it, it works as you planned," said Damadeo, noting that the capability could save NASA money on future projects. "This is much more efficient when compared to the build, test, fail, and redesign cycle that has often been deployed in the past."

Among Quartus' commercial offerings are custom science payloads, and Halterman said the work could validate individual components that could be reconfigured for different purposes, from astronomical telescopes to Earth-imaging cameras and lidar sensors that build three-dimensional images. "One value this brings to the table is a high confidence in the building blocks of an architecture that can be repurposed for future instruments," he said.

Halterman said these capabilities are especially interesting to entities like NASA and Quartus, which build a lot of unique systems, each requiring its own design, rather than higher-volume manufacturing. "We really just like working on cool projects," he said. "We are drawn to the one-off instruments, because half of what's interesting to us is learning about the science and how engineering can make that science a reality." ●

Flipping NASA Tech and Sticking the Landing



Akeem Shannon showcasing Flipstik attached to a smartphone. The product's design was improved by looking at NASA research to inform its gecko-inspired method of adhering to surfaces. *Credit: Flipstik Inc.*

NASA tech adds gecko grip to phone accessory

Akeem Shannon's story began with a phone call.

Finding his sales job unfulfilling and unsure what to do next, he got a call one night from his uncle, Karl Liggin, a systems engineer for the SLS (Space Launch System) at NASA's Marshall Space Flight Center, and the two discussed technologies the agency develops. For Shannon, it was the spark of inspiration he needed. Soon after that fateful call, he began looking through published research on NASA's website and came across a sticky invention that would help him launch a new product — a phone accessory that mounts nearly anywhere, instantly and repeatedly.

In the early 2010s, a team of roboticists at NASA's Jet Propulsion Laboratory in Southern California were exploring methods for robots to hold tight to surfaces in weightless environments. They hit upon the Van Der Waals force — a weak electrostatic bond that forms at the molecular level when points on two surfaces make contact, and the same force that geckos use to skitter along walls.

"We really learned from geckos. They are able to exploit these Van Der Waals forces by having many tiny hairs," said Paul Glick, who worked on these adhesives at JPL. "No matter how smooth it looks, in reality almost every surface is actually quite rough. Each hair is able to flex independently and create surface contact at the microscopic scale."

The microscopic hairs on the gecko's toe pads are called setae, which gives the technology the moniker of "synthetic setae." While Shannon originally had the idea to use synthetic setae as a method for wall-mounting a television, the grip was far too weak. But Shannon saw in the NASA work a way it could be used to mount a much smaller screen, one that everyone had in their pockets — a cellphone.

With a synthetic setae attachment on a phone case, the phone could stick to most surfaces, such as a mirror or the back of an airplane seat. With a product design in hand, Shannon founded Flipstik Inc. in St. Louis, Missouri, in 2018. There had been some prior commercialization of synthetic setae, but Shannon said most of the industrial suppliers had issues making a reliable product, and Flipstik would have to be used over and over in a variety of situations. He said the published NASA research, which describes methods of molding and casting the tiny hairs to be more durable, was indispensable to making it portable and reusable.

"We used the NASA research to inform our suppliers and better tailor it to our utility. We were able to help them to improve the product and make it practical for the pocket," Shannon said.

Initially sold at one mall kiosk, Flipstik was slow to gain traction, but a successful Kickstarter campaign, an appearance on the TV show Shark Tank, and endorsements from major stars in the hip-hop community allowed the company to slowly grow and promote itself. Today, Flipstik has sold more than a million units to several kinds of smartphone

users. In addition to people who use a phone to watch videos, it has become popular among online content creators who use it to make them, capturing camera angles on their phones that they couldn't before. Shannon even said he's seen users who are deaf purchase Flipstik to keep their hands free, enabling them to make video calls in sign language. ●



The blue material contained inside Flipstik is synthetic setae, which allows it to stick to almost any flat surface, such as a mirror or the back of an airplane seat. *Credit: Flipstik Inc.*

Dust-Powered 3D Printing



AI SpaceFactory won NASA's Centennial Challenge in 2019 with a 3D printed habitat structure designed for Mars. *Credit: NASA*

Planetary construction technology makes large-scale 3D printing more accessible on Earth

After 3D printing a habitat designed for Mars and working with NASA on print material made from synthetic Moon dust, AI SpaceFactory Inc. has commercialized two separate 3D printers.

The Secaucus, New Jersey company's latest offering, Starforge, is a large-capacity 3D printer that uses innovative print material inspired by SpaceFactory's work with NASA's Kennedy Space Center in Florida under an Announcement of Collaboration Opportunity agreement.

The project, with work performed mostly at Kennedy's Swamp Works innovation environment, focused on developing 3D print material using simulated lunar regolith, which mimics the crushed rock and dust on the Moon's surface. Using local material for planetary constructions dramatically reduces the amount of material that a spacecraft would need to carry. It can also reduce environmental impacts of printing on Earth.

Starforge uses pellet "inks" that draw on the same principles as the Moon regolith project by mixing plastic — recycled plastic waste, for instance — with a dry fill material, such as talc or gypsum, that could be obtained in the field. The pellets can also be strengthened with glass or carbon fibers.

"It's really an innovation in pellet printing," said SpaceFactory's cofounder and chief executive, David Malott, explaining that traditional filament inks can cost up to \$150 per pound, making larger printing impractical.

"Our pellets come to about a couple dollars a pound," Malott said, "so it's completely disruptive in terms of making large-scale 3D printing much more accessible and opening pathways to material diversity."

SpaceFactory's work with NASA began with the Centennial Challenge program's 3D Printed Habitat Challenge, which the company won in 2019. The project involved printing one-third-size model living quarters designed for Mars. The company began working with innovative print materials for that challenge, incorporating crushed basalt, which resembles Martian surface cover. This work inspired the company to think about Earth-based applications using bioregenerative materials.

Tracie Prater, now a technical manager in habitation systems development at NASA's Marshall Space Flight Center in Huntsville, Alabama, who was a subject matter expert for the challenge, said sustainable materials were an overarching focus of the competition.

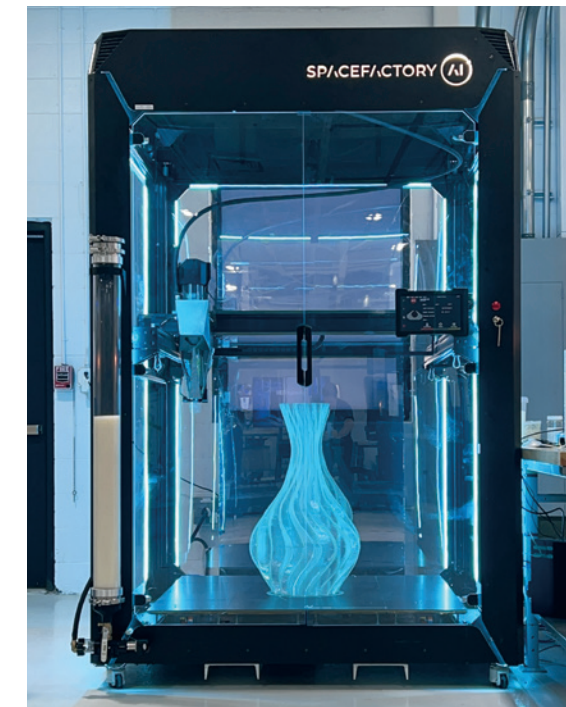
"We were seeking the use of local resources to reduce the amount of mass which would need to be launched to support construction on a planetary surface," she said.

NASA's Monsi Roman, who managed the challenge, agreed. "They had a lot of interest in Earth applications and working with bioregenerative materials," she said. "They were thinking about the environment on Earth, and that was an area most of the other companies weren't thinking about."

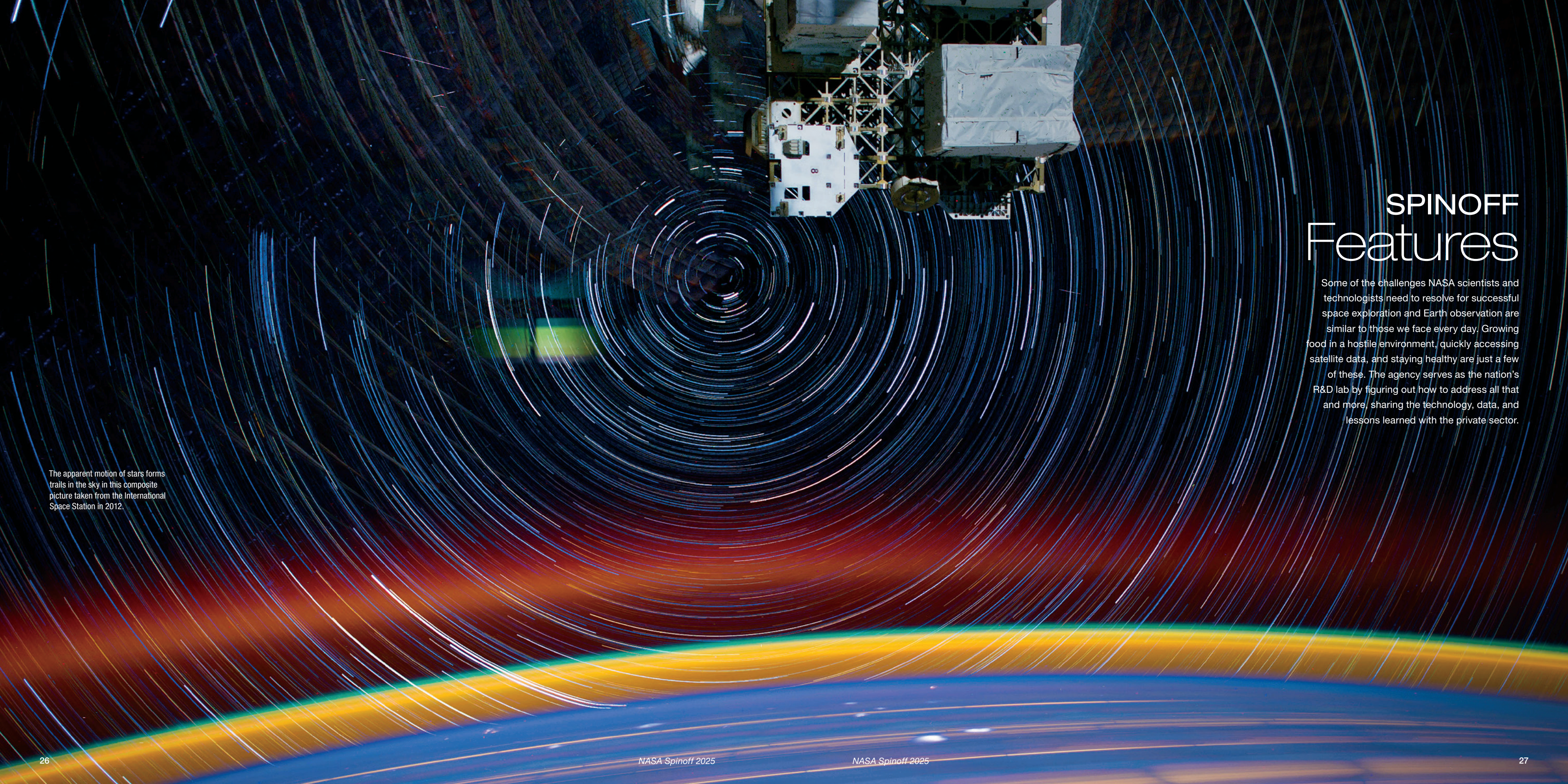
SpaceFactory has since used the robotic arm printer it developed for the challenge, which it calls Astra, to print unusual jobs for its customers. Running shoe company On, for instance, hired SpaceFactory to print a full-scale model of a boulder it had scanned in the Swiss Alps and wanted to display in its Manhattan store. Another company commissioned SpaceFactory's Astra printer to create a seawall that could promote the growth of mollusks and algae, serving as a habitat in addition to absorbing wave energy.

NASA's Prater said the Centennial Challenge "was designed to incentivize innovation in large-scale additive construction."

The call worked on SpaceFactory, which had not previously built a large-scale 3D printer, according to Malott. "We started as a group of architects and engineers," he said. "We had to learn pretty quickly. By focusing on the space use case, we're now at the leading edge of terrestrial applications." ●



AI SpaceFactory's latest commercial offering, Starforge, is a large-format 3D printer with "ink" that mixes with a variety of materials. *Credit: AI SpaceFactory Inc.*



SPINOFF Features

Some of the challenges NASA scientists and technologists need to resolve for successful space exploration and Earth observation are similar to those we face every day. Growing food in a hostile environment, quickly accessing satellite data, and staying healthy are just a few of these. The agency serves as the nation's R&D lab by figuring out how to address all that and more, sharing the technology, data, and lessons learned with the private sector.

The apparent motion of stars forms trails in the sky in this composite picture taken from the International Space Station in 2012.

NASA Data Helps Beavers Build Back Streams

Nature’s engineers, beavers get help from NASA to mitigate drought, wildfire

When beavers move into a stream to start a homestead, they also improve their ecological neighborhood. By engineering their ideal environment — a marshy, plant-rich area — they provide homes, food, and refuge for countless other animals.

Beaver dams slow down streams to create ponds, thereby preventing erosion, providing plant and wildlife habitats, and protecting vital watersheds. The wetlands they create can slow the progress of wildfires and offset the effects of drought. This has made returning beavers to the arid western United States a decades-long effort. And now Earth-observation data, much of it from satellites whose construction was managed by NASA’s Goddard Space Flight Center in Greenbelt, Maryland, is helping.



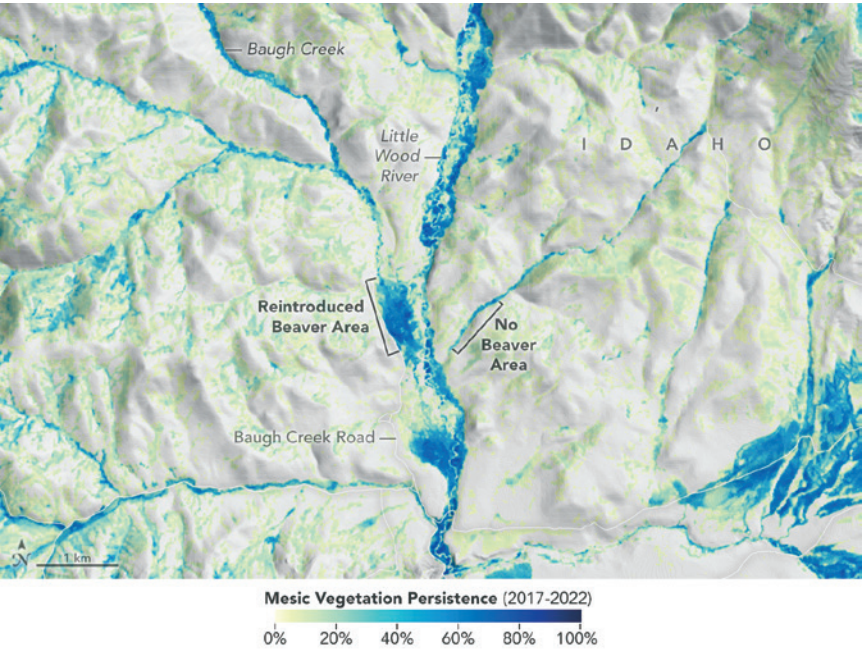
A beaver family nibbles on aspen branches just up Logan Canyon from Utah State University, in Spawn Creek, Utah.
Credit: Sarah Koenigsberg

Boise State University received a space agency grant to develop a suite of monitoring tools to help plan restoration projects and track changes in river systems. Utah State University was included in the funding, and both schools use data from NASA-built satellites to support the return of beaver populations for stream restoration. Observations from low-Earth orbit play a key role in all of this work, from choosing sites with the best likelihood of successful restoration to monitoring the subsequent impacts of these efforts.

When NASA’s Research Opportunities in Space and Earth Science (ROSES) program sought projects that could benefit from remote sensing data, Boise State proposed its Mesic Resource Restoration Monitoring Aid (MRRMaid) program. Mesic environments are those with moderate amounts of water throughout the growing season. The open-source MRRMaid program uses data from the Landsat satellites, as well as other satellites, to observe the abundance of streamside vegetation over time, a measure of a mesic environment’s health.

Not many ROSES proposals have commercial outcomes, said Cindy Schmidt, associate manager for NASA’s Ecological Conservation program. She welcomed the opportunity to see benefits for farmers, ranchers, and others who rely on local water to support their livelihood.

“Idaho Fish and Wildlife and other organizations are extremely interested in bringing beavers back, but they have challenges working with landowners and ranchers. There’s a perception that beavers destroy things,” said Schmidt.



Landsat data helps Utah State University identify streams where beavers can be reintroduced to help improve an ecosystem. Boise State University also uses Landsat data to show just how much beavers help. The vegetation in this satellite image indicates where streams or creeks are flowing and reveals the benefits of beaver activity.
Credit: NASA

Boise State University in Idaho and Utah State University in Logan are using a NASA grant and data from satellites supported by Goddard Space Flight Center to identify streams that could benefit from restoration efforts by humans and beavers and then track those improvements from space.



Beaver dams and canals create wetlands and retain water, providing a wildfire-resistant safe haven for wildlife and speeding post-fire recovery, as this region in Baugh Creek, Idaho, shows.
Credit: Schmiebel, CC BY-SA 4.0

Leveling the Pond

After beavers were nearly eradicated by hunters and trappers in many Western states, runoff from mountains and human development could run through streambeds unimpeded. With no barriers to slow the flow, wetlands drained, and streambeds became straighter and deeper, causing the water table to drop and leaving some streams dry for long periods each year.

To support ecosystem restoration, the online Beaver Restoration Assessment Tool (BRAT), created by Utah State and supported in part by the NASA ROSES grant, identifies ideal restoration sites to attract beavers. Sarah Koenigsberg, a graduate student at Utah State studying riverscape restoration, has been working with the BRAT team.

One factor that can raise opposition to employing beavers in stream restoration is concern about the damage they might cause, but Koenigsberg said there are simple ways humans can support a harmonious coexistence.

For example, if a beaver dam is close to human infrastructure, a pond leveler can set the maximum water level. Then beavers have the water necessary for protection and their underwater lodge entrance, while excess water escapes downstream. “You’re basically outsmarting the beavers by using a pipe to make a hidden leak in

“Idaho was one of the first places thinking about re-wilding with beavers.”

Jodi Brandt, Boise State University

the dam,” said Koenigsberg, noting that beavers can benefit the environment without harm to homes or businesses.

“We have to pay attention to human concerns as well as ecological ones for long-term success, and that’s one of the things I love about BRAT,” she added.

BRAT uses satellite data to analyze stream conditions and rank areas that are likely to benefit the most from beaver-assisted restoration while encountering the least conflict. The tool considers factors such as vegetation for food, available trees for dam building, water flow, and existing human infrastructure. Watershed managers, nonprofits, and others work with Utah State to assess proposed locations. Once a site is chosen, attracting beavers might be as simple as constructing a temporary beaver-dam analog or a post-assisted log structure. These begin to make degraded areas hospitable to beavers.

Buck-Toothed Ecosystem Engineers

“Idaho was one of the first places thinking about re-wilding with beavers. Way back in the ’30s and ’40s, ranchers were already trying to get beavers on their lands,” said Jodi Brandt, associate professor in Human-Environment Systems at Boise State. Funding is available to implement restoration, said Brandt, but frequently there is not money available to monitor the results. Satellite data offers a solution.

“The MRRMaid approach to monitoring uses satellites that are repeatedly passing overhead, so we can map changes from above,” explained Brandt. Data from Landsat satellites along with the ESA’s (European Space Agency) Sentinel missions can be analyzed to measure changes in water and vegetation over time. One rancher who attracted beavers back to his land hopes drawing attention to his success will demonstrate

the benefits of stream restoration. With satellite data, “we can provide empirical evidence of what’s happening on his land,” said Brandt.

Businesses and organizations need proof of conservation success to secure funding or build support for projects. Among MRRMaid’s users are state and federal agencies, conservation groups including the Nature Conservancy, land trusts, and watershed managers.

In addition to creating habitats for fish and other wildlife, and thereby supporting recreational activities and offering natural beauty, wetlands serve as an animal refuge during wildfires. Beavers build canals into neighboring woodlands, spreading water and nutrients, making vegetation fire-resistant, and creating places that can shelter wildlife in the event of a fire. Those ponds also filter toxins and pollutants from the water before and after a wildfire, making the area healthier and more resilient.



This beaver dam analog was built by crews from Anabranch Solutions in the summer of 2023, as part of their effort to restore stream processes and prepare the watershed for beaver reintroduction. Such human-made dams can entice beavers to areas that will benefit from their work. *Credit: Sarah Koenigsberg*

Filling Data Gaps

The current versions of MRRMaid and BRAT require users to understand GIS — geographic information systems — to run simulations and generate reports. Because most people don’t have that knowledge, the Boise State and Utah State faculty and students run query requests from the public as resources permit. Work is underway to make the tools easy for anyone to use.

Even with access to the best remote sensing and data, though, there’s value to seeing change on the ground from a human vantage point, and that’s where Phlux comes in. This new smartphone photo app makes it easy to set a photo point and allow anyone to upload their photos from that exact spot again and again, creating a series of images of a restoration site that shows change over time.

Brandt said public engagement is critical for success. “We have worked with ranchers in Idaho who are doing a lot of stream restoration. They are often excellent stewards of the land,” said Brandt. Those success stories, together with data from BRAT and MRRMaid, help build public support for conservation efforts, she said.

A 3-month-old beaver kit enjoys its new home after its family was relocated from a concrete drainage ditch in urban Aurora, Colorado, to a private ranch in the foothills of the Rocky Mountains. Credit: Sarah Koenigsberg

Federal agencies like the Forest Service and the Bureau of Land Management, which manage more than half of Western land, are engaged in multiple restoration projects. GIS allows them to use BRAT and MRRMaid to maximize those efforts. Once the updated programs are available, anyone in Idaho, Utah, Oregon, and other Western states will be able to identify the best stream restoration sites.

“That’s what applied science is all about — getting the users whatever is needed for environmental decision making,” said Schmidt of NASA Ecological Conservation. “We can’t do it without private companies. The future of our planet relies on these commercial partners working with us to do things more sustainably.”

And sometimes those commercial partners need a little help from animal allies. ●

“You’re basically outsmarting the beavers by using a pipe to make a hidden leak in the dam.”

Sarah Koenigsberg, Utah State University



“The future of our planet relies on these commercial partners to work with us to do things more sustainably.”

Cindy Schmidt, Ames Research Center

This is one of the primary dams on the downstream edge of an expansive beaver complex that survived the catastrophic Bootleg Fire of 2021 in Klamath Basin, Oregon. Beaver ponds create wet areas with fire-resistant vegetation that can hold off wildfires and provide refuge for fleeing wildlife. *Credit: Sarah Koenigsberg*

Seeing Is Communicating

Eye-tracking technology makes ‘talking’ possible for people who can’t

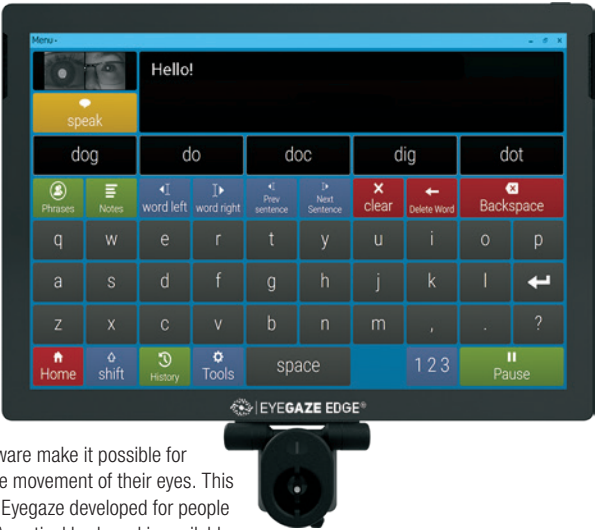
Communicating when traumatic brain injury, stroke, or disease has made speech impossible can be daunting. But specialized eye-tracking technology uses eye movement to enable people living with disabilities to connect one-on-one, over the phone, or via the internet.

The technology isn’t new, but it has become much more widely accessible, thanks in part to a collaboration between NASA’s Jet Propulsion Laboratory in Southern California and a Fairfax, Virginia-based company called Eyegaze Inc. In the late 1990s, the two entities worked together to miniaturize and

improve the company’s Eyegaze Edge system, eliminating barriers to ownership of this communications technology.

Eye-tracking systems for computers pinpoint a person’s gaze — where the eye is looking on a screen — by reflecting infrared light off the cornea and capturing it with a camera, using image-processing software to determine the eye’s orientation. Looking at a specific button on the screen initiates an action. That could be a letter on a keyboard or a command to open a web browser. When the company built the first model in 1988, its computers were bulky, requiring three shipping boxes for equipment and a company staff member to set up the system. That cost limited access, and the learning process could be intimidating.

In 1998, Congress provided funding for NASA to make the hardware smaller, more portable, and more affordable without compromising efficiency. The public-private partnership accomplished that and much more. It reduced the weight of the original system by six times and its volume by nearly the same factor (Spinoff 2002). Other advancements served as a springboard for two more decades of development.



When a physical condition limits mobility, getting around is easier with Eyegaze Edge. The eye-tracking technology integrates with the Ability Drive application used with motorized mobility devices, enabling hands-free control of a wheelchair’s motion. *Credit: Eyegaze Inc.*

Eye-tracking hardware and software make it possible for people to communicate using the movement of their eyes. This keyboard screen is one of many Eyegaze developed for people with a full range of eye motion. A vertical keyboard is available for those who can only look up and down. *Credit: Eyegaze Inc.*

An effort funded by Congress to improve and miniaturize eye-tracking communication technology for people with disabilities brought Eyegaze together with NASA’s Jet Propulsion Laboratory. The Fairfax, Virginia-based company now helps people in 44 countries use its Edge hardware to communicate.

“Working with NASA, we were able to make the device less bulky,” said Preethi Vaidyanathan, an engineer with Eyegaze. “Since then, we integrated the external components into a small camera.” It mounts above or below a standard computer screen and requires less than 15 seconds to calibrate to an individual’s gaze.

Visual Surfing

As personal electronic devices and internet access became commonplace, Eyegaze customers wanted to do more than type. The company’s work with NASA and other government partners put it in a position to meet that demand.

The company’s Eyeworld software integrates with computers, mobile phones, and tablets, allowing the Eyegaze camera to function as an external mouse and keyboard. By enabling almost any computer function, it lets users chat online, post to social media, send email, text, or make phone calls. It’s also possible to change room lighting, adjust thermostat settings, and operate other

environmental controls using Amazon Echo and Google Home via pages of specialized buttons with one-glance button controls.

During the COVID-19 pandemic, Eyegaze integrated communications programs such as Zoom and WhatsApp to allow people to connect with their family and friends. To help combat a sense of isolation, the company added meditation apps and Window Swap, which streams the views from different windows around the world. Virtual museums take the viewer on guided tours. And a music streaming service syncs to favorite music apps and offers the International Radio Garden app to sample music from other cultures. Access to online gaming communities provides another way to connect.

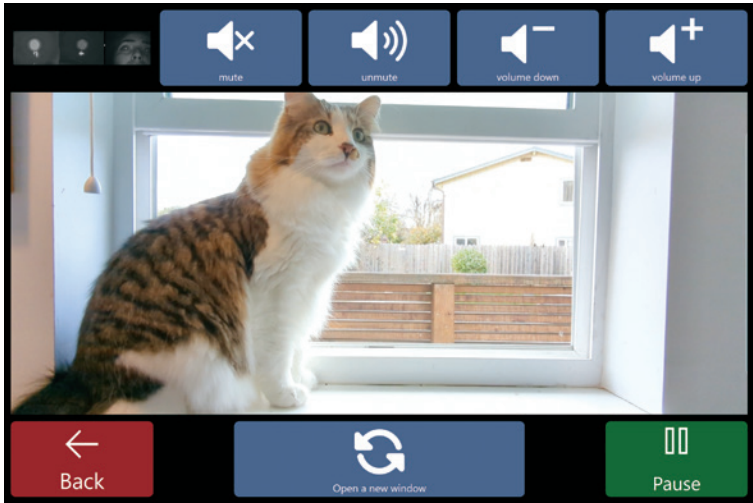
“We are constantly thinking about what the customers want. One thing is some freedom of movement, so controlling a wheelchair gives them that to some extent,” said Vaidyanathan. Eyegaze Edge integrates with the Ability Drive application used with motorized mobility devices. Looking at specific buttons enables hands-free control of a wheelchair’s motion.

The Right to Speak

Numerous medical conditions can lead to the kind of physical paralysis that makes it impossible to speak. Well-publicized brain and spinal cord injuries in athletes have led to wider awareness. But there are a host of other causes such as cerebral palsy, ALS, multiple sclerosis, muscular dystrophy, and spinal muscular atrophy. Strokes, infections, and other traumas can result in

locked-in syndrome, which paralyzes all voluntary muscles except those that control eye movement. For all of these patients, eye-tracking software is a lifeline, making use of what may be their only remaining voluntary movement. But even that can be impeded.

Eyegaze Edge measures several eye features, making it possible for the tracker to work even when less of the pupil is visible. The company employs clinical specialists who can troubleshoot issues



Anyone stuck in bed knows how boring it can be to stare at the same walls all day. Eyegaze Edge offers the opportunity to watch the world go by via WindowSwap—different livestream views from video cameras set up in windows around the world. *Credit: Eyegaze Inc.*



The Eyegaze Edge technology is so easy to use that children who might never speak are able to learn to communicate by using their eyes to “type” messages or select pictures to share their thoughts. *Credit: Eyegaze Inc.*

that could prevent customers from using the system — eye conditions like cataracts, dry eyes, and eyelids that droop, partly covering the pupil.

The company is now serving individuals in 44 countries including India and Pakistan and nations in Africa. Adults, children as young as 18 months old, military veterans, and others are able to communicate using only their eyes. If only vertical eye movement is possible, Eyegaze Edge offers a special vertical keyboard screen. Pages of commonly used phrases communicate a statement with a single glance. Common medical needs are also connected to large, easy-to-use buttons that allow patients to communicate directly with healthcare providers and caregivers.

Clinicians use Eyegaze Edge and teach their patients how to communicate using the technology. Those same medical professionals are also able to advocate for their clients with insurance companies, documenting the need for them to own such an assistive device. In some cases, Vaidyanathan said, this technology even allows people to share their final thoughts with family and friends.

“NASA helped us get our technology to the size of a laptop — small and sleek. But we continue to investigate and design our solutions to meet ongoing needs. Communication is a key right, so we have to accommodate these different challenges,” she said. ●

Home-Grown Housing

Cultivating mushrooms to build housing on Earth, the Moon, and Mars

Smurfs have been doing it since the 1950s, but a group working with NASA is making it possible for people to finally enjoy the benefits of living in mushroom houses. Collaborating with an architecture studio, NASA's Ames Research Center in Silicon Valley, California, developed a way to use space-grown filamentous fungi to create a new kind of astronaut habitat — one that can also confer advantages on Earth.

