

National Aeronautics and Space Administration



# SPINOFF



2017

# Welcome



Stephen Jurczyk  
Associate Administrator  
NASA's Space Technology  
Mission Directorate

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

Fifty-eight years ago, in 1958, Congress established NASA with a mandate not only to explore space but also to ensure the results of that research and technology come back down to Earth in the form of practical benefits for the public. From its earliest days, NASA has been known for spinoff technologies making a commercial impact, 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 high-speed cameras, developed to monitor Orion's parachute deployment, now being used in car crash tests, military weapons tests, and more; precision GPS technology that helped create the world's first self-driving tractors; and laser imagers that not only discovered snow on Mars but have also identified important archaeological sites on Earth.

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 *Spinoff*, 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>.



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**TECHNOLOGY  
TRANSFER  
PROGRAM**

BRINGING NASA TECHNOLOGY DOWN TO EARTH

# NASA Spinoff Technology across the Nation

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## Consumer Goods

CMOS Sensors Enable Phone Cameras, HD Video  
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Computer Learning Program Inventories Farmers' Fields

## Information Technology

Laser Imaging Helps Archaeologists Dig Up History  
Program Predicts Aerothermodynamics of Reentry, Subsonic Flight  
Data Acquisition System Captures Machine Performance  
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## Industrial Productivity

3D Weaving Technology Strengthens Spacecraft, Race Cars  
Vibration Tables Shake Up Aerospace, Car Testing  
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Polyimide Aerogels Boost Antennas, Insulate Pipes (MA)  
Privately Built Facility Offers Advantages in Space Exposure Testing  
Optical Filters for NASA Imagers Focus on Cutting Edge  
Zinc-Silicate Coating Blocks Corrosion  
Outgassing Test Facility Brings New Materials into Space Industry  
Shuttle, Hubble Work Lead to Strength in Custom Current Sensors  
High-Heat Cement Gives Ashes New Life



# Health and Medicine

From tools for brain surgery to dental X-rays, NASA research yields technologies that enhance medical treatments and save lives. In this section you can learn—among other things—how fabrics, cooling suits, and diagnostic tests designed for astronauts have led to new medical products for infants, injured athletes, and those most at risk for sudden epidemics.



# Active Pixel Sensors Lead Dental Imagery into the Digital Age

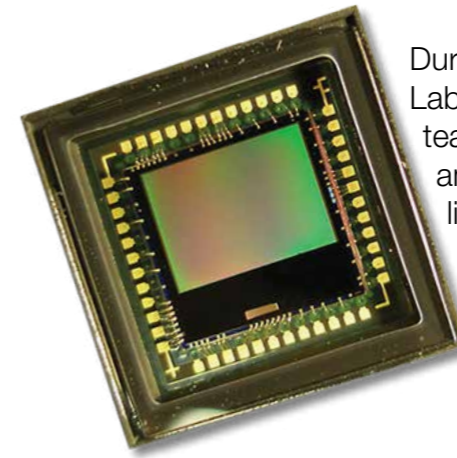
They're in your cell phone camera and DSLR, but they were likely in your dentist's X-ray machine first: CMOS digital image sensors.

NASA spent much of the 1980s developing imagers based on charge-coupled device (CCD) technology, which had enabled the first digital cameras. But in the early 1990s, Jet Propulsion Laboratory (JPL) engineer Eric Fossum set out to build a more efficient image sensor based on complementary metal oxide semiconductors (CMOS), which are microelectronic transistors that had been integral to computers since the 1960s. It had been tried before, but Fossum and his team figured out how to correct for noise that plagued earlier versions.

To develop the sensors, JPL entered into several Technology Cooperation Agreements with companies, including dental device manufacturer Schick Technologies of Long Island City, New York, which wanted to use them for dental X-rays. Engineers from Schick and JPL worked together to advance the technology and adapt it to X-ray imaging.



Schick's dental imagers have benefited not only from the initial enhanced capabilities of NASA-invented CMOS image sensors but also from the rapid improvements and lower costs that have come with the technology's explosion across the digital imaging industry.



During his time at NASA's Jet Propulsion Laboratory, engineer Eric Fossum and his team created the CMOS Active pixel sensor, an innovation that Schick Technologies licensed for dental imagery when it was young. CMOS imagers have since taken over the digital imaging industry.

In 1995, Fossum and colleagues founded Photobit with an exclusive license for CMOS imaging, and Schick obtained an exclusive license for CMOS dental imagers.

What came to be called the active pixel sensor was more energy-efficient than CCD imagers, which was important for imagers Schick wanted to power with batteries. Active pixel sensors also allowed for smaller devices, which translated to patient comfort in imagers that are placed in the mouth. They were also less susceptible to electrical noise.

As CMOS sensors came to dominate the entire digital imaging industry, Schick, now owned by Sirona Dental Systems, benefited from rapid improvements in size, speed, memory, and quality, as well as cheaper mass production.

Today any company using CMOS dental image sensors has licensed the technology from Sirona, which still holds the license from JPL's managing entity, the California Institute of Technology.



An X-ray by one of Sirona's CMOS-based digital X-ray devices shows a tooth implant. Through Schick Technologies, which it acquired in 2006, the company holds an exclusive license for use of the NASA-invented technology for dental imagery.



# Mini Heat Pipes Wick Away Heat in Brain Surgery

Neurosurgery requires tools that are as precise and reliable as possible. Bipolar forceps, one important tool of the trade, use electricity to cut and cauterize tissue, but that produces unnecessary and potentially dangerous heat.

To avoid singeing healthy brain tissue, that heat needs to be drawn out. One method to do that is installing heat pipes—a technology that owes a lot of its development to NASA funding and which has proven useful to the agency in a number of ways over the years.

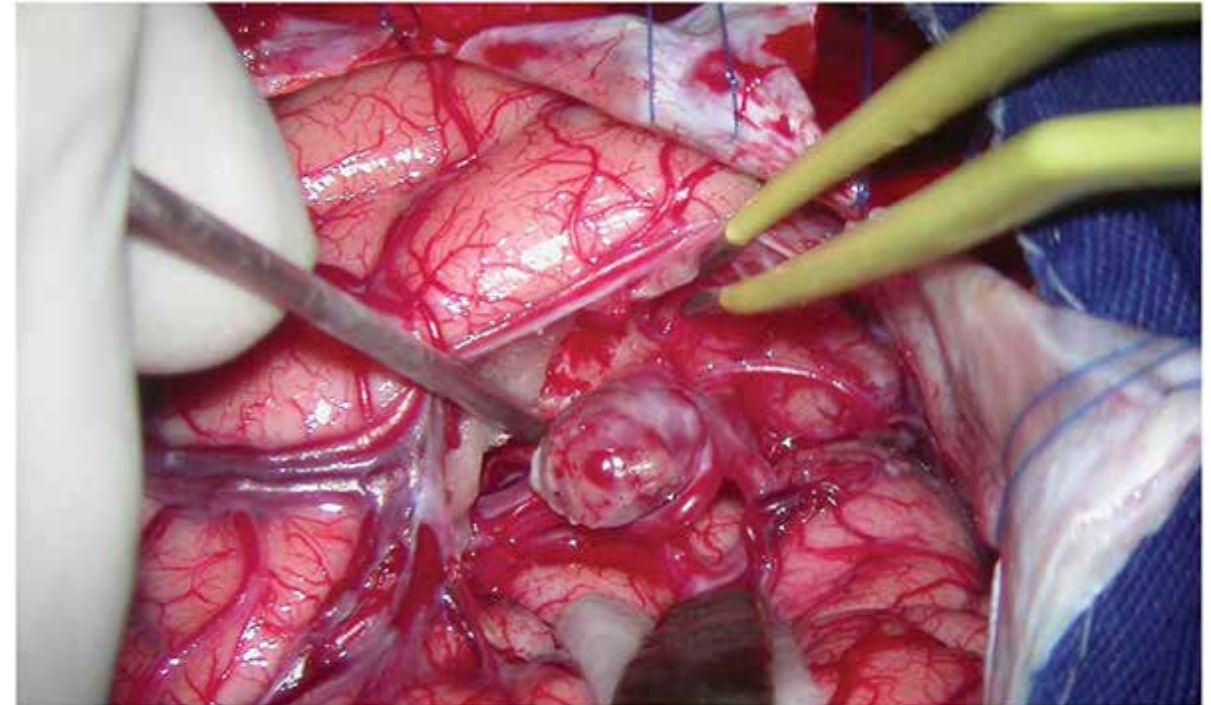
Heat pipes “are like a superhighway for heat,” explains Glenn Research Center’s Kenneth Burke. First developed decades ago, they work essentially like a heating system with boilers and radiators. Inside the pipe, a liquid heats up and evaporates. It travels to the cooler end where it loses that heat through convection, effectively transferring the heat from one end of the heat pipe to the other.

Over the course of more than 40 Small Business Innovation Research (SBIR) contracts since the 1980s, many of them from Glenn, NASA has helped Lancaster, Pennsylvania-based Thermacore advance the technology of heat pipes for high-tech applications, including most recently for the thin spaces between fuel cells, a design that Burke says will likely find other applications at NASA as well.

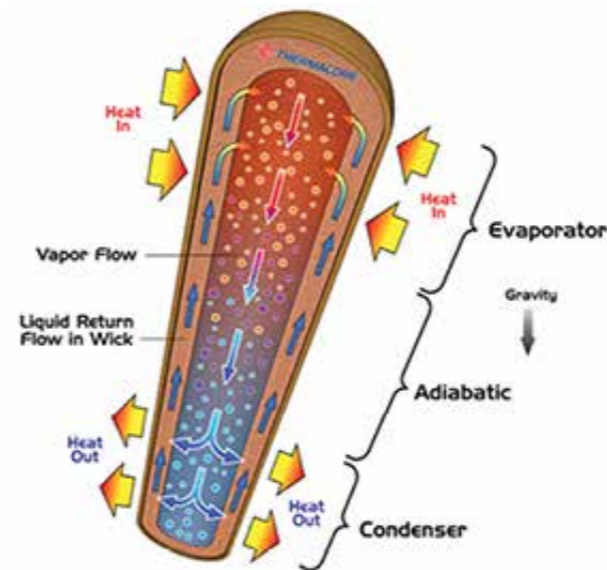
“There are lots of applications where heat needs to get removed from very tight spaces,” he notes. “We’re always trying to cram 10 pounds of heat-producing electronics in 5-pound boxes.”

And in the last decade or so, Thermacore has taken that expertise in heat pipes, honed in part through its NASA SBIR contracts, and adapted it to medical uses.

The medical applications include bipolar forceps used in brain surgery, where “the result was a dramatic improvement in surgical precision, reduced procedure times, and better patient outcomes,” says Thermacore’s Michael Bucci.



A surgeon uses bipolar forceps (yellow) in an operation to repair an aneurysm. Thermacore has designed a miniature heat pipe to help dissipate extra heat generated by the electricity in the forceps, which has improved surgical precision, reduced procedure times, and improved patient outcomes.



Heat pipes help dissipate heat or move it where it’s needed. Thermacore makes them in a variety of sizes and configurations for different applications, but they all work based on the same basic design.



# Fluorescent Diagnostic Test Readers Offer Fast, Low-Cost Results

Interested in developing small, efficient medical diagnostic tests for astronauts—ones more akin to home pregnancy tests than traditional tabletop lab equipment—Ames Research Center awarded two Small Business Innovation Research (SBIR) contracts to Intelligent Optical Systems in 2011 to integrate a diagnostic sensor platform with a smartphone.

The idea was to use the phone's camera and processing power to analyze lateral flow test strips, the same detection technique used in a pregnancy test. The strips would combine bodily fluids with molecules that glow in ultraviolet light and also bind with certain biomarkers—substances that indicate a biological condition, such as antibodies that signal the presence of specific illnesses.

To build the smartphone interface, the company subcontracted Los Angeles-based Holomic LLC, now Cellmic LLC, which was already marketing smartphone-based diagnostic hardware. Cellmic already had a reader for analyzing test results in the visual spectrum. To meet NASA's needs, the company developed a version that illuminated test strips with ultraviolet light and could use the phone's microprocessor to evaluate the resulting images and determine whether or not a given biomarker was present. Fluorescence amplifies the test results, making the tests more sensitive than traditional, chromatographic lateral flow strip assays.

Through this work, Cellmic developed its HRDR-300 Fluorescent Immunoassay Reader, available as a smartphone attachment or in a benchtop version. Rather than selling complete test kits to end users, the company markets the readers to companies that want to develop their own tests. They were officially released in July 2014.

The tests are fast, cheap, and easy to administer, making them especially useful in remote locations, and the smartphone platform's communications capability gives them another advantage. Test results, along with the locations where they are obtained, can be transmitted to a central database, so the devices could map a disease outbreak.



As a NASA subcontractor, Cellmic LLC (formerly Holomic LLC) developed a sensor platform that uses a smartphone's camera and processing power to read the results of custom-made rapid diagnostic tests of bodily fluids.



Cellmic's smartphone-based test reader presents several advantages for medical field work in remote locations, such as portability, ease of use, speed of test results, and the ability to transmit diagnoses and geographical locations to a central database, for example to map the spread of an outbreak.





# Cooling Garments Find New Medical, Athletic, and Industrial Uses

In the 1960s and '70s, Bill Elkins worked as a contractor to NASA and the military, developing liquid cooling garments to be worn inside spacesuits and flight suits. Typically, they were threaded with tubes carrying liquid cooled by a heat exchanger, but Elkins worked with Ames Research Center engineers to develop a system with thin panels holding liquid-filled channels, each covering a muscle mass. They also introduced a cooling system for the helmet.

The design was never used in space, but these elements would appear in Elkins' later commercial creations.

In the 1980s, after founding Life Support Systems Inc., Elkins worked with Ames engineers to create a cooling system to treat multiple sclerosis and other conditions. To adapt the technology to sports therapy, he later founded CoolSystems Inc., which found great success as Game Ready after Elkins sold it.

In the mid-1990s Elkins founded WEIkins LLC, now based in Downers Grove, Illinois. A neurosurgeon looking for a way to cool the brains of stroke and head trauma patients contacted Elkins through NASA, and, following a 2004 pilot study, the company started working on new medical applications for the technology.

WEIkins' Cooling Headliner, which the Food and Drug Administration approved for medical uses in 2012, employs cooling panels similar to those Elkins developed with Ames 40 years ago. By cooling the brain after a heart attack or stroke—or during surgery—the device reduces its need for oxygen, thereby reducing the risk of brain damage. It also reduces damage from a concussion or traumatic brain injury.

The company also markets a Sideline Cooling System to athletes and sports teams, who use it to combat heat stress and improve performance, and a cap and vest system aimed at workers who wear heavy protective clothing or work in hot environments.



One application for WEIkins LLC's NO SWEAT! Work Enhancement System is to cool workers who have to wear heavy protective clothing, such as bomb squad personnel. In fact, one of his earlier companies' products earned Elkins a Commander's Award for Public Service from the Army for its usefulness in cooling these military personnel during operations Desert Shield and Desert Storm.



WEIkins LLC's Sideline Cooling System is marketed to athletes and sports teams as a way to improve performance, reduce inflammation in the event of a concussion, and reduce the effects of minor head impacts.



Technology pioneered to keep astronauts and pilots cool now finds a commercial market in sports, where a liquid-cooled headliner can reduce inflammation in the event of a concussion and also improve performance by maximizing oxygen uptake, lowering heart rate, decreasing sweating, and increasing blood flow.





Through an agreement with NASA, astronauts conduct the experiments that use Techshot's bone densitometer. The company maintains a payload operations center from which it can monitor its space-based equipment and download data in real time.



Techshot worked with NASA and the Center for the Advancement of Science in Space to develop a commercial bone densitometer suitable for operation on the ISS. The device, dubbed Bone D, is primarily used by companies to study the effects of microgravity on mice.

## Space-Based Bone Scanner Expands Medical Research

What happens to bones after months in microgravity? The answers are of keen interest to researchers, who can use the information to offer new insights into healthcare on the ground.

But since research space is at a premium on the International Space Station (ISS), cutting-edge equipment is needed that can help ground-based researchers connect with the orbiting lab.

As a part of an effort to upgrade ISS research facilities managed by Johnson Space Center, the Center for the Advancement of Science in Space (CASIS) worked with Techshot Inc. to build a bone densitometer suitable for use in space. Techshot started with a device widely used by biomedical researchers to take X-rays of rodents, called the GE Lunar PIXImus X-ray densitometer. It modified the device to make it smaller and lighter, as well as to ensure ground-based scientists could make apples-to-apples comparisons between ISS scans with those taken on Earth.

The Greenville, Indiana-based company's product, dubbed Bone D, is operating commercially on the station for a number of clients looking to take advantage of studies performed in microgravity. Researchers for the first time have the ability to observe changes in test animal musculature and bone density in real time, a boon for biologists and pharmaceutical companies interested in developing treatments for musculoskeletal ailments. Right now it's only being used for rodent research, although it's possible other living creatures could be scanned with it in the future.





Embrace Innovation's NASA-derived product line includes baby swaddles and sleeping bags in various sizes, as well as a quilted blanket. Phase-change materials in the products' fabric regulate body temperatures, absorbing heat when babies get too warm and releasing it when they are cool.

## Temperature-Regulating Fabrics Keep Babies Comfortable

In 1988, Johnson Space Center awarded a Small Business Innovation Research (SBIR) contract to Triangle Research and Development Corporation to incorporate phase change materials (PCMs), contained in tiny microcapsules, into fabric to line a spacesuit glove.

Like ice cubes, PCMs absorb heat as they change from solid to liquid, and, if exposed to colder temperatures, release heat as they refreeze. For gloves, the researchers needed PCMs that could hold and transfer heat more effectively than water and would change phase at a temperature comfortable for humans, problems Triangle had tackled under previous NASA SBIR contracts.

Under the new SBIR funding, the company figured out how to incorporate PCMs into fabrics and fibers, after which a company called Gateway Technologies licensed exclusive rights to the technique. Now called Outlast, the company supplies fabrics to other companies that use them in everything from bedding to clothing and sleeping bags.

In 2007, Stanford University MBA student Jane Chen and classmates came up with an infant incubator that could be manufactured for just \$200 using PCMs. The group started a nonprofit called Embrace, with Chen as CEO, and started working to reduce infant mortality rates among premature babies in areas with limited medical care.

To help fund these efforts, in 2012 the group spun off a San Francisco-based for-profit company, Embrace Innovations, with Chen as CEO. She'd heard new parents complain about not knowing if their babies were too hot or cold. Already familiar with PCMs, she looked for a solution and discovered Outlast. Following a 2015 Kickstarter campaign, the company launched its Little Lotus line of infant swaddles, sleeping bags, and blankets.

The products help babies sleep and reduce the risk of overheating, which is associated with sudden infant death syndrome. For each purchase, Embrace helps a baby in the developing world with an infant warmer.



Embrace Innovations' product line spun out of an MBA-student project to supply baby warmers to populations lacking access to modern medical care. Today, every item purchased from the company results in a warmer donated to an infant in need.



# Transportation



**H**owever you get around on the road or in the air, NASA is with you when you travel. Technologies developed by NASA track flights worldwide, help aircraft designers minimize the effect of sonic booms, keep commercial space cargo safe during landing, monitor vehicle carbon-dioxide emissions, and more.



# Reconfigurable Radio Tracks Flights Worldwide

When Malaysia Air Flight 370 disappeared over the Indian Ocean in 2014, it had flown far beyond radar range. Under a new space-based air tracking system, no plane would ever be off the grid that way—thanks in part to a reconfigurable radio developed with NASA.

NASA uses powerful radio transmitters that allow us to see everything from pictures of cryovolcanoes on Pluto to tweets from the International Space Station (ISS). In recent years, the Agency decided that to send larger quantities of data back and forth faster, it needed higher-frequency radios that can be reprogrammed from a distance using software updates.

Through a 50/50 cost-share cooperative agreement, Glenn Research Center developed one with Harris Corporation, and the final product flew in the ISS SCan Testbed and was honored with an R&D 100 Award.

The Palm Bay, Florida-based company used what it built to create its AppSTAR radio, which quickly became a popular seller in part because of how easily it can be reconfigured for new applications.

Basically, “this is a box, and inside there are a bunch of cards that plug in,” explains Harris

program manager Kevin Moran. “So when a customer has a different mission, we only have to change out a subset of the hardware.”

One early contract with a huge potential impact is with Aireon LLC, which is sending the radios into orbit on Iridium’s new satellite constellation.

These AppSTARs are programmed to receive signals from new airplane transceivers called ADS-B, which automatically send out the flight number, location, heading, and other flight details. Currently, they require line-of-sight to land-based receivers—so many planes flying over the ocean and other remote areas can’t be tracked at all.

Putting the receivers into orbit on the NASA-derived AppSTARs solves that problem. “Within seconds you can keep track of all the aircraft in the world,” explains Harris systems engineer Jeff Anderson. The first iteration of the system is scheduled to go live in 2018.

With real-time flight tracking, planes can safely optimize their flight routes and fly with less space between them. And if a plane disappears, emergency responders will have exact tracking information to start their search.

# Design Software Shapes Future Sonic Booms



This photo, taken to help NASA engineers working on making sonic booms quieter, shows the air flow around an airplane as it surpasses the speed of sound—a visual representation of breaking the sound barrier.

