National Aeronautics and Space Administration

SPINOFF

2018

Introduction

Stephen Jurczyk

Associate Administrator
Space Technology Mission Directorate

Hi, I’m Stephen Jurczyk, associate administrator of NASA’s Space Technology Mission Directorate.

NASA expands the boundaries of human knowledge and exploration through its space and aeronautics missions, and this cannot be done without continually pushing the limits of what we are capable of achieving. Every day, NASA researchers and engineers must constantly advance the Agency’s technological capabilities. The Technology Transfer Program then takes on another critical part of the Space Agency’s mission—to ensure that the entire country benefits from those advances.

From its earliest days, NASA has been known for commercialized spinoff technologies making an impact in Americans’ lives, with the Agency’s Spinoff publication highlighting the best examples of these technologies annually.

Spinoff has been published for more than 40 years and in that time has featured more than 2,000 products and services demonstrating the secondary, practical applications of the results of NASA’s scientific and exploratory endeavors.

This app presents highlights from the latest issue of Spinoff, along with videos and image galleries that let you explore the benefits of NASA technology for yourself. Among my favorites in this year’s publication are a device that locates the survivors of disasters who are stuck under rubble, a sterilizing fogger that makes ambulances safer, and high speed cameras used to test a wide range of materials’ performance on impact.

If you’d like to learn more about any of the technologies in this app, or if you’d like to request your own free print version of the full Spinoff publication, please visit us at http://spinoff.nasa.gov. To learn more about NASA’s Technology Transfer Program, where spinoff technologies get their start, please visit http://technology.nasa.gov

NASA Spinoff Technology across the Nation

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Health and Medicine

Sometimes it's an innovation to meet the unique health challenges of the space environment. Other times it's a technology for analyzing distant objects or protecting components from the harsh conditions of space that happens to find a medical application on Earth. This section highlights exercise equipment, sterilizers to prevent the spread of infection and disease, and a device to improve cancer and stem cell research, all built on innovations to support space exploration or the deep expertise NASA's missions require.

Sterilizing Fogger Cleans Ambulances with a Breeze

When paramedics come racing, the last thing anybody worries about is where the ambulance was that morning. But traces could be lingering—and they could be spreading disease.

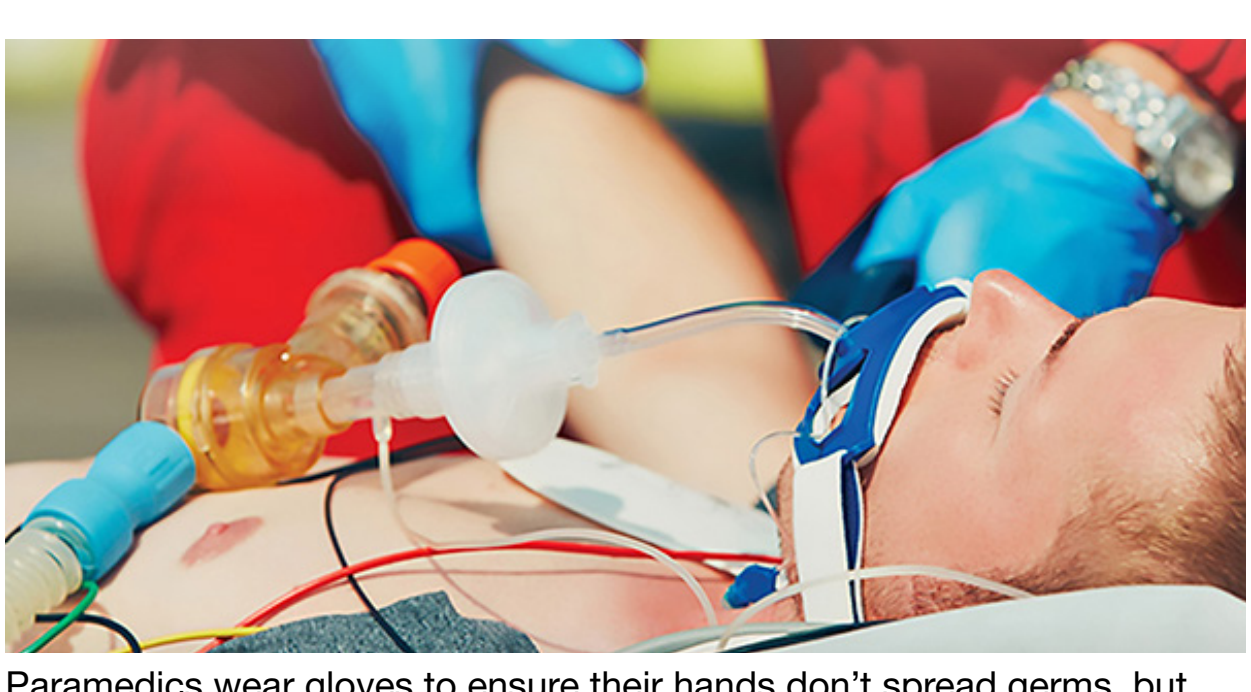
An innovative new product, designed with NASA's help, aims to sterilize the rig and gear to make it safer for the patients and the paramedics.

Emergency Products + Research consulted with NASA to determine the best way to deliver atomic oxygen in a device to sterilize ambulance interiors. This small, inexpensive device creates a mist that can kill close to 99 percent of microorganisms in less than an hour.

The product uses atomic oxygen and oxidation, two things NASA is familiar with, explains Glenn Research Center's Sharon Miller. In stable form, oxygen is made up of two oxygen atoms bonded as a pair. In contrast, atomic oxygen is a single O atom. The atom will react with anything to find a pair.

High in the atmosphere, atomic oxygen is far more prevalent than here on the ground, and it can become a destructive problem. But atomic oxygen can also be harnessed for good: sterilization. "Atomic oxygen removes any hydrocarbon from a surface," Miller explains, which includes most of the infectious material left on surfaces.

Kent, Ohio-based Emergency Products + Research (EP+R) planned to make a device that used this process, known as oxidation, to sterilize ambulances, which it had realized could contribute to spreading disease.



Paramedics wear gloves to ensure their hands don't spread germs, but the rest of the equipment, from oxygen tubes to gurneys to the medic's uniform, could all carry traces of previous calls. EP+R's device sterilizes everything, making it safer for both patient and medics. An international aid group has already expressed interest.

But the team had many questions and didn't know where to find the answers.

Enter NASA. Through the Regional Economic Development Program, field centers offer consulting. "If we can help a company make a better product or create new jobs, improve on a process they need help with, those are all part of the goal," explains Glenn's Laurel Stauber.

Stauber paired EP+R with Miller. "It was a key turning point," says EP+R Vice President Jason Thompson.

Just a few months following the NASA consultation, Thompson says, EP+R was delivering its first units. EP+R has fulfilled orders across the United States, and the interest continues to grow.

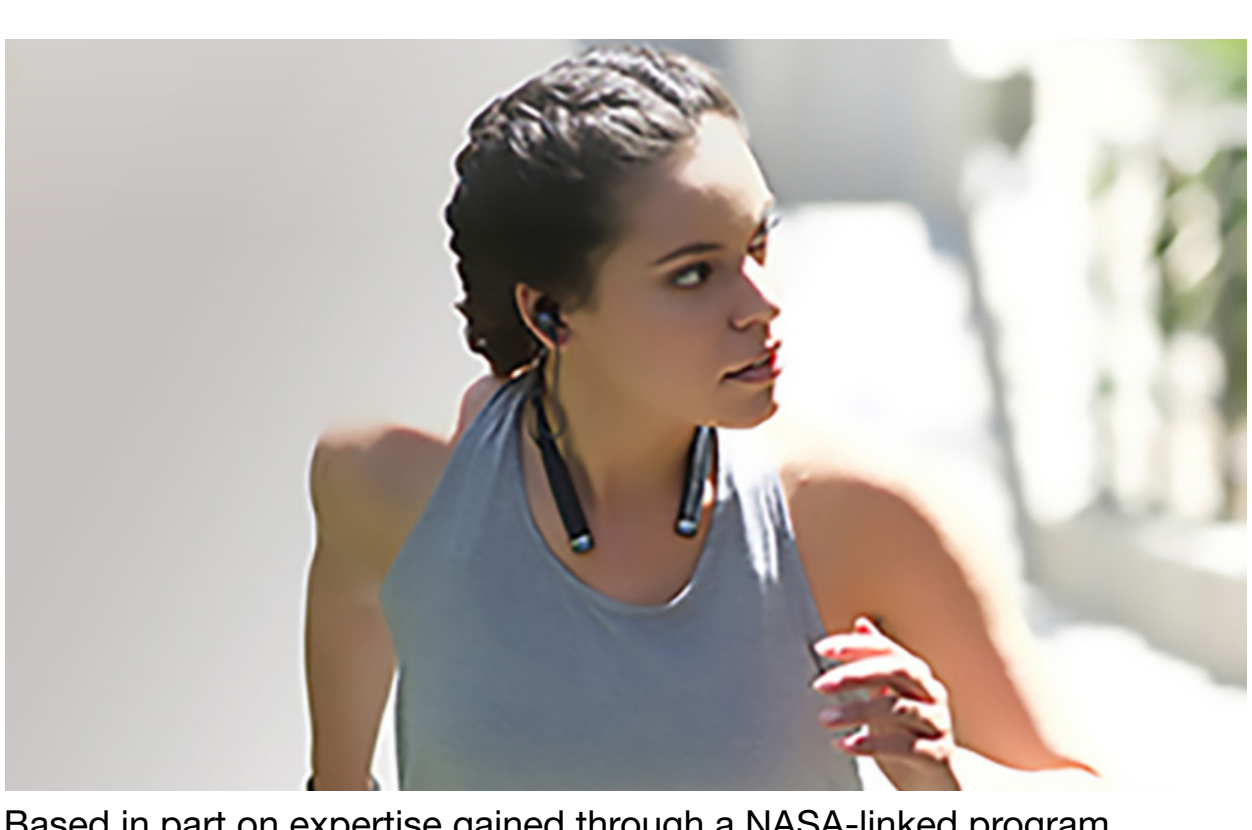
"Now we're getting courted by an international aid group for Liberia and Sierra Leone," Thompson says. "I'm really hopeful. Talk about making a difference around the world."

Biometric Sensors Optimize Workouts

What if, as a pilot was headed toward a blackout from heavy G-forces, a voice told him or her to "pull out of the turn"? What if ground control got a warning when an astronaut's biometric readings indicated a danger zone?

It could be helpful, says astronaut Yvonne Cagle, not least because astronauts and fighter pilots tend not to say that they're feeling funny: "We're very driven to complete the mission, and we may not be as aware of physiologic urgencies until it actually interferes with our performance."

That was the motivation behind a research project Cagle mentored with Omri Yoffe, an Israeli entrepreneur whose team won the opportunity to work with NASA personnel in 2011 as part of a program run by Singularity University. The organization, which has a Space Act Agreement with NASA's Ames Research Center, aims to create "exponential technologies to tackle the world's biggest challenges."



Based in part on expertise gained through a NASA-linked program, LifeBEAM built an artificially intelligent "personal trainer" that aims to use a biometric sensor to maximize the impact of exercise.

Yoffe and his team came up with a prototype during the three-month Singularity program, which he says helped when they decided to create a commercial biometric sensor.

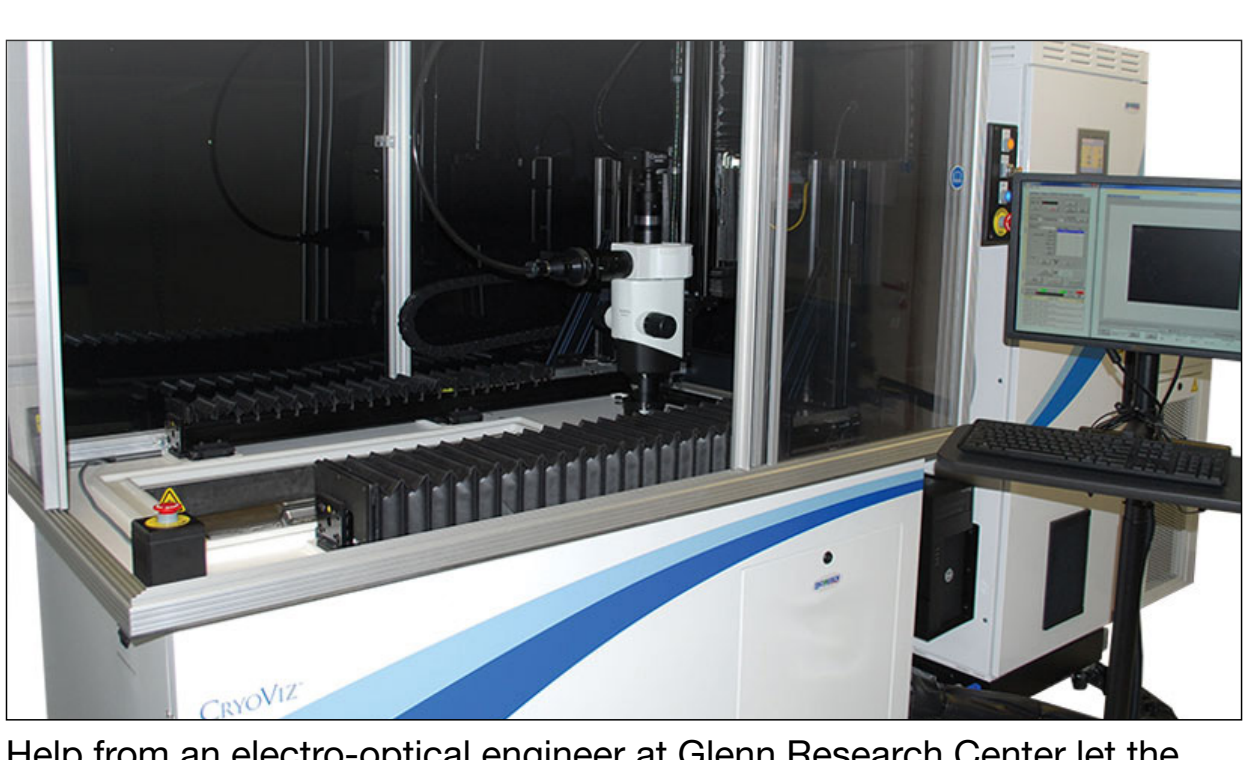
"It really set the bar, to be able to measure biometrics in a very noisy, very dynamic aerospace environment," Yoffe says. That experience "trained the team and trained our know-how to be able to approach the consumer market in an easy way."

New York City-based LIfeBEAM has now incorporated that know-how into the artificially intelligent exercise trainer Vi. Like the biometric sensor the team worked on at Singularity University, Vi tracks heart rate, but since it is designed for exercise rather than aerospace, it also tracks steps, mileage, weather, elevation, and more. It is built into voice-activated earphones, so it can communicate directly with the user.

An initial funding round through Kickstarter raised nearly $1.7 million and sold more than 8,000 units.

Optimized Imager Tracks Cancer, Stem Cells in Medical Research

After earning his doctorate, Debashish Roy set about creating a business from the biological imaging device he'd helped invent as a graduate student. The system held promise for cancer and stem cell research, among other possible applications. But he soon realized he could use some help.



Help from an electro-optical engineer at Glenn Research Center let the BioInVision company make its CryoViz imaging device more sensitive, more efficient, and cheaper to manufacture. The optimized optics design will also figure into a smaller desktop version the company is working on.

The task of selecting and configuring optical and robotic parts required a high level of expertise, as well as sophisticated equipment and a lab, which Roy's fledgling company, BioInVision, lacked. NASA's Glenn Research Center, just on the other side of Cleveland however, had that lab, equipment, and expertise.

The system Roy had developed was a device that could take a frozen block containing a biological sample—typically a mouse—and slice off extremely thin sections while taking multiple high-resolution images of the block face to capture any cells tagged with a fluorescent marker, creating a digital three-dimensional version of the specimen with locations and counts of all the tagged cells. The goal is to track the movement of cells, especially cancer and stem cells, through the body.

A CryoViz image shows stem cells tagged with fluorescent markers in a mouse liver. After a specimen, usually a mouse, is frozen in a block, the device shaves thin slices off the block, taking multiple high-resolution images of the block face to create a threedimensional image showing the location of every tagged cell within the body.

Roy wanted to develop a smaller, cheaper version of his CryoViz device, and it was with this in mind that he applied for Glenn's first round of the Adopt a City program. Under the program, Glenn, local municipalities, and the Manufacturing Advocacy and Growth Network selected local businesses to receive 40 free hours of technical expertise from NASA scientists.

In the case of BioInVision, that expert was the head of Glenn's optics lab, who put together a spreadsheet of several possible configurations of existing, commercial optical components.

While the company is still working on the desktop version, it immediately applied Lewis' designs to its original product, resulting in a version that is more sensitive, more efficient, and cheaper to make than the original.

Weightless "Weight"-Lifting Builds Muscle on Earth

In zero gravity, the human body quickly loses significant muscle and bone mass, making a rigorous workout schedule crucial to long-term health. OYO Fitness founder Paul Francis worked with NASA to develop a resistive exercise device suitable for use on the space station, pictured here in use by NASA astronaut Garrett Reisman. The innovation led to several lines of Earth-bound exercise devices, most recently OYO Fitness' DoubleFlex Silver portable gym.

In the 1990s, it was common for astronauts to be carried off spacecraft after lengthy stays in space, due to loss of muscle and bone density in zero-gravity.

As it prepared for the International Space Station, NASA knew this was a problem it needed to address. The Russian space station Mir had a bicycle and treadmills with elastic harnesses that attached users to them, but these weren't maintaining the muscles people use to simply stand around on Earth. Johnson Space Center put out a call for countermeasures.

That call for solutions caught the attention of inventor Paul Francis, who was developing exercise equipment using rubber elastomer springs for resistance. He called it SpiraFlex.

After Francis demonstrated the system to NASA personnel, it was selected for development. Through contracts with Lockheed Martin and Wyle Labs, Francis' new company created the Interim Resistive Exercise Device (IRED). SpiraFlex core units, or FlexPacks, were stacked inside canisters, each with a spiral pulley system that enabled up to 300 pounds of resistance.

The DoubleFlex uniquely applies resistance to both sides of a muscle group through one motion, which Francis claims greatly improves the efficiency and of workouts. It boasts an extremely portable form factor, and, while the device itself weights just 2 pounds, it provides up to 25 pounds of resistance.

Following that work, Francis licensed the technology to Nautilus, a fitness device company that incorporated SpiraFlex into its Bowflex Revolution exercise equipment.

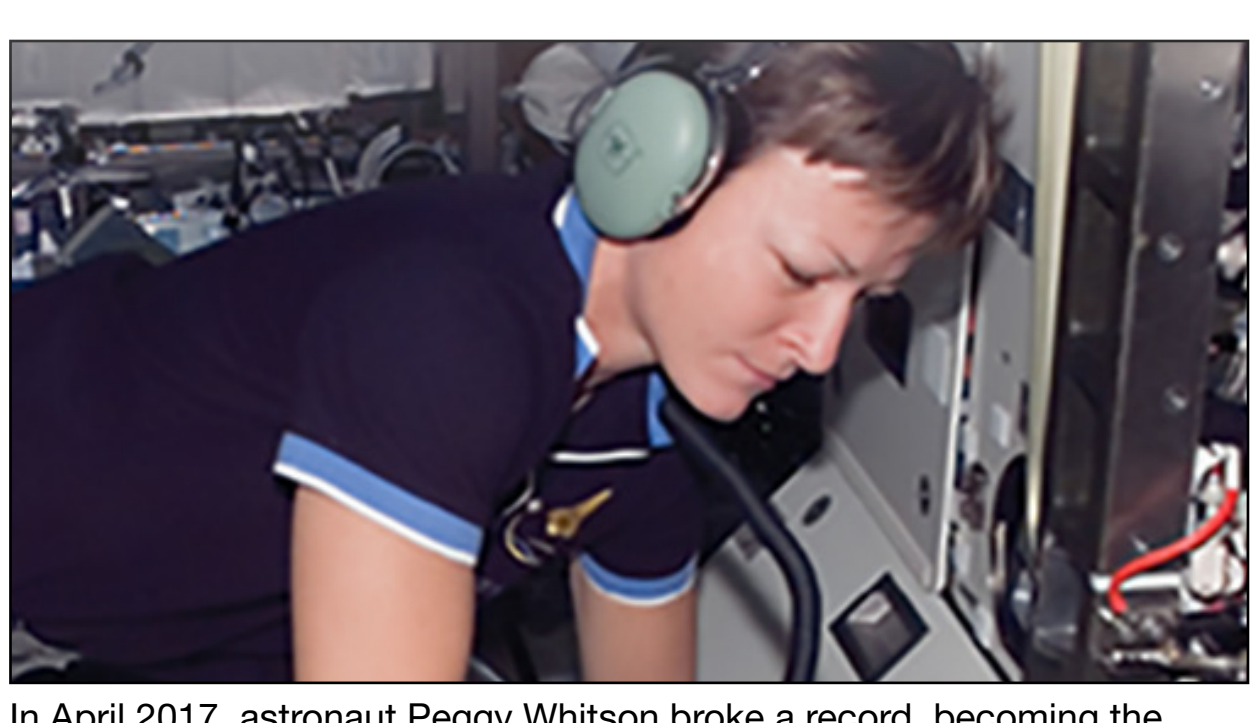
NASA, meanwhile, kept working with him to develop a more reliable, maintainable, and durable version of the technology. Eventually, Francis used royalties from the Nautilus license to develop his own line of SpiraFlex-based equipment, which he sells through his new venture, OYO Fitness. OYO's first product, the DoubleFlex Silver portable gym, launched in 2016, followed quickly by Black and Pro versions.

The DoubleFlex weighs only 2 pounds but produces up to 25 pounds of resistance and fits in a backpack. Users add resistance by snapping on FlexPacks.

Francis says his is the only exercise device that applies resistance to both sides of muscle groups in one motion, enabling balanced bodybuilding in half the time.

Virtual Therapist Offers Out-of-This-World Depression Treatment

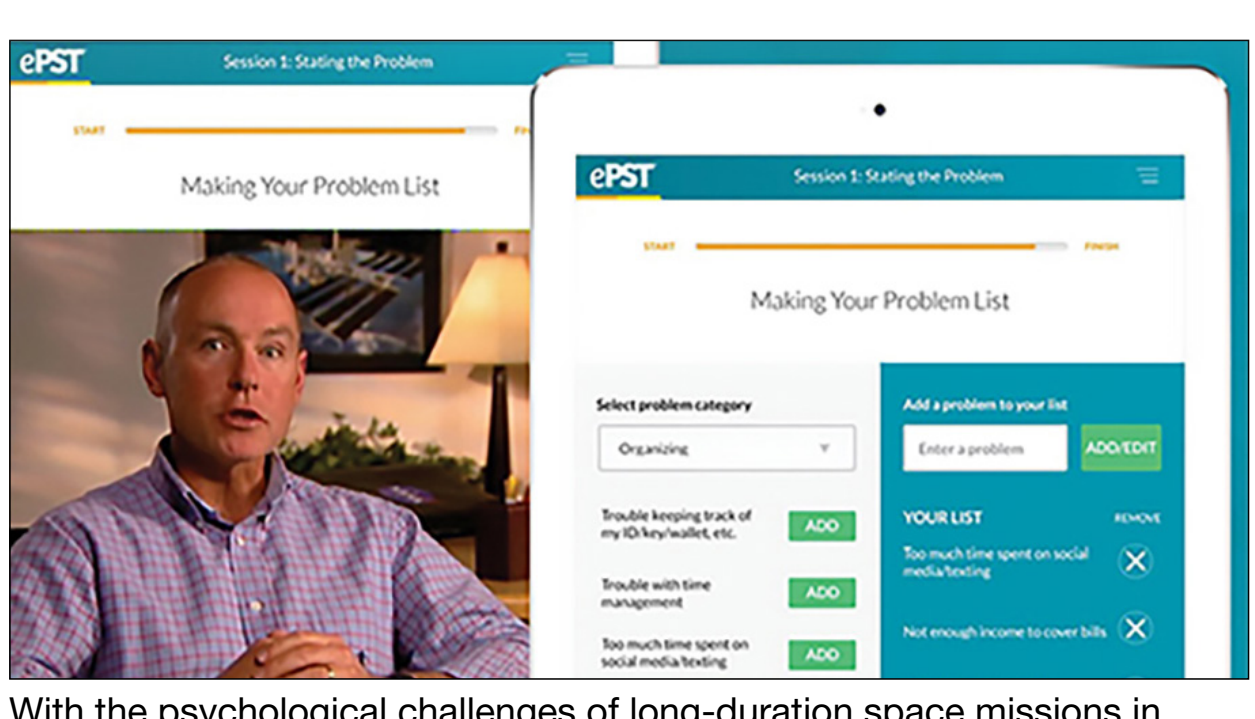
Imagine being stranded with just a few coworkers for months at a time. Now imagine someone, or several people, start to feel depressed or anxious or annoyed at a colleague. NASA has done more than imagine it, because these could be very real problems on long-duration missions, and help could be tens of thousands of miles away.



In April 2017, astronaut Peggy Whitson broke a record, becoming the American who has spent the most cumulative days in space. "Working aboard the space station for long duration is definitely a challenge," she wrote in a Tumblr post a few weeks later, adding that "psychological and emotional support is extremely important in space."

Researcher and psychologist James Cartreine was interested in creating video-based software to increase access to mental health treatment on Earth, but when looking for funding, he realized his project was of interest to the Johnson Space Center-funded National Space Biomedical Research Institute (NSBRI) as well.

In total, he spent 13 years developing a "Virtual Space Station" for NASA with grants from the NSBRI and feedback from flight surgeons at Johnson. It included multiple interactive modules to help astronauts diagnose and treat mental health issues and interpersonal conflicts. However, Cartreine says, all along it was "with the idea that everything I'm building is very easy to convert into something that can benefit thousands and millions of people" on Earth.



With the psychological challenges of long-duration space missions in mind, the Johnson Space Center-funded National Space Biomedical Research Institute supported an initiative to develop video-based software to help diagnose and treat mental health and interpersonal issues. everMind has adapted the depression module for the ground, aiming to greatly expand access to evidence-based treatment.

In 2009, he negotiated to transfer the intellectual property to his private company, which he later merged with another company he founded with a colleague, called everMind.

In 2015, the Norwich, Vermont-based company released a direct translation of the Virtual Space Station module for depression. ePST, for electronic problem-solving treatment, "was the first software cleared by the FDA for depression treatment," Cartreine notes.

Problem-solving treatment has been shown in trials to be very effective for most people and translates well to software because the treatment is brief, often just six sessions, and extremely structured.

A desktop version of ePST is available at Michigan State University health center, and the company is working to expand access elsewhere. everMind also plans to upgrade in 2018 to a web-based version that patients can use from their own devices—but they intend to continue to make it available through clinical settings to ensure oversight from health professionals.

Compact Spectrometers Unveil Clues to Diagnose Cancer

Arsen Hajian builds small but mighty spectrometers—he likes to say his company's hyperspectral imagers pack the high resolution of machines nearly 30 times larger and as much as 10 times more expensive.

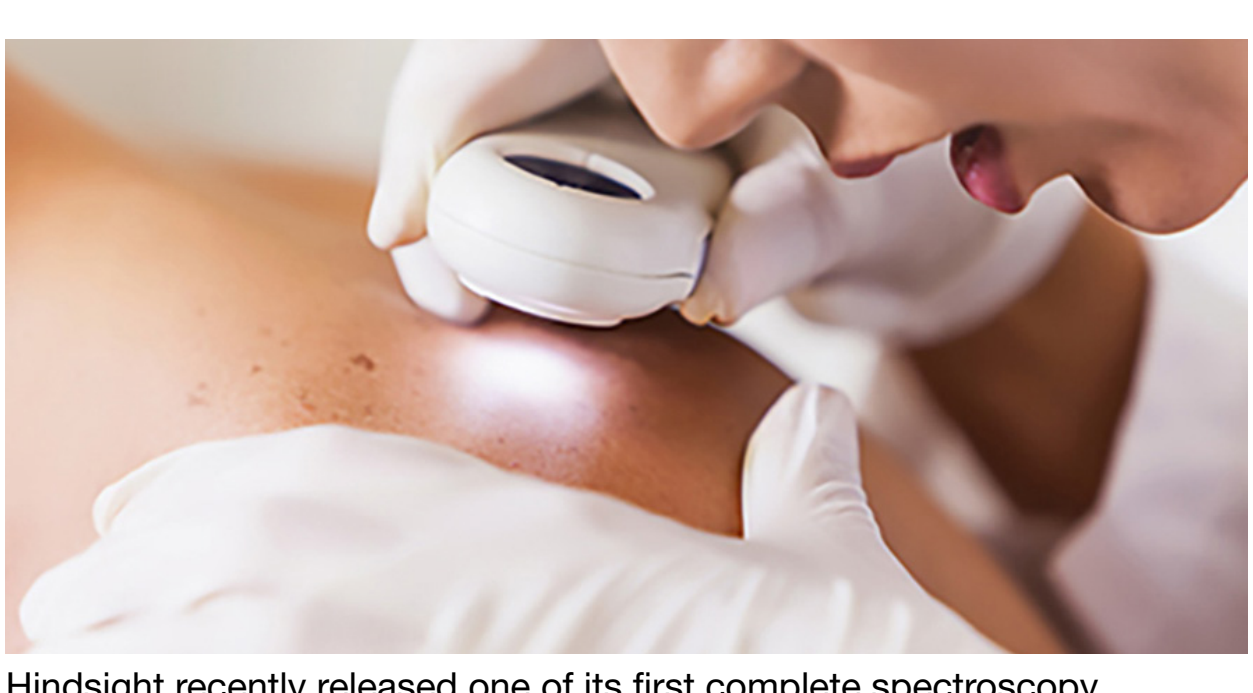
Hindsight Imaging Inc.'s spectrometers are nearly 30 times smaller than conventional instruments with similarly high resolution.

He has been working on spectrometers for more than 20 years, since he started at the U.S. Naval Observatory. Although spectroscopy had been around since the 1800s, the existing tools weren't precise enough to get the results astronomers wanted to search for distant planets. Hajian was one of the engineers working to make better ones.

"Back when Arsen was first working on some of this stuff, exoplanets were really something of a new field," recalls Goddard Space Flight Center astrophysicist Stephen Rinehart.

Hajian, who received multiple NASA grants, including through the Advanced Technology Initiative (ATI) and ROSES, or Research Opportunities in Space and Earth Sciences, made his breakthrough by breaking what he calls "one of the basic rules of optics," which was that most spectometers were either small and low-resolution or very large and high-powered.

Because his background was in radio astronomy, Hajian was open to looking for a new approach. He found one, essentially adding two extra reflecting surfaces to the standard optical design to change the shape of the light as it enters from a round point to a long and skinny ellipse, without changing the focal ratio.



Hindsight recently released one of its first complete spectroscopy systems, designed to detect melanoma in the skin without a biopsy.

"It allowed us to build spectrometers that are a bit more than three times smaller in all three directions than conventional instruments," Hajian says.

For now, Boston-based Hindsight mainly sells spectrometers as components to be integrated into larger instruments, and the company has quickly amassed "a wide variety of customers in multiple spectrometry markets," Hajian says.