Mushroom stems and caps can add flavor and nutrients to food, but fungal mycelia — the root-like parts that grow underground — can form part of an excellent building material. NASA and the architecture studio, known as redhouse, along with a few universities, researched the concept with funding from the NASA Innovative Advanced Concepts (NIAC) program. That research became the basis for Mycohab Foundation, a nonprofit focused on using mushrooms to create both sustainable building materials and economic opportunities.

To continue funding this effort, the foundation's commercial arm, Mycohab Ltd. of Windhoek, Namibia, sells gourmet mushrooms to local retailers, markets, and hotels. Revenue pays for Mycohab's other product — one-cubic-foot construction bricks. All this mushroom agriculture also serves another purpose: eliminating and reusing a destructive, overgrown, and water-hungry plant.

Growing lunar and Martian habitats from mushrooms requires a special process, so Ames Research Center used NASA Innovative Advanced Concepts (NIAC) funding to create and test a growth system. It's been adapted and used by Mycohab of Windhoek, Namibia, to produce gourmet mushrooms and eco-bricks for housing.



Sales of gourmet mushrooms, available in Africa, fund Mycohab's low-cost housing initiative. *Credit: Mycohab Ltd.*

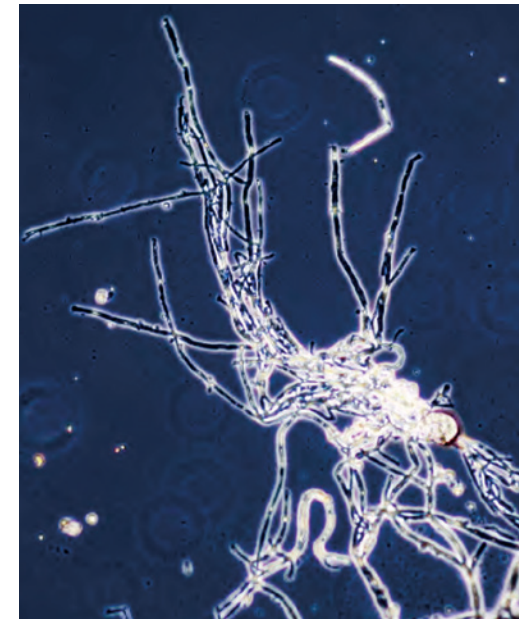
Mycohab is growing gourmet mushrooms in areas of Africa where farming is difficult, using a technique developed for lunar farming. *Credit: Mycohab Ltd.*

Acacia mellifera has been allowed to spread virtually unchecked in the African bush since the introduction of cattle farming. But when the environmentally harmful plants are ground into mulch, they become the perfect substrate, or soil replacement, for growing mushrooms. After the mushrooms are harvested for consumption, the mycelia-bound mulch they leave behind can be dried and baked into bricks.

Chris Maurer, principal architect with redhouse studio and cofounder of Mycohab, said the growing process the company is using has to be proven successful on Earth before growing the first habitats on the Moon from fungus.

Mycotecture

Not just any mushroom or substrate will do to grow habitats. For the strongest building material produced in the shortest amount of time, NASA scientists chose the *Ganoderma lucidum* strain of mushrooms. The team then experimented with different kinds of substrates including one with lunar soil simulant to use with a custom nutrient hydrogel to produce nutritious mushrooms that won't become toxic as they mature. But the substrate couldn't have too many nutrients either, as it would encourage dangerous bacterial overgrowth. Finally, the fungal mycelia bound the substrate together while extracting nutrients in the growth process, forming the building material.



This microscopic image shows fungal mycelia, the root-like threads that grow in a substrate and feed nutrients to the part we see — mushrooms. *Credit: NASA*



The Mycohab staff uses a NASA-developed growing technique to create sustainable food and housing while removing a plant that chokes Namibia's water supply and damages wildlife habitats. *Credit: Mycohab Ltd.*

The experiments proved the viability of the dual use of fungus as food and construction material. But the real-life application of the theory is an economic success. Mycohab is using local waste as a substrate backed by NASA know-how to grow nutritionally balanced mushrooms in Africa. Mycofood requires less land, water, energy, and time to produce food with a level of protein comparable to meat. And the waste from cultivation provides a cheap construction material in communities with little to no extra resources.

"Mycotecture" — mycelia-based architecture — could flourish just as well using material available in off-planet locations, providing food and shelter anytime, anywhere.

And because the fungi can grow anywhere, it won't be necessary to choose a landing site that suits the habitat — it'll conform to the site, explained Lynn Rothschild, senior research scientist at Ames and principal investigator for the NIAC-funded project.



This stool created by a NASA-funded project proves it's possible to fabricate furnishings using the same fungal mycelia that create bricks on Earth. *Credit: NASA*

“If we’re going to do something long-term like plans are for human settlements on the Moon, we’re going to have to recycle materials,” she said. “What we’re trying to do by developing technologies to use off-planet is the ultimate sustainability experiment. Here, we go to the hardware store to get things we need, but there is no hardware store on the Moon. We have to think this through.”

For structures on another planetary body, NASA will use a lightweight scaffold and a nutrient hydrogel to serve as a substrate to grow the mycelia. All of this is enclosed in plastic-bag-like sheets that serve as the mold that controls the shape of the building. Think of a self-inflating raft: air flows in until it’s full. As the mycelia grow and consume the nutrients, they reproduce, expanding to fill the available space. If the sheets are dome-shaped, a rigid dome structure is the end result.

All of this could be done even before astronauts arrive. After humans land, more structures could be grown on nutrients from organic waste streams rather than feedstock launched from Earth. Incorporating dust and rocks from the lunar surface could save even more weight.

Moon-Shrooms

After proving the growing process worked, Maurer from redhouse created all kinds of objects — chopsticks, plates, furniture, and now a house. Ultimately, he wanted to find a way to use bio-fabrication in architecture where building materials are scarce or cost-prohibitive. Working with NASA gave him the opportunity to do just that.

“We sequester one pound of carbon dioxide for every pound of material we make, compared to concrete that emits a pound of carbon dioxide for every pound created,” he said. As long as it’s protected from moisture, this material will remain structurally sound and last as long as the conventional wood framing found in cathedrals and homes a hundred years old.

Using locally available biowaste requires a unique recipe to produce the desired building material. If a dense brick is needed, it’s necessary to choose the right type of mycelia and processing techniques such as compression and air drying or even baking.



Ivan Severus, site manager for Mycohab, holds a brick made from substrate used to grow mushrooms. This mycomaterial comes from woody mulch bound together by the fungal mycelia. Credit: Mycohab Ltd.

Because Mycohab is using the waste created by the Acacia mellifera bushes, it can produce bricks cheaply and rapidly — in days and, in some cases, hours — thanks to the abundant supply. Using the bricks as the primary building material makes it possible to produce a small house for about \$8,000, enabling the rapid construction of humanitarian housing or emergency shelter during a natural disaster or a refugee crisis.

These houses have the added benefit of generating almost no waste.

“Instead of putting demolished houses into landfills like we do now and generating a lot of harmful gases and toxins as they decompose, this building material can be mixed into soil, converting that carbon into new crops,” said Maurer.

Mycohab completed a demonstration house in 2024 that uses mycelia as the structure of the building to provide an example of how the company’s bricks can be used to build an inexpensive, comfortable home.

A Bit of Home

While additional research is still needed, there are many benefits for terrestrial and planetary habitats. Mycelial materials are proven fire-resistant thermal insulators that don’t off-gas like plastic and glue. The density and material properties can be fine-tuned during production and have the potential to absorb indoor air pollutants, improving the interior environment. NASA is looking into these factors and more.

Melanin-rich fungi can also absorb radioactivity, even at levels found in space, so enhancing this characteristic could provide astronauts with additional protection. Adding lead from the Martian soil to the feedstock could provide even more shielding.

Materials made with mycelia also absorb sound and vibrations, ideal for long-duration spacecraft in low-Earth orbit. Rothschild is working with project partners to send an experiment to the future public-private space station, Starlab.

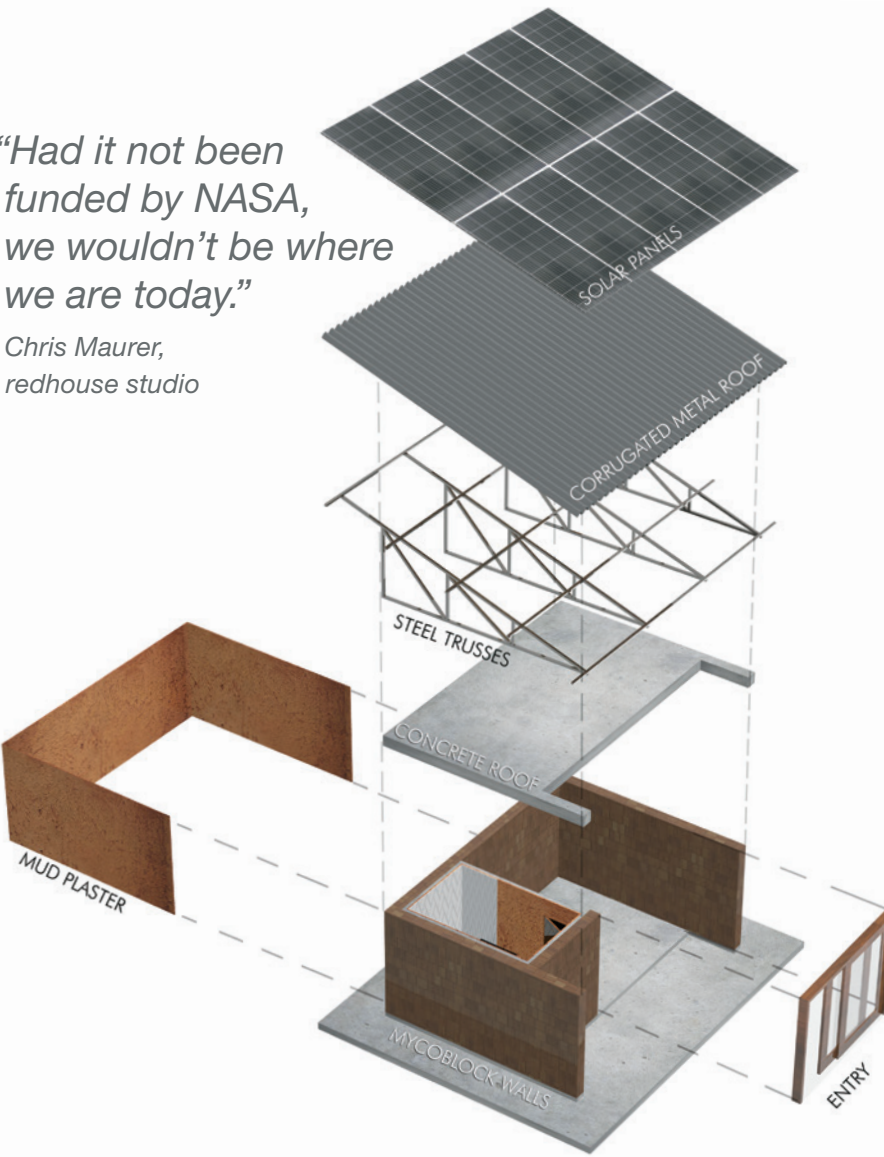
“There is no hardware store on the Moon. We have to think this through.”

Lynn Rothschild, Ames Research Center

“Mycomaterials, even as a veneer, have psychological benefits. If you have the mycelia binding dehydrated woodchips, that veneer reminds you of home rather than trying to live in a stainless steel structure, which isn’t very human-friendly,” said Rothschild. “It’s also got acoustical benefits. There is a lot of vibration and noise on the space station. So if panels can do some noise absorption, that would be fantastic.”

In the meantime, Mycohab is growing and selling mushrooms while developing additional retail products such as teas and dietary supplements that can be exported around the world. Eventually, licensing for the proprietary mycelia growing process will be available to commercial builders wishing to take advantage of cheap biowaste near construction sites. Anything, from the straw that results from wheat or rice harvesting to acacia bushes, could be used in new homes or businesses.

“It’s a long detour to outer space to actually land this project in Africa,” said Maurer. “But it would have never happened if we hadn’t had this project with Lynn Rothschild, with NIAC. Had it not been funded by NASA, we wouldn’t be where we are today.” ●



“Had it not been funded by NASA, we wouldn’t be where we are today.”

Chris Maurer, redhouse studio



The first house constructed with mycomaterials demonstrates that it could be possible to build structures from in situ materials on the Moon and Mars. The illustration at left shows the building’s construction plan, while the top photo shows construction in progress. The photo above shows the final product, with mud plaster covering “mycoblock” walls capped with a concrete roof. On top sits a metal roof supporting solar panels. Credit: Mycohab Ltd.

A Better Backup Plan for the Unthinkable

Autonomous self-destruct technology eliminates the cost of human error

When a rocket launches, the ground command only has three to five seconds to abort if needed — allowing the rocket to continue to fly or losing millions of dollars and years of work with a destruct order. But it takes time to send a command, so that leaves only 2.5 seconds to interpret data and make the decision. That can lead to a mistake resulting in the loss of a rocket when it isn't necessary. That's the way it was always done until the development of NASA Autonomous Flight Termination Unit (AFTU) hardware. The company that helped develop the first commercial version, Sagrad Inc., offers a smaller, cheaper, more advanced version of the technology for rockets, military applications, and uncrewed vehicles such as drones.

Starting in 2025, any vehicle launching from a federal launch site, called a range, will be required to install and use an AFTU. It replaces the conventional ground-based, human-operated range safety system, which requires specialized staff and extensive infrastructure, much of which is owned by the military. With that infrastructure aging, in 2015, the Department of Defense requested that NASA develop an alternative. The idea was simple — an onboard unit that could evaluate data from navigation sensors in flight using customized algorithms to make flight termination decisions. The reality, however, was complicated.

Nothing like it existed at the time. Creating this custom technology would have required private space companies to invest years and millions of dollars, which most don't have, according to Lisa Valencia, who managed the project at NASA at the time. It's the kind of problem the agency is good at solving, so the development team asked for input.

"We called together all these companies in the industry and asked about the conditions they experience — the environment, vibration, thermal issues — because we wanted to build something that everybody can use," said Valencia. The partnership between NASA's Kennedy Space Center in Florida and Melbourne, Florida-based Sagrad had contributions from the Defense Advanced Research Projects Agency, Air Force, and Federal Aviation Administration (FAA).

With NASA providing technical expertise, the company helped build the first AFTU — an independent, self-contained subsystem for launch vehicles. The hardware and software use algorithms to compare in-flight performance data from various sensors to mission-specific flight parameters, determining if systems are operating correctly and executing a termination when problems can't be corrected.

Sagrad of Melbourne, Florida, offers a technology to automatically end the flight of any rocket that experiences difficulty. The technology will soon be required at every federal launchpad. A contract with Kennedy Space Center to build the prototype spawned two smaller, cheaper versions available for commercial use.

There are only a few seconds for ground command to decide to terminate the flight of a rocket after launch if something goes wrong. Terminating a flight over the ocean, like this one, prevents any debris from posing a risk to people on the ground. *Credit: NASA*

Multiple Launches, Multiple Sites

Now retired, Valencia said the team expected the project to take a year. The system proved reliable after four years of development work, hundreds of mandatory tests, and multiple test flights, including a NASA Flight Opportunities test flight. Independent verification of AFTU performance, improved safety, and significant cost savings per launch are spurring industrywide adoption.

"Back in the day, you could only fly one rocket at a time. It took days to configure the range. Even if you used the backup range, you could only fly two at most. But now you can fly multiple vehicles," said Valencia. That's partly because most of the technology required for range safety is now located on the rocket, limiting the work required on the ground. A standardized technology, the AFTU offers global coverage, meaning a launch vehicle no longer needs to be launched from a dedicated range.

The new system is universal, designed to work for a single rocket or large vehicles with multiple boosters. Each rocket with this small piece of hardware can be tracked independently. If multiple rockets are returning to Earth while another is flying the second stage into orbit, each has its own program to evaluate flight conditions and automatic termination instructions, protecting the public.

Making the technology effective and available for both commercial and military applications is important, Valencia said.

"When I see these commercial companies as well as our military using something that we developed, it's extremely rewarding. I know we're saving them a lot of time and money and stress," she said.

To make the hardware available only to U.S. entities, NASA didn't patent it but instead distributes the design package at no cost through technology transfer agreements. To date, the

agency has completed 46 such agreements, one of which was with Sagrad, allowing the company to develop its own version.

Sagrad offers the SG901-1229 AFTU using the NASA specifications for autonomous flight termination, as well as the next-generation, SG901-1250-1, called the Integrated Autonomous Flight Termination Unit (IAFTU). John Rizzo, senior vice president of business and programs for the company, said the IAFTU is 45% smaller and supports multiple sensors manufactured by different companies.



Starting in 2025, any rocket that launches from a federal launchpad like this one at Space Launch Complex 41, Cape Canaveral Space Force Station, will be required to have an autonomous flight termination unit (AFTU). The device automatically terminates the flight if data indicates the flight parameters aren't met. *Credit: NASA*

"We wanted the IAFTU to have the adaptability to plug and play, adding different GPS receivers into the box without having to change the real estate," said Rizzo. As sensor technology changes and improves, it will be possible to continue to use the same, low-cost integrated hardware.

Just Turn Off the Motor

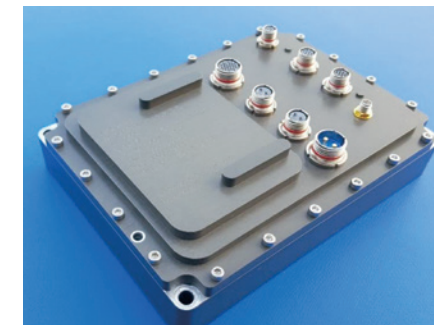
Once the FAA allows remote pilots to operate drones that go beyond operators' line of sight, it will be necessary to have a system that can automatically terminate a flight. The IAFTU is also designed to work on heavy-lift drones and other uncrewed vehicles used for purposes like shipping, ground observation, or infrastructure inspection.

Just as a rocket could experience a problem right after takeoff, a drone could veer off course due to environmental or mechanical issues. However, instead of self-destructing like a rocket and potentially scattering debris over a wide area, the AFTU can send a command to turn off the fuel source of the motor. The drone can then crash land in an area away from people or property.

Because the Sagrad AFTU was designed to work for any vehicle that might fly over populated areas, it has greater processing power, allowing a remote pilot to send multiple commands to the vehicle. Quickly correcting a technical difficulty or changing the flight plan could prevent the need to prematurely end the flight.

"The electronics are designed to continue to operate through very adverse weather and applications using the same kind of redundant systems required for airlines," said Rizzo. He credits NASA's willingness to make the AFTU available at no cost as instrumental to the availability of this advancement in flight safety.

"We were happy to be at the forefront of this technology development." ●



AFTU hardware tested by NASA's Flight Opportunities program (left) replaces the human decision-making step required to assess any problems a rocket might have and then send a destruct command. Sagrad helped build the technology and now sells smaller, cheaper versions—the original AFTU (center) and the new Integrated AFTU (right). *Credit: NASA (left), Sagrad Inc. (center, right)*

Better Data for Bodies in Motion

A wearable device to monitor astronauts' tumultuous return to Earth is helping industry

The return to Earth is a rough ride for astronauts, from the violent turbulence of atmospheric entry to a jarring landing. Hitting the ground in a Soyuz capsule is the equivalent of driving a car backward into a brick wall at 20 mph, and it's resulting in more head and neck injuries than NASA computer models predicted. To collect more data, NASA's Johnson Space Center in Houston commissioned a Small Business Innovation Research (SBIR) project to develop a wearable data recorder for astronaut spacesuits. One result, created by Diversified Technical Systems Inc. (DTS), is a miniature commercial device that now collects and transmits data for any application from airplane test flights to tracking high-value shipments.

Common data recorders, such as those used for laboratory testing and automotive crash testing, can be bulky and require external power sources. But even smaller versions of that technology weren't going to work for astronauts, according to Nate Newby, occupant safety analyst at Johnson. The occupant protection tools NASA uses to predict the likelihood of injury under the unique conditions of capsule landings require kinematic measurements defining the motion of a body through space.

"Our predictive tools were adapted from the automotive world and from the military," he said. "But our environment is a little bit different." The head and neck are subjected to high rates of acceleration in every direction. The kind of injuries astronauts are prone to don't occur under other conditions, so NASA had to fill that data gap to improve the predictive model.

DTS already had extensive experience in miniaturizing data recorders, including one data logger that's embedded in the mouthguard worn by NFL players. NASA engineers worked with the company to adapt that technology and refine it during Phase I and II SBIR projects.

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Astronaut Safety

DTS's work to create a self-contained wearable device that didn't rely on a wired data connection and was powered by an integrated battery benefited from the agency's experience with space travel — including proven materials,

Astronaut Anne McClain returns to Earth after 204 days in space, a duration that weakens bones and muscles. To better understand how the velocity of descent and landing can cause head and neck injuries, Diversified Technical Systems (DTS) created a wearable data recorder. *Credit: NASA*

To discover why astronauts returning to Earth frequently experience head and neck injuries, Johnson Space Center awarded Diversified Technical Systems of Seal Beach, California, SBIR contracts to miniaturize an acceleration data recorder. It's now used in safety testing for parachute drops, cars, drones, and more.

knowledge of conditions that affect battery longevity, and more. The housing had to contain the hardware and software necessary to take and store motion measurements, with enough room for the power source and wireless communications technology. The project envisioned a small data recorder that could attach to an astronaut's communications cap and automatically begin recording data when it reached a predetermined velocity.

"The astronauts are in the spacecraft for a while, and you don't want it to record that whole time, to minimize power and storage," said Newby. To meet NASA's specifications, the company needed to gather data about the kind of acceleration astronauts experience and use that information to create a mechanism that could automatically record both launch and re-entry forces.

DTS started with its core technology, designed to capture data for "dynamic testing," primarily crash, blast, and injury biomechanics testing, according to Mike Beckage, the company's CTO. The existing hardware and software provided reliable shock and vibration data, which NASA, a DTS customer, already relied on for a variety of aeronautics and aerospace testing.

The agency used this off-the-shelf technology to verify the structural integrity and occupant safety of the Orion crew capsule. Newby also uses a DTS device to collect data from hard landing crash tests performed using test dummies. This work and more helped the Seal Beach, California-based DTS, a brand of Vishay Precision Group Inc., build a good working relationship with NASA for over 20 years.

"A development project like this is a very interactive process, so we had regular meetings to discuss our progress. We identified technology and capabilities that we could build into the product," said Beckage. Tapping NASA's expertise was challenging as the COVID-19 pandemic disrupted much of the project, but the company still met the final deadline.

Parachute Drops and Car Crashes

The prototype design, named DXR, met every specification except for size — it's still a little too big for NASA's applications. But Beckage said the company based its new TSR AIR data logger on the DXR design. NASA input on everything from new features to the final design made the 2.75-square-inch device ideal for numerous commercial applications.

Adding the TSR AIR to a tailfin or other places on an airplane makes it possible to collect in-flight data. It can also be attached to a trailer transporting high-priority cargo, not only tracking its location in real time but recording the conditions of that trip. The device has wireless charging and wireless communications capability, making it easy to keep powered and to continuously share data.

Safety testing that includes drones, parachute drops, and automobile crashes can also use the device. It can be used to track batches of pharmaceuticals as they go through production lines and the shipping process to provide information about exposure to environments that can degrade medicines as they're moved around.

In addition to providing an array of hardware, DTS provides the services necessary to help companies get their applications up and running. Beckage said he hopes to continue integrating what the company learns from NASA technologists, serving as a conduit for sharing that store of knowledge.

"We're thankful to have those opportunities to work on really cool applications for NASA and redefine what's possible when it comes to testing," said Beckage. ●

The TSR AIR data recorder measures the velocity and motion of an object. DTS created a wearable version for NASA, but now industry uses the device for safety test flights, tracking the location of high-values assets, and more. *Credit: Diversified Technical Systems Inc.*



A "soft" landing in a Soyuz capsule is like driving a car in reverse into a brick wall. To help NASA gather information about the cause of head and neck injuries experienced by astronauts, DTS developed a wearable miniature data recorder. *Credit: NASA*

"A development project like this is a very interactive process."

Mike Beckage, Diversified Technical Systems



Folding NASA Experience into an Origamist's Toolkit

Math for designing lasers becomes artist's key to creating complex crease patterns

What does origami have in common with electronics? Here, math once again proves to be a universal language, spanning not just cultures but disciplines.

The discovery of the mathematical underpinnings of folded paper art helped Robert Lang leave a 20-year engineering career, including over four years at NASA's Jet Propulsion Laboratory in Southern California, to pursue his lifelong passion for turning paper into impossibly intricate three-dimensional forms.



"Flying Peace," a collaboration between origami artist Robert Lang and sculptor Kevin Box, stands outside White Rock Branch Library near Los Alamos, New Mexico. *Credit: Box Studio LLC*

While working on optical computing and similar technology in NASA's Jet Propulsion Laboratory, Robert Lang learned a mathematical technique that became key to his math-based approach to creating otherwise impossible origami designs. Lang is now a full-time origamist based in Altadena, California.

"Over the years of solving mathematical problems to describe lasers and optoelectronics, I built up a toolkit to use as I worked on a hobby basis on this problem of computational origami design," said Lang. The Altadena, California-based artist holds dozens of patents for optoelectronics — technology that combines light and electricity — but after years of innovating in both fields, the tools he designed for origami are the ones he chose to move ahead with.

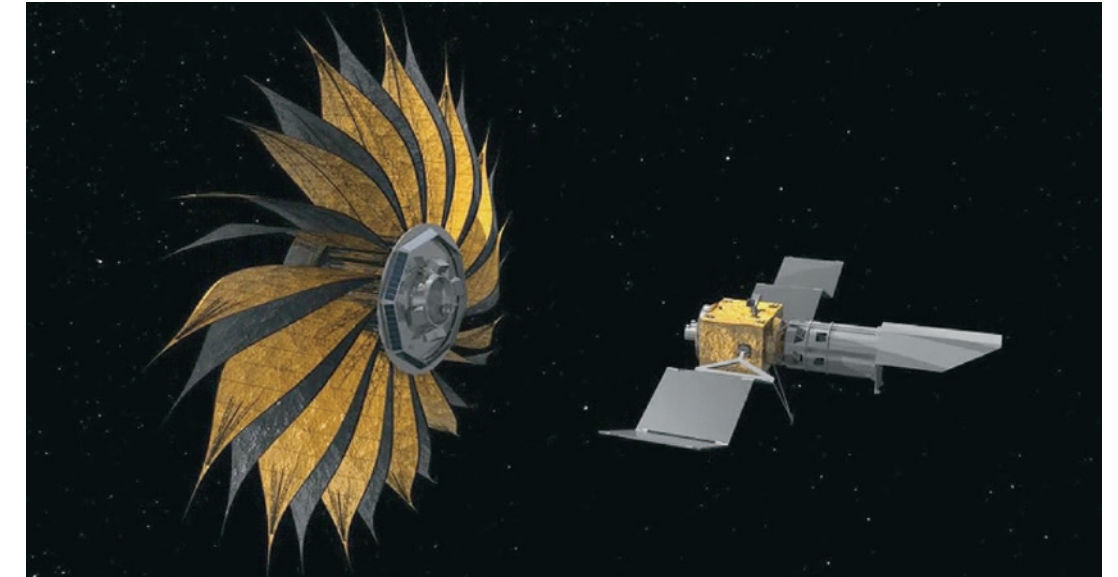
In the Microdevices Laboratory at JPL in the late 1980s and early '90s, Lang worked on integrating components like semiconductor lasers and spatial light modulators onto chips, with the ultimate goal of building an optical computer — one that uses light, rather than electricity, to transmit information and carry out calculations.

Steady advances in electronic computing have since removed some of the incentives to develop optical computers.

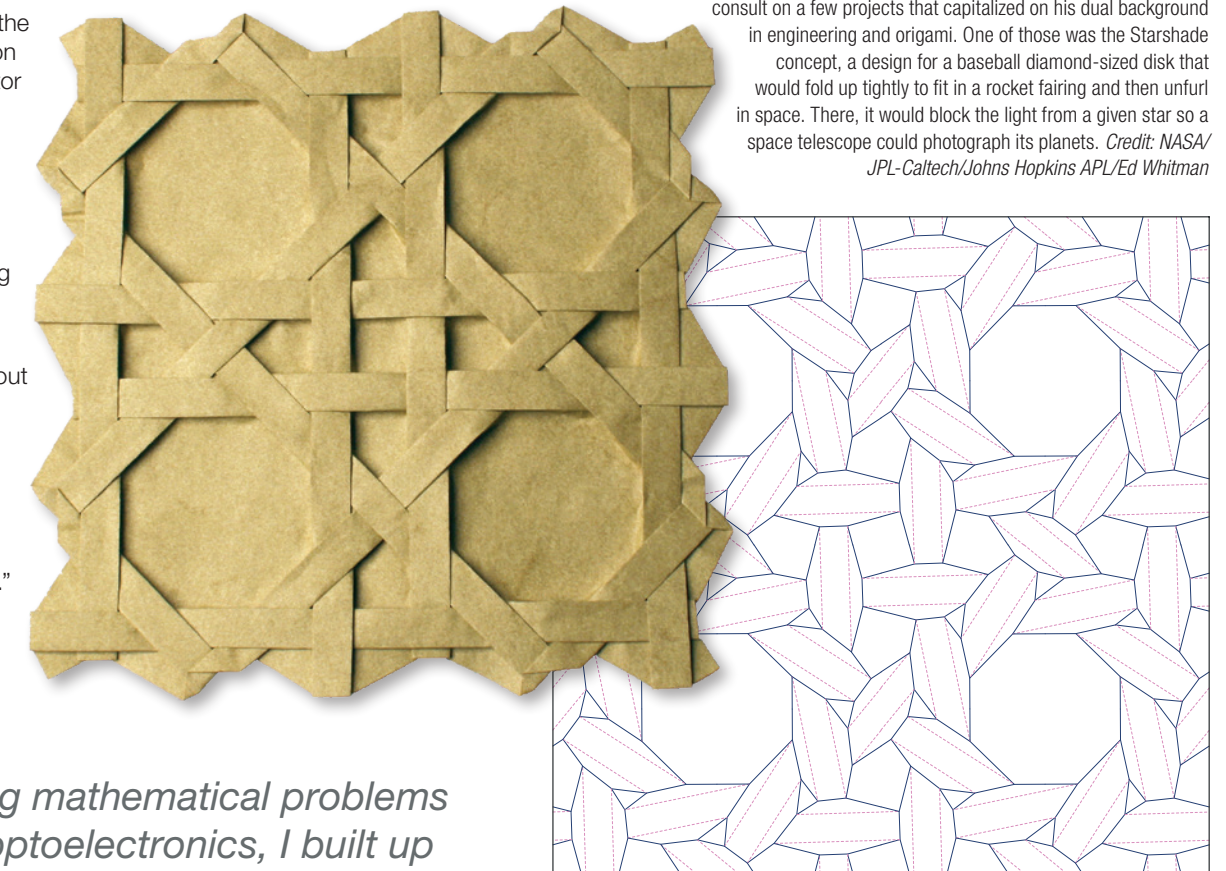
"One of the theoretical fields I learned about at JPL turned out to be the key to being able to plug in a description of a shape you wanted and then find the best possible design in great detail — every single crease you needed to make that shape," said Lang. "And that turned out to be nonlinear constrained optimization."