It's been more than 70 years since an airplane first broke the sound barrier, and yet supersonic flights remain mostly out of reach for civilian passengers, in large part because of the massive sonic boom when an aircraft hits supersonic speeds.

NASA wants to change that and in 2016 announced an initiative build an experimental airplane that can break the sound barrier without rattling windows. Some of the software it is using is also useful to private industry likewise interested in developing quieter supersonic jets.

Testing a new aircraft design in a wind tunnel is costly and time-consuming, and doing it virtually with computational fluid dynamics (CFD) helps reduce the burden. But early versions of the software were also time-consuming and costly to implement.

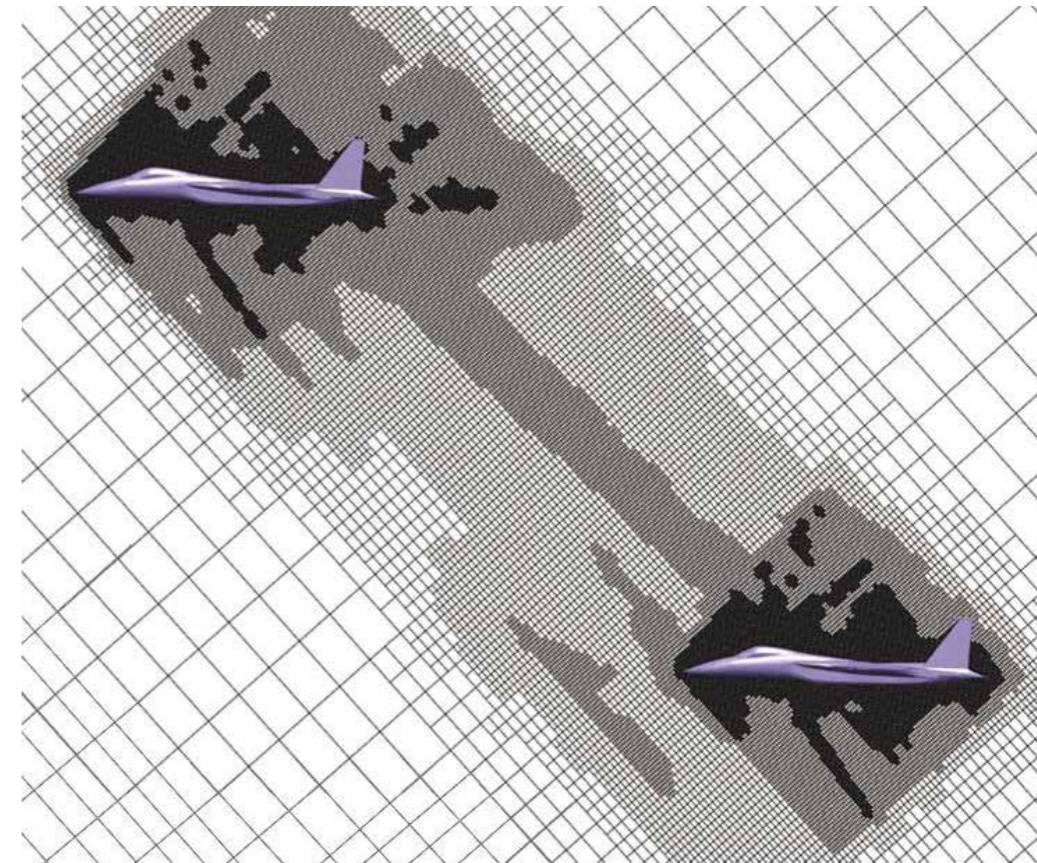
Michael Aftosmis at Ames Research Center devised a way to simplify and automate CFD processes, and Ames released the resulting software, Cart3D, in 2001. Aftosmis says it added a new way for engineers to use CFD: "Rather than just doing one solution that you try to extract a lot of data from, it makes it very easy for the engineer to do many solutions from which they can extract trends and behavior."

The software is now used by every mission directorate, helping to simulate everything from the flight of the Space Launch System to what may happen as a meteor enters Earth's atmosphere.

Desktop Aeronautics, now owned by Reno, Nevada-based Aerion Corporation, acquired the commercial license and added features to make it more user-friendly, creating a software package it markets as GoCart.

"We've actually packaged Cart3D to be user-friendly enough that students are able to work with it in their design projects at universities," says Aerion Technologies' Colin Johnson.

Aerion uses the software for the design of a supersonic business jet, and it also sells the software to universities, government contractors, and commercial aerospace companies.



Cart3D automatically generates the mesh—the 3D grid—around the airplane, a process that had previously been complicated and time-consuming. The mesh, in this case around fighter jets flying in tandem at supersonic speed, helps the software run calculations about how the planes would perform in real life.



# Orion Parachute Innovations Carry Commercial Rockets Back to Earth

With their familiar orange and white stripes, the Orion capsule's three main parachutes hark back to the chutes that signaled the completion of each Apollo mission. There have, however, been updates to this crucial system since the early days of spaceflight, and commercial space companies are also benefiting from them.

Airborne Systems, whose Space and Recovery Systems branch is in Santa Ana, California, has provided parachutes for a number of NASA missions. In 2006, the company was hired as a subcontractor to build the parachute system for the Orion spacecraft at Johnson Space Center. In some ways, such as the layout of the drag surface, these parachutes borrow from Apollo's, but NASA has made advances since then, such as replacing the vent lines that crossed the vent at the top of Apollo's chutes with a "vent hoop" that reduces the risk of tangling and textile loops to hold the reefing lines rather than metal ones that can get crushed during packaging. Nylon straps are now Kevlar.

NASA asked that all these and other features be included in the parachutes Airborne Systems built. The company, in turn, has incorporated them into parachute systems it has provided for commercial space companies like SpaceX, Boeing, and Blue Origin. A crucial selling point: NASA has rigorously tested the parachutes.

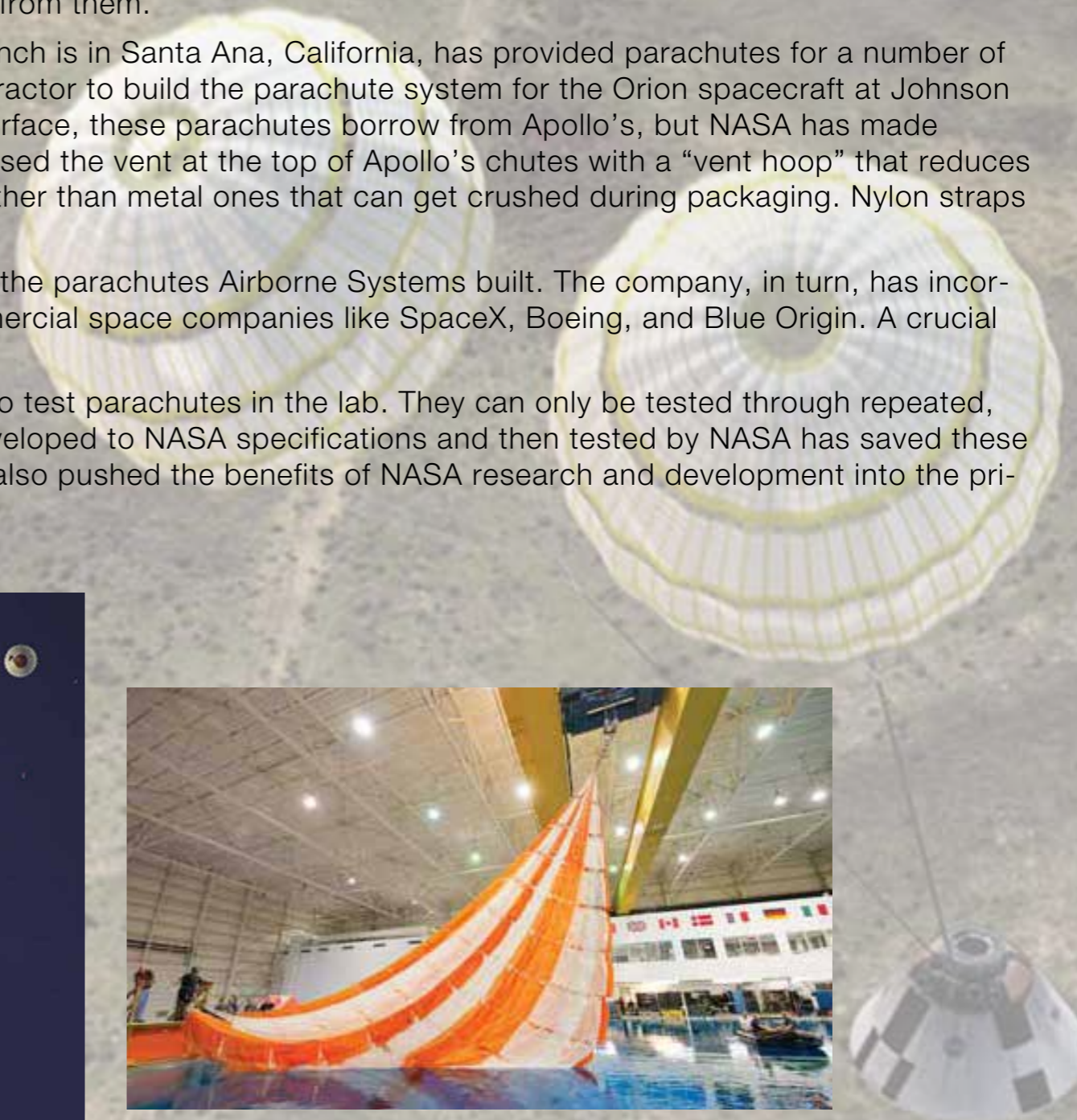
Unlike many other aerospace components, there is no way to test parachutes in the lab. They can only be tested through repeated, costly drops. The ability to buy parachutes based on those developed to NASA specifications and then tested by NASA has saved these companies what could have been prohibitive expenses. It has also pushed the benefits of NASA research and development into the private sector.



Orion's parachutes deploy in stages. First, drogue chutes are deployed to stabilize and slow the spacecraft (background). After the drogues are cut loose (left), three tiny parachutes help pull the main chutes out of the capsule's forward bay. After the main parachutes are deployed, the reefing lines that hold them partially closed are cut one by one until they're fully open, carrying the craft to safety.



Members of the Orion parachute team, the Exploration Flight Test 1 recovery team, and the U.S. Navy practice parachute recovery procedures in the Neutral Buoyancy Lab at Johnson Space Center. As part of the parachute team, Airborne Systems built the chutes to Johnson's specifications and has commercialized them for spacecraft companies.



## CO<sub>2</sub> Sensors Monitor Vehicle Emissions from Above

Through the ASCENDS project, NASA hopes to learn more about how carbon dioxide (CO<sub>2</sub>) concentrates and dissipates seasonally in the atmosphere. Langley's submission to the mission is an active remote sensor comprising of a trio of lasers that can take CO<sub>2</sub> readings from space in darkness and during the day, as well as through cloud cover.

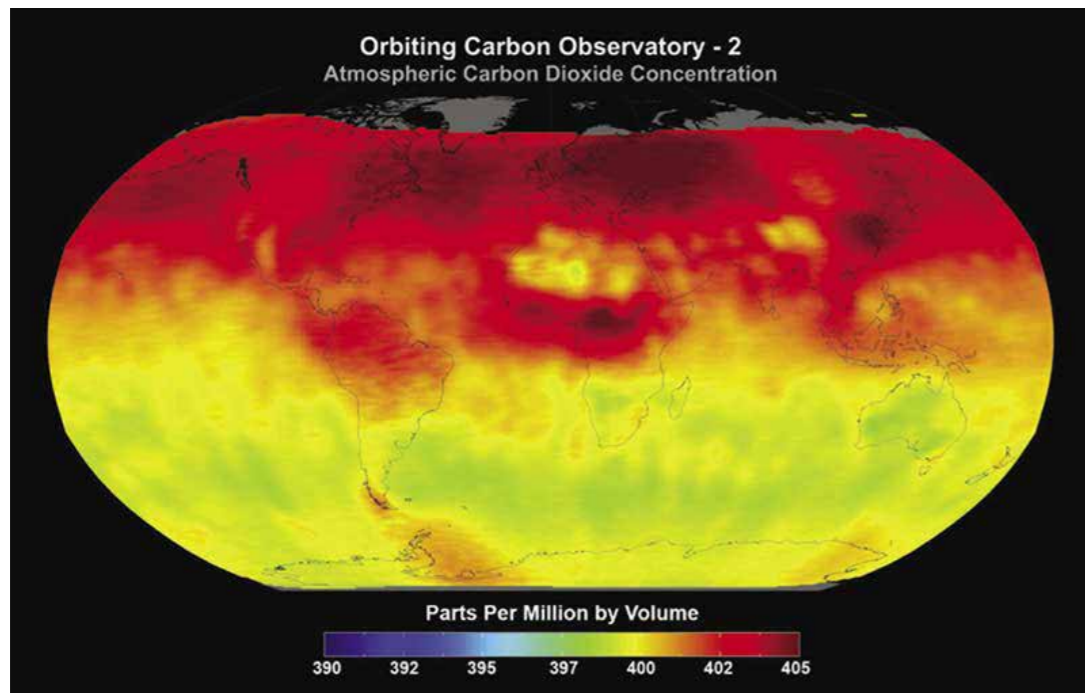
Realizing that the same concept could be used for Earth-based instruments, John Hager, a contractor who worked on the project, went on to found Knoxville, Tennessee-based Hager Environmental and Atmospheric Technologies (HEAT) Inc. HEAT's first product, called EDAR, is based on the Langley ASCENDS technology and remotely measures car and truck emissions from poles installed over high-traffic roads.

Arizona, Connecticut, and Tennessee are the first states to deploy EDAR. Agencies in those

states are using the sensors "to audit the fleet of registered vehicles in cities where air quality does not meet the Environmental Protection Agency's emission standards in order to assess the effectiveness of their vehicle emission testing program," says Hager.

HEAT also has a research project underway with the California Air Resource Board, directed toward heavy-duty diesel trucks and evaporative emissions, such as gasoline vapors that escape from leaky gas tanks, loose hoses, or cracked pipes.

If the technology were adopted nationally, Hager envisions that drivers whose cars pass emissions standards could receive a notification absolving them of having to come in for a test, while owners of out-of-compliance vehicles would have to be inspected.



NASA's Orbiting Carbon Observatory-2 satellite is helping scientists solve mysteries related to how carbon dioxide (CO<sub>2</sub>) concentrates and dissipates in Earth's atmosphere seasonally. This map shows CO<sub>2</sub> concentrations in early 2016. Work on a similar instrument at Langley Research Center led to the development of commercial sensors used to monitor vehicle emissions remotely.



Hager Environmental and Atmospheric Technologies' Emissions Detection and Reporting (EDAR) system has been purchased and installed by four states for various programs related to validating vehicle emissions compliance. In the future, EDAR could make drive-in emissions tests obsolete, replacing them with remote, laser-based sensors that can scan cars and trucks as they pass underneath.





# Software Opens Computational Fluid Dynamics to the Uninitiated

Sukra Helitek Inc.'s simplified, user-friendly computational fluid dynamics (CFD) software package began with Ganesh Rajagopalan essentially trying to work himself out of a job.

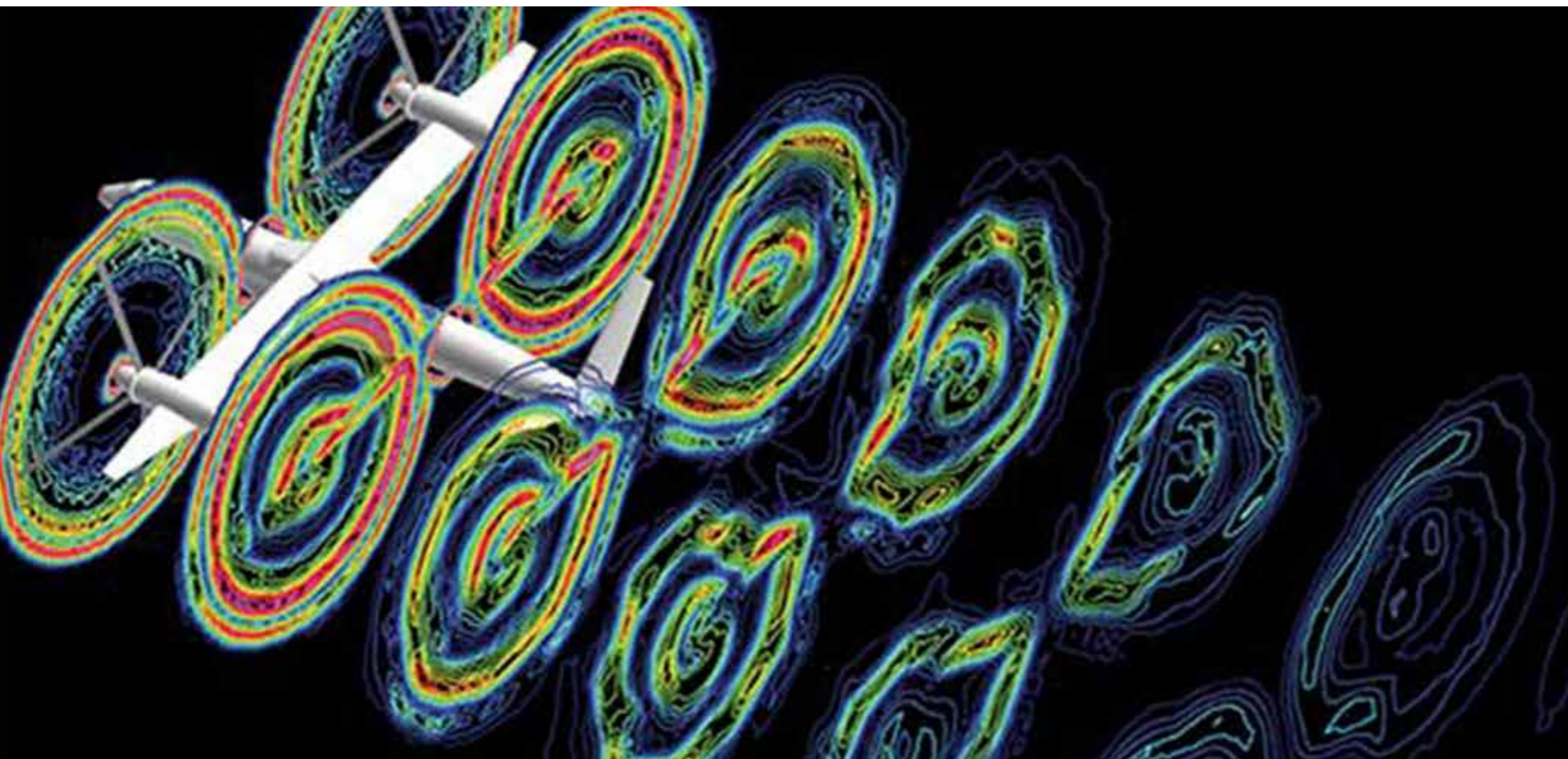
In the 1980s, the Iowa State University professor, who teaches courses on subjects like CFD, aerodynamics, and rotorcraft, often worked as a consultant to Boeing Rotorcraft Systems. Sometimes, though, the company had projects too secret to share with Rajagopalan, so executives asked him for a program that their engineers—or just about anyone—could use to model air flows generated by rotors without his help.

He founded his Ames, Iowa-based company in 1991 and landed his first Small Business Innovation Research (SBIR) contract with NASA's Ames Research Center in 1999. By the following year, Boeing, Sikorsky, and Bell Helicopter were all using his Rot3DC program. An ensuing series of SBIR contracts with Ames and the military led to the RotCFD—short for “rotor CFD”—program by 2010.

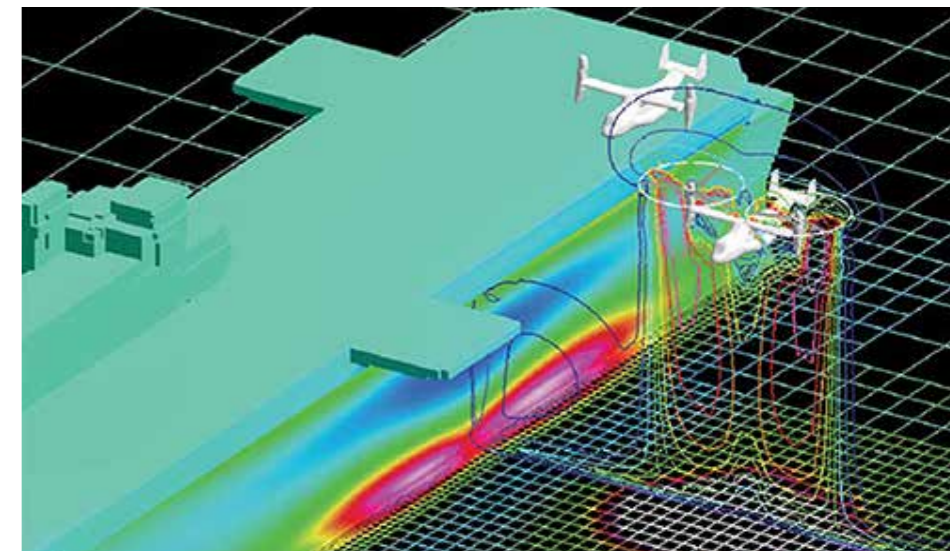
“The main point is that this is a tool that everyone from high school kids on to NASA scientists can use,” Rajagopalan says.