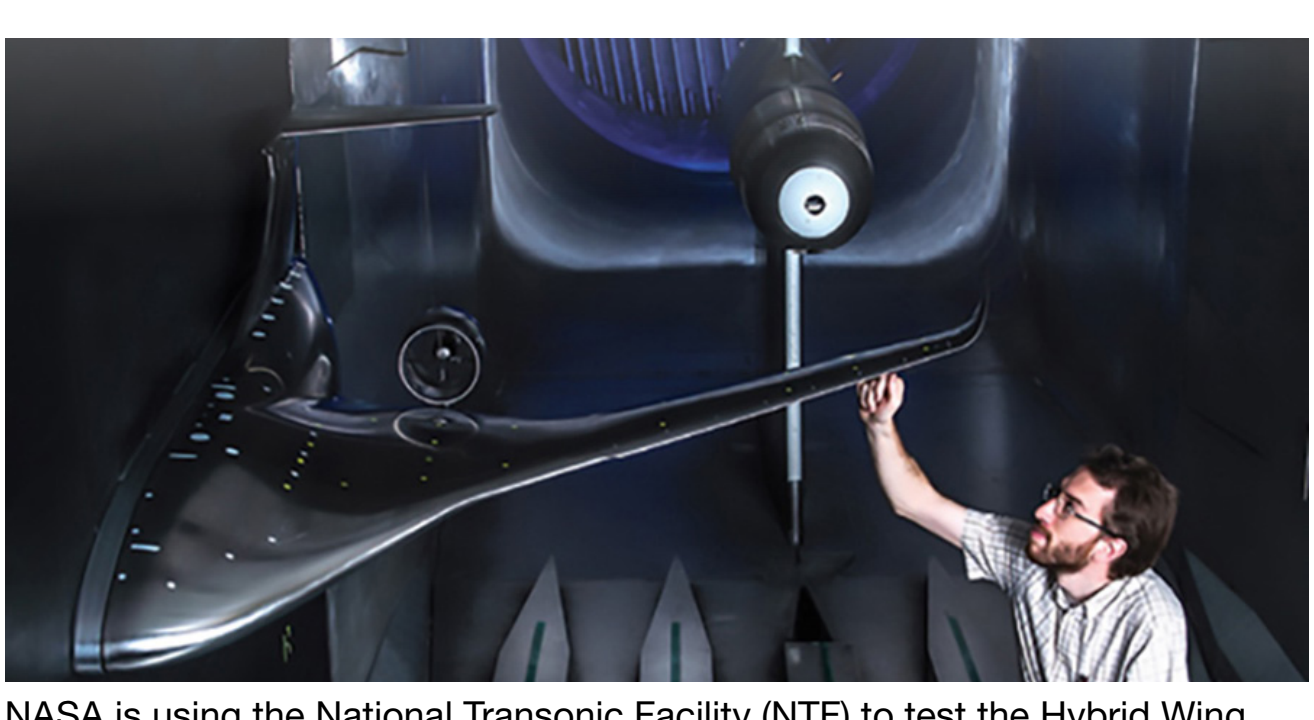
In mid-2017, the company also released its first two complete spectroscopy systems, one for detecting drugs and explosives at a short distance and another for detecting skin cancer. Down the road, he envisions using spectrometers like his melanoma-detecting device to diagnose tumors underneath the skin and for needle-less blood tests.

Transportation

Technology is never finished confronting the challenges of air and space travel, and we all benefit from these steady improvements to flight technology, from software to ease aircraft design to advanced avionics capabilities that apply to planes, wind turbines, and selfdriving cars. Also in this section is the highperformance rocket engine that's put countless commercial and defense satellites in space and the specially outfitted NASA facility that tested the world's fastest light business jet.

Innovative Design Propels Small Jet Faster, Farther with Less Fuel

Honda is best known for budget-friendly, fuel-efficient family cars, not high-powered jets. But that's just what its new Honda Aircraft subsidiary sells: high-speed business jets—that are also fuel-efficient and budget-friendly.



NASA is using the National Transonic Facility (NTF) to test the Hybrid Wing Body airlifter, which could be more fuel-efficient and aerodynamic than the traditional airplane shape. The NTF is pressurized and can pump in pure nitrogen gas, which makes it better able to mimic real conditions in the air than other wind tunnels.

The plane body and its breakthrough over-the-wing engine mount were designed after "extensive research using computational fluid dynamics," explains Honda Aircraft Company CEO and President Michimasa Fujino. "We found that if we put the engine at the optimum location relative to the wing, we find a sweet spot to reduce wave draft."

But before Honda was ready to invest in building the planes, it needed to test design variables in real-world conditions. That's where NASA came in.

HondaJet was tested at the NTF to see whether the computer models of its innovative over-the-wing engine mount were accurate in real flying conditions. The successful test results gave the company more confidence to move to the commercial phase.

"We were searching for a wind tunnel all over the world," Fujino recalls. NASA's National Transonic Facility, or NTF, housed at Langley Research Center, was the clear choice.

Greensboro, North Carolina-based Honda Aircraft negotiated to conduct a week of testing at the NTF. The team also worked with NASA wind tunnel experts in advance to ensure their model was properly designed to withstand the high-speed testing and could interface with all the instruments.

"Because I could confirm my concept from test results, I had more confidence to go into the commercial phase," Fujino says.

The over-the-wing engine mount design allows the plane to fly faster using less fuel, but it also increases space and comfort in the cabin, since the engine is no longer attached to the plane body.

The HondaJet has the fastest maximum cruising speed in its class, 422 knots (nearly 500 miles per hour), and can fly at a maximum altitude of 43,000 feet, also highest in its class. The lower drag also increases the jet's fuel efficiency by up to 17 percent, which makes it less expensive to operate than other light jets.

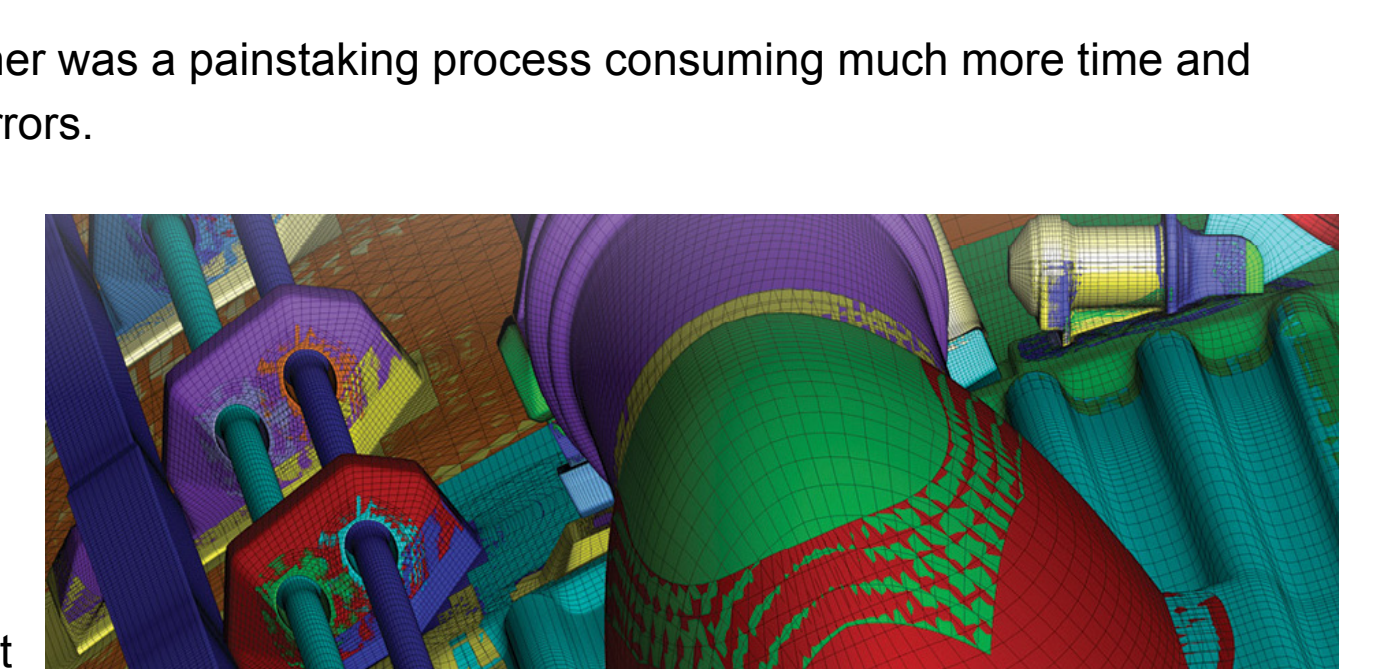
The company markets to owner pilots, attracted by the high performance, and to small business owners who need to travel frequently. Since late 2015, it has already sold more than 100 planes, with prices starting around $5 million, in North and South America and Europe. The company recently expanded to Central America and is looking to the Middle East as well.

Design Software Transforms How Commercial Jetliners Are Built

In the late 1990s, computers were becoming vastly more powerful, with no slow-down in sight. As people in all kinds of fields pondered how to use this power, Stuart Rogers began working on Pegasus 5—software to dramatically transform how airplanes and spacecraft are designed and built.

Boeing has used the Pegasus 5 software widely, including on its 777X, which is slated to fly in 2020.

The software is a preprocessor for overset-grid computational fluid dynamics (CFD) simulations. This CFD approach divides large domains into smaller, more workable segments. Pegasus 5 reassembles the pieces, stitching together the parts of this complex geometry for what's called a flow solver. The solver then computes the fluid dynamics for the problem at hand. Before Pegasus 5, piecing these segments together was a painstaking process consuming much more time and user input and creating opportunities for errors.



Overset grids on the surface of the external tank of the Space Shuttle illustrate the complex geometry capabilities of the Pegasus 5 software.

Rogers, an engineer at Ames Research Center, began work on Pegasus 5 in 1998 at NASA's Advanced Subsonic Technology (AST) Program, a joint research effort with Boeing that supported the program's development for two years. Boeing, which helped define the project's technical requirements, was one of the first companies to apply Pegasus 5 to aircraft configurations.

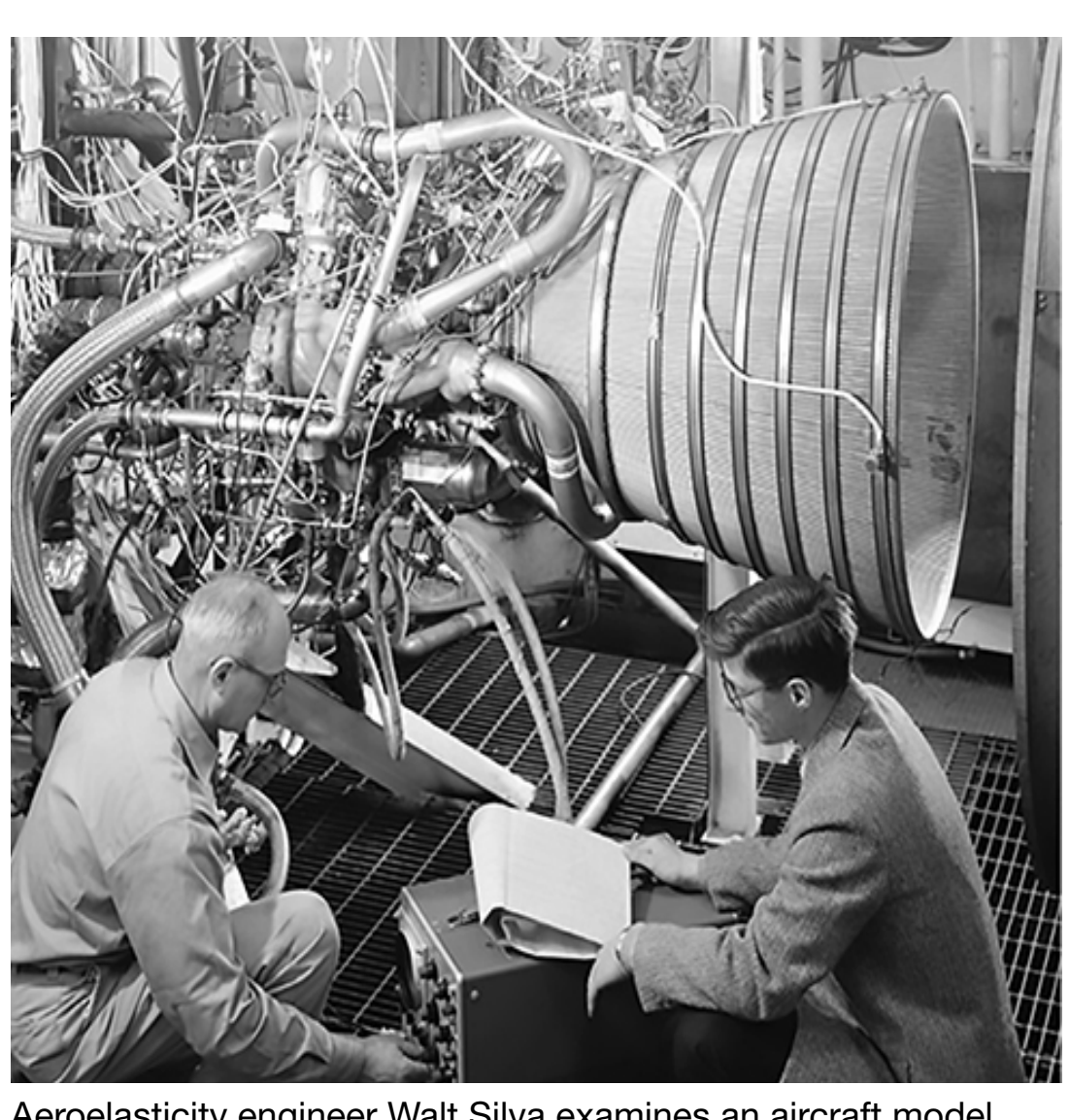
Rogers went on to use Pegasus 5 on numerous NASA projects, including the Space Shuttle and the upcoming Orion capsule and Space Launch System, and has continued to develop and add features to it, releasing new versions every so often.

The code has been distributed to more than 470 organizations in industry, academia, and the Department of Defense, with the latest version available on NASA's online software catalog. It won the 2016 NASA Software of the Year Award.

Boeing has used the software to develop and support its commercial airplanes, military aircraft, and spacecraft. While Pegasus 5 has saved Boeing untold time and money, the company says, the most important benefit has been the reduction in potential user errors.

Original Cryogenic Engine Still Powers Exploration, Defense, Industry

At a time when cell phones and automobile features are outdated after a few short years, it may seem impossible that any technology would remain virtually unchanged over decades. But the world's first cryogenic fuel-powered rocket engine remains the most-used upper-stage rocket engine in the United States more than 50 years after its creation.



Aeroelasticity engineer Walt Silva examines an aircraft model undergoing testing in the Transonic Dynamics Tunnel at Langley Research Center. Silva created innovative software that speeds up computational modeling of aircraft to reduce the need for costly wind tunnel tests.

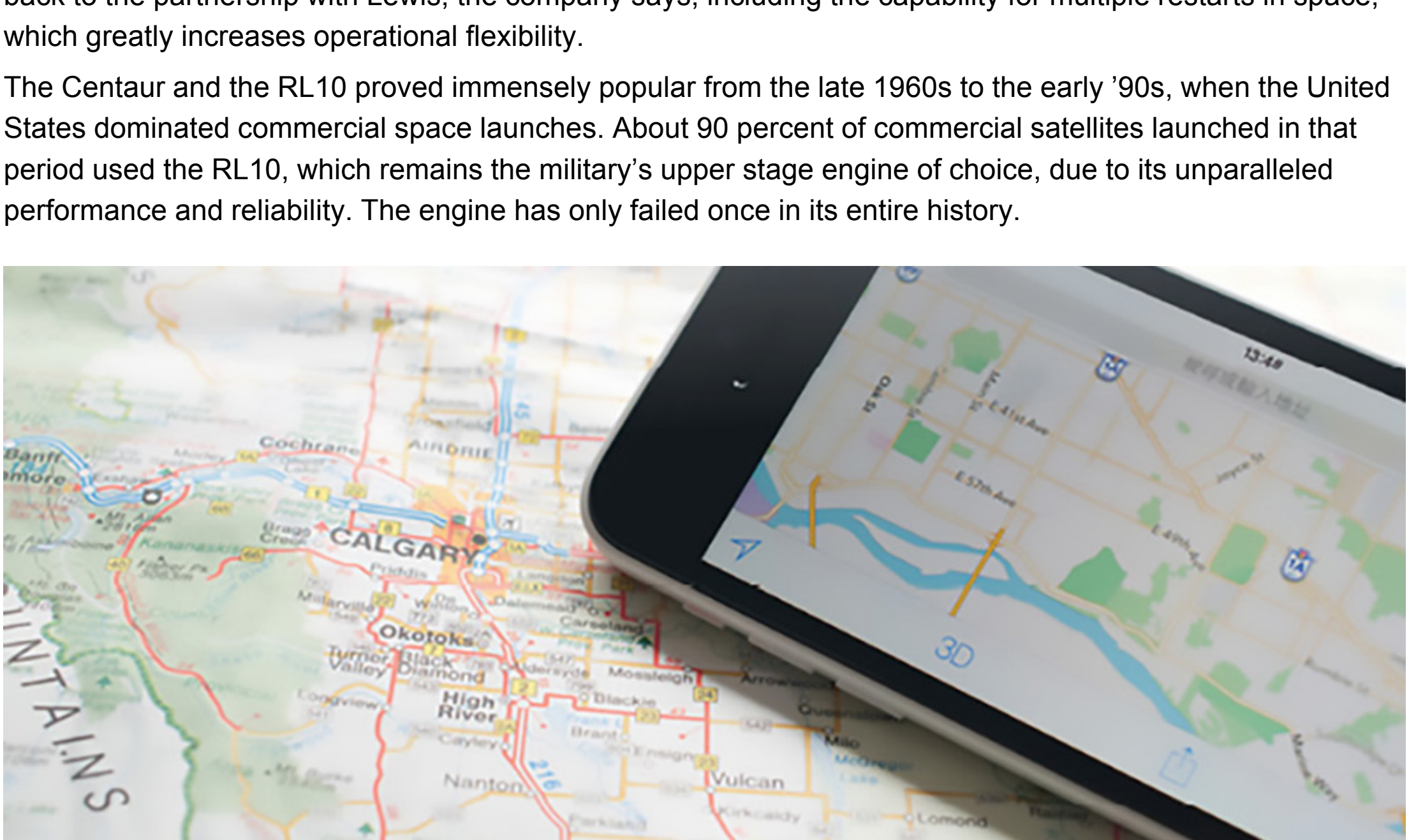
The RL10 engine has been crucial to NASA's space exploration and has also put hundreds of commercial and military payloads into orbit, enabling satellite communications and satellite-based defense operations. After half a century, only a handful of countries have cryogenic engine technology.

In the 1940s, Lewis Research Center, then part of NASA's predecessor, the National Advisory Committee for Aeronautics, and now known as Glenn Research Center, carried out extensive research and testing on harnessing cryogenic fuels. The project of building the world's first cryogenic upper-stage rocket, the Centaur, and the RL10 engine that would power it began at the Department of Defense, passed to Marshall Space Flight Center, and ended up at Lewis, led by an engineer who had worked on cryogenics there in the 1940s. The primary contractor was Pratt & Whitney Aircraft, now part of Aerojet Rocketdyne.

The company still builds RL10s in West Palm Beach, Florida, just as Pratt & Whitney did.

Much of the current model's heritage can be traced back to the partnership with Lewis, the company says, including the capability for multiple restarts in space, which greatly increases operational flexibility.

The Centaur and the RL10 proved immensely popular from the late 1960s to the early '90s, when the United States dominated commercial space launches. About 90 percent of commercial satellites launched in that period used the RL10, which remains the military's upper stage engine of choice, due to its unparalleled performance and reliability. The engine has only failed once in its entire history.



From the 1960s to the 1990s, most GPS, weather, and communications satellites were put into orbit with the help of RL10 engine-powered upperstage rockets.

Time-Triggered Ethernet Slims Down Critical Data Systems

Ethernet computer networks are virtually everywhere, including in space. Inexpensive and easy to use, Ethernet has often connected astronauts' noncritical devices in spacecraft. Until recently, though, Ethernet couldn't be used for critical systems like spacecraft electronics—known as avionics—because it couldn't guarantee how long it will take to transmit a message or even whether it would arrive at its intended destination.

TTTech products like this 24-port AFDX Switch A600 Pro, which meets civil aerospace standards for bandwidth-regulated traffic filtering and policing, are built on Time- Triggered Ethernet technology the company refined and expanded under a NASA subcontract to develop avionics for the Orion space capsule.

Critical spacecraft subsystems have traditionally been housed on separate computers, creating a large, complex, heavy, inefficient system. On the International Space Station, for example, subsystems communicate indirectly by sending messages up a tiered network "tree" and back down.

TTTech Computertechnik AG developed a new approach.

The company, whose U.S. headquarters is in Andover, Massachusetts, has been building networks for flight applications since a 2000 project under NASA's Aviation Safety Program that put the company's Time-Triggered Ethernet in several popular jet engines.

Time-Triggered Ethernet creates three classes for message transmission. The most critical data is time-triggered—scheduled into time slots that never interfere with each other. Less-critical but high-priority data is transmitted reliably within strict timing constraints. The rest of the bandwidth is available for noncritical messages.

Even before TTTech began developing avionics for the Orion capsule, the company's work under NASA's Aviation Safety Program applied its Time-Triggered Ethernet to a number of commercial airliners, including the double-deck Airbus A380, the world's largest passenger plane.

TTTech was a subcontractor on Johnson Space Center's work to develop Orion's avionics. Under a 2009 Space Act Agreement, Johnson helped develop an official standard for Time-Triggered Ethernet that would help others adopt the technology.

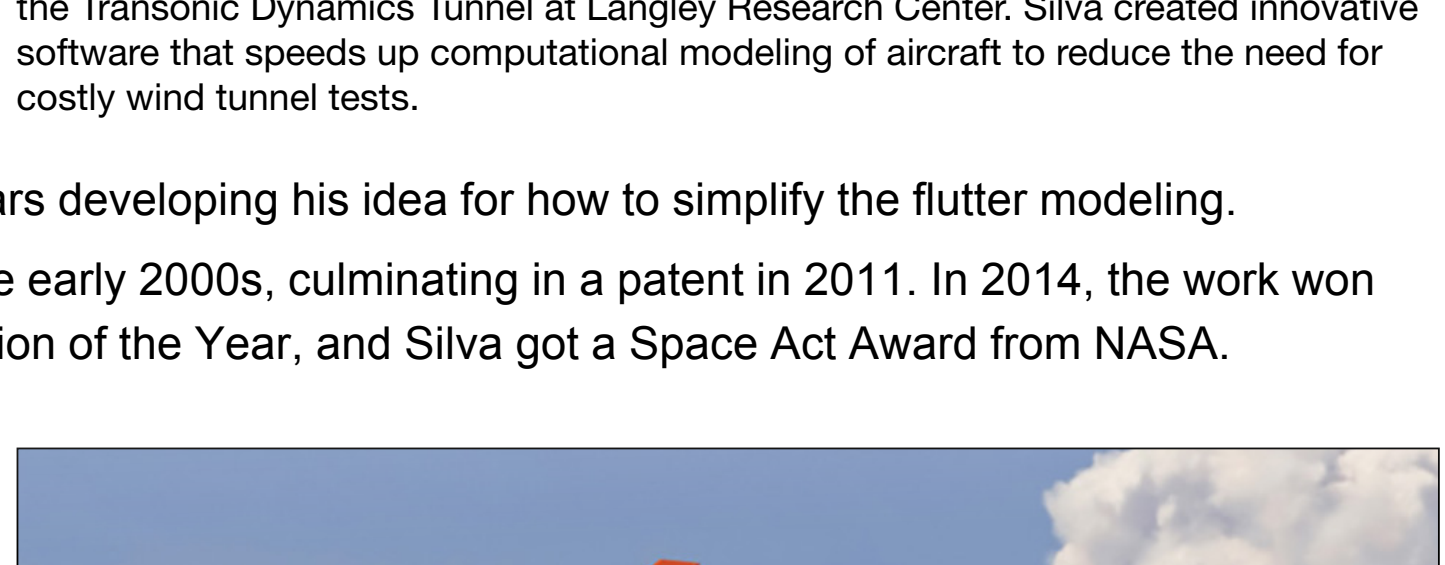
In Orion's avionics, multiple functions can be housed on the same computer, and subsystems communicate directly with each other. Functions can be added or removed without affecting the rest of the avionics. All this makes the system far more efficient than its predecessors.

The feedback and lessons learned from the Orion work—and the subsequent standardization—ensured Time-Triggered Ethernet products that are more refined, robust, and marketable, the company says. The technology is now in other spacecraft, wind turbines, and driver assistance systems, and it is being developed to enable self-driving cars.

Simplified Aircraft Modeling Packs Weeks of Analysis into Minutes

It wasn't Walt Silva's job to invent a technique to dramatically speed up computational modeling of aircraft. But the NASA researcher did it anyway.

Over the last couple of decades, computational fluid dynamics (CFD)—software that models how an aircraft performs while flying—has become increasingly relied on. But even supercomputers sometimes need weeks to solve these incredibly complex scenarios.



Aeroelasticity engineer Walt Silva examines an aircraft model undergoing testing in the Transonic Dynamics Tunnel at Langley Research Center. Silva created innovative software that speeds up computational modeling of aircraft to reduce the need for costly wind tunnel tests.

One of the more demanding is aeroelasticity: how much air movement causes a structure to vibrate or bend, and how that flexing will impact the airflow. The two factors can create a feedback loop, or "flutter," which, under certain conditions, can destroy the structure.

A full analysis of aeroelasticity requires running and re-running the equations under different flight conditions—which can take weeks.

Between one thing and another—and his actual day job at Langley Research Center—Silva spent 20 years developing his idea for how to simplify the flutter modeling.

It finally started coming together in the early 2000s, culminating in a patent in 2011. In 2014, the work won honorable mention for NASA's Invention of the Year, and Silva got a Space Act Award from NASA.

CFD Research Corporation used Silva's Reduced Order Modeling software in a project to design aircraft with an extra-long wing span to increase fuel efficiency. Designs were tested on the X-56 MUTT, which stands for multi-use technology test bed.

The software uses a mathematical tool called system identification to create a simplified version of a structure, or a Reduced Order Model (ROM), to model the aerodynamics. That process could take hours, but it makes the rest of the work go much more quickly.

You don't get 100 percent of the information you'd get from running the full CFD models, he says, but "it allows you to capture 90 percent of the essence," and to pinpoint the specific areas that need further investigation.

Now the code is starting to spread beyond NASA, provided to big companies like Boeing and smaller ones like Huntsville, Alabama-based CFD Research Corporation. The latter used it for a NASA project and is now adapting it for the Air Force for its Digital Twin program, aimed at reducing maintenance costs and increasing safety.

Public Safety

The Space Agency is renowned for its culture of safety and ability to protect astronauts in the harshest environments—but even seemingly unrelated scientific missions can end up keeping us safer here on Earth. Technology used to map gravity is repurposed to find survivors trapped under rubble. Software to direct a robot construction team improves warehouse safety. These and more are featured in the following pages.

Radar Device Detects Heartbeats Trapped under Wreckage

NASA has long analyzed weak signals to identify slight physical movements, such as minor alterations in a satellite's path that might indicate gravity fluctuations. Beginning in the early 2000s, a couple of federal agencies approached engineers at the Jet Propulsion Laboratory (JPL), wondering about using this capability to remotely detect human vital signs.

JPL called the prototype it developed FINDER.

By picking out the faint but correlating movements of human breathing and heartbeats, FINDER can detect up to five separate victims buried under rubble in a given area.

The founders of R4 Inc., based in Edgewood, Maryland, came across an article about FINDER when the California Institute of Technology, which manages JPL, was looking for a company to commercialize it. Before long, R4 had licensed FINDER, and the company spent the next couple of years developing it into a device first responders could use in real-world situations.

A major success came when a 7.8-magnitude earthquake rocked Nepal just northwest of its capital of Kathmandu in April 2015. One of R4's founders arrived with two FINDER prototypes and detected four victims trapped under debris. All four men who had been buried as deep as 10 feet, survived.

FINDER has since proven capable of detecting humans through 30 feet of dense rubble with 80 percent accuracy. The company is working on what it calls "persistent detection"—continuous scanning while the FINDER is in motion, searching for survivors as it passes heaps of rubble. R4 has also developed prototype versions that would mount on a remote-controlled octocopter, a pickup truck, and a motorcycle.

In October 2015, FEMA officially announced it would provide funding to municipalities that apply to purchase FINDER units. Meanwhile, FINDER's first official customers are the Army's Intelligence and Information Warfare Directorate and the Quito Fire Department in Ecuador.

R4 is developing a model that can continually scan for trapped victims while passing over mounds of debris on an octocopter drone. Other models are meant to fit on a truck or a motorcycle.

After a magnitude 7.8 earthquake hit Ecuador in April of 2016, R4 President David Lewis Sr. brought the company's FINDER system to look for victims trapped under rubble. Here, Lewis, right, shows local firefighters how to operate the system.

Surveillance System Captures, Maps Lightning Strikes

Just one day before Space Shuttle Atlantis was due to make the final voyage of NASA's 30-year Shuttle program, lightning struck. Twice.

But where exactly did those strikes hit, and were they close enough to do any damage to the Shuttle's electrical systems? Neither of two existing lightning monitoring systems at Kennedy Space Center had a great track record—which is why NASA had already begun working on a new system focused directly on the launch pads. "to make sure that if lightning struck within a certain radius, we will detect it. Period," says Carlos Mata, who was the lightning expert at Kennedy for more than a decade before moving into the private sector.

The new system incorporated a suite of high-speed cameras designed to capture visual evidence of any lightning striking the pad directly or nearby. The cameras are mounted on three lightning protection towers, as well as on the vehicle assembly building seven miles away. Electromagnetic field sensors are also installed at ground level to measure both the intensity and strike location.

In 2011, with the system partially installed nearby, still pictures and video were able to show the bolts did not directly hit the pad. As a result, STS-135 was able to launch on schedule.

Mata since has founded Titusville, Florida-based Scientific Lightning Solutions LLC, which sells commercial versions of the system he designed for NASA. Recently, SLS released its Optical Jupiter Precision Lightning Surveillance system, which detects 100 percent of strikes within the area under coverage, Mata says, a significant improvement over other commercial lightning detection systems.

The solar-powered standalone units cover an area up to three kilometers in diameter and are useful on wind farms and in the insurance industry. SLS also builds custom systems for customers including businesses that provide lightning location services across wider areas.

In 2011, Space Shuttle Atlantis launched for the final voyage of the Shuttle program—but the launch was almost delayed because of a lightning storm the day before. An advanced lightning detection system, then still under development, helped show that the bolts had not been close enough to damage the spacecraft.

After debuting his lightning detection system at NASA, Carlos Mata left and founded Scientific Lightning Solutions to develop a commercial model, which includes high-speed video cameras powered by solar panels (inset). The company's first customer will maintains the system at Cape Canaveral, and in December 2016, it helped ensure the ULA/NASA satellite launch could proceed on schedule despite a fierce lightning storm days earlier.

Virtual Reality Platform Helps Pilots Land in the Sky

When a plane overshoots the final approach for a landing, often the pilot's natural—and dangerous—instinct is to pitch up the aircraft to slow down and land.

It's one of the leading causes of accidents, especially with small airplanes. But what if that same mistake happened at 5,000 feet instead?

A new virtual reality tool, branded Fused Reality and developed in cooperation with NASA's Armstrong Flight Research Center, can help pilots train for such potentially dangerous scenarios in real life, in the air, but with far less danger.

The new simulator hooks into any airplane and layers a virtual reality scene over the real world outside the cockpit. "You actually get the dynamics of the exact airplane you're flying," says Bruce Cogan, an aeronautical engineer at Armstrong.

With a virtual runway created by the software, "you can train for this landing task at 5,000 feet, so if you mess up, you won't hurt the airplane. You can go try again."

Thanks to Small Business Innovation Research contracts from Armstrong Flight Research Center, Hawthorne, California-based Systems Technology Inc. (STI) turned a ground-based system first developed for the Air Force into an in-flight simulator.

The beauty of the Fused Reality platform, says STI CEO David Landon, is that "going forward, every aircraft can become its own simulator." The system is commercially available, and STI has been in talks with airplane manufacturers interested in using Fused Reality both to evaluate their planes—and potentially use it as a marketing tools as well as to help in designing new features.