"Over the years of solving mathematical problems to describe lasers and optoelectronics, I built up a toolkit to use as I worked on a hobby basis on this problem of computational origami design."

Robert Lang



Since Lang left NASA, the agency has called him back in to consult on a few projects that capitalized on his dual background in engineering and origami. One of those was the Starshade concept, a design for a baseball diamond-sized disk that would fold up tightly to fit in a rocket fairing and then unfurl in space. There, it would block the light from a given star so a space telescope could photograph its planets. *Credit: NASA/JPL-Caltech/Johns Hopkins APL/Ed Whitman*

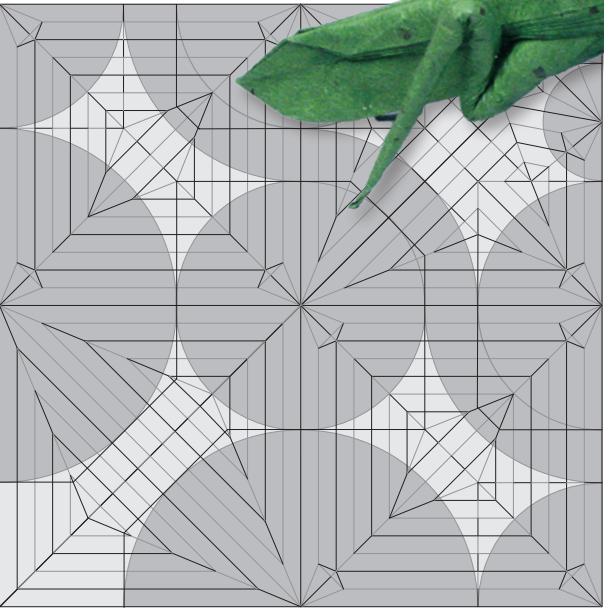


Many of Lang's geometrical creations started as math problems related to folding, which he then worked into a design. For example, "Open Rattan Weave, Opus 663," seen here, began when Lang discovered mathematical techniques to create folding patterns that gave the appearance of woven strips. Though the piece looks like several strips woven together over a flat backing, it's made from a single, continuous sheet of paper folded according to the adjacent crease pattern. *Credit: Robert J. Lang*

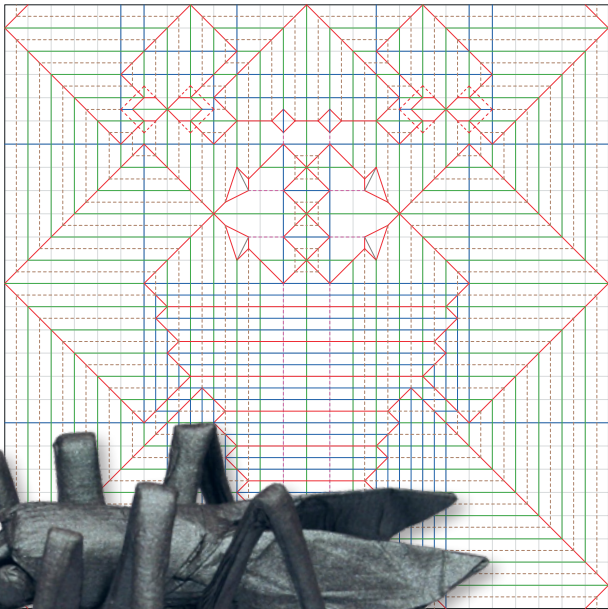
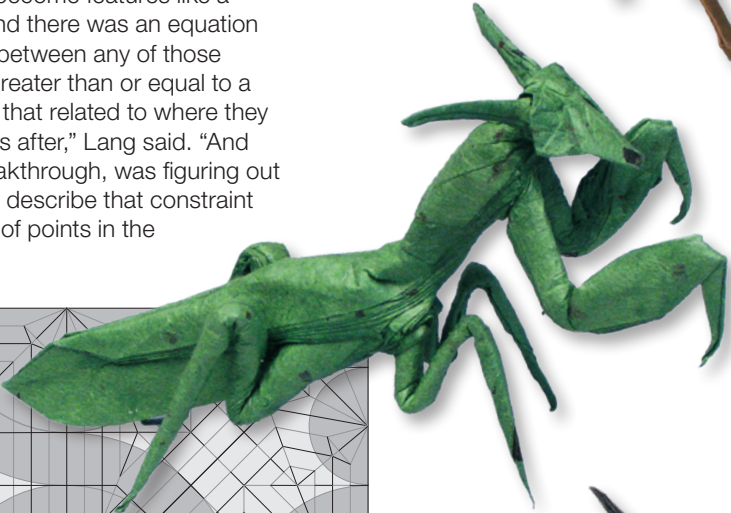
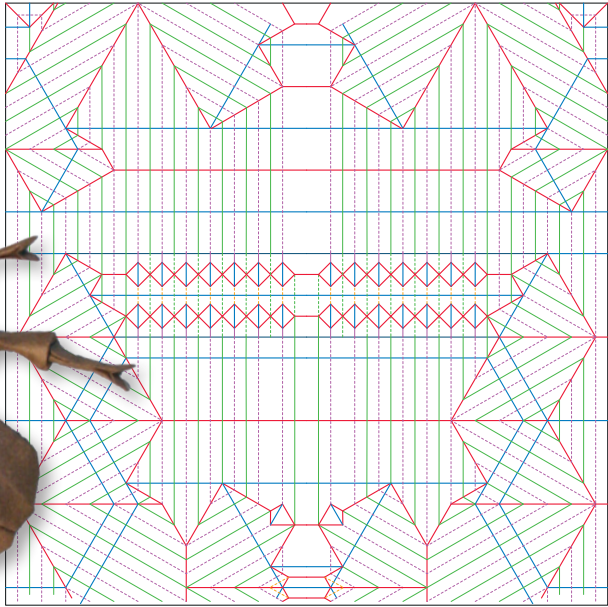
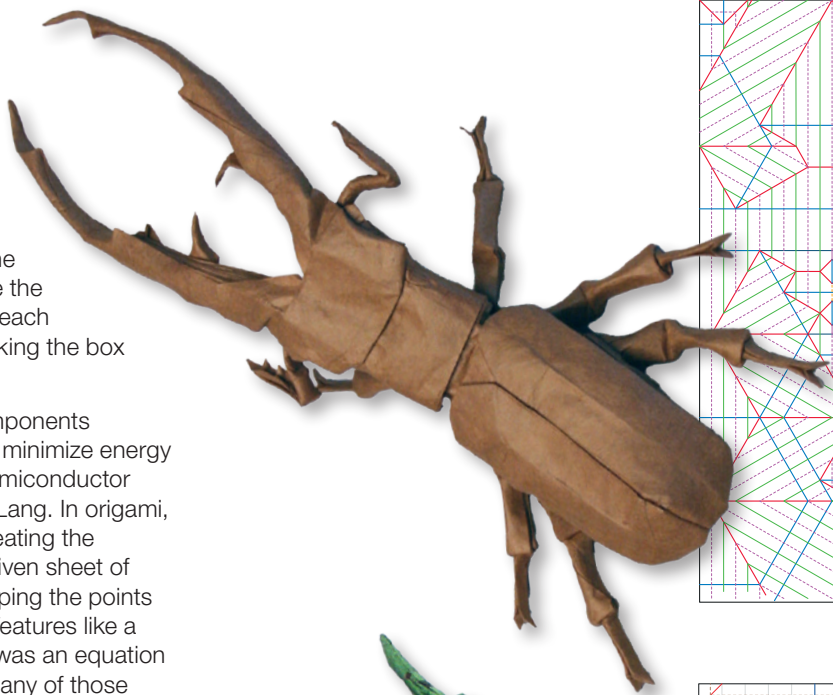
It's All About the Numbers

A simple nonlinear constrained optimization problem would be the challenge of packing several different-sized balls into the smallest possible box, Lang explained. The constraint is that the balls can't overlap each other, and the solutions are nonlinear because the balls can be any distance from each other. The optimization is in making the box as small as possible.

Designing lasers and other components required a similar calculation to minimize energy consumption, the amount of semiconductor material, and other costs, said Lang. In origami, he said, optimization means creating the largest form possible out of a given sheet of paper. Design begins with mapping the points on that sheet that will become features like a head and limbs. "I found there was an equation that said the distance between any of those two points had to be greater than or equal to a mathematical function that related to where they were in the shape I was after," Lang said. "And that was really the breakthrough, was figuring out how to mathematically describe that constraint for every possible pair of points in the crease patterns."



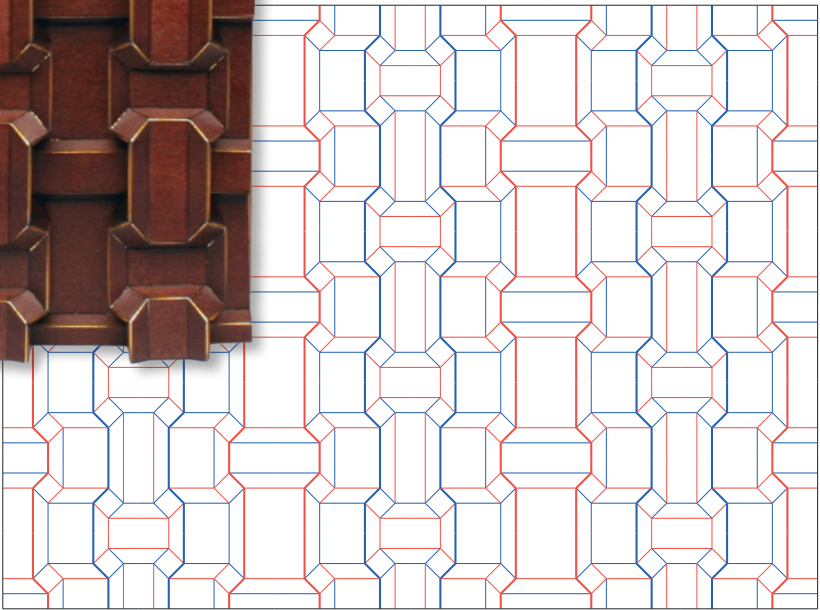
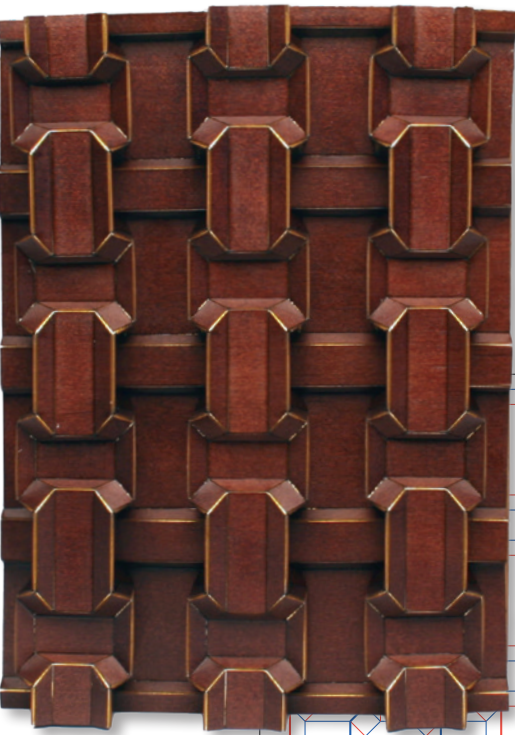
Though the art of origami is centuries old, until the late 20th century it was considered virtually impossible to make insects or other figures with many long, complex protrusions. That changed with the introduction of math-based origami design, which Lang helped pioneer. Today, he's still drawn to the challenges presented by insects and other arthropods, and they are well-represented in the menagerie of his origami gallery. Here are a stag beetle, a mosquito, and a praying mantis, along with the mathematically derived folding patterns to build them. Credits: Robert J. Lang



The math was too complex to solve by hand but easy for a computer to resolve using known algorithms. The ability to put the problem into accurate mathematical terms "lets you tap into all of the existing mathematics and computer techniques to solve it," Lang said.

By the mid-1990s, he had created an open-source software called TreeMaker, the first program that could be used to design complex origami figures. Many other artists soon followed with their own software. Around this time, a new emphasis on mathematical modeling led to a renaissance in origami. Paper figures previously considered impossible, such as insects, with their bulbous bodies and long, skinny appendages, suddenly proliferated. Lang became, and remains, one of the world's leading figures at the intersection of math and paper folding.

In 2001, he left his last engineering job to become a full-time origamist.



Engineered Origami Leads back to NASA

Lang has written or coauthored around 20 books on origami and often gives talks and classes. He also designs, creates, and sells origami art. His work ranges from small paper sculptures to huge works made from metal, polymers, and other materials, which he's cocreated with other artists. Among these are a giant piece designed by conceptual artist Glenn Kaino that hangs in the newly opened Airport Metro Connector station in Los Angeles, as well as metal origami sculptures of a 10-foot crane outside a New Mexico library and a 25-foot Pegasus at a Texas business park, both created in collaboration with sculptor Kevin Box.

His portfolio is filled with animals, plants, and the occasional human figure, as well as tessellations, polyhedrons, and other geometrical designs. In his representational art, he's drawn to complicated, challenging subjects like insects. "Because I'm able to design fairly complex figures using these mathematical design techniques, I'll take on subject matter that requires a very technical approach," Lang said.

In designing his nonrepresentational pieces, he often reverses the process, beginning with the math and then working out a subject, he said. "If you look at some of the more geometric or abstract pieces I've done, those were driven by solving a mathematical problem related to folding and then saying, 'OK, now that I have a solution, how can I create a beautiful

piece of artwork that illustrates that solution?'" As an example, Lang cites a tessellation he folded from a laser-scored rectangle of wood laminate after collaborating with Brigham Young University on the mathematical problem of foldable rigid quadrilateral meshes. The purpose of the collaboration was to create engineering mechanisms, but after the team won an award for its scientific paper, he set about applying the principles to his art.

The initial project was not the first time Lang had used origami to solve an engineering problem, either. As the art of folding has crept into technology in recent years, he applied his origami and engineering backgrounds to consulting with companies to design products that involve folding, such as a collapsible radio antenna. Several years ago, he consulted with Lawrence Livermore National Laboratory on its Eyeglass space telescope concept, which aims to fold a 100-meter-wide thin-film lens into a rocket fairing in such a way that it could unfold in space without any creases affecting its performance.

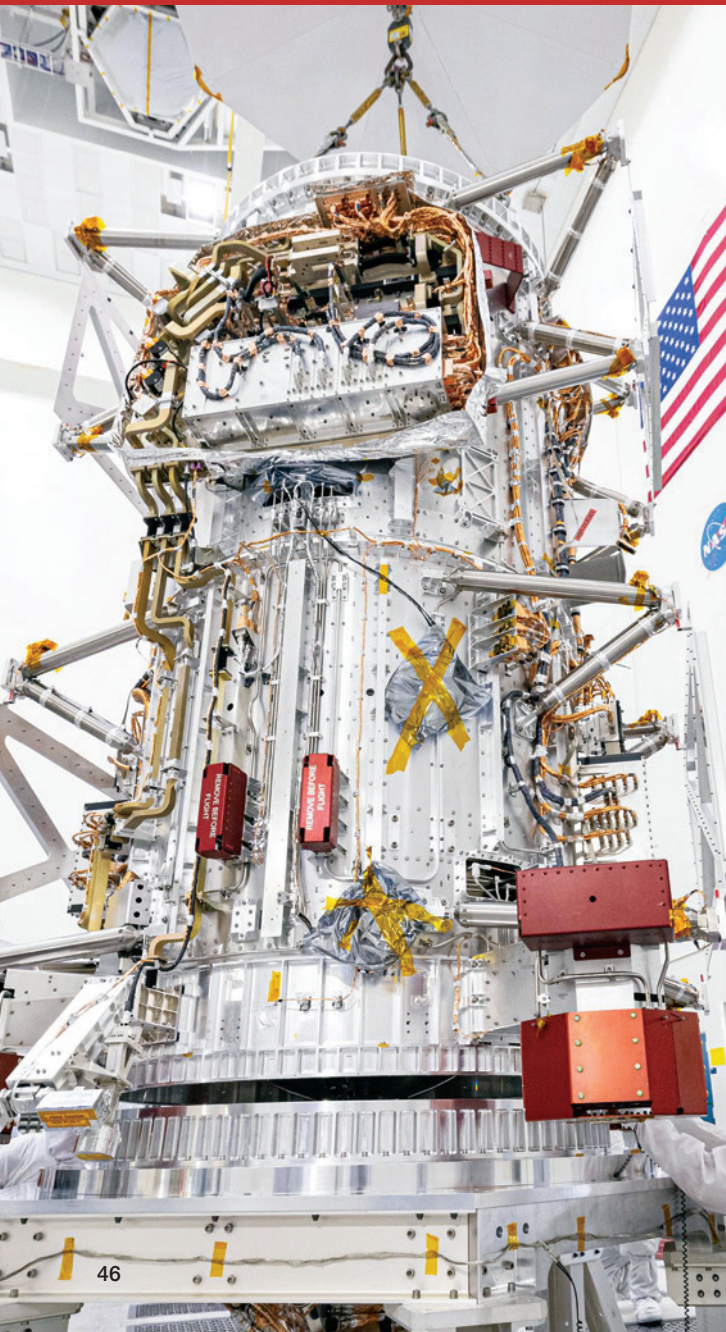
He said it's his engineering background, including his NASA experience, that prompts engineers to turn to him before other origamists. Indeed, NASA too has brought him back for consulting, including work on a computer model for folding the space agency's Starshade concept, a huge disc that, when unfurled, would block the light from a star to give a space telescope a clear view of that star's planets.

"So the irony is that, when I was employed full-time at NASA, I was not working on origami, but after I left, I was invited back a couple of times to work on origami-related projects," he said, noting that these relied on his ability to describe and model origami mathematically and write computer code that could generate folding patterns — skills he'd honed years earlier as a NASA employee. ●

"MMMV Pillars, Opus 667" stemmed from a collaboration between Lang and Brigham Young University to design flexible figures with moving surfaces. After the team arrived at a mathematical solution and shared an award for the resulting scientific paper about "rigidly foldable quadrilateral meshes," Lang turned the concept into this tessellation, created from a single rectangle of wood laminate, scored with a laser according to the accompanying pattern. Credit: Robert J. Lang

Space-Based Tech for Home Health Monitoring

Contactless monitoring for vital signs uses radio-frequency technology created by NASA



Even before we're aware of heart trouble, breathing problems, or physical stress, our bodies give off warning signs in the form of vibrations. Early technology to detect these signals used uncomfortable electrodes, patches, and other devices attached to the body. Wearable devices such as watches are more convenient but can chafe and damage delicate skin, a potentially serious issue for older adults in need of constant monitoring. Now, a wall-mounted technology that monitors vital signs is so unobtrusive it's easy to forget monitoring is taking place. Advanced TeleSensors Inc. developed the Cardi/o Monitor with an exclusive license for a hardware design and software created by NASA's Jet Propulsion Laboratory in Southern California.

Creating a smaller, inexpensive, contactless device to measure vital signs accurately and safely was so complicated it took NASA engineers nearly five years to figure out how to do it. That's because the human body is complex.

Breathing and pumping blood are just two ways the body creates vibrations. The motion of a single breath causes the diaphragm to move about one inch. By comparison, a heartbeat causes an incredibly small motion, about one three-thousandth of an inch, according to Sajol Ghoshal, CEO of Austin, Texas-based Advanced TeleSensors. Detecting that kind of vibration without touch has stumped technologists for decades.

Radio waves seemed the ideal approach. Radars were already remotely monitoring boats and airplanes. Radar emits a radio wave in a specific direction, and the wave bounces off an object. The reflected wave returns to the same device, where a receiver transmits its characteristics to a computer. Data extracted can include information such as direction and speed. But monitoring vital signs meant picking out much tinier movements that are easily swamped by other vibrations in the environment and recognizing them as actions of the heart, lungs, and more.

In the late 1990s, hardware and computing technology were sophisticated enough to meet the challenge, according to Steve Monacos, a JPL engineer who worked on the software. The working prototype was large, the size of a thick text book, and attached to a desktop computer.

Our Vibrating Bodies

After figuring out the best radio frequency to use, NASA designed a prototype to continuously emit a radio beam toward a stationary person such as a burn patient in a hospital bed. The device would be placed on a table a few feet away from the patient and send vital signs to a nurse's station via a WiFi connection. Even though it was never tested in an institutional setting, the prototype successfully performed continuous monitoring.

The algorithms trained by machine learning differentiated the signals — identifying cardiac and respiratory activity, as well as "noise" produced by nearby people and other medical equipment. While each heartbeat is as individual as a fingerprint, the characteristics of that motion fall within a specific range of vibrations. Breathing patterns also have their own characteristics, so once the software has a baseline, it can parse the related data.

NASA uses radio frequency (RF) for a variety of tasks in space, including communications. The Europa Clipper RF panel — the box with the copper wiring near the top — will send data carried by radio waves through the spacecraft between the electronics and eight antennas. *Credit: NASA*

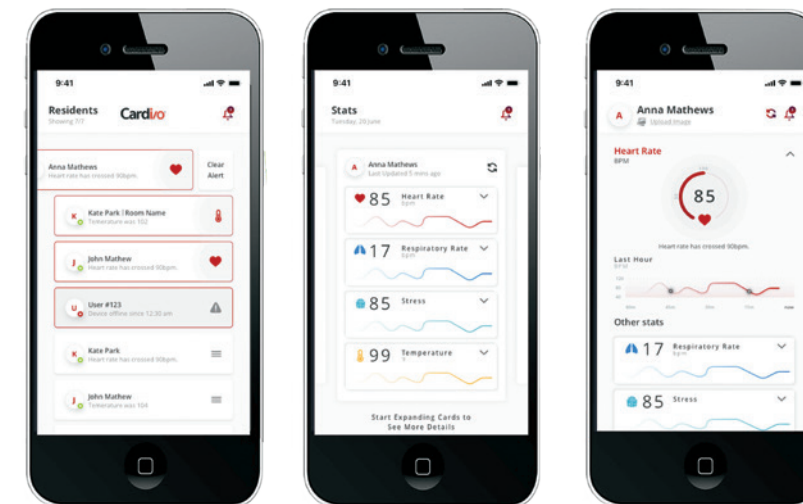
Radio-frequency technology developed by the Jet Propulsion Laboratory and licensed by Advanced TeleSensors of Austin, Texas, makes it possible to monitor vital signs remotely. The unobtrusive device continuously measures heart rate and breathing from several feet away.

The software can track multiple vital signs, revealing trends. For example, if breathing becomes labored in a person with congestive heart failure, that could indicate a problem. The constant monitoring offers healthcare providers more — and more consistent — data to inform decisions.

"Nobody had been able to come up with the methodology to make this technology very reliable, but we got it far enough along that we had use cases we could work with," said Monacos. Overcoming the biggest problem — differentiating the return signals — was "the pot of gold at the end of the rainbow" for a commercial technology, he said.

When Ghoshal participated in a demonstration of the prototype, he immediately saw the potential for in-home monitoring. Developing an affordable device was finally possible due to advances in the miniaturization of radar sensors and computing technology.

"We went through the entire design component by component," said Ghoshal. Maintaining the specifications NASA developed, the company



All that's needed to monitor heart rates, breathing, and related data is a smartphone and the Cardi/o Monitor by Advanced TeleSensors. The device mounts to a wall or sits on a tabletop and monitors vital signs of one or more people — no wearable required. *Credit: Advanced TeleSensors Inc.*



The Cardi/o vital sign monitor uses NASA-developed technology to continually monitor vital signs. The data collected can be sent directly to medical care providers, cutting down on the number of home healthcare visits. *Credit: Advanced TeleSensors Inc.*

looked for smaller, cheaper hardware to perform the same functions. A blind-spot radar used in automobiles and a single computer chip to store code and process data were smaller and required less power to operate. Analysis conducted by NASA showed the performance was very close to the prototype.

Horse-Sense Technology

The Cardi/o Monitor is compact, just 3 inches square, and mounts inconspicuously to a ceiling or wall. It doesn't require recharging or software updates like wearable devices. And it can detect vital signs from up to 10 feet, with the best performance between 5 and 7 feet. Multiple devices can be scattered throughout a house without adversely affecting the performance of each unit, with the smartphone app controlling settings and displaying all data on a single dashboard.

The algorithms developed by NASA detect heartbeat and

respiration, but the company added heart rate variability detection that indicates stress and sleep apnea. The ability to identify heart arrhythmia and other deeper cardiac issues is in development.

Filters developed by Advanced TeleSensors block potential interference from nearby technology such as microwave ovens and cellphones. Another safety feature is the radio signal. It's far below the maximum radio-frequency emission standards, making it safe for people and pets. "Our emissions level is close to 100 times lower than what's emitted by a WiFi router," said Ghoshal.

Some of the company's first clients were in equine rehabilitation clinics. The device was placed in a horse stall and needed to be waterproof, withstanding any disinfectant used to clean the stall. Medical staff were able to collect necessary vital signs without disturbing the animals, allowing them to rest. This application also helped the company prove the Cardi/o Monitor worked effectively.

'Transforming the World'

Contactless monitoring offers numerous benefits for managing any medical condition. When there's an anomaly, such as a dramatic heart rate increase, a customizable alert in the app calls attention to the situation. Combined with a regular stream of data, this information can potentially prevent an emergency room visit or hospital readmission.

Up to six months of data is stored in a secure cloud that meets medical regulatory requirements, making it easily accessible to healthcare providers. This in turn limits the need for regular in-person visits from home health workers, who could unintentionally introduce germs and prolong illness.

This is particularly important for high-risk conditions such as infectious diseases. Medical professionals doing in-person monitoring could also be at risk, as they were during the COVID-19 pandemic. Cardi/o is not a medical device and isn't intended to diagnose conditions but rather collects wellness data individuals and caregivers can use.

Describing the NASA engineers as very supportive, Ghoshal said the agency's willingness to do the research and development has made contactless monitoring possible.

"NASA has a phenomenal set of engineers. The depth and strength of their knowledge means they can develop some really cutting-edge technologies," he said. "They don't always realize the extent to which they are transforming the world, because it's just part of what they do." ●

Scaling Up Hydrogen

NASA tech for measuring insulation efficiency is helping expand the hydrogen industry

When NASA engineer James Fesmire needed to measure the thermal performance of his flexible aerogel material three decades ago, there was no instrument sensitive enough to do it. So he invented one.

The latest iteration of that device, called a cryostat, is now poised to enable widespread industrial adoption of hydrogen, in liquid form, as an energy carrier.

The Cryostat CS900 is poised to enable widespread use of liquid hydrogen as an energy carrier, according to James Fesmire, who invented the technology for his company, Titusville, Florida-based GenH2, building on his career developing cryostats at NASA's Kennedy Space Center.

"This is important for progress and the future," Fesmire said, explaining that the new Cryostat CS900 system is key to the practical handling of hydrogen, including liquefying, storing, and dispensing it.

The device is a simulation test platform that replicates real-world (and real-space) environments to demonstrate how liquid hydrogen and other cryogenic liquids behave under controlled conditions, generating data that is critical for developing advanced liquid hydrogen tanks for land, sea, and air vehicles; ground storage tanks; and the transfer piping between them.

The Vision to Carry It Forward

Fesmire's work over 30 years ago to quantify the small amount of heat transmitted through blankets made with aerogel, which is still the best insulator on Earth, resulted in his first cryostat, a liquid nitrogen-based device to test thermal insulation at cryogenic temperatures. A second-generation version of that instrument, the Cryostat CS100, has been operating since 2006 at the Cryogenics Test Laboratory, which Fesmire founded at NASA's Kennedy Space Center in Florida.

Fesmire went on to design a series of cryostats for NASA (Spinoff 2013) with different capabilities and improvements, all of which are now sold by GenH2 Corp., a Titusville, Florida-based company Fesmire cofounded just before retiring from the space agency in 2021.

GenH2 has licenses from NASA for four cryostat models and offers several others for which the space agency patents have expired. The company has successfully commercialized and sold three of those devices nationally and internationally to industry and academia.

"We are the inventors," said Dr. Martha Williams, who joined GenH2's founding team after a nearly 30-year career at Kennedy. "We have the licenses, but we also have the knowledge base and the vision to be able to carry the technologies forward."

GenH2 cofounder James Fesmire stands next to the Cryostat CS900, the latest and most capable device in his series of cryostats, most of which he originally developed for NASA's Kennedy Space Center. *Credit: GenH2 Corp.*

Keeping Up Standards

The body of knowledge Fesmire built at NASA with his cryostats and the libraries of data it generated provided the foundation for the first international standards for testing cryogenic insulation systems.

Adam Swanger, a colleague of Fesmire and Williams at NASA who now heads the Cryogenics Test Laboratory, said Fesmire's standards and the ability to measure heat transfer at cryogenic temperatures have made fluid systems and liquid storage in general far more efficient.

For spaceflight, in the absence of air, rocket fuel requires an oxidizing propellant, typically liquid oxygen, with an extremely cold boiling point. Liquid hydrogen, NASA's rocket fuel of choice, and also used for electrical power generation in space, is even colder.

"Insulation and proper characterization of it at these temperatures is crucial for designing efficient cryogenic propellant systems, especially for very large storage tanks like we have at Kennedy, and for long-duration spaceflight," Swanger said.

Some boiloff losses are generally inevitable for liquid gases. "You can never stop the heat from getting to the liquid from the ambient environment — you can only slow it down, but you can slow it down significantly," Swanger said. "The better the insulation is, the more you can slow it down. With less heat coming in, you reduce your losses for a more efficient and cost-effective system."

GenH2's Cryostat CS900, in addition to generating test data to guide the design of hydrogen storage and transportation systems, is poised to help GenH2 and other companies around the world develop additional standards for thermal insulation for cryogenic and other extreme applications. These standards will go on to inform even more efficient liquid hydrogen systems for everything from residential uses to the largest industrial applications.

"The field of cryogenics is foundational to some of the most impressive achievements in human history, including spaceflight."

Adam Swanger, Kennedy Space Center



NASA's Cryostat CS-500, pictured here as it cools down to cryogenic temperatures, was developed by GenH2 cofounder James Fesmire when he headed the Cryogenics Test Laboratory at NASA's Kennedy Space Center. *Credit: NASA*

'We're Doing This Because We Should'

"The field of cryogenics is foundational to some of the most impressive achievements in human history, including spaceflight," Swanger said, citing MRI machines, particle accelerators, and space telescopes as technologies that depend on cryogenics. Cryostats, such as those offered by GenH2, also help optimize insulation for medical research, refrigeration, and food processing and transportation.

Liquid hydrogen is currently attracting significant investment around the world. "You can both produce and consume hydrogen — full life cycle — without any emissions," Swanger noted. "Presently, it's the only fuel that can claim that."