The program is distinguished by its user-friendly interface, its focus on rotorcraft, and its automation of some of the more complex functions of CFD. While it's comprehensive in terms of the rotorcraft CFD problems it can solve, RotCFD simplifies some modeling to speed up the code and automatically generates the complex grids that traditionally were created by hand.

It can also model the airflow of propeller-driven airplanes, jet engine exhausts, and wind flows around buildings, and it has modules for additional capabilities, such as acoustic assessments. While it's a valuable tool for professionals from Boeing to NASA, Rajagopalan especially hopes RotCFD will find a foothold in education, opening an esoteric discipline to a younger, wider audience.



Sukra Helitek's RotCFD program, short for “rotorcraft computational fluid dynamics,” models air flow generated by rotor configurations. The software is noted for being easy enough for high school students to use while retaining enough functionality to be useful to doctoral students and NASA engineers.



RotCFD is often used to model the ways that air flows from rotorcraft will interact with surrounding buildings and other objects, for example at airports.



# Hydraulic Carts Streamline Structural Tests for Aircraft

A typical structural loads test measures the strength and endurance of aircraft structures by applying mechanical forces to simulate the stresses of takeoff, flight, and landing. This is accomplished with multiple hydraulic actuators, load sensors, and strain gauges, each connected to a central control system. Facilities for these crucial tests are often jungles of cables, wiring, and hoses.

While looking to replace its outdated hydraulic system in the mid-2000s, the Flight Loads Laboratory at Armstrong Flight Research Center found a way to reduce the volume of wiring and piping in



The Flight Loads Laboratory at Armstrong Flight Research Center (formerly Dryden Flight Research Center) tests the strength and endurance of aircraft structures, using hydraulic actuators to apply forces that simulate the stresses of takeoff, flight, and landing. The testing involves many cables, hoses, and wires, which the lab minimized by requesting a fleet of hydraulic carts that can be parked near the aircraft and connect to a front-end computer with just two wires. Two of the carts can be seen to the left rear of the plane.

its high bay. The team drew up specifications for a series of hydraulic carts that could each run multiple servo valves to multiple actuators, with just one or two connections to a central computer.

In 2006, Armstrong contracted Moog Inc. to build its next-generation hydraulic system. The company specializes in motion control systems and is headquartered in East Aurora, New York.

The company designed a multi-function mobile cart that houses hydraulics for up to eight actuators and includes most of the necessary electronics, which were previously housed in the control room. Each of the SmartCARTs connects with just two wires to the Real-Time Front-End (RTFE) computer Moog also built, which can connect to up to 48 carts. Armstrong pur-

chased 10 carts and an RTFE, which it now relies on for day-to-day operations. Engineers use only the carts required for a given test, while the rest are stored away. The setup is easily reconfigured by simply rolling the carts around.

The SmartCART is the only system of its kind, and at least one major helicopter manufacturer has purchased a set of 10. The system is especially useful to facilities that run shorter-term tests on a variety of aircraft, requiring frequent reconfiguration.



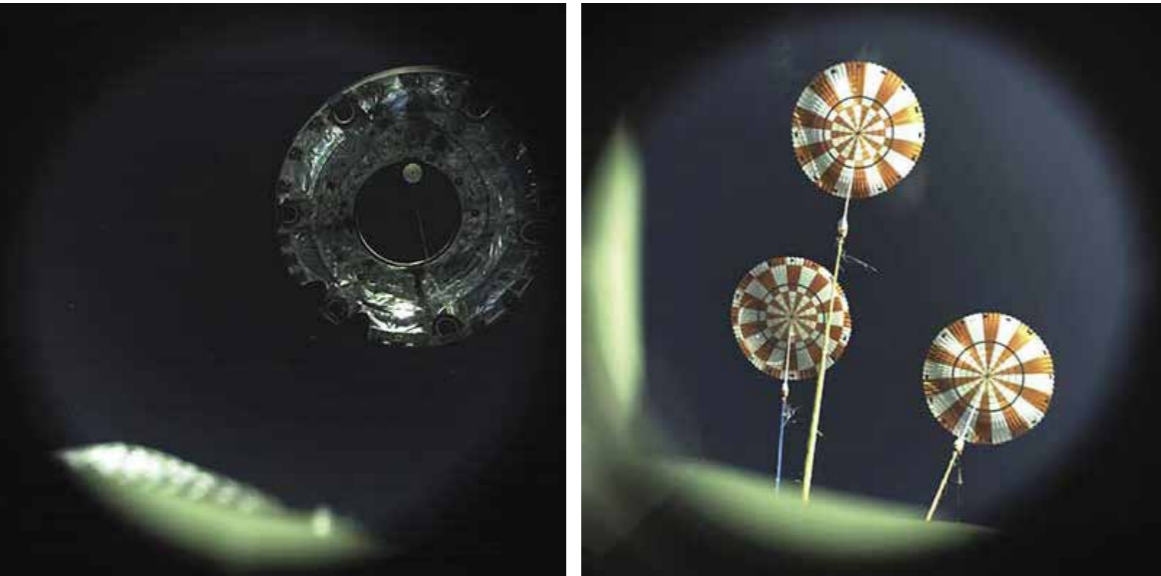
Moog Inc. custom-built a set of 10 hydraulic carts to meet the needs of Armstrong Flight Research Center's Flight Loads Laboratory, reducing the amount of cables and hoses in the lab, creating a more flexible setup, and bringing test operations into the digital age. The company now offers the carts, along with the accompanying Real-Time Front-End computer, for sale to commercial aircraft testing facilities.



# Public Safety

The day-to-day environments NASA deals with are nothing if not extreme: the vacuum and wildly fluctuating temperatures of space, the fiery reentry into Earth's atmosphere, and the explosive rigors of rocket launches. The tools the space agency has created to navigate these harsh conditions often have applications on Earth, as you'll learn in this section. Earthquake dampers that stop buildings from shaking, high-speed cameras used in car crash safety testing, and vibration sensors monitoring railway lines are just a few examples of how NASA keeps people safe through public safety spinoffs.





Integrated Design Tools (IDT) built a compact, rugged camera with an unprecedented rate of memory storage to record parachute deployment during the Orion spacecraft's flight test in high-speed, high-resolution video. To capture the left image, showing the capsule's forward bay cover immediately after it was ejected, the camera had to adjust from total darkness to broad daylight within a few milliseconds. By the end of the deployment, the capsule's three main parachutes had released perfectly to deliver the craft safely to splashdown, with the process captured on film at rates up to 1,000 frames per second.



The Os V3 video camera takes advantage of some of the advances in high-speed, solid-state memory storage, as well as compactness and sturdiness, that the company had to make to meet the requirements for filming parachute deployment during the Orion spacecraft's first test flight.

## Orion Video Requirement Advances High-Speed, Compact Cameras

Parachute deployment is usually a fairly simple—if crucial—operation. This isn't the case, however, for a space capsule returning to Earth, which relies on a series of pilot parachutes, mortar-fired drogue parachutes, and main parachutes, with the drogues cut loose by pyrotechnic cutters to make way for the main chutes.

To monitor parachute deployment during the Orion spacecraft's 2014 test flight, engineers at Johnson Space Center needed a compact, lightweight, high-speed video camera that could store data almost as fast as it captured it and could endure all the rigors of liftoff, the space environment, atmospheric reentry, and splashdown. They and contractor Lockheed Martin approached Pasadena, California-based Integrated Design Tools (IDT), which specializes in cameras mainly aimed at the industrial and scientific markets for uses like crash testing.

The camera the company created is capable of incredibly fast memory storage, backing up data at rates of 10 to 12 gigabits per second. At the same time, it's small and light, rugged, radiation-hardened, waterproof, and capable of adjusting for exposure in milliseconds. To capture the deployment at various frame rates, IDT created a "mission mode," in which the parameters for a sequence of up to 64 recording events can be entered into a spreadsheet and loaded into the camera.

Many of these improvements have already been incorporated into IDT's Os series of cameras, in which the "O" stands for "Orion," including the high-speed, solid-state memory developed for NASA. This and the cameras' durability are important for capturing crash tests or military weapons testing. Even broadcast film crews can benefit from lighter cameras that don't take all day to back up high-speed sequences. And the

mission mode can allow preprogramming of recording sequences, for example when a military test is too dangerous for personnel to approach.



One application for IDT's highest-speed cameras is in automobile crash testing, where every millisecond must be immediately and permanently stored. The company's cameras can be seen here mounted on both the car and the crash-test device.



# Rocket Technology Stops Shaking in Its Tracks

Rocket launches—or earthquakes—are already punishing experiences. But it turns out there are some things that can make them worse: like if the vibrations hit the structure you're in at just the right frequency to cause resonance, where the vibrations become self-reinforcing and get bigger and bigger, in some cases up from bearable to all-out disastrous.

But what if you could turn off that resonance with the flip of a switch?

NASA took on the problem when engineers at Marshall Space Flight Center discovered in testing that the Ares I launch vehicle displayed a serious vibration problem that could be potentially hazardous to the crew sitting right above the booster.

Their solution, appropriating the mass of the hydrogen fuel in the second-stage rocket to dampen the vibrations, worked better than they had even imagined. In testing, “they were getting a knock-down on vibrations that was 50 to 100 times more than could be explained,” recalls project manager Rob Berry.

Team members began to realize they hadn't designed a variation of standard dampers—they'd come up with something fundamentally new.

When they put their new device in the fuel tank, they expected to dissipate the force of the vibrations into the liquid. But instead, they realized they were actually causing the fluid to act as if it was no longer part of the spacecraft structure, which meant the resonance no longer occurred.

The result, a brand-new, low-cost, lightweight damper, could become the industry standard for buildings, bridges, and many other structures susceptible to vibrating or shaking. New York City-based Thornton Tomasetti markets the technology to make buildings safer against the wind and from earthquakes. The first device to hit the market was installed in a Brooklyn building constructed in 2016.

“This is a clear paradigm shift versus what we've been taught,” Berry says. “It's hard for people to give up a century's worth of thinking. But we've made that century's worth of thinking obsolete.”

The uncrewed Ares-1X launched in October 2009 on a successful test flight, but the rocket caused vibrations that would have been dangerous to humans on board. Engineers at Marshall Space Flight Center came up with a solution using the mass of hydrogen fuel in the second-stage rocket.



The NASA-developed devices are installed in four specially designed water-filled pipes along the roof of B2 BKLYN. The damper, which Thornton Tomasetti is marketing as Fluid Harmonic Dampers, is cheaper and more flexible than previous vibration dampening options.



Engineering firm Thornton Tomasetti has licensed the disruptive tuned mass damper technology for commercial use in buildings and bridges. Here a crane lifts a damper to the roof of B2 BKLYN, the first project they are using the NASA derived technology on.



## Micromachined Sensors Monitor Train Rails, Predict Failures

Sensors originally designed to predict failures in a helicopter transmission have found an unexpected use detecting problems in train tracks. Tucson, Arizona-based Ridgetop Group created its RotoSense rotational vibration sensor under Small Business Innovation Research contracts with NASA's Glenn Research Center, which wanted a sensor that could be fixed to a gear inside a helicopter transmission to detect vibration anomalies that could indicate problems. But train axles, too, rotate at high speed and can indicate anomalies by vibrating irregularly.

To pick out variations in vibration while sitting on a whirling part, the little microelectromechanical systems-based accelerometers Ridgetop developed required exquisite sensitivity, as well as fine-tuned software to process the data they wirelessly transmit. Testing of a prototype at Glenn's Helicopter Transmission Test Stand showed they worked at least as well as a traditional sensor housed on the outside of a transmission. Further testing at Glenn is planned.

To develop its RailSafe system, which detects and locates problems with train rails, Ridgetop repackaged the sensors to sit on each end of a train axle and rewrote the programming that identifies the significance of any anomalies. Testing at the Federal Railway Administration's Transportation Technology Center returned promising results.

Ridgetop launched RailSafe in mid-2015 as a kit containing the necessary sensors, data collection hub, and software packages to outfit and monitor trains. Next, the company plans to program the technology to look for any anomalies in a train's wheels. Ultimately, the kit should be able to perform prognostic reasoning for both wheels and rail, predicting their lifetime and warning of possible failures before they occur by monitoring long-term changes in vibration.



Ridgetop Group's RailSafe sensor fits on the ends of a train's axles, where it monitors for vibrations caused when the wheels roll over anomalies in the rails.

Ridgetop Group adapted its RotoSense microelectromechanical systems-based accelerometers, originally developed to monitor components of helicopter transmissions, repackaging the hardware for use in detecting potentially dangerous anomalies in train tracks.



# Wire Sensors Alert to Dangerous Conditions in the Clouds

One common hazard facing airplanes is ice in the air, where it can coat wings or engines. A tool NASA helped develop to better measure that icing risk is turning out to be useful well beyond passenger planes.

One of the best ways to determine how much supercooled liquid water—the culprit behind airborne icing—is lurking in the skies is by sending up a sophisticated sensor on a specially equipped research aircraft, explains Michael King, an aerospace engineer at the Icing Branch of NASA’s Glenn Research Center. However, although the probes work extremely well for research, instrumented aircraft are not flown day-to-day to provide real-time icing hazard information, which is what pilots and operators could use to improve flight safety.

Enter NASA’s ground-based Icing Remote Sensing System (NIRSS), which could potentially fill that gap. Its three ground-based instruments can provide information to help infer the icing risk at any given time.

To help test the system, NASA put out a call in the early 2000s for a lightweight, inexpensive sensor that could be sent into the clouds on weather balloons. John Bogнар, an atmospheric chemist with an affinity for lightweight instruments, thought he could make something work.

Under two Small Business Innovation Research contracts with Glenn, Bogнар’s Anasphere Inc. designed a vibrating wire sensor that measures supercooled liquid water.

Now the Bozeman, Montana-based company is also selling it to others, including the Department of Energy and the Chinese affiliate of German radiosonde company GRAW.

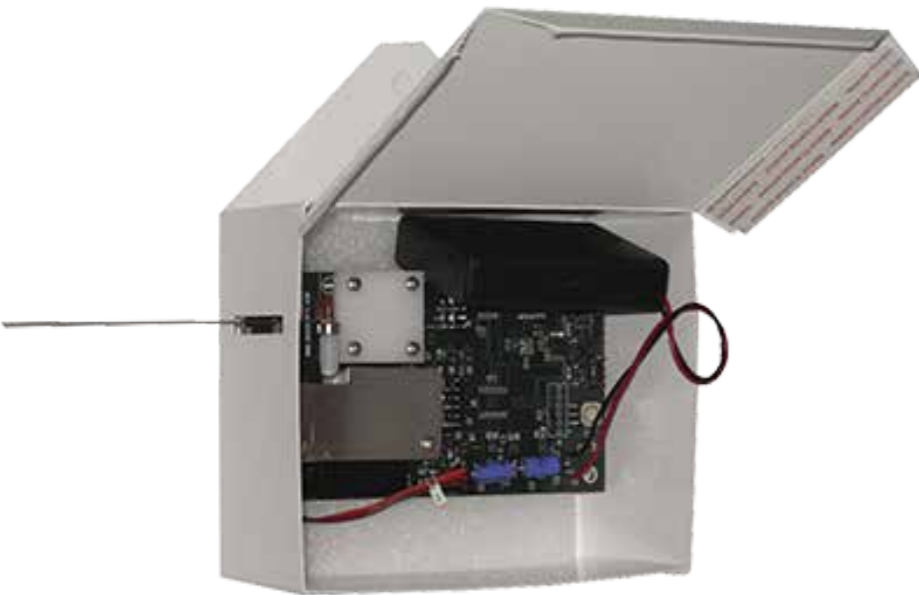
“When you’re using the big expensive sensors, you will have one sensor,” explains Bogнар. “The advantage of our sensor is you’re able to deploy multiple sensors all at once and see upper and lower altitudes simultaneously to see how the cloud is evolving.”



Glenn Research Center icing expert Michael King (left) prepares to launch a weather balloon equipped with a supercooled liquid water sensor designed by Anasphere Inc. Results from balloon launches such as this one will help verify whether a ground-based NASA system can effectively predict icing conditions aloft.



Ice poses a significant hazard to planes in the air, where it can accumulate on wings and engines. NASA is studying ways to better predict when icing conditions are particularly dangerous, and one tool it is using to test its research, a lightweight, inexpensive sensor, is proving useful outside the agency as well.



Anasphere’s supercooled liquid water sensor detects changes in the wire’s vibrations as ice accumulates. The sensor is a fraction of the cost of traditional sensors to detect airborne icing and has found users among the Department of Energy as well as in the agricultural industry.



A firefighter battles a fire in northern California. Water Pure Technologies and its dealer networks have sold mobile, handoperated water filter systems to California fire jumper brigades, who parachute into forest fires and need drinking water onsite.

## Fast-Flow Nanofiber Filters Purify Water at Home and in the Field

**M**ore than a billion people around the world lack easy access to clean water. Even where the liquid is in abundance, it is often contaminated with viruses or bacteria that can cause deadly diseases, especially in vulnerable young children.

Astronauts also lack access to abundant, safe, clean drinking water: in space, they have to take what they need with them and reuse and recycle every precious drop. With plans in place for ever more distant human space missions, NASA has used its resources to help come up with some of the best water-filtering technology available.

In 2000, Florida-based Argonide was working with nanomaterials and discovered its NanoCeram fibers had properties that made them excellent as water filters. NASA took note and awarded the company two Small Business Innovation Research contracts to develop the technology with the Johnson Space Center.

The main benefit to the nanofibers was their unusually strong “bioadhesivity”—meaning particles, including viruses and bacteria, were easily attracted to the fibers and got stuck there.

Filters made with woven nanofiber allow water to pass through rapidly

while still eliminating better than 99.9 percent of viruses and bacteria, outperforming other filters on the market without using chemicals.

Tom Smokoff, founder of Water Pure Technologies Inc. in Murray, Utah, determined these filters were the best available for his goal to build low-cost water filtration systems that worked fast enough to efficiently supply whole villages.

Smokoff buys the NASA-created filters from licensed dealers and now sells portable, battery-operated or hand-cranked systems that can be packed up and brought to a water source. The company also sells systems designed to be installed under a sink or on a house’s water main.

“My whole goal is to bring clean water to humanity at an affordable price,” he says.



Water Pure Technologies builds multi-level filtration systems in a variety of configurations—installed and portable, battery-operated and hand-cranked. The Water ResQ U.V. system operates with a 12 volt battery and has four stages of filtration, including the NanoCeram filter. It can produce 174 gallons of safe drinking water per hour.





# Miniaturized Vacuum Pumps Play Big Roles on Mars and Earth

As its name implies, the Curiosity rover lowered into Gale Crater on Mars by sky crane in August 2012 has a lot of questions to answer. The most pressing, though, is whether the Red Planet has or ever had the necessary conditions to harbor life. One of the most important instruments the car-sized rover is using to investigate Mars' surface is called Sample Analysis at Mars (SAM). SAM includes a mass spectrometer that studies ionized samples of gas and rock by measuring the mass of the ionized molecules to determine their compositions and microstructures.

Like any instrument that is to be blasted out of Earth's gravitational field, SAM and its various components needed to be small and tough.

Through a series of Small Business Innovation Research contracts with the Jet Propulsion Laboratory, Creare Inc., based in Hanover, New Hampshire, built the vacuum chamber for the spectrometer by heavily modifying existing technology. It was able to reduce the part in size from something comparable to a can of soda to a unit about the size of a C-cell battery.

The vacuum pump Creare developed for NASA's Curiosity rover was based on a device about the size of a soda can, which the company was able to miniaturize to the size of a C battery (inset). Creare is now working on a similar vacuum pump for the ExoMars planetary rover (right), a joint mission between the European Space Agency and the Russian space agency Roscosmos scheduled to launch in 2018.



Image courtesy of the European Space Agency



Instruments used to assess chemical dangers following industrial accidents or terrorist attacks are currently too cumbersome to take into the field. Creare's vacuum pumps could help mass spectrometers achieve the kind of reduction in size that would make them practical for use in the wake of a disaster, as well as in inspections and security screenings.

The company has since commercialized its smaller, more rugged vacuum pumps for Earth-based applications, including mining operations, chemical-weapon and bomb detectors, and more.

"There is a significant potential terrestrial market for miniature turbopumps with growth in compact and portable mass spectrometers," says William Brinckerhoff, an assistant chief in the Planetary Environments Laboratory at Goddard. "Defense, health care, environmental, and industrial applications each have requirements for the type of mass spectrometer that this pump would enable. Some of the recent work making the pumps tolerant to vibration and shock could parlay into remote, autonomous, or field environments on Earth."

On Mars, meanwhile, Creare's pump has allowed Curiosity to find key ingredients for life such as sulfur, nitrogen, hydrogen, oxygen, phosphorus, and carbon, along with clay minerals that suggest a past aqueous environment—one that probably even included drinkable water.



# Consumer Goods

**Y**ou might be surprised by the number of space technologies in your home and among the products you use every day. This year's *Spinoff* shows how NASA technology can be found in your cell phone camera, golf clubs, ski goggles, and bottle of wine. Spinoffs are also improving large-scale 3D printers, enabling rechargeable hearing aid batteries, and strengthening sporting goods with nanomaterials.



# CMOS Sensors Enable Phone Cameras, HD Video

“People told me, ‘You’re an idiot to work on this,’” Eric Fossum recalls of his early experiments with an alternate form of digital image sensor at NASA’s Jet Propulsion Laboratory (JPL).