Training academies are also interested, and the company has a new contract with Johnson Space Center to investigate use of the system on the International Space Station, where astronauts could use it to practice complicated maneuvers with the station's robotic arm, among others.

Using virtual reality software designed and tested in part with NASA funding, pilots can practice difficult maneuvers much more safely. The pilot here just landed the plane—on a virtual runway some 5,000 feet in the air.

There are many possible applications for Systems Technology Inc.'s Fused Reality system, including in space. A new contract with Johnson Space Center investigates use of the system on the space station, to practice complicated maneuvers of the robotic arm.

Autonomous Robots Take On Dangerous Warehouse Jobs

"Where does a 600-pound spider go? Anywhere she wants to."

The spider in question, dubbed "Spidermail," was part of a prototype robot team built in 2005 to assemble a solar array on the moon, an effort led by Johnson Space Center. The goal was not only to have robots do the manual labor but for them to work cooperatively without human direction.

To achieve that, engineers needed robots optimized for various tasks as well as software capable of directing the entire operation from start to finish. This type of work continues at NASA to this day, and some of the team members programming Spidermail and her sisters have taken that experience into the commercial world, where their software is poised to automate difficult and dangerous drudge work in warehouses and beyond.

Fred Heger, who worked on the project as a graduate student at Carnegie Mellon University, is now a senior research scientist at Cambridge, Massachusetts-based Vecna Technologies. The company recently released a suite of robots designed to move items through warehouses, which is built in part on the work Heger did for NASA.

"The physical shape is standard, commercially available equipment that people use today in warehouses. Except today, people are riding them and controlling them. Our computers, sensors, and robot software based on artificial intelligence enhance traditionally manual equipment to automate that," explains Vecna cofounder and chief innovation officer Daniel Theobald.

The software, which Heger was integral in developing, traces directly back to the software he worked on for NASA. "The math and the models are the same, but new lines of code have been written to implement it in more modern frameworks," Theobald explains.

"Spidermail" is part of a team of robots designed at Johnson Space Center to autonomously assemble a solar array on the moon. Vecna Technologies cofounder Daniel Theobald and Fred Heger honed his programming skills on the project, develop a system to ensure the robots completed the tasks in the optimal order.

Using expertise built on NASA projects, Vecna Technologies has built an "autonomy kit" for commercial warehouse equipment to automate, for example, package handling. Software coordinates the robot's tasks to ensure that packages are moved through the warehouse in the most efficient possible manner.

Vecna's autonomy kit is designed to work in places like shipping warehouses, where one truck brings packages that must be distributed to different delivery trucks. Beyond speeding up the process, the robots also significantly reduce accidents, which cause thousands of injuries each year.

Drone Traffic Forecasts Show Commercial Skies of the Future

The skies of the future will surely host more drones than they do today. Beyond the low-flying delivery drones, higher-flying autonomous aircraft will monitor air quality, map floods, gather news, and maybe even carry passengers as air taxis.

Some of these activities are in development, but they require permission from regulators who haven't yet determined the details of how to let everyone fly at once. Regulators want large drones to operate according to existing civilian aircraft rules, but this requires specifications regarding what sensors and communication systems they should have.

To that end, a team at Ames Research Center worked with the Federal Aviation Administration (FAA) to reduce barriers to introducing drones into the airspace.

The researchers focused on how drones might detect and avoid objects, and they opted to rely on simulations. But they needed realistic information about drone routes. It became a chicken-and-egg problem: to write drone regulations, they needed data on drone flights, but until regulations were in place, that data wouldn't exist.

So, beginning in 2012, Ames funded Small Business Innovation Research contracts with Rockville, Maryland-based Intelligent Automation Inc. (IAI) for research on future drone traffic. The company contacted scores of experts at companies and other organizations, expecting little more than a shrug.

Shown here are flight plans for routes drones might fly to provide early detection of nascent wildfires. Intelligent Automation Inc. used burn probability data to determine what types of flights would be useful and then mapped possible routes.

The skies of the future will likely host many drones doing tasks ranging from package and food delivery to monitoring air quality, gathering news, and perhaps carrying passengers. Software developed by IAI has helped regulators predict future drone traffic and develop the regulations that will allow them to function safely and smoothly.

Every group the company contacted, however, already had people analyzing the logistics of future drone flights. They had calculated routes, altitudes, and schedules.

Ames used the information to write drone requirements in a several-hundred-page document it gave the FAA. IAI, meanwhile, built an interface that allows users to filter drone flight categories, altitude, duration, or any aspect of the data, and the company sells the dataset as a product called UAS-Max.

IAI doesn't discuss customers or sales but says drone researchers, airspace regulators, and military organizations have shown interest, with NASA remaining the largest government consumer.

Offshore Oil Workers Learn Survival Skills in Astronaut Training Pool

To simulate weightlessness while rehearsing for NASA's 1966 Gemini 12 mission, astronauts Buzz Aldrin and Gene Cernan practiced spacewalks underwater, floating fully suited around a mockup of the space capsule in the swimming pool of a Maryland prep school.

NASA's underwater astronaut training has come a long way since then. But in the mid-1990s to accommodate mockups of the enormous International Space Station (ISS), the Neutral Buoyancy Lab (NBL) at Johnson Space Center, the world's largest indoor pool, with 6.2 million gallons of water. It is also well equipped, with features such as overhead cranes, audio and video communication systems, skyjock-style control rooms, nearby staging areas, a hyperbaric chamber to treat decompression sickness, and an onsite medical team.

With the U.S. portion of the space station largely completed in 2011, though, not all of that training capacity is needed, so Johnson decided to offset the cost of maintaining the lab and its full-time staff by allowing outside entities to use the facility for a fee. Under a Space Act Agreement, Houston-based Barbion Technologies, which provides divers and engineering services at the NBL, began offering offshore survival and fire training classes at the facility, taking over and expanding a service previously offered by Raytheon.

At the Neutral Buoyancy Lab at Johnson Space Center, participants in offshore survival training at Barbion Training Center escape a helicopter mock-up and board a life raft.

Offshore oil and gas workers going into the Gulf of Mexico and European waters are required to have certain levels of survival training, standards that are set by the Offshore Petroleum Industry Training Organization. Originally, three basic courses were offered at the NBL. Bastion has since earned certification for seven more courses.

By using the NBL, Bastion takes advantage of a top-notch safety system that was already in place, as well as comforts like temperature-regulated air and water. The overhead cranes are useful, as is the ample staging area, which the company uses for its smoke maze.

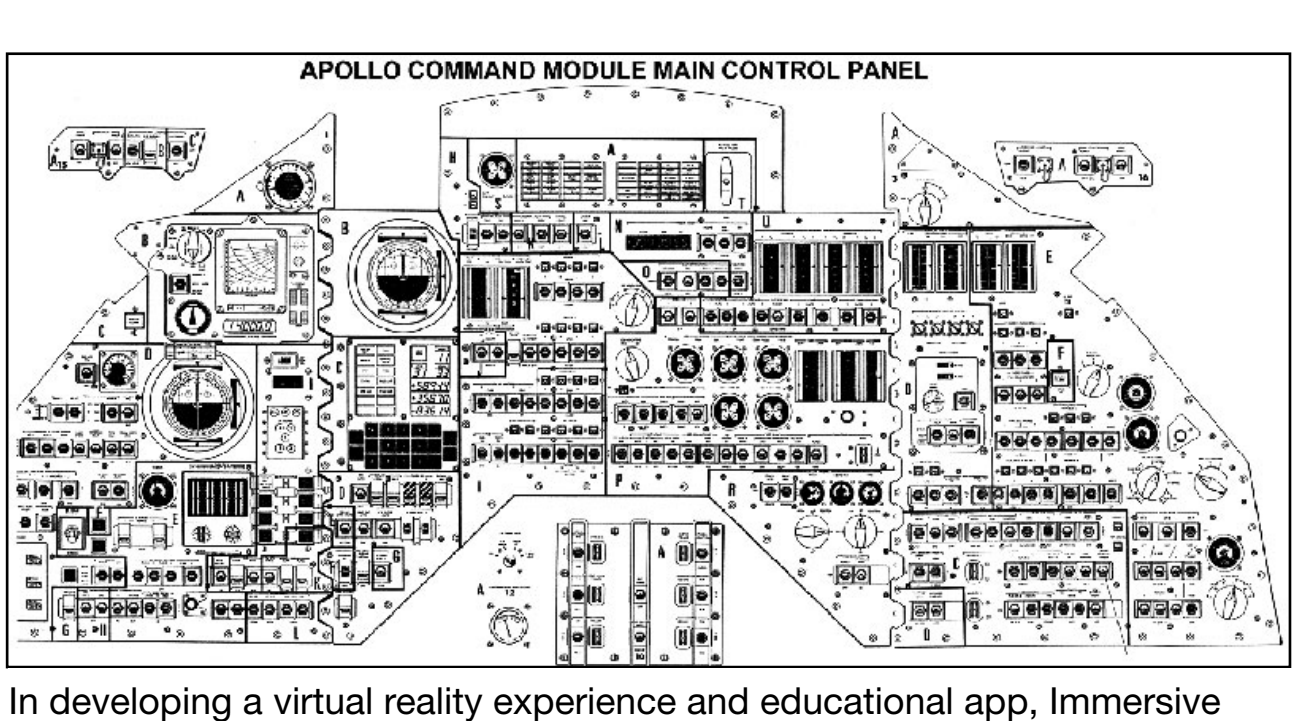
Workers who will deploy to offshore oil and gas rigs are often required to have certain levels of fire and survival training, a need that Bastion Technologies is able to meet through the use of NASA's Neutral Buoyancy Lab.

Consumer Goods

Many of NASA's most memorable spinoffs have been consumer goods, such as memory foam and the Dustbuster. This year's issue of Spinoff adds to that list advanced LED lighting for greenhouses, art made with magnetic fluid, a system for retraining sleep cycles, a long line of air purifiers, and more.

Apollo 11 History Archive Helps Virtual Reality Program Come to Life

Imagine yourself in the cramped cockpit of the Apollo spacecraft heading to the moon. Look around to see Earth out one window and stars lighting up black space from another. Reach out to the control panel.

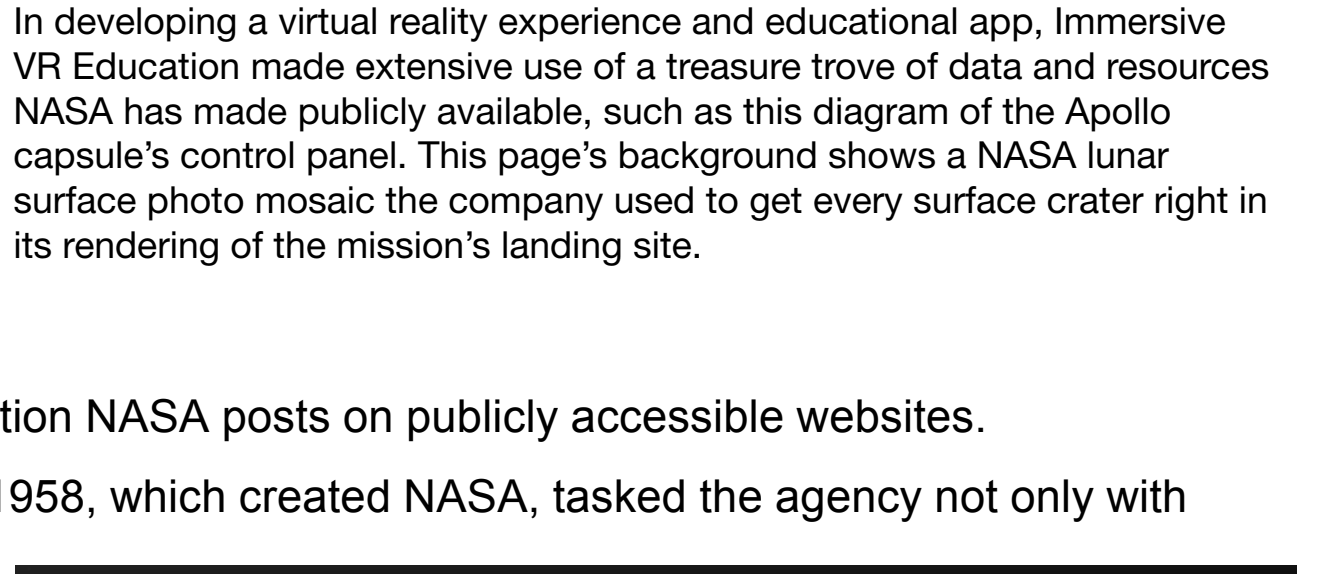


In developing a virtual reality experience and educational app, Immersive VR Education made extensive use of a treasure trove of data and resources NASA has made publicly available, such as this diagram of the Apollo capsule's control panel. This page's background shows a NASA lunar surface photo mosaic the company used to get every surface crater right in its rendering of the mission's landing site.

This is Apollo 11 VR, a virtual reality experience that enables users to relive the Apollo 11 mission and take some of the first steps on the moon. The company behind the project, Waterford, Ireland-based Immersive VR Education, calls it an "experience" and "a new type of documentary."

The project required extensive study, and the company says it wouldn't have been possible without the vast amounts of information NASA posts on publicly accessible websites.

The National Aeronautics and Space Act of 1958, which created NASA, tasked the agency not only with exploring space and studying aeronautics but also with the "widest practicable and appropriate dissemination of information concerning its activities."



In addition to scenes that put users in the pilot seat of the command module (inset), Apollo 11 VR also features a number of cinematic sequences intended to inspire users with the grandeur anddrama of spaceflight (background).

That phrase is central to the work of NASA Headquarters' History Division, which maintains the agency's historical websites. The two historians there coordinate with volunteers to offer information on a variety of projects, and the Apollo mission pages are among the most popular NASA archives online.

These repositories provided the company with detailed design plans for the interiors of the spacecraft, the lander, and the command module. The developers found a photo mosaic of the initial landing site, created from many photos taken on earlier Apollo flights stitched together, and drew their virtual world on top of that image. Apollo 11 VR also includes original audio heightened with stirring music.

Though popular as a paid app, the program is free for teachers wishing to show it to their students. In its first year, Apollo 11 VR was purchased more than 40,000 times. The company went on to develop a free Mars rover experience and is planning projects about other NASA missions.

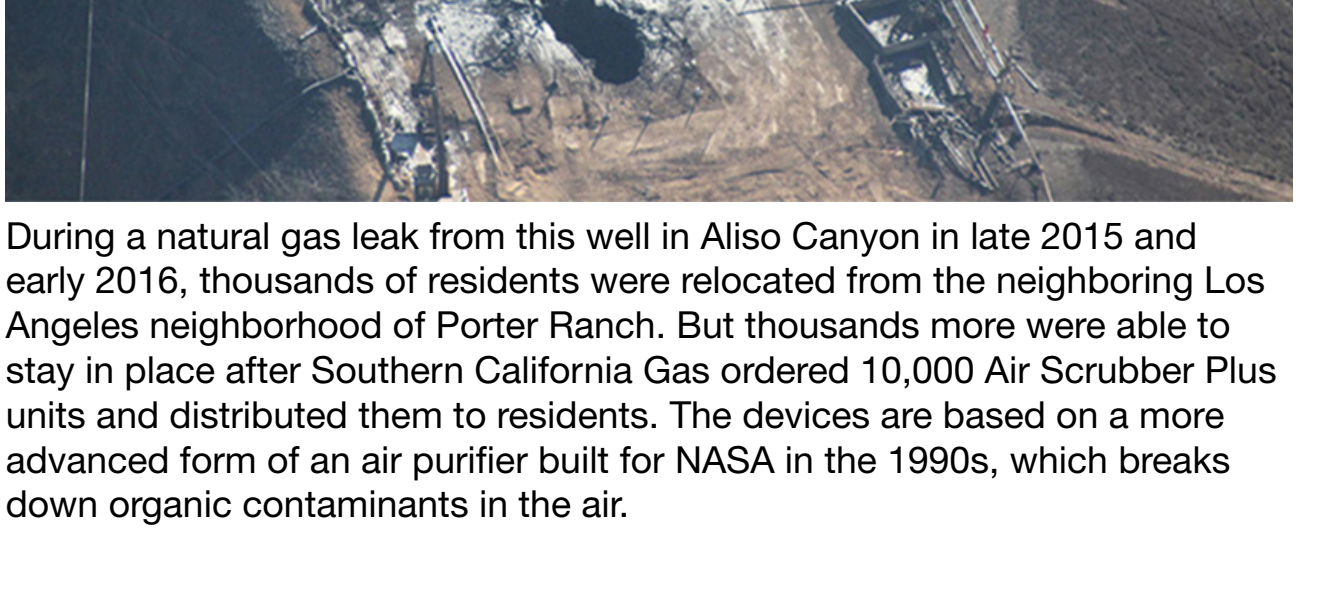
Light-Induced Oxidation Cleans Air, Surfaces, Clothes

In late 2015 and early 2016, while Southern California Gas workers struggled for months to stop a natural gas leak from a well at Aliso Canyon in Los Angeles, thousands of residents of the neighboring Porter Ranch community—and even two of its schools—were relocated. A device based on a NASA invention, however, allowed thousands more to stay in their homes.

During a natural gas leak from this well in Aliso Canyon in late 2015 and early 2016, thousands of residents were relocated from the neighboring Los Angeles neighborhood of Porter Ranch. But thousands more were able to stay in place after Southern California Gas ordered 10,000 Air Scrubber Plus units and distributed them to residents. The devices are based on a more advanced form of an air purifier built for NASA in the 1990s, which breaks down organic contaminants in the air.

SoCalGas ordered and installed more than 10,000 of Aerus Holdings' Air Scrubber Plus air- and surface-purifying devices in Porter Ranch homes.

Central to the devices is a discovery made in the 1990s at the Wisconsin Center for Space Automation and Robotics, a NASA Research Partnership Center that was funded by Marshall Space Flight Center. Researchers there were trying to eliminate ethylene that accumulates around plants when they hit on photocatalytic oxidation, which eliminates not just ethylene but other airborne organic compounds and also neutralizes bacteria, viruses, and molds.



Aerus has adapted its NASA-derived ActivePure technology to a variety of products. The Beyond Guardian Air unit (top) can purify the air in a 2,000 square-foot space at one air change per hour, while the Laundry Pro product line (bottom) makes unlikely use of this air purification technology with units that hook up to clothes washing machines to eliminate the need for detergent, bleach, and hot water.

Several companies have capitalized on the discovery, creating products for home, industrial, office, and outdoor use. In 2009, Aerus acquired a company that had a proprietary form of the technology called ActivePure, which sent oxidizers out into the surrounding environment, where they could not only purify the air but also settle on and clean surfaces.

Aerus, based in Dallas, made further improvements and incorporated ActivePure into a host of product lines for use in homes, hospitals, hotels, athletic facilities, schools, and even automobiles and clothes washing machines.

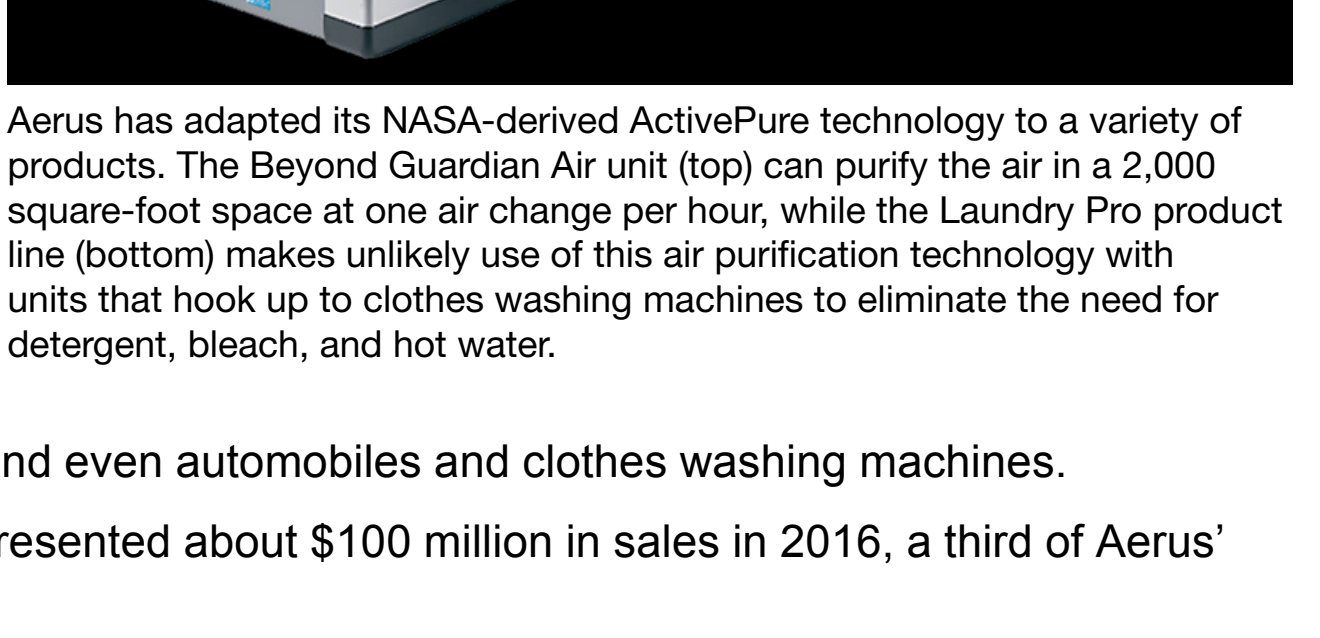
The devices are sold in 72 countries and represented about $100 million in sales in 2016, a third of Aerus' total sales.

Studies found that even seemingly sterile hospital environments benefit from the technology, which has also been found to reduce rates of MRSA and staph infections, school absences, allergies, and asthma.

Ferrofluid Technology Becomes a Magnet for Pioneering Artists

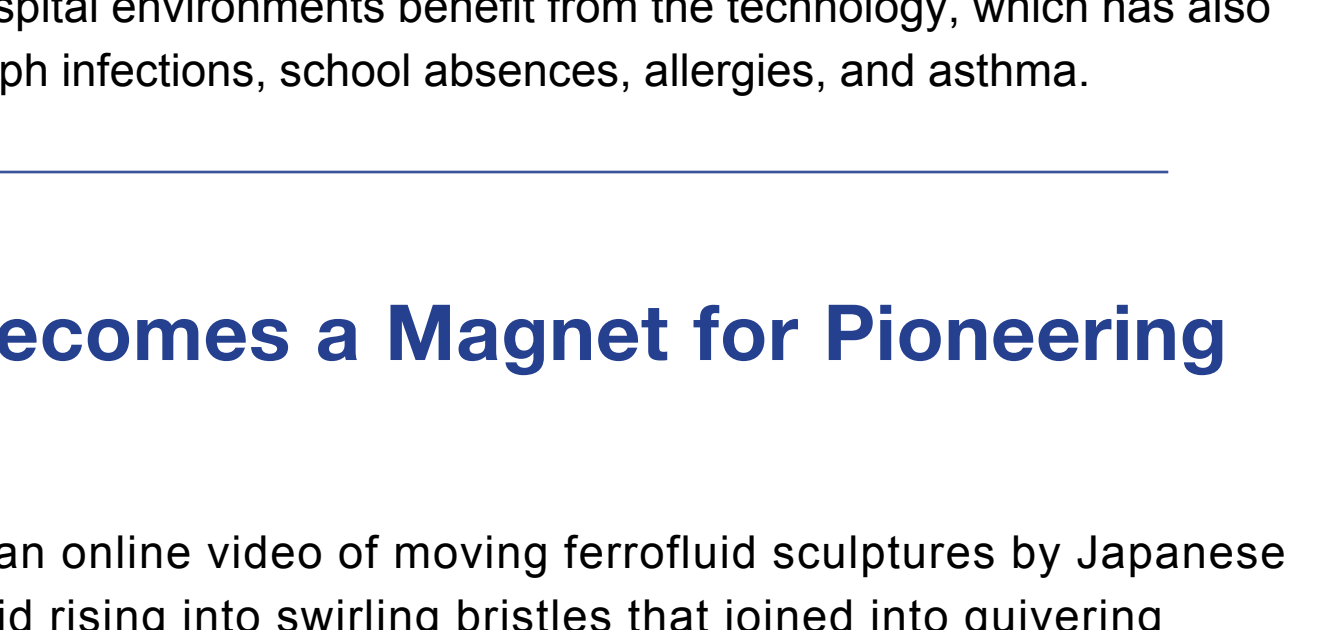
In 2008, when Nikola Ilic came across an online video of moving ferrofluid sculptures by Japanese artist Sachiko Kodama, with black liquid rising into swirling bristles that joined into quivering spikes, the artist-entrepreneur immediately wanted a ferrofluid display for his desk.

But he couldn't find a display of the magnetized liquid available for sale anywhere online. So he decided to make his own—and soon learned why more people weren't doing it. In a typical display, a small amount of dark ferrofluid is placed in a clear glass chamber full of a clear suspension liquid. It's then manipulated by a magnet outside the chamber. But if the ferrofluid mixes with the suspension liquid, it stains the glass and makes a mess.



Magnetic ferrofluids invented at Glenn Research Center have lately found their way into the art world.Nikola Ilic developed a suspension liquid that keeps ferrofluid from staining its container and founded Concept Zero, which sells products like Motion, pictured here.

The first magnetized liquid was made at Glenn Research Center in the 1960s as a way to draw fuel from a tank to an engine in the absence of gravity. A few years later, a NASA contractor called Avco Space Systems further developed ferrofluid and created liquids that ranged up to 10 times the magnetic strength of the initial invention. Two Avco employees founded a company now known as Ferrotec to capitalize on the technology, which has found a number of industrial uses.



Concept Zero recently partnered with artist Linden Gledhill to launch a line of Gledhill's art. He created the images by using a magnetic field to manipulate ferrofluids diluted with solvents and photographing the results.

In the last 20 years or so, artists have begun working with ferrofluid.

Ilic, who gets his ferrofluid from Ferrotec, finally hit on a practical suspension liquid and founded Hamburg, New Jersey-based Concept Zero, which now markets a line of ferrofluid displays.

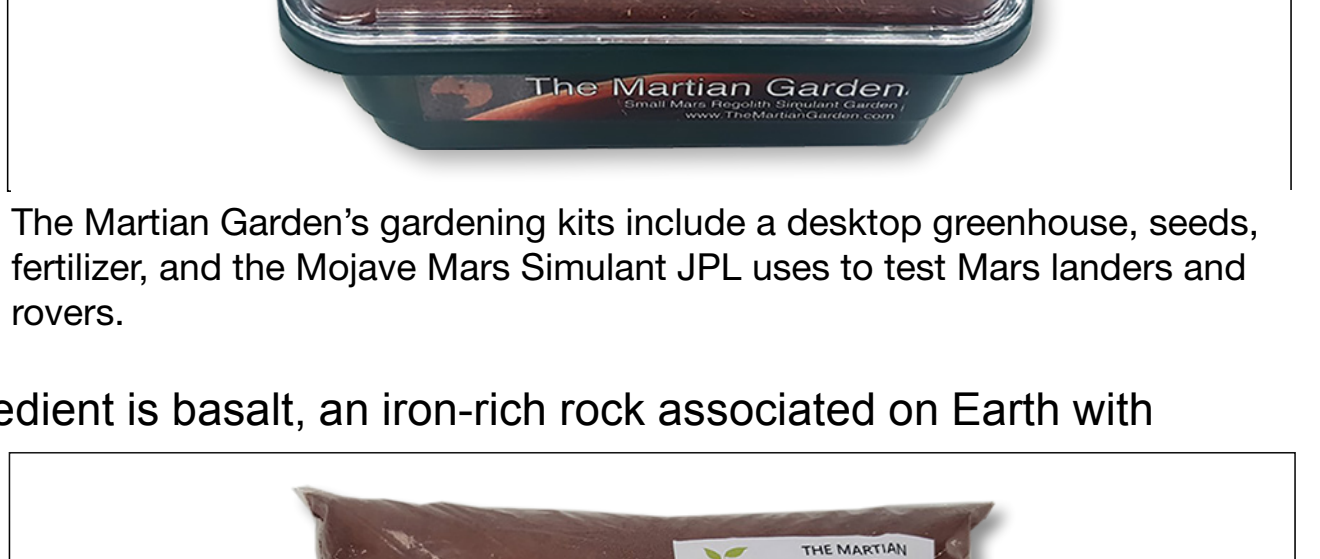
Ilic partners with a number of other ferrofluid artists, including providing suspension fluid or coordinating publicity. These artists have used ferrofluid to create lava lamp-like displays, abstract photography, a digital clock, and even a horror movie that uses the substance as its monster.

The Martian Garden Recreates Red Planet's Surface

Unexpected difficulties that have confronted rovers and landers on other worlds might have been avoided if engineers building them had more accurate testing environments, including "simulants" imitating the dirt, dust, and rock of a given planet. As a 2012 NASA paper notes, technology sent to other planets and moons "is only as good as the simulants used to test it."

The Martian Garden's gardening kits include a desktop greenhouse, seeds, fertilizer, and the Mojave Mars Simulant JPL uses to test Mars landers and rovers.

No surface samples from Mars have been returned to Earth. But orbiters have recorded surface compositions across the planet, and robotic explorers have investigated various sites. A major ingredient is basalt, an iron-rich rock associated on Earth with volcanoes—so that's where NASA researchers go to look for Mars simulants.



While The Martian Garden sold enough gardening kits to meet its Kickstarter fundraising goal, the company has found that individual bags of its Mars surface simulant, based on JPL testing that found crushed basalt from a quarry in the Mojave Desert to be similar to the surface of the Red Planet, may be an even better seller. It's marketed in packages of up to 10 pounds.

Since the 1990s, they've used particles ejected from Pu'u Nene volcano in Hawaii, but these tended to attract moisture and become clay-like. In 2006, an engineer at the Jet Propulsion Laboratory (JPL) tested material from a mountaintop basalt quarry in the Mojave Desert and found it was chemically and mineralogically similar to the Martian surface. It also didn't attract water and become muddy. Mojave Mars Simulant (MMS) was born.

Meanwhile, two friends in Austin, Texas had the idea to market a kit that would simulate the challenge of gardening on Mars. But they only knew of the Hawaiian simulant, which was cost-prohibitive because of the shipping distance. When they learned of MMS, they founded The Martian Garden.