The liquid hydrogen capability of the Cryostat CS900 "builds on a foundation of 30-plus years of NASA work," Fesmire said. "Now we're doing this because we should and because the markets require it." ●

Cosmic Experiments Make Cosmetic Nutrients

Antigravity bioreactor grows robust stem cells, extracts plant nutrients for anti-aging creams

Most Earthlings will never escape gravity, but an invention by a trio of NASA scientists has been making the benefits of weightlessness available to everyone on Earth.

Since it was introduced more than 30 years ago, the ability to simulate weightlessness in a laboratory has been used around the world to help develop drugs and stem cell therapies in the fight against cancer, diabetes, and other illnesses. Meanwhile, in the world of dermatology, one company is using it to repair skin, reduce wrinkles, and combat the effects of aging.

“Let’s face it, the cosmetic landscape is filled with brands whose claims fall short of scientific validation,” said David Pollock, president and CEO of Brand Labs USA LLC, headquartered in Fort Lauderdale, Florida. “Our mission is anchored in delivering scientifically substantiated results to our customers.”

It was this mentality that was triggered when another cosmetic company came to him several years ago asking what to do with a NASA license for using the Rotary Cell Culture System (RCCS) to obtain ingredients for skin-treatment products. “My jaw just dropped,” he said. “I’m like, wait a minute, you’ve got the greatest breakthrough I’ve heard of in my career. What are you doing with it?”

The RCCS was not new when the company Renu  l approached Pollock with it in 2018, but it was new to the world of cosmetics, with Renu  l having licensed it only five years prior.

Grounded, NASA Brings Space Environment to Earthlings

The technology itself dates back to the aftermath of the space shuttle Challenger disaster in 1986. At the time, a few researchers at NASA’s Johnson Space Center in Houston were working on a bioreactor to grow human kidney cells in the weightless environment of space. When the shuttles were grounded following the Challenger explosion, the team members’ access to weightlessness was cut off, so they came up with an alternative solution.

They found that if they placed the kidney cells and culture medium in a gently rolling horizontal cylinder, the cells stayed suspended, as if weightless, in the center of chamber. Better yet, they discovered that the multiplying cells organized themselves in much the same way they would in the body, building an orderly, three-dimensional tissue structure rather than the smooshed layers that cell cultures

form in Petri dishes in Earth’s gravity. As a result, the cells were healthier and grew faster, and they also secreted molecules similar to what they would produce in the body — and at high volumes and purity. This was key for many applications. For example, the Johnson team was originally growing kidney cells for their ability to produce erythropoietin, a hormone that regulates red blood cell production and can treat anemia.

Two of the team members licensed their technology from NASA to form Synthecon Inc., which began selling RCCS devices in 1992. Both NASA and the company continued to develop and patent methods for using the technology, including space agency patents on the use of an electromagnetic field to facilitate the growth of cells within the RCCS, which Renu  l had licensed in 2013 to create its Rejuvel skin care cream.

Rejuvenating a Skin Care Spinoff

Pollock had built a name in brand development and contract manufacturing, leading Renu  l to approach his company for commercial strategies. Impressed by the potential he saw, he immediately entered into a joint venture with the company. When NASA’s patent on the cell growth technique expired and entered the public domain shortly after, he bought out Renu  l’s portion of the business and consolidated it under Brand Labs USA, which now offers more than a dozen products that begin in the RCCS.

There, plant stem cells grown in a culture medium secrete various molecules that are key to skin care, creating a rich suspension of nutrients including

The Rotary Cell Culture System invented by researchers at Johnson Space Center lets cells grow faster and healthier than they would in a dish. Brand Labs USA of Fort Lauderdale, Florida, uses secretions from plant stem cells grown in the devices to produce nutrient-rich skin care products.

growth factors that boost the production of skin cells, vascular cells, and collagen. Also present are more than a dozen amino acids, various vitamins, a handful of anti-inflammatory cytokines, and both hyaluronic and polyglutamic acids, which help keep skin moist and flexible.

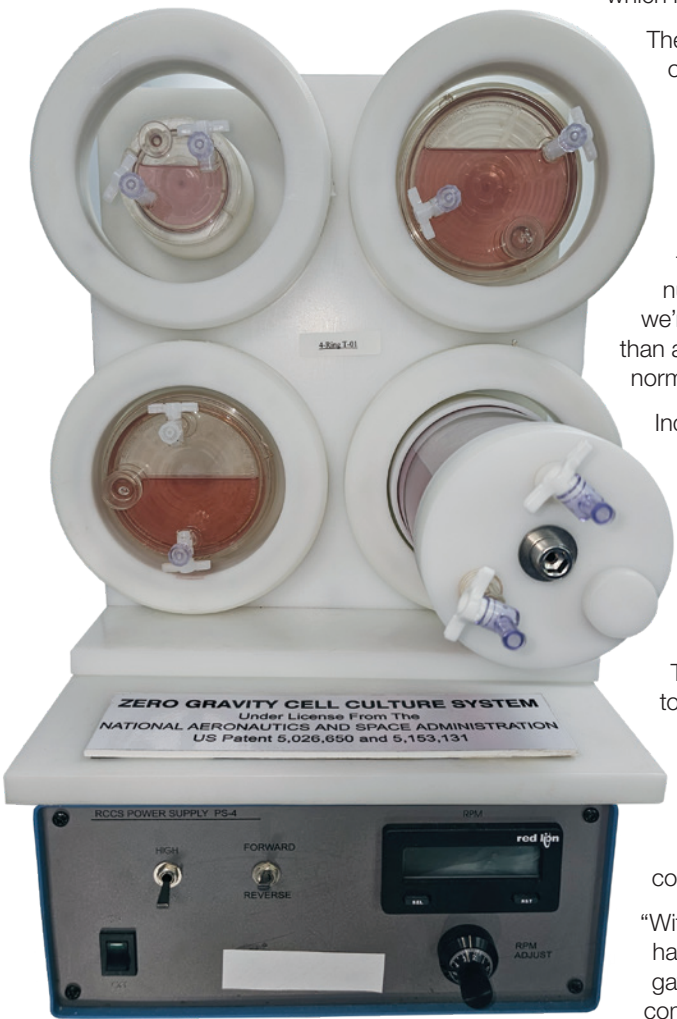
These are incorporated into a diverse range of products in Brand Labs’ Clinical Results 24/7 line, from facial moisturizers to exfoliators.

While some other skin care companies use stem cell secretum, Pollock said, the RCCS produces healthier stem cells faster, and these produce richer, more nutrient-dense secretions. “In other words, we’re harvesting so much more out of them than anybody else would be able to do in normal gravity.”

Independent clinical trials demonstrated that the products significantly reduced wrinkles, dark circles, and skin roughness, and caused a dramatic increase in skin hydration. “These weren’t minor. These were dramatic results,” Pollock said.

The company first sold the products to dermatologists and spas, but sales took off when they became available on a television shopping network, he said. He credits the products’ basis in NASA science for much of their — and the company’s — success.

“Without that, I don’t think we would have gotten to the size we are. It gave us credibility starting as a small company,” he said, noting that Brand Labs began in 2015 with one employee in a 1,000-square-foot space and has now grown to more than 30 employees filling a 15,000-square-foot facility.



Brand Labs USA owns this four-cylinder Rotary Cell Culture System from Synthecon, the company founded by two members of the team that invented the technology at Johnson. Credit: Brand Labs USA LLC

Healing Babies, Courting Brands

The company has also started using RCCS technology to obtain botanical extracts for a new line of skin care additives called BotaniCell. Rather than culturing stem cells for the molecules they secrete, BotaniCell is based on a technique for using the RCCS to extract nutrients from plant clippings, including carbohydrates, amino acids, vitamins, and other skin-rejuvenating ingredients.

Most companies obtain extracts from plants using either heat or chemical solvents, both of which can destroy many of the nutrients, said Pollock. “We discovered we can create more potent extracts in the RCCS. If it spins in that system long enough, we’re able to get a liquid from those plants with those nutrients.” Again, he said, independent testing found the resulting extracts were significantly richer in active ingredients than the products of other top brands.

In a side project, the company is also working with a nonprofit to treat epidermolysis bullosa, a rare and often fatal genetic skin disease that causes a baby’s skin to blister and peel off. Brand Labs has been helping to develop a treatment based on sulforaphane, a compound obtained from broccoli in the RCCS. “It has actually been healing the blistering of the skin that literally will kill these kids at a young age,” Pollock said, noting that the extract could eventually become the basis for an approved drug to treat the disease.

Meanwhile, he’s been in talks with major brands about incorporating both stem cell secretum and botanical extracts into their products.

“In a small amount of time with no private equity, no big loans, everything on our own, we’ve grown at a significant pace, and I feel the RCCS technology is a key component of it,” Pollock said. “As Brand Labs continues to explore the possibilities offered by antigravity bioreactors, we not only chart a new course in cosmeceuticals but also contribute to a future where the benefits of space technology are accessible to all, transforming our approach to health and beauty.” ●

A number of products in Brand Labs USA’s Clinical Results 24/7 line, including this moisturizer, incorporate secretions from plant stem cells grown in NASA-invented Rotary Cell Culture System devices. Credit: Brand Labs USA LLC



3D Printed Engines Propel Next Industrial Revolution

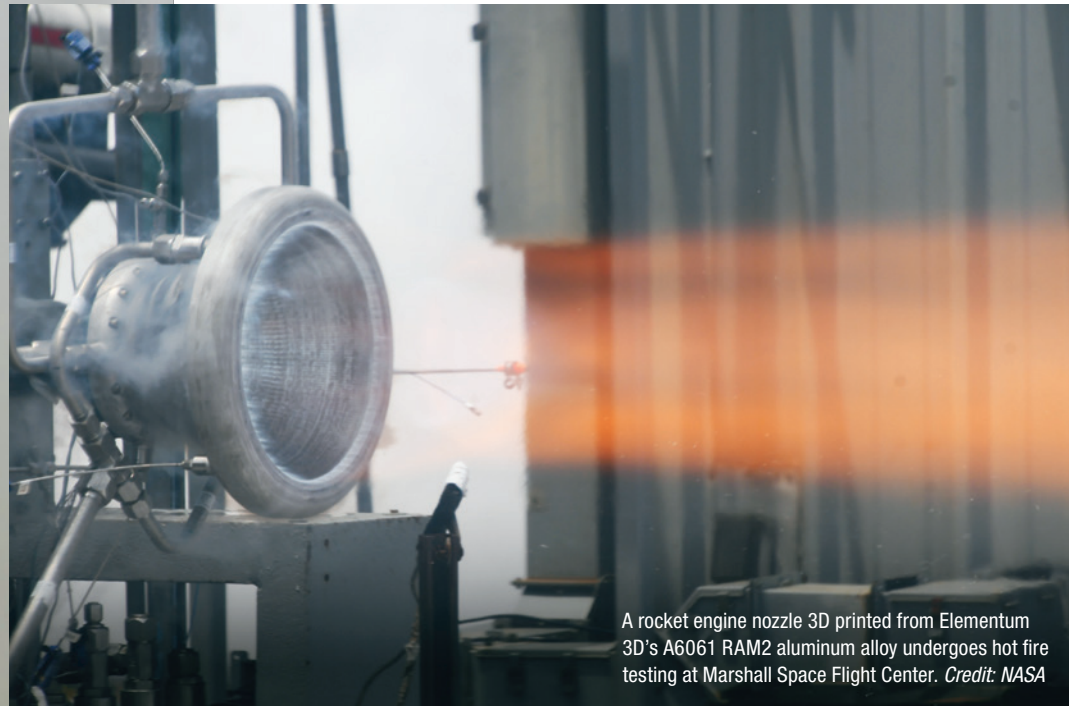
Converging efforts to 3D print engines promise major savings in rocketry and beyond

In the fall of 2023, NASA hot fire tested an aluminum-based, 3D printed rocket engine nozzle. What made the event remarkable is that aluminum isn't typically used for additive manufacturing because the process causes it to crack, and it isn't used in rocket engines due to its low melting point. Yet the test was a success.

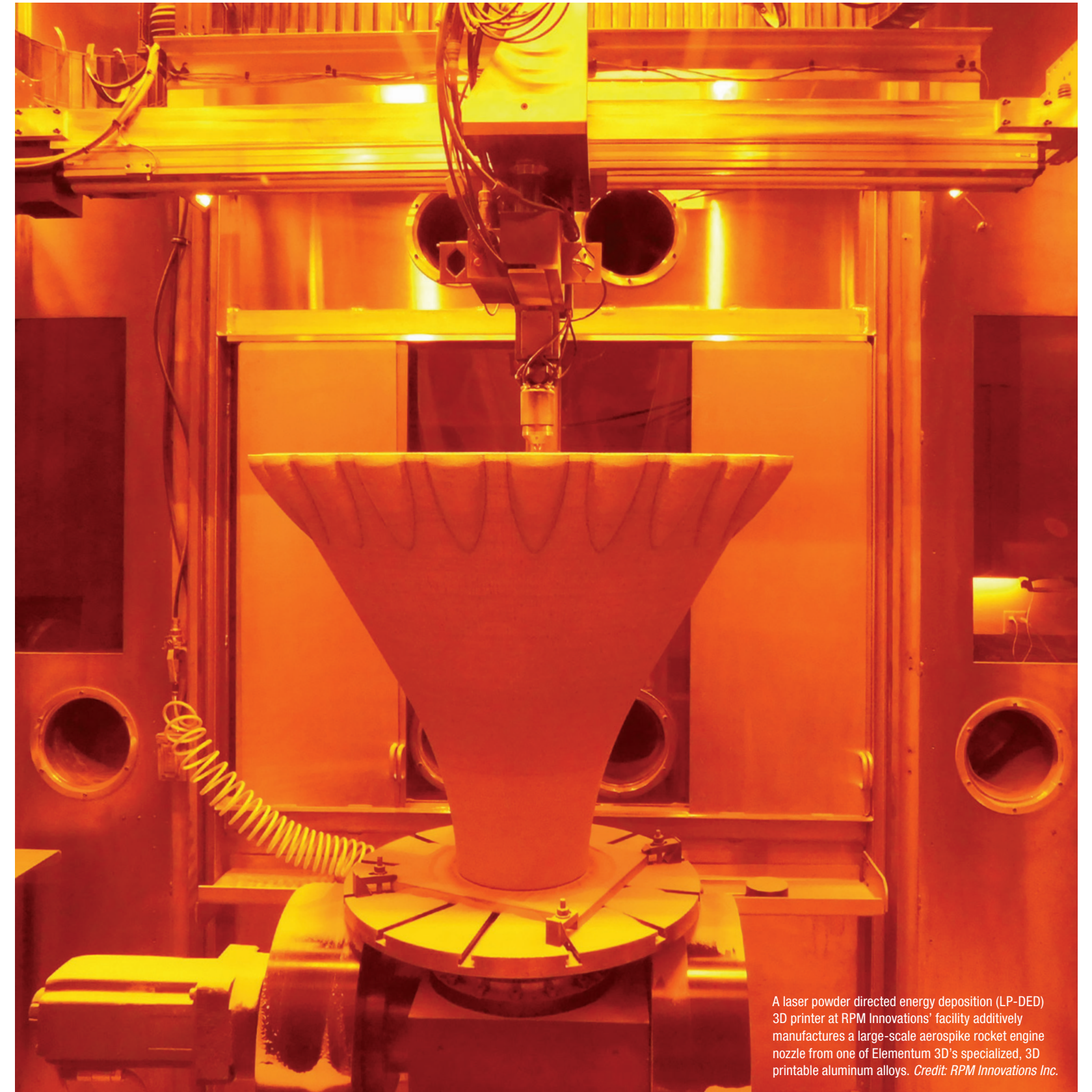
The new possibility of printed aluminum engine parts will mean significant savings for NASA in terms of time, money, and, most importantly, the weight of future spacecraft. And Elementum 3D Inc., a partner on the project, is now bringing the benefits of that technology to its customers, including not only rocket engine manufacturers but also makers of race cars, lighting fixtures, computer chips, and more.

NASA's Marshall Space Flight Center in Huntsville, Alabama, has been working on making engines with 3D printing — also known as additive manufacturing — for several years. NASA is interested in the technique because it would allow engines to be developed and built much more quickly, and they could be made in a few large pieces rather than hundreds of small components fastened together.

Tipping Point funding and an Announcement of Collaborative Opportunity, both from Marshall Space Flight Center, helped Erie, Colorado-based Elementum 3D refine its 3D printable aluminum alloys and processes to print large objects, including rocket engines.



A rocket engine nozzle 3D printed from Elementum 3D's A6061 RAM2 aluminum alloy undergoes hot fire testing at Marshall Space Flight Center. *Credit: NASA*



A laser powder directed energy deposition (LP-DED) 3D printer at RPM Innovations' facility additively manufactures a large-scale aerospike rocket engine nozzle from one of Elementum 3D's specialized, 3D printable aluminum alloys. *Credit: RPM Innovations Inc.*



NASA engineers Tessa Fedotowsky and Ben Williams inspect an aluminum nozzle that was 3D printed under Marshall's Reactive Additive Manufacturing for the Fourth Industrial Revolution (RAMFIRE) project, following its successful hot fire testing. *Credit: NASA*

The ability to print engine parts with aluminum promises all these advantages, along with substantial weight savings.

This was the culmination of a relationship between NASA and Elementum 3D that began shortly after Jacob Nuechterlein founded the company in 2014 with the goal of expanding the number and quality of materials available for 3D printing. In its early days, the Erie, Colorado-based company worked on infusing alloys — mostly aluminum — with particles of other materials to alter the metal's properties and make it amenable to additive manufacturing. This became the company's signature Reactive Additive Manufacturing (RAM) process. Without this treatment, aluminum alloys cannot be welded and therefore can't be 3D printed.

The work drew the attention of the Materials Development and Manufacturing Technology Group at NASA's Jet Propulsion Laboratory in Southern California, which became the RAM technology's first customer. Soon, JPL qualified the RAM version of a common aluminum alloy for 3D printing. "NASA was one of the very first early adopters, which helped us translate our understanding and findings to then find commercial customers," said Nuechterlein.

Engine Printing Takes Off

One company whose interest was piqued was Masten Space Systems, which ended up working with Elementum 3D on a couple of NASA-funded projects before being acquired by another company in 2022. In 2017, the two companies won Tipping Point funding from the

space agency to work on a 3D printed aluminum rocket engine, the experimental Broadsword engine that had begun under military funding. That engine, printed from one of Elementum 3D's earliest metal alloy composites, was tested in late 2019. It operated at lower chamber pressures than an engine would in real-world applications but began to prove the viability of the 3D printed, aluminum-based engine concept.

Meanwhile, a team at Marshall was working with a 3D printing company called RPM Innovations to adapt an emerging metal additive manufacturing technology, known as laser powder directed energy deposition (LP-DED), to print entire rocket engines from various alloys (see page 20). LP-DED had the potential to print much larger pieces than laser powder bed fusion, the technique used to build the Broadsword engine, but it needed to be

refined. The Rapid Analysis and Manufacturing Propulsion Technology (RAMPT) initiative spent about five years honing LP-DED printing and building larger and larger parts, ultimately leading to a nozzle five feet in diameter and selection as NASA's 2024 Invention of the Year.

The Next Industrial Revolution

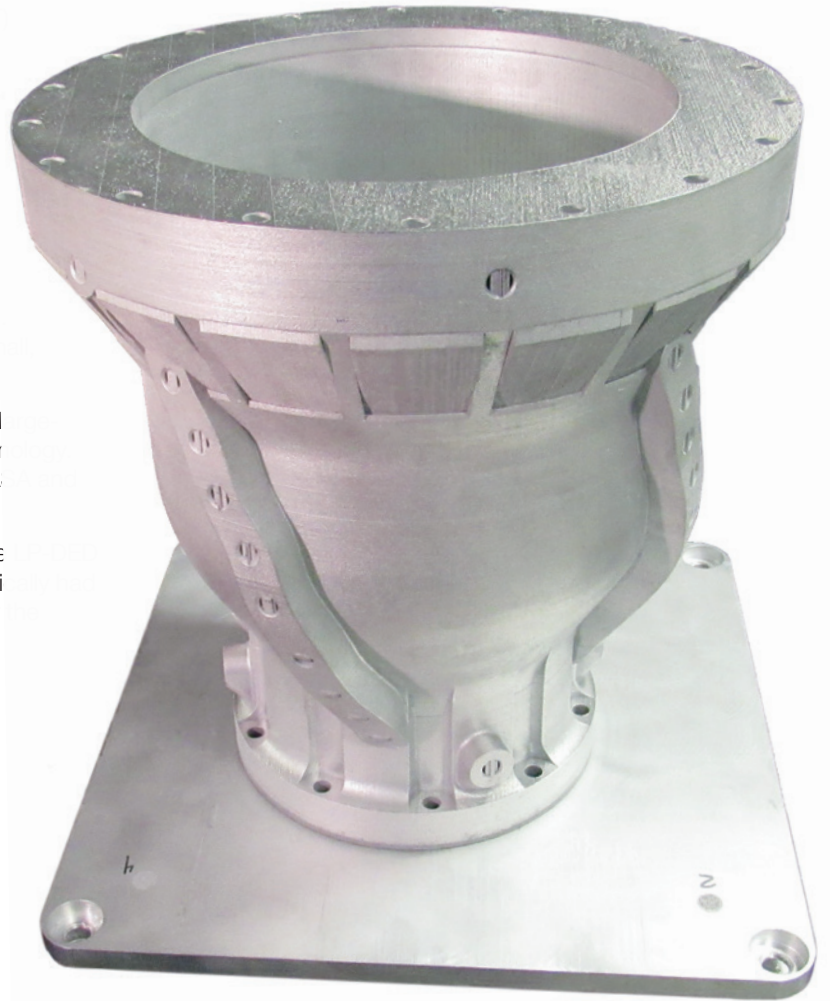
In early 2021, the LP-DED process was maturing, and an Announcement of Collaborative Opportunity (ACO) was awarded to Elementum 3D to modify their RAM technology for this new 3D printing technique. This was the Reactive Additive Manufacturing for the Fourth Industrial Revolution (RAMFIRE) project that culminated with hot fire testing in late 2023. Overseeing the work was Paul Gradl, a principal propulsion engineer at Marst who was also the principal investigator for RAMPT.

Elementum 3D reengineered its A6061 RAM2 aluminum alloy powder for the large scale printing process, and RPM Innovations again provided the printing tech. As an ACO, RAMFIRE was managed by Marshall with costs split between NASA and the participating companies.

"We went through various iterations of the powder to make sure it flowed in the machines, and there are a lot of challenges with that," said Gradl. "So we basically reinvented the way the powder was being manufactured to make it usable for the LP-DED process."



This 3D printed aluminum nozzle was then welded with wire from Elementum 3D spinoff Fortius Metals. *Credit: NASA*



Under Tipping Point funding from Marshall, Elementum 3D worked with Masten Space Systems to 3D print this experimental rocket engine, known as Broadsword, from Elementum's A1000-RAM10 3D printable aluminum alloy. *Credit: Masten Space Systems Inc.*

Aluminum weighs about a third as much as the iron-nickel-based alloys used in RAMPT, and Elementum 3D's new LP-DED-printable materials can now offer that weight savings to NASA, commercial rocket builders, and others as a result of all this work.

Cutting weight at this scale has major implications for space missions because it means that they can carry that much more payload.

Rocket Tech RAMs Its Way into New Markets

The work got the attention of Ball Aerospace, which is now using the same aluminum alloy that was reengineered for RAMFIRE to print large satellite components.

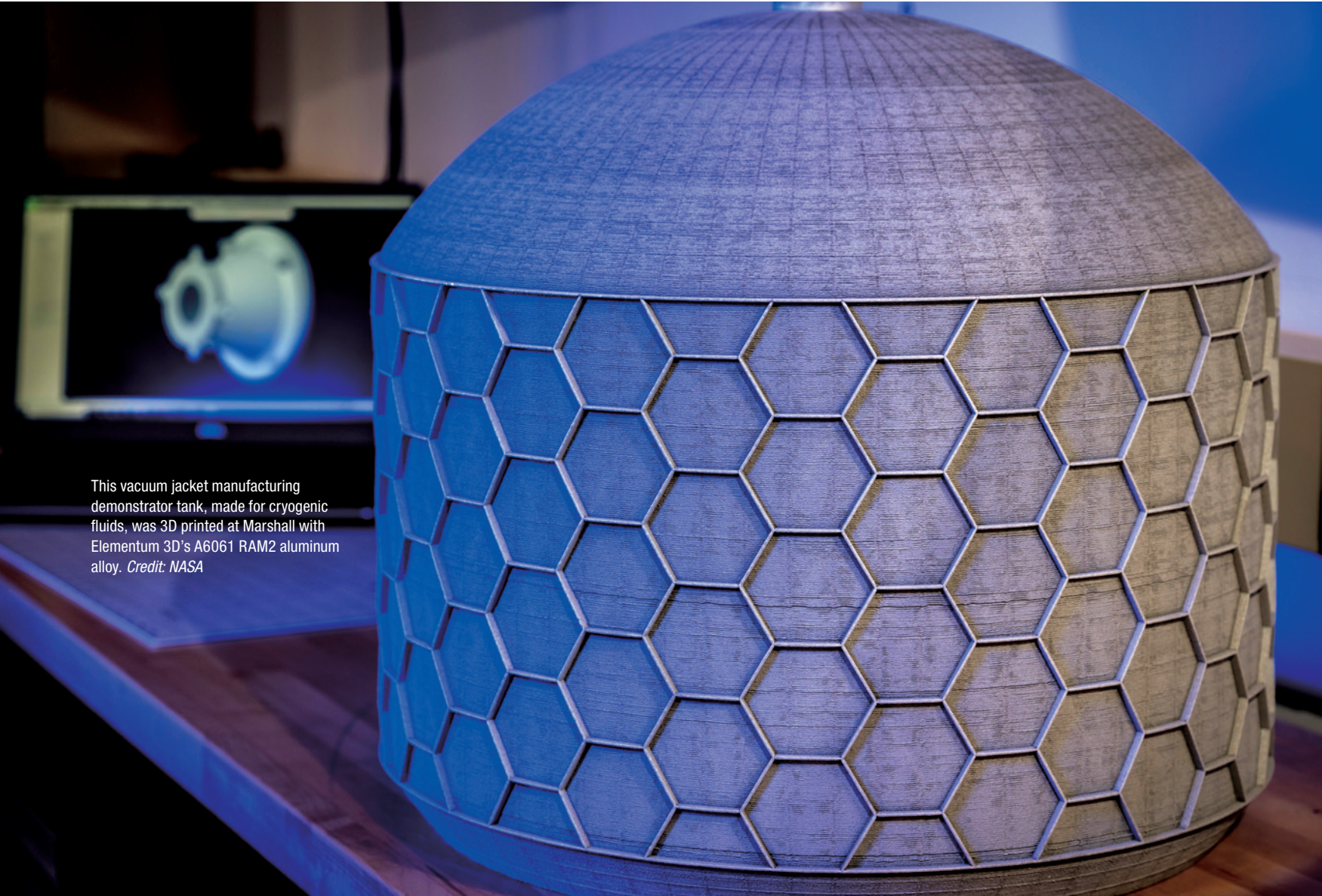
Not by accident, A6061 is one of the world's most commonly used aluminum alloys, and the RAMFIRE work has now made it available for large-scale 3D printing in industries beyond aerospace. Elementum 3D already had customers

for its original A6061 RAM2 alloy in the microchip manufacturing industry, where aluminum is used in components that handle caustic materials, and its most common application is in parts for Formula 1 race cars, where it can replace heavier steel parts to save weight. Neuchterlein said some of these companies are now investigating the possibility of using the reengineered version of the alloy for LP-DED printing.

Meanwhile, the company Ceramic Disc Technology is using the printable aluminum alloy refined under Tipping Point funding, known as A1000-RAM10, in aftermarket brake rotors for the Dodge Challenger SRT Hellcat, where it offers advantages in weight, strength, wear resistance, thermal conductivity, and temperature tolerance. Nuechterlein said other automakers are looking at it as a lighter-weight option for high-strength suspension and structural components.

Another company is turning A1000-RAM10 into prototype lighting fixtures because it's inexpensive, scratch-resistant, and strong without requiring heat treatment, and because 3D printing allows for designs that are otherwise impossible.

“We’re not just building for rocket industries,” said Anthony Manerbino, senior materials and applications engineer at Elementum 3D. “We’re building materials and alloys that can help people in their everyday life.” ●



This vacuum jacket manufacturing demonstrator tank, made for cryogenic fluids, was 3D printed at Marshall with Elementum 3D's A6061 RAM2 aluminum alloy. *Credit: NASA*



*“We’re not just building for rocket industries,
We’re building materials and alloys that can
help people in their everyday life.”*

Anthony Manerbino, Elementum 3D

Thin as it is, the wall of this 3D printed aluminum rocket engine nozzle is actually hollow, filled with tiny channels that the cryogenic fuel flows through to cool the nozzle. *Credit: NASA*

Space Tech Gives Treadmill Users a ‘Boost’

Creators of the original antigravity treadmill continue to advance technology, affordability with new company



NASA astronaut Nicole Stott works out on a treadmill on the International Space Station in 2009. Astronauts are held to the treadmill with a bungee harness. In the late 1980s, a NASA engineer came up with an alternative that would use air pressure to simulate gravity, a concept he later reversed to simulate weightlessness on Earth. His son has helped turn the idea into two companies. *Credit: NASA*

Boost Treadmills of Palo Alto, California, is the second company cofounded by the son of a former Ames Research Center employee to capitalize on a concept his father developed for exercise in space and then modified for use on Earth as an antigravity treadmill.

When Sean Whalen and a couple of friends founded Boost Treadmills LLC in 2017, they'd already helped bring the world its first antigravity treadmill. Now they wanted the technology to help more people.

"We knew we could improve the machines in a bunch of different ways, but ultimately, it's a price thing," said Tom Allen, cofounder and CEO of Boost which is headquartered in Palo Alto, California. "We could make things that professional sports teams could buy, but could we make things that go to homes or to the VA, that could also be successful?" he asked, referring to the Department of Veterans Affairs.

Allen and Whalen had started a company called AlterG in 2005 to commercialize technology Whalen's father, Robert, pioneered at NASA's Ames Research Center in Silicon Valley, California, in the 1980s and '90s. The company successfully developed and marketed treadmills that used air pressure to buoy users, taking weight off their feet and legs during exercise and benefiting people with a range of injuries and conditions (Spinoff 2009). After leaving AlterG, Allen, Sean Whalen, and former AlterG commercial director Jimmy Bean founded Boost to take the technology in a new direction.

Setbacks Burst Engineer's Bubble

The elder Whalen began considering equipment to help astronauts maintain bone density while he was a graduate student at Stanford University, after attending a talk by a researcher from nearby Ames. Astronauts were already using treadmills with harnesses to counter the loss of bone density that comes with prolonged weightlessness, but Whalen thought the system could be improved.