His invention of the complementary metal oxide semiconductor (CMOS) image sensor would go on to become NASA’s single most ubiquitous spinoff technology, dominating the digital imaging industries and enabling cell phone cameras, high-definition video, and social media as we know it.

By the early 1990s, sensors based on the charge-coupled device (CCD), had enabled high-quality digital photography, but Fossum believed he could make imagers with smaller and lighter machinery using CMOS technology to create what he called active pixel sensors. It had been tried before, but CMOS technology had since improved, and Fossum and his team figured out how to eliminate visual noise that had stymied earlier attempts.

Using CMOS sensors, they were able to produce images using lower voltages and charge transfer efficiencies than CCD imagers required, and almost all the other camera electronics could be integrated onto the computer chip with the pixel array, a development that would make CMOS imagers more compact, reliable, and inexpensive.

With a license from the California Institute of Technology, which manages JPL, in 1995 Fossum and colleagues founded a company, which they later sold, to develop the technology.

In the end, it was the cell phone camera, which needed to be small and energy-efficient, that drove the widespread mass production of CMOS image sensors. Resulting improvements to the technology and its manufacture drove costs down and quality up until CCD-based devices couldn’t compete.

CMOS imagers have enabled small, high-definition video cameras, including the popular body-mountable action cameras marketed by San Mateo, California-based GoPro.

By 2015, the technology’s market, which also includes the automotive, surveillance, and medical industries, reached nearly \$10 billion.



The action camera company GoPro takes maximum advantage of the small size and high efficiency of CMOS digital image sensors, using the technology to build tiny, high-definition video cameras that users can affix to themselves, selfie sticks, or surfboards to capture their adventures in high fidelity.

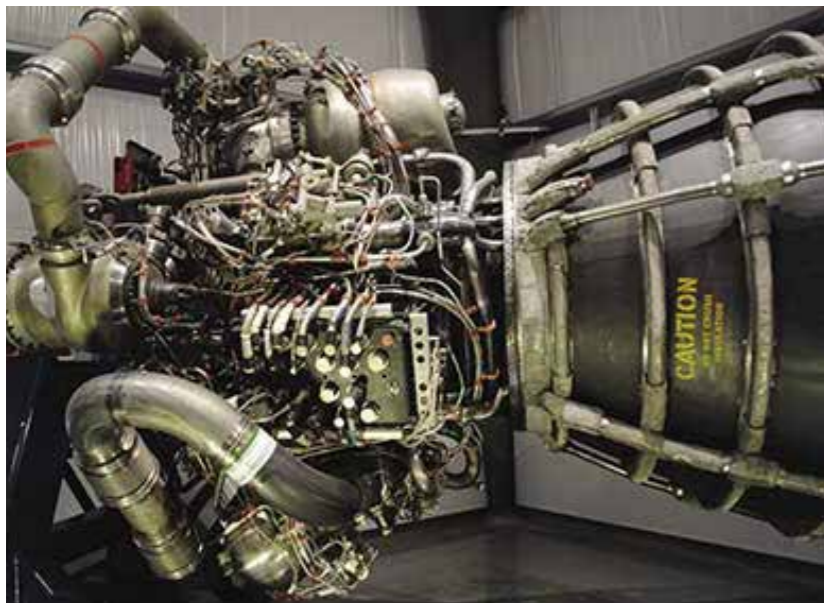


GoPro cameras, which leverage the small size and high efficiency of NASA-invented CMOS active pixel sensors, were originally conceived as surfboard-mounted video cameras, an application that remains popular today.



CMOS-enabled cell phone cameras gave rise to the “selfie” phenomenon, as well as a broader culture of online photo and video sharing. Here, President Barack Obama poses for a selfie with science popularizers Bill Nye, left, and Neil deGrasse Tyson, right.





In the early days of the Space Shuttle Program, which employed reusable rocket engines, NASA looked for fasteners that could endure repeated, intense vibrations without jarring loose. A researcher at Goddard Space Flight Center came across Holmes Tool Company's patented Spirallock threading. He tested the invention meticulously and found it exceeded the agency's demand. Spirallock came to be used on more than 750 tube clamps, joints, and brackets in Space Shuttle main engines and, after the test results were published in 1984, a wide array of industry applications, from diesel engines to pacemakers.

## Novel Threading Enables New Approach to Golf Clubs

In the early days of the Space Shuttle Program, which used the first reusable rocket engines, NASA started looking for fasteners that could endure the vibrations of repeated liftoffs. These could eventually loosen screws in engines and other components.

That's when Goddard Space Flight Center researcher James Kerley came across Spirallock. In 1979, Holmes Tool Company patented an altered bolt threading that had stronger clamping power. In traditional nuts and bolts, about 80 percent of the load is carried by the first two threads. Holmes' threading distributed pressure more evenly, with the first two threads carrying just 25 percent of the load.

The design was used in a few car engines, but after NASA published the results of Kerley's extensive study of Spirallock threading in 1984, it was incorporated into missiles, diesel engines, oil wells, fiber optic networks, human joint implants, pacemakers, and many other systems.

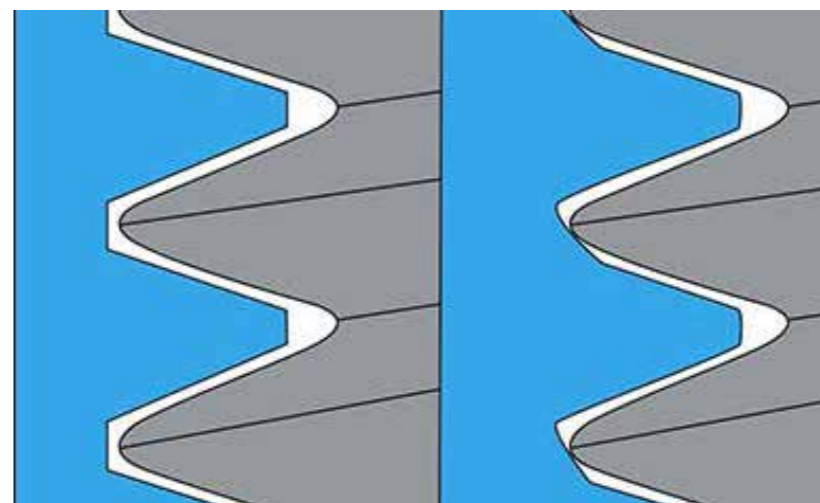
Spirallock was applied to more than 750 fasteners in a set of Space Shuttle main engines.

In 2014, Cobra Puma Golf, based in Carlsbad, California, partnered with NASA to experiment with material deposition in zero gravity. The company wanted to recognize the partnership with a "spaceport door" that screwed into the head of its new KING LTD driver but discovered that repeated golf ball strikes jarred the little portal loose. Having come to respect NASA's problem-solving, the company researched the agency's use of fasteners and came upon Spirallock, which it ended up using to hold the portal in place.

By allowing access to the driver's hollow head, the company was able to place a precise tungsten weight in each club. Together with the weighted portal, this resulted in the first clubs with a center of gravity at the center of the driver's face, maximizing the transfer of energy from club to ball.



Cobra Puma Golf wanted a "spaceport door" to screw into the bottom of its KING LTD Driver in celebration of the testing the company was doing on the ISS. The vibration of repeated drives, however, would cause the little portal to come unscrewed. The company researched NASA's techniques for dealing with intense, repeated vibration and came upon Spirallock threading, which now holds the doors firmly in place. The access to the inside of the club head also allows the clubs to be more precisely weighted, with a lower center of gravity.



The innovation behind Spirallock threading, on the right, is a 30-degree wedge ramp in the trough of the female thread. This forces the thread on the bolt against the ramp in the nut, distributing pressure along the length of the thread, whereas standard threading, shown on the left, puts about 80 percent of the clamp load on the first two threads, with most of the threading making little contact.



# Blue-Light-Cancelling Lens Gives Skiers a Clearer View

Of all the colors the human eye is capable of seeing, it is particularly sensitive to blues and greens, which comprise the middle wavelengths of the visible electromagnetic spectrum. But our sensitivity to these colors comes at the expense of peripheral hues, like red, when the two colors are seen simultaneously. The phenomenon, called center-loading sensitivity, can interfere with visibility in certain situations like spotting targets or judging distances.

In the 1990s, a scientist at Ames Research Center developed optical filters to block blue and green light, allowing other hues to stand out and making camouflaged objects more visible in forests. His work was later commercialized through a Space Act Agreement with NASTEK, which then partnered with Wheatridge, Colorado-based Optic Nerve Inc. to create a line of ski goggles that filter about 95 percent of blue light, giving professional and amateur skiers alike a clear view on the slopes.

Optic Nerve's rose-tinted spherical lens ski goggles, which arrived on the market in fall of 2015, are a cut above the rest in filtering blue light, says company vice president Tom Fox. "The industry standard lies at around 79-80 percent filtration," he notes. "Our lens is up there around 95 percent, which results in an incredible definition of terrain in flat light as well as bright sun conditions." NASTEK CEO Robert Brock adds that for people who aren't color blind, that means an average increase of 12-15 percent in visual acuity and depth perception.

The blue light scattered by air molecules creates a particular haze around mountainsides that interferes with human vision. NASA optical filtering technology is now used in ski goggles that can increase visual acuity and depth perception in these conditions by an average of 12-15 percent.



Following research and development that began in a partnership with NASA, NASTEK now manufactures ski-goggle lenses that use NASA technology to optimize visibility on the slopes. In 2015, the company worked with Optic Nerve to create a line of ski goggles that are used by professional and amateur skiers and snowboarders, as well as ski patrollers.



# Rechargeable Hearing Aid Batteries Draw from NASA Research



Disposable hearing aid batteries die unpredictably, which tends to encourage users to turn them off at times to conserve power and inevitably leaves them without hearing at inconvenient times. On a full charge, the rechargeable silver-zinc batteries that ZPower built off of previous research and development by NASA and the military reliably last all day and then some.



Several early NASA spacecraft, including the Apollo command module, used silver-zinc batteries. The Agency worked hard to make such batteries rechargeable, with some major advances made at Glenn Research Center, then called Lewis Research Center. Rechargeable silver-zinc batteries didn't make it into space, but NASA's research and development served as a starting point for anyone trying to develop them.



ZPower rechargeable silver-zinc hearing aid batteries fit into a specialized door that can be retrofitted onto most existing hearing aids. The door carries a charge from the charger to the battery, eliminating the chore of removing and inserting the batteries.

**T**he silver-zinc battery offers more energy per ounce than any other battery couple, but technical issues and its cost have long impeded commercialization, especially in rechargeable form.

In its early days, NASA was interested in a rechargeable version for long-term, lightweight power. The problem was that a few deep discharge cycles deteriorated the electrodes.

In 1965 researchers at Glenn Research Center, then called Lewis Research Center, began working with the Astropower Laboratory of Douglas Aircraft Company to produce an inorganic battery cell separator that might mitigate electrode deterioration. The resulting battery could survive 200 charging cycles at 50 percent discharge without impeding performance.

The research was made public and was part of the starting point for Camarillo, California-based ZPower to begin developing rechargeable silver-zinc batteries. President and CEO Ross Dueber had also collaborated with NASA during his time in the Air Force's Battery Branch at Wright Aeronautical Laboratories.

Following 17 years of research and development, in 2013 the company released a line of silver-zinc hearing aid batteries—price being less of an issue for such small cells—that can survive 500 to 1,000 discharge cycles without losing significant capacity. They're the first rechargeable silver-zinc batteries on the commercial market and the first rechargeable hearing aid batteries that retain a charge for a full day.

The company developed a battery door that can be retrofitted into existing hearing aids, which holds the batteries and can be removed and placed into the charger so users don't have to handle the tiny cells directly. ZPower also developed a recycling process to help with a related problem: today, 1.5 billion hearing aid batteries end up in landfills every year.



# Large-Scale 3D Printer Brings Manufacturing to the Masses

Finding spare parts or a new tool can be challenging in many places, whether you're orbiting through space or in a shantytown in Kenya.

In recent years, with the spread and increased sophistication of 3D printers, NASA has been exploring a new solution: printing what it needs.

A team including engineers from Marshall Space Flight Center and 3D printing company Made In Space built the first 3D



In 2014, astronauts printed a functional ratchet on the ISS from a design created on Earth and emailed into space. NASA is interested in developing 3D technology to help supply long-duration missions with items the crew didn't, or couldn't, bring with them.



The founders of re:3D drew on experience at Johnson Space Center to design and sell a large-scale 3D printer at a low cost. The standard configuration prints items up to eight cubic feet, or 30 times larger than competing desktop models.

printer ever shown to work in zero gravity. Installed on the International Space Station in 2014, it successfully performed a number of test prints, including, most famously, a functional ratchet from a design transmitted from Earth.

“If you can transmit a file to the station as quickly as you can send an email, it opens up endless possibilities for all the types of things that you can make,” Marshall’s Niki Werkheiser said in an article published by NASA soon after the ratchet printed. “We even may be able to make objects that previously couldn’t even be launched to space.”

The same idea appealed to a group of young innovators then working at Johnson Space Center, who hope to bring the technology to developing countries, where they believe it could alleviate some difficulties facing entrepreneurs and aid workers.

They founded re:3D in Houston, Texas, drawing on skills they honed at NASA to build an inexpensive printer 30 times



A re:3D customer printed the propeller cap for this plane—and then flew it.



re:3D printed this surfboard in four pieces and brought it to Sligo, Ireland to surf it for an event called SurfSummit. The company says its goal is to democratize manufacturing, so as many people as possible, including in the developing world, can print their ideas in solid form.

larger than competing desktop models. They have customers worldwide, including NASA, but they continue to work toward their development mission by donating one for every 100 printers sold, including one to a community group teaching business skills in Kenya’s Kibera slum.

“The thing that I most enjoy is democratizing the capability to manufacture: offering the most capability possible for the lowest possible price. That way you can get it out to as many people as possible,” says cofounder and chief engineer Matthew Fiedler.



# Professional Development Program Gets Bird's-Eye View of Wineries

Virginia might not yet rival California when it comes to wine production, but a growing number of wineries and vineyards are cropping up across the commonwealth.

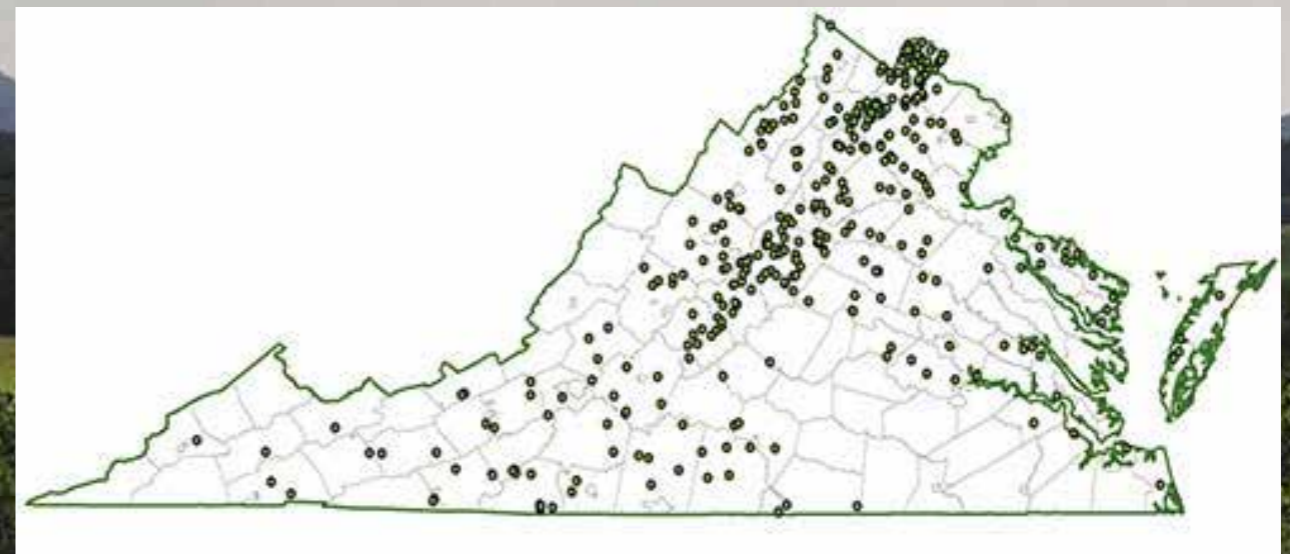
Several years ago, though, the U.S. Department of Agriculture stopped providing the Richmond-based Virginia Wine Board with vineyard acreage data, and the board found that self-reported responses to an annual member survey weren't providing such data at the same level of confidence.

Luckily, Langley Research Center found some researchers eager to help Virginia and its winemakers understand where grapes are being grown. Langley houses the National Program Office for NASA's DEVELOP Program, in which up to 400 students and professionals across the country get the opportunity to build their capacity to work in science, technology, engineering, and math. The program takes on approximately 80 projects each year that make use of Earth observations collected from NASA tools.

In 2015, a handful of participants advised by a Langley researcher started with the results of the survey and vineyard addresses and then used data and images obtained by NASA-built Landsat satellites to help identify the boundaries of vineyards across Virginia.

The team was able to verify about 80 percent of the acreage tracked on the surveys, but they also discovered some discrepancies, including the counties in which some of the grapes were grown. Vineyards often sprawl across county lines.

"We're getting into an additional level of detail with this data that we just didn't have with the voluntary data collection," says Anette Boyd, director of the Wine Board's marketing office. "As we go forward, it'll allow us to really perfect our measurements of Virginia vineyards."



This map shows the location of Virginia's many vineyards, which plant hundreds of acres of grapes annually, almost all used for wine. NASA data helped local government officials take stock of the commonwealth's wineries and devise strategies for increasing production to meet rising consumer demand.

NASA data revealed exactly where wineries were located and also yielded information that could be used to monitor the health of the crops in the future.





# Carbon Nanotube Resin Shores Up Boats, Bikes

At 100 times the strength of steel and just one-sixth the weight, it is easy to see why engineers, and not just at NASA, were immediately excited by the potential in carbon nanotubes. But the nano-scale material was challenging to work with, and NASA funding was instrumental in helping move forward the early research needed to put it to good use.

Carbon nanotubes, made from flat carbon sheets that roll up on themselves into a tube, were first discovered by a Japanese scientist in 1991. “The theory has always been, if you can take these extremely strong particles and incorporate them into a wide variety of materials, then you can impart their strength onto those other materials,” explains Zyvex Technologies President Lance Criscuolo.

But it proved difficult. “If you take raw carbon nanotubes and try to put them into a composite, they just all clump up together. Think of it as a poorly made cake batter. You’ve got lumps of stuff in there,” he says.

NASA funded four Small Business Innovation Research contracts with Zyvex, based in Columbus, Ohio, between 2003 and 2006. “Funding from NASA was really key and important in getting us to develop the technology so that we could functionalize carbon nanotubes and get good properties with the host matrix,” emphasizes John Randall, now president of Zyvex Labs, which spun off from Zyvex Corporation in 2007.

Now Zyvex sells its carbon nanotubes as an additive for resins, under the ZNT product name, as well as its own line of composites, under the Arovex product name, in which carbon fiber, glass fiber, and other materials are pre-treated with a carbon-nanotube-infused epoxy.

The products are used on boats and sporting goods, while other industries, including aerospace and medical, are also exploring ways to use the super-strong, lightweight nanomaterial.

Carbon nanotubes, made from flat carbon sheets that roll up on into a tube, offer 100 times the strength of steel at just one-sixth the weight. NASA funding, including several SBIR contracts with Zyvex, helped advance early research to put the material to good use.



Special composite materials, reinforced with a carbon-nanotube-infused epoxy, make for very light, extremely tough race cars, better able to withstand the forces of a crash. The material has also been used on sporting goods, including bicycles and baseball bats.



One of Zyvex’s latest customers is using the material for ship landing decks designed to allow smaller boats to drive onto them—sometimes with propellers still spinning. The carbon-nanotube-reinforced composite is tough enough that it doesn’t get torn up, without adding extra weight.



# Energy and Environment

With eyes on Earth through more than two dozen satellites, plus a range of ground-based observation missions, NASA keeps close watch on our ever-changing planet. These scientific data have found numerous applications among public and private initiatives, including software tools that spot rainforest wildfires and monitor agricultural water use. The agency has also transferred technology to industry, leading to self-driving farm equipment, improved fertilizers, new mineral analyzers, and much more.



# GPS Correction Technology Lets Tractors Drive Themselves

There has been much talk of self-driving cars lately, but farmers have enjoyed self-driving tractors for more than a decade, in part due to a partnership between John Deere and the Jet Propulsion Laboratory (JPL).

In the 1990s, scientists at JPL, where the first global tracking system for Global Positioning System (GPS) satellites had been developed, were working to stream satellite tracking data in real time via the Internet. The result was the Real-Time GIPSY (RTG) software. GIPSY refers to the GNSS-Inferred Positioning System, wherein GNSS stands for Global Navigation Satellite System.

RTG ended up being one of NASA's most important contributions to modern society, enabling accurate GPS navigation anywhere on the planet.

In 2001, NavCom, owned by John Deere, licensed the RTG software and also contracted with JPL to receive data from the center's global network of reference stations. John

Deere, based in Moline, Illinois, had already developed its own GPS receivers for tractor guidance, but when the company released the first receivers to tap into NASA's ground stations and incorporate JPL's software in 2004, it could finally offer self-driving equipment worldwide.