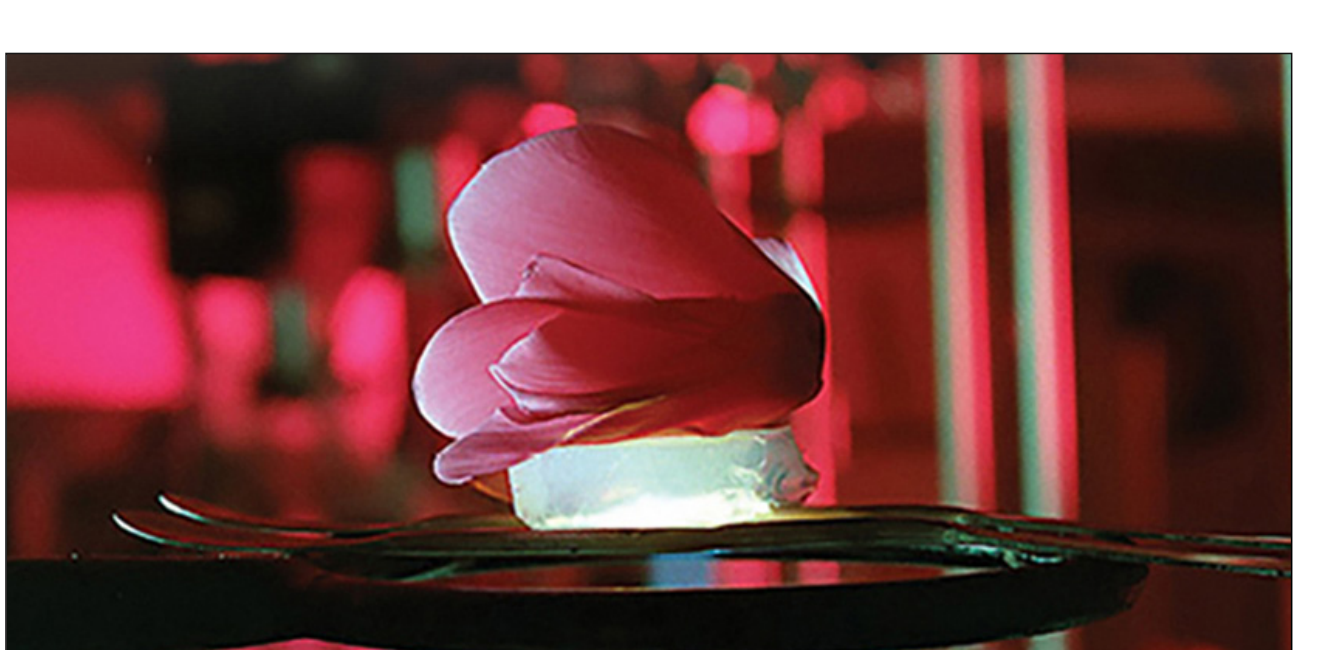
By April of 2017, the company had already sold more than 1,500 pounds of simulant and about 160 garden kits, complete with a desktop greenhouse, seeds, and fertilizer. The Mars-like dirt on its own has proven to be the biggest seller, with orders of up to 200 pounds. The company also now offers an even more accurate version, called MMS-2, for research purposes.

The primary markets for The Martian Garden's products are elementary through high school teachers and researchers at universities.

Aerogel Insulation Makes Thinner, Warmer Outerwear

When Michael Markesbery, future cofounder of Oros, climbed the tallest mountain in the Swiss Alps with friends, he was so bundled up he could barely move his arms.

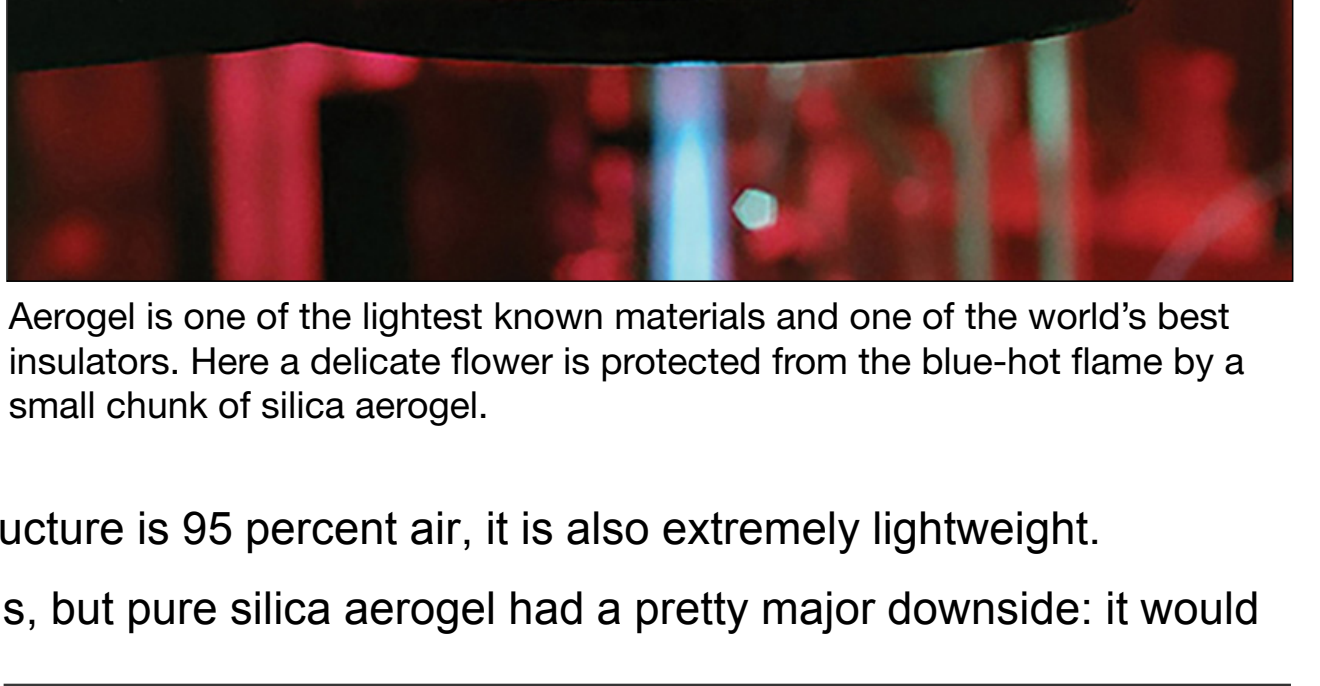
"I remember thinking, it's the 21st century, but I still have to wear all this bulk and layers to stay warm?" recalls Markesbery. Actually, something already existed to make incredibly warm outerwear with far less bulk, and it owes much of its development to NASA.



Aerogel is one of the lightest known materials and one of the world's best insulators. Here a delicate flower is protected from the blue-hot flame by a small chunk of silica aerogel.

The material, silica aerogel, was first invented nearly 100 years ago. A solid filled with nanopores, silica aerogel is an incredibly good insulator, and because its structure is 95 percent air, it is also extremely lightweight.

The possible space applications were obvious, but pure silica aerogel had a pretty major downside: it would crack under the slightest pressure. So for decades, it was hardly ever used.



Oros makes extra-lightweight outwear lined with aerogelinfused insulation. NASA helped drive the innovations that made aerogel practical for apparel—in its original form, silica aerogel was extremely brittle, but it can be used in composites that are durable and flexible.

In the 1990s, NASA helped change that. Aspen Technologies, under Small Business Innovation Research contracts from Kennedy Space Center, infused the brittle material into flexible, durable composite blankets.

Decades later, Markesbery learned of the aerogel insulation when he won a scholarship from the Astronaut Scholarship Foundation. He took the $10,000 award and additional seed money and started making jackets with Aspen Aerogel insulation.

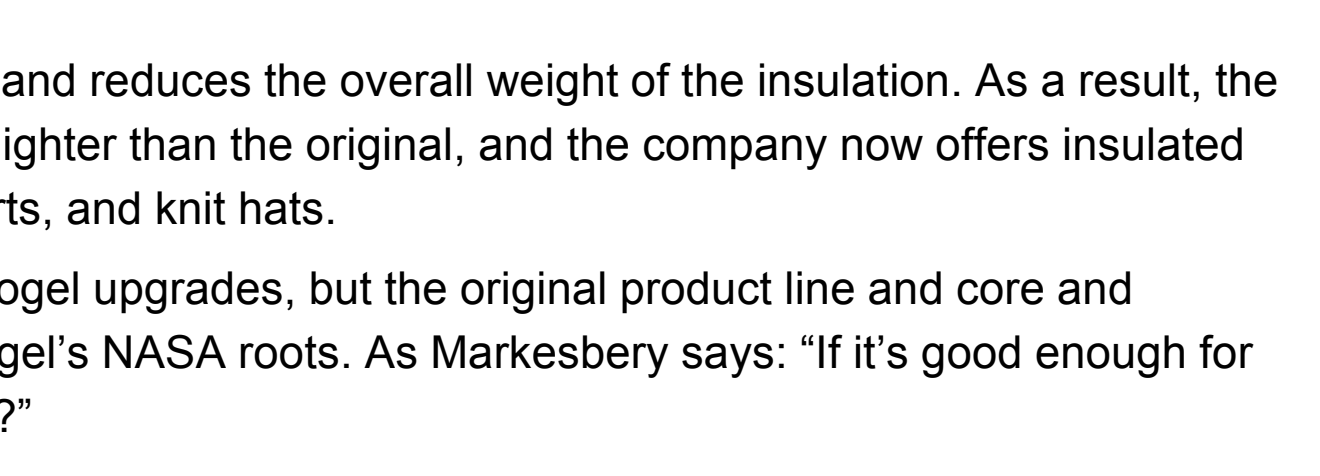
An initial Kickstarter campaign quickly raised more than $300,000 and sold more than 1,100 jackets—and the Cincinnati-based company continues to improve the aerogel insulation in its ever-expanding product line. Its proprietary SolarCore insulation increases breathability for comfort and reduces the overall weight of the insulation. As a result, the next-generation jacket is at least 40 percent lighter than the original, and the company now offers insulated gloves, leggings, snow pants, base-layer shirts, and knit hats.

The company continues its research into aerogel upgrades, but the original product line and core and inspiration for development started with aerogel's NASA roots. As Markesbery says: "If it's good enough for space, shouldn't it be good enough for Earth?"

Space-Grade Insulation Keeps Beer Colder on Earth

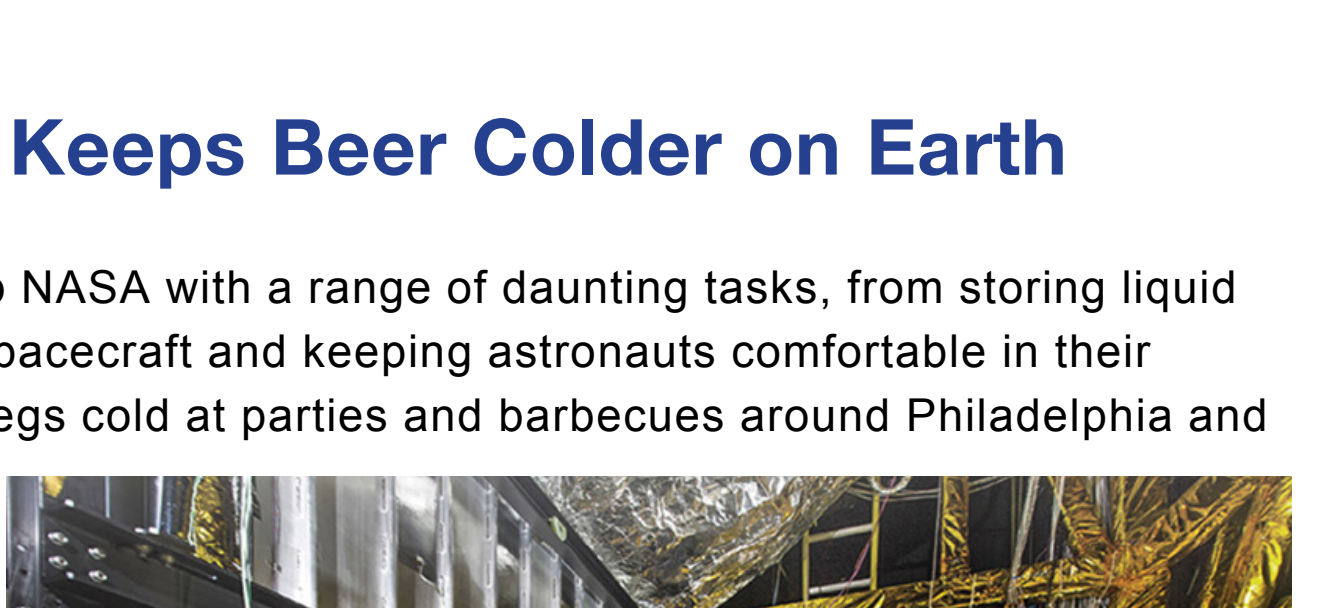
A class of insulation invented to help NASA with a range of daunting tasks, from storing liquid hydrogen or helium to insulating spacecraft and keeping astronauts comfortable in their spacesuits, is now keeping beer kegs cold at parties and barbecues around Philadelphia and beyond.

In the early days of the space agency, its engineers calculated that, to protect an astronaut from the temperature extremes of space, traditional insulation, which prevents temperature conduction, would have to be several feet thick. Instead, NASA pioneered and mastered reflective insulation, now known as radiant barrier technology.



In Goddard Space Flight Center's Space Environment Simulator, an engineer lays radiant barrier insulation over wires on the floor, keeping the heat they generate from contaminating the chamber, which is used to mimic the environmental conditions of space.

The first multilayer reflective insulations were made under contract to Marshall Space Flight Center in the mid-1960s. Insulation made from crinkled, aluminized sheets of polyester thin film proved remarkably effective for their weight, and NASA went on to make improvements to all aspects of the technology, resulting in a host of "superinsulators" that are strong, lightweight, inexpensive, highly effective, and used in every spacecraft and spacesuit.



KegSheet beer keg insulators made with multilayer reflective thin-film insulation pioneered by NASA, are not just effective but also lightweight and low-mass, folding up small enough to fit in a back pocket.

Radiant barrier insulation has found countless applications on Earth.

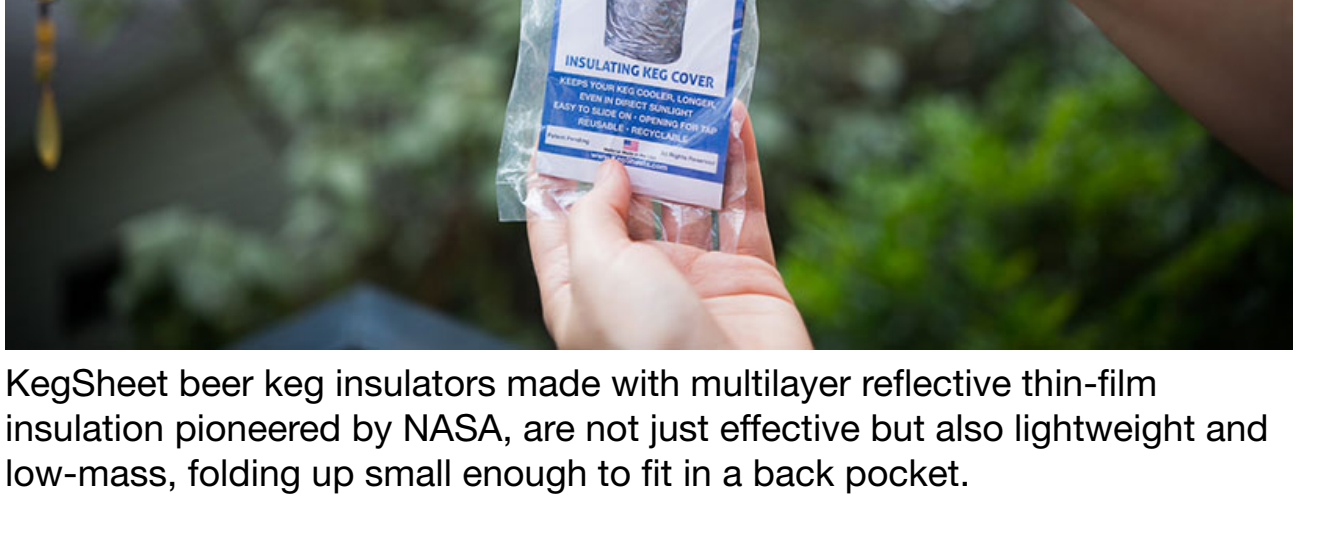
In June of 2015, the evening before the annual Philadelphia International Cycling Classic, Dan Gwiazdowski and friends were contemplating how to keep a keg cold for the next day's backyard get-together along the race route. A radiant-barrier emergency blanket ended up working better than expected, and Gwiazdowski had an idea.

Ultimately, a company founded by a former employee of an early supplier of NASA radiant barrier insulation agreed to manufacture Gwiazdowski's product—radiant-barrier keg jackets he calls KegSheets. He now sells them through the company he had founded in 2011, Philadelphia-based JUNTO LLC.

The KegSheet is strong, reusable, and recyclable, and it folds up small enough to fit in a back pocket. And it keeps a keg cold all day, particularly when used together with ice.

High-Efficiency LEDs Grow Crops, Stimulate Alertness

NASA harnesses the power of light for purposes as varied as laser communications, 3D mapping of land surfaces, and spectroscopy to determine the composition of distant stars.



Neil Yorio, vice president of lighting research for agriculture at BIOS Lighting, prepares to test one of the company's Icarus LED grow lights in a light chamber. Yorio started using LED lighting for agriculture as a NASA contractor in the 1990s.

The most important light-driven organic process on Earth is photosynthesis, by which plants convert sunlight into chemical energy, driving the entire food chain. But light also plays a crucial role in biological cycles related to sleeping and waking. In 2001, an advisor to NASA demonstrated the existence of a light receptor in the mammalian eye that is responsible for regulating both pupil constriction and circadian rhythms.

The space agency has been a pioneer in adapting LEDs to agricultural uses since the 1990s, interested in a safe and efficient light source for growing plants in space, and NASA also collaborated in groundbreaking studies that found that certain blue wavelengths regulate circadian rhythms by suppressing melatonin to induce wakefulness.

BIOS Lighting's SkyBlue interior LED lighting technology mimics sunlight, including the melatonin-suppressing blue-green light that induces wakefulness, while producing true colors. BIOS partners with other companies to create both small-scale home lighting and systems for offices and retail space

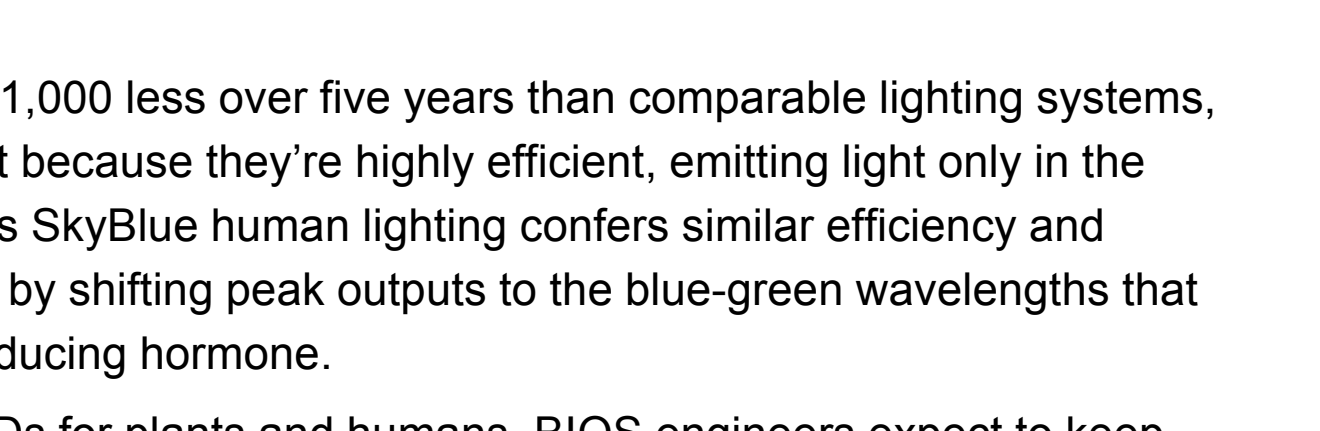
Two former Kennedy Space Center contractors—one who worked on space agriculture, including LED grow lights, and one who helped design a tunable LED module to provide astronauts on the space station with lighting that would help regulate their sleep cycles—are now lead engineers at Melbourne, Florida-based BIOS Lighting, which produces LED systems for indoor agricultural and human lighting.

The company's LED grow lights cost about $1,000 less over five years than comparable lighting systems, in part because they last for years and in part because they're highly efficient, emitting light only in the frequencies that drive photosynthesis. BIOS's SkyBlue human lighting confers similar efficiency and also stimulates wakefulness and productivity by shifting peak outputs to the blue-green wavelengths that suppress production of melatonin, a sleep-inducing hormone.

As NASA continues to pioneer the use of LEDs for plants and humans, BIOS engineers expect to keep incorporating lessons from the space agency into their products.

Paired Sleep Tracker, Light Therapy Tools Retrain Circadian Rhythms

Lack of sleep could be costing the U.S. economy around $411 billion a year, according to a 2016 estimate by the RAND Corporation. That same year, a National Sleep Foundation survey found that 3 percent of American adults—amounting to more than 7 million drivers—had dozed off behind the wheel during the two weeks before the survey.



Maintaining a regular sleep schedule is difficult for astronauts, who don't experience 24-hour daylight cycles, so the NASA funded National Space Biomedical Research Institute has collaborated on several groundbreaking studies to understand how artificial light can be used to retrain circadian rhythms.

Many factors contribute to sleeplessness, but researchers are finding that a major one is light exposure—and not just the amount of light but its color. In today's indoor culture, most people get little exposure to sunlight.

Since around 2000, the National Space Biomedical Research Institute, funded by Johnson Space Center, has collaborated with a number of other institutions in several groundbreaking studies to advance understanding of light's influence on circadian rhythms. NASA's interest is that astronauts don't experience the 24-hour daylight cycle and thus often have trouble sleeping.

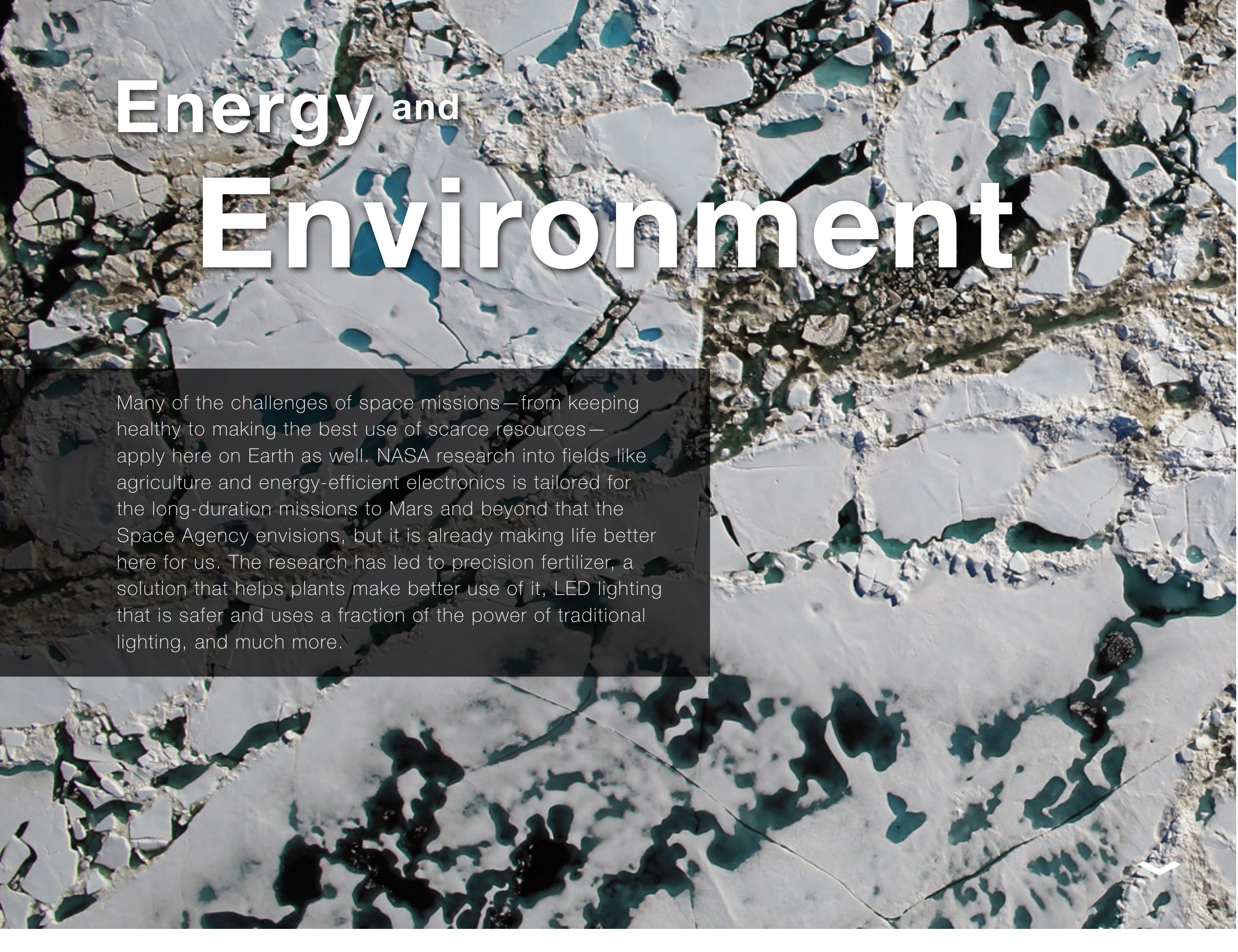
These have demonstrated that, in addition to image-forming rods and cones, the human eye has a third type of photoreceptor that influences circadian rhythms. The intrinsically photosensitive retinal ganglion cell suppresses production of melatonin, a sleep-inducing hormone, when exposed to light in the blue-green wavelengths.

A tunable LED lamp, the portable Circadia light therapy device provides alertness-inducing shortwavelength light for much of the day, followed by redder light toward bedtime. Precise times and wavelengths are based on the user's sleep patterns.

Circadia, a startup based in London and San Francisco, built on the research to create a system that provides light therapy based on the user's sleep patterns.

The company's wall-mounted, radar-based sleep tracker monitors the user's sleep phases. This data is fed to a smartphone app built on software created with partial NASA funding, which programs the day's light therapy, delivered by a portable, tunable LED unit. Short, blue-ish light during the day stimulates wakefulness, which promotes sleepiness at night, but specific wavelengths and exposure durations are determined by the user's sleep data.

Circadia says it is the only system that combines sleep diagnostics and light therapy in a closed loop.



Energy and Environment

Many of the challenges of space missions—from keeping healthy to making the best use of scarce resources—apply here on Earth as well. NASA research into fields like agriculture and energy-efficient electronics is tailored for the long-duration missions to Mars and beyond that the Space Agency envisions, but it is already making life better here for us. The research has led to precision fertilizer, a solution that helps plants make better use of it, LED lighting that is safer and uses a fraction of the power of traditional lighting, and much more.

Organic Compound Turns Toxic Waste into Harmless Byproducts

In 2004, researchers at New Mexico Highlands University (NMHU) were trying to develop a substance that would glow to indicate the presence of hydrazine, a toxic, flammable, unstable compound often used as rocket fuel. To their surprise, the first attempt did more than they'd hoped. It didn't just react with hydrazine—it neutralized it.

Hydrazine Neutralizing Solutions Inc., which markets AKGA-based hydrazine cleanup products as ZeenKleen, found its first customers in nuclear power plants, which use hydrazine to prevent corrosion in their boilers.

Since signing a 1997 Space Act Agreement with Johnson Space Center, the team had worked to improve a hydrazine-absorbing pad originally developed by Johnson's White Sands Test Facility. In this new attempt to make hydrazine glow, organic chemist Rudy Martinez, who had just joined the group, identified alpha-ketoglutaric acid (AKGA), a common metabolite, as a molecule that would likely react with the substance. Indeed, it quickly and irreversibly broke hydrazine down into harmless byproducts.

The university contacted the hydrazine specialist at Kennedy Space Center, where about 15,000 gallons of hydrazine waste are generated each year. Disposing of that waste is costly and presents safety concerns.

Kennedy funded a series of experiments to determine the effectiveness and ideal procedures for neutralizing hydrazine with AKGA. This came to the attention of the Cape Canaveral Air Force Station Sewage Treatment Plant, which partnered with Kennedy and the University of Central Florida to evaluate the possible impacts of disposing of the byproducts through the sewer system.

The Mars Atmosphere Volatility Evolution (MAVEN) propulsion system is powered by a 450-gallon tank of hydrazine. Although hazardous, hydrazine and its derivatives are efficient fuels that require no ignition or oxidation, so they are often used in secondary thrusters for large spacecraft and primary thrusters for probes and satellites.

Image courtesy of Lockheed Martin

Following those tests and Kennedy's creation of procedures for disposal into the sewer, the Air Force obtained permits for the center to treat hydrazine with AKGA and dump the end product down the drain.

NMHU licensed its invention to Millennium Enterprises, which created Marietta, Georgia-based Hydrazine Neutralizing Solutions Inc. to market it, in various forms, under the name of ZeenKleen. Martinez is the business's director of chemistry.

The company has found customers in the nuclear power industry and could find more in plastic, pesticide, and pharmaceutical manufacturing, all of which use hydrazine.

LED Lighting Improves Efficiency, Imaging, Cuts Maintenance

When Stennis Space Center officials wanted to try more energy-efficient lighting for rocket engine test stands, they couldn't simply go out and buy the latest LED bulbs. Anything that will share a room with a rocket engine generating half a million pounds of thrust, 120 decibels of vibration, and temperatures in the thousands of degrees by ejecting hot gases at more than a dozen times the speed of sound needs special engineering.

Under contracts with Stennis Space Center, Energy Focus designed LED floodlights that could withstand conditions inside a rocket engine test stand and would not pose a hazard themselves.

Stennis wanted to try LEDs in floodlights to illuminate rocket engine testing in one test stand and for general area lighting in a testing complex, and in 2009, it issued two Small Business Innovation Research contracts to Solon, Ohio-based Energy Focus to develop the lights.

To meet Stennis' needs, the company had to improve its heat management techniques, which led to longer lifespans in virtually all of its products. Meanwhile, the work led to floodlights and general area lights for commercial use in hazardous areas. To boost efficiency, the company also came up with highly efficient optical cones that minimize stray light, which have worked their way into other products.

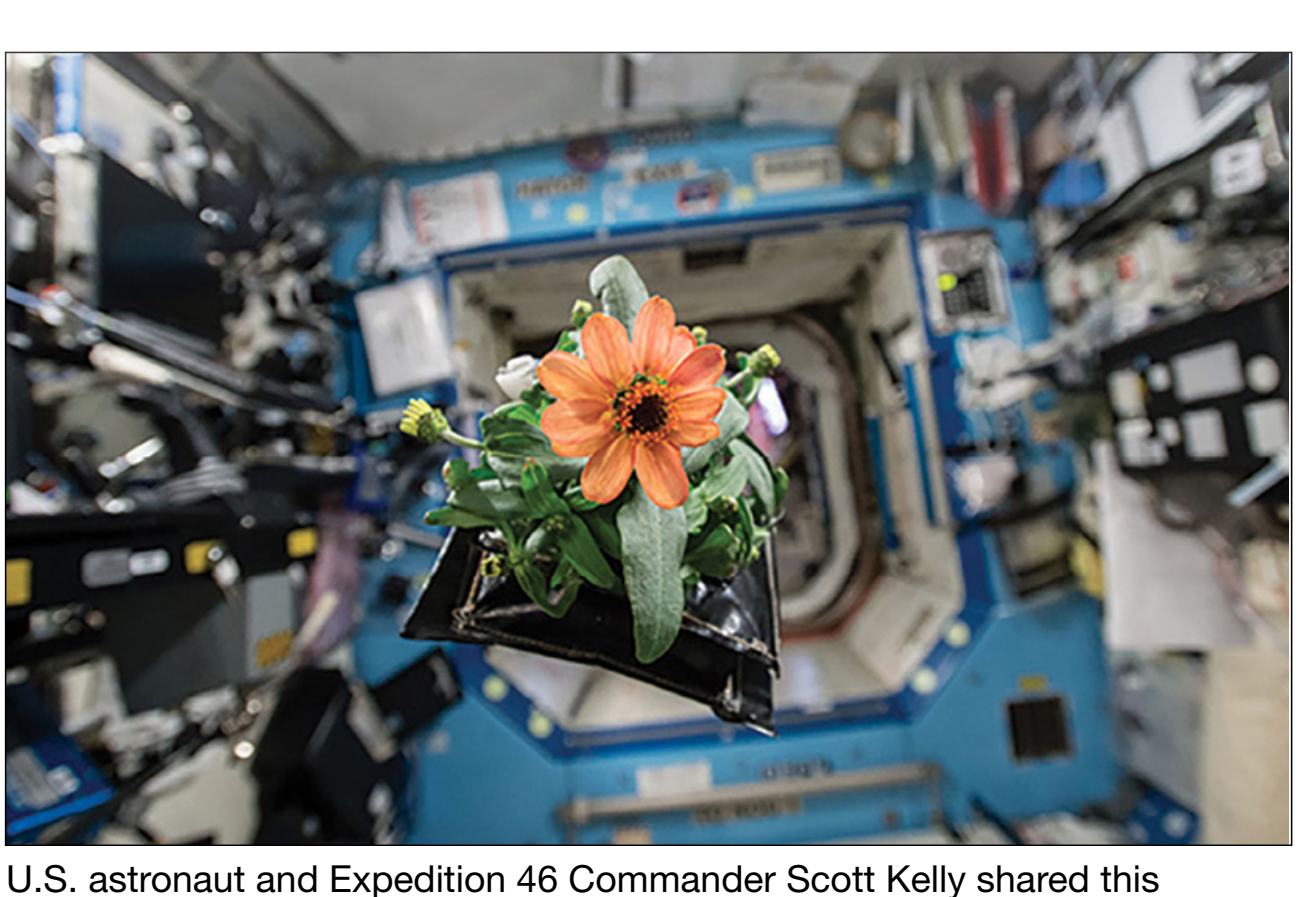
Some of the first lighting designed for hazardous areas was for use in coal mines. Energy Focus now offers more energy-efficient, long-lived LED lighting for hazardous areas, following work the company did to provide general area lighting in a rocket engine testing complex.