He eventually hit on the use of differences in air pressure to replace the downward force of gravity. "I realized that if I were to pull a complete vacuum around the lower body, it would produce about seven body weights of force at the waist," he said. "So you could easily develop a one-body-weight force. That seemed pretty doable, and that was basically it. Like, oh, this thing actually can work."

After becoming an Ames employee in 1989, he built a system he called "the onion" for its bulb of white, airtight fabric that went over the user's upper body and inflated to create a downward force. When his proposal to test it on the Russian Mir space station wasn't accepted, he realized that if he moved the air pressure to the lower body, he could create the opposite effect — relative weightlessness.

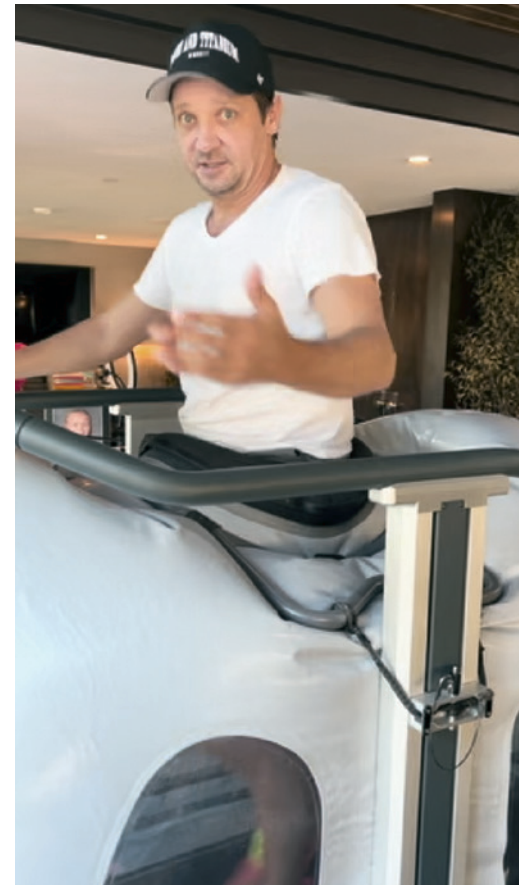
With the idea of offloading weight during rehabilitative exercise, he reached out to contacts at a Veterans Affairs research center his graduate program had worked with during his Stanford days. The center initiated a study on the concept, but in the end the idea did not gain traction.

He went on to build another prototype air pressure-differential device in his garage with funding from Ames before his other NASA research finally pulled him away from the effort. Years later, though, his son took inspiration from that prototype in the family garage, which became the basis for the AlterG antigravity treadmill.

Space Idea Becomes Home Reality

Offloading weight during exercise is an obvious rehabilitative solution for patients whose injuries prevent them from walking or running at their full body weight, but Boost says it can be just as valuable for people with long-term mobility impairments, such as obesity or arthritis. "You give them the ability to take some weight off and reduce the pain, reduce the risk of injury, and all of a sudden you've opened up a whole new world to do something they thought they'd never do again," said Sean Whalen.

Even people whose age prevents them from running as much as they'd like can benefit from offloading weight, Allen said. "If you think of someone at NASA working on something to protect the bone density of astronauts when they go to space, it's like the most niche thing you could possibly imagine," he said. "But that technology can benefit so many people — anyone with some sort of orthopedic or most neurological injuries, anyone dealing with obesity or joint issues, stroke, anyone who just wants to run faster or run more. It's probably 98% of the population over 40 years old in this country."



Antigravity Concept Continues to Soar

Now Boost has cut the price of an antigravity treadmill by almost two thirds, partly by finding efficiencies in materials and construction but also by connecting the machines to the internet, making it possible to diagnose issues and push out updates remotely. This often saves the cost of sending out technicians.

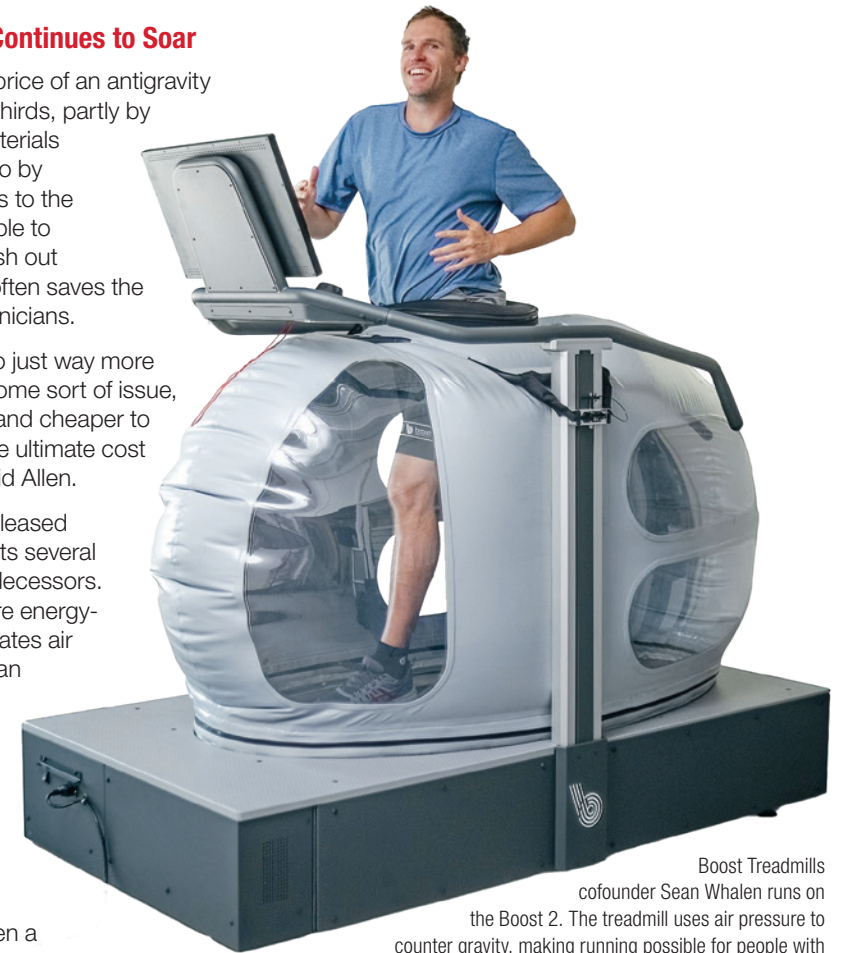
"These machines are also just way more durable, and if there is some sort of issue, they're way easier to fix and cheaper to fix, and so that brings the ultimate cost down for everybody," said Allen.

In 2022, the company released the Boost 2, which boasts several advantages over its predecessors. It's both quieter and more energy-efficient because it regulates air pressure input, rather than pumping air in at a constant rate and controlling the pressure with a release valve, said Whalen. It also automatically conforms to the user's height, ensuring comfort and eliminating what had been a cumbersome adjustment process.

The latest model also includes the capability to support blood flow restriction training, a relatively new technique that builds strength and muscle mass by impeding blood flow to muscles, forcing them to work harder even at lower weights and intensities. It's especially helpful to people with conditions that prevent them from lifting heavy weights. "We've been able to combine a strength component together with the mobility side to give the best overall option for recovery," said Sean Whalen.

The company estimates it's sold about 600 units to date, with steady growth year over year. And while, like its predecessors, it's become popular among professional sports teams and rehabilitation clinics, the Boost 2 also has roughly tripled sales to individuals, progressing on the company's goal of moving into the home, said Allen.

Actor Jeremy Renner works out on a Boost 2 treadmill. Renner has spoken publicly about the role the treadmill has played in his recovery from an accident on New Year's Day 2023, when he was run over by a snowplow and broke 38 bones. *Credit: Boost Treadmills LLC*



Boost Treadmills cofounder Sean Whalen runs on the Boost 2. The treadmill uses air pressure to counter gravity, making running possible for people with injuries and other conditions. *Credit: Boost Treadmills LLC*

The company is making its next treadmills even more affordable. "For a lot of people, the way to get the most benefit is to have a Boost in their home," said Allen, noting that many conditions are best treated with daily exercise. In early 2025, the company is beginning to take preorders for its next treadmills, which are specifically designed and priced for in-home use.

Although NASA has not yet tested the concept in space, Robert Whalen said he still thinks it's possible astronauts will one day use air pressure-based exercise equipment to maintain muscle mass and bone density. But the technology's terrestrial application has proven more rewarding than any space-based device could have, he said, noting the broad range of users it's already helping.

"I can't imagine it having a better outcome," said the elder Whalen. "Any research I would have done, I don't think would have been as valuable to society as what Sean and his group have done." ●

Coral Expertise Finds Broad Application

Remote sensing company helps customers navigate data, guided by NASA know-how

Miami-based HySpeed Computing offers remote sensing services using code the company's founder developed under funding from NASA Headquarters as a graduate student studying coral reefs.

When a Florida company wanted to incorporate new satellite data into its location forecasts for tuna, marlin, and other fish for offshore fishing tournaments, it called on Miami-based HySpeed Computing LLC.

HySpeed's founder, James Goodman, has worked with space agency data since the early 2000s, when he was a NASA-funded Ph.D. student at the University of California, Davis, focusing on remote imaging of coral reefs.

There, as a NASA Earth Systems Science Fellowship recipient, he began writing code that he has used in several agency projects since then and that has also evolved into the foundation of the services his remote sensing company offers today.

The fish forecasting company, ROFFS Inc., was interested in European Sentinel-3 satellite data to augment the satellite information it was already using. Goodman wrote an automated script to identify the relevant Sentinel data, automatically download it, and send it through a series of preprocessing steps before introducing it into the company's existing analysis pipeline.

"Instead of cloud computing, it's space computing."

James Goodman, HySpeed Computing

Variations in the seafloor at the southern tip of the Tongue of the Ocean, Bahamas, are made visible using Landsat 9 data processed by HySpeed Computing, whose founder has worked with space agency data since the early 2000s, when he was a NASA-funded Ph.D. student. *Credit: HySpeed Computing LLC*

NASA Spinoff 2025

"The data is there, and companies can get to it," Goodman said. "We just help them streamline that access and transform the data into formats or products they can more easily run through their own analyses."

Complicated and Diverse Systems

NASA uses remote sensing to monitor Earth and other planets, often with sensors mounted on satellites or aircraft to detect reflected or emitted energy in greater detail than what is visible to the human eye. People can see red, green, and blue — a basic multispectral observation capability.

The space agency's multispectral Landsat satellites orbit Earth collecting information in additional bands of the electromagnetic spectrum, including deep blues, violets, and infrareds. Hyperspectral imagers, meanwhile, which have been Goodman's focus since his Ph.D. days, can monitor hundreds of bands, giving a broader, more detailed read on the spectrum.

Woody Turner, program scientist for biological diversity at NASA Headquarters in Washington, explained the space agency's interest in imaging and studying nuanced environments. "Systems like rainforests with multiple species of trees in the canopy or coral reefs with multiple reefs and different types of algae — they're complicated, they're diverse, and that complexity is really well captured through these hyperspectral imaging spectrometer systems," he said.

Increasingly high resolution helps detect smaller details in coral reefs, for instance, giving a more refined understanding of the environment as a whole.

"We care about coral reefs because we care about having a healthier system, we care about healthy fisheries, we care about maintaining biodiversity, we care about water quality and water health," he said.

Coral reefs and reef flats along the northern coast of Vanua Levu, Fiji, mapped with Landsat 9 data processed by HySpeed Computing. Remote sensing enables large-scale monitoring and assessment of coastal ecosystems around the world. *Credit: HySpeed Computing LLC*

NASA Spinoff 2025

Automating a Reliable Approach

After earning his doctoral degree, Goodman went on to work on NASA-funded coral projects at the University of Puerto Rico, refining his software code along the way.

"I always felt I wasn't just solving one question. I was focused on the code and developing software that could be applied at least regionally and ideally globally — wherever there are coral reefs," he said.

"Beyond the academic side of this research, and beyond just looking at coral reefs, it soon became apparent that there was commercial potential for the types of applications I was developing, and it led me at one point to realize I could start a company based on this expertise."

HySpeed Computing was founded in 2010, and in addition to private-sector clients, the company also still works with academics, including most recently a team at the University of the Virgin Islands that was setting up its remote sensing capabilities to monitor coastal sedimentation.

"They were looking at sediment plumes in the water column and wanted to explore options for automatically detecting and monitoring them," Goodman said.

Working with HySpeed, the team identified the appropriate applications and algorithms, he said. "Then we worked on the question of, how do you take what you've now identified as a reliable approach and automate that?"

Space Computing

HySpeed has also continued to work with NASA, developing a web-based hyperspectral processing system for data collected from an imaging spectrometer on the International Space Station. Goodman said this work further informed his software, inspiring him to continue making his code more automated and user-friendly.

More recently, in a project aimed at enabling high-performance computing in space, HySpeed software made it to the space station itself, this time working with Hewlett Packard Enterprise's Spaceborne Computer project, which runs a commercial, off-the-shelf computing system on the station (see page 12).

"As we move further away from Earth, crews are going to need more autonomy and computing power to do what they need instead of transmitting all that data back and forth," Goodman said. "Instead of cloud computing, it's space computing."

Back on Earth, HySpeed continues to make remote sensing data more accessible, whether clients need it for conservation efforts or business efficiency. Goodman said his company is still working with ROFFS, developing new capabilities to improve the fish forecaster's analysis products. ●

Measuring Buzz, Hum, and Rattle

Wireless microphone array quickly, cheaply, accurately maps noise from aircraft and much more

Airplane manufacturers running noise tests on new aircraft now have a much cheaper option than traditional wired microphone arrays. And it's sensitive enough to help farmers with pest problems. The wireless microphone array that one company recently created with help from NASA can locate crop-threatening insects by listening for the sounds they make in fields. And now, it's making fast, affordable testing possible almost anywhere.

Since releasing its first commercial product in 2017, a sensor for wind tunnel testing developed with extensive help from NASA (Spinoff 2020), Interdisciplinary Consulting Corp. (IC2) has doubled its staff size and moved to larger lab and office space to produce its new WirelessArray product. Interested in making its own flight tests more affordable, NASA's Langley Research Center in Hampton, Virginia, supported this new project as well, with multiple Small Business Innovation Research (SBIR) contracts and expert consulting.

The result is a series of small, saucer-shaped bases equipped with multiple sensors that measure the air pressure changes created by overhead sounds. Airplanes go through noise testing and require certification so that they don't exceed the noise level set for their body type by the Federal Aviation Administration. When an airplane flies directly overhead, the array collects noise data to build a two-dimensional map of the sound pressure and its source. A custom software package translates that information for the end user.

Thanks to support from NASA, the more affordable testing tool is seeing applications beyond aircraft, from animal monitoring to energy generation.

Neither Rain nor Snow

NASA Aeronautics has always used wired systems to collect the same data but saw the potential for a less cumbersome approach, said Tony Humphreys, chief engineer with Langley's Measurement Sciences. Humphreys oversaw the WirelessArray SBIR contracts and also provided consulting and even a prototype device the company used as a starting point.

"Previously, when we went out to Edwards Air Force Base for a series of flight tests, we used a large array with hundreds of sensors. We had about 15 miles of cabling to hook up all of them, and it took a crew of six people three days to set up and tear down," he said. The cables had to be positioned in a specific pattern to avoid overlapping, and if it rained, each sensor had to be covered to protect it from precipitation. Multiple semi-trucks hauled all of that equipment, along with power generators, racks of servers, and other equipment.

By contrast, two IC2 staff arrived at Langley's flight-test range driving a minivan with all the hardware needed to test the WirelessArray system. Yet Humphreys said the data generated by the smaller wireless system was comparable to a conventional system.

Collecting flight test noise data or chirps from insects in a field is as simple as laying out a wireless microphone system. Interdisciplinary Consulting Corp. of Gainesville, Florida, worked with Langley Research Center on multiple SBIR contracts to replace the existing bulky and expensive wired systems.

The flight testing NASA and commercial airlines perform with a wired system is so expensive that it's usually out of reach for smaller companies, said Chip Patterson, vice president of IC2, which is based in Gainesville, Florida. This technology, designed to meet NASA specifications, is changing that. Whether using one or 100 of the sensor nodes, anyone can afford to do flight testing.

"Each node contains a small computer system," said Patterson. "It's able to acquire and store data in memory on an SD card. It also has a small web server that allows the end user to poke it, asking it to start acquisition, stop recording, download files, check on the battery health, and more."

A traditional wired system requires the simultaneous and instant download of all data, meaning the array is limited to the capacity of the hard drives it feeds into. IC2's smaller system acquires significantly larger datasets, allowing that data to sit in each node until it's collected. If, for example, a single node is placed in the field to collect community noise measurements over several months, it won't be necessary to go to the site daily to download measurements.

The WirelessArray supports a variety of sensors, so a microphone can easily be swapped for an optical sensor or a variety of other types. Each unit has its own self-charging battery and solar

panel, supporting long-term deployment. Built-in GPS maintains synchronized sampling across multiple nodes, and wireless communication allows users to download data remotely and monitor the health of each device. The nodes' environmentally hardened enclosures make it possible to take measurements in any weather without additional protection from dust, snow, or extreme temperatures.

A startup developing a new remotely piloted vehicle can now get sophisticated flight test data to quickly identify noise issues during takeoff, flight, or landing. Multiple test flights for every modification can speed the time to market because the cost to set up, operate, and take down the system is so low.

Bugging Bugs

All it takes to operate an individual node or an extensive array is an off-the-shelf wireless access point and a standard laptop loaded with IC2's software application. The nodes are also easily integrated into existing systems.

This small, portable technology is finding its way into a variety of projects and applications beyond aircraft testing. IC2 is working with an entomologist to use acoustic data to listen for high-frequency insect sounds in agricultural settings. Discovering where insects feed on crops will make it possible for farmers to intervene before they do too much damage while limiting pesticide use to those areas.

Researchers are exploring ways to monitor mice and rats in a laboratory setting by swapping the standard acoustic sensor that matches human hearing for an ultrasonic sensor. This will make it possible to monitor squeaks and other sounds that indicate an animal's health and well-being. A similar ultrasonic sensor could monitor the flight path of supersonic aircraft, identifying when a sonic boom is approaching an area.

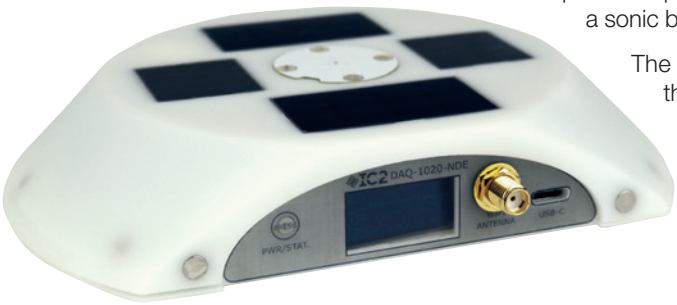
The technology can be applied to anything that generates sound, collecting data according to a preset schedule or on demand. Rocket engine test stands and environmental observations



The WirelessArray developed by IC2, laid out here for a test flight at Langley Research Center, makes flight testing for drones quick and cost-effective. *Credit: NASA*

such as the noise level at airports are just a few possibilities. NASA could also use this system to collect data for entirely new airplane designs.

"We've been pushing the acoustic side as aeronautics move into more advanced concepts like the truss-braced wing, maybe distributed electric propulsion, or others. That raises the need for noise testing and noise certification for new configurations," said Humphreys. So NASA engineers could soon trade the semitrucks and servers for a couple of minivans and laptops. ●



The WirelessArray developed by Interdisciplinary Consulting Corp. (IC2) uses self-powered, weatherproof nodes, like this one, to detect noise. The microphone can be replaced by other sensors to collect data for a day, a week, or even year-round. Solar panels on the top power the internal battery, and data is stored internally on a memory card. *Credit: Interdisciplinary Consulting Corp.*

"Each node contains a small computer system."

Chip Patterson, Interdisciplinary Consulting Corp.

Test flights help airplane and drone manufacturers identify which parts of the aircraft are creating the most noise. Using hundreds of wired microphones makes it an expensive and time-consuming process to improve the design to meet noise requirements. *Credit: NASA*

NASA Sets Standard for Nutritional Health Products

Early NASA partnership becomes foundation of reborn dietary health company

Among the most enduring medical mysteries of space travel are the effects of prolonged weightlessness on the eye. Some astronauts experience changes in vision and eye anatomy that quickly resolve after their return to Earth, while others develop issues that persist long after spaceflight. Some see little change at all. Despite a number of NASA studies, the precise cause of so-called spaceflight-associated neuro-ocular syndrome remains unknown.

The rest of us now stand to benefit, however, from the mysterious and varied nature of astronauts' eye afflictions, because it's resulted in a dietary supplement that addresses just about every possible source of eye problems. The OS2 Ocular Support Solution is one of the



Astronaut Karen Nyberg undergoes an ocular health fundoscopic exam on the International Space Station. Many astronauts experience changes in vision and eye anatomy during long stays in space, which prompted the creation of Nugevity's OS2 Ocular Support Solution. OS2 is now Nugevity's most popular product within the United States. Credit: NASA

Houston-based Nugevity is a restructured version of the company AmeriSciences, which worked with Johnson Space Center to develop dietary supplements for astronauts and then commercialized the results, both in terms of formulas and quality control standards. Nugevity has continued to expand that product line.

products Nugevity co-developed with NASA and has released since the company restructured and rebranded from its earlier incarnation as AmeriSciences (Spinoff 2012). Others include sports nutrition products based on work the Houston-based company did to support astronaut training and a bone-health supplement stemming from efforts to counteract the atrophy caused by long-term weightlessness.

OS2 is now Nugevity's most popular product within the United States, while its biggest seller internationally is still the AS 10 Life multivitamin and antiaging supplement released in 2011, one of AmeriSciences' first products developed with NASA. Nugevity now markets about a dozen dietary supplements, all of which have benefited to some degree from work with the space agency.

Answering NASA's Call

AmeriSciences LP was only a few years old when NASA reached out in 2004, proposing a partnership to develop countermeasures to the health hazards of long-term space travel. These include not only eye and vision troubles but also bone and muscle atrophy, immune dysfunction, and issues related to oxidative stress caused by radiation from the Sun and from the galaxy outside our solar system.

Under a Space Act Agreement, the company collected input from various departments at NASA's Johnson Space Center in Houston, which handles human spaceflight research for the agency. "Every time we talked to a different office, they added different requirements or changed the requirements the prior people had set, so it was definitely a lengthy and very thorough journey," said Carlos Montesinos, who was chief scientist at AmeriSciences and is now managing director and chief scientist at Nugevity.

One of the most productive relationships, he said, was a collaboration with the center's chief pharmacologist, who was "very skeptical at first, to put it mildly," of any dietary supplement company. Her long list of requirements raised the company's quality control standards for product safety, consistency, and performance to at least

those of a pharmaceutical company. These became what Nugevity now calls its Pharma-IQ standards, which Montesinos said exceed pharmaceutical best manufacturing practices.

Another important result of working with Johnson's pharmacologist is what the company now calls its BioRelease technology, he said. Pharmaceuticals are required to dissolve in the body such that at least 75% of their active ingredients are available for uptake within an hour. No such requirement exists for dietary supplements, but, to satisfy the pharmacologist, Nugevity managed to achieve a dissolution rate of 95% in the first hour, ensuring that the products are effective.

Ingredients included a wide variety of vitamins, minerals, and other nutrients, but a major focus was antioxidants to combat the oxidative stress triggered by space radiation. Oxidative stress, which increases with age, is also the major cause of the symptoms of aging, as it damages cells and their organelles and DNA, resulting in increased risk of age-related illnesses such as cardiovascular diseases, cancer, and neurodegenerative diseases. Relieving oxidative stress, therefore, is of interest to the general population, regardless of radiation exposure.

"Every time we talked to a different [NASA] office, they added different requirements or changed the requirements the prior people had set, so it was definitely a lengthy and very thorough journey."

Carlos Montesinos, Nugevity



Several of Nugevity's supplements, such as AS 10 Life and OS2 Ocular Support Solution, are based on formulas created for astronauts with NASA's input. Others that are based on Nugevity's own recipes still meet NASA's standards for quality control and the release of active ingredients. Credit: Premium Vitamins and Supplements LLC

After the company came up with formulations that met the needs raised by various NASA teams and the standards set by the pharmacologist, it manufactured pilot products and then worked with NASA flight surgeons to try them out on mice. “We ran a few experiments at the University of Pittsburgh, where we would collaborate on developing the method,” Montesinos said. “We were coinvestigators in the drafting of the experiment, and we would work together to publish the results.”

AmeriSciences ultimately commercialized several products stemming from its partnership with NASA, including targeted multivitamins, antioxidants, and omega-3 fatty acid supplements.

Pill-Based Space Tech

Not long after, however, the company ran into financial difficulties and went out of business. Montesinos credits the collaboration with NASA for the interest he subsequently received from investors, who helped him revive the company as Premium Vitamins and Supplements LLC, doing business as Nugevity. In a dietary supplement industry that “leaves a lot to be desired in terms of credibility, in terms of quality control, and in terms of regulatory oversight,” he said, the space agency’s input and approval inspired confidence from both consumers and investors.

Upon its revival, Nugevity incorporated the Pharma IQ standards and BioRelease technology it had developed with NASA into all of its products, including several that were otherwise developed independently of the space agency. The company continued producing supplements born from AmeriSciences’ work with NASA and added a few more that stemmed from that partnership. These include the OS2 supplement for eye health, a few sports nutrition products stemming from work to help astronauts cope with the stresses of training, and a supplement called Osteo BHR, which incorporates a slew of ingredients aimed at increasing bone mineral density, as well as cardiovascular health.

Among the users of the sports nutrition products are the U.S. Paralympic Wheelchair Basketball team. Montesinos said the multivitamins remain popular. Meanwhile, the newer eye-health product has caught on due to the unusual range of ailments it works against, he said, noting that it includes ingredients for avoiding age-related macular degeneration, as well as other countermeasures stemming from the company’s work with NASA. These help alleviate radiation-induced changes that can lead to cataracts, glaucoma, poor night vision, and reduced tear function. “It’s a much more comprehensive product than what’s currently in the marketplace from traditional sources,” Montesinos said. “So I think that’s probably the best illustration of how the consumer benefits from the work we’ve done with NASA.”

Reaching New Markets, Reviving Old Partnership

In the years before the pandemic, much of Nugevity’s growth was in Asia, where the company picked up distributors in Japan, South Korea, and Hong Kong. Montesinos said this growth was interrupted by COVID-19 but has since picked back up, with new distribution partners emerging in Malaysia and Indonesia.



Among the products Nugevity has released since its rebranding from AmeriSciences are sports nutrition supplements, some of which are based on formulas the company created to help astronauts with their physical training. Credit: Premium Vitamins and Supplements LLC



Matt Scott, a five-time Paralympian and a double gold Paralympic medalist, poses with Carlos Montesinos, managing director and chief scientist at Nugevity. The U.S. Paralympic Wheelchair Basketball team uses Nugevity’s sports nutrition products, which stem from supplements the company developed to help astronauts cope with the stresses of training. Credit: Premium Vitamins and Supplements LLC



A major focus of the company's work with NASA, and many of Nugevity's subsequent multivitamins and other products, was combating the oxidative stress triggered by space radiation. Oxidative stress, which increases with age, is also the major cause of the symptoms of aging, so counteracting it is of interest to the general population. Credit: Premium Vitamins and Supplements LLC

And he’s once again working with NASA. Nugevity, Johnson, and the Navy are now searching for any molecules in the body that are affected by radiation injury or oxidative stress during long-term spaceflight, known as biomarkers. “The work we did during the Space Act Agreement days was a lot more ‘macro’ in nature,” Montesinos said. “Now we’re digging deeper into the science, looking at molecular biomarkers and how cells control gene activity, which can then steer the development of nutritional interventions tailored to each individual need.”

It’s a continuation of the partnership that he said has been foundational to the business’s resurrection, its brand, and its products. “It was that project of working with the agency when I was chief scientist at AmeriSciences that helped me develop a passion for this work,” Montesinos said. “It has benefited us greatly, and I think that ultimately has benefited the consumer — or if we want to be romantic about it, humanity — because of the standards that we and NASA codeveloped.” ●

Out-of-This-World Organs

Commercial spaceborne research platform grows drug crystals, human tissue, more

Recent successes in cultivating human heart tissue, knee cartilage, and pharmaceutical crystals in space have relied on technology that was initially developed decades ago with support from NASA.

The Redwire Advanced Space Experiment Processor, or ADSEP, is a locker system currently on the International Space Station that houses removable cassettes containing individually designed science experiments with unique capabilities. Companies, research institutions, and government agencies pay Redwire, directly or indirectly, for use of the platform to carry out experiments in space. The cassette-based science capabilities have become increasingly sophisticated over the years, and the ADSEP unit itself has also evolved, with the latest iteration of the system, ADSEP-4, scheduled to launch in 2024.



NASA astronaut Megan McArthur installs a new Advanced Space Experiment Processor (ADSEP) experiment locker on the International Space Station in this photo from 2021. The cassettes it holds have unique capabilities designed around specific experiments, which have included bioprinting human tissue. *Credit: NASA*

Heart tissue, knee cartilage, and pharmaceutical crystals have been cultivated in space using Jacksonville, Florida-based Redwire’s ADSEP shelving unit, which was developed for and has been improved by NASA, including through Johnson Space Center funding.

“It’s a multi-purpose processor of mini laboratories based in these cassettes,” said Rich Boling, who works on in-space manufacturing for Redwire Corp., which is headquartered in Jacksonville, Florida.

“ADSEP has been around since the 1990s, and it’s still a workhorse,” Boling said. “It’s at the center of many things that we do.”

In the last few years, Redwire has announced a series of space-based biomedical achievements, including the first bioprinted human meniscus created in space. The knee cartilage cells were printed for the Uniformed Services University’s biomedical research, which explores new technologies for the U.S. Army Walter Reed Medical Hospital.

Meniscus tears are among the most common injuries for U.S. military personnel, frequently occurring both in combat and training. Current treatments include cutting away shredded or damaged cartilage and suturing what remains. The ability to introduce new meniscus tissue could be a game changer for both military and civilian patients.

Why Print in Space

Gravity is a significant obstacle to bioprinting cells and growing human tissue on Earth. Heavier components settle to the bottom of petri dishes, so scientists have to add chemicals and “crosslinking” ingredients that have damaging and sometimes lethal side-effects on cells.

“You can make something on Earth that looks like a heart, for example, but it won’t function like one,” Boling said.

“In space the great news is you can print thick constructs, and each cell layer stays where you want it,” he said. “The problem is you can’t bring it back down to Earth right away because then you’re back to that puddle you would get if you did it all on Earth.”

That’s where ADSEP comes in. The meniscus Redwire grew aboard the space station for the Uniformed Services University was then cultured for two weeks in a cassette stored in an ADSEP locker.

Redwire maintains two ADSEP units aboard the space station, one dedicated to conditioning and culturing tissue from cells printed by the company’s bioprinter, while the other runs a variety of experiments, including drug crystallizations.

Typically, crew will put an ADSEP cassette that houses a bioreactor, camera, and microscope directly into the bioprinter on the space station.

“Then they float off and do other things they need to do,” Boling said of the astronauts.