The trackers were accurate down to about four inches, not quite as accurate as John Deere's real-time kinematics (RTK)-based trackers, but much more affordable. The RTK system required the purchase of one or more signal towers.

Typically, when a farmer crisscrosses a field pulling a seeder, plow, or other equipment, the rows overlap by about 10 percent, meaning a significant portion of the field receives double the necessary resources, and the job takes longer than necessary. Eliminating overlap also cuts down on fuel costs and wear and tear on the machinery. And higher accuracy also means more reliable yield maps, which are created by combining location data with mass flow data from sensors on a harvesting combine.



For more than a decade, John Deere's Starfire GPS receivers used NASA's global network of ground stations and JPL software, which the company licensed, to enable self-guided tractors.

Among other benefits, accurate GPS helps farmers manage their fields, for example enabling more accurate observations and crop mapping.



A long partnership with the Jet Propulsion Laboratory helped John Deere spread self-driving tractor capabilities all over the world, lowering costs and improving yields for farmers while popularizing the idea of precision agriculture.



# Controlled-Release Fertilizer Takes Root in Fields, Groves Worldwide

Astronaut ice cream may be an exotic treat for kids, but for real space explorers, it turns out a fresh, crunchy salad could sometimes hit the spot. The ability to grow food in space could prove crucial for longer-duration voyages envisioned over the next decades.

Growing plants in a spaceship, and one day on another planet, is a complicated endeavor, as Gioia Massa, science team lead for the NASA Veggie project at Kennedy Space Center, will tell you. But one tool she and her fellow researchers have adopted that is making it much easier is a specially formulated fertilizer, developed years ago with NASA help, that has also drawn huge accolades from growers on Earth.

Ed Rosenthal, founder of Sarasota, Florida-based company Florikan, was not intending to push the frontiers of where plants are grown when he first began developing his award-winning fertilizer. But he saw an opportunity to use technology to improve how nutrients are delivered to plants.

The fertilizer is coated in polymers that control when and how much of each ingredient—macronutrients like nitrogen, phosphate, and potassium, and micronutrients like magnesium and zinc—is released over six months to a year.

He perfected the formula thanks in part to 40 hours of NASA consulting, which he was awarded after an early iteration was recognized in 2004 by Florida and by the National Society of Professional Engineers as one of the year's most innovative new products.

Today, the fertilizer is now sold around the world by Florikan as well as by agribusiness giant J.R. Simplot Company, which bought Florikan's patents and sells the product as Gal-XeONE.

The fertilizer is also used on the International Space Station for project Veggie, growing lettuce and other crops.

"NASA's expertise helped us advance our development by years," Rosenthal emphasizes. "We were happy to pay it back."



Fertilizer made with Florikan's patented formula, now owned by J.R. Simplot and sold as Gal-XeONE, nourished this lush grass at a golf course in Arizona. J.R. Simplot was interested in the product because it was more efficient and better for the environment.



NASA astronaut Steve Swanson harvests red romaine lettuce on the ISS, the first fresh produce grown and eaten in space. The Veggie project, which is ongoing, uses Florikan's controlled-release fertilizer to nourish the growing plants.



Here, large batches of the Florikan fertilizers await quality control testing before being bagged up and sold. The high-tech process to coat the fertilizer in a porous polymer to control how quickly the nutrients dissolve in water was perfected with help from NASA.



# Satellite Imagery Sheds Light on Agricultural Water Use

More than 70 percent of Earth's surface is covered in water, but freshwater is still in heavy demand. The most significant draw on the water supply is crop irrigation, accounting by some measures for nearly two-thirds of U.S. surface-freshwater withdrawals.

Keeping track of just how much water gets used—and making sure it gets used efficiently and legally, where and when it's needed—across millions of acres of crop land is no easy task.

Researchers armed with data from the Landsat Earth-observing satellites recently teamed up with Google to make it a whole lot easier. The researchers from the University of Idaho, the University of Nebraska, and the Desert Research Institute are using the satellite images to map evapotranspiration—water evaporating from the ground or transpiring from the plants.

The software they created, called EEFlux, works with Earth Engine from Mountain View, California-based Google to quickly map evaporation and transpiration based on infrared images captured by the satellites, which are built and launched by NASA and managed by the U.S. Geological Survey.

Landsat 8 was sent into orbit in February 2013 and produces high-resolution images of the entire planet every 16 days. With the help of Landsat 7, which is still in operation, full



EEFlux is already being used by the California Department of Water Resources, the California Water Control Board, and the World Bank, and the researchers expect to expand its use more widely as the program completes beta testing. The program helps water managers know who is pumping water, how much, and if the current usage is sustainable.

coverage is available every eight days. Both satellites carry a thermal imager that captures images in the infrared band, which shows warmer and cooler spots across Earth's surface.

EEFlux is most useful for groups of water users who “need to know, who's pumping, is it sustainable? What are we going to do about getting extraction in line with sustainable recharge?” explains University of Idaho water resources engineering professor Richard Allen.

Early adopters of EEFlux include the California Department of Water Resources, the California Water Control Board, and the World Bank, and the developers expect to expand its use more widely as the program completes beta testing.



Using infrared imagery captured by Landsat satellites and publicly available on the Internet through Google Earth Engine, EEFlux can quickly create maps of evapotranspiration, a way to measure how much water is being used. In this map of an agricultural region in California, dark blue and dark green represent higher levels of evapotranspiration, while light brown represents low levels.



# Building Sensor Monitors Power Usage, Device by Device

When NASA wanted to build the most energy-efficient federal building in the United States, it needed to keep track of the energy being consumed. After all, good design is only the first step—at a certain point, people were going to use the space.

“We need ground truth. What’s consuming the most energy?” explains Ames Research Center lead researcher Rodney Martin.

Enter Verdigris Technologies Inc.: the Moffett Field, California-based company designed a sensor that “listens” to electronic signals as they pass through a circuit panel and analyzes their fluctuations using a deep packet inspection algorithm—the same technology the National Security Agency uses to moni-

tor text messages between suspected terrorists.

The algorithm allows the sensor to differentiate between the devices using electricity in the building, whether it’s an iPhone charger, a space heater, or the building’s air conditioning compressor.

The company tested its sensor at Ames Research Center’s Sustainability Base, an innovative building that showcases environmentally friendly design, under a nonreimbursable Space Act Agreement, which helped fast-track the product to market.

“It absolutely got us going faster than we would have otherwise,” Verdigris co-founder Mark Chung emphasizes. “Working with NASA also extended some credibility to us. It opened the doors for conversations with other customers.”

The Verdigris system continuously monitors electricity consumption and sends alerts when there are problems, whether lights are turning on automatically when no one is around or a machine is no longer working the way it should and could be heading toward a breakdown.

That function has proven to be a big selling point for Verdigris’ commercial

Verdigris sensors at a Marriott Marquis hotel in the U.S. capital, seen here lit for the evening, helped building managers realize that lights in several ballrooms were being automatically turned on every night between midnight and six in the morning, even though the rooms were empty. They were able to fix the faulty programming, saving electricity and wasted lamp light for the bulbs.



Verdigris sensors plug directly into the circuit panel and are able to monitor just how much energy is being consumed by which device, even when the circuit contains multiple devices. The system generates automatic reports that can be emailed or checked right on a smartphone.

customers, who include major hotels, corporate offices, hospitals, and manufacturers.

“One example, at the San Francisco W Hotel, was that we found dishwasher equipment not going through its heat cycle properly,” recalls Chung. The system reported dishwasher wasn’t using as much power as expected to reach the heat needed to properly sanitize the dishes.

“They wouldn’t have caught this through their normal inspection process,” says Chung.



# Earth Observation Spots, Helps Prevent Rainforest Fires

With about two dozen NASA missions charting and recharting Earth's 196.9 million square miles of surface, the agency is constantly working to enhance software and systems to manage that growing mountain of data and find new ways to use it.

Several NASA programs recently helped Arlington, Virginia-based environmental organization Conservation International (CI) upgrade, overhaul, expand, and combine its fire-alert and fire-risk forecasting systems to create Firecast, which uses Earth-observation data to prevent deforestation from fires in rainforests.

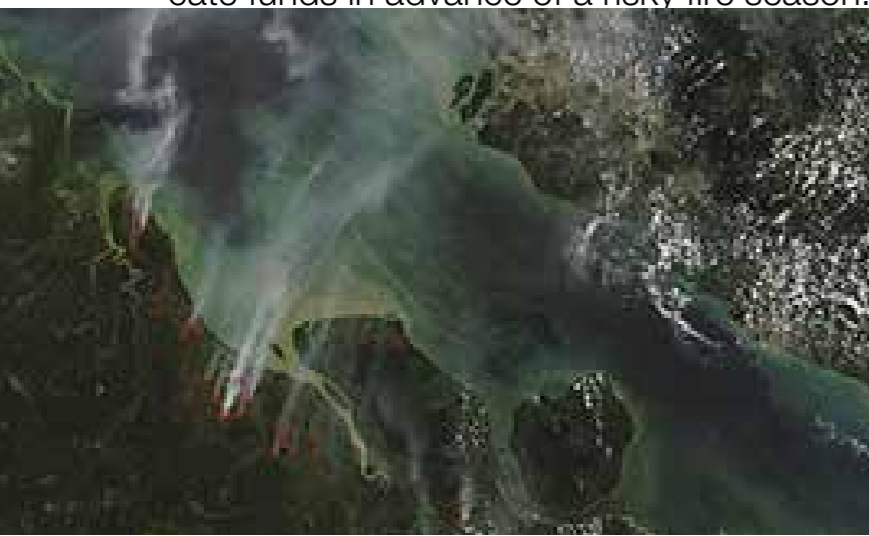
Funding came from NASA's annual Research Opportunities in Space and Earth Sciences (ROSES) solicitation in 2012. Among the work the grant helped fund was use of the NASA Earth Exchange (NEX) supercomputing facility at Ames Research Center. NEX has more than 800 terabytes of data CI used to develop, prototype, and test its new fire-risk forecast model. The data also allowed CI to expand its coverage from Bolivia to include Colombia, Peru, Venezuela, Ecuador, Guyana, Suriname, Paraguay, Madagascar, and Indonesia.

In addition to daily fire-risk forecasts, the system now incorporates seasonal risk forecasts for Peru and Bolivia developed at Goddard Space Flight Center, based on Atlantic Ocean temperatures.

To augment the fire-alert system, which monitors for active fires, a research scientist at California State University, who was using NEX to determine the effects of drought on California's Central Valley, suggested adding details uploaded from users in the field. The scientist suggested using a crowdsourcing program called OnSight, developed by GeoVisual Analytics under Small Business Innovation Research contracts with Stennis Space Center. Users can upload photos and other observations.

Managers of protected areas in Peru and Madagascar can now use OnSight to investigate fires and plan patrols.

Firecast has already helped spot and shut down illegal burning, and it helps farmers know which days are risky for legal burns. CI hopes seasonal forecasts will help governments allocate funds in advance of a risky fire season.



Smoke from forest fires in Indonesia can be seen in an aerial image from NASA's Fire Information for Resource Management System. Conservation International's Firecast system uses imagery and data from a number of NASA satellites for both spotting and forecasting rainforest wildfires. Satellite data is just one of NASA's several contributions to the system.



Members of the Friends of Nature Foundation in Bolivia adjust a fire risk indicator for the day. Daily and seasonal fire risks are among the products Conservation International's Firecast system offers.



Park rangers patrol the Alto Mayo protected forest in Peru. There and in Madagascar, Conservation International is incorporating the OnSight platform, which GeoVisual Analytics created with NASA funding, into Firecast. OnSight lets patrollers on the ground make observations to validate and augment fire data from satellites.



# Mineral Analyzer Shakes Answers Out of Soil and Rocks

A small, rugged X-ray diffraction (XRD) tool, CheMin, went to Mars on the Curiosity rover, where it helps scientists determine just what minerals make up the Martian landscape and whether organisms, single-celled or more complex, could once have thrived there.

The key innovation of the new device was the way it prepared and manipulated the mineral samples. Traditional XRD requires samples ground into an extremely fine powder, pressed into a flat cake, and then analyzed in a massive XRD machine, which points an X-ray beam at it from different directions.

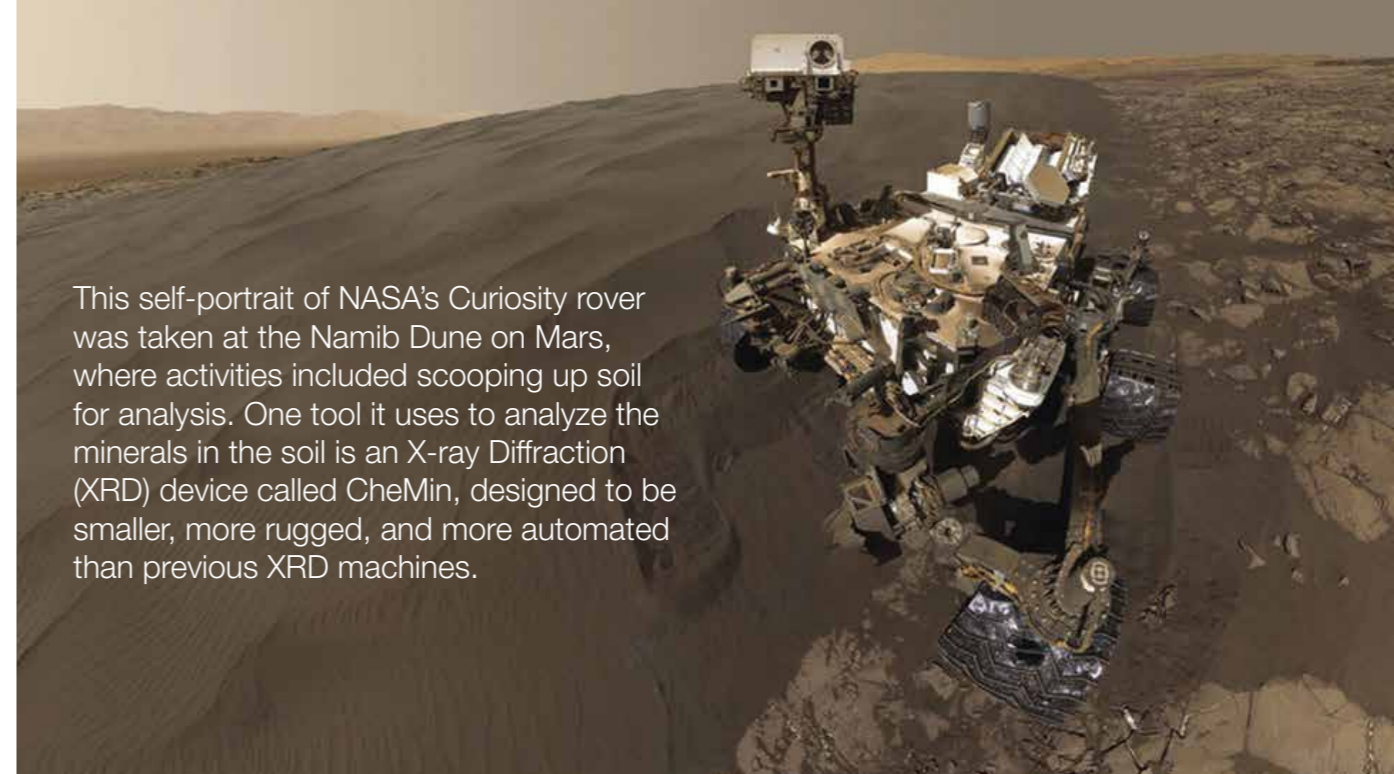
“Everything relies on very precise motions and very heavy equipment,” says Phillippe Sarrazin of Ames Research Center—supremely impractical for a robot on Mars.

Sarrazin and a team at Ames stumbled onto a game-changing discovery: when you vibrate a bed of grains, they flow in a predictable, cyclical pattern. Because they were able to see many different grains from so many different orientations, they could use fewer, bigger grains, about the texture of sand.

“Bigger grains are easy to transfer from one place to another. They’re also easy to make,” says David Blake, CheMin principal investigator at Ames. Once the sample was loaded, the device was also far easier to use than traditional XRD machines, and it could be sold for much less.

Sarrazin left Ames to found a company, inXitu, and continued working on the device, in part through Small Business Innovation Research contracts with NASA. In 2011, Olympus Scientific Solutions America, based in Waltham, Massachusetts, bought inXitu, and now it sells the XRD devices in portable and benchtop models to mining and drug companies as well as government watchdogs.

“Believe it or not, doing mineralogy on Mars is very similar to doing mineralogy in a mine in the outback in Australia. You need something robust. You need something that can handle harsh environments,” says Jeffrey Walker of Olympus Scientific Solutions America.



This self-portrait of NASA's Curiosity rover was taken at the Namib Dune on Mars, where activities included scooping up soil for analysis. One tool it uses to analyze the minerals in the soil is an X-ray Diffraction (XRD) device called CheMin, designed to be smaller, more rugged, and more automated than previous XRD machines.



The key innovation of CheMin was that it didn't require samples to be finely ground into powder. In fact, the rock grains need only to be small enough to fit through this screen installed on Curiosity, through which the Mars rover funnels the samples it collects with its robotic arms.



The easy sample preparation requirements—knock a rock fragment loose and crush it with a small hammer—plus the portability, low cost, and one-button operation have made the Olympus TERRA and BTX II Benchtop XRD devices popular in the oil and gas industry, as well as with pharmaceutical companies and drug watchdog groups.





# Low-Cost Flow Meters Bring Efficiency, Reliability to Nuclear Plants

The technology looks unassuming: circular metal plates with multiple holes in them. The plates usually sport a large central hole surrounded by a few smaller ones, although there may be anywhere from 2 to 200 openings.

But these deceptively simple devices have won awards and saved millions—possibly billions—of dollars across a gamut of industries, including, most recently, nuclear energy.

The balanced flow meter was born after Marshall Space Flight Center entered into a Space Act Agreement in 2001 with the company Quality Monitoring and Control (QMC) to develop a better device to measure the flow of liquid oxygen in Space Shuttle engines.

Plates with a single hole were among several existing flow meter designs, and the innovation QMC devised with the help of NASA engineers and funding was to replace the single hole with a calculated series of holes. QMC software determines the optimal number, size, shape, and placement of the openings, depending on factors like flow rate, pipe diameter, and temperature.

The resulting meter is highly accurate and causes almost no pressure drop in the fluid or gas passing through it, whereas previous designs caused pressure drops that significantly hampered operating efficiency. They also produce very little of the noise made by previous flow plates.

QMC spun off A+ FlowTek to market the technology. The company uses its software to design balanced flow meters for clients. Among the latest is Graftel LLC of Elk Grove Village, Illinois, which obtained an exclusive sublicense for selling the meters to nuclear plants. Graftel brings each customer's specifications to QMC, which designs the plates, and Graftel manufactures them and outfits them with manifolds, temperature sensors, and other devices, tests them, and sells them to nuclear plants.

The plants enjoy cheaper, more durable, more accurate, more efficient meters that meet the specific needs of the nuclear industry.



This is a typical balanced flow meter assembly Graftel might supply for a nuclear plant, with a flow plate custom designed by A+ FlowTek and a manifold integrated by Graftel.



Since the early 2000s, balanced flow meters created through Marshall Space Flight Center's partnership with Quality Monitoring and Control have increased the accuracy of flow readings and improved efficiency in plants across a variety of industries. Since 2013, Graftel LLC has introduced the technology to the nuclear power industry, which has its own strict rules, requirements, and procedures.



The Computer Learning Imagery Platform (CLIP) that GeoVisual Analytics developed with NASA funding was designed to map global land cover classifications using satellite imagery. To chart farmers' fields, the company uses CLIP to analyze higher-resolution drone imagery.



## Computer Learning Program Inventories Farmers' Fields

With more Earth-Imaging satellites being put into orbit each year, there is still no program to stitch all these the images together into a complete and regularly updated portrait of the planet. This was what GeoVisual Analytics, based in Boulder, Colorado, proposed: an automatically updated, global land classification map based on imagery from the Landsat mission.

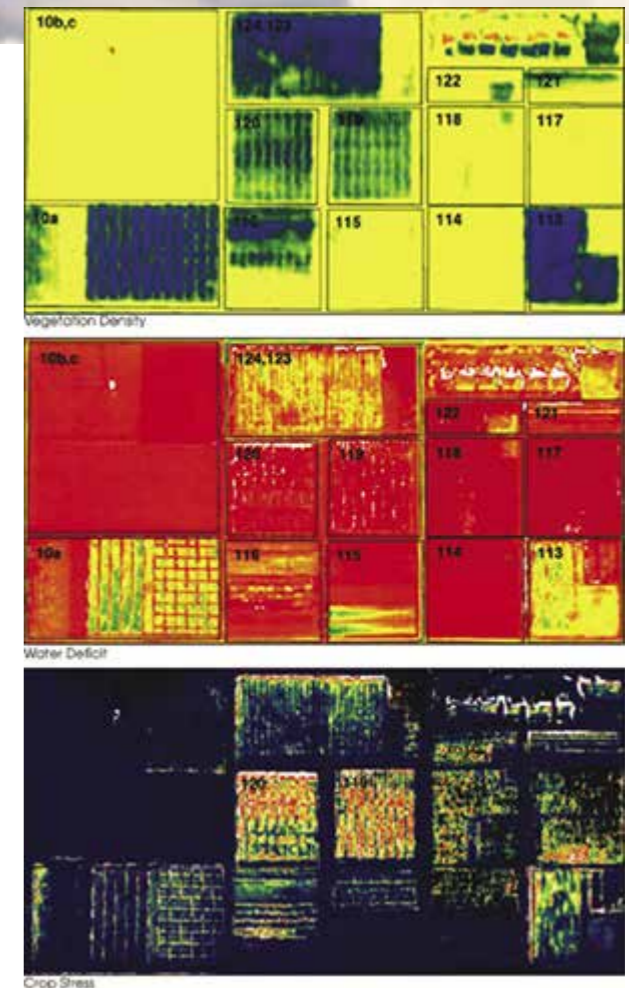
With funding from a 2014 Small Business Innovation Research contract with Goddard Space Flight Center, the company developed an algorithm that could analyze imagery pixel by pixel, assigning a vegetation index number and one of 30 or 40 land-cover classifications to each dot.