The company says its popular Intellitube—an LED replacement for fluorescent tube lighting—is twice as efficient as its original version, thanks in part to better heat management. The floodlights at Stennis use less than a third of the energy consumed by their metal halide predecessors to produce the same amount of light. The new lights also produce a cleaner, whiter light that's better for scientific imaging.

The biggest advantage of Energy Focus' lighting, though, is its lifespan. The company offers an unqualified 10-year guarantee on most products—five years for hazardous areas. This saves money and, in the case of very large customers, like a Navy destroyer, manpower.

Plant Food for Space Grows Crops on Earth

The goal is a fresh, tasty salad on Mars. While other NASA programs are working on getting to the Red Planet, the agency's Veggie team at Kennedy Space Center is figuring out how to grow fresh ingredients there, with an interim goal of a salad on the International Space Station (ISS).



U.S. astronaut and Expedition 46 Commander Scott Kelly shared this photograph of a blooming zinnia flower in the Veggie plant growth system aboard the space station in early 2016. This experiment in flowering plants precedes planned tests of growing tomatoes and peppers in space.

To grow romaine lettuce on the ISS, NASA worked with Sarasota, Florida-based Florikan, a company that had already partnered with the agency to develop polymer-coated, controlled-release fertilizer systems. By 2015, astronauts on the ISS became the first to eat food grown in space.

But flowering vegetables like tomatoes and peppers are key to excellent salads, and they require a different balance of nutrients in fertilizer. On Earth, farmers might just grow them with the original formula and some added potassium, but this isn't practical in space, where astronauts have more important things to do.

Florikan came up with a new formula, specifically designed for hydroponically grown flowering plants, still coated for controlled release. The result was a 14-4-14 NPK formulation—14 parts nitrogen, 4 parts phosphate, and 14 parts potassium.

By the time the formula was patented in 2016, it was already being used in NASA experiments and commercial hydroponics. It's the first controlled-release fertilizer to work successfully in vertical hydroponic farming, eliminating liquid feed and the need for multiple applications.

These Red Robin tomatoes, shown growing in vertical hydroponics at Sweetgrass Farms, benefited from a special fertilizer formula developed by Florikan for use in space.

An early commercial adaptor of the formula was Sweetgrass Farm in Sarasota. After just a single, initial application, the hydroponic farm says, plants grew up "healthy, vibrant, productive, and of exceptional quality."

The company's timed-release fertilizers, all of which were improved when the company was granted 40 hours of consulting with a Kennedy researcher in 2005, also save money and reduce pollution, because farmers don't have to use as much, as less gets lost in runoff that contaminates watersheds.

Remote Sensing Technology Fights Forest Fires Smarter

Fires were raging in Northern California in June 2008, at the height of one of the state's most destructive wildfire seasons, and one blaze was headed right toward the town of Paradise. Well, maybe.

NASA used its unmanned Ikhana aircraft to test technology it helped develop or recommended to the U.S. Forest Service, including a system to send sensor data to decision makers on the ground in near real time.

It's not so easy to figure out the future path of a forest fire—a lot depends on wind and other constantly changing factors. But it's crucially important to be as accurate as possible when making predictions.

Sensors mounted on an airplane or drone can help—and that's where NASA comes in. For decades, the Space Agency has shared technical expertise with the Forest Service. "It's a positive feedback loop: we have the information needs, and NASA has the requisite expertise in those areas," says Everett Hinkley, National Remote Sensing Program manager for the Forest Service.

One collaboration included testing how to send data in near real time to the ground via communications links installed directly on an aircraft.

Remote sensing data helps ensure trucks like these are sent to the most effective points to battle wildfires. This map shows results from a night flight over a 2014 fire in New Mexico: the yellow represents fire spots detected by the autonomous modular sensor, andv the red shows fire intensity (hot spots and intense burning, versus smoldering) as detected by an infrared sensor.

For the Forest Service, based in Washington, D.C., this was a much-needed upgrade to its original system: rolling up a printout of thermal sensor data into a plastic tube and dropping it out of the airplane with a parachute. With a downlink connection, the data would arrive faster and could be sent to multiple recipients at once.

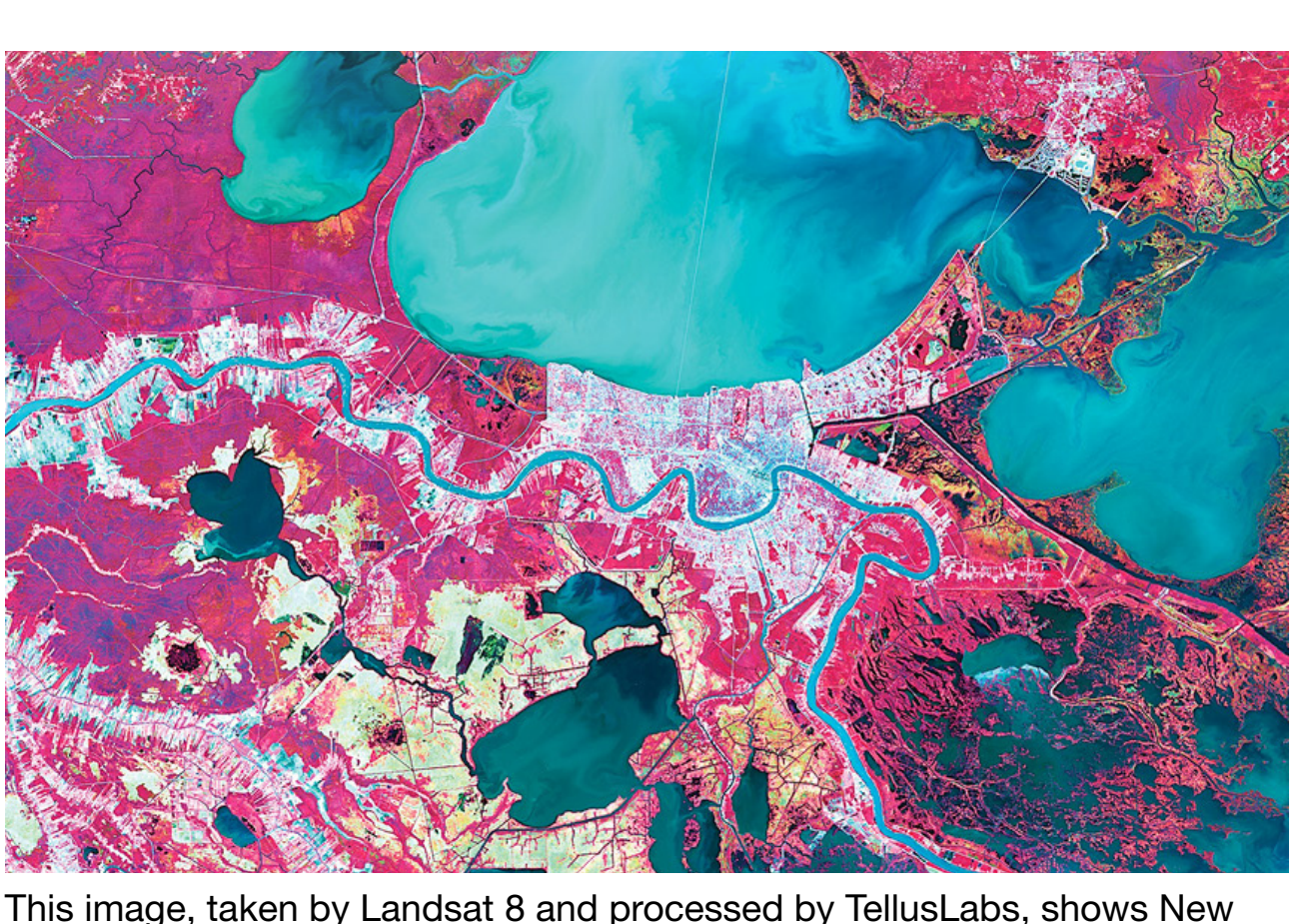
"NASA helped us with the evaluation and testing of the various systems to see which one would work best for us," Hinkley says, and ultimately recommended a commercial aircraft-to-ground wireless system.

"It means we can do more fires per night, 10 or more on busy nights," says Hinkley. "And it means fewer takeoffs and landings, which increases safety for the pilot and crew on board."

In California in 2008, all that paid off—big time—when a NASA test flight using a data downlink system was able to provide updated information to the incident managers around the town of Paradise. Without that timely information, says Ames Research Center's Don Sullivan, "there likely would have been injuries and certainly property damage that was worse than it turned out be."

Earth Images Enable Near-Perfect Crop Predictions

NASA has been taking pictures of Earth from space for as long as the Space Agency has been around—and well before Boston-based startup TellusLabs began using these images to predict corn and soy yields with near-perfect accuracy.

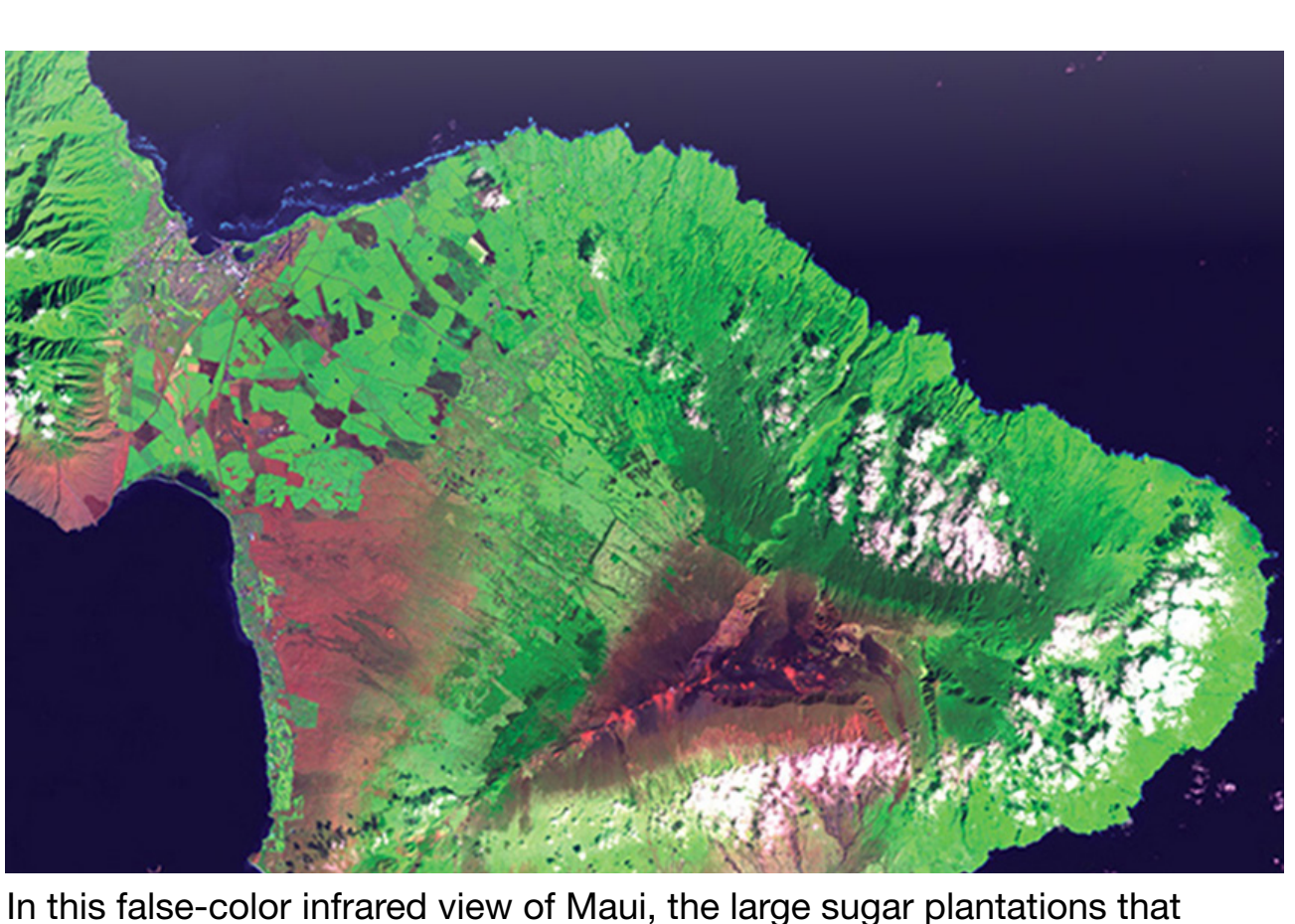


This image, taken by Landsat 8 and processed by TellusLabs, shows New Orleans as it sits along the Gulf of Mexico. Agriculture, largely sugar cane, can be seen along the banks of the Mississippi in light pink and blue. Also apparent are sediment swirls in Lake Pontchartrain to the north and the loss of coastal land south and east of the city.

The Landsat satellite series—built by NASA and managed by the U.S. Geological Survey—has been photographing the planet since 1972 and holds the longest continuous record of space-based Earth observations. Since 1999, the Moderate-Resolution Imaging Spectroradiometer (MODIS) instruments, two of which now orbit Earth on separate satellites, have also been acquiring data on the entire planet every one to two days in 36 spectral bands.

As a remote-sensing scientist at Boston University, TellusLabs cofounder Mark Friedl has worked on the MODIS science team and has affiliate membership on the Landsat science team. His academic work—often involving or funded by NASA—has included mapping global land cover and seasonal variability in growth.

By the time Amazon Web Services began offering significantly simplified access to the Landsat and MODIS datasets in 2013, Friedl was well familiar with them. Over the following years, he and fellow cofounder David Potere built a crop-prediction model that combines current NASA and USGS data streams with historical data and blends them with several other data sources, including weather models.



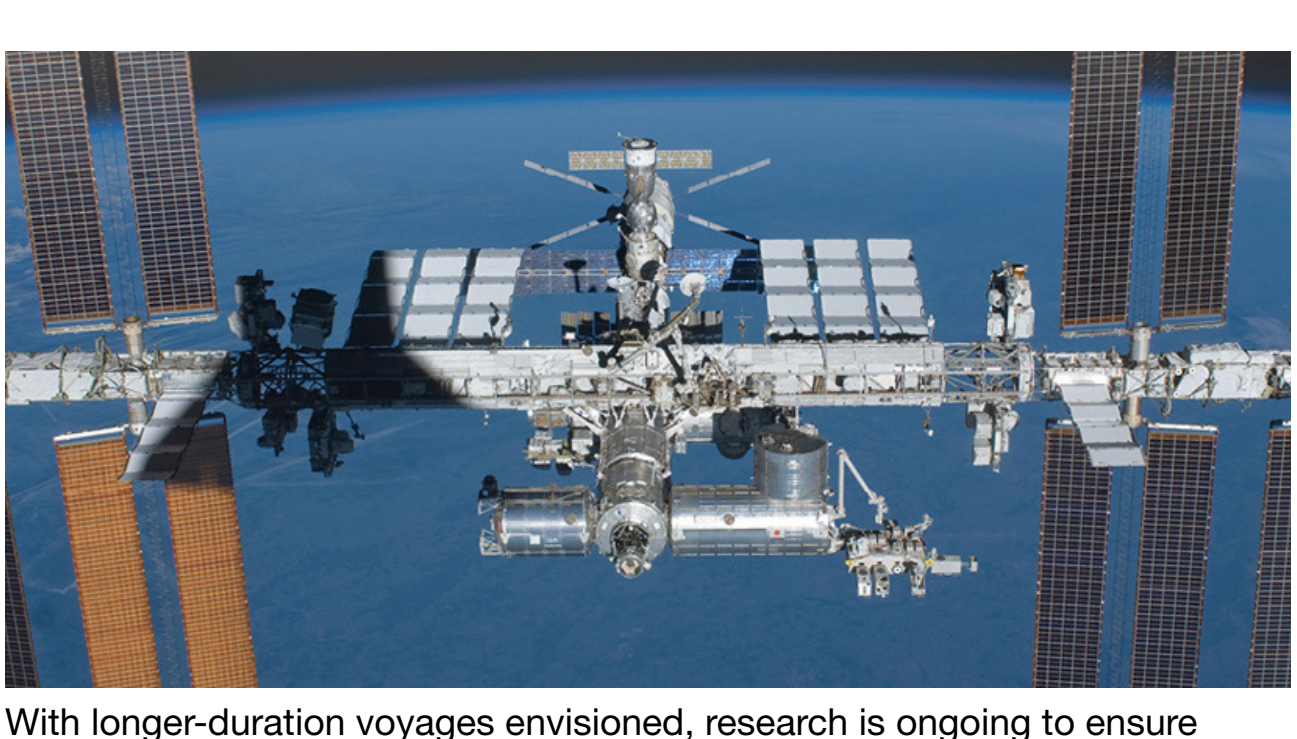
In this false-color infrared view of Maui, the large sugar plantations that dominate the agriculture of that island are on view, wedged in the lowlands between the mountains of Pu'u Kukui on the east and Haleakala in the west.

In its first year, the beta version of TellusLabs' initial product, Kernel, consistently predicted final 2016 yields on U.S. corn and soy crops ahead of all publicly available in-season forecasts and ended up predicting both within 1 percent accuracy.

After a year, TellusLabs had more than 600 subscribers from a wide range of fields. Key groups, the company says, are large institutional investors, individual investors and advisors, a variety of organizations engaged up and down the agricultural value chain, and individual farmers and farming consortia.

Micronutrient Formula Strengthens Plants, Increasing Yields

An apple a day keeps the doctor away—but how do you bring enough apples to Mars and back? Astronauts already take vitamins, but what if extra nutrients could be added to food as it grows? That could also help many areas of Earth, where malnutrition continues to be a terrible problem.



With longer-duration voyages envisioned, research is ongoing to ensure astronauts will be able to maximize nutrition while minimizing cargo space. In 2017, NASA delivered to the ISS broccoli seeds to be grown with a micronutrient formula developed under Space Act Agreements.

The technology comes from Boca Raton, Florida-based Zero Gravity Solutions Inc. (ZGSI), founded by 19-year U.S. Department of Agriculture veteran John Wayne Kennedy. Kennedy was already working with NASA on another project when he began investigating how to increase the nutritional value of plants as they grow. The key, he theorized, was increasing the level of minerals like zinc and copper, which nutritionists include among the "big four" micronutrients.

These micronutrients, explains Ames Research Center plant scientist John Freeman, are crucial for human health and are often lacking in sufficient quantities in the food we eat: "Deficiencies in these four minerals cause illnesses and disease in billions of people worldwide."

The minerals are also necessary for efficient metabolism, so increasing their levels "also makes the plant much healthier," explains ZGSI CEO Harvey Kaye. When treated with BAM-FX, crop yields increase on average by 25 percent, in some cases even when growers used 25 percent less fertilizer, ZGSI says.

Rice plants grown with the micronutrient formula, called BAM-FX, are bigger and healthier than ones grown with traditional methods alone, as seen in this picture from Pakistan. The formula can be applied to the seed at planting time or, as this helicopter is doing in California, sprayed over the leaves as they grow.

In early 2017, Ames Research Center and ZGSI sent a trial batch of broccoli to the International Space Station. Freeman says he hopes future iterations will be given to astronauts to eat.

In the meantime, the formula is already sold around the world as BAM-FX, which stands for Bio-Available Minerals, Formula X.

The company has filled orders from Malaysia, India, and Indonesia, with new studies being conducted in South America.

"Everybody talks about the need to feed 9 billion people in the next number of years, with the same acreage. The notion of continuing to do the same thing we've done for 50 years is not the answer," Kaye says. New technology like BAM-FX, he says, could be.

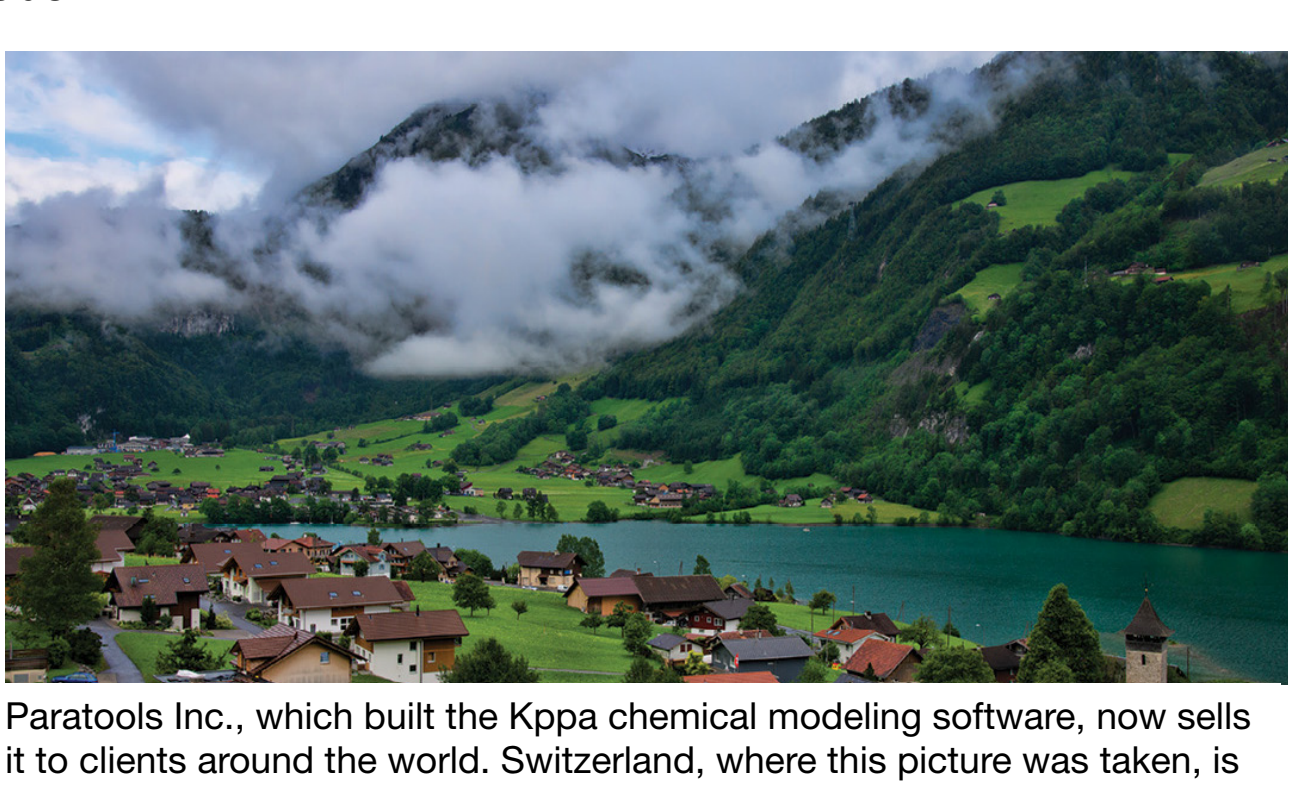
Chemical Simulation Software Predicts Climate Change, Air Quality

Climate scientists need to observe what is happening across the entire planet over long swaths of time—but data from satellites, aircraft, and ground stations are intermittent, unable to offer a complete and continuous picture. Researchers fill the gaps using complex computer models, which smooth out the data for factors like temperature, wind direction, and, one of the more complex dynamics, chemical reactions.

Simulating the many chemical reactions that occur constantly across the atmosphere is a complex task. New software designed with NASA funding is helping scientists study climate and weather.

"The chemicals in the atmosphere all interact with each other and with light from the sun," explains Tom Clune, a senior computational scientist at Goddard Space Flight Center. That makes the calculations very expensive in terms of processing power. NASA began using computers to help back in the 1970s, but with new microprocessors increasingly powerful and cheap, the software was due for an upgrade.

Clune had begun trying to work up a new solver for chemical reactions when he found out that a private company already had taken on the challenge—and received a Small Business Innovation Research contract from Ames Research Center to help fund the project.



Paratools Inc., which built the Kppa chemical modeling software, now sells it to clients around the world. Switzerland, where this picture was taken, is using it to run their national air quality reports.

The company was Baltimore-based ParaTools Inc., and the software was Kppa, developed by John Linford. "Talking to him, I quickly realized that all of the things I had been planning to do, he had done already—and then some," Clune says.

There are at least three projects at NASA that could benefit from Kppa, Clune says, including the GEOS-5 model he works on, which needs to solve the chemical reactions to model climate and weather.

The Agency is exploring whether to license Kppa from ParaTools—and NASA isn't the only entity interested.

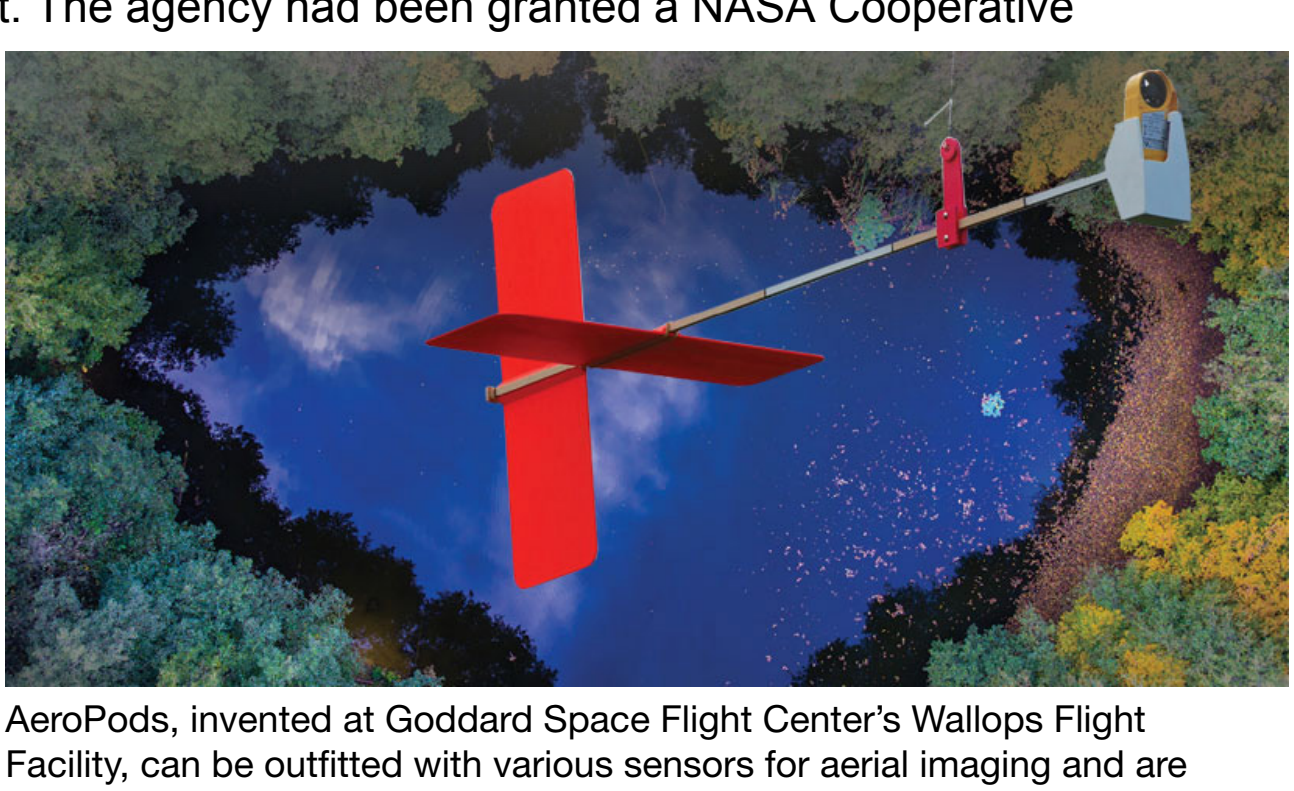
"The Swiss National Supercomputing Centre has used Kppa to run their national air quality reports," Linford says, and other customers include universities and the air quality research division of Environment and Climate Change Canada.

NASA Kite Invention Spurs Ever-Growing Educational Program

When an educational agency contacted NASA engineer Geoff Bland in 2010 about a way to monitor water sampling sites, he gave what may have seemed an unconventional answer: "Would you be interested in flying kites?"

Bland and a coworker at Goddard Space Flight Center's Wallops Flight Facility, interested in a cheap, simple way to conduct aerial imaging, had invented an aerodynamically stabilized device that could hang from a string that, in turn, essentially hung from a kite string. They called it the AeroPod.

The group that contacted Bland was Wayne Regional Educational Service Agency (RESA), which supports schools in Wayne County, just outside Detroit. The agency had been granted a NASA Cooperative Agreement Notice (CAN) award to explore options for capturing pictures of study sites for a science project.



AeroPods, invented at Goddard Space Flight Center's Wallops Flight Facility, can be outfitted with various sensors for aerial imaging and are aerodynamically stabilized, designed to hang from kite string as a simple, low-cost alternative to drone imaging.