At this point, Redwire staff back on Earth take charge, commanding the printer to print cells into the ADSEP container with the lid off. “We talk directly to the astronauts, and we control our own machinery in real time,” he said.

Once the cells are printed, Redwire asks space station crew to put the lid back on the bioreactor cassette and install it into the ADSEP locker. This is where the assemblage of cells becomes tissue.

A Series of Successes

Redwire announced in May it had printed and grown the first live human heart tissue sample in space using ADSEP, a demonstration ordered by the company’s own scientists, not an outside customer.



Redwire’s latest iteration of the device, ADSEP-4, pictured here, is slated to launch in 2024. *Credit: Redwire Corp.*

Like human tissue, pharmaceutical crystals also grow more uniformly in the absence of gravity, and Redwire has worked with companies including drug giant Eli Lilly and Company to grow active ingredients using ADSEP.

Many medications, including aspirin and antihistamines, are formulated as crystals using solid-state chemistry. Cultivating them in space using ADSEP enables even more precision in the formulation of these crystals, and they can be monitored throughout the process.

“We’ve been watching video inside cassettes on the space station to see drug crystallization in real time,” Boling said. The ultimate goal is to produce small seed batches of new or improved drugs in their optimal crystalline form and then

return those to Earth to enable batch-size production in the drug manufacturer’s factory while maintaining the microgravity form.

In addition to designing experiments for the space station lockers, Redwire has also sold full ADSEP systems, including to Sierra Space for its inflatable space habitat.

History of ADSEP

The ADSEP locker was initially developed by Techshot Inc. (Spinoff 2008) with Small Business Innovation Research, or SBIR, funding. Techshot went on to develop new capabilities and more sophisticated cassettes for the locker before being acquired by Redwire, where the research continues.

Redwire itself has received additional NASA funding to further develop ADSEP, which is also part of the company’s indefinite delivery/indefinite quantity contract with the space agency. Redwire hosts NASA’s experiments through a Space Act Agreement.

ADSEP first flew in 1996 on space shuttle mission STS-77, when the device’s acronym stood for Advanced Separation Process for Organic Materials, instead of Advanced Space Experiment Processor.

The system had “a moment in the sun,” as Boling put it, in 1998, when astronaut and U.S. Senator John Glenn handled cassettes during his return to space at the age of 77. Glenn was impressed enough by ADSEP that he mentioned the locker by name in his memoir a few years later, describing how he facilitated an experiment to produce genetically engineered hemoglobin.

ADSEP’s in-space production technologies are likely to contribute to the development of the low-Earth orbit economy, according to NASA’s Kevin Engelbert, who has managed the space agency’s funding contracts for ADSEP development from the Johnson Space Center in Houston.

“The Redwire ADSEP facility has been very effective in supporting scientific research on the space station for a number of years now,” he said, noting that it has evolved as new customer requirements have emerged.

Redwire’s Boling said, “It’s an iterative process that has responded with the market pull of each era.” ●

“ADSEP has been around since the 1990s, and it’s still a workhorse. It’s at the center of many things that we do.”

Rich Boling, Redwire



Legendary astronaut and U.S. Senator John Glenn facilitates ADSEP experiments on a space shuttle Discovery mission in 1998. Glenn was impressed enough by the device and the experiments it enabled to mention them in his memoir a few years later. *Credit: NASA*

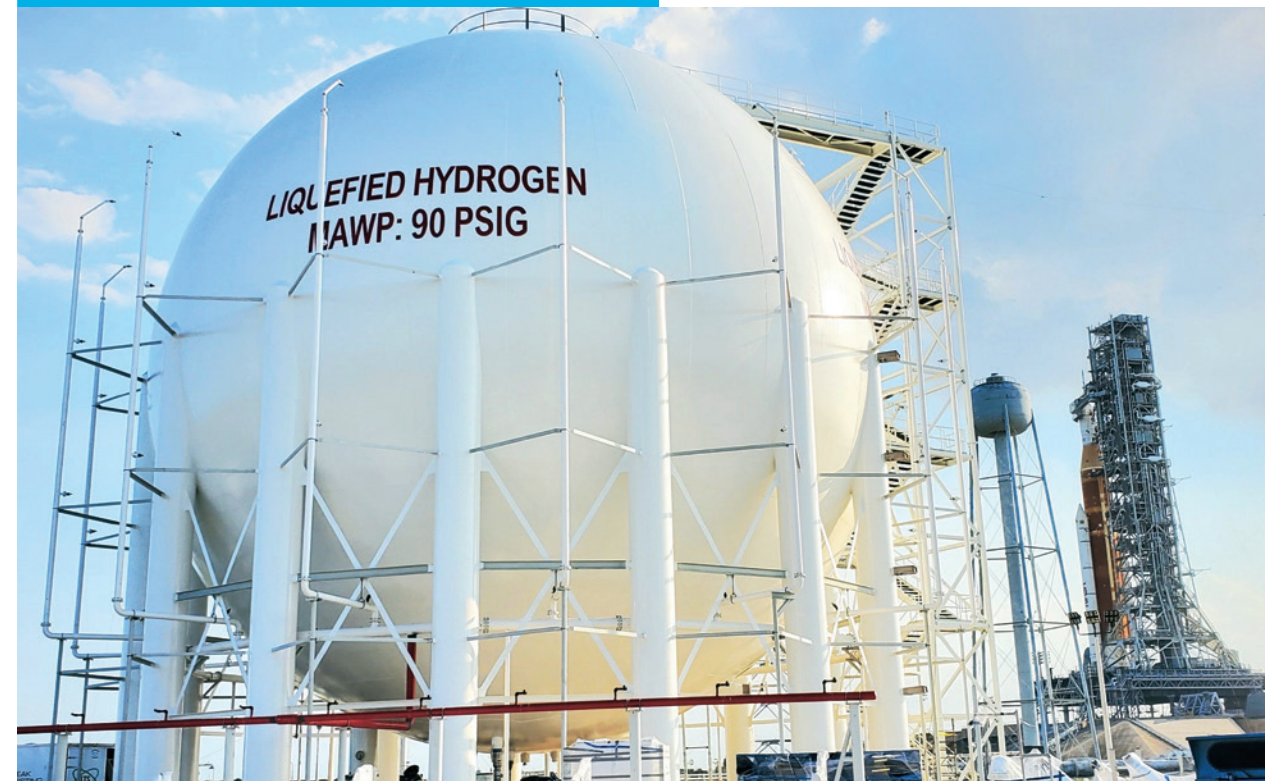
NASA Hydrogen History Informs World’s Hydrogen Future

World’s largest liquid hydrogen tank is a model for much bigger things to come

The biggest liquid hydrogen tank in the world, a sphere 83 feet in diameter, sits at NASA’s Kennedy Space Center in Florida, at the historic Launch Complex 39B, where it was completed in 2022. The previous record-holder is just a few hundred feet away. That tank, which has about two-thirds the capacity of the new addition, was built in the 1960s to support the Apollo launches.

“NASA was the largest user of liquid hydrogen in the world for many decades,” said Adam Swanger, principal investigator at Kennedy’s Cryogenics Test Laboratory. “Rockets have historically been a huge user of liquid hydrogen, but in the big scheme of things, that is a very small, niche application.”

CB&I of The Woodlands, Texas, built the world’s largest liquid hydrogen tank at Kennedy Space Center to support Artemis launches. The experience with new construction techniques, novel insulation, and cryogenic refrigeration capability will help the company and others build bigger, better tanks for hydrogen energy infrastructure.



The liquid hydrogen tank CB&I just built, the largest in the world, sits at Kennedy Space Center’s Launch Complex 39B, where it will support launches of NASA’s SLS (Space Launch System), seen here in the background. Since its inception, the space agency has been a leader in hydrogen technology, which was little used outside rocketry. *Credit: CB&I*

There simply hasn’t been much of a market for hydrogen, especially in its cryogenic liquid form. That may be about to change, and the new tank at Kennedy is helping to pave the way toward a future where this fuel type plays a much larger role.

Both cryogenic tanks at 39B were built by CB&I, formerly known as Chicago Bridge & Iron Company, headquartered in The Woodlands, Texas, and now a subsidiary of McDermott International Ltd. According to the company, lessons learned and techniques developed during this last job — and over its decades of work with NASA — will help it build even larger tanks.

Liquid hydrogen is NASA’s preferred rocket fuel, and the new tank, together with the old one, will give the agency the capacity not only to accommodate the larger fuel requirements of its new SLS (Space Launch System) heavy-lift rocket but also to carry out more back-to-back launch attempts. Launches are often delayed, or “scrubbed,” due to weather or other circumstances, and a lot of hydrogen is lost as it’s transferred from the rocket fuel tank back to storage after a scrub.

“The work at NASA really helped develop and demonstrate some of these large-scale construction techniques.”

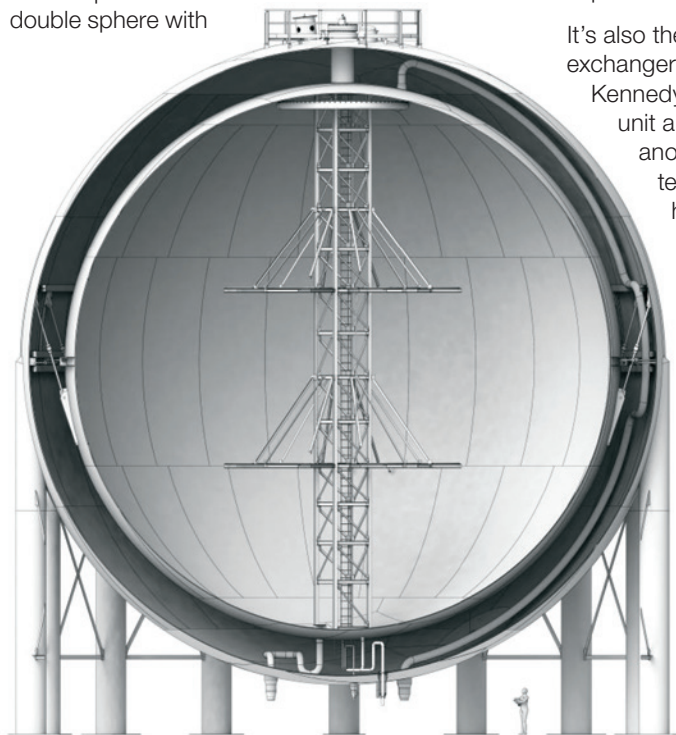
Mark Butts, CB&I

Meeting the Challenges of Scaling Up

Liquid hydrogen is difficult to handle at any scale. With a boiling point of minus 423°F — so cold it will freeze solid any gas it comes in contact with except for helium — it must be thoroughly insulated from the ambient environment. To achieve this, most liquid hydrogen storage tanks employ vacuum insulation within the walls, which makes pressure an issue, especially in a larger tank.

“Just building a sphere inside a sphere is challenging,” said Mark Butts, vice president of engineering at CB&I, noting that the size of this tank required the company to build both the inner and outer sphere simultaneously on site. “We had to develop an innovative construction sequence.”

Then, once the space between the inner and outer walls was filled with insulation, which had to be completely dry, all the air had to be drawn out of it, which was a lengthy process. The pressure differential caused by the vacuum can require steel so thick — especially in such a large tank — that it would require heat treatment to relieve welding stress, which Butts said would have been impractical in a double sphere with



This cutaway shows the interior of Kennedy's new liquid hydrogen tank, including the vacuum between the inner and outer spheres and the heat exchanger that will pump liquid helium through two horizontal coils suspended from a vertical scaffolding in the middle of the tank. Helium is the only element with a lower boiling point than hydrogen. *Credit: NASA*

stainless steel on the inner shell. “We precluded that need by managing steel thicknesses with innovative design techniques,” he said.

This tank is also the first to use a new kind of insulation, which the Cryogenics Test Laboratory at Kennedy validated through extensive testing beginning in the early 2000s. While other vacuum-insulated tanks that are built in the field are insulated with perlite, an expanded volcanic rock best recognized as the white crumbs in potting soil, NASA's testing revealed that about a 46% reduction in boiloff losses could be achieved by employing a type of tiny glass bubbles normally used as lightweight filler material, not insulation.

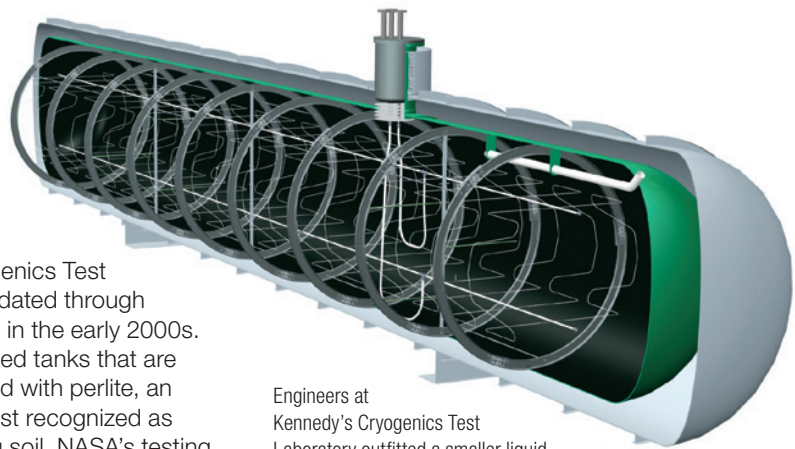
Boiloff occurs as some heat inevitably seeps into a tank from the environment, causing the liquid to continuously evaporate into gas that must be vented.

“The glass bubbles were very challenging to work with,” said Butts. “CB&I gained valuable experience working with this new material.”

It's also the first tank of its kind with a heat exchanger built into its interior, which will allow Kennedy to hook it to a cryogenic refrigeration unit and eliminate boiloff entirely. This is another concept that Swanger and his team proved using a smaller liquid hydrogen tank between 2015 and 2016. The testing found that every dollar spent on electricity for refrigeration saved \$7 worth of liquid hydrogen.

Swanger said a NASA analysis of the supply chain for propellant over 30 years of the Space Shuttle Program revealed that about half the liquid hydrogen purchased was lost, through boiloff and other modes. And he noted that hydrogen prices can be volatile, adding to the urgency of controlling losses.

NASA is still figuring out how to refrigerate such a large tank, and the current supply chain for the glass bubbles would make their



Engineers at Kennedy's Cryogenics Test Laboratory outfitted a smaller liquid hydrogen tank, seen here, with a heat exchanger to try out the concept of refrigerating such a tank between 2010 and 2015. The tank that was just built at Kennedy's launch complex will be the first to use the integrated refrigeration and storage concept operationally. *Credit: NASA*

widespread use in storage tanks a challenge, but Swanger said both these developments have potential to be widely adopted in the future. He likened the refrigeration technology, especially, to the modern refrigerators and freezers that displaced the icebox.

Currently, he said, operators have no direct control over the conditions inside a storage tank and the resulting losses from boiloff. “You just buy some liquid, and you use whatever you use, and you lose what you lose, and you buy more.” Introducing refrigeration, he said, would be “much more than just saving money through zero boil-off. It's about gaining control, which has a positive ripple effect on the entire enterprise. And that's why this tank can really set an important precedent for the future of liquid hydrogen storage.”

The Capacity for Change

The new tank can hold about 4,730 cubic meters of liquid hydrogen, but CB&I is now offering commercially the ability to construct liquid hydrogen tanks with capacities up to 40,000 cubic meters, “based on our 60 years of experience, but especially based on this project,” said Butts. “The work at NASA really helped develop and demonstrate some of these large-scale construction techniques.”

Hydrogen is the only fuel that can be produced and consumed without releasing any harmful gases — “an option the universe was not obligated to give us,” Swanger pointed out. “Therefore, we should be eager to capitalize on it.” Governments and companies around the world have begun to invest heavily in technology for hydrogen production, transport, and consumption. Last year the United States announced a \$7 billion investment in hydrogen hubs across the country. Kennedy

and CB&I are also part of a consortium led by the Shell oil company and partially funded by the U.S. Department of Energy that has set out to demonstrate construction of a tank with a capacity of 100,000 cubic meters of liquid hydrogen, more than 20 times the size of Kennedy's new tank.

Hydrogen can be harvested from water using renewable energy and then used either in fuel cells or by burning it to power turbines. But

the best places for generating renewable energy — think solar farms in the desolate, sunbaked Australian interior — are often far from the population centers that need energy. Ships and ports will need the capacity to move and store large quantities in liquid form.

“Will we use some of the things we learned working for NASA? Yes, definitely,” said Butts. ●



Here the heat exchanger is hoisted in the interior of NASA's new liquid hydrogen tank before the tank's concentric spheres are completed. It will enable the world's first integrated refrigeration and storage of liquid hydrogen. *Credit: NASA*

Toxin-Eating Plants

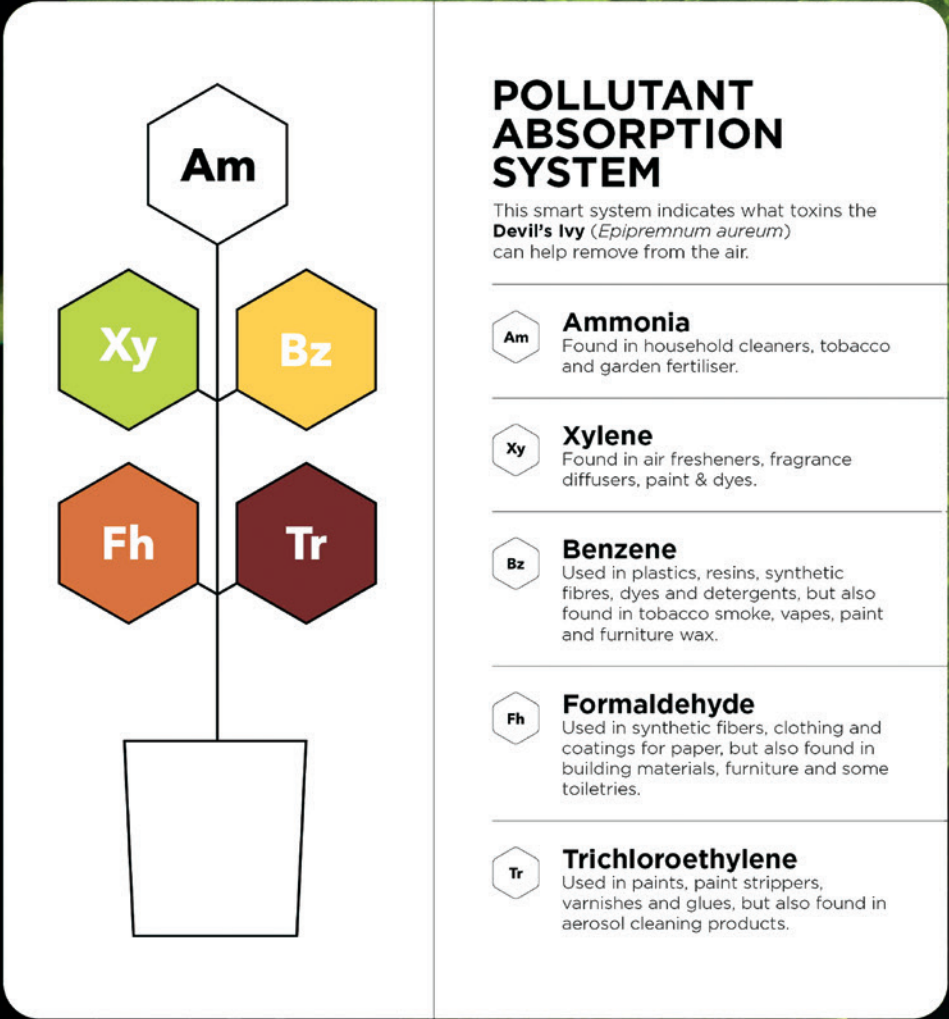
NASA research makes choosing houseplants to remove indoor air pollution easy

Making buildings more energy-efficient usually involves making windows and doors airtight. While this keeps out excess cold and heat, the downside is reduced ventilation — and that traps indoor contaminants. Air circulation and fresh air help remove airborne toxins, but so do certain plants. To help identify the right plants for a given indoor environment, Plant Drop Ltd. developed a Pollution Absorption System that describes the contaminant-absorbing efficacy of various houseplants.

DEVIL’S IVY

Epipremnum aureum

Plant research published by NASA helped Plant Drop create an open-source rating system to choose the right houseplants to improve indoor air quality. Credit: Plant Drop Ltd.



Crosby believes the colorful graphic and simple presentation of this information can help educate buyers about the impact plants can have. Instead of buying houseplants based on how they look or fill a space, customers can make a better selection with a label listing what toxins each plant removes from the air.

“If you’re a plant retailer in the States or anywhere in the world, you can download the system for yourself to put into your point-of-sale or online,” said Crosby. “You don’t have to be into botany or horticulture to have an appreciation for plants and for the good that plants can do for us.” ●

“NASA published a really interesting bit of data that we thought could make a difference.”

James Crosby, McCann London

Cleaning solutions, furniture, and building materials emit chemicals, potentially making indoor air unhealthy to breathe. Choosing the plants to remove toxins that can be found in your home is easy, thanks to a plant-rating system that uses NASA data. Credit: Plant Drop Ltd.



THE HOUSEHOLD TOXINS FOUND IN A KITCHEN

Ammonia Xylene Benzene Formaldehyde Trichloroethylene



Instant Innovation for Plastic Products

New family of composite plastics offers multiple benefits for countless applications

When NASA researchers set out to make plastics into better insulators by infusing them with lightweight, highly insulative aerogels, they didn’t anticipate that the resulting composite materials also would be less brittle at cryogenic temperatures than the original plastics.

When a company licensed the technology from NASA, its engineers were surprised to discover that these composite materials also were extremely water-repellant. In addition, they’re also sound-damping, fire-resistant, and lightweight. This versatility is one of two reasons the materials are desirable for a staggering range of applications. The other is that they’re easily incorporated into existing manufacturing practices. Anyone

A Kennedy Space Center technologist figured out how to infuse plastics with aerogel to make them better insulators. It also made them more fire-resistant, water-repellant, sound-damping, lightweight, and resistant to cryogenic temperatures. Now Okhata of Cheyenne, Wyoming, markets these “aeropolymers” to various industries.



As the world’s preeminent launch complex, Kennedy Space Center handles large quantities of cryogenic materials, including liquid hydrogen for rocket fuel, which must be kept below minus 423°F. So when a polymer chemist at the center received a NASA doctoral fellowship, she decided to focus on improving the insulative properties of plastics. Credit: NASA

making something out of engineered plastics can simply swap out their current plastic for an “aeropolymer” version without altering their production line at all.

“It’s got applicability for really specialized, high-end stuff, but it could also improve very mundane, everyday things that most of us don’t think about,” said Martin Knaust, one of the owners of Aeropolymer Holding Group, doing business as Okhata, of Cheyenne, Wyoming, which licensed the technology. “It’s got such a wide range of applications that we’re starting to see a lot of use cases we might not have even originally considered ourselves.”

In the early 2000s, Martha Williams, then a polymer chemist at NASA’s Kennedy Space Center in Florida, got a NASA fellowship that allowed her to focus on research and invention to advance the agency’s missions while earning a doctorate. Insulation is a constant challenge for the space agency, especially at Kennedy, which handles large amounts of cryogenic fuel for rocket launches. Williams decided to work with other Kennedy chemists and the center’s Cryogenic Test Laboratory to increase the insulative properties of plastics by infusing them with aerogels.



Okhata customers purchase aerogel-infused plastics, or “aeropolymers,” as tiny pellets and then melt them down to manufacture products, usually through injection molding or extrusion. *Credit: Aeropolymer Holding Group*

‘The Best of Both Worlds’

Aerogels are the world’s most effective insulators. More than 99 percent air, these highly porous materials weigh almost nothing and have more than 1,000 square feet of surface area in each gram. They’re made by preparing a gel — usually silica — and then removing all the liquid while leaving the gel structure intact. Their major disadvantage is that they’re extremely fragile. For this reason, although aerogel was invented over 90 years ago, it couldn’t be put to much practical use until the 1990s. That was when a Kennedy engineer conceptualized and funded the invention of the first usable aerogels, in the form of blankets with aerogels infused into their fibers (Spinoff 1998, 2001, 2008, 2009, 2010, 2018, 2020, 2021, 2022).

Aerogel is an extreme example, but most of the best insulators are relatively fragile. And the strongest structural materials, such as metals, are heat conductors. Plastics are at the center of this spectrum, sturdy enough to build some structures and neither great conductors of heat nor highly effective insulators. Williams and co-inventors proposed NASA could benefit from changing the latter, and the work was funded.

“You’re trying to get the best of both worlds,” she said. “You need the polymer properties, but you’re trying to use the additive to enhance their thermal and other mechanical and physical performance properties.”

Williams led the development of innovative techniques for blending different ratios of various aerogels and plastics. The team tried different approaches for blending the ingredients. And they experimented with different manufacturing techniques for the resulting composite materials, from injection molding to extruding them into tapes and spinning them into fibers. They tested the resulting composites for many properties, including thermal conductivity as insulators as well as strength and elasticity, especially at cryogenic temperatures, publishing many of their results.

They found that the addition of aerogels increased the plastics’ insulative properties by up to about 50% and that the resulting composites retained more strength and elasticity at cryogenic temperatures than the original plastics — advantageous properties to an agency that not only handles a lot of cryogenic materials but also regularly sends craft into the temperature extremes of space.



As part of its experimentation, the team at Kennedy melted down some of its aerogel-infused plastics and extruded them into tapes. *Credit: NASA*

Many Problems, One Solution

Okhata, however, is currently focused on much broader markets beyond cryogenic applications. “Through this NASA technology, you could make a whole universe of new products, but what I found to be particularly interesting is that you could take all of these products that are already being produced commercially and make better versions of them,” said Knaust. “The technology steps right into existing processes with existing equipment, and you’re able to make a better iteration of something you’ve already made.”

The biggest challenge, he said, is adapting the process to each customer’s specific materials. “A lot of customers have a very specific material they’re making their product out of, so we have to work back from their unique grade or formulation of resin and dial in the compounding process, said Knaust, though he added that the company has now developed versions of many of the most common thermoplastics, letting it meet customers’ needs faster.

The rewards are often numerous, especially because the incorporation of aerogel introduces several different properties. “There are a lot of products where you try to keep the water out with one material and approach, and then you



Bloem Living, a popular home and garden company, is experimenting with aeropolymer flowerpots, wherein the water-repellant materials prevent water from clinging to the inside and dirt from clinging to the outside. *Credit: Bloem Living LLC*

insulate the same space with a completely different material and approach,” said Knaust, noting that an aeropolymer does both. “So this is combining things that are often considered exterior and interior characteristics into one in a way that has a lot of potential to both save space and money and improve manufacturing efficiencies.”

Or, he noted, plastic body panels in vehicles could benefit from the thermal and acoustic insulation and weight reduction the materials offer.

After licensing the technology in 2020, the company spent the pandemic working through the technical aspects of turning it into products and then made its first sales a couple of years later. Knaust said the early focus was on taking the technology from the laboratory and readying it for mass production, because many of the most promising commercial applications require immense volumes of material. While Okhata has targeted some applications, the materials’

versatility and ease of incorporation into existing manufacturing processes make its possible uses almost boundless. So Knaust said he also looks to potential customers to come up with applications that would improve their products.

Okhata is working with a major lighting manufacturer on fixtures that manage heat and repel water, while Bloem Living, a popular home and garden company, is experimenting with aeropolymers in flowerpots, where their hydrophobicity both keeps water from clinging to the inside of the pot and keeps debris off the outside. Defense companies have shown interest in the materials for keeping grips and handles cool and dry. An international automobile lighting and accessory company is a customer. Okhata is also in talks with a major petrochemical manufacturer and an international capital equipment manufacturer and is looking into medical and construction applications where aeropolymers could provide insulation and other characteristics.

“You’re trying to get the best of both worlds. You need the polymer properties, but you’re trying to use the additive to enhance their ... performance properties.”

Martha Williams, Kennedy Space Center, retired

“It’s a simple solution to what previously had been pretty complex problems,” said Knaust. “And once you start playing around with it, you start finding solutions to problems you didn’t know you had or hadn’t prioritized.”

In a way, the technology’s multitude of characteristics and applications reflects its cross-discipline development, which brought together researchers in chemistry and cryogenics. “The opportunity that NASA gives to work across disciplines in solving problems allows these technologies to be developed that maybe in other environments would not be developed,” said Williams. ●



One Okhata customer used an aeropolymer to produce a beverage lid that is insulative and doesn’t let liquid cling to it. *Credit: Central Custom Molding LLC*



Another Okhata customer made this case from an aeropolymer to test the material’s thermal insulation properties. *Credit: Aeropolymer Holding Group*

Intelligent Machines Remove Humans from the Loop

Autonomous artificial intelligence lets machines communicate without human intervention

Artificial intelligence might be the hottest topic in tech circles today, as intelligent software proves itself capable of a growing number of tasks — often with better speed and accuracy than humans, though sometimes not. The technology almost always requires a “human in the loop,” someone to train the software and ensure its accuracy. But long before the arrival of AI models that caused a sensation by writing coherent paragraphs and creating stylish images, a different kind of AI was born with the help of NASA’s Ames Research Center in California’s Silicon Valley — one that only exists between machines, running autonomously without any human intervention.

Today, that technology is poised to automate recordkeeping for international shipping and trade, one of the world’s largest industries, as it finally goes digital. Back in 2006, it was just an idea in Geoffrey Barnard’s head as he founded Machine-to-Machine Intelligence Corp. (M2Mi) at Ames’ NASA Research Park.

Barnard’s relationship with the space agency had begun a couple of years earlier, when Steve Gonzalez invited him to speak at a conference on “grid computing” — what would today be considered a subset of cloud computing. Gonzalez, chief of the Operations and Strategic Development branch at NASA’s Johnson Space Center in Houston at the time, was looking at technology that would allow astronauts to bring some mission control capabilities with them to distant locations like the Moon and Mars. Barnard was then senior director of emerging and advanced technologies at Oracle Corporation.

Gonzalez also introduced Barnard to Bruce Pittman, who worked as a contractor in the newly formed Space Portal Office at Ames, a team promoting commercial space activity through public-private partnerships. At the time, Barnard envisioned an automated, satellite-based communication network, an idea that interested Pittman enough that he suggested M2Mi lease office space in the center’s research park. Ames then established a Space Act Agreement with the fledgling company, aimed at developing an artificial intelligence that would automate communications, privacy, security, and resiliency between satellites and Earthbound computers, with no human input required.

“The biggest things we got from NASA are risk management and root cause analysis.”

Geoffrey Barnard, Machine-to-Machine Intelligence

Machine-to-Machine Intelligence Corporation of Tiburon, California, operates an automated, secure, ground-based global communications network. The technology started with a Space Act Agreement and Cooperative Research and Development Agreement, both from Ames Research Center.