A regularly updated map of Earth surface cover would have a multitude of uses, such as providing a higher-resolution map for climate and weather models, more accurately observing changes such as icecap melt and deforestation over time, and predicting global crop yields. However, the company ran up against

the limitations of its available computing power and also found that Landsat imagery did not have high enough resolution for the agricultural applications it was hoping to capitalize on initially.

But the work was enough for GeoVisual to develop what it calls its Computer Learning Imagery Platform (CLIP). The company took the software to a 2015 business accelerator where, as a finalist, it received mentoring from Taylor Farms, the world's largest producer of fresh-cut vegetables. By fall of 2015, GeoVisual was working on a contract basis for Taylor Farms, using CLIP to analyze drone imagery of fields and take inventory of crops.

The software can determine a crop's stages of growth and its health, allowing Taylor Farms, which partners with growers throughout the Salinas Valley, to predict yields throughout the season. Eventually, the company wants to move toward the global crop mapping that would enable yield prediction for the world's staple crops.



A wealth of information can be gathered about vegetation using hyperspectral imaging, such as vegetation density, top; water deficit, middle; and crop stress, bottom. Using algorithms and techniques it developed with funding from Goddard Space Flight Center, GeoVisual Analytics uses images of farmers' fields to let them learn more about their crops, including predicted yields.



# Information Technology

**W**hen NASA wants to model the dynamics of atmospheric reentry, capture data from the launch pad, or undertake any number of ambitious data-driven projects, it develops cutting-edge software and information technology to get the job done. These innovations are often valuable in other applications ranging from archaeology and consumer product design to oil drilling and commercial space missions.



# Laser Imaging Helps Archaeologists Dig Up History

Some 10,500 years ago, hunters gathered each year near the Beaver River in what is now western Oklahoma. There, they killed bison en masse, sliced off the choicest meat, and left behind piles of skeletons.

Today there is little visible evidence of these hunting expeditions. But laser-based remote sensing equipment called lidar can give archaeologists hints of the fossils and bones hidden below the surface. And the technology owes a lot of its development to scientists looking at something very different: planets, moons, and asteroids.

In lidar scanning, one or more lasers send out pulses that bounce back when they hit an obstacle, like clouds

or rocks. Using that information, the instrument can build up a high-resolution 3D topographical map.

NASA has been incorporating lidar devices into missions dating as far back as Apollo 15 in 1971. More recently, the OSIRIS-REx asteroid return mission managed at Goddard Space Flight Center was equipped with a lidar scanner designed by Canadian firm Teledyne Optech.

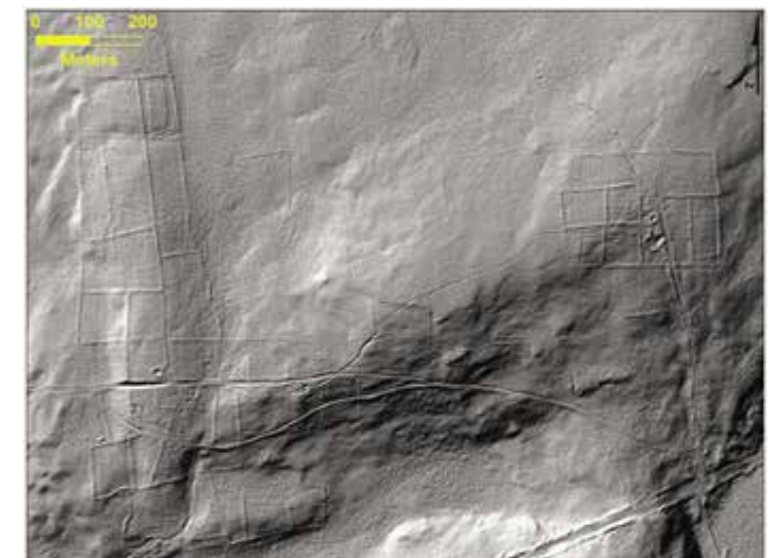
The 40-year-old company, which also has offices in Henrietta, New York, as well as Mississippi, specializes in designing and building lidar instruments and has contributed to more than one NASA mission. It has incorporated the innovations needed for those space-ready devices into commercial models that are now also helping archaeologists.

“The things we’ve learned on space programs, to build more compact lidars, that’s helped us immensely in miniaturizing our commercial lidars,” emphasizes Paul LaRocque, vice president of special projects at Teledyne Optech.

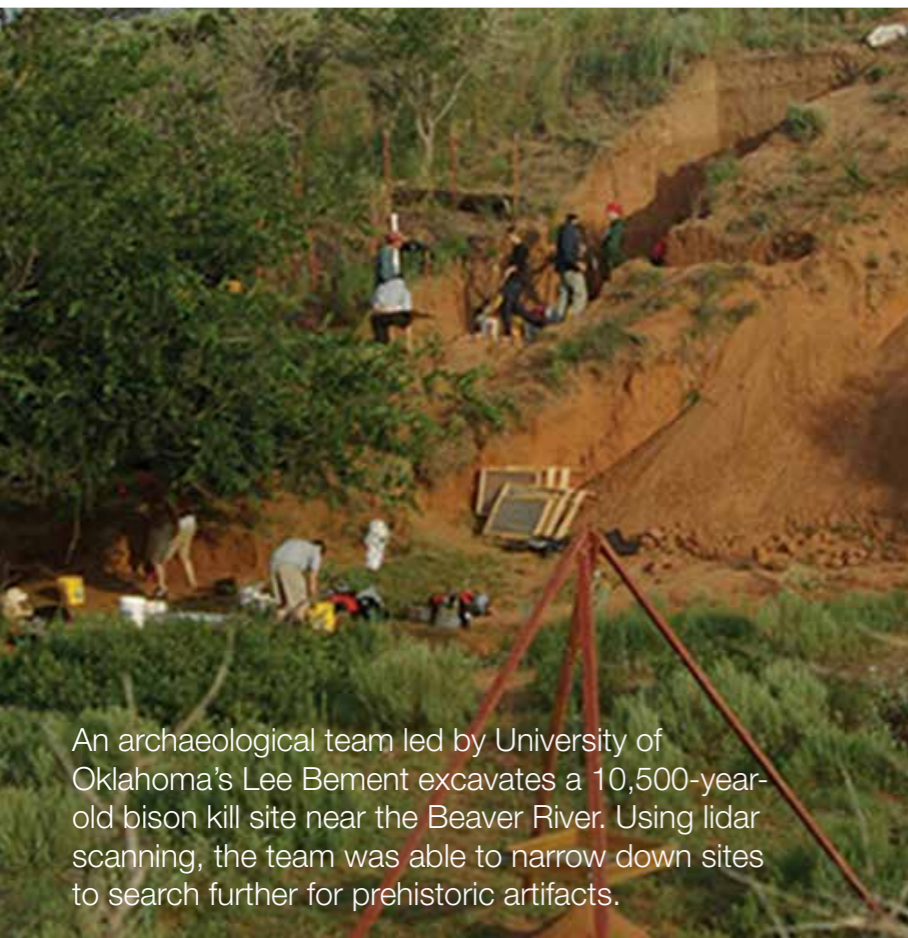
In the Beaver River area, the archaeological research team flew overhead scanning with an Optech ALTM-3100C airborne laser mapping system, operated by the West Virginia University National Resource Analysis Center. Then, software stripped away the vegetation to show the “bare earth,”

allowing archaeologists to spot features that suggested buried artifacts.

Lidar imaging has “been useful in delineating where we need to concentrate our efforts,” says archaeologist Lee Bement. “It saved us a lot of time and effort.”



On the top is an aerial photograph of a forest in Connecticut. On the bottom, a bare-earth lidar image gives a view beneath the overgrown vegetation, where there are remnants of stone walls, building foundations, abandoned roads, and what was once cleared farm land.



An archaeological team led by University of Oklahoma’s Lee Bement excavates a 10,500-year-old bison kill site near the Beaver River. Using lidar scanning, the team was able to narrow down sites to search further for prehistoric artifacts.





The Russian Soyuz spacecraft streaks across the night sky, generating an electrically charged, white-hot plasma trail. Traveling at hypersonic speeds, spacecraft returning to Earth experience extreme stresses, including temperatures in the thousands of degrees, as they decelerate through the planet's atmosphere.

## Program Predicts Aerothermodynamics of Reentry, Subsonic Flight

Anyone designing a craft to withstand the forces and temperatures of atmospheric entry has many tradeoffs to take into account. Larger wings, for example, add weight but also generate more lift. Quicker deceleration achieved by a larger wing would also mean less heat, which would allow for a thinner heat shield.

One problem NASA researchers ran up against in the early 2000s was that computational fluid dynamics (CFD) software, while capable of producing high-fidelity aerodynamic and aerothermodynamic performance predictions, could take thousands of hours on hundreds of computers. Faster, simpler codes couldn't predict both aerodynamics and heating, and each of those required a hand-mapped simplification of the original computer-aided design (CAD) vehicle model.

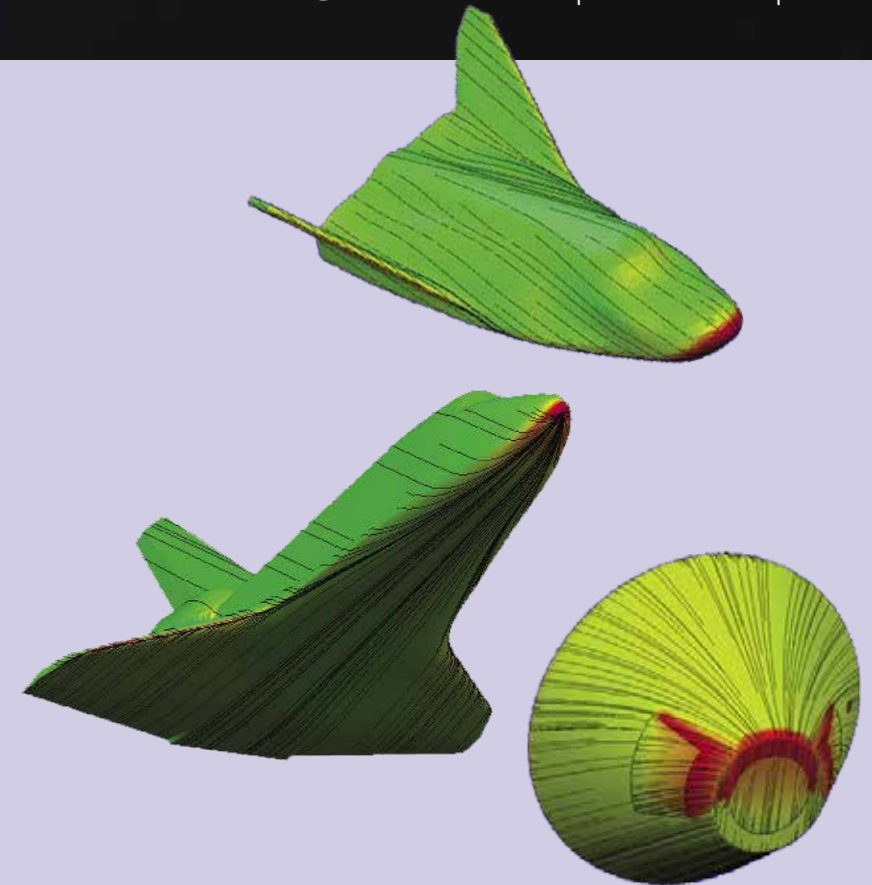
To fill this need, Ames Research Center engineer David Kinney and his team created the Configuration-Based Aerodynamics (CBAERO) program. It is capable of importing a model from a CAD program and running simultaneous aerodynamic and aerothermodynamic analysis.

The code was used to create an aerothermal database to guide the design of the Orion spacecraft's heat shield. The database predicts forces and temperatures across the vehicle's surface at a range of speeds, dynamic pressures, and angles of trajectory.

CBAERO can also produce results in "batch mode," automatically running results for a family of vehicles with a range of design parameters, eliminating the need to set up each model up by hand.

Made available through software usage agreements in 2006, it has been used by more than 20 businesses, including just about every company building commercial space vehicles, as well as at least half a dozen Department of Defense agencies and four universities.

Often, the software is able to accomplish in a few seconds what previously would have taken thousands of hours. For final, high-fidelity modeling, models can easily be transferred from CBAERO to CFD software.



The Configuration-Based Aerodynamics (CBAERO) software created at Ames Research Center is the first to predict both the aerodynamics and temperatures of spacecraft atmospheric entries and allow models to be imported directly from computer-aided design programs. CBAERO is now widely used by commercial space companies, the Department of Defense, and various defense contractors.



# Data Acquisition System Captures Machine Performance

When you launch rockets, even the smallest deviation from design can create big problems—and they're hard to fix unless you know exactly what happened. The same is true for any venture where even a small malfunction can translate into major lost revenue.

That's where data acquisition systems come in. Designed to capture and store information about the performance of and environment around a machine, they give engineers the information they need to see what happens when the machine is working—or not.

For NASA, that information is especially crucial when designing something new, like the Space Launch System (SLS), the vehicle planned to propel the first humans to Mars one day.

Under contract with Kennedy Space Center, Wakefield, Rhode Island-based Dewetron delivered a powerful system to monitor performance on the SLS mobile launch platform.

“Our instruments measure strain, pressure, acceleration—basically, if you can sense it with your body, with your senses, then typically we need to measure it. And we do,” says Dewetron President Grant Smith.

The easy-to-use system captures all that data with one universal signal conditioner—allowing easy analysis across multiple signals—something that was difficult to do, Smith says.

“It's a tough balancing act, and it took a lot of engineering to make it all happen.”

Now, the system designed for NASA, sold first as the DAQP-STG signal conditioner and incorporated into subsequent models with upgrades, is a popular part of Dewetron's product line.

“It can handle nearly every kind of resistive sensor, it provides higher isolation than we ever did before, and it has a very high bandwidth. It's a triple threat,” Smith says.

Customers include aerospace firms and car companies from Ford to BMW, as well as many other industries.



Sensors measuring anything from strain to temperature, pressure, load, or acceleration plug into the Dewetron system, which records how each performs so engineers can analyze the data later. Many systems have separate systems for different kinds of sensors, but at NASA's request, Dewetron built a machine that could read every kind of sensor.



The mobile launch platform for the Space Launch System (SLS) travels to the launch site at NASA's Kennedy Space Center in Florida. One of the important roles of the Dewetron data acquisition system installed throughout the structure is to capture information on important details like whether the platform base is stable and balanced before launch.



# Light-Analysis Software Explodes across Industries

Lambda Research Corporation was founded in 1992 with the idea of developing software to simulate the behavior of light. “We had an educated hunch there were other applications for this kind of software,” says cofounder Ed Freniere. Little did they realize just how many.

The Jet Propulsion Laboratory (JPL) granted the Littleton, Massachusetts-based company a Small Business Innovation Research (SBIR) contract in 1993 to develop a user-friendly program to predict how light from objects outside its imagers’ fields of view would affect the pictures they produced.

There was a program available for modeling ray behavior, but it was expensive, difficult to use, and incompatible with both Windows and computer-aided design (CAD) software NASA used to design the instruments. The user had to redraw the geometry of any instrument to be modeled.

Lambda licensed the geometry engine at the heart of CAD programs and built its software around it, making it completely CAD-compatible. Before the end of its second JPL SBIR contract, the company had released the first commercial edition of its light-behavior-modeling TracePro software, still its flagship product.

TracePro’s largest market is in optimizing overhead lighting, from street lamps to offices. Another application is the design of light pipes—tubes carrying light from internal LEDs to indicators on an electronic device’s exterior, which might help locate buttons. Engineers designing solar collectors can use TracePro to determine where mirrors should be and how they should be angled and bent.

In medicine and life science, there are many ways light can noninvasively monitor functions, from pulse monitors to cell imaging, tissue characterization, microscopy, and monitoring blood-sugar levels. In all these devices, TracePro helps engineers maximize results.

The program can also help design everything from car dashboards to signs and lamps to cameras and telescopes.

Countless NASA imagers have also benefited from TracePro.



One of the many medical uses for TracePro is validating designs for blood oximeter pulse monitors. The monitors measure oxygen in the blood by observing how light travels through the fingertip.



Automakers use TracePro to model dashboard displays. In the inset, the program predicts the behavior of light rays through a computer-aided design of a speedometer needle.

Image courtesy of David Sadtler



## Connectors Link Data Networks for Orion, Industry

As Johnson Space Center engineers were designing the Orion spacecraft, they wanted a single, integrated, time-triggered, one-gigabit Ethernet master network, to allow any system to communicate with anything else at the lowest possible mass and with the fewest possible connections.

Previous spacecraft had used several data networks to transmit information.

To do this, Johnson needed lighter, smaller connectors that could transmit large amounts of data and survive the harsh conditions of space travel, criteria that existing connectors couldn't meet. The engineers also wanted connectors with higher impedance ratings than the standard for communications, to transmit more data at lower voltages.

Following a call for submissions and two rounds of review, NASA selected Smiths Connectors of Thousand Oaks, California, part of the Interconnect division of London-based Smiths Group PLC. The branch specializes in electronic components for harsh environments. For five years, the company worked under a subcontract to Lockheed Martin to design and develop connectors for Orion.

Orion's first test flight in December 2014 used the connectors, which performed perfectly, transmitting more data than the networks used in the Space Shuttles while also eliminating extraneous signal noise.

With some modifications, Smiths Connectors released the High-Speed Ruggedized D-Sub connector to industry in July 2015. The company is courting customers in other demanding fields, touting the connectors' ability to endure harsh environments and quickly transmit large amounts of data.

Military aerospace is a natural market, as is commercial aviation, where engineers are putting sensing equipment closer to where operations take place and vibrations are higher, such as near the wings or engine. The oil and gas industry's equipment must withstand high pressures and vibration, and the company has also received interest from rail companies, whose entertainment and communication systems on vibrating trains transmit massive amounts of data.

This 2013 test of Orion's avionics systems shows some of the capsule's complex wiring. Smith's Connectors developed rugged, reliable devices to move large amounts of data around the spacecraft, even in extreme environments.



Smith's Connectors developed high-speed data connectors for NASA that have found applications in Ethernet networks used in military, aerospace, and commercial aviation markets. It also sells spinoff products in the oil and gas industry.





# Scheduling Software Plans Public, Private Space Missions

When Alex and Ella Herz worked at Johnson Space Center in the late 1980s and early '90s, one Shuttle flight might carry two or three primary payloads along with a dozen smaller ones, so scheduling and keeping track of where each payload was on a given day was a challenge. Payload engineers might spend an entire year preparing for one seven-day flight. They were just starting to get their own computers, and there was little in the way of scheduling software.

Alex, as a payload project engineer, and Ella, who supported payload operations as a software systems engineer, saw a lot of changing requirements but also were exposed to the types of operations and situations that arose repeatedly.

Later, at Goddard Space Flight Center, Alex and colleague Doug George, unable to find a useful off-the-shelf scheduler, created scheduling software from scratch for the planned Vegetation Canopy Lidar.