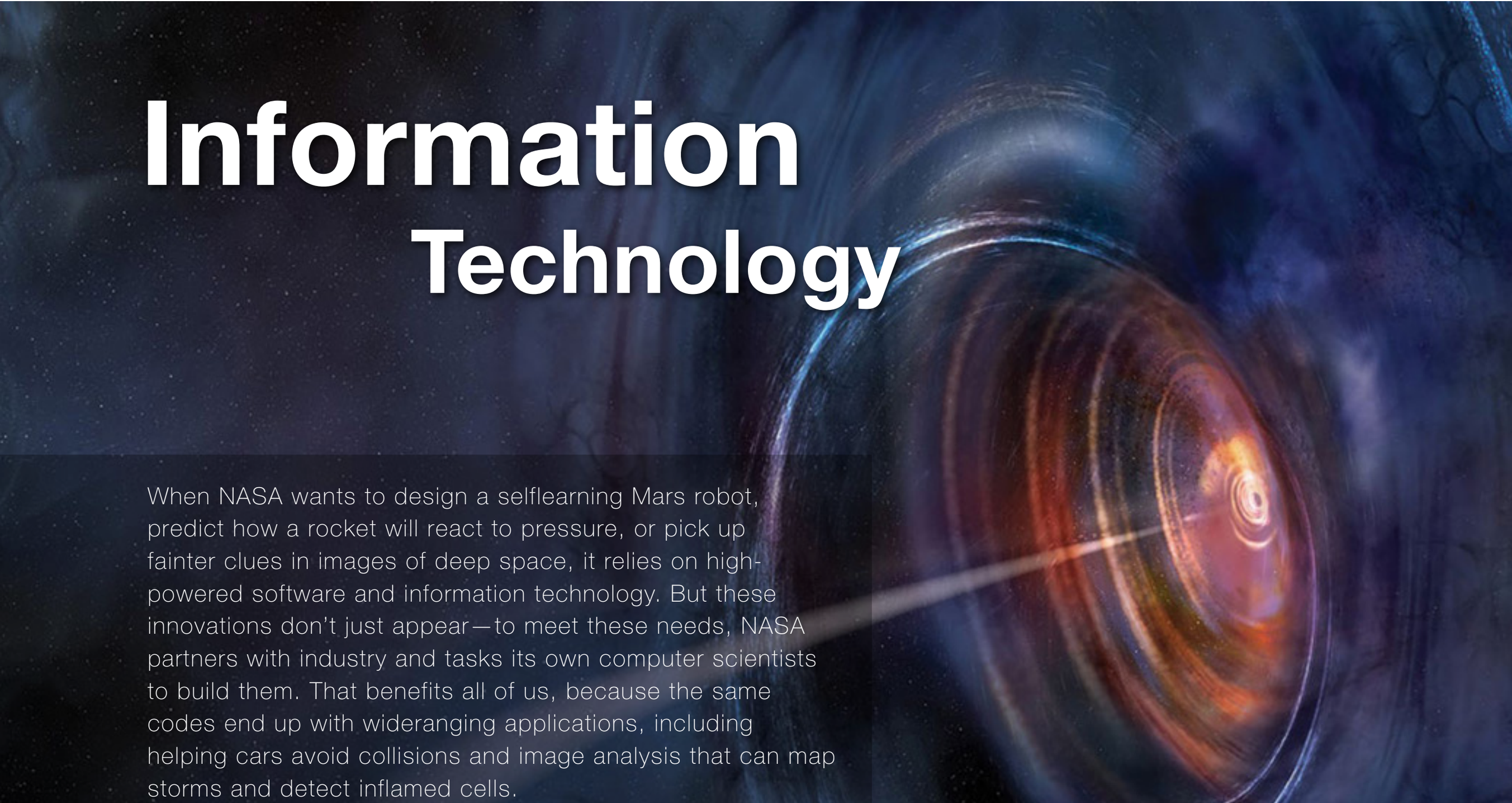
Wayne RESA's leadership, with Bland's collaboration, ultimately came up with the Investigating Climate Change and Remote Sensing (ICCARS) Project, which was piloted in 2010 and included 60 lesson plans for middle and high school students. The program uses imaging data to understand climate change and its relationship to changes in land use and land cover.

To license AeroPod technology, Goddard created a new educational license that requires feedback rather than monetary payment.

In 2016, NASA granted Wayne RESA a five-year CAN award to expand the program to include remote-controlled watercraft for collecting water data, which Bland and his coworker also designed.

Along the way, many partners have joined in as co-investigators or collaborators, including universities, schools, and environmental organizations across the country, as well as at least one company.

Organizers say the programs caught on because they allow students to collect real-world data and come up with their own questions to answer with that data, rather than having information and questions fed to them.



Information Technology

When NASA wants to design a selflearning Mars robot, predict how a rocket will react to pressure, or pick up fainter clues in images of deep space, it relies on high-powered software and information technology. But these innovations don't just appear—to meet these needs, NASA partners with industry and tasks its own computer scientists to build them. That benefits all of us, because the same codes end up with wideranging applications, including helping cars avoid collisions and image analysis that can map storms and detect inflamed cells.

Planet-Navigating AI "Brain" Helps Drones and Cars Avoid Collisions

If you can design a robot that can autonomously explore planetary terrains, putting the same technology in cars, toys, and drones seems almost easy. That's why NASA-funded development of deep-space computing was a natural fit for Boston-based startup Neurala.

Under contracts with Stennis Space Center, Energy Focus designed LED floodlights that could withstand conditions inside a rocket engine test stand and would not pose a hazard themselves.

The company's core technology is artificial intelligence (AI) software modeled on the human brain that can interact with and learn from its environment using ordinary cameras and sensors. It can process its surroundings and store memory onboard, so it doesn't require a cloud-based supercomputer like other AI systems. This capability would be crucial for a self-learning robot on Mars, where communication with Earth can be delayed by 25 minutes.

The company's founders have worked since 2005 on programs that slowly compute large amounts of information in parallel, operating more like brains than traditional central processing units, which process bits of information fast but one after another.

From left to right: Matt Luciw (Neurala), Mark Motter (Langley Research Center), and Massimiliano Versace (Neurala). Neurala developed and commercialized its neural-network software thanks in part to a series of STTR contracts with Langley.

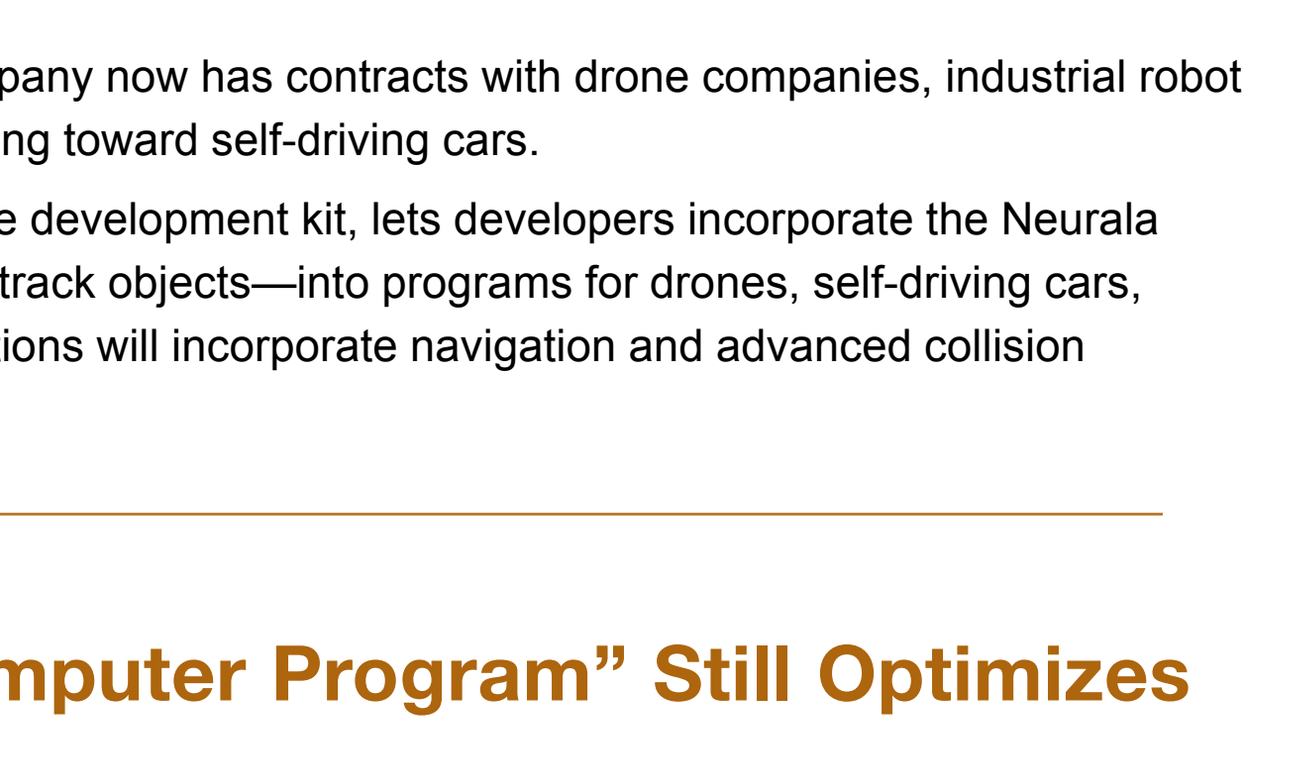
After a Langley Research Center engineer learned of the work, the center contacted the team. Under a Phase I Small Business Technology Transfer (STTR) contract, Neurala worked on unsupervised learning and navigation capabilities, and Phase II STTR funding helped the company develop visual processors based on passive sensors to identify and interact with objects. A Center Innovation Fund award let the team create collision-aversion capabilities.

With private capital and NASA STTR Phase II Enhancement money, Neurala created several apps for consumer robots and drones and also licensed technology to consumer drone manufacturers. The company now has contracts with drone companies, industrial robot manufacturers, and a major automaker looking toward self-driving cars.

Its main product, the Brains for Bots software development kit, lets developers incorporate the Neurala Brain—which can learn to identify, find, and track objects—into programs for drones, self-driving cars, industrial robots, toys, and more. Later iterations will incorporate navigation and advanced collision avoidance.

Early NASA "Dream Computer Program" Still Optimizes Designs

At the top of the food chain, an apex predator hunts without fear of being hunted. That's why MSC Software Corporation branded its latest software line MSC Apex and dubbed the original, 2014 release "Arctic Wolf," confident the computer-aided engineering program would soon, like its namesake, dominate the landscape.



Thomas G. Butler, right, an engineer at Goddard Space Flight Center in the 1960s, is credited as the father of NASTRAN, perhaps NASA's most successful software spinoff. Butler recruited supporters from various NASA field centers for the creation of general-purpose finite element analysis software, forming a committee that outlined their "dream computer program."

But a lot of the computer coding that enables Apex, as well as a number of other programs, was first found in the product of a long-ago partnership between Newport Beach, California-based MSC and NASA: NASTRAN.

In the 1960s, Goddard Space Flight Center engineer Thomas Butler championed the creation of a general-purpose finite element analysis (FEA) program. FEA is a now-common computerized numerical method for modeling structures and predicting how they will react to outside forces. Butler recruited supporters from the various NASA field centers and several Department of Defense agencies and formed a committee, asking members to come up with all the things their dream computer program would do.

The NASTRAN program, created at Goddard and released to the public in the 1970s, has since been used to design everything from roller coasters to cars, steam turbines, oil platforms, buildings, aircraft, and much more.

MSC was one of three companies recruited to build the program, and the end product was modular, flexible, and extensively documented. It was meant from the start to be a general-purpose structural analyzer, useful not just for flight vehicles but for any structure.

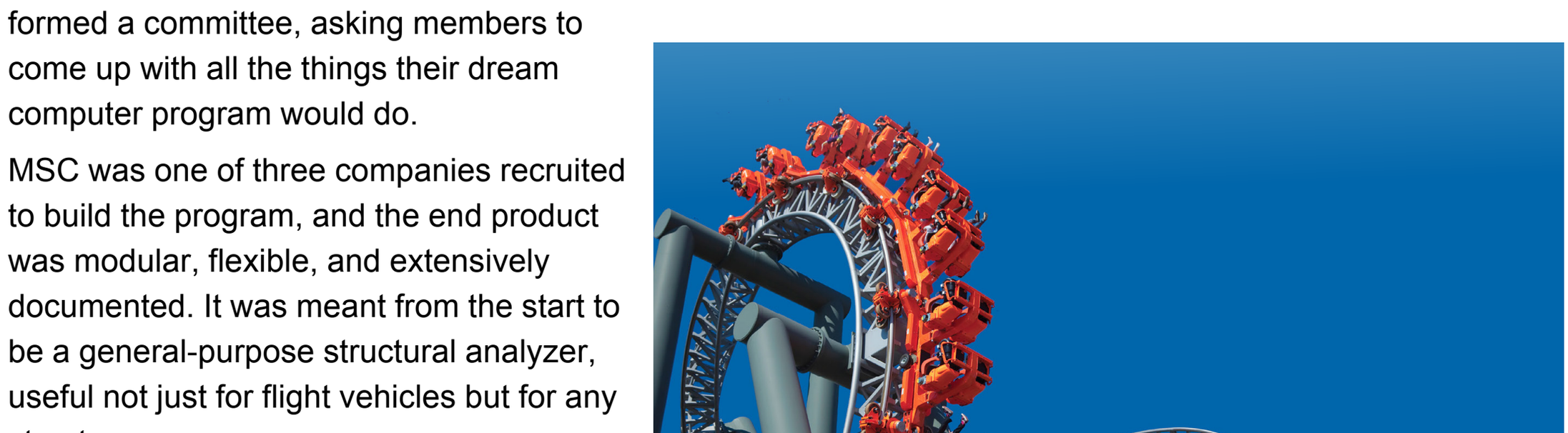
In the 1970s, NASA released NASTRAN to the public, and MSC and other companies soon began marketing their own versions. Companies have used them to design countless vehicles, buildings, and objects over the years.

Now, Apex integrates NASTRAN's solver capabilities with a modern, easy-to-use graphical user interface and automates much of the labor-intensive preprocessing work. Designers can finish a job in a fraction of the time it once took, and the ease of use opens up computer-aided engineering to non-experts and allows it to be used earlier in the design process, saving time and money.

2D Analysis Software Clarifies Medical, Weather, Intelligence Images

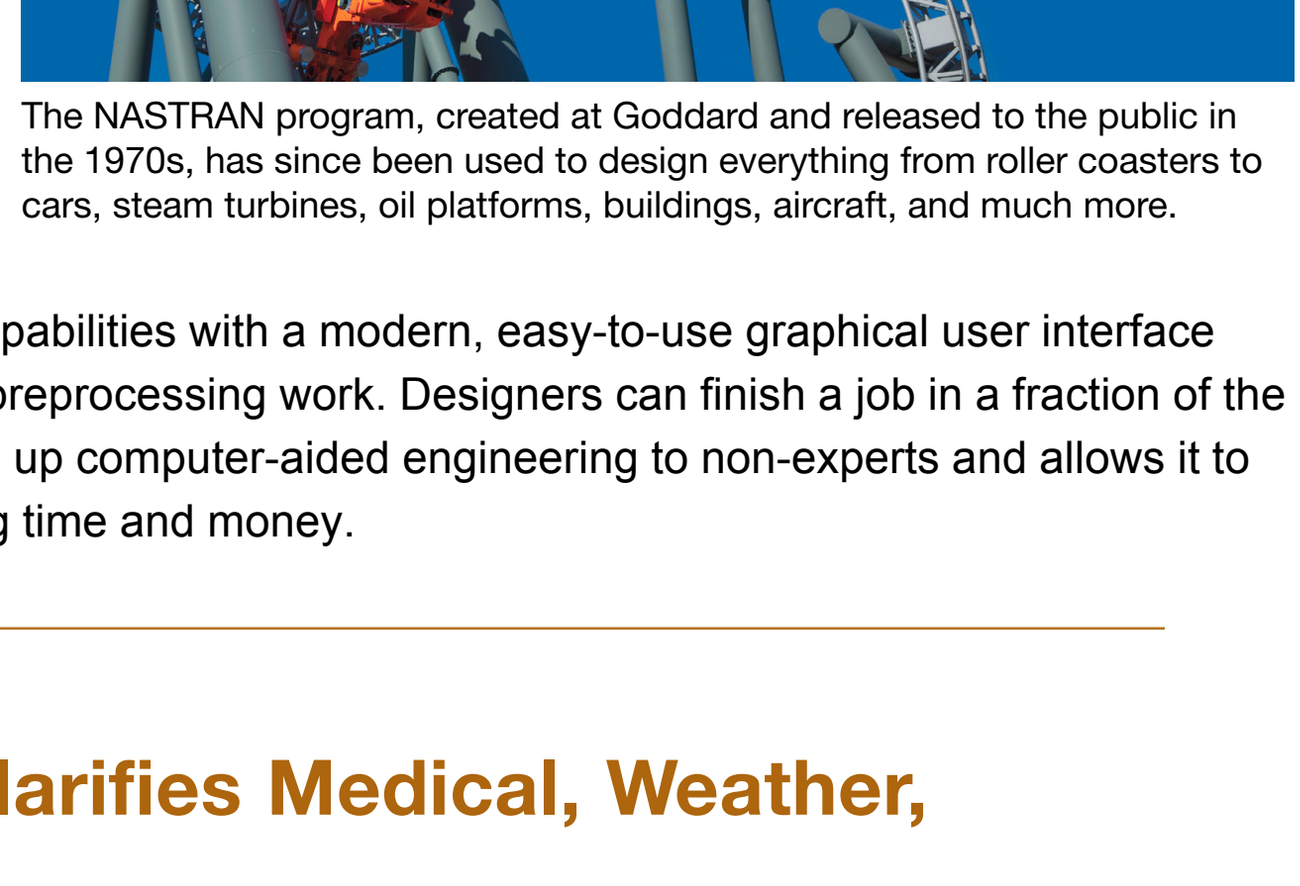
NASA engineer Semion Kizhner spent an entire week trying to understand the Hilbert-Huang Transform (HHT) with the colleague who had developed it, but to no avail. Nevertheless, he hoped to develop software that would get people using this powerful but complex algorithm, because he saw great potential in it.

Fortunately, no one needs to fully understand a transform to use it, says Kizhner, now retired from Goddard Space Flight Center.



SIETech image-processing software, based on a two-dimensional version of the Hilbert-Huang Transform created at Goddard Space Flight Center, eliminates "noise" such as haze (left) or radio interference (right). It has possible applications in fields as diverse as medical imaging, weather forecasting, and defense.

A transform—a particular type of mathematical formula—helps scientists gather information from complex data. For example, Kizhner says, he might not understand raw data from an electrocardiogram, but transforming it into the frequency domain might show something happening once a second—a clue suggesting the phenomenon is probably associated with breathing.



One possible use of SIETech image-processing software is in oil spill cleanups, where it could pinpoint the areas of highest oil concentration and prioritize them for remediation.
Image courtesy of the Federal Emergency Management Agency

He and a student managed to write software to apply it, resulting in the HHT Data Processing System, which can be licensed from Goddard and is in use all over the world. But Kizhner also wanted to find a way to use the transform in two dimensions to analyze images.

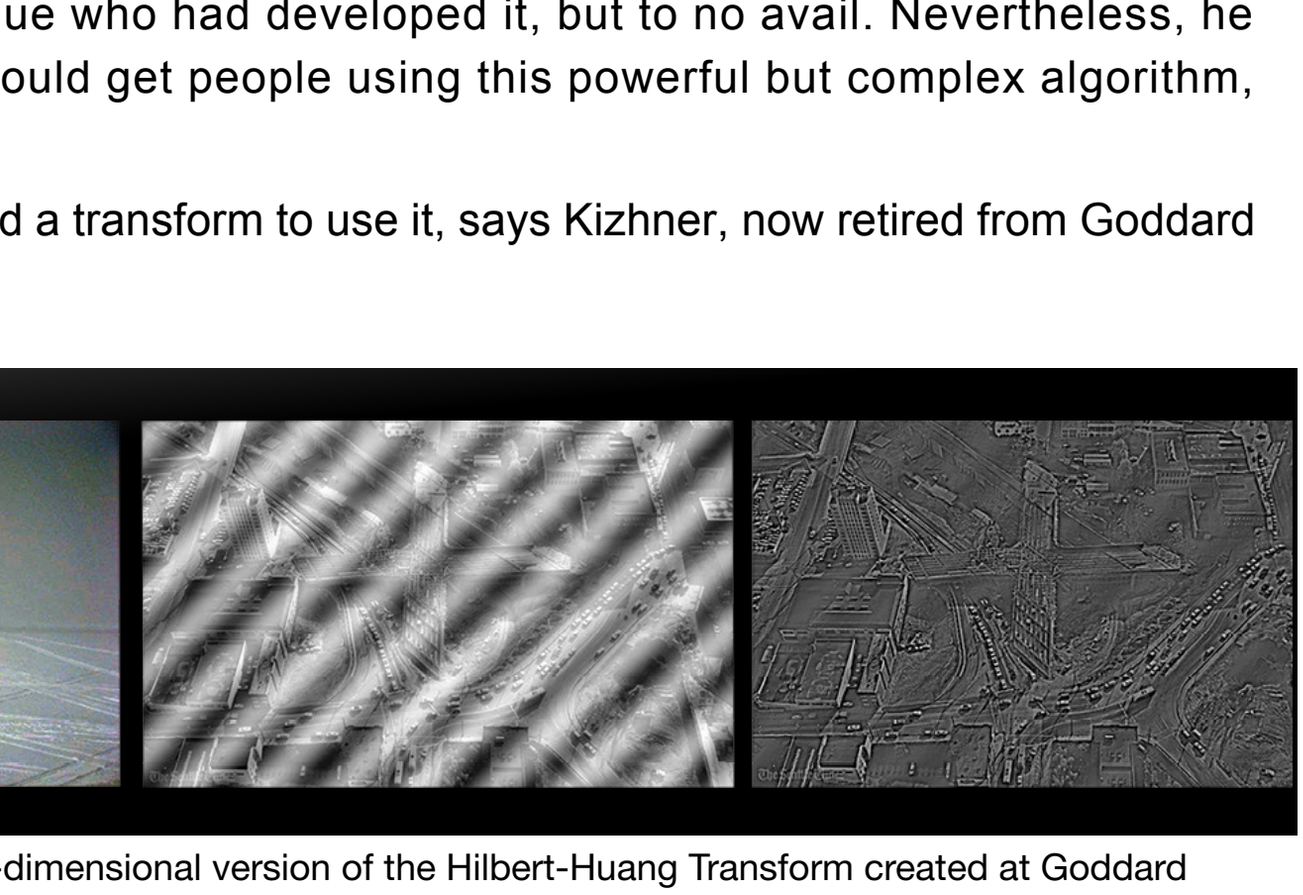
Following years of attempts, on a camping trip, Kizhner was struck by an idea he thought would work. With Goddard funding, he developed and patented a prototype.

Arlington, Virginia-based Syneren Technologies Corporation expressed interest in commercializing the program and obtained an exclusive field of use license. Under a Space Act Agreement, Kizhner consulted with the company weekly. Syneren rewrote the program, worked out any bugs, and by the end of 2016 was in talks with several companies and government agencies about tailoring the program to their needs.

The program has proven highly successful in analyzing weather images, distinguishing normal cells from abnormal ones, identifying manmade structures among foliage, and removing visual obscurants or radio interference from images. Virtually any industry that uses image analysis could likely benefit from the technology.

Quake Hunter Maps a Century of Quakes Worldwide

Earthquakes are among the most destructive natural disasters. They're also nearly impossible to predict—but a new tool will help seismologists and amateurs alike better understand the behavior of the planet's crust. An open source virtual globe developed by NASA and used by countless government agencies, institutions, and companies around the world now provides the ability to visualize 100 years' worth of global earthquake data.



In Quake Hunter, a visualization of about a year's worth of earthquakes in the Western Hemisphere, between 2016 and 2017, makes the fault lines unmistakably clear.

The original World Wind was a standalone application much like Google Earth. It was released under a NASA Open Source Agreement in 2004 and soared in popularity. Soon, a Java-based software development kit funded by the U.S. Department of Energy made it easier for users to base their own apps on the software. Government agencies at home and abroad snapped it up. Major corporations provided development funding.

Like many capabilities added to World Wind, Quake Hunter wasn't created by NASA engineers. In this case, NASA interns developed the application. In the summer of 2016, Patrick Hogan, World Wind project manager at Ames Research Center, had an international group of computer science students at his disposal.

A visualization of all the satellites in space, as seen with SpaceBirds, another application built on World Wind, reveals dense rings in geostationary orbit and an even denser satellite population just off the planet's surface in low-Earth orbit. The satellite representations move in real time, and their orbits can be tracked.

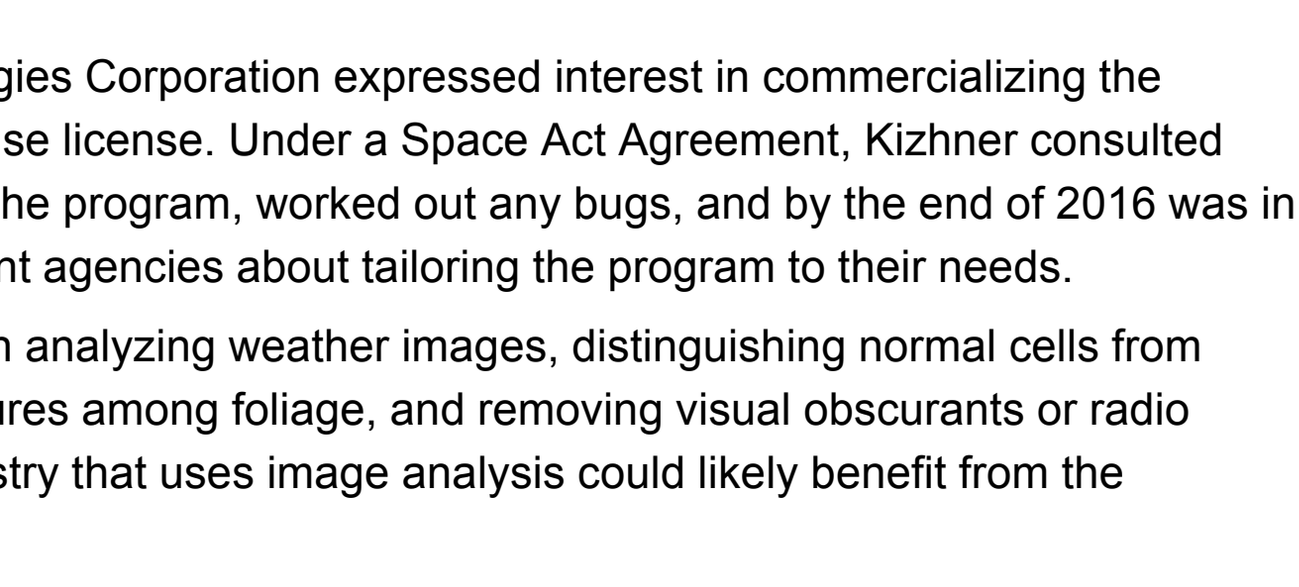
He had recently received support from the U.S. Geological Survey (USGS), which stores historical earthquake data, to allow subsurface data to be visualized in World Wind. With this newly enabled model of Earth, the students used USGS data to map every quake in the last century, represented by dots of different sizes and colors depending on their magnitude and date.

Quake Hunter is the first visual representation of the planet's seismic history.

"No one had ever had this degree of immediate access to the data," Hogan says, noting that, while the data was publicly available, looking at numbers and coordinates on a spreadsheet is not at all like looking at a visual representation of the data in the context of the real world.

Free Aerodynamic Simulation Code Supports Industry, Education

In the mid-1990s, NASA, the Air Force, and McDonnell Douglas Corporation realized they were duplicating each other's efforts to make better software simulating interactions between air and aircraft. So they decided to team up.



These images from Wind-US show how a jet engine intake duct can be broken into a handful of zones and thousands of tiny cells for analysis. The cells can take on a variety of shapes.

Computational fluid dynamics (CFD) software, which simulates the interaction of fluid—including air—with surfaces, was relatively new at the time, and it was not well-trusted by many flight engineers. NASA's Lewis Research Center, now Glenn Research Center, and the Air Force were each working on their own version of CFD software for spacecraft and formed the National Program for Applications-Oriented Research in CFD (NPARC) Alliance in 1993.

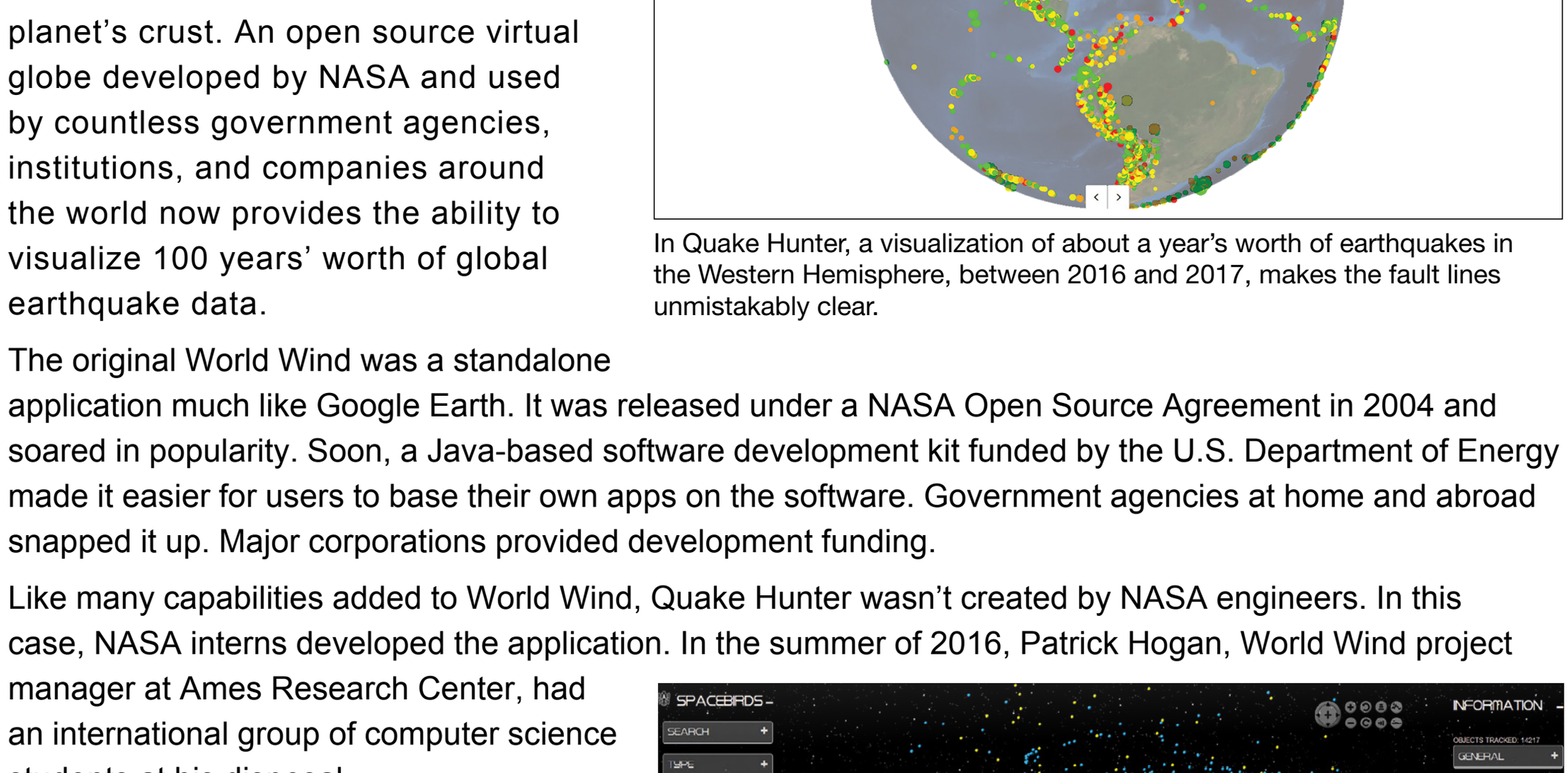
McDonnell Douglas, now part of Boeing, soon got involved, offering its own CFD program, which became the basis for NPARC's Wind code, later evolving to Wind-US.

The program quickly caught on among government agencies, aircraft and aerospace companies, and universities. It's still available today, even if it's not as widely used as it once was, having peaked in the early 2000s as one of the country's most widely used aerospace CFD solvers.

One company that still uses the program is Chesterfield, Missouri-based Innovative Technology Applications Company (ITAC) LLC. The founder, Alan Cain, who worked on the original code at McDonnell Douglas, started the business largely based on his knowledge of Wind-US. The company uses it for consulting and also helps clients make their own changes to the program.

Cain says Wind-US is still remarkable for its unusually broad range of capabilities, and it was one of the programs that helped earn more engineers' trust in CFD, which is now widely used in many industries.

The program also made not just CFD software but its own source code freely available to colleges, where students have used it to learn CFD and even experiment with making changes to the code, gaining valuable experience.



One of many projects in which Innovative Technology Applications Company has relied on Wind-US software was a Navy contract to explore the use of a wavy leading edge, similar to that of a humpback whale fin, on the tower-like Image courtesy of the U.S. Navy Image courtesy of Andrew Kalat, CC BY-ND 2.0 "sail" of a submarine.

Software Models Atmosphere for Spacecraft

When the Curiosity rover made its spectacular landing on Mars, most attention was focused on the revolutionary "sky-crane maneuver" that helped slow the spacecraft down. But NASA atmospheric modeling software helped with another make-or-break factor: choosing the landing site. This same software is used for commercial spacecraft to ensure they can fly—and land—safely.