Rooting Out Problems, Managing Risk

Central to the technology was automating a problem-solving approach known as root cause analysis, which NASA has honed over the decades. It’s a methodology that doesn’t only seek to identify and correct the immediate cause of a problem but also tries to discover all the factors that contributed to the direct cause. A common application for root cause analysis at the space agency is accident investigation, and many of the root causes are often organizational. In M2Mi’s application, it would allow a communications network to identify its own issues and fix itself. “The biggest things we got from NASA are risk management and root cause analysis,” said Barnard, who is now CEO and chief technology officer at Tiburon, California-based M2Mi.

“The thing that NASA is, in my opinion, the best at in the world is their attitude and approach to risk management,” he said. “The level of engineering around risk management underpinned by root cause analysis is without parallel. So I learned a lot about that process and automating it so we could have autonomous equipment.” He wanted the system to be able to quickly handle its own decisions.

The work caught the attention of Ames’ director of nanotechnology, who was interested in developing a communications network based on small, low-powered satellites. “Obviously, if you could do that, it would be a really cool thing to do,” said Pittman, noting that such a system could provide internet access to people in remote locations on Earth and enhance NASA’s capabilities in distant locations like the Moon and

Mars. “If you could have that kind of connectivity with low power and a minimum of infrastructure, then a lot of the things NASA wanted to do in the future would get a lot easier.”

Pittman helped establish a Cooperative Research and Development Agreement (CRADA) between Ames and M2Mi — one of the few such agreements in NASA’s history — that would develop the necessary technology. He credited the center’s new director at the time, Pete Worden, with having the foresight to understand that small satellites could have a large role in the future. “Everybody else was kind of, ‘go big or go home,’ and Pete was saying, no, these small satellites were the way forward,” said Pittman.

In the end, though, the technology to allow small, low-powered devices on Earth to communicate with small, low-powered satellites in orbit simply didn’t exist at the time, said Pittman. The CRADA was cancelled, although Barnard noted that the blueprints and business plan he laid out with NASA under the agreement bear an obvious resemblance to the satellite-based communication networks being rolled out today.

Nonetheless, Barnard said both the Space Act Agreement and the CRADA laid the foundation for his company, which now employs the same technology in a ground-based network.

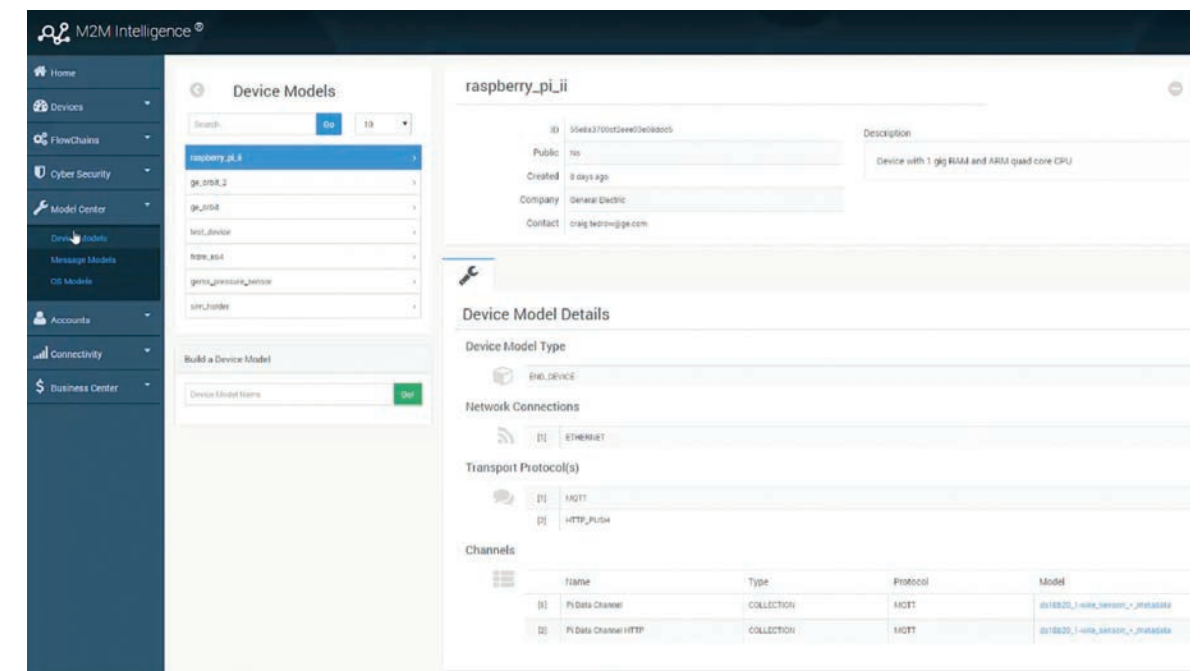
In addition to the Ames nanotechnology team, he worked with the center’s Columbia Supercomputer team, cybersecurity team, and Intelligent Systems Division, learning about cloud computing, end-to-end privacy and security, and the automation of communications, in addition to root cause analysis and risk management.

From the Space Agency to the High Seas

Following the CRADA’s cancellation, Barnard set about establishing and commercializing his M2M Intelligence software, a modular platform enabling secure, resilient, automated communications between machines, including servers, cellular devices, and the “internet of things.” The technology includes modules for managing connectivity, devices, analytics, and other aspects of communication. It uses AI to automatically provision network bandwidth for devices, to connect and restore those networks when issues arise, and to allow all different devices to understand each other.

Barnard said the necessary level of security and risk management and the speed and complexity of a communications system running across hundreds of networks, connecting thousands of devices — many of which may not have been built to communicate with each other — is more than human operators could feasibly handle. The

Multinational corporations are using the M2M Intelligence platform in data centers and other settings. The system offers automated, secure communications on a ground-based global 5G network. Credit: Getty Images



Here, the M2M Intelligence user interface shows the configuration for a Raspberry Pi device, a tiny, inexpensive computer popular with educators and hobbyists. Credit: Machine-to-Machine Intelligence Corp.



As international trade begins to digitize documentation and transactions, M2Mi hopes to provide the platform for that modernization, which is expected to dramatically reduce the time and cost of international shipping. Two companies are already using the platform for transportation logistics. *Credit: Getty Images*

system required autonomy, which “is faster and more efficient in pretty much every way, and it eliminates human error,” he said. “Other factors are the physical locations of infrastructure around the world and the time it takes to resolve issues.”

Oracle became the first major customer, with M2M Intelligence in its data center configuring the company’s global IT network. M2Mi worked with Vodafone to build out a worldwide, ground-based 5G network across more than 500 smaller telecommunication networks in more than 190 countries. IBM, Ericsson, Intel, and Siemens all became customers.

Now Barnard has his eyes on a new market: international trade is finally beginning to digitize its documentation and transactions, opening the way for automation. “The big use case for automated intelligence and 5G today is global supply chain digitization and modernization,” he said. Paper-based trade documentation

has incurred massive costs of both time and money, as cargo travels between ports that use different currencies and languages, in different jurisdictions and time zones. Barnard said he expects digitization to dramatically reduce shipping times and bring down costs by up to 80%, creating a powerful incentive to buy into any enabling technology.

“My intent is to use our M2M Intelligence as a key component of electronic trade, because it’s proven. The risk is driven out of it,” he said, noting that the companies M2M Wireless and TriGlobal have begun using the platform for transportation logistics. “It is happening already.”

Supply chain logistics may not be an obvious application for technology stemming from NASA, but Barnard said it was the space agency that enabled his company from the start. “I think if NASA wasn’t involved in any of this, we would not have this knowledge and capability, because

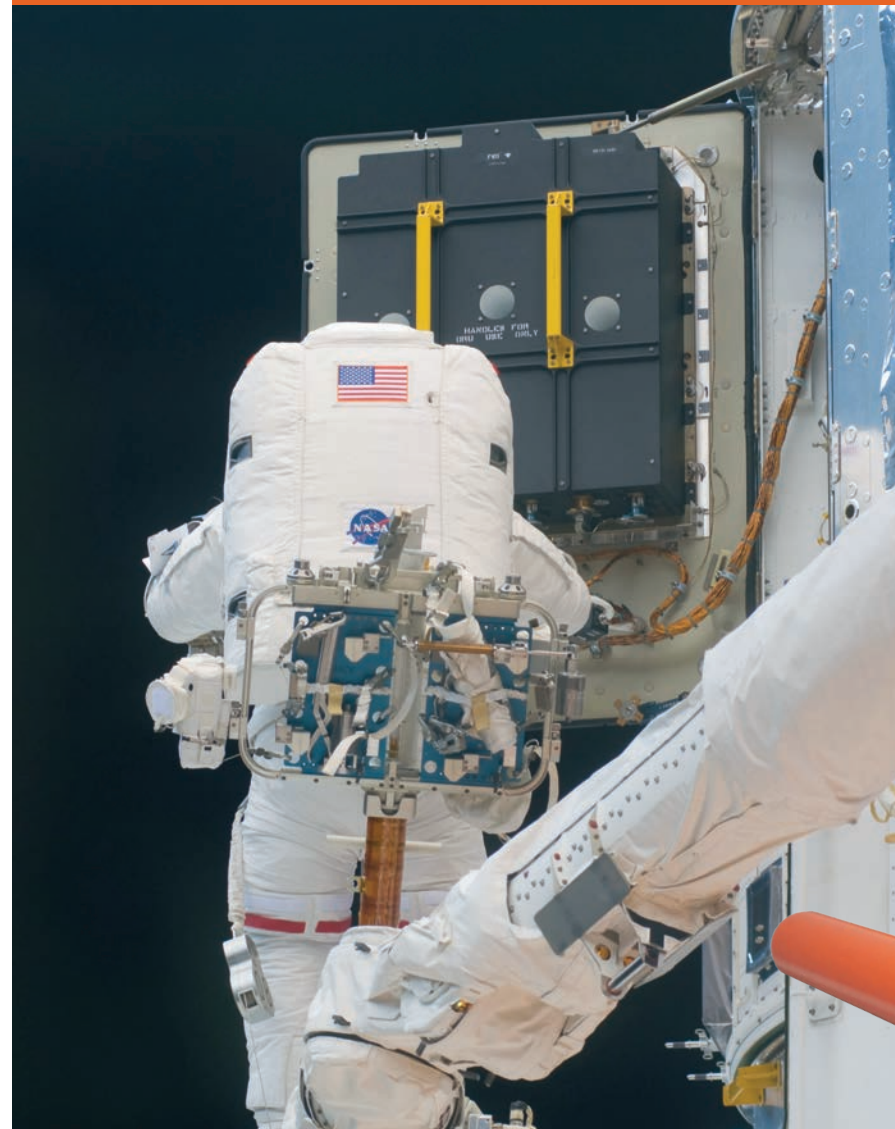
NASA had the supercomputer, NASA had the end-to-end networks, NASA had all the cyber networks, and NASA had all the autonomous operations I knew very little about,” he said. “It was really the risk management and root cause analysis that we codified in automated M2M Intelligence.”

Barnard noted that the generative artificial intelligence that has surged in popularity in the last year, which is based on language, can produce false information, or “hallucinations,” which require human correction. M2Mi’s artificial intelligence, on the other hand, is based on geometry and removes errors without intervention.

“NASA and M2Mi were ahead by 15 years,” he said. “Our work is now emerging as the next generation of AI.” ●

Hubble Battery Tech Holds Power on Earth

Nickel-hydrogen technology is safe, durable, and long-lasting — now it’s affordable too



The Hubble Space Telescope’s original nickel-hydrogen batteries were designed to operate for five years but were still working after 19, when astronauts, including John Grunsfeld, pictured here, replaced them in 2009 with new, more efficient nickel-hydrogen batteries. *Credit: NASA*

Battery technology that has powered the International Space Station, the Hubble Space Telescope, and numerous satellites is now storing energy on Earth, enabling intermittent renewable energy sources to provide steady power.

Nickel-hydrogen batteries store renewable energy for power plants, businesses, and homes, thanks to innovations from Fremont, California-based EnerVenue, informed by NASA papers out of Glenn Research Center about the technology’s performance on the Hubble Space Telescope, International Space Station, and more.

The batteries are “crazy durable in every sense of the word,” said Jorg Heinemann, CEO of Fremont, California-based EnerVenue Inc., which was able to bring down the cost of the technology by removing the need for expensive platinum, making terrestrial applications more feasible.

“With our cost-saving innovations, we believe it’s the best battery for power plants, businesses, and homes,” he said.

Space Station Power

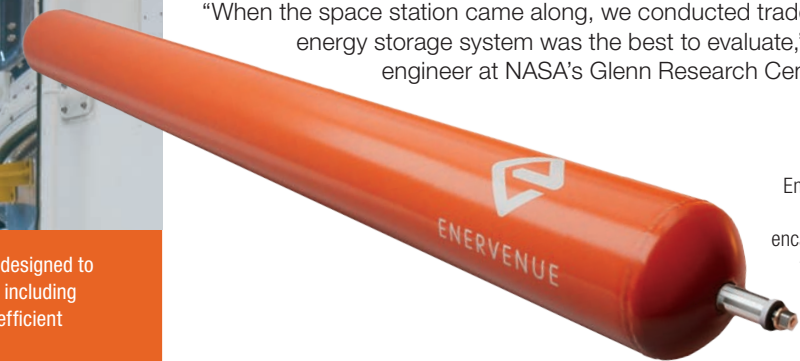
Nickel-hydrogen battery technology has been around for decades. These batteries were first developed in the 1970s, and in the 1980s they began replacing nickel-cadmium technology on geosynchronous communications satellites run by the global consortium Intelsat. They were attractive for space applications because they’re safe, reliable in extreme temperatures, and long-lived.

NASA first used nickel-hydrogen batteries in 1990 for the Hubble Space Telescope — the technology’s debut in low-Earth orbit on a major project. Hubble’s original power system included six 125-pound nickel-hydrogen batteries that went through thousands of charge-discharge cycles a year, drawing energy from the telescope’s solar panels when the Sun was in sight and expending that power in the eclipse.

The batteries were designed to operate for five years, but all were still working 19 years later, when astronauts replaced them with new, more efficient nickel-hydrogen batteries.

Meanwhile, the technology continued to fly on new missions.

“When the space station came along, we conducted trade studies on which energy storage system was the best to evaluate,” said Thomas Miller, an engineer at NASA’s Glenn Research Center in Cleveland who



EnerVenue brought down the cost of nickel-hydrogen technology and encased it in safe, robust vessels, like the battery pictured here, ready to store renewable energy in a wide range of terrestrial situations. *Credit: EnerVenue Inc.*

has worked on battery technologies for the space agency for more than 40 years.

Nickel-cadmium batteries and hydrogen-oxygen fuel cells were also considered for the space station power system, Miller said, in an analysis that examined reliability in extreme temperatures, cost with domestic suppliers, technology readiness, and longevity.

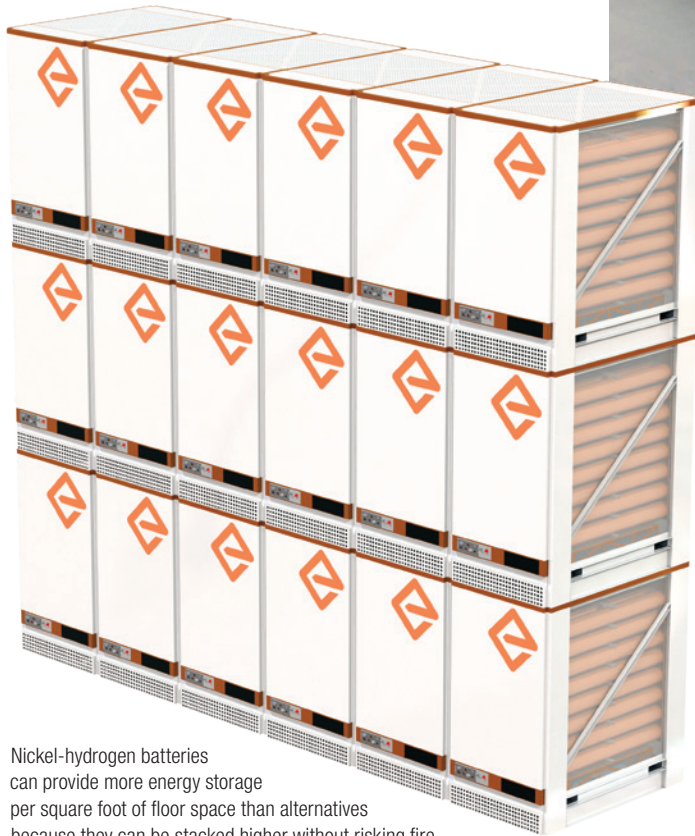
“The nickel-hydrogen batteries surpassed everything,” Miller said.

Six of them launched in 2000, powering the space station for more than 18 years before eventually being replaced by lithium-ion batteries.

“The nickel-hydrogen batteries were the primary energy storage coupled with the original solar arrays,” Miller said. “The power system was very robust. It was one of the most reliable subsystems on the International Space Station.”

Lowering the Cost

The batteries are heavy — don’t look for them in future cars or phones — but they are no longer prohibitively expensive. EnerVenue’s most significant improvement was to bring down the cost of making them.



Nickel-hydrogen batteries can provide more energy storage per square foot of floor space than alternatives because they can be stacked higher without risking fire, even in extreme temperatures. *Credit: EnerVenue Inc.*



Each nickel-hydrogen cell consists of a nickel cathode — the positive electrode — and a hydrogen-catalyzed anode, which typically uses expensive platinum. Charging the battery generates hydrogen inside the highly pressurized vessel, which then gets reabsorbed on discharge.

“You can think of it as storing energy in the form of hydrogen,” Heinemann said.

EnerVenue Chief Technology Advisor Dr. Yi Cui developed a technique to remove platinum from these batteries, dramatically reducing costs of technology that had grown more sophisticated over decades of NASA adapting it to high-level missions. Much of the groundwork for EnerVenue’s batteries was laid by NASA and described in papers published by Glenn, said Heinemann.

Lasting Forever

Although they are bigger and heavier than lithium-ion cells, the batteries provide more energy storage per square foot of floor space than alternatives, the company said. This is because they can be stacked higher without risking fire, even in extreme temperatures.

These batteries also don’t require energy-consuming temperature control or maintenance, and EnerVenue said its nickel-hydrogen batteries will work at nearly 90 percent capacity after 20 years.

“It basically lasts forever,” Heinemann said.

EnerVenue has an automated assembly line in Fremont and a much larger factory in the works in Kentucky. Heinemann said the company’s batteries are “basically sold out for the next five years,” primarily to large-scale utilities and renewable power plants that need to store energy generated by intermittent sources like solar and wind. And more than 20,000 of the batteries are already in operation, purchased for pilot projects in which both the site owners and EnerVenue are collecting performance data.

The company said it has about \$500 million worth of purchase orders, plus another \$1.3 billion worth of memoranda of understanding from large-scale customers, with a potential market of more than \$8 billion in North America alone. It raised \$125 million in a Series A funding round that closed in late 2021, and in June it announced it had raised more than half of another \$515 million fundraising round.

“As long as it doesn’t move, we’ve got the best energy-storage answer,” Heinemann said, noting that the batteries’ longevity makes them a game changer, though their size and weight still make them inappropriate for cars and phones.

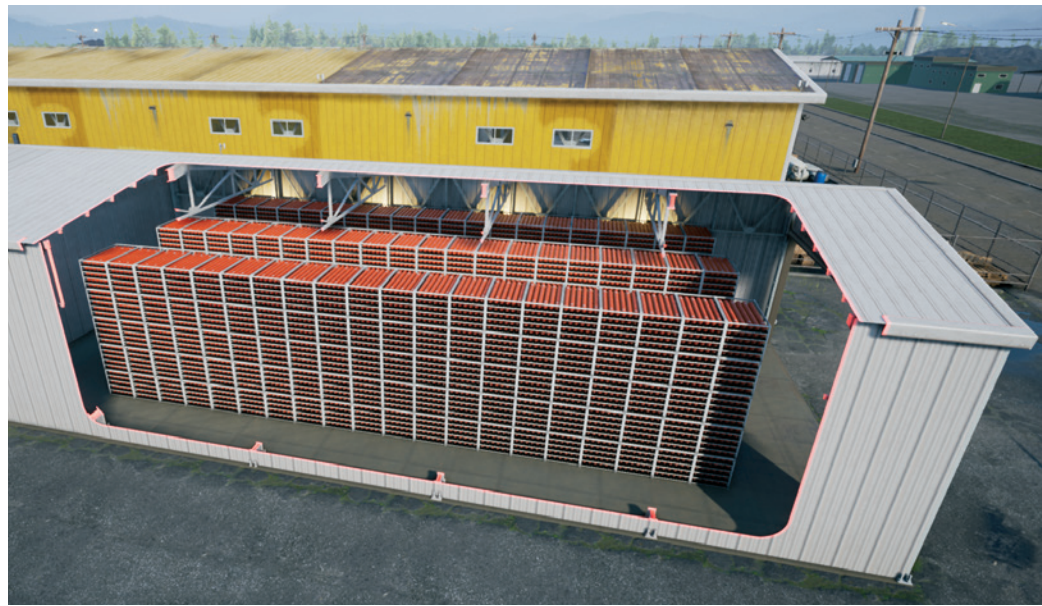
NASA’s Miller was optimistic about using this battery technology on Earth. “It’s a great concept,” he said. “I’m glad they were able to improve the cost of manufacturing.” ●

“We believe it’s the best battery for power plants, businesses, and homes.”

Jorg Heinemann, EnerVenue



Nickel-hydrogen batteries were the primary energy storage for the International Space Station for more than 18 years before being replaced and, pictured here in 2020, returned to Earth. *Credit: NASA*

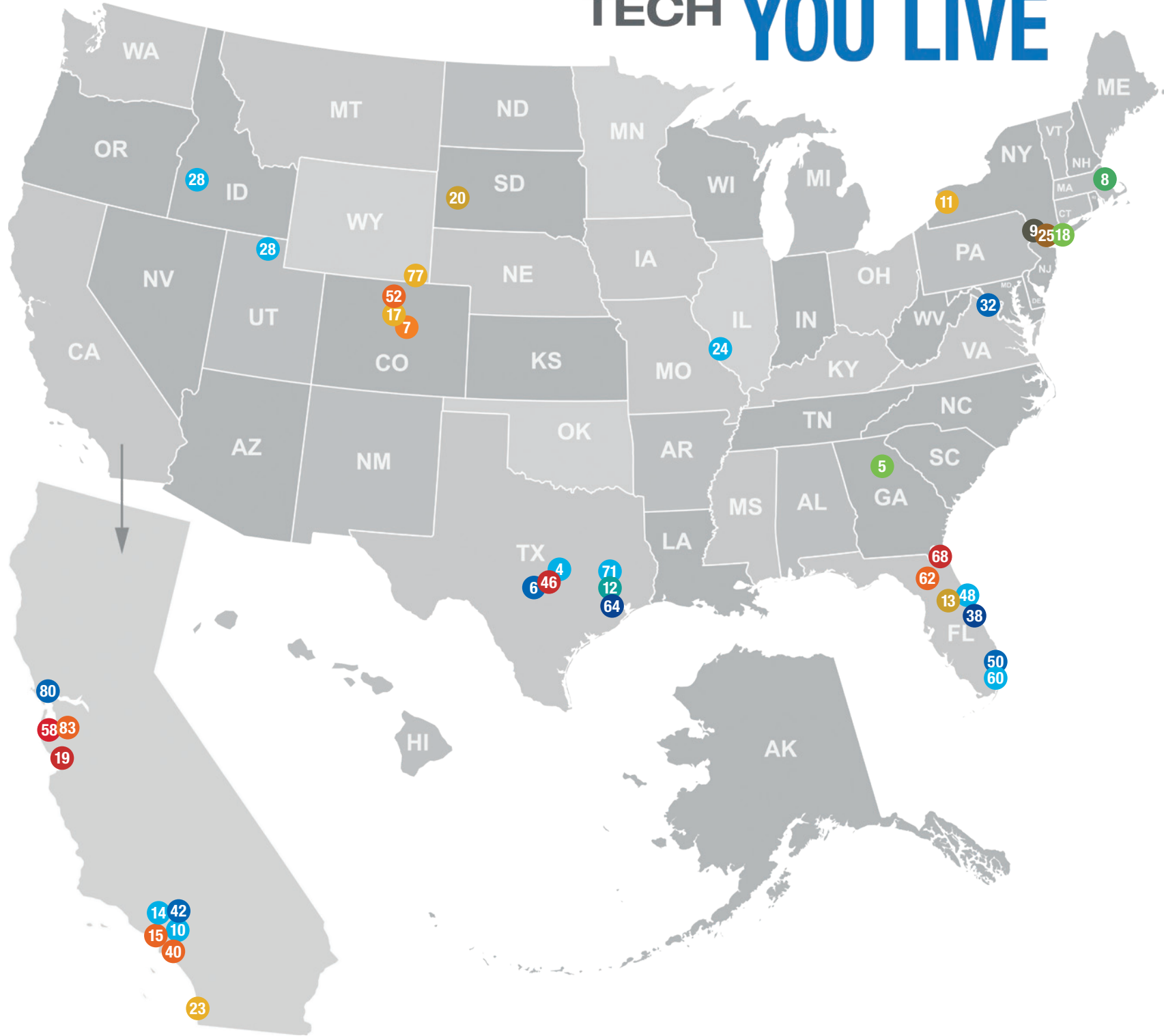


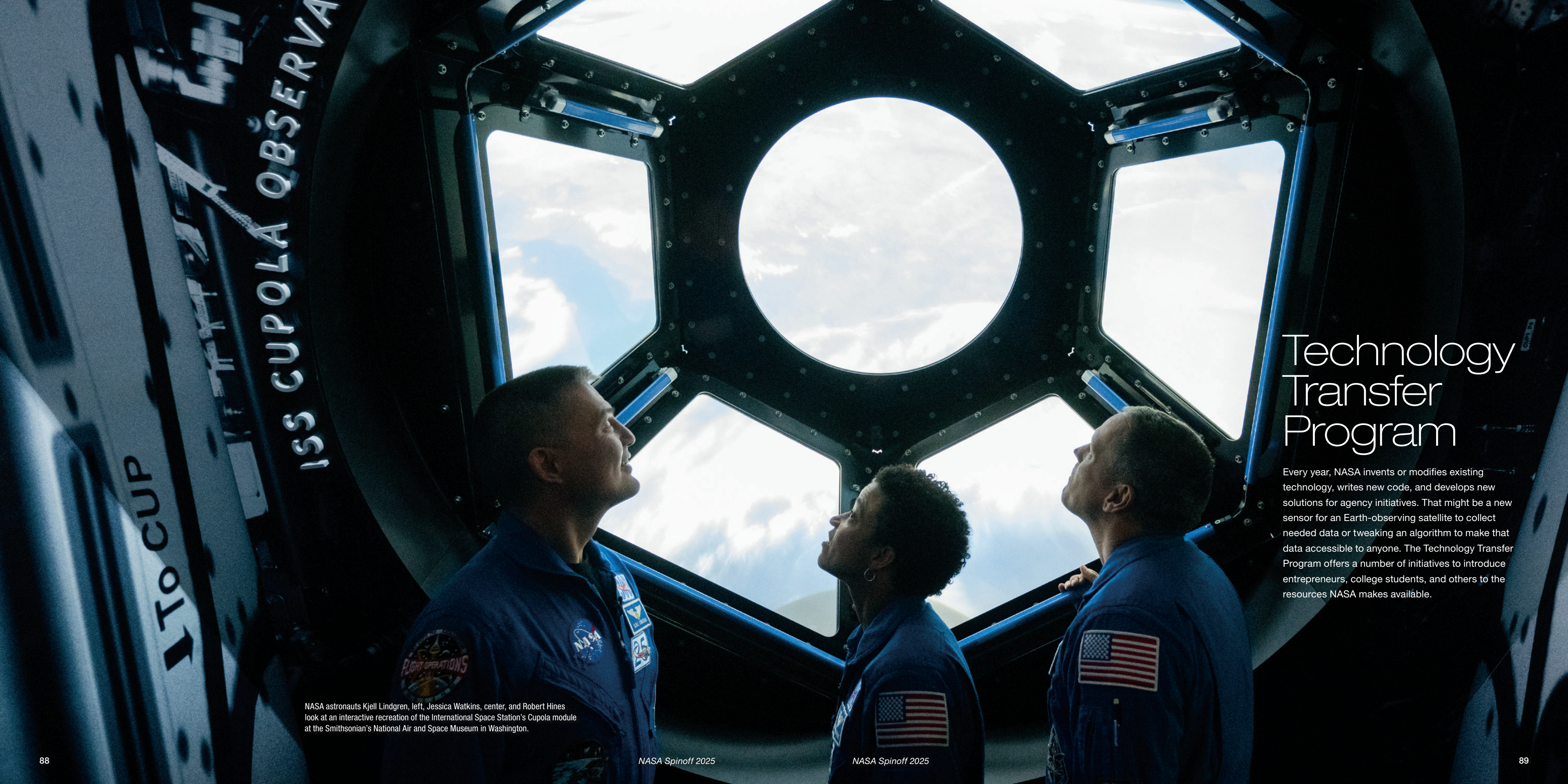
EnerVenue’s nickel-hydrogen batteries are ideal for stationary energy storage, where their safety, low maintenance, and longevity surpass their alternatives. *Credit: EnerVenue Inc.*

Spinoff Technology Across the Nation

Page	Article	Technology	Company, Location
4	Equalizing Internet Access	Wordpress accessibility review plugin	Equalize Digital, Georgetown, TX
5	Spraying for Food Safety	Electrostatic spray nozzle	Electrostatic Spraying Systems, Watkinsville, GA
6	Giving Sensors Good Optics	Flexible fiber-optic sensors	Sensuron, Austin, TX
7	Launch, Return, Repeat	Thermal protection system	Canopy Aerospace, Littleton, CO
8	From Mars Rovers to Factory Assembly Lines	AI vision inspection software	Neurala, Boston, MA
9	Commercial Sales Flow from NASA Valves	Specialized spacecraft valves	Marotta Controls, Montville, NJ
10	Cloud Software for Above the Clouds	Mission planning software	Continuum Space Systems, Pasadena, CA
11	Controlled Propulsion for Gentle Landings	Pyrovalve	Eaton, Orchard Park, NY
12	Cutting-Edge Computing Goes Spaceborne	Radiation hardening with software	Hewlett Packard Enterprise, Spring, TX
13	From Cockpit Controls to Dashboard Data	User interface design software	DiSTI, Orlando, FL
14	Hard(ware) to the Core	Space computer and emulator	Aitech Systems, Chatsworth, CA
15	NASA and Education Make Quite the Pear	Interactive educational presentations	Pear Deck, El Segundo, CA
16	Intelligent Processing at the Edge	Edge computing platform	Ubotica Technologies, Dublin, Ireland
17	Make Way for Satellites	Space situational awareness software	Kayhan Space, Broomfield, CO
18	Using AI to Predict the Sky	AI analytics software	KX Systems, New York, NY
19	Bringing Hybrid Power to the Rescue	Parallel hybrid rotorcraft	Parallel Flight Technologies, La Selva Beach, CA
20	NASA 'RAMPT' Up 3D Printed Engine Size	Large-scale 3D printed rocket engines	RPM Innovations, Rapid City, SD
21	Innovation Comes Out of the Wool Work	Wool-based air filters	Lanaco, Auckland, New Zealand
22	View from the Sky Helps Predict Crop Yields	Crop prediction tool	SIMA, Rosario, Argentina
23	Tweaking Analysis Tools to Give SAGE Advice	Design analysis tools for optics	Quartus Engineering, San Diego, CA
24	Flipping NASA Tech and Sticking the Landing	Gripping smartphone accessory	Flipstik, St. Louis, MO
25	Dust-Powered 3D Printing	Large-scale 3D printer	AI SpaceFactory, Secaucus, NJ
28	NASA Data Helps Beavers Build Back Streams	Satellite-supported stream restoration by beavers	Boise State University, Boise, ID Utah State University, Logan, UT
32	Seeing Is Communicating	Eye-tracking communication technology	Eyegaze, Fairfax, VA
34	Home-Grown Housing	Mushroom growing technique	Mycohab, Windhoek, Namibia
38	A Better Backup Plan for the Unthinkable	Autonomous flight termination technology	Sagrad, Melbourne, FL
40	Better Data for Bodies in Motion	Wearable data recorder	Diversified Technical Systems, Seal Beach, CA
42	Folding NASA Experience into an Origamist's Toolkit	Computational origami design	Robert J. Lang Origami, Altadena, CA
46	Space-Based Tech for Home Health Monitoring	Contactless cardiac monitor	Advanced TeleSensors, Austin, TX
48	Scaling Up Hydrogen	Family of cryostats	GenH2, Titusville, FL
50	Cosmic Experiments Make Cosmetic Nutrients	Skin care creams	Brand Labs USA, Fort Lauderdale, FL
52	3D Printed Engines Propel Next Industrial Revolution	3D printed aluminum rocket engines	Elementum 3D, Erie, CO
58	Space Tech Gives Treadmill Users a 'Boost'	Zero-gravity treadmill	Boost Treadmills, Palo Alto, CA
60	Coral Expertise Finds Broad Application	Remote sensing solutions	HySpeed Computing, Miami, FL
62	Measuring Buzz, Hum, and Rattle	Wireless sensor array	Interdisciplinary Consulting, Gainesville, FL
64	NASA Sets Standard for Nutritional Health Products	Dietary supplements	Nugevity, Houston, TX
68	Out-of-This-World Organs	ADSEP experiment locker	Redwire, Jacksonville, FL
71	NASA Hydrogen History Informs World's Hydrogen Future	World's largest liquid hydrogen tank	CB&I, The Woodlands, TX
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77	Instant Innovation for Plastic Products	Aerogel-infused plastics	Okhata, Cheyenne, WY
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NASA SPACE TECH WHERE YOU LIVE





Technology Transfer Program

Every year, NASA invents or modifies existing technology, writes new code, and develops new solutions for agency initiatives. That might be a new sensor for an Earth-observing satellite to collect needed data or tweaking an algorithm to make that data accessible to anyone. The Technology Transfer Program offers a number of initiatives to introduce entrepreneurs, college students, and others to the resources NASA makes available.