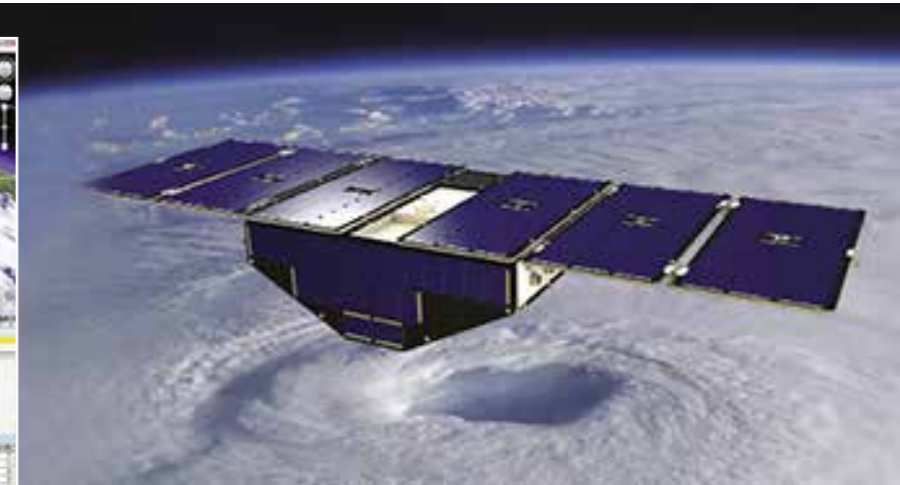
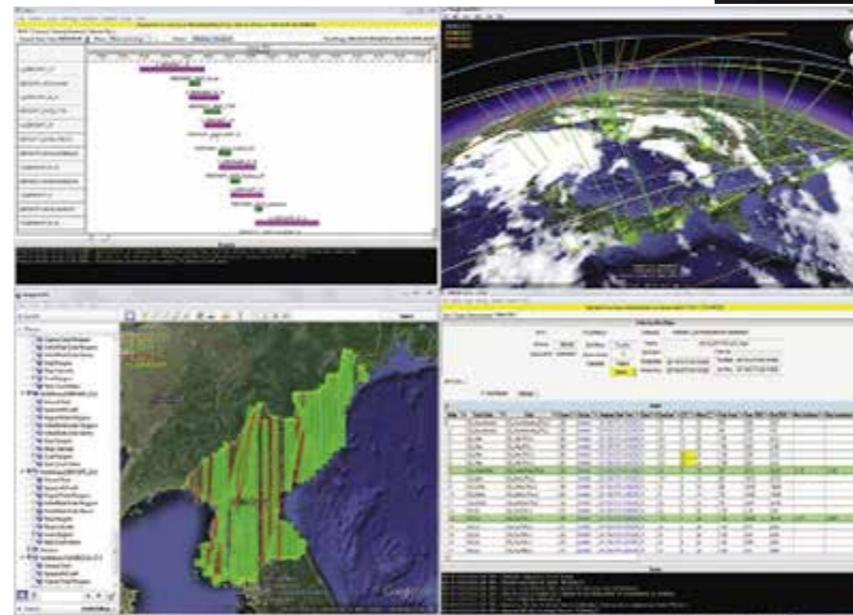
In 2000, the trio founded Greenbelt, Maryland-based Orbit Logic, initially to build ground control centers. But when they needed scheduling software and again couldn't find any, they partnered with Analytical Graphics Inc., the company that offers Systems Tool Kit (STK), and Optwise Corporation to create the first generic, reconfigurable scheduling program for space operations.

The work, including the system of defining tasks, resources, priorities, and constraints to build an optimized space mission schedule, was based both on Alex and Ella's experience

scheduling payloads at Johnson and on Alex and George's creation of scheduling software at Goddard.

STK Scheduler was released in 2002, and has since been licensed by around 250 customers, including almost every NASA field center and various other government agencies and companies.

"Before, they would have used a huge spreadsheet, and changing anything might have taken days," Ella says. "Now, you make a change and"—she snaps her fingers—"like that, it's updated."



Among the many NASA programs that now use STK Scheduler to build their mission timelines is Cyclone Global Navigation Satellite System, designed to improve hurricane forecasting.

Orbit Logic's STK Scheduler, informed by its founders' experience working for NASA, is a generic, reconfigurable scheduler for space missions that generates optimized timelines based on input tasks, resources, priorities, and constraints.



NASA's Space Network Ground Segment Sustainment project, refurbishing ground systems supporting the satellites that provide communications capabilities to spacecraft in low-Earth orbit, is using STK Scheduler to plan its activities. The ground network consists of three stations—two in New Mexico and this one on the island of Guam.





QuinStar and NASA shared the cost of developing a high-power W-band solid-state power amplifier for Goddard Space Flight Center's Cloud Radar System, which flew on the ER-2 high-altitude Earth science aircraft as part of the 2014 Integrated Precipitation and Hydrology Experiment. The power amplifier helped researchers collect data on precipitation distribution in clouds to improve understanding of precipitation over mountainous terrain, such as this supercell thunderstorm, photographed from the ER-2 as it passed over North Carolina on the evening of May 23, 2014.

## Power Amplifiers Boost Radar, Communications, Defense Systems

Normally, state-of-the-art technology comes at a cost. But when QuinStar Technology was subcontracted in 2009 to build a power amplifier for a Jet Propulsion Laboratory (JPL) radar, the company delivered one that was more compact and reliable—and also cheaper.

JPL needed a solid-state power amplifier (SSPA) to boost signals from a radar aboard the Ka-Band SWOT Phenomenology Airborne Radar (KaSPAR). This was a test bed for instruments for the Surface Water Ocean Topography (SWOT) mission, planned to use radar interferometers to create the first topographical map of Earth's oceans, lakes, and rivers.

The initial subcontractor was unable to build the amplifier, so Torrance, California-based QuinStar, which had a history of pushing SSPA technology, was contracted.

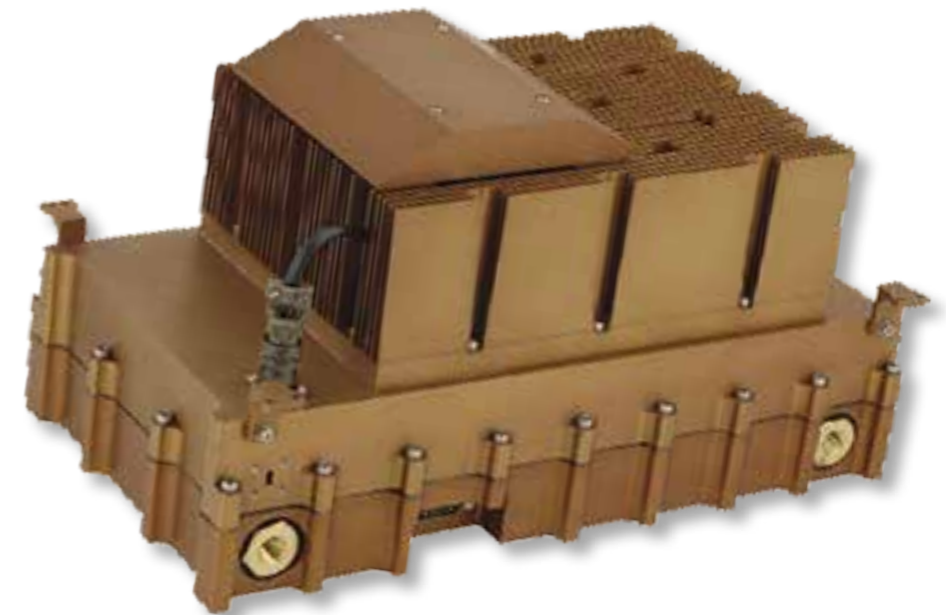
Until recently, power amplifiers for radars were tube-based, but SSPAs have lower voltage requirements and are lighter, more compact, and more reliable. The reduction in size and weight makes SSPAs ideal for unmanned aerial vehicles.

They represent a relatively new technology, and the model QuinStar developed for JPL was remarkable for its efficiency. An SSPA routes a

signal through an array of amplifiers, each of which boosts its portion of the signal, and then recombines the channels into a single, intensified output. But power is lost as the signal is recombined. While most SSPAs lose around 20 percent of their amplified energy at recombination, QuinStar's now lose only 8 percent, making the company a favorite NASA supplier.

The signal boosters are useful for environmental research but will probably find larger markets in communications and electronic warfare.

Through other JPL Small Business Innovation Research contracts, QuinStar is developing gallium nitride chips that promise a major increase in SSPA power density, which would make them highly attractive for satellite communications, weather and environmental radars, aircraft landing systems, surveillance radars, and helicopter collision-avoidance radars.



QuinStar developed this dual-frequency, solid-state power amplifier for NASA's Dual-Frequency, Dual-Polarized Doppler Radar, a scanning weather radar system created in support of NASA's Global Precipitation Measurement Project.



# Industrial Productivity



To explore the frontiers of space and other worlds, NASA often has to engineer technologies unlike anything seen before. It might partner with a company to produce 3D-woven heat shields, for example, or to create a vibration table large enough to test a space telescope the size of a tennis court. Other innovations come about from NASA's unique facilities, such as a laboratory for testing how materials perform when exposed to space. Commercial spinoffs from these and other endeavors are playing a big part in our Nation's industrial base.



## 3D Weaving Technology Strengthens Spacecraft, Race Cars

Weaving processes created millennia ago have helped create some of the most cutting-edge technology on NASA's Orion spaceship, helping shield heat for humans who may one day ride it to Mars and back.

Most of the heat shield is low-density and very good at insulating, but it's not very strong. There are points across the surface, though, that must connect the crew capsule to its service module and, ultimately, the rocket. "At these points, you have to use a very strong, robust material," says materials engineer Jay Feldman of Ames Research Center.

Previously used materials proved insufficient, but Feldman and others at Ames working with partners at high-tech weaving company Bally Ribbon Mills on next-generation heat-shielding materials had a good new candidate.

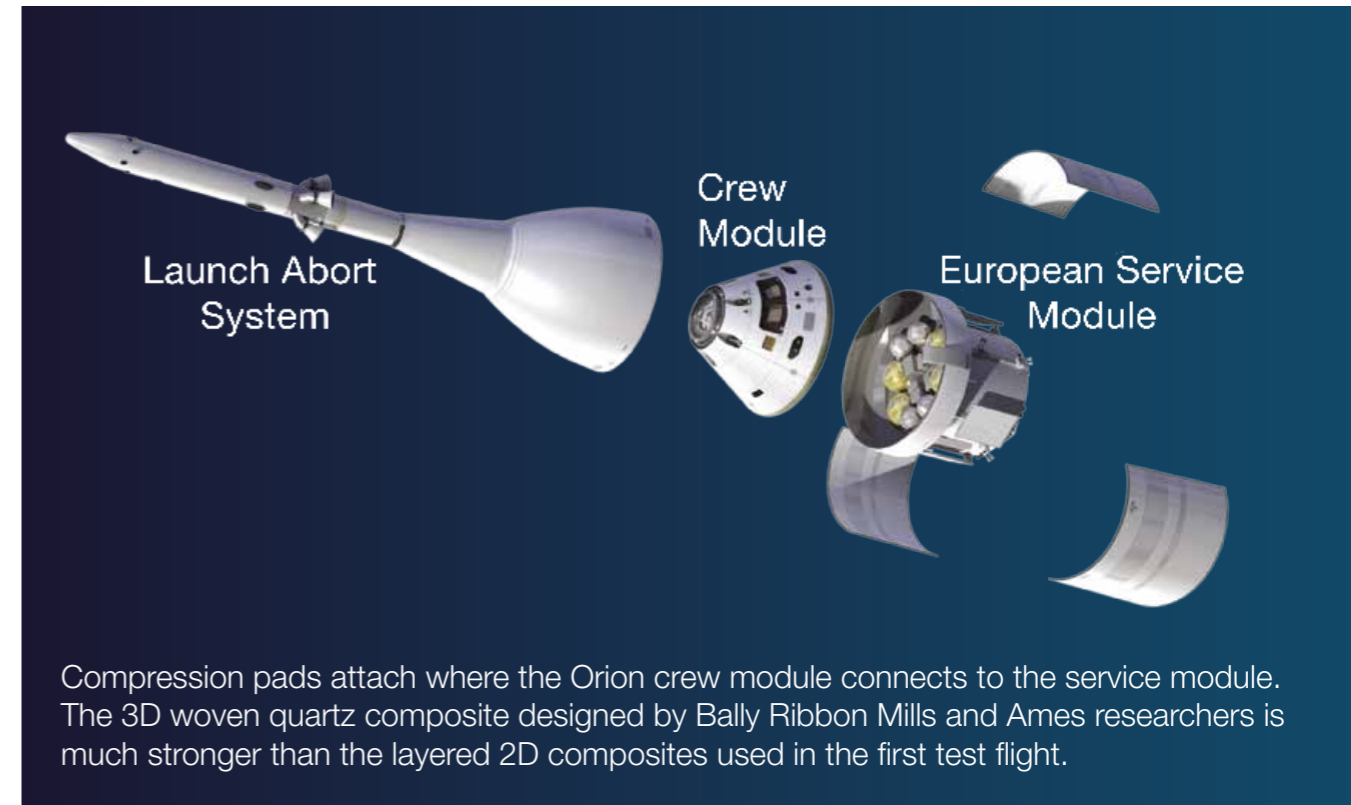
Where previous materials layered 2D woven composites, this new material was comprised of 3D woven blocks. "When you have fibers going in all three directions, it's very, very strong," explains Feldman. "And we can also tailor the composition so it has relatively low thermal conductivity."

The final material, a quartz composite, was first developed with seed money from Ames. Then, under Small Business Innovation Research contracts and with funding from NASA's Game Changing Development Program, Bally continued working on the material and modified its equipment to weave blocks 50 percent thicker than it previously could.

The result "is like a brick," explains Bally Ribbon Mills' Curt Wilkinson. "We are packing a lot of fiber in there."

Unlike many designs that tend to focus on doing just one thing really well, the 3D composite is versatile: it can carry loads, act as a shock absorber, conduct electricity well, and serve as thermal insulation.

Now the Bally, Pennsylvania-based company sells the quartz composite material to aerospace companies and uses the modified weaving equipment to make larger, denser blocks of 3D carbon composites for race cars.



# Vibration Tables Shake Up Aerospace, Car Testing

**W**hen handling a multi-billion-dollar space telescope, you want to be pretty careful. Unless it's your job to shake it with 100,000 pounds of force, that is.

The James Webb Space Telescope, currently under construction at the Goddard Space Flight Center, is planned to replace the Hubble in 2018. To ensure the hardware can survive a launch through the atmosphere at 32 times the speed of sound—on its way to a destination a million miles away, where it would be nearly impossible to fix—engineers will strap the telescope to vibration tables and shake it in every direction. Hard.

The vibration tables were built by Burlington, Washington-based Team Corporation, which has been building vibration-testing equipment for NASA since the 1950s. Under one of its first NASA contracts, the company developed what it calls Model 1830 T and V bearings, which are stiff and frictionless and can carry both tension and compression.

The first shaker using these bearings was delivered to NASA and was used to test the Vanguard 1 satellite, one of the first U.S. satellites ever launched into orbit. Today thousands of these T and V bearings are used around the world in vibration testing equipment.

In addition to a rocket launch, Team's shakers can recreate conditions of a bouncing road or a massive earthquake. It's all aimed at determining just how well a structure will hold up in real life in a moment of extreme stress or over a lifetime of wear and tear.

For example, using four small vertical shakers, one under each car wheel, automakers like Ford Motor Company test how well the fully assembled car or light truck will perform once it hits the road.

The James Webb Space Telescope, set to succeed Hubble in 2018, is equipped with 18 separate, intricately engineered mirrors and carefully calibrated sensors, all of which will require testing before being sent to space.

Here the mirrors emerge from deep-freeze testing at Marshall Space Flight Center.

Later, once the telescope is fully assembled, it will be shaken on super-sized vibration tables, custom built by Team, to ensure it can withstand the forces of a rocket launch.



Team Corporation designed and built a system to mimic the forces this cannon turret, made by BAE Systems, would experience when driven at high speed over rough terrain. The testing showed 147 different hardware failures that the company was able to correct before the machine was ever deployed in the field.





Two planes from IFTI's fleet fly over the Mojave Desert, where the institute is located. Top is a MB-326 Impala used for high acceleration and unusual attitude flight, and below is a Rockwell Sabreliner, used for the zero-gravity experiences that are part of the organization's spaceflight curriculum.



Scott Glaser, vice president of operations for the International Flight Test Institute (IFTI), center, and former astronaut Rick Searfoss, right, speak with future spaceflight course participants in front of the institute's T-38 Talon supersonic jet trainer.

## Astronauts Instruct Newcomers on Peculiarities of Spaceflight

Few people are more thoroughly trained for their work than astronauts. After all, their already-complex work is carried out in an unforgiving environment that plays by completely different rules than life on Earth. But for the many thousands of non-astronauts who work in the space industry, some of that training would come in handy.

Beginning in 2016, the International Flight Test Institute in Mojave, California, is working to fill that gap with the help of two former astronauts. As instructors for the school's new spaceflight course, they bring the full weight of their NASA astronaut training and flight time to bear.

It's training that can only really be offered by the few people who have direct experience of operations like docking a vehicle in orbit or using tools in a zero-gravity environment, where Newton's "equal and opposite reaction" can mean inadvertently flipping head over heels or sailing backwards across a module.

The course can be tailored to clients' needs but typically consists of a week of classroom instruction and a week of hands-on training. It is intended for the design analysts, test engineers, program managers, technicians, and a host of others in the space industry who can benefit from an understanding of spaceflight. The classroom portion covers subjects from orbital mechanics to legal regulations and from spacecraft design and testing down to administrative paperwork, while the second week applies some of these concepts, with students designing a payload and planning and carrying out a mission in zero gravity and high gravity, simulated by flying a plane in parabolas.

The material is based largely on NASA's astronaut candidate training, but it's intended to give non-astronauts the practical knowledge they need to walk into a job in the space industry and be productive from day one.



## Polyimide Aerogels Boost Antennas, Insulate Pipes

The challenge: make a powerful insulating material that is lightweight, strong, and flexible. The goal: an inflatable decelerator that can be folded up inside a spacecraft and then whipped out to create drag during landing. The bonus: a new material for warmer pipes, better antennas, and, potentially, gloves for Martian astronauts.

Senior researcher Mary Ann Meador at Glenn Research Center knew where to start. Meador is an expert in aerogels: low-density solids that make excellent insulators.

They are created by dissolving a material in a solution to create a gel, almost like Jell-O. Then the solvent is dried out, leaving just the gel structure: a network interspersed with tiny pockets of air where the solvent used to be.

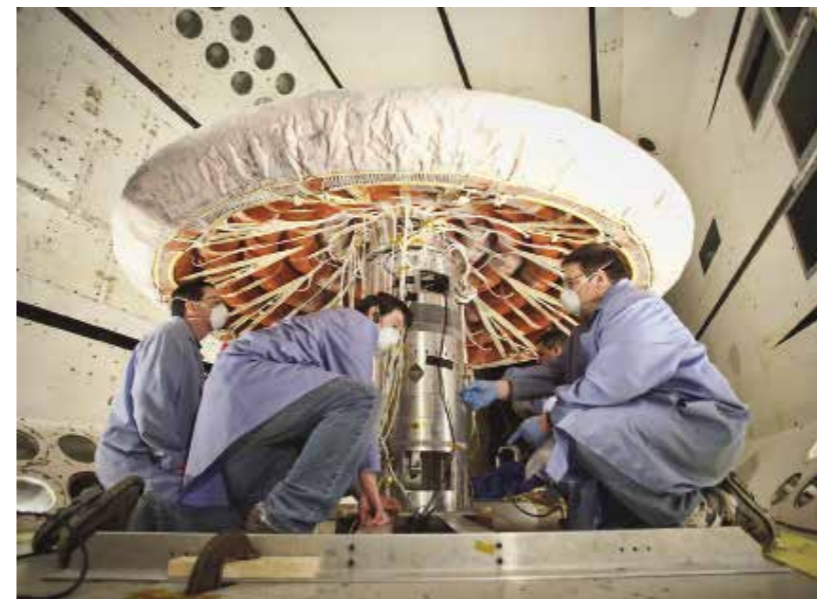
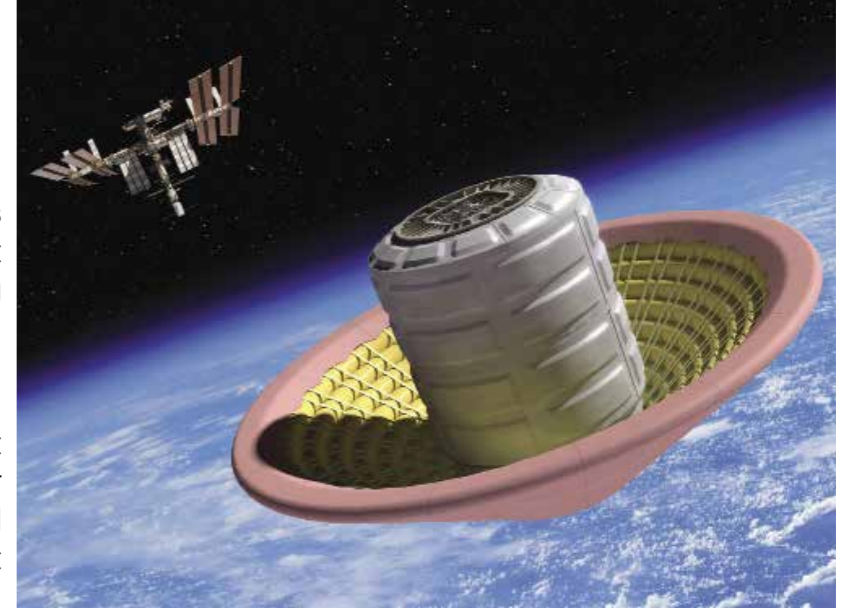
When made out of silica, the traditional base for aerogels, they are brittle, like glass. Using polyimide polymers, Meador and her team created a new aerogel five times stronger than earlier polymer-reinforced silica aerogels, and one that can be cast into a thin, very flexible layer.

FLEXcon, in Spencer, Massachusetts, licensed the patent in 2015. “We sell 100-foot rolls from 2 mils, or 2 thousandths of an inch, (0.05 millimeters) up to 80 mils (2 millimeters),” says Ken Koldan of FLEXcon. “We’re able to give formats of both thin film and blocks where in the past that wasn’t available to the consumers.”

The thin film format is sold to make protective wraps to insulate pipes in extreme environments, and the company is exploring markets for consumer goods as well, like a high-end jacket for outdoor athletes.

“Because it’s an open-cell structure, it allows moisture to get out but then also has the ability to insulate,” Koldan says. And the thin, flexible material means a less bulky product.