Boeing says it uses Earth-GRAM on many projects, including to help design the Starliner, a spacecraft intended to shuttle astronauts to the ISS, and to help train the craft's future crew.

The code is part of the Global Reference Atmospheric Model (GRAM) family of software. The first, Earth-GRAM, was originally developed in 1972, with versions developed for Mars, Venus, Neptune, and Saturn's moon, Titan.

Other atmospheric models exist and can give more details, but they take longer. The GRAMs are "an easy way to get a snapshot of what's occurring in the atmosphere," says Marshall Space Flight Center's Hilary Justh.

For Curiosity, the entry, descent, and landing team developed a set of acceptable parameters for a safe landing. "Mars-GRAM was utilized as part of the process to determine which sites met the parameters," helping rule out sites that were unacceptable, Justh explains.

The GRAM software family is one of many packages NASA offers to the public for free. All versions are used by researchers, and recently, SpaceX began using Mars-GRAM for the Red Dragon spacecraft it plans to send to Mars.

However, Earth-GRAM is used most often, especially among commercial aerospace companies. For example, Boeing began uses it for the Starliner, a spacecraft intended to shuttle astronauts to the International Space Station.

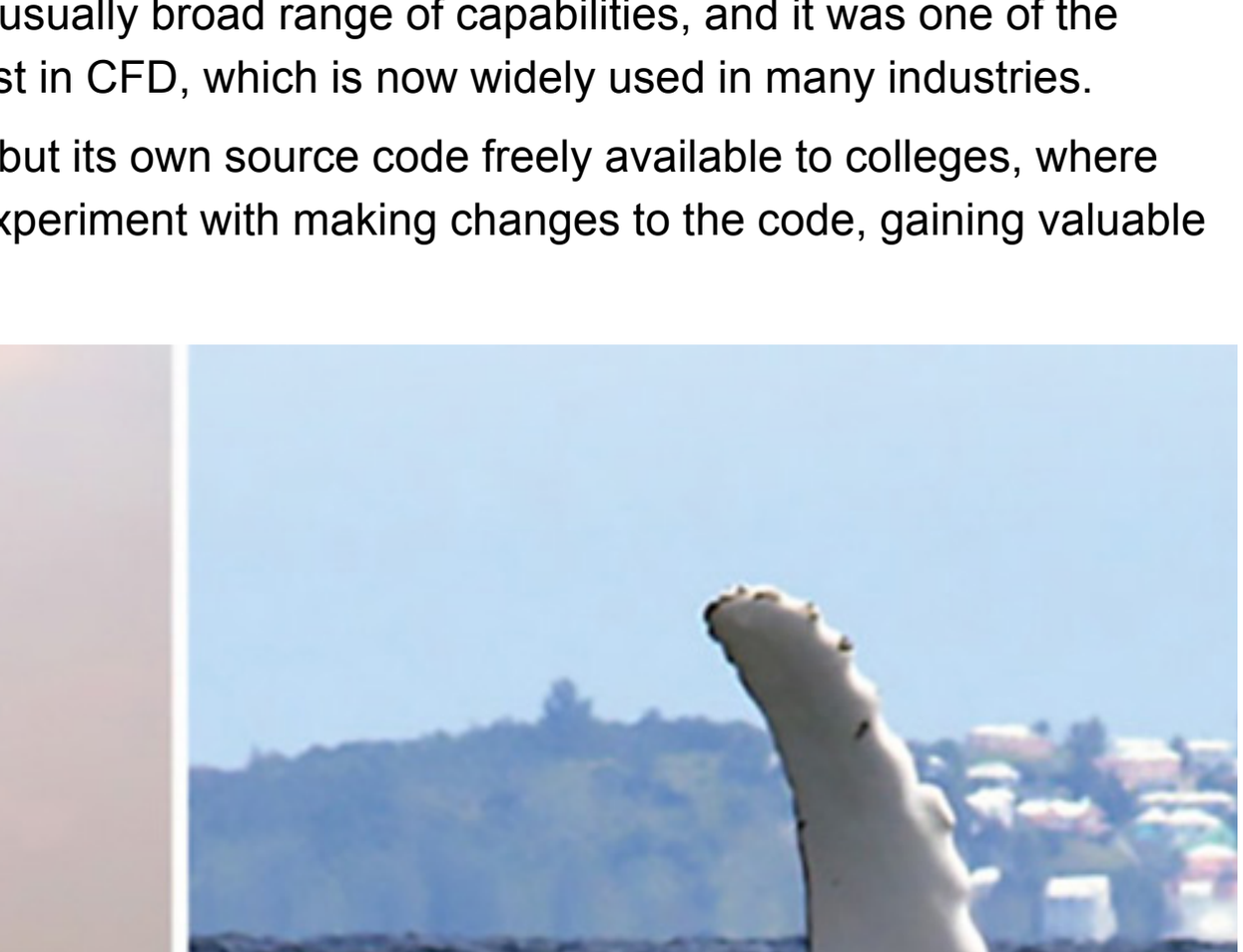
The team chose to use the software for the NASA project in part because a database already approved by the Agency would ease approval of the proposal, explains Boeing engineer Thomas Tanita, but now "we use GRAM on many other projects, simply because it's becoming an industry standard."

"The good thing about GRAM—and the reason why we moved over to it—is that there's a wealth of statistical data that stands behind GRAM, and it's also applicable to many locations around the globe," says Tanita.

GRAM also helps predict the how the winds will impact the spacecraft's reentry. And because the models are so accurate, Boeing is also using GRAM to simulate the atmosphere for crew members training to fly the Starliner.

Software Takes Cost Estimating to the Stars

When imagining what it takes to design a spacecraft, few people think about the engineering that goes into getting an accurate cost estimate before the building begins. And yet, software designed at NASA's Marshall Space Flight Center to do just that has become one of the center's most-downloaded codes.



Estimating the cost of new spacecraft, like the Space Launch System that aims to bring the first humans to Mars, is a complicated feat. Software designed at Marshall Space Flight Center incorporates the many algorithms needed to do it into an easy-to-use and fully customizable Excel add-in—and has become one of the center's most-downloaded codes.

Every industry relies on cost estimates when taking on a project, but few estimates are more complicated than those for aerospace, where the industrial base is small and specialized and everything is typically custom made for its application.

"We use historical data to estimate the cost of a future system," explains Marshall cost engineer Andy Prince, "because in the space arena, you don't have a production-type environment that you can rely on for data to feed your estimates."

NASA's latest cost-estimating model is called the Project Cost Estimating Capability, or PCEC. It was first released in 2014 and has been updated yearly since. It can be downloaded for free in the United States and internationally.

Dozens of companies, universities, government agencies, and international organizations have already taken advantage, both because it can be used for any type of space mission and because there are no other publicly available competitors.

At universities, the software tends to be used in design classes. "Good engineers want to make the most efficient, effective system possible," Prince says, "and this software helps them see that there's a cost dimension that has to be factored into the efficiency and effectiveness of their design."

In the commercial world, Bethesda, MD-based Lockheed Martin has found PCEC useful as a cross-check for its own cost-estimating models, especially in proposals for NASA. The company also uses the software as an industry baseline more generally, explains parametrics estimating manager Nichole Renda. "We have a strong in-house parametric and data-analytics database of our own history, but there are times we want to get a cross-reference to see how that is trending or compares with industry. We use PCEC as that cross-check or validation tool."

Communication Devices Ease Contact with Commercial Spacecraft

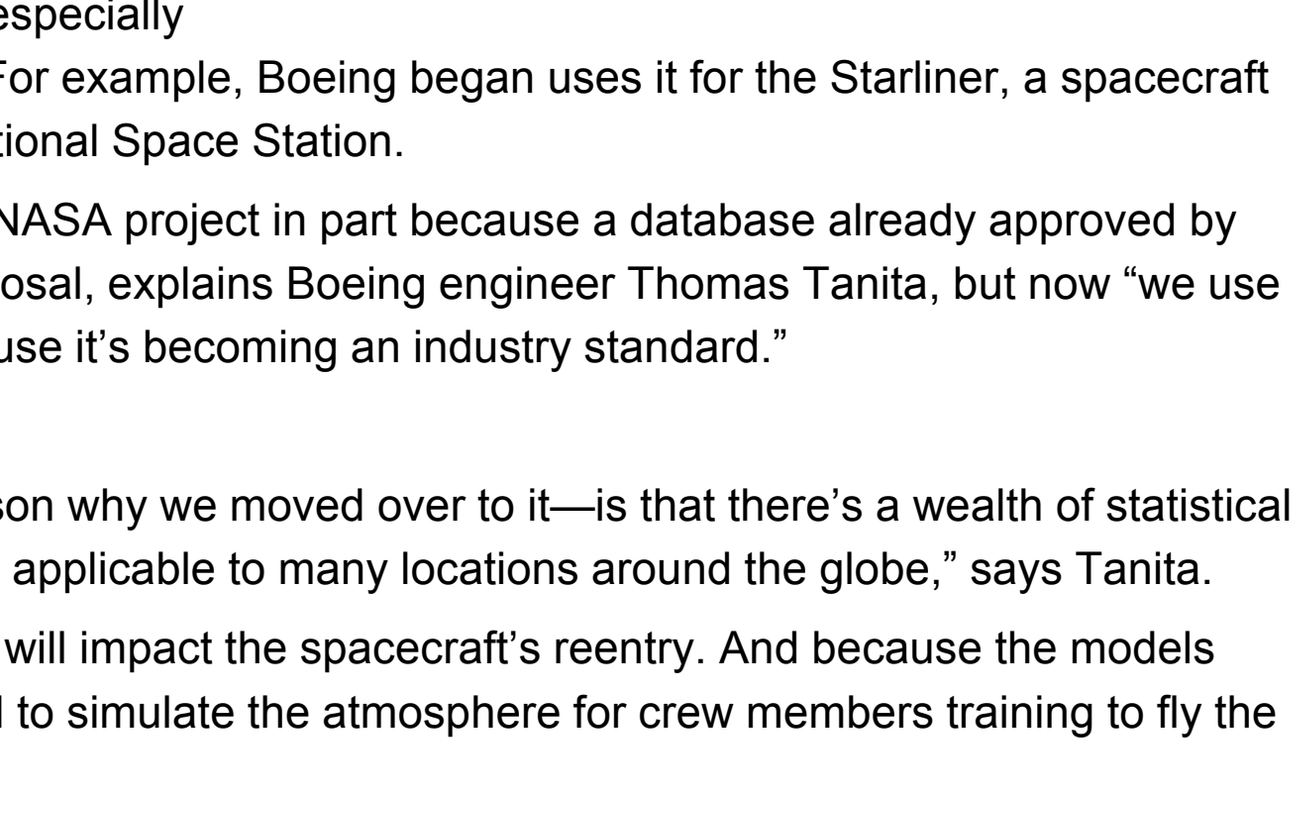
We've all seen the videos, photos, and tweets astronauts send from the International Space Station (ISS), but most of the information transmitted from the ISS to Earth is actually scientific experiment data.

Russian cosmonaut Dmitri Kondratyev and Italian astronaut Paolo Nespoli take pictures of Earth from the ISS Cupola. Astronaut photography is just one small example of the massive amount of data that streams from the space station to the Communications Data Processer AMERGINT built for Johnson Space Center with its flexible SOFTLINK architecture.

As early as 2010, however, the system for downlinking this data was operating at full capacity, limiting the station's ability to carry out its primary mission of scientific exploration.

AMERGINT Technologies Inc., based in Colorado Springs, won a contract to replace the Communications Data Processor at Mission Control at Johnson Space Center as part of an overhaul of the ISS communications system.

The company was already developing its SOFTLINK architecture, consisting of what it calls Software Devices—modules of code, each carrying out a discrete function, which can be virtually chained together in endless configurations to serve different applications. This is a departure from traditional spacecraft communications, which have comprised a suite of complex and costly hardware devices installed in a rack.



After expanding and refining its SOFTLINK architecture to meet NASA's needs for space station communication, AMERGINT has gone on to provide space communications systems and devices for numerous other Government and commercial clients

It was this customizable software architecture that won AMERGINT the job with NASA. The company already had a small library of Software Devices in its toolbox when it took the project on, but to finish it, the engineers would have to design many more.

The new software building blocks, along with the high throughput and ability to meet rigorous testing and security requirements, all developed to meet Johnson's needs, have found their way into AMERGINT's commercial line, which now has clients in space agencies abroad as well as in the private satellite and spacecraft industries.

Its systems are far more flexible than earlier, hardware-based architectures, allowing clients to make their own modifications or even add their own software. In addition to building custom systems, the company offers Software Devices with assembly instructions for more generic systems, as well as code templates to help users build their own software modules.

Mission Control Software Manages Commercial Satellite Fleets

The task of monitoring and diagnosing spacecraft health is getting out of hand.

As satellites have become more complex, the amount of data they send back, including information about their own components, has mushroomed. Meanwhile, more operators are launching constellations that may include dozens of orbiters. Crews are left to confront this deluge of data through text-based interfaces on several different computer programs simultaneously.

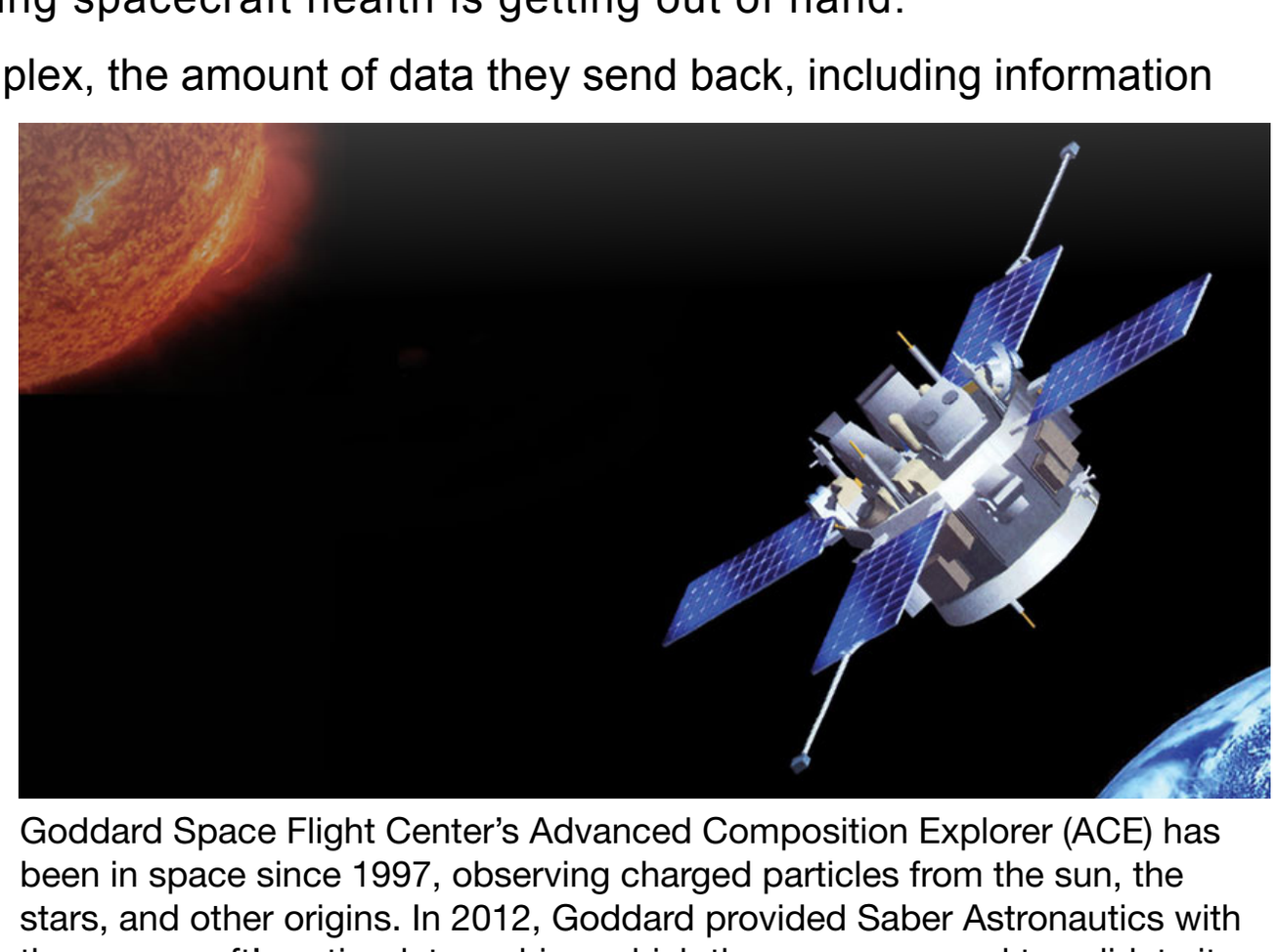
Goddard Space Flight Center's Advanced Composition Explorer (ACE) has been in space since 1997, observing charged particles from the sun, the stars, and other origins. In 2012, Goddard provided Saber Astronautics with the spacecraft's entire data archive, which the company used to validate its data-mining software for use in modeling and predicting spacecraft health and behavior. Following successful validation against the ACE archive, the company set about creating its Predictive Interactive Groundstation Interface software.

By 2012, Saber Astronautics, based in Sydney, Australia, and Denver, Colorado, had a likely solution—data-mining software capable of modeling and predicting a complex system's behavior.

But the company needed to validate the program against actual spacecraft data.

That's where Goddard Space Flight Center's Advanced Composition Explorer (ACE) came in. ACE was launched in 1997 to observe charged particles from the sun and other origins. Saber asked for the craft's entire data archive, and NASA obliged.

The company trained its software using ACE data from two weeks around a massive 2003 solar flare, building a system map—a model of the relationships between everything that affects anything else on the spacecraft. The engineers used that model to predict performances for later periods. Estimations were about 97 percent accurate, so Saber started building its Predictive Interactive Groundstation Interface (PIGI) mission control software.



Saber Astronautics' Predictive Interactive Groundstation Interface software can monitor and predict the behavior of systems and countless individual components on entire constellations of satellites, a task that would overwhelm even a team of engineers.

Instead of spreadsheets, PIGI presents a visualization, with users able to zoom out to see an entire fleet, zoom in on a craft, and explode it to see its components. It consolidates monitoring of system health and performance with telemetry and command functions and is easy enough to use that high school students can operate it.

Saber's first commercial offerings are a "casual" license for students and hobbyists, as well as mission control services for satellite companies. The company plans to offer a license for small businesses in 2018, which would include most of PIGI's functions, and a full, enterprise-level license will be available shortly thereafter.

Industrial Productivity

To ensure everything goes right in space— and to fix any problems that arise—NASA pioneers cutting-edge technology that then finds uses in every industry, in every phase of manufacturing. These innovations make our lives safer and even enable research that will power future medical advances, including a tunable light filter designed to facilitate remote sensing that now enables biologists to manipulate microscopic genetic material. They also turn up in unexpected places, like a gold-plating technique improved for space that puts the shine on the Oscars.

High-Speed Cameras Test Material Performances on Impact

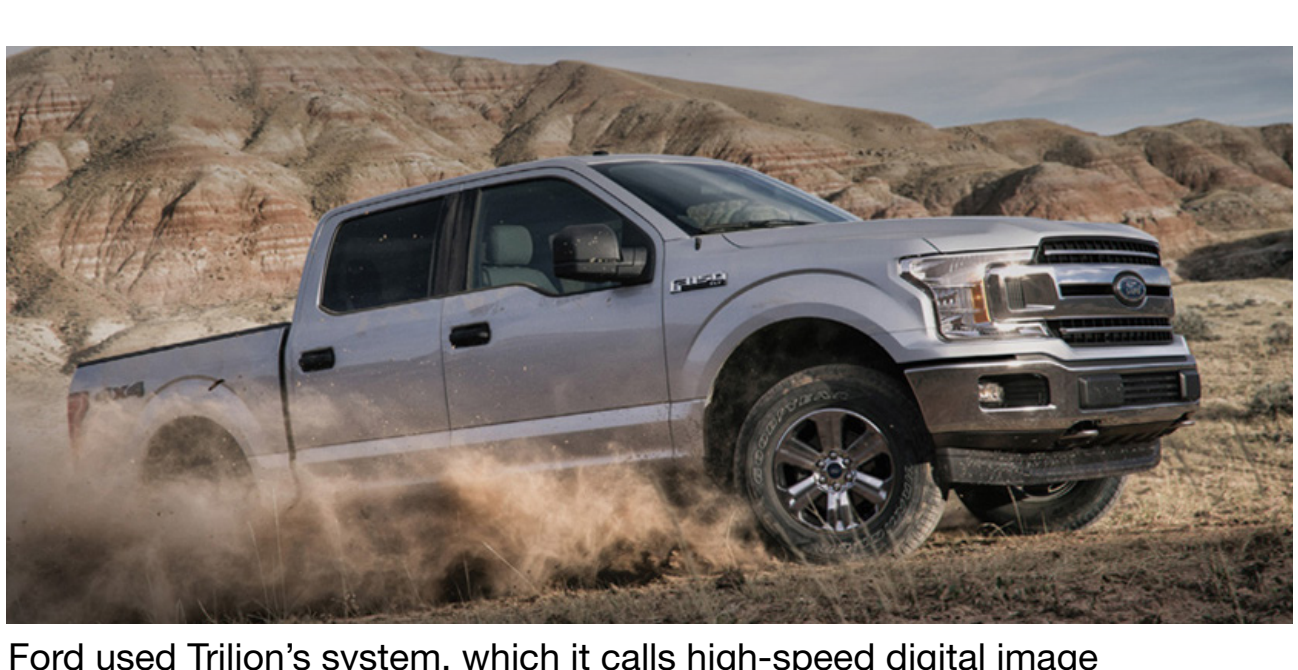
After Space Shuttle Columbia suffered a catastrophic failure, NASA spent months investigating what went wrong and how to prevent it ever happening again.

To investigate the tragic 2003 Space Shuttle Columbia accident and understand how to prevent a future one, a team at Glenn Research Center used high-speed cameras and stereo photogrammetry software to analyze impact. The system, used here in 2004 to test a fiberglass surface on Space Shuttle Enterprise, had to be custom-built to meet NASA's needs.

One of the tools it needed, a high-speed stereo photogrammetry system, didn't exist yet. High-speed photogrammetry uses two synchronized cameras to film an impact, and then software to analyze how the materials deform during the event. Those movements translate to stress and strain.

"It's like using your two eyes to know where something is in 3D space," explains John Tyson, president of Philadelphia-based Trilion Quality Systems. "With two cameras, we can precisely measure if something comes closer to you or goes further away, and can estimate the distances it's traveling."

But ARAMIS, the photogrammetry software NASA uses, "didn't have the ability to work at 30,000 frames per second," which is the speed needed for "a ballistic event on par with what Columbia experienced," explains Matthew Melis, a ballistics expert at Glenn Research Center.



Ford used Trilion's system, which it calls high-speed digital image correlation, when it wanted to change the F-150 truck body from steel to aluminum. The lighter material saved on cost and fuel, but Ford wanted to ensure it wouldn't sacrifice toughness.

So Glenn worked closely with Trilion to take the existing ARAMIS software and adapt it to work with high-speed cameras. The resulting product helped complete the Columbia investigation and get the Shuttles back to flight—and now helps make cars and airplanes safer, and much more.

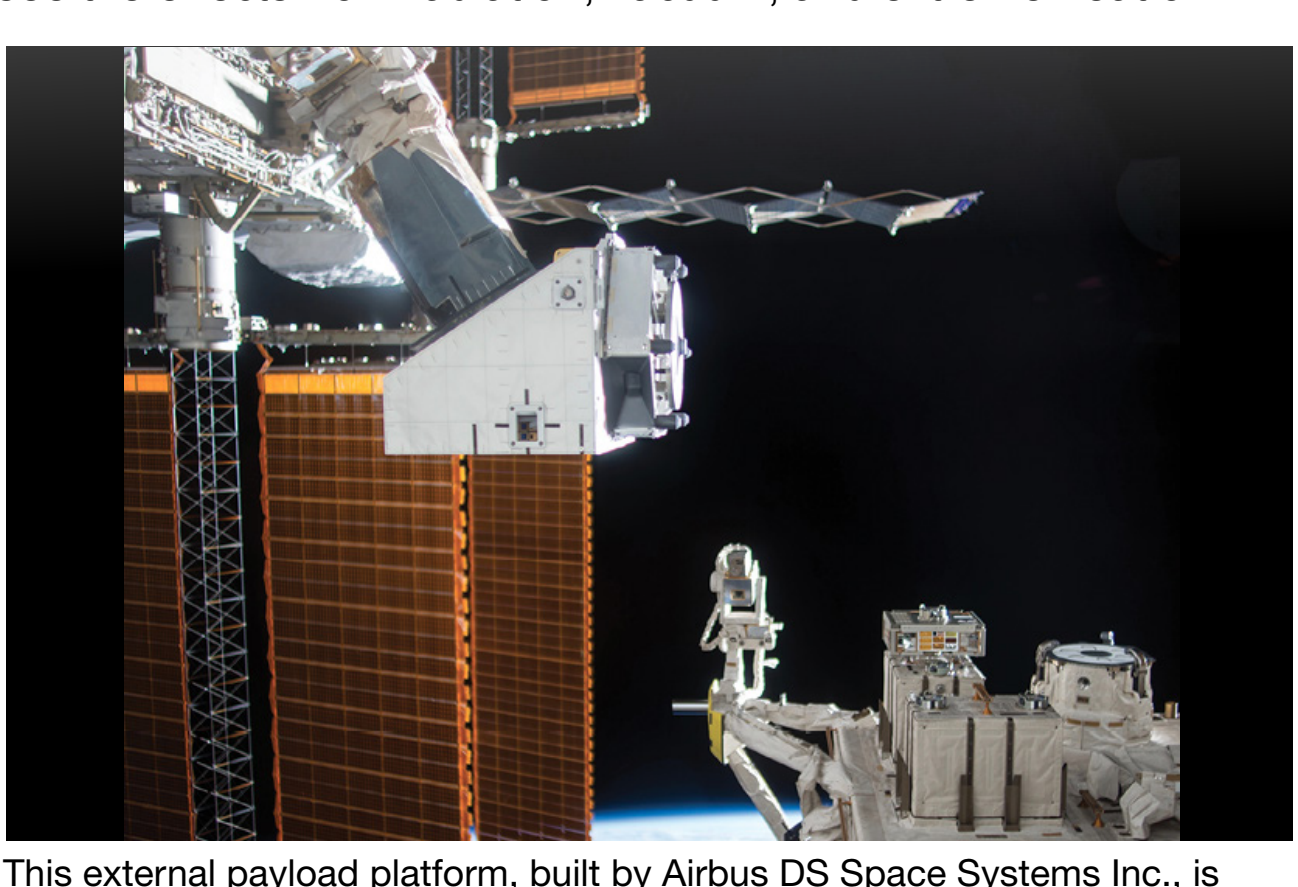
Boeing used Trilion's systems to confirm its Dreamliner 787 was structurally sound. Ford used it to test materials for its F-150 trucks when it wanted to switch the body from steel to aluminum without compromising the toughness of its signature trucks. Adidas used it to design an advanced running shoe based on the gait of Olympic marathoners.

Tyson says the high-speed ARAMIS system also saves money over traditional sensor measurements over time. According to an estimate from Boeing, he says, ARAMIS was 10 times cheaper than buying and replacing sensors, and required a fiftieth of the labor.

External Platform Enables Space Research

Not all space station research happens on the inside: a good portion takes advantage of the orbiting outpost's perch some 250 miles above Earth's surface. As the commercial space industry grows, more and more companies need that platform—and a new module that deployed in 2016 is expanding the options for all.

NASA has been conducting external space research nearly as long as it's been sending objects into space. Engineers test materials and components to see the effects from radiation, vacuum, and extreme heat or cold. External platforms on the space station are also a good perch for Earth-, sun-, and star-observing instruments.



This external payload platform, built by Airbus DS Space Systems Inc., is small enough to be assembled on the ISS, sent in and out through an airlock, and maneuvered by a robotic arm, making it less expensive and easier than ever to send samples for testing or mount imagers in space.

Airbus DS Space Systems Inc. has plenty of experience building these platforms: "we have a long history of external carriers going up in Shuttles," recalls Carl Kuehnel, technical programs director for Airbus DS. "We have two already attached to ISS," he adds, External Stowage Platforms 2 and 3.

Thanks to that experience, "we understand external environments, and how to build electronics for an external environment," Kuehnel says.

The Houston-based company built its latest external platform for NanoRacks (although that company did have a Space Act Agreement with NASA, which provided some resources).

The NanoRacks External Platform, or NREP, became operational in August 2016. It is small enough to be assembled inside the space station, sent through an airlock, and installed using a robotic arm controlled from the ground. After the test period ends, the platform is brought back inside the station the same way, to gather test samples and load the next batch.

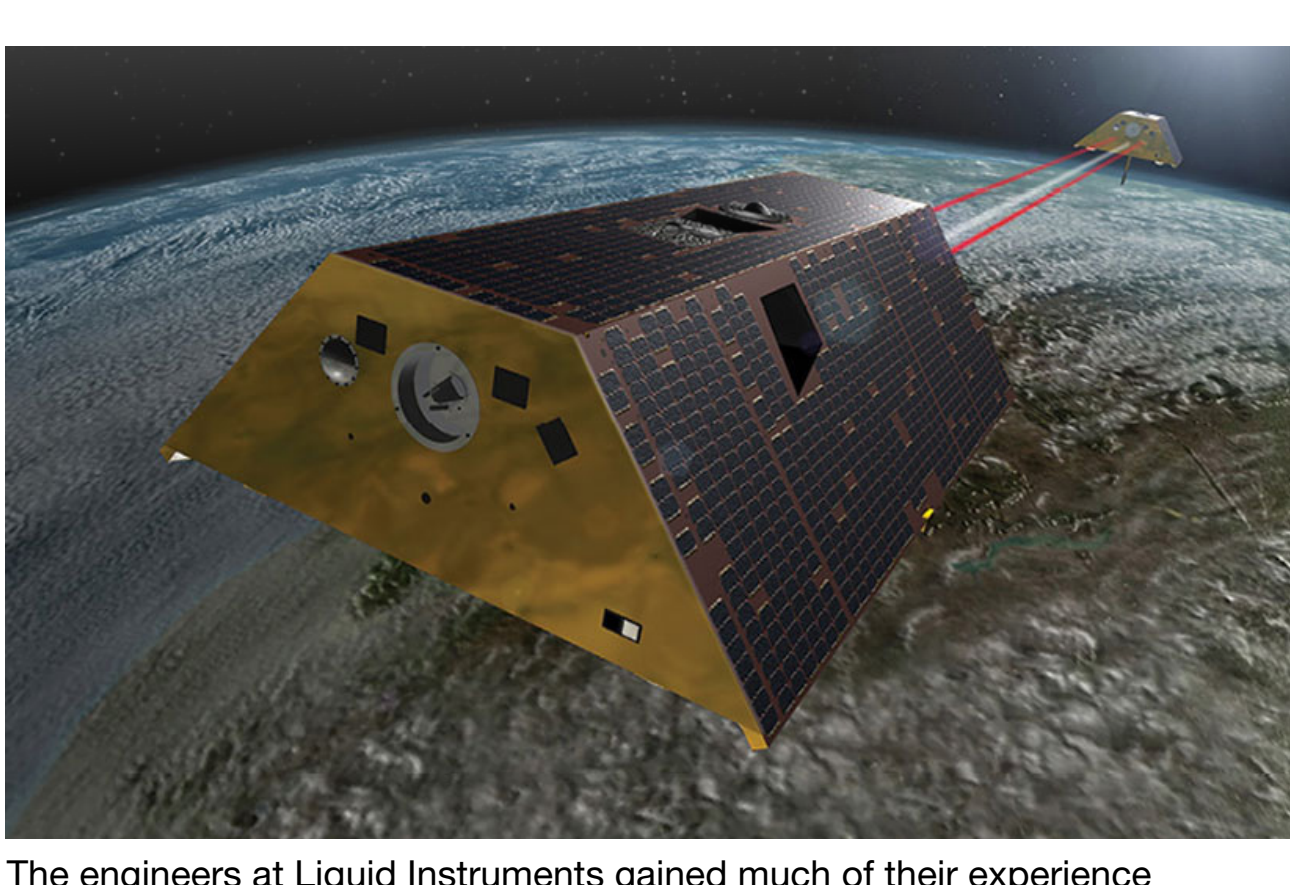
That's a huge cost savings, because it means astronauts don't need to suit up for spacewalks to set up or retrieve the device.