NASA astronauts Kjell Lindgren, left, Jessica Watkins, center, and Robert Hines look at an interactive recreation of the International Space Station's Cupola module at the Smithsonian's National Air and Space Museum in Washington.

Students Create Assistive Technology Prototypes

New demo tools help transfer NASA technology to industry



Michael Nizich, director of the Entrepreneurship and Technology Innovation Center at the New York Institute of Technology, talks about the school's work with the NASA Technology Transfer Expansion program, in which students developed prototypes of commercial products based on patented NASA technology. *Credit: NYIT/Altay Melikoglu*



Winston Wang, along with teammate Derrick Chiu, gives a presentation on glasses that darken or clear depending on the wearer's concentration, based on technology originally developed to train pilots. *Credit: NYIT/Altay Melikoglu*

Technology that NASA has developed to help astronauts live and work in space has a long history of improving the lives of people with disabilities here on Earth. To continue this trend, NASA contracted with the New York Institute of Technology (NYIT) Entrepreneurship and Technology Innovation Center (ETIC), a business incubator that develops prototypes for startups, to turn multiple NASA patents into demonstration models for assistive technologies that could help make buildings, knowledge, and communication more accessible.

NASA's Technology Transfer Expansion (T2X) program encourages new startup businesses and accelerates the commercialization of NASA technology by partnering with academic institutions and empowering students to use their skills in innovation, creativity, and entrepreneurship. The NYIT College of Engineering and Computing Sciences' ETIC has unique capabilities and frameworks to meet its mission.

First, the T2X team worked with T2 offices across the agency to develop a list of high-priority technologies that could enable assistive devices. Then the NYIT group chose patents they felt were best suited to commercial development and turned them into prototypes, which provide potential entrepreneurs and licensees with visual aids to spur imagination and creativity to develop new products. Taking patents from paper and turning them into physical demonstration models mitigates some of the most substantial barriers to early-stage technology commercialization. With working prototypes in hand, NASA can market and license technology quickly, resulting in the infusion of space-grade technology into our global community.



Anila Khan gives a presentation on her group's work with NASA technology that can monitor cardiac activity at a distance. Originally developed to monitor astronaut's vital signs, the technology can help in early detection of diabetes and other diseases. *Credit: NYIT/Altay Melikoglu*



Tyler Hradek worked with a NASA technology called Portable Unit for Metabolic Analysis (PUMA), which was developed to monitor oxygen consumption and carbon dioxide production rates of astronauts exercising on long missions. *Credit: NYIT/Altay Melikoglu*

"Innovation is what makes humanity unique. We will always find a way to adapt and survive," said Dan Lockney, program executive for NASA's Technology Transfer program. "Working with new talent is essential to innovation because they have the energy and optimism to try something new. Or even update something not so new to fit the needs of people today."

The patented NASA technology students used this year included glasses that darken or clear depending on the wearer's concentration originally invented to train pilots, and a laser-based vibrometer capable of remotely measuring cardiac activity and blood circulation. Originally developed to noninvasively monitor astronauts' vital signs, the technology can help in the early detection of diabetes and other diseases. While assistive technology was the main focus of this round of prototyping, some students were able to use their expertise to create demos for other industries, such as aeronautics or commercial space. In addition to the prototypes, students delivered marketing materials, demonstration videos, and a website that houses everything related to their prototype.

The current batch of technologies will be fully encapsulated in cases with screens, eliminating the need to plug them into computers to demonstrate. This is a big improvement, as the prototypes are intended to travel and be exhibited on the go.

"Working with NASA has been a dream come true for the ETIC at New York Tech," said the ETIC's director, Dr. Michael Nizich. "This work has provided our students with real-world experiential learning opportunities and has transported them from the classroom to the engineering workforce before they even graduate."

Joanna Sroka, junior computer science and data science major, said, "Building prototypes for NASA and working as a team has been the most exciting part of ETIC. We learn from each other and gain experience working with new technologies to implement them into our prototypes."

The future looks bright in Technology Transfer. With the proper investment, support, and encouragement, our nation will continue to push the boundaries of innovation, accessibility, and entrepreneurship. ●



From left, Lincoln Dover talks about his team's prototype with teammate Pranaav Venkatasubramanian, Technology Transfer Expansion program manager Christie Funk, and Jeanne King of Glenn's Technology Transfer Office. Their team worked with a remote cardiac monitor developed by NASA. *Credit: NYIT/Altay Melikoglu*



Joanna Sroka explains her team's prototype to Dennis Dannemiller of Glenn Research Center's Technology Transfer Office. The device, based on technology originally invented to help pilots train their attention, manipulates a miniature putting green to make the putt easier when the user is fully focused. *Credit: NYIT/Altay Melikoglu*



Brandon Castellano talks about his team's work on a valve for refueling satellites in orbit, as Aaron Rumsey of Armstrong Flight Research Center looks on. *Credit: NYIT/Altay Melikoglu*



Spinoffs of Tomorrow

When a company, academic institution, nonprofit, or individual has a technology problem, NASA might just have the solution in the agency's patent portfolio. The Technology Transfer staff helps anyone consider which of the 1,000-plus patented technologies might be exactly what they're looking for. To learn more about the technologies in this section or any others — and get started licensing — contact Agency-Patent-Licensing@mail.nasa.gov

This artist's concept depicts the Orion spacecraft approaching the Gateway space station in lunar orbit.

Ames

Adaptive Wind Estimation for Small Drones

A unified approach to autonomous flights of multi-rotor vehicles in urban environment

Their affordability is making small drones increasingly popular, but the light weight and simple structure that keep their cost down also make them vulnerable to wind disturbances, especially in urban environments where the wind field is more complex. Ames Research Center has developed a novel technology that provides fast, reliable wind estimation without requiring expensive components and computational power. Algorithms use readings from the drone's existing motion sensors to estimate wind and generate trajectories.

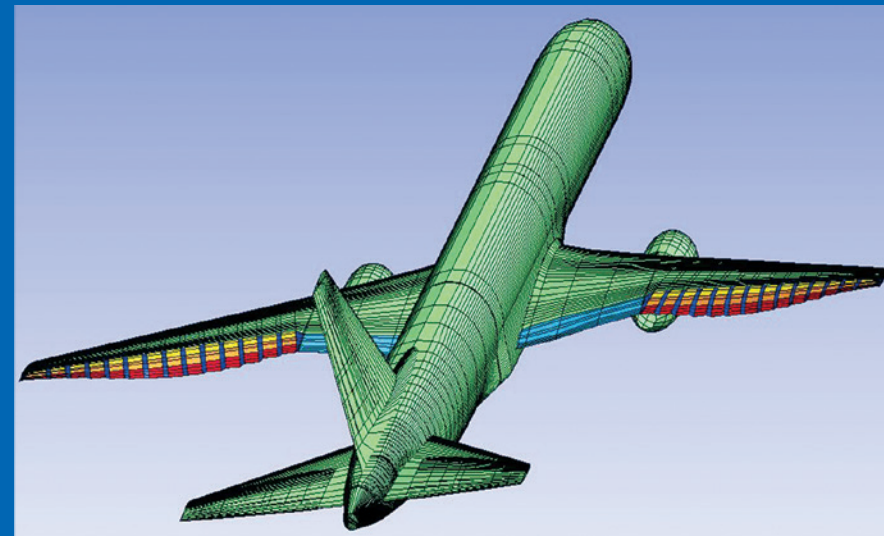


Benefits

- Fast, reliable estimation of drag coefficients on conventional onboard computers
- Lightweight, low cost, and low power
- Increased safety

Applications

- Commercial drone manufacturing industry
- Aerospace industry
- Air traffic management



Benefits

- Increase in lift-to-drag ratio, thus increased range and endurance
- Decreased fuel costs
- Reduced vertical tail size
- Reduced environmental impact

Applications

- Commercial and military transports
- Drones
- Rotorcraft
- High-altitude, long-endurance aircraft

Aeroelastic Wing Shaping

Method for aeroelastic wing shaping using distributed propulsion

Ames Research Center has developed the new concept of wing shaping using distributed propulsion, which could revolutionize aircraft design. Distributed propulsion envisions multiple small, electric propulsion units distributed along the wings. With increased wing flexibility afforded by the use of lightweight composites, a wing's aeroelastic deflection can be shaped in flight for optimal aerodynamic efficiency by varying the amount of thrust from each motor. Initial analysis indicates this concept could achieve about a 4% increase in lift-to-drag ratio.

Armstrong



Benefits

- Improved shape-sensing accuracy
- Works in real time
- Compatible with a wide range of fiber-optic sensing systems
- Improved structural safety

Applications

- Structural health monitoring of buildings, bridges, and other large structures
- Designing truck and automobile frames and suspension
- Controlling flexible aircraft wings and designing aircraft structures
- Performing robotic surgery

Improved Fiber-Optic Shape Sensing

Enables flexible aircraft wings, improved structural design tools

Armstrong Flight Research Center has dramatically improved upon earlier fiber-optic shape-sensing tools to develop next-generation flexible aircraft wings. Algorithms use data from distributed fiber-optic sensors to determine shape deformation of large, flexible structures, improving on earlier technology by simultaneously tracking displacement, twist, and rotation. By converting strain data into shapes that can be displayed and analyzed, the technology will help engineers design stronger bridges, buildings, ocean vessels, and more.

Interactive Sonic Boom Display

Provides pilots with real-time sonic boom information

Armstrong Flight Research Center has developed a real-time sonic boom display that enables pilots to control boom placement. The system can be integrated into a cockpit or flight control room to help pilots place loud booms in locations away from populated areas or prevent them from occurring. The system leverages existing tools co-developed and enhanced by the U.S. Air Force and NASA to predict sonic boom propagation to the ground.

Benefits

- Enables in-flight boom predictions, control room flight planning, and analysis
- Reduces noise pollution
- Provides information in real time

Applications

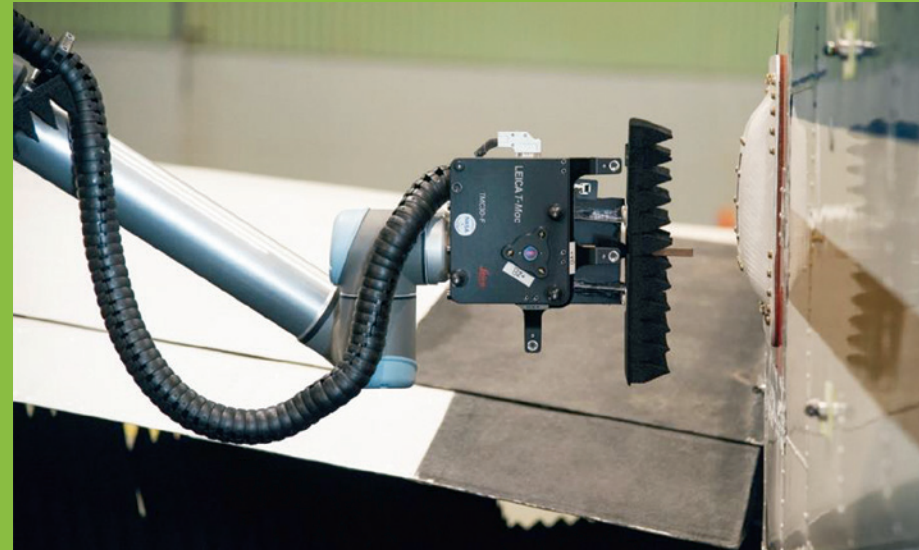
- Commercial supersonic vehicles
- Enables government regulation and oversight of supersonic aircraft
- Aerospace research and development



Portable Laser-Guided Robotic Metrology (PLGRM)

Portable antenna testing tool

Researchers at Glenn Research Center have developed this system which allows an antenna to be characterized in an aircraft hangar, as opposed to a specialized test chamber. The flexibility and portability of this system while maintaining precision and accuracy are what make PLGRM unique. While developed for aerospace, PLGRM can be used to characterize antenna systems across a range of applications.



Benefits

- Portable: can be shipped, saving time and money
- Easy to use: can be deployed by two people and powered by standard wall outlets
- Flexible: can accommodate different scan sizes

Applications

- Aircraft
- Telecommunications
- Automotive
- Research and development



Benefits

- Lightweight design is easily integrated into aircraft
- Overall system efficiency increases from 40% to 60%
- No hot moving parts, plumbing, or wiring
- Leads to significant savings in fuel, material, and maintenance costs

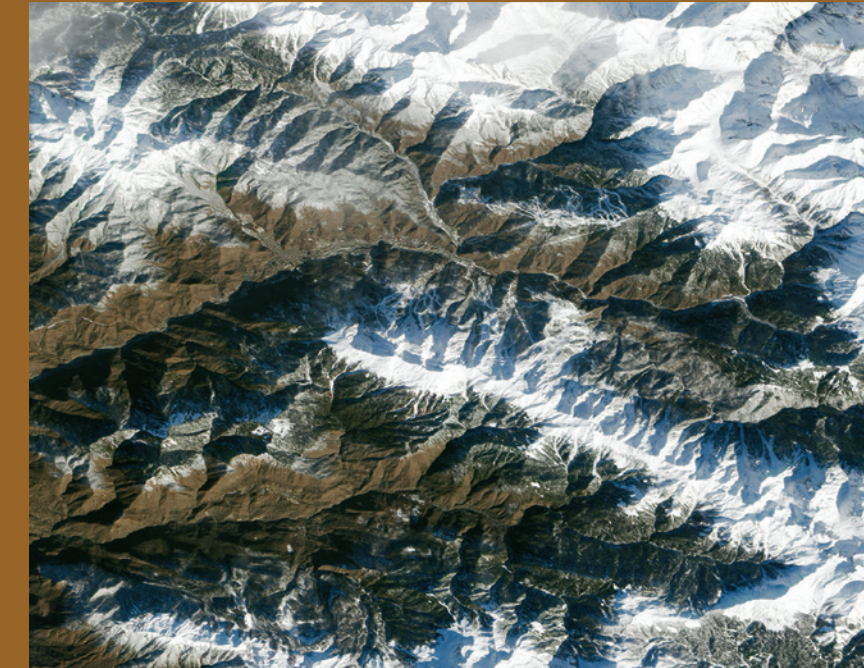
Applications

- Electric aircraft
- Aircraft auxiliary power units
- Remotely piloted vehicles
- Satellites

Thermal Management for Aircraft Propulsion Systems

Waste heat power generation

Innovators at Glenn Research Center have developed a thermal management system that uses the normally wasted energy from turbofan propulsion to cool electronics and power equipment. The waste heat produces a high-intensity acoustic wave, created from temperature differences between hot and cold heat exchangers. This propagates through thermoacoustic power tubes, where it can be used for component cooling or converted to electric power via an alternator.



Benefits

- Easily scalable for size requirements
- Cost effective

Applications

- Nondestructive evaluation
- Manufacturing quality control
- Medical X-ray equipment

Pyramid Image Quality Indicator

Improved X-ray analysis tool

Image quality indicators (IQIs) for industrial 2D X-ray radiography have been used in practice for many years, but the same can't be said for computed tomography (CT). To rectify this, innovators at Goddard Space Flight Center have made the Pyramid Image Quality Indicator. The system can be economically 3D printed and then coated with X-ray absorbing material. When a CT system operator is scanning a part, this IQI and associated methods will allow an effective level of detail.

Gear Bearings

Specialized moving parts for motors

Researchers at Goddard Space Flight Center have developed a mechanical breakthrough by combining gear and bearing functions into a single unit that significantly improves gear drives across the board for electrical, internal combustion, and turbine motors. Because it combines gear and bearing functions, it reduces weight, number of parts, size, and cost, while also increasing load capacity and performance.

Benefits

- Enables precise control
- Low cost, simple design
- High strength
- Versatile

Applications

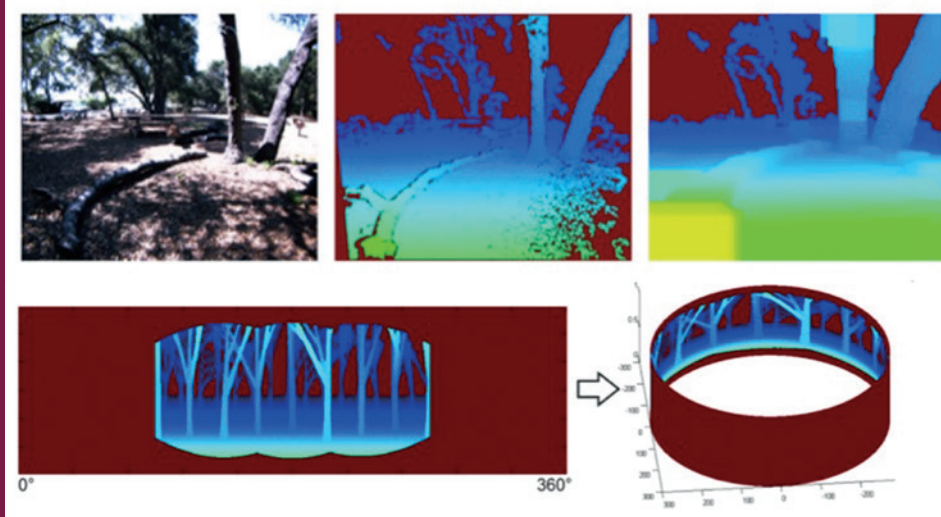
- Transportation (including automotive, aircraft, marine, and rail)
- Power tools
- Industrial machinery
- Toys



Autonomous Vehicle Control in 'Egospace'

Autonomous navigation around static and mobile objects

This precision control approach automatically maneuvers robotic vehicles such as drones, watercraft, or ground vehicles around static and moving objects simultaneously. The invention relies on a new method for representing potential motion planning paths called "egospace," short for ego-centric — as in self-centered and representing only the area a vehicle will traverse.

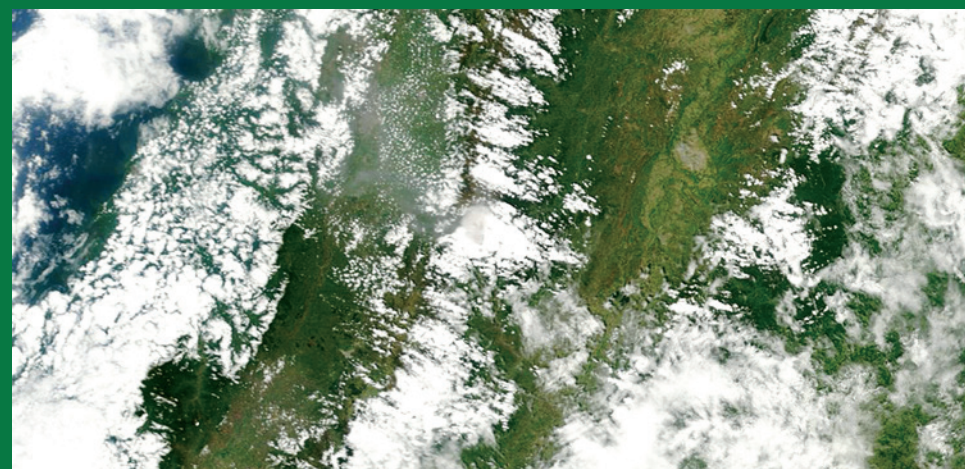


Benefits

- Reduces likelihood of collisions
- Allows modification of planned path to the original goal
- Prevents damage to vehicles
- Improves chances of successful execution

Applications

- Autonomous vehicles—cars, farm equipment
- Industrial robotics
- Search and rescue
- Planetary rovers



Benefits

- Cost-effective design
- Miniaturized without sacrificing performance
- Lightweight and robust
- Intrinsically maintains alignment

Applications

- Remote sensing for astronomy
- Medical applications
- Scientific research

Reflective Spatial Heterodyne Spectrometer (RSHS)

Using one piece of glass to create an RSHS interferometer

Observing extreme ultraviolet radiation requires specialized spectrometers, and state-of-the-art technology has difficulty maintaining alignment due to tight tolerances of the optics. This new RSHS instrument design offers a way to fabricate the device from a single piece of glass, which intrinsically maintains alignment. It can be scaled without major technical changes for more flexibility.

Programmable Vehicular Control

Tri-rotor steering wheel prevents operator fatigue

This novel hand controller was designed to improve control capabilities beyond those of a joystick. The hands-only operation gives an astronaut the ability to easily operate a vehicle on the surface of a planet or moon. It also overcomes the limited dexterity imposed by any protective gear like that worn for handling hazardous materials and other safety attire.

Benefits

- Features hands-only operation for all vehicle functions
- Fine motor control for precision operation
- Fully programmable
- Can be constructed from multiple materials

Applications

- Assistive technology
- Manufacturing
- Robotics
- Automotive



RFID Inventory Tracking

Smart enclosures help track in-stock items

This innovation can track individual items inside a smart container regardless of item placement or the shape of the vessel. And the read accuracy of items moving on a conveyor belt is so advanced it can enable the use of smaller, cheaper tags, reducing costs.



Benefits

- Cost-effective tagging/tracking for small items
- High-level read accuracy
- Supports many container shapes

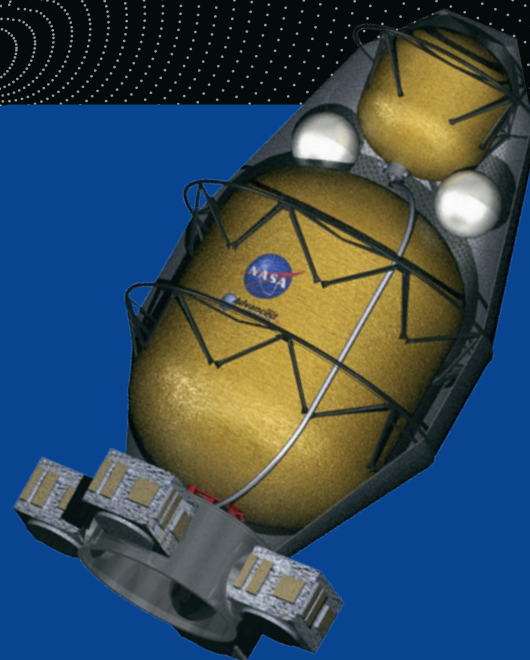
Applications

- Inventory management
- Smart shelves, drawers, containers
- Shipping containers
- Security

Capacitive Microgravity Fluid Mass Gauge

An accurate method of measuring fluid or gas inside a vessel

Measuring fluid mass in microgravity, where a fluid's behavior is dominated by its properties, is challenging. To address this problem, engineers at Kennedy Space Center developed a capacitance-based gauge for vessels containing two-phase fluids. The vessel volume is enclosed with an array of electrodes, which make a set of capacitance measurements of the enclosed volume. The capacitance measurements are scaled with weighting factors to compensate for the non-uniform electric fields inside the measurement volume and improve accuracy.



Benefits

- Accurately measures fluid mass
- Senses entire tank volume
- Scalable to different-sized tanks

Applications

- Tank and vessel transport
- Gas and liquid systems
- Cryogenic liquids storage, including liquid natural gas and liquid hydrogen



Benefits

- Withstands heavy compressive mechanical loading, compression of 75% of original thickness, with full elastic recovery
- Increases reliability and reduces life cycle costs by mitigating moisture intrusion
- Insulating performance on par with the best foam materials

Applications

- Residential and commercial construction
- Piping, tanks, and vessels
- Cryogenics

Layered Composite Insulation for Extreme Conditions

Insulation system for non-vacuum applications and extreme environmental exposure

This insulation system created by Kennedy Space Center is suited for complex piping or tank systems that are difficult or impossible to insulate by conventional means. Consisting of several functional layers, the aerogel blanket-based system can be tailored to specific thermal and mechanical performance requirements. It not only withstands impact, vibration, and the stresses of thermal expansion and contraction, but can help support pipes and other structures, all while maintaining its effectiveness as a thermal insulator.



Benefits

- Produces more tensile materials
- Inexpensive manufacturing process
- Electrical properties of yarns and sheets can be tailored

Applications

- Structural materials for aerospace vehicles
- Materials for lightweight, mechanically robust consumer devices

Sucrose-Treated Carbon Nanotubes and Graphene Yarns

Carbon nanomaterial strengthening process

Scientists at Langley Research Center have developed a method to consolidate carbon nanotubes, woven sheets, and graphene yarns via the dehydration of sucrose. The resulting materials are lightweight and high-strength. Sucrose is relatively inexpensive and readily available, therefore the process is cost-effective.

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

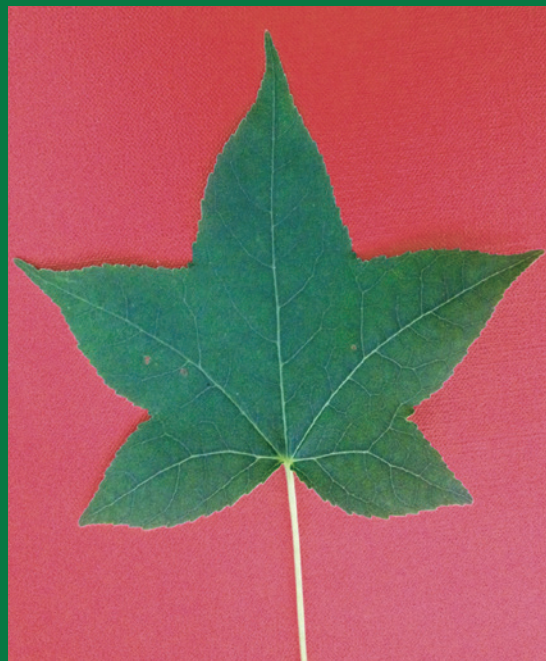


Marshall

Rapid Identification of Contaminated Plants

Support for identifying a prevalent groundwater toxin

Working with other organizations, Marshall Space Flight Center technologists are creating a hyperspectral estimator to detect trichloroethylene (TCE) in plants. The chemical is toxic to people and animals and can be located in groundwater and absorbed by plants. The technology can scan data from individual leaves and wide areas. Current testing methods are often destructive, slow, and expensive.



Benefits

- Nondestructive surface scan, eliminating plant damage
- Anticipated to provide near-real-time TCE presence/absence estimates
- Anticipated to cost less than current methods

Applications

- Screening sites for contamination
- Verifying wetland health
- Assessing the progress of remediation
- Monitoring phytoremediation projects

Stennis

Cryogenic Butterfly Cam Valve

No-leak valve performs in broad range of temperatures

In typical butterfly valves, the disc must create a tight seal with the seat when it hits 90 degrees. If additional torque is added, the disc will rotate further, reopening the valve. These valves also fail liquid nitrogen leakage tests. Researchers at Stennis Space Center have created a butterfly valve that allows additional rotation of the shaft so the disc can slide toward the valve body until it seals tightly, preventing leaks regardless of temperature changes.



Benefits

- Improves performance over a wide range of temperatures
- Zero leakage
- Simple design

Applications

- Aerospace
- Natural gas
- Cryogenic plants

Ruggedized Infrared Camera

Space-rated camera system for harsh environments

Based on a FLIR Systems Boson Model 640, this modified camera tolerates harsh conditions and has improved heat removal required for successful operation. Designed for use in Earth orbit and beyond, the camera qualities aren't currently available in commercial offerings. Qualified for extreme conditions — vibration, shock, vacuum, temperature cycling — it's ready for harsh Earth environments.



Benefits

- Low cost: uses standard components
- Compatibility: supports USB standard for plug-and-play communication
- Enhanced operability: enables use of standard infrared camera in extreme environments

Applications

- First responder imaging capability
- Industrial machinery for process/quality control
- Drone collision avoidance
- Satellites and spacecraft

Remote Sensing Toolkit

Online portal offers easy access to NASA Earth-observation data

NASA's Technology Transfer program created an online resource to promote wider use of the agency's freely available remote sensing data and the software to work with it. Through its constellation of Earth-observation satellites, NASA collects petabytes of data each year. The Remote Sensing Toolkit lets users find, analyze, and use the most relevant data for their projects. The toolkit's simple system quickly identifies relevant sources based on user input.



Benefits

- Free and easy to use
- Centralized online repository with unified file formats
- Includes data from more than 20 satellites and missions

Applications

- Precision agriculture and crop forecasting
- Conservation and resource management
- Natural disaster planning and response

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An artist's concept of NASA's Advanced Composite Solar Sail System spacecraft in Earth orbit.