This artist's rendering shows an inflatable heat shield that is expanded to create drag during landing. To build it, NASA needed a lightweight, strong, and flexible material that was also an excellent insulator. Glenn researcher Mary Ann Meador created a polyimide aerogel that fit the bill.



Engineers examine an inflated heat shield after it was tested in a vacuum at NASA's Langley Research Center. These Hypersonic Inflatable Aerodynamic Decelerators, or HIADs, may prove more economical and efficient for carrying heavy loads to planets with an atmosphere.



NASA researcher Mary Ann Meador chose to make aerogel out of polyimides because these polymers are very strong and able to withstand extremely high temperatures. Making it in layers that were thin enough to be truly flexible was a challenge, but she and her team ultimately were able to cast layers just half a millimeter thick.



## Privately Built Facility Offers Advantages in Space Exposure Testing

Most of the universe is a void full of dangerous radiation and other conditions that can harm not just organisms but also many materials. Recreating all these conditions simultaneously in a laboratory on Earth is too difficult to be practical.

This is why, since 2001, NASA has carried out its Materials International Space Station Experiment (MISSE) series, affixing containers of specimens—mostly materials and components considered for use in space—to the outside of the International Space Station (ISS) to see what happens to them over time.

MEI Technologies (MEIT) has long packaged the payloads and ensured they met constraints for NASA and the Department of Defense. The next deployment, set for mid-2017, and all future MISSE payloads will be managed entirely by Alpha Space, a spinoff from MEIT located in Houston, which will not just integrate the payloads but build the containers and housing that hold them.

Some of the new facility's space will be reserved for NASA research, but the rest is available for use by customers including companies, universities, and other government agencies.

Alpha Space will keep costs to customers down by installing a permanent facility so just sample containers need to be carried to and from Earth, and by installing and removing containers by robotic arm, eliminating the cost of spacewalks.

While earlier units faced one or two directions and were opened by astronauts when installed and closed upon retirement, the new one will face four directions, with the carriers opening and closing independently. This allows samples to be exposed to different elements and for different lengths of time. The new facility will have stronger data connections, allowing near real-time monitoring of samples, as well as a new, highly sensitive contamination sensor and a high-resolution camera in each of the 12 carriers.



An astronaut installs a Materials International Space Station Experiment (MISSE) facility on the exterior of the ISS during a spacewalk in 2001. Future iterations of MISSE, handled by Alpha Space, will be installed and maintained via robotic arm, eliminating reliance on spacewalks.



A prototype of Alpha Space's MISSE containers unfolds. Each will carry dozens of material samples, testing their reaction to prolonged exposure to the elements of space.



This is a prototype of Alpha Space's MISSE facility. With containers facing in four directions and able to open and close independently, the facility can customize space exposure for different samples.





# Optical Filters for NASA Imagers Focus on Cutting Edge

With camera and detector technologies improving at a rapid pace, NASA engineers were already planning missions to improve the Hubble Space Telescope's imagers by the time the agency's flagship observatory was launched.

Optical components on space telescopes must often filter out all but specific wavelengths of light, and they search well beyond the visible spectrum into the ultraviolet and infrared. They also must be nearly flawless.

To create optics for Hubble's Wide Field Camera 3 (WFC3), Goddard Space Flight Center selected a company with a proven record of providing custom optical devices for aerospace and other industries: Barr Associates, now part of Materion Precision Optics in Westford, Massachusetts.

This and other work for NASA led the company to improve its processes and products in a number of ways. For example, WFC3 needed four different filters applied to a single optical component, a feat Barr had never attempted, and also required unprecedented precision in spectral wavelength and uniformity control and placement of filters in relation to each other. The company later used techniques it developed to meet those specifications to create devices that use multiple color coatings on one substrate to match paint colors in hardware stores.

Astronaut Andrew Feustel pushes off the Space Shuttle's remote manipulator system arm to deliver the Wide Field Camera 3 (WFC3) to the Hubble Space Telescope in 2009. Major process improvements that Barr Associates, now part of Materion Precision Optics, had to make to supply optical filters for the WFPC cameras and other NASA imagers led to improvements to the company's entire product line.



Subsequent work for imagers on the Curiosity Mars rover required optics that couldn't tolerate defects larger than a hundredth of what would normally be acceptable. Processes Barr developed to create such perfect components are now part of its daily operations.

As part of Materion, the team experimented with filter materials and deposition methods to achieve ultra-precise filtering of mid-length and long-wavelength light frequencies for optics for the James Webb Space Telescope. Materion now uses the resulting formulation and process in three of its coating chambers every day.

The technical challenges that Barr Associates, now part of Materion Precision Optics, had to overcome to put four filters on a single optical element to meet the requirements for Hubble Space Telescope imagers later led to paint-matching devices for hardware stores, with multiple wavelengths evaluated by a single lens. This is just one example of improvements and innovations the company made to meet NASA's needs that then made their way into commercial products.



Materion Precision Optics developed a whole new lens-coating process to produce the unprecedented uniformity and wavelength positioning required for the James Webb Space Telescope's Near Infrared Camera, pictured here. It's a process the company now uses to create standard products on a daily basis.



# Zinc-Silicate Coating Blocks Corrosion

NASA needs materials that are strong and that can hold up over time. Sometimes that means the space agency designs brand-new, high-tech materials—but sometimes it sticks to industry standards, like steel, and creates a game-changing coating to protect it from the elements.

The good news is that anyone else using that tried and true material can benefit from the new coating too.

That's just what happened in the 1970s, when a team at Goddard Space Flight Center developed a mixture of zinc powder and potassium-silicate to protect metal surfaces from corrosion.

The new coating was an incredibly effective and durable treatment that didn't even allow water damage or corrosion to seep into protected areas if the coating was scratched or incomplete. And because the product is water-based, it's a lot safer to use and more environmentally friendly than coatings that include solvents or thinning agents.

NASA put the coating to use on structures at the seaside Kennedy Space Center, where it protects launch facilities not just from the salty, tropical environment but also from the temperature spikes and high-heat exhaust of rocket launches.

Outside the space agency, the coating was soon put to use on a range of metal structures, from bridges to boats to the Statue of Liberty, through a patent license with Inorganic Coatings.

Polyset of Mechanicville, New York, helped Inorganic Coatings perfect the manufacturing of one of the key ingredients, the liquid potassium-silicate, and supplied it to the company for many years.

Inorganic Coatings later went out of business, in part because it tried to manufacture the liquid potassium-silicate itself and was unable to achieve a reliably effective formulation. Now Polyset is producing the coating itself, for use in bridges, hydroelectric facilities, rail cars, and offshore oil rigs.



Polyset sells its coating to companies that operate offshore oil rigs like this one, which can suffer corrosion from the seawater. The company is also targeting ship and train builders, hydroelectric plants, and the departments of defense and transportation.



In a recent test at Kennedy Space Center, engineers applied environmentally friendly coatings to steel samples. After 18 months' exposure in the salty sea air, the Polyset coated samples, bottom, remained nearly pristine, while the ones coated with another product, top, became riddled with rust and corrosion.



# Outgassing Test Facility Brings New Materials into Space Industry

Windform materials invented by the Italian CRP Group provide high strength at low weights—attractive qualities for the aerospace industry. The materials, polyimides reinforced with carbon or glass microfibers, are also very versatile: they can vary in properties like electrical conductance and elasticity.

And they can be 3D printed using selective laser sintering, which can print almost any shape as one solid object, create multiple objects simultaneously, and ensure the absence of voids that can occur with other additive manufacturing processes.

But space imposes requirements for materials beyond what is needed to use them on Earth—and manufacturers unfamiliar with space missions may not even know about them. So CRP USA, headquartered in Mooresville, North Carolina, wasn't aware of something called outgas testing until the company

was asked about using Windform in satellites.

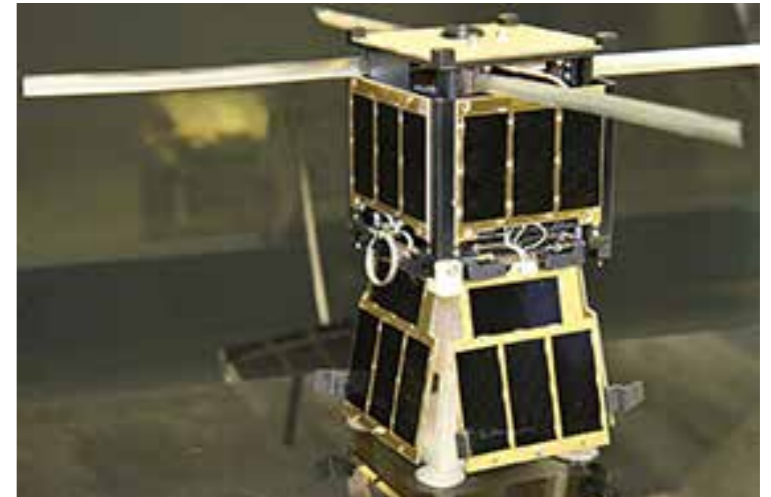
The testing is to ensure the material doesn't contain volatile compounds that could evaporate upon exposure to the sun's unfiltered heat. Such vapor would be drawn to cooler surfaces, including the lenses, mirrors, and windows that are crucial to many spacecraft functions, where they would form a film, with nobody around to clean them.

The Outgassing Laboratory at Goddard Space Flight Center is one of the first stops for any new material considered for space applications, and that's where four varieties of Windform found themselves in 2013. At the time, the lab offered testing to outside entities as schedules allowed.

Testing showed that all four varieties had low enough levels of outgassing to make them acceptable for space applications, and two—LX 2.0 and XT 2.0—had no outgassing at all.

Since the testing, CRP USA has worked with 10 to 15 space companies, producing components for use in space as well as in supporting roles, such as prototypes or tooling devices.

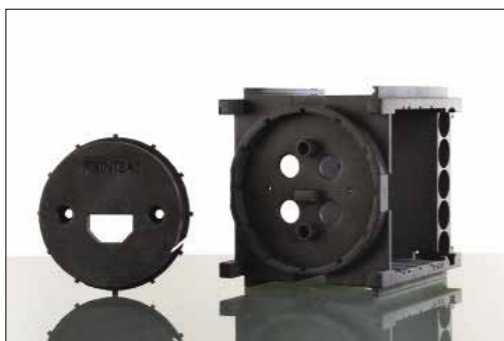
University students have also built a handful of satellites using Windform materials.



Students at the University of Kentucky and Morehead State University used 3D-printed Windform material to build their KySat-2 CubeSat, a proof-of-concept spacecraft to demonstrate technologies the students developed.



Engineers at Goddard Space Flight Center use carbon dioxide "snow" to clean a test mirror for the James Webb Space Telescope. Because they're cold, components like mirrors and lenses, which have to be completely clean and flawless in space imagers, are among the first places any volatile compounds outgassed from a spacecraft's materials will condense, causing fogging. To prevent this, all materials used in spacecraft have to demonstrate extremely low outgassing.



Montana State University's PrintSat satellite's housing (left) is made with 3D-printed Windform material, as is a hybrid rocket engine built by Experimental Propulsion Lab (right).



# Shuttle, Hubble Work Lead to Strength in Custom Current Sensors

When the Space Shuttle was built, it boasted the world's most complex avionics system. Its controls were entirely digital, with all subsystems able to communicate with each other and automatically control functions like flight stabilization or engine performance. The electrical systems had to be fail-safe, so they were redundant and closely monitored.

Meanwhile, the Hubble Space Telescope, like other satellites, relies entirely on energy gathered by its solar panels and stored in batteries. During each orbit, it has 61 minutes of sunlight to store at least enough energy to operate throughout the entire 97-minute circuit.

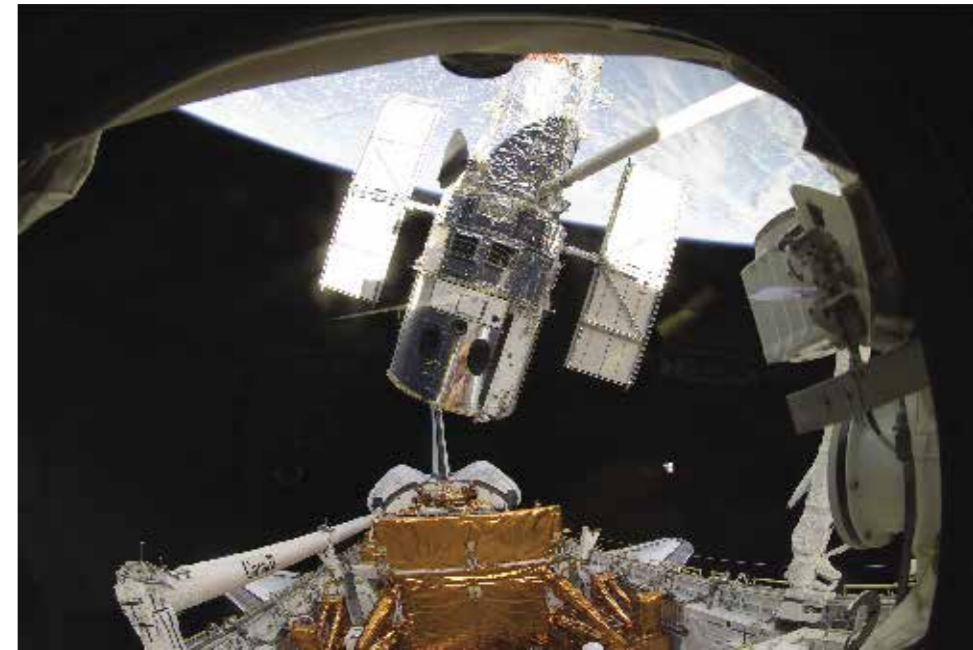
To monitor power flows on both of these iconic spacecraft, American Aerospace Controls (AAC), based in Farmingdale, New York, supplied current sensors. As a subcontractor for both projects, the company supplied noninvasive sensors, based on a coil that surrounds a wire without making contact with it.

The custom Shuttle work, coming out of Johnson Space Center, led to AAC's first products in space.

As more Shuttle work, and then Hubble projects for Marshall Space Flight Center, rolled in, the company built up its ability to meet NASA's needs for small, energy-efficient parts that could resist intense vibrations, extreme temperatures, radiation, and electromagnetic interference and also included precautions like redundant functions and a backup mode.

Rather than farm out product testing to another party, AAC developed its own in-house quality control capability, including equipment, testing personnel, and even engineers to handle test documentation. This helped lower costs and speed turnaround.

While working with NASA, AAC changed from a producer of standardized parts to a leading manufacturer of high-reliability custom current sensors. NASA is still a major customer, as is the military, contractors to the European Space Agency, and companies across the commercial space, aviation, and rail markets.



The remote manipulator system on the Space Shuttle Atlantis lifts the Hubble Space Telescope from the cargo bay during the final mission to service Hubble in 2009. American Aerospace Controls' first parts in space were current sensors in the Shuttle's avionics system, and the company's sensors are still orbiting Earth on Hubble.



The larger silver-colored unit is a current sensor American Aerospace Controls supplied for the Hubble Space Telescope and similar programs, while the smaller one is a more recent sensor the company supplies for satellite launch vehicles. Both are space-qualified, radiation hardened, and hermetically sealed to eliminate electromagnetic interference. The two black current sensors are used on NASA's RQ-4 Global Hawk and the U.S. Navy's MQ-8 Fire Scout, where they monitor the unmanned aerial vehicles' main electrical distribution systems. The company based them on designs originally created for the Shuttle program.



# High-Heat Cement Gives Ashes New Life

One structure at Stennis Space Center that takes more punishment than almost any other is the trench that deflects flames and exhaust during a rocket test. It needs a high-performance lining to withstand the extreme heat—thousands of degrees Fahrenheit, though temperature probes have struggled to get accurate measurements, because they burn up during testing, says Nick Cenci.

The lining also needs to be able to resist wear and abrasion as much as possible. Typically, the Stennis engineer says, “as a material gets hotter, it gets a little softer and then it wears away faster.”

A Louisiana Tech University team was working on an environmentally friendly material that could be a good fit for the lining: geopolymer concrete made with fly ash left over after burning coal. Unlike traditional concrete, in which cement, typically composed of limestone and clay, is mixed in a water-based solution with sand and gravel aggregates, the geopolymer concrete is mixed with an alkali solution and aggregates.

By tailoring those ingredients, the researchers found they could achieve extremely high heat and corrosion resistance.

Stennis tested the material under a dual-use cooperative agreement, and the results confirmed the material’s strong resistance to heat and corrosion. The successful trial prompted the Louisiana Tech team to start Ruston, Louisiana-based Alchemy Geopolymer Solutions LLC.

Fly ash is not an environmental hazard by itself, but it is a waste product that would otherwise be sent to a landfill. Additionally, using waste ash replaces the need to manufacture traditional limestone cement, a process that produces greenhouse gasses and consumes energy. And unlike many ingredients for high-performance cements, fly ash is relatively inexpensive.

For some of Alchemy Geopolymer Solutions’ clients, these environmental and cost benefits are the main draw. Other clients, however, are attracted to the high-performance properties of the geopolymer concrete, and the environmental benefits are a bonus.

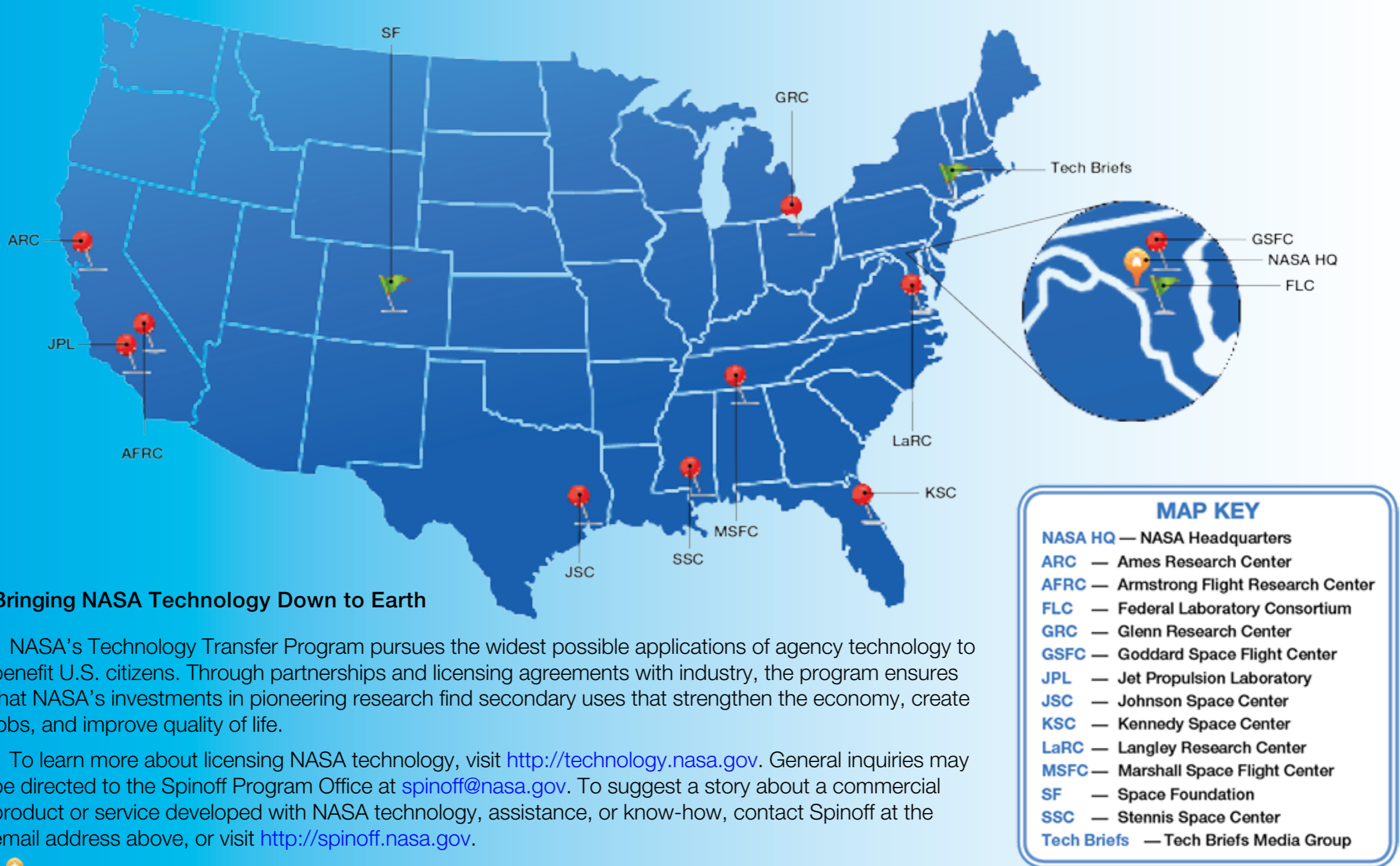


After the successful Stennis tests, the Louisiana Tech team founded Alchemy Geopolymer Solutions, leveraging their expertise in designing concrete made with fly ash. A pipemaker in Texas was interested because of the material’s high resistance to corrosion and its impressive compression strength.

The AJ26 rocket engine was flight tested at Stennis Space Center in 2012. That plume of flame wears away at the trench under the test stand, so Stennis teamed up with a team from Louisiana Tech to explore using a new kind of concrete, made with fly ash, to line the trench.




# NASA Technology Transfer Program Network Directory




## Bringing NASA Technology Down to Earth

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