NREP is the first platform to use the external Wi-Fi installed on the ISS.

NanoRacks manages the platform and seeks out clients, but Airbus DS collaborates to help with interface testing and development of the payloads.

All-in-One Lab Device Gets New Instruments via Software Update

Devices for testing electronics haven't changed much in decades, and Daniel Shaddock, CEO of the startup Liquid Instruments, thinks clunky equipment may even drive down recruiting. "Kids grow up using iPads, and then they get into the lab in college and it's like the Soviet era," Shaddock says. "They get turned off and move on to other things."



The engineers at Liquid Instruments gained much of their experience designing instruments for the Jet Propulsion Laboratory's Gravity Recovery and Climate Experiment Follow-On mission, which maps Earth's gravity field by using a laser interferometer to register tiny changes in the distance between two orbiting satellites.

His company is updating the field.

At the Jet Propulsion Laboratory, Shaddock was the interferometer architect for the Laser Interferometer Space Antenna (LISA). Later, under an agreement between NASA and the Australian space program, he led a team at the Australian National University that adapted LISA's technology to the Gravity Recovery and Climate Experiment (GRACE) Follow-On mission, also run out of JPL. At the heart of both projects' instrumentation is a phasemeter, which is also an instrument commonly used for electronics testing and measurement. The trick was to reconfigure LISA's field-programmable gate array (FPGA) processor for the GRACE Follow-On.

The Moku:Lab replaces stacks of electronics test and measurement instruments with a single, small device that uses an iPad for its user-friendly interface. The device reconfigures its computer chip to essentially transform itself from one instrument to another.

Then the Australian space program ended. Shaddock was left with a team with extensive expertise in signal processing and chip programming, and one of them figured out how to remotely reconfigure an FPGA so it could essentially become a different instrument.

With some funding, the team founded the Canberra, Australia-based company and developed its initial Moku:Lab, which could reconfigure into three instruments: an oscilloscope, a spectrum analyzer, and a waveform generator. As Liquid Instruments develops configurations for more instruments, users can simply download them for free. The device now can switch between eight instruments, including a phasemeter, and is planned to be a 20-instrument device by 2019.

By combining several expensive instruments in one affordable package, Moku:Lab offers enormous cost savings. A slick, iPad-based interface and Wi-Fi capability are also advantages.

Having sold out its initial product run, the company hoped to sell about 600 new and improved units in 2017 and then 6,000 in 2018.

Gold Coating Keeps Oscars Bright

The Academy Awards ceremony is probably the last place most people would look for NASA technology, but it's there: the coveted Oscar trophy is coated in the same gold that helps telescopes glimpse distant galaxies.

Gold is highly reflective and doesn't tarnish— great for the James Webb Space Telescope's main mirror but also to block radiant heat from instruments in the telescope's interior. Longtime NASA partner Epner Technology didn't coat the main mirror, but its extremely durable and shiny plating was perfect for a cooling tube on the interior.

Gold is useful in space, because it is good at reflecting infrared wavelengths of light, which help to detect celestial objects from very far away. Even better, says Goddard Space Flight Center physicist Jim Tuttle, "gold is really inert. It doesn't oxidize at all." That means it won't tarnish.

Because of both of those properties, gold is also a good way to block the absorption of radiant heat. That's why the James Webb Space Telescope team chose gold to coat a 32-foot refrigerant tube that cools the Mid-Infrared Instrument, or MIRI.

But the telescope's designers wanted a gold-plating method that would maintain the high reflectivity of solid gold and be extremely durable. For that, they turned to Brooklyn-based Epner Technology, which has been working with NASA since the 1970s and perfected its electroplating technique doing aerospace work in the 1990s.

Some Oscar winners found the gold coating wore off over time. In 2016, Epner Technology began gold-plating the statuettes, using a technique improved in part for the Mars Orbiter Laser Altimeter. Epner guarantees the coating for life.

For the Mars Orbiter Laser Altimeter (MOLA), NASA told Epner it needed better reflectivity from gold plate without losing strength. At around the same time, the team building the Keck Observatory needed additional hardness to ensure its gold-plated secondary infrared mirror was cleanable without any scratching. (Keck was not a NASA mission, though the Space Agency later joined as a partner.)

To meet the needs of both aerospace projects, Epner tweaked its proprietary processes to ensure the highest possible reflectivity while also achieving a hardness triple that of pure gold.

Now that process is used for art, medical instruments, Webb—and the Oscars.

"They were awestruck that we were going to give them a gold that had been in space for 30, 35 years," company President David Epner recalls.

3D Printer Aims to Accelerate Materials Development

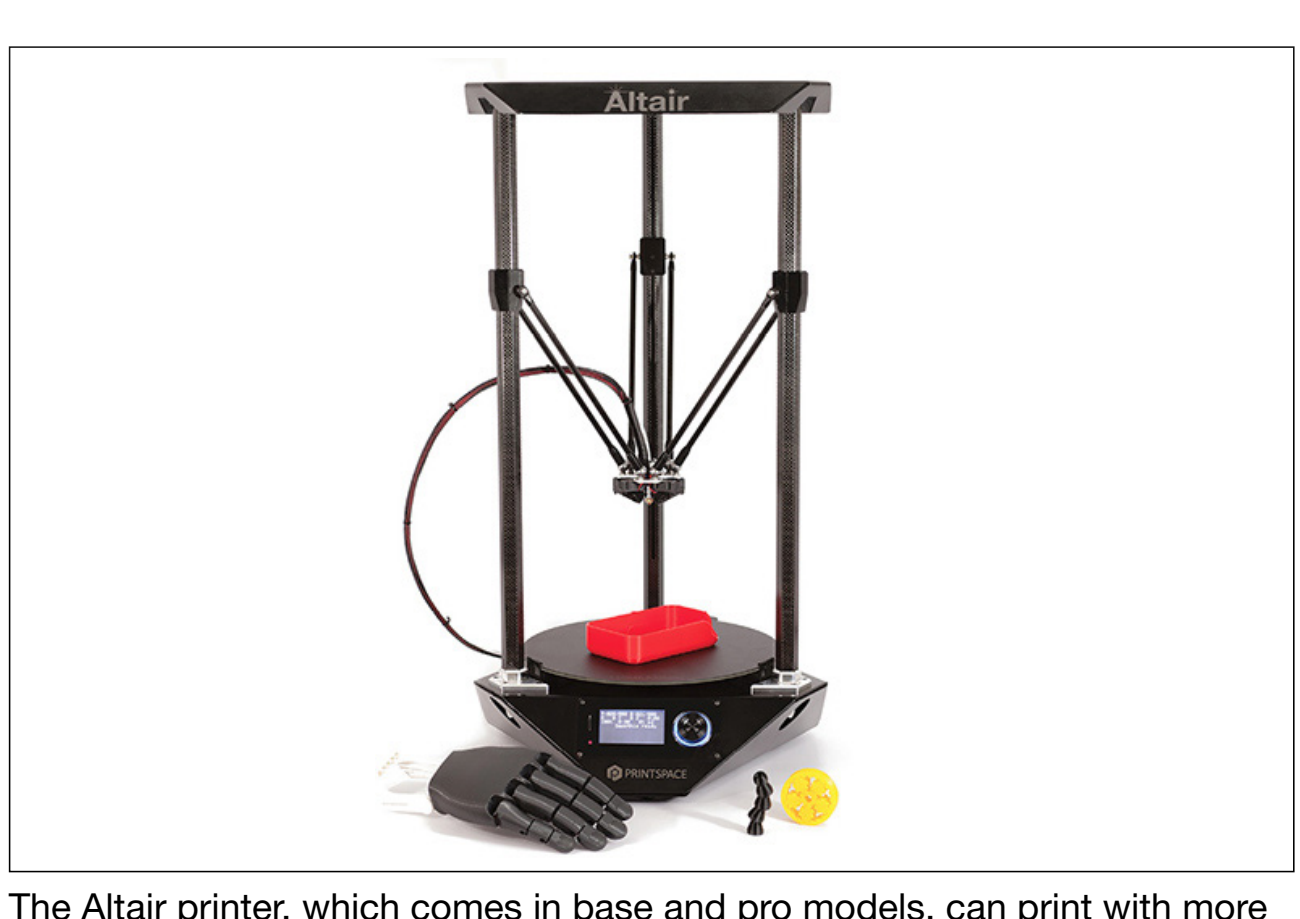
Mark Jaster landed a coveted job at NASA's Glenn Research Center as a brand-new grad, after two summer internships there, in the heat treatment facility. A decade or so later, Jaster continues putting the skills and knowledge he learned to good use, building a high-end 3D printer that he hopes one day will change how the researchers he worked with at Glenn do their jobs.

PrintSpace 3D founder Mark Jaster built his expertise in 3D printing and cutting-edge materials during his time at NASA's Glenn Research Center, including a project to build a superalloy seal for hypersonic aircraft like the X-43, which can fly at least five times the speed of sound.

At the heat treatment facility, Jaster helped materials engineers process materials to make them harder, tougher, and stronger as needed. "Mark, with his high aptitude, mastered that job pretty quickly," recalls Frank Ritzert, a senior materials research engineer at Glenn, who first selected Jaster as an intern and also recommended him for the full-time position.

He encouraged Jaster to look for additional opportunities with his spare time, like an effort to build a complex seal for a hypersonic aircraft, which required casting from mold created from a 3D-printed plastic model.

The project sparked Jaster's interest in 3D printing, but he envisioned a new printer that could print directly with the super-alloy metal instead of just a plastic model. In 2014, after an additional year of working on 3D printing at another company, Jaster founded PrintSpace 3D in Rexburg, Idaho, and began building the Altair 3D printer aiming to do just that.



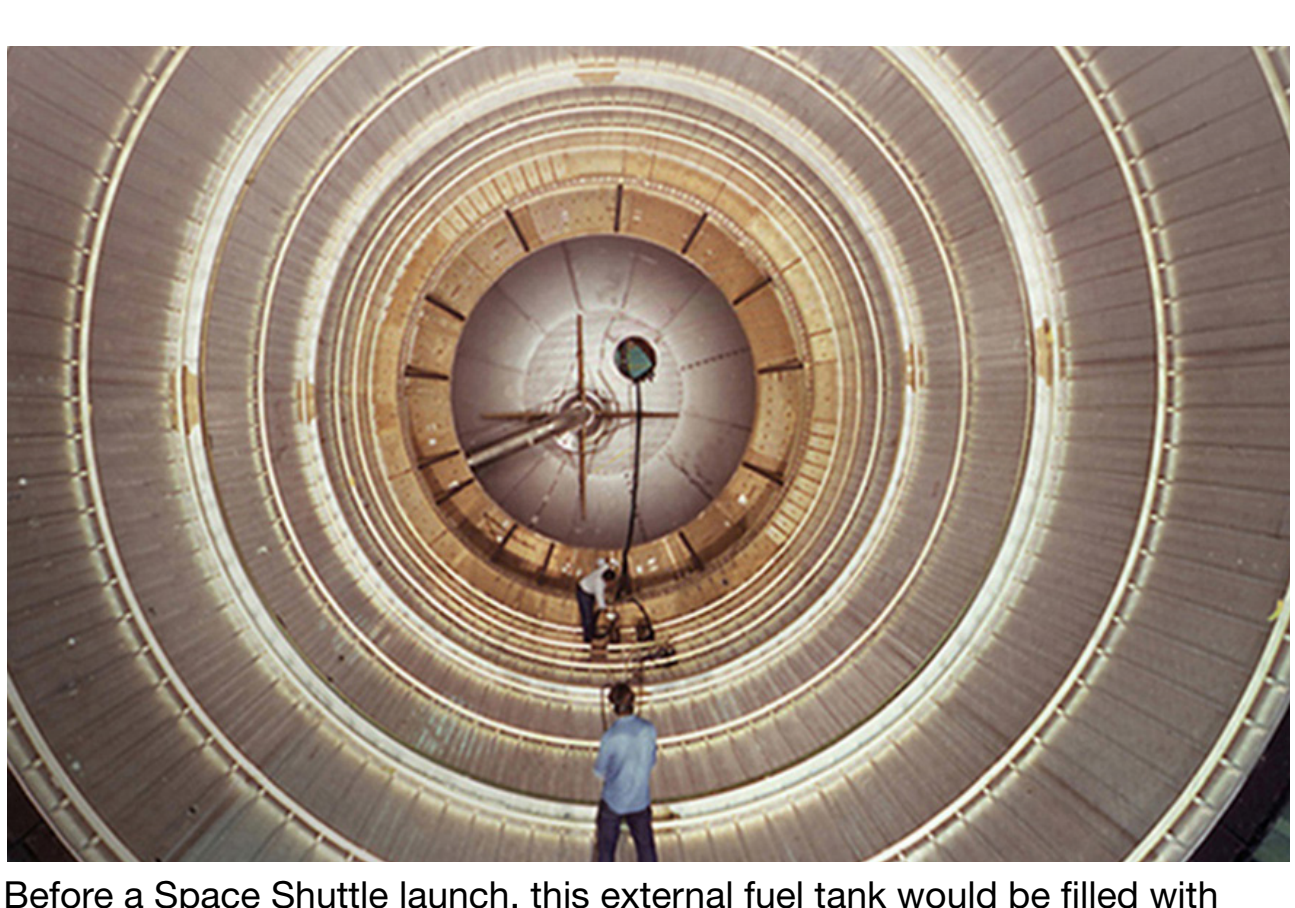
The Altair printer, which comes in base and pro models, can print with more than 25 materials, and PrintSpace 3D is working on incorporating more. The company hopes the printer will help users make end-use products and not just prototypes.

The Altair can print with more than 25 materials currently, and the list continues to grow. It is also extremely fast and has a user-friendly interface, Jaster says, both features which benefited from his NASA experience in thermal management and automation at the heat treatment facility.

Soon after PrintSpace3D launched, it won a local business contest, earning the startup $5,000 and increased local recognition. The company sells printers to local customers and beyond, and recently launched a partnership with the Department of Energy's Oak Ridge National Laboratory.

Silicon Diode Sensor Tracks Extreme Temperatures

Most people probably have a thermometer lying in a drawer somewhere. But engineers need something a little more high-tech to get an accurate read on the temperature of rocket fuel.

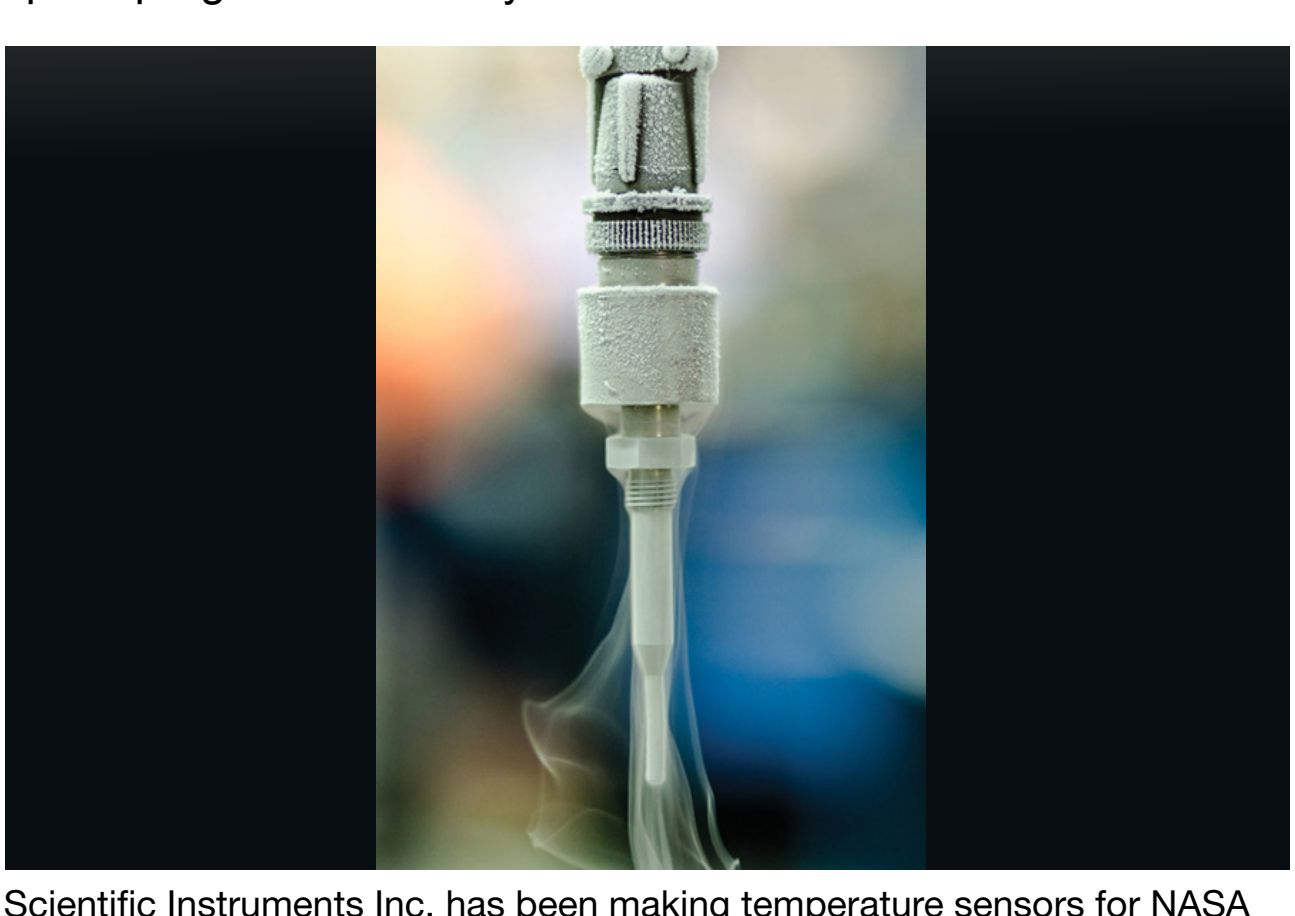


Before a Space Shuttle launch, this external fuel tank would be filled with liquid fuel, which must be kept at hundreds of degrees below zero. NASA used special sensors to monitor the temperature in fractions of degrees, to ensure the fuel didn't start to warm up and form gas bubbles.

That's because NASA needs to keep the fuel, which consists of hydrogen and oxygen, cold enough to stay liquid—and that requires keeping both substances hundreds of degrees below zero.

Once the fuel starts warming up, gas bubbles can form, which degrades the flow along the pipeline, explains Kennedy Space Center's Jose Perotti. "We wanted to read in fractions of degrees at those lower temperatures to better know whether the quality of the fluid was good."

Kennedy turned to Scientific Instruments Inc., the West Palm Beach, Florida-based company it had been relying on for temperature sensors since the Apollo program. "Kennedy was one of the first customers we ever had as a company," explains Austin Capers, who oversees cryogenic thermometry sales for the company.



Scientific Instruments Inc. has been making temperature sensors for NASA since the Apollo era. For the Shuttle program, it improved an existing silicon diode sensor, which it now sells to private aerospace companies and the medical industry.

"They ended up using our sensors on the oxygen tanks during the Apollo missions, which was the biggest first step that our founders took in this business."

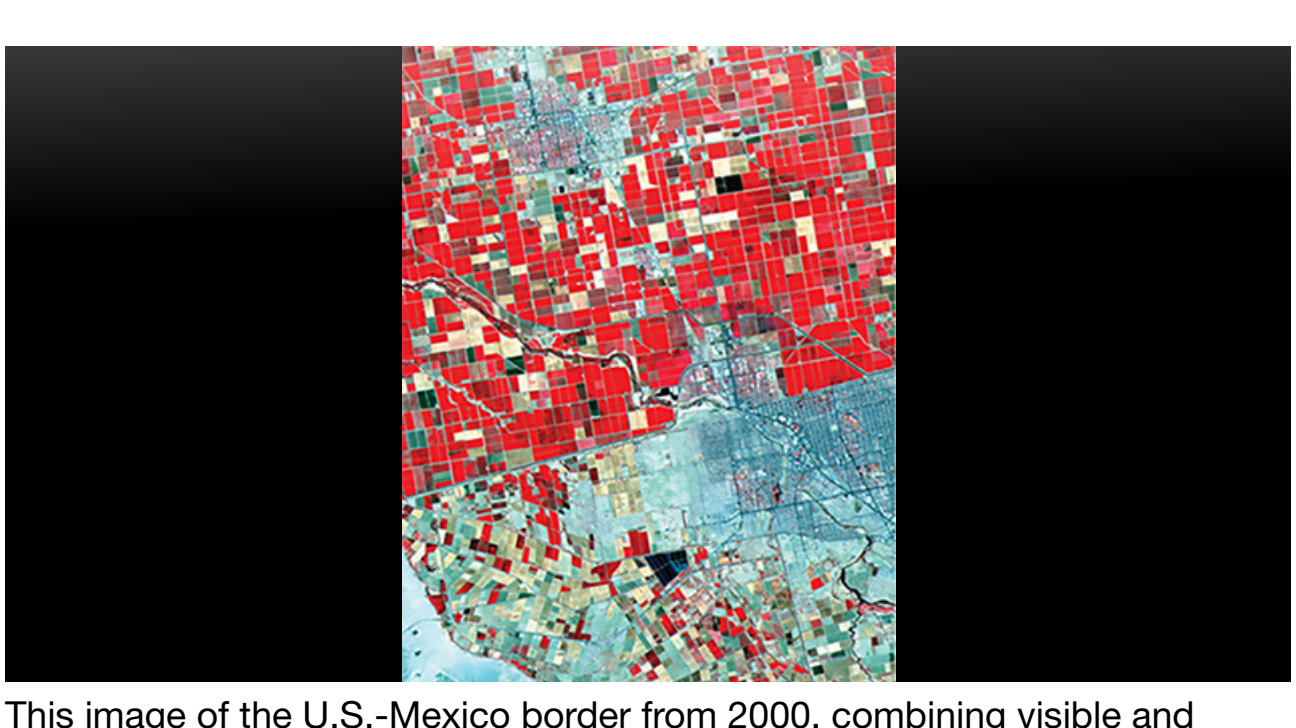
By the Shuttle era, Scientific Instruments had a better option: silicon diode sensors. However, Capers says, the sensor needed a more robust package, because "it needs to withstand harsher conditions."

NASA's specifications also included accuracy levels, probe lengths, and that the probes could withstand a certain pressure rating. To achieve all that, Scientific Instruments designed a hermetically sealed stainless-steel enclosure, with the sensor mounted inside at one end, with a connector on the exterior.

"We sell a similar model today to several private space exploration companies. It's a similar design, similar concept," he says, though "the actual design of the probe is a little different." In the mid-1990s, Scientific Instruments also supplied silicon diodes for the production of MRI magnets.

Tunable Filter Grabs Particles and Cells Using Only Light

Images taken from the sky can offer clues to plant growth and water needs. The key is in filtering the light—infrared wavelengths can reveal chlorophyll content, for example, which dips when plants are starting to fail.

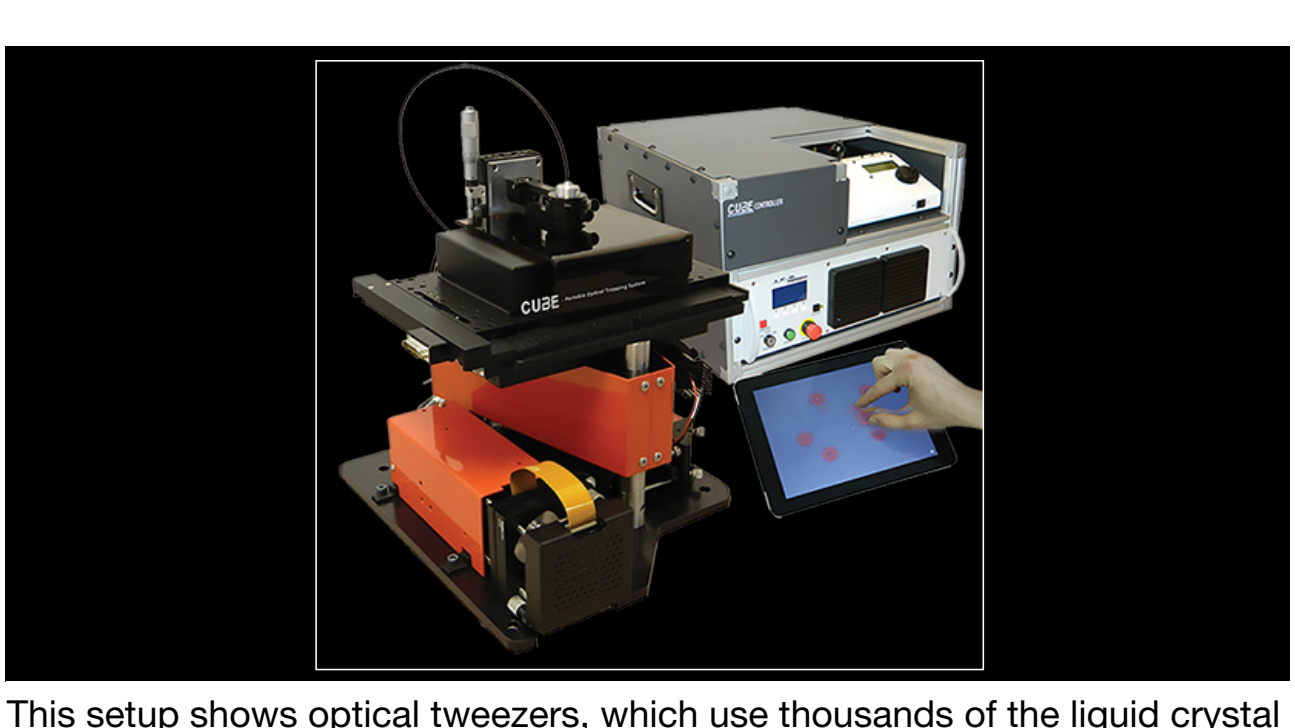


This image of the U.S.-Mexico border from 2000, combining visible and infrared bands, shows lushly growing, gridded fields (in red) on the U.S. side, compared to more sparse and irregular growth in Mexico. Tunable liquid crystal filters help focus in on different light wavelengths, which can reveal insights like which plants need more water or which might be diseased.

NASA helped develop a light filter that could be tuned to different wavelengths, intending it for its many Earth-observing missions, but the result turned out to have many applications, from nuclear fusion to brain research.

The project took place in the 1990s, explains Meadowlark Optics Chairman Tom Baur, under Small Business Innovation Research (SBIR) contracts from the Air Force and the Jet Propulsion Laboratory.

Baur and his team came up with a device that uses a thin layer of liquid crystal—around 5 or 10 microns thick—between two windows with a transparent conductive coating. Electricity varies the alignment of the liquid molecules, which allows different light wavelengths to pass through.



This setup shows optical tweezers, which use thousands of the liquid crystal variable retarders invented under SBIR by Meadowlark Optics to direct a laser beam through a microscope to "grab" tiny particles.

"Without any mechanics, you can change the optical performance electrically," Baur explains. These "liquid crystal variable retarders" earned the Frederick, Colorado-based company some $5 million in business, as well the Photonics Circle of Excellence award from Photonics Spectra magazine.

"They are now sold by a number of companies—but we were the first," Baur says.

The devices have many applications. "It's like saying, 'Well, we invented a lens, what category would you put that in?' Could be used in a microscope, telescope, a laser system," Baur says.

Currently, the technology's largest market is in biology research, where it's used in optical tweezers—essentially a laser fed through a microscope that creates a highly focused beam to trap and move tiny particles, like cells or even genetic material.

The laser is focused through thousands of liquid crystal variable retarders in an array called a spatial light modulator, also used in nuclear research, optical communications, and adaptive optics.

"In some way, 30-40 percent of all the products we sell use the technology that was developed in those SBIRs," Baur says.

Technology Transfer Program Network Directory

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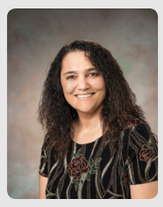
NASA Headquarters

National Aeronautics and Space Administration

Daniel Lockney
Technology Transfer Program Executive:
Phone: (202) 358-2037
Email: daniel.p.lockney@nasa.gov
300 E Street, SW
Washington, DC 20546

Field Centers

Ames Research Center
Technology Transfer Office Chief:
Rose Grymes
Phone: (650) 604-4724
Email: rose.grymes@nasa.gov
Moffett Field, California 94035



Armstrong Flight Research Center
Technology Transfer Office Chief:
Laura Fobel
Phone: (661) 276-3967
Email: laura.j.fobel@nasa.gov
4800 Lilly Drive, Building 4839
Edwards, California 93523-0273

Glenn Research Center
Technology Transfer Office Chief:
Harvey Schabes
Phone: (216) 433-8047
Email: harvey.l.schabes@nasa.gov
21000 Brookpark Road
Cleveland, Ohio 44135

Goddard Space Flight Center
Technology Transfer Office Chief:
Nona Cheeks
Phone: (301) 286-5810
Email: nona.k.cheeks@nasa.gov
8800 Greenbelt Road
Greenbelt, Maryland 20771

Jet Propulsion Laboratory
Technology Transfer Office Chief:
Debora Wolfenbarger
Phone: (818) 354-3829
Email:debora.l.wolfenbarger@jpl.nasa.gov
4800 Oak Grove Drive
Pasadena, California 91109

Johnson Space Center
Technology Transfer Office Chief:
Charlene Gilbert
Phone: (281) 483-0474
Email: charlene.e.gilbert@nasa.gov
2101 E. NASA Parkway
Houston, Texas 77058

Kennedy Space Center
Technology Transfer Office Chief:
Dave Makufka
Phone: (321) 867-6227
Email: david.r.makufka@nasa.gov
Kennedy Space Center, Florida 32899

Langley Research Center
Technology Transfer Office Chief:
Kathy Dezern
Phone: (757) 864-5704
Email: kathy.a.dezern@nasa.gov
Hampton, Virginia 23681-2199

Marshall Space Flight Center
Technology Transfer Office Chief:
Terry Taylor
Phone: (256) 544-5916
Email: terry.taylor@nasa.gov
Huntsville, Alabama 35812

Stennis Space Center
Technology Transfer Office Chief:
Duane Armstrong
Phone: (228) 688-2180
Email: curtis.d.armstrong@nasa.gov
Stennis Space Center, Mississippi 39529

Allied Organizations

Space Foundation
Kevin Cook, Vice President, Marketing and Communications
Phone: (719) 576-8000
Email: kcook@spacefoundation.org
4425 Arrowswest Drive
Colorado Springs, Colorado 80907

Federal Laboratory Consortium
Diana Hoyt, Collaboration Program Manager
Phone: (202) 358-1893
Email: diana.hoyt@nasa.gov
300 E Street, SW
Washington, DC 20546

Spinoff Program Office
Email: spinoff@nasa.gov

Daniel Coleman, Editor-in-chief
Phone: (301) 286-4058
Email: daniel.p.coleman@nasa.gov

Mike DiCicco, Senior Science Writer
Naomi Seck, Science Writer
John Jones, Senior Graphics Designer

Goddard Space Flight Center, Building 26
8800 Greenbelt Road
Greenbelt, Maryland 